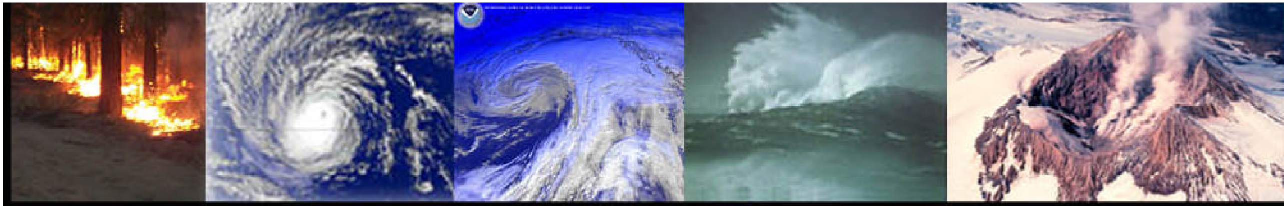

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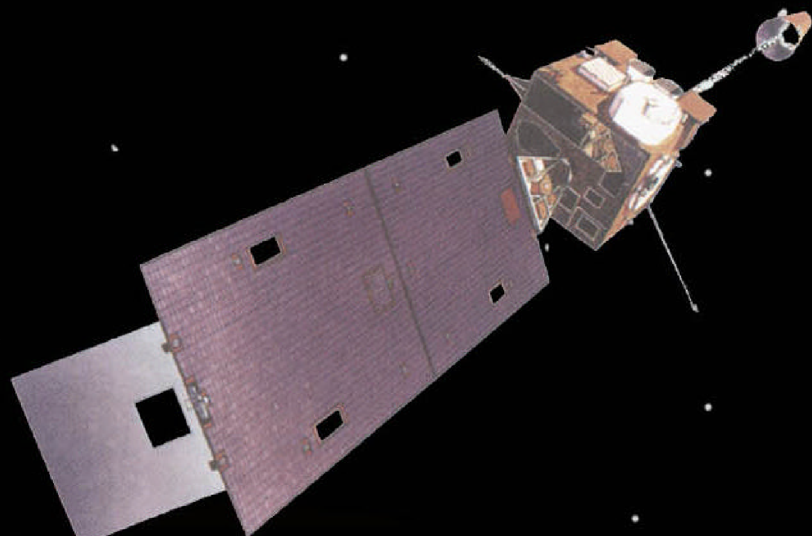
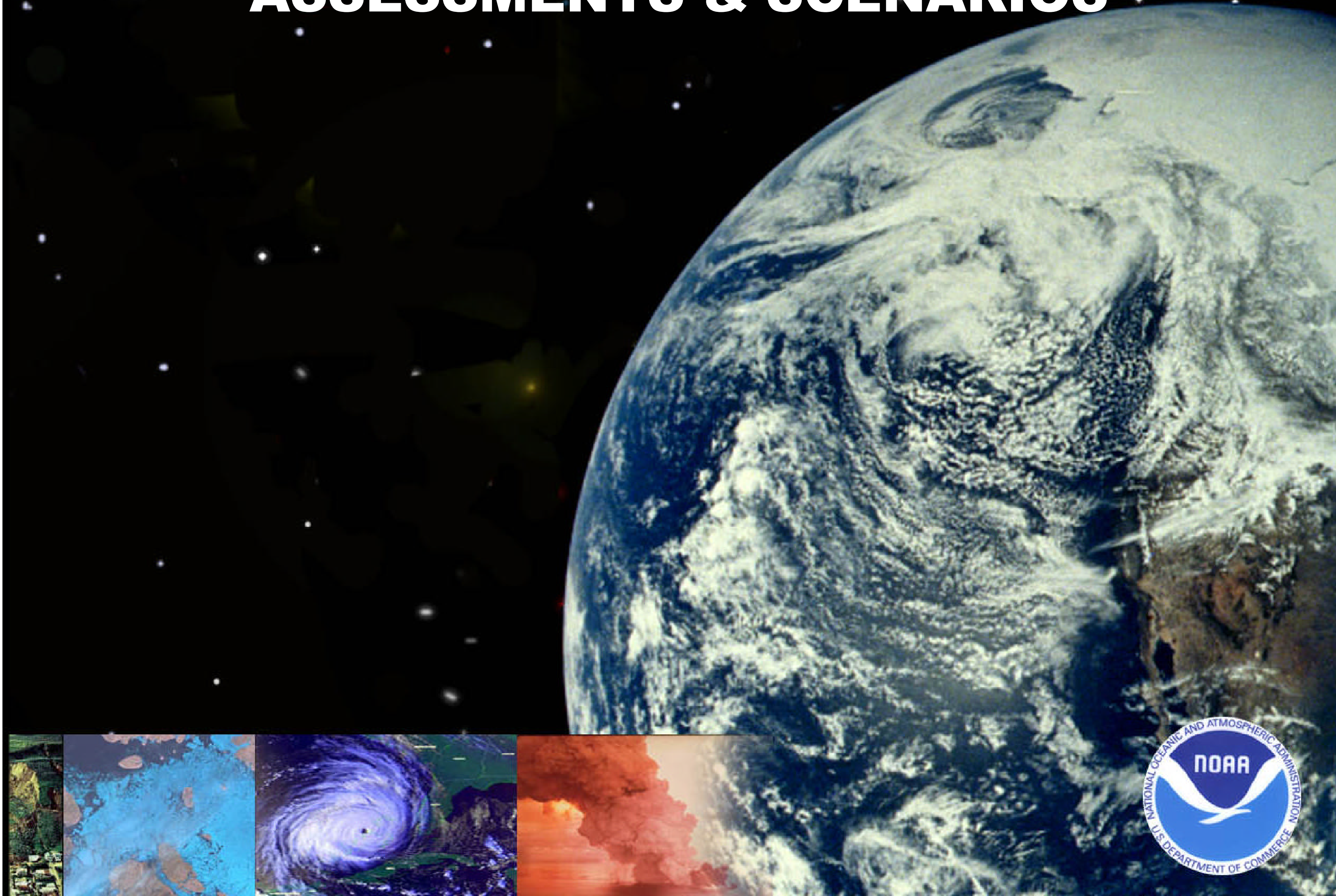


THE USE OF EARTH OBSERVING SATELLITES FOR HAZARD SUPPORT: ASSESSMENTS & SCENARIOS



COVER IMAGES:

The cover includes a range of images drawn from the NOAA Library (www.noaa.gov and http://www.lib.noaa.gov/) and (http://www.photolib.noaa.gov/)

The satellite image is one of NOAA's geostationary satellites.

Composite banner images were drawn from the disaster-related Internet site of the Pacific Disaster Center in Hawaii (http://www.pdc.org/).

Additional hazard images were drawn from NOAA's National Geophysical Data Center Internet site (www.noaa.ngdc.gov), which provides collections of slide images of various hazards, such as landslides, earthquakes, volcanoes, and fires: (http://www.ngdc.noaa.gov/seg/hazard/hazards.shtml).

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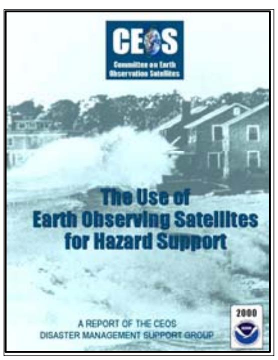
CEOS

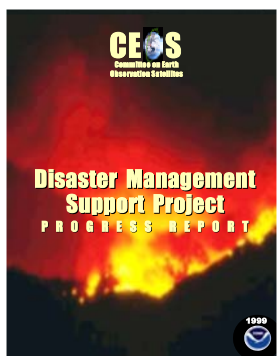
COMMITTEE ON EARTH OBSERVATION SATELLITES

THE USE OF EARTH OBSERVING SATELLITES FOR HAZARD SUPPORT: ASSESSMENTS & SCENARIOS

FINAL REPORT OF THE

CEOS DISASTER MANAGEMENT SUPPORT GROUP





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Helen M. Wood, Chair
National Oceanic and Atmospheric Administration (NOAA)
United States Department of Commerce

INTRODUCTION

Weather satellites have long been used to support forecasting of intensive weather hazards such as tropical cyclones, severe storms and flash flooding. Although there have been numerous research and operational demonstrations that illustrate the potential usefulness of EO satellite data for a broader range of hazards, the operational application of these data to other hazards is still quite limited. Recognizing the benefits that could be gained from better application of EO satellite data to natural and technological hazards, the Committee of Earth Observation Satellites (CEOS) initiated an activity for disaster management support in 1997, which later became the Disaster Management Support Group (DMSG). As a result of the work done in this activity, three annual reports and this Final Report have been published.

The goal of the CEOS Disaster Management Support Group (DMSG) has been to support natural and technological disaster management on a worldwide basis by fostering improved utilization of existing and planned Earth Observation (EO) satellite data. The DMSG has focused on developing and refining recommendations for the application of satellite data to selected hazard areas. Hazard teams for these selected areas were formed to document specific user requirements, findings, and recommendations. An information tools team has addressed information location, access and utilization requirements, with particular attention on the development of a pilot server intended to demonstrate timely access to satellite-derived data and information products (i.e., "one stop shopping") for support of various facets of disaster management.

The CEOS DMSG Background & Activities

CEOS was formed in 1984, in response to recommendations from the Economic Summit of Industrialized Nations Working Group on Growth, Technology, and Employment's Panel of Experts on Satellite Remote Sensing. This group recognized the multidisciplinary nature of satellite-based Earth Observations (EO) and the value of coordination across all proposed missions. In CEOS, providers and users of civil EO satellite data work together to promote the effective use of satellite data. Recognizing the benefits that could be gained from better application of EO satellite data to natural and technological hazards, CEOS initiated an activity on disaster management support in 1997.

A resolution to form an *ad hoc* working group was presented at the 13th CEOS Plenary in November 1999. It was agreed that the group would continue the essential functions of the former project, address improved space agency coordination, as well as outreach to commercial space operators, and other issues. The DMSG was charged to serve as a forum to identify, and interact with, current and potential users of space-derived data as one of the tools to deal with disasters. The group addresses policy and technical issues including a focus on conducting a comparison of requirements against capacity, and recommends steps to correct any mismatches between the two where possible. With strong support among the representatives, the DMSG was formally established and the Terms of Reference (TOR) approved by the 13th CEOS Plenary. NOAA agreed to continue to provide the Chair of the activity, which it has maintained up to the present. The Resolution and TOR are attached at the end of this report.

The DMSG has seven hazard teams whose members include representatives from satellite agencies and emergency management users' organizations. There are hazard teams for earthquake, fire, flood, ice, landslide, oil spill, and volcanic hazards. In the early stages of the work of the DMSG, a Drought Team was formed. It completed its work and continued in other fora (the initial report of this team is included in an annex to this report). Teams were charged with compiling user requirements; identifying shortcomings and gaps in the provision of required satellite data; and developing recommendations for alleviating them. Particular emphasis was placed on working closely with space agencies, international and regional organizations, and commercial organizations on the implementation of these recommendations.

In general, timely information on the development of hazards as well as general information on risks, hazards, and opportunities remains fragmented and difficult to locate. To begin to address these and other gaps, prototype tools have begun to be developed. NOAA has sponsored a prototype information server to demonstrate timely access to satellite-derived data and information products — "one stop shopping" — to support various facets of disaster management. A number of agencies have participated in the development of the server, providing links to their data and information services, and developing additional support tools under the auspices of the DMSG. The Information Tools Team oversees the development of the server.

Accomplishments

Since its inception in 1997, the work of the DMSG has focused on a primary objective to define user requirements and provide specific recommendations to CEOS agencies for addressing gaps in observations, products, and services to meet those requirements. Over the last few years, the DMSG has conducted annual planning meetings and a series of workshops to implement its plan of work. The work was initially supplemented by regional workshops to reach more emergency management users. With over 300 participants from more than 140 organizations, the DMSG found strong support among CEOS members and associates, as well as an enthusiastic reception from numerous international, regional, and national emergency managers, including distinct interest from the commercial sector. The DMSG also developed close ties to a number of international organizations and has received substantial encouragement and recognition from these organizations.

The DMSG has developed a number of findings and recommendations over the last four years. These have included twelve overarching recommendations derived from nine findings. The findings note that disaster managers often recognize the value of, and are willing to use, new satellite technology, but may be reluctant to do so, since the technology is unfamiliar and unproven in an operational environment. The recommendations suggest ways that the space community might respond (for example, by promoting mutual dialogue, creating user friendly tools, performing compelling demonstrations, and using integrated approaches to create more user friendly products and services). The full set of findings and overarching recommendations are listed at the end of this report in Annex II. These include fostering more aggressive cooperation amongst space agencies, with the commercial sector, and with international disaster organizations.

The overarching recommendations (Annex II) are in part, a consolidation of recommendations common to several hazard teams. As a part of their assessment and identification of requirements, each hazard team also developed hazard specific recommendations. Hazard team recommendations and other accomplishments are included as a part of each hazard team report within this publication. The Information Tools team has investigated a number of tools. One was a "hot events" page of links to web sites with data and products for recent significant hazard events. Another, a "contacts" page, points potential users to providers of data and products that can support disaster management. The Information tools team report expands on these and other related activities. Also, the DMSG has worked with the CEOS Working Group on Information Systems and Services (WGISS) to find ways to leverage tools and capabilities developed by WGISS for broader community use.

Cooperation with Space Agencies

In 2000, CEOS instructed the DMSG to promote and support use of space systems in all phases of disaster support, with specific emphasis on the *International Charter for Space and Major Disasters* (the "*International Charter*"). In this way, the work of the DMSG evolved from investigation and demonstration of technical coordination of civil satellite systems in support of disaster management, to defining Emergency Scenarios specifically to assist the *International Charter.* The *International Charter* was initiated by the Centre National d'Etudes Spatiales (CNES) and the European Space Agency (ESA). It allows space agencies to conduct multi-mission tasking of existing satellites, on a "best efforts" basis, as demonstrations of joint support for specific hazards. The Canadian Space Agency (CSA), the United States National Oceanic & Atmospheric Administration (NOAA), and the Indian Space Research Organization have subsequently joined.

In sum, the DMSG has both supported and learned from the experiences of agencies that participate in the *International Charter* and has helped to promote the demonstration of coordination of space agency responses to specific disasters using guidelines based on the *International Charter*. For this final report, leaders of the DMSG Hazard Teams, in collaboration with users and other experts from around the world, have pulled together final recommendations to space agencies and developed preliminary emergency scenarios for each hazard area.

International Cooperation

The DMSG has worked closely with key international organizations and partnerships that have roles in coordinating aspects of disaster management. These are primarily the United Nations International Strategy for Disaster Reduction (ISDR), the UN Office of Outer Space Affairs (OOSA) which supports the UN Committee on Peaceful Use of Outer Space (COPUOS) in its work following decisions taken at UNISPACE III, and as described above, the *International Charter for Space and Major Disasters*. The ISDR is the successor to the UN International Decade for Disaster Reduction (IDNDR) that ended in 1999. The ISDR is focusing on creating a global culture for disaster prevention. COPUOS has launched a three-year work plan to develop an integrated, global disaster management support system through its Scientific and Technical Subcommittee (STSC). An Action Team on Disaster Management has been formed to implement the COPUOS work plan drawing, in part, from the work of the DMSG. ISDR and OOSA have both maintained a close liaison with the DMSG regarding coordination of disaster management related to remote sensing, including support for the *International Charter*, through cross briefings, workshops and joint activities.

Cooperation with the Commercial Sector

The Group's work has also pursued a closer relationship with the commercial sector. In 2000, the DMSG invited representatives from four commercial remote sensing operators (Spot Image, RADARSAT International, Orbimage and Space Imaging) to convene a panel that would provide perspectives on using satellite data for disaster management support. The panel was tasked to introduce the capabilities of each of their respective companies, to identify barriers to improving the use of satellite data for disaster management, and to identify potential areas for collaboration to mitigate such barriers. Perceived barriers and some possible remedies were identified. In most cases they mirrored barriers identified by users and space agencies. It was recognized that requirements must be sufficiently identified; but they often are not. Funding and contracts must be in place and available when disaster strikes; they often are not. Realistic training is essential and experience is needed (for example, through pilot projects). It was also recognized that there are no robust stand-alone solutions. Information must often be derived from multiple data sources and be integrated into a usable format — a particular challenge that requires a highly knowledgeable user or value-added services provider.

Using CEOS Working Group on Information Systems and Services (WGISS) Information Tools

The CEOS WGISS has responsibility for developing several information tools that can be useful for DMSG activities. More recently, WGISS has supported the Information Tools team in developing a contact list for providers of data and products that can support disaster management. DMSG has also used the CEOS International Directory Network (IDN) database of contact information for providers of Earth observation data and World Wide Web based tools developed by the Canadian Centre for Remote Sensing (CCRS) to search the IDN.
For more information see: http://wgiss.ceos.org

The Final DMSG Workshop, June 2001

The final DMSG workshop, held in Brussels, Belgium, focused on development of the Emergency Scenarios for hazard support described above. The scenarios were developed to serve as guidelines for identifying appropriate satellite data and products to support emergencies under specific disaster circumstances, and to assist the Parties to the *International Charter* with scenario definition. Taken together, the scenarios comprise a handbook of what to do, regarding the use of EO satellite data, when each type of disaster occurs.

While the *International Charter* addresses the provision of data only during the crisis/response phase of a disaster, the DMSG mandate has been to address all phases of disaster (mitigation, preparedness/warning, and relief/response/recovery). Each hazard team determined which disaster management phase(s) to define when they developed the Emergency Scenarios that are included in this report.

The final DMSG Brussels workshop covered a number of key topics, including:

- Focus on the *International Charter: Space and Major Disasters*
- Update on the European Global Monitoring for Environment and Security (GMES)
- Involvement of the UN International Strategy for Disaster Reduction & the Office of Outer Space Affairs
- Briefing on the British small satellite constellation for disaster support

DMSG 2002 Workplan

The 2002 work-plan for DMSG is focused on refining hazard support scenarios, assisting CEOS space agencies with consideration and responses to the specific recommendations, and working with other bodies — including UN OOSA, UN ISDR, the *International Charter*, and others, on a smooth transition of the DMSG's work. This also includes the formulation of final recommendations for the CEOS Plenary in Fall 2002 for a way forward in the future.

CEOS will also co-host, with UN OOSA and ESA, two regional workshops on the use of Earth observing satellites for disaster support on behalf of CEOS — one in Africa and one in Asia. These will be similar to the workshop co-sponsored by OOSA, ESA, and the Government of Chile that was held in Santiago, Chile in November 2000, entitled: "Use of Space Technology for Disaster Management."

Synergy with the Integrated Global Observing Strategy (IGOS)

The development of an IGOS Geohazards Theme is moving forward, and will play a key role in continuing and supplementing the work initiated within the DMSG. Several of the DMSG hazard teams (earthquake, landslide, and solid Earth dimensions of volcanoes) have joined the effort to develop a theme proposal.

The Integrated Global Observing Strategy (IGOS) unites the major satellite and surface-based systems for global environmental observations of the atmosphere, oceans and land. IGOS is a strategic planning process, involving a number of partners, that links research, long-term monitoring and operational programmes, as well as data producers and users, in a structure that helps to determine observation gaps and identify the resources to fill observation needs. The IGOS Partnership brings together a number of international organizations working on the observational components of global environmental issues, both from a research perspective as well as an operational point of view. The IGOS Partners have adopted a theme concept, which allows for a coherent definition and development of an overall global strategy for observing selected areas of common interest. These selected areas are based on the assessment of the relevant scientific and operational priorities for overcoming deficiencies in current information. Several themes have already begun, covering areas such as Oceans, the Carbon Cycle, the Water Cycle, Coasts/Coral Reefs, and Atmospheric Chemistry. The IGOS Geohazards Theme will provide an integrated geological/geophysical approach that addresses geo-spatial information needs for Volcanoes, Earthquakes, and Ground Instability Hazards. For further information on IGOS see: http://ioc.unesco.org/igospartners/igoshome.htm

DMSG Transition

The efforts of the DMSG have served to demonstrate the great value of inter-regional facilitation and cooperation. The final phase of work for the DMSG is focusing on completing the mandate from the CEOS Plenary, addressing areas where there is a need for refinement, and defining the way forward in an orderly fashion. The work of the DMSG will continue in the various other groups with which it has actively collaborated and supported in the past — particularly, the Integrated Global Observing Strategy (IGOS), the UN ISDR, and UN OOSA in its support of COPUOS. As described below, continuing activity will occur under the prospective IGOS Geohazards Theme, in which there is involvement of a number of experts from the DMSG Hazard Teams. In addition, CEOS will co-host Regional Workshops, in collaboration with UN OOSA and ESA on "The Use of Space Technology for Disaster Management." The workshops will bring together practitioners and space agencies that have developed space technology solutions, including those responsible for dealing with disaster management and space technology in developing countries. These workshops will, among other things, enhance the awareness of managers and decision-makers involved in disaster management to the potential benefits of using space-based technologies.

The Hazard Team reports and the Information Tools Team report that are included here in the Final DMSG Annual Report are available in a limited number hardcopies, mini-CD's, and electronically via the DMSG information server web site at http://disaster.ceos.org.

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T E A M R E P O R T
Earthquake

EARTHQUAKE HAZARDS

CEOS DISASTER MANAGEMENT SUPPORT GROUP

SUMMARY

This Report is a summary of the current and projected utility of Earth Observation (EO) space technology applied to the management of earthquake risk. The study is compiled by the Earthquake Hazard Team of the Disaster Management Support Group of the Committee on Earth Observation Satellites compiled the study.

Currently, *operational* EO capabilities have some limited use in the <u>mitigation</u> and <u>response</u> phases of earthquake risk management, but not in the <u>warning</u> phase.

In terms of mitigation, EO is useful, particularly in developing countries, for base-mapping for emergency relief logistics, and estimation of settlement and structure vulnerability (e.g. building design) and exposure (e.g. proximity to active areas). In the response phase, EO's improving contribution is in damage-mapping – of prime concern to relief agencies that need to locate possible victims and structures at risk. EO is also valuable to the insurance industry, which needs to assess losses (the insurance industry is important because of the influence it has over the instigation of and adherence to earthquake-sensitive building codes). As for the <u>warning</u> phase (and in the case of earthquakes) this means prediction of an impending event, and any warning must meet stringent accuracy requirements. Currently, no EO approach comes near to the required level of reliability.

Improvements in damage mapping capability are marked by the new generation of Very High Resolution (VHR) missions, such as SpaceImaging's Ikonos-2, though bottlenecks in the data supply chain strain any claim to offer a Near-Real-Time (NRT) service (and additionally, the system's utility is reliant on cloud-free conditions). Although at the time of writing, IKONOS-2 is the only civilian VHR mission in operation, a number of similar missions are promised for the future (including cloud-penetrating radar) which should promote competition and be efficacious to faster delivery of less expensive data.

SAR interferometry (InSAR) holds increasing utility for the mapping of seismic ground deformation (as widely applied over Turkey for the Izmit earthquake of August 17 1999). By using InSAR to study pre- co- and post-seismic deformations, the technique contributes to the mitigation phase by adding to the spatial understanding of fault mechanism dynamics and strain. InSAR is also useful in the response phase as ground displacement can correlate with damage in built environments. Though a remarkable capability, system and process constraints preclude a routine or global application. There are, however, promising developments underway with the development of naturally occurring and man-made SAR signal reflector arrays in two hybrid techniques called Permanent Scatterer InSAR and Corner Reflector InSAR respectively. The three complementary InSAR techniques together, in combination with an appropriate SAR data acquisition strategy, promise an economic substitute or supplement for expensive ground-based GPS and laser-ranging networks in many circumstances.

Recently, commendable efforts have been made by a number of space agencies under the auspices of the *International Charter on Space and Major Disaster'* to acquire and disseminate 'response' data in terms of damage mapping for some earthquake events. We consider this a major step forward in co-operation and co-ordination, and foresee significant progress as other agencies enroll.

However, in general, such provisions are not co-ordinated or integrated with other services, and are not widely accessible to, or understood by the earthquake disaster management community. With the hopefully increasing availability of VHR data (and possible constellations of VHR satellites), co-ordination of effort and motivation to acquire imagery will become paramount.

In terms of capability, it is the conclusion of this report that base-mapping and damage-mapping will become the main operational contributions of EO to earthquake disaster management, with operational strain-mapping showing good potential for the future.

SUMMARY OF RECOMMENDATIONS

Adoption of the following specific recommendations would considerably enhance the utility of EO space technology for earthquake risk management:

Recommendations that are technically feasible now:

1. Compile base-maps of high risk areas: Expand existing global database of seismic risk zones, and integrate with population distribution, infrastructure and building stock databases, seismic history, relevant geology, known strain and EO/topographic map merges for base-maps.
2. SAR data providers to optimize the raw data supply chain for InSAR analysis.
3. SAR data providers to consider the acquisition of strategic datasets over high-risk areas to facilitate Permanent Scatterer InSAR strain mapping and co-seismic interferogram generation.
4. Undertake Permanent Scatterer InSAR over high risk areas to identify virtual positioning arrays and produce 9 year (period covered by ERS SAR data archive) record of strain.
5. Continue investigation into areas of earthquake forecasting research (e.g. thermal, electromagnetic).
6. Agency certification of EO products.

Recommendations for the future:

1. Support diversity of VHR missions to improve temporal resolution and coverage.
2. Bring VHR providers into the *International Charter* to facilitate damage assessment (though CNES already a signatory and SPOT 5 should make significant contribution).
3. Lobby for planned VHR SAR missions to be InSAR-friendly, e.g. orbit control, metadata, and strategic acquisition.

Recommendations internal to the CEOS working group:

1. Consider the instigation of a single co-ordinating, expert body that will serve the EO requirements of the earthquake disaster management community, whilst negating any need for them to become involved in EO technically.
2. Look for common recommendations between disaster types for a possible method of prioritisation.
3. Determine audience(s) for the Disaster Management Support Group website and establish links from/to other relevant sites.

I. SCOPE AND BACKGROUND

Due to the devastating socio-economic impact of earthquakes, considerable scientific and technological effort is expended towards understanding and assisting in the disaster phases of mitigation, warning and response. However, this effort can result in inflated aspirations or claims. For this reason, this document, if it is to be well grounded, must carefully weigh the claims and evidence for the effectiveness of results. Furthermore, especially inasmuch as disaster management practitioners are responsible for lives and property, there is every need to ensure that proposed science/technological solutions or contributions are reliable as well as effective. There is little room in this community for techniques or methods, which have not been proven. A comprehensive literature survey forms the basis for this report.

In this document, categories of EO capability are distinguished thus:
Operational: Where science is proven and technology, systems and processes exist to provide a continuing operational service (not necessarily everywhere).
Developmental: Methodology/technology has been validated and is in the process of being implemented operationally.
Research: Results are uncertain or form the basis for ongoing research and understanding. Not expected to be directly used by the practitioner. The mechanisms and occurrence of earthquakes are not understood as well as they are in the case of most other disasters. For this reason, in comparison with other disasters, more emphasis and effort are placed on earthquake-related research.

Three phases of operation are recognised – mitigation, warning and response. For earthquakes specifically, these terms mean the following:
Mitigation: Involves risk reduction and monitoring to lessen socio-economic impact of a possible earthquake event. Can be GIS-based and include mapping of population vulnerability (including building stock) and exposure as input to planning and building regulations. Mapping strain (particularly by ground-based networks) and geology, planning logistics for response scenarios, planning evacuation routes, public education programmes.
Warning: Forecasting and warning processes and systems. For earthquakes, this implies predicting an event to within 15km, a few days, and one order of magnitude – a current impossibility by accepted scientific methods.
Response: Mapping damage extent and nature; primarily for purposes of relief. The information required in the first hours after an event is not necessarily the same as that required days or weeks afterwards, e.g. mapping damage for insurance loss estimation.

The rest of the document discusses each of these three phases in turn, considering:
- The disaster manager's information requirement
- The current EO capability, stating whether the capability is operational, developmental or for research
- Ideal EO capability
- Recommendations for next steps

II. MITIGATION

Earthquake disaster mitigation means trying to protect the public against the possible impact of future earthquake events. The obvious course for action is to remove populations from zones of known high seismic risk. In most cases this is not economically practical, and, particularly in developing countries, the reverse is in fact occurring.

Alternatively, it is possible but very costly to construct an environment, which will withstand almost any earthquake. But the high cost is often prohibitive and therefore dictates the need for an accurate assessment of the exposure and vulnerability of settlements in terms of the probability of occurrence and magnitude, and the accelerations likely to be experienced. EO can certainly help in mapping exposure (e.g. settlement proximity to areas at risk) and can go some way in identifying vulnerability (e.g. building characterisation). Assessing the probability of occurrence, magnitude and likely accelerations, however, is an extremely difficult task in regions where earthquakes occur frequently, and a practically impossible challenge where they are rare.

Where there are enough seismic data, the frequency of large-magnitude events can be gauged by extrapolation from the frequency of smaller events. This, however, is providing only a first approximation; to get a better assessment, geophysicists try to locate, map, and understand local faults and their frequency and mechanism of rupture. This understanding is placed in the context of the regional tectonic setting of crustal motion (neo-tectonics). In areas of low seismicity (where earthquakes can still pose a serious threat), assessments of frequency and magnitude are based on geological evidence (slickensides, sand blows, etc.) as well as tectonics. It is important to recognise that this fundamental geophysical research makes a direct and important link to the practical issues of effective earthquake mitigation.

There is consequently a requirement for a variety of spatial and temporal information from different sources: demographics, building stock characterisation, seismic history and neo-tectonic understanding, the location of faults and an understanding of their mechanism dynamics, including fault motion and strain.

Information requirement summary

- Demographics
- Infrastructure (communications, utility and high risk installations, hospitals, relief centres)
- Building stock
- Seismic history
- Neo-tectonics
- Lithology
- Fault locations and fault mechanism dynamics
- Strain estimates and budgets

Information user

- National to local authorities (planners, building regulators).
- Government agencies with specific charge to mitigate against earthquake risk.
- National survey agencies.
- Possible disaster management co-ordinating body (see recommendations).
- Possibly some relief agencies (planning for disaster scenario).
- Insurance/re-insurance industry (assess liability).
- Risk management consultancies.
- Private enterprise (to mitigate financial impact and losses)

Current EO capability

Following are areas of contribution of space technology to earthquake disaster mitigation (ranging from operational to research):

Demographics and infrastructure: Basic maps simply showing the location of settlements are still considered secret intelligence in many parts of the world. After the Afghanistan earthquake of February 20 1998 which killed approximately 10,000 people relief efforts were hampered by the unavailability of such simple maps – aid workers simply did not know the location of affected villages. High resolution, e.g. SPOT panchromatic, and VHR data could play a significant role in this type of base-mapping of all regions in the developing world in zones of high seismic risk. Augmenting the locations of settlements, risk managers ideally want databases of building stock. With this information, rapid estimates of damage can be made for any given earthquake scenario, either pre-event for planning, or post-event for response. With the right political will, such databases could be instigated now within a GIS environment, coincided with other data layers including seismic history, geology, known strain, locations of relief centres, hospitals, etc. This would have the added benefit of highlighting vulnerability and exposure in a more systematic and consistent fashion than is currently performed. Such a database would be invaluable in providing rapid base information to those administering relief and managing disaster logistics. ***Status: operational*** (if resourced).

Tectonic setting: The regional tectonic setting of an area forms the basis for assessing its seismicity. In some cases, e.g. Japan and Southern California, the setting is well known, but in others, e.g. Central and Eastern US, the origin of seismicity is less clear. Several space-based techniques continue to contribute significantly to our understanding of regional tectonics including satellite geodesy (satellite laser ranging, very long baseline interferometry and use of GPS). Radar, and in the future laser altimetry, is useful, especially over the ocean to map the geoid and gravity field. Even satellite data on the magnetic field are used to study and interpret regional tectonics. Geophysical contributions from these satellites will increase as their capabilities in terms of sensitivity and resolution improves. ***Status: operational.***

Neo-tectonics: Recent tectonic activity is closely associated with contemporary seismicity and is studied in several ways using satellite observations. Both optical and radar data are used to image, for example, active fault scarps, actively growing folds at the surface that record buried tip-line thrusting and stream offsets or topographic breaks of slope that relate to active faulting. Multispectral or hyperspectral optical satellite data may, under some circumstances, be used for lithological discrimination that must be mapped to allow geo-chronological correlation. Most of these techniques require as good a resolution as is available, though Landsat TM at 30m (and now ETM) is often the standard tool. In addition, satellite data can be used to map lithology within a seismic zone to infer potential mechanical responses to an earthquake, such as liquefaction in flat lying coastal or lacustrine environments or slope failure for a continuum of rock competencies. ***Status: operational.***

Lineament mapping: These often-obscure features are observed in synoptic space images as, for example, alignments of vegetation and topography. They may be the surface manifestation of active faults and evidence of seismicity. Virtually constant (solar or radar) illumination angle can seriously bias results and the relationship between lineaments and seismicity is not very strong. Nevertheless, in areas susceptible to occasional earthquakes and/or where other data are sparse, lineament mapping is a useful operational tool. Visible and infrared imagery with moderate (>10m) resolution is generally used. Synthetic Aperture radar (SAR) may also be used but the self-illumination of radar can create false impressions of linearity. ***Status: operational.***

Fault-motion and strain: For two decades satellite laser ranging and very long baseline interferometry have been used to monitor strain and crustal motion respectively in the vicinity of active faults. These techniques have since been superseded by GPS as rapid development of receivers has made it possible to install them in dense networks to monitor large areas, e.g. the Los Angeles Basin and the whole of Japan. Using these arrays, it is possible to improve maps of known faults, detect possible unknown faults, and locate places on these faults which are locked and therefore susceptible to sudden rupture and earthquakes.

Measurement of ground strain and stress accumulation is a direct and valuable input to models of earthquake risk, and for prone countries that have the money, wide-area GPS arrays are now used to monitor horizontal ground motions. In recent years, InSAR has demonstrated the ability to map line-of-sight ground motions, and work is underway to develop hybrid InSAR technologies to supplement or even replace GPS networks.

Three complementary InSAR techniques are appropriate in earthquake risk management: conventional (imaging) InSAR, Permanent Scatterer InSAR (PSInSAR), and Corner Reflector InSAR (CRInSAR).

Conventional InSAR: This technique can deliver spectacular measurements of the large-scale ground deformations associated with main earthquake events, *provided* the temporal separation and horizontal baseline between the two SAR scenes used are kept within appropriate limits. Many examples exist. Such results on their own offer unique input to strain models and support the understanding of fault mechanisms, and have even been successfully used for the verification of insurance claims. Though usually applicable to the main co-seismic event, and so is perhaps a ‘response’ technique, the deformation information can provide valuable understanding of fault mechanisms and thus input to forecast models in the mitigation phase. However, conventional InSAR is not considered a tool for the measurement of the millimetre-scale motions associated with interseismic activity; the displacement resolution of the technique becomes degraded by temporal decorrelation and/or atmospheric heterogeneity resulting in phase ambiguites of similar orders of magnitude as the ground displacements anticipated.

Corner reflector InSAR: This technique involves the placement of man-made radar reflectors, against which precise, sub-centimetre measurements of displacement can be measured over time. CRInSAR is appropriate for the motion monitoring of specific structures (dams, bridges, power stations, etc) or more localised areas at risk The attraction of using corner reflectors is their positional stability, zero maintenance requirement and, in particular, their persisting high coherence over the time-spans needed to detect tectonic motion. However, the techinique is invasive and there can be issues of reflector security on the ground.

Permanent scatterer InSAR: This technique involves the processing of more than 30 interferograms over the same place to identify a network of temporally-stable, highly reflective ground features – permanent scatterers. The phase history of each scatterer is then extracted to provide interpolated maps of average annual ground motions, or more importantly, the motion history, up to 9 years (length of SAR data archive), of each individual scatterer, thus providing a ‘virtual’ GPS network with ‘instant’ history. Due to the relatively high density of scatterers that occur in built environments (a few hundred per square kilometre) and the large number of atmosphere samples (SAR scenes) used, the heterogeneity of the atmosphere can be accurately modelled so that measurements of sub-millimetre accuracy can be calculated. A limitation of PSInSAR is the lack of control over precise scatterer location, but with the densities obtained in built environments this is not considered an issue for the mapping of interseismic ground motions.

Status for InSAR techniques: Developmental & operational (dependent on land cover characteristics and SAR data coverage).

Ideal EO capability

InSAR synergy: None of the three InSAR techniques on their own offer a complete solution to the monitoring of co- and interseismic ground motions. Each technique has its own advantages and disadvantages. The degraded resolution of conventional InSAR renders the technique more appropriate to the mapping of larger scale displacements in terms of both magnitude and coverage, in other words it is more appropriate to the measurement of main earthquake events. Given sufficient repeat SAR data, the sub-millimetre accuracy of PSInSAR does represent an effective tool for the measurement of interseismic ground motions. However, the PSInSAR model makes assumptions about the atmosphere that might not be true from one urban conurbation to another (within the same SAR frame) that might be separated, for example, by 25km of non-scattering, rural farmland. Interpolating PS results between such large distances could be misleading. Depending on the density of scatterers, PSInSAR is more appropriate to the monitoring of contiguously developed areas. The advantage of CRInSAR is that the target against which measurements are made can be sited exactly where required - across a bridge, around a dam, along a pipeline, across a fault. Because of the invasive nature of CRInSAR and the costs associated with the manufacture and deployment of reflectors, CRInSAR is considered more appropriate to localised installation[1].

If we assume an existing 30-scene + archive of SAR data, and a promised continuity of repeat acquisitions, then the InSAR technique to apply is determined by a) area to be monitored, b) ground velocity, and c) distribution of existing scatterers. Consider the table below.

Apply this technique	When	Area to be monitored	Ground velocity (slow= interseismic) (fast=coseismic)	Scatterer distribution
Conventional InSAR		Regional	Fast	Poor
CRInSAR		Structure specific	Slow or fast	Poor
PSInSAR		Contiguous development	Slow or fast	Good

Assuming a supply of data, the ideal strategy might be as follows:

- Continuous acquisition of data over the area at every opportunity to enable PSInSAR as soon as possible.
- Installation of CRs around sensitive developments or faults. Measurements against these can be made after only two post installation acquisitions.
- The acquisition strategy allows for the generation of a conventional interferogram should an earthquake of large magnitude strike.

[1] A new and promising hybrid to CRInSAR is the development of a small and inexpensive 'active transponder' that will emit SAR frequency radiation when illuminated by the same. Providing such devices can prove phase-stable over time, the possible applications are widespread.

If a mission existed that could acquire coverage say twice a day, coherence should be adequate for all but the most rainforested of areas. This, plus continuous additions to the interferogram time-series could allow the atmosphere to be modelled out. If such a mission existed, conventional InSAR on its own might enable the reliable measurement of interseismic motions (above some millimetre threshold).

It is important to note that in all InSAR techniques, phase change measurements are line-of-sight between the satellite and the target. The InSAR result on its own does not de-couple horizontal from vertical displacements. The technique also becomes progressively less sensitive if the vector of displacement nears that of the satellite track. For these reasons, until such times as mulit-view angle satellite constellations exist, InSAR techniques are likely to be largely supplemental to other ground-based monitoring systems.

Recommendations for earthquake disaster mitigation

1. Compile base-maps and building stock databases of high risk areas: Expand existing global database of seismic risk zones, and integrate with population distribution, vulnerability and exposure, seismic history, relevant geology, known strain, estimated InSAR coherence levels and optical VHR-derived base-maps.
2. SAR data providers to optimize the raw data supply chain for InSAR analysis.
3. SAR data providers to consider the acquisition of strategic datasets over high-risk areas to facilitate Permanent Scatterer InSAR strain mapping and co-seismic interferogram generation.
4. Undertake Permanent Scatterer InSAR over high risk areas to establish virtual positioning arrays and produce 9 year record of strain.
5. Agency certification of EO products.

III. WARNING

A prediction of earthquake can be extremely dangerous. It can ignite fear and anxiety, resulting in disorder and chaos and a level of damage and injury that might approach that of the predicted earthquake itself. It is for this reason that some authorities have established strict protocols for the evaluation and issuance of earthquake warnings. In addition to being validated and issued by an official authority, an effective prediction should be specific and accurate in three regards: time, place, and magnitude. The accuracies required vary with respect to the purpose of the prediction: public alerts should be accurate to within (about) 15km of the epicenter, a few days of occurrence and within 1 unit of magnitude. For other purposes (for example, advanced warning to officials and public works) they may be less accurate but, in this case, care must be given to avoid public release or disclosure.

There are no generally accepted operational methods for predicting earthquakes. Although some successes have been claimed, they are questionable and, in any case, not sufficiently reliable. Techniques being investigated range from the reaction of animals, to inert gas content of well waters. Variations in the electrical field have also been claimed to be precursors to earthquakes. Some of these “signals” have been observed from space and reported in Russian and Chinese literature. However, the validity of this technique is hotly disputed. Thermal anomalies, particularly over the ocean, are also claimed as earthquake precursors but here again the reliability (and physics) of the process is questioned. While research on these space-based (and other) techniques continues, it seems that we are still far from a method, which will provide predictions of sufficient accuracy to meet operational requirements.

Information requirement summary

- Timing of event accurate to within a few days.
- Location of predicted epicentre, accurate to within around 15km.
- Magnitude of event accurate to within 1 unit of measurement.

Current EO capability

None. Claims that thermal and electromagnetic signals may provide warnings are being investigated.

Ideal EO capability

Science and technical issues not understood sufficiently to recommend any ideal EO capability.

Recommendations for earthquake disaster preparedness/warning

Maintain awareness of, and support investigations into areas of earthquake forecasting research (e.g. thermal, electromagnetic).

IV. RESPONSE

Earthquakes can completely devastate a region in a very short space of time, so it is necessary to provide emergency help quickly. Emergency managers must therefore have some information, even if it is approximate, on what they are facing within hours after the event. The urgency for information following a severe earthquake is so immediate that some major relief organizations depend on damage assessment models. These models will contain data on building stock, infrastructure, utilities and other important aspects of the built environment (e.g. hazardous chemical stockpiles). In addition, the models will contain data relative to seismic acceleration (depth to bedrock, soil type etc). With specific data on location, depth, magnitude and first arrival of a seismic event, these models can provide very valuable timely approximations to the extent of damage. An example of such methodology, though still in its infancy, is the Russian 'Extremum' system. *Note that the database recommended for the mitigation phase is relevant to response.*

The information required is a function of both time and geographic distribution. For buried victims to have any chance of being brought out alive, information on the location of damage and access routes is needed from immediately after the event to within a few days. The information need not be cartographically accurate, as most emergency services able to respond within this time frame will have some knowledge of local geography. It is when more formal, non-local relief arrives that accurate, georeferenced maps become essential. Registered data are also needed to map the fires, which frequently accompany earthquakes.

In the days following an earthquake, more detailed information on structural damage is needed. As days become weeks, additional information becomes less and less important. The rate at which the life-saving value of new information decays depends, in large part, on the geographic extent and communication infrastructure of the affected area and the concentration of population. In sparsely populated mountainous areas for example, information on villages affected by large earthquakes may be valuable days and even weeks after the event as rescue teams try to locate people in need of assistance.

It is important to recognise the needs of the insurance industry and the risk management consultancies that serve them. This is because the insurance industry influences the instigation and adherence to earthquake-sensitive building codes, therefore mitigating against future loss of life and damage. Insurers need to map risk and damage to assess their liability and validate claims. To this user, there is no NRT requirement, damage maps still being useful weeks after an event.

Information requirement summary

- Location, nature and extent of damage
- Databases of infrastructure and building stock
- Location of fires
- Location of utilities (including both those of potential use and those of high-risk, e.g. chemical plants, nuclear reactors, dams, etc)
- Changes to access (e.g. roads or bridges destroyed)
- Extent of any flooding

Information user

- Emergency services
- Relief agencies
- National and local authorities
- Insurers and risk management consultancies
- National surveys and mapping agencies
- Construction industry
- Media

Current EO capability

Damage mapping using image-differencing: As stated within the mitigation section, pre-prepared GIS databases and delivery systems would be of value in the response phase when relief services are planning logistics to reach victims and make safe damaged structures. Using post-event acquisitions, the EO imagery contained within such databases could also be used to generate difference images to assist in the mapping of damage. 1m VHR data, such as that acquired by IKONOS-2 can map damage directly to useful degrees of accuracy, though utility is much improved given pre-event imagery with which post-event imagery can be differenced (though differences in incidence angle and solar azimuth between the two acquisitions can cause mis-classifications).

Recent work performed for the *International Charter* on the Indian Gujurat earthquake illustrated some of the difficulties in classifying damage (*Chiles, NPA, 2001*). 10m resolution pre- and post-event SPOT panchromatic imagery was acquired and differenced to map change. Results were then compared against a single post-event IKONOS image where damage was directly and thus more easily identifiable. Only one classification of damage out of 30 made from the SPOT temporal difference image was verified as correct using the single post-event 1m IKONOS image. Differing incidence angle and solar azimuth between the pre- and post-event SPOT acquisitions caused many misclassifications of the SPOT data.

<table>
<tr><td rowspan="5">IKONOS interpretation of sites from SPOT change detection processing</td><td rowspan="3">Sites with no apparent damage</td><td>Large or brightly reflective building</td><td>24</td></tr>
<tr><td>Flat ground or possible low buildings</td><td>3</td></tr>
<tr><td>Trees and ground only</td><td>2</td></tr>
<tr><td rowspan="2">Sites with damage</td><td>Collapsed building</td><td>1</td></tr>
<tr><td>Partially damaged building</td><td>0</td></tr>
</table>

Comparison of damage classification between SPOT temporal difference image and single post-event IKONOS

Useful results have also been produced using pre- and post-event 5.8m resolution IRS data over Izmit with effective results, clearly revealing many of the changes to the built environment that occurred due to the quake. The use of IRS data is not currently an NRT application and so is only of relevance to those estimating losses and planning for reconstruction. Ideally, pre- and post-event VHR data should be used for the most accurate damage classification, as there was still some confusion with the single post-event IKONOS scene caused by the extreme density of building stock in this particular Indian town. ***Status: operational*** (if resourced and cloud free).

Non-NRT deformation field mapping: There can be correlation between ground deformation and damage when mapped using conventional InSAR, though damage in this case is dependent on building design and the ground accelerations experienced. This is not currently an NRT application, and so is largely of relevance to those estimating losses and planning for reconstruction. However, it can and has been of significance to those analysing vulnerability and exposure in efforts to re-site populations to safer locations. ***Status: operational*** (where land cover characteristics and SAR data coverage allow).

Damage mapping using night-time differencing: Some useful 'emergency' assessments of urban damage have been made by the Japanese Disaster Prevention Research Institute of Kyoto by differencing pre- and post-event night-time optical imagery from NOAA's AVHRR instrument which makes up to six passes a day. By mapping changes in the distribution of artificial lighting, estimates can be made of potential damage. However, caution is required due to the low, 2.5km spatial resolution, the fact that damage to a single power station might cause large regions to be blacked-out, and of course issues of cloud cover. ***Status: operational*** (where cloud-free imagery exists)

Ideal EO capability

An ideal capability would allow us to map the extent and nature of damage within hours and the deformation field within a few days. Such an NRT service could only be facilitated by multi-platform VHR constellations, preferably SAR, which would have the all-weather capability needed. Besides the hardware in space, supply chains would have to be optimised to ensure the fastest data access and delivery mechanisms.

It is likely that such constellations will one day exist, but be commercially driven and operated by a number of disparate consortia. There are consequently issues of co-ordination to ensure the most efficient imaging regimes for a given event, and commercial/altruistic motivation (who is going to pay?). These issues are common to all disaster types that will benefit from VHR - being the first to image a spectacular volcano is of high promotional value, but the loss of crops after a storm?

Recommendations for earthquake disaster response

1. Compile base-maps of high risk areas: Expand existing global databases of seismic risk zones, and integrate with population centres, infrastructure and building stock databases, seismic history, relevant geology, known strain and optical VHR-derived base-maps.
2. SAR data providers to optimize the raw data supply chain for InSAR analysis.
3. Bring VHR providers into the *International Charter* to facilitate damage assessment (note CNES is already a signatory and SPOT 5 should make significant contribution).
4. Lobby VHR providers for assurance of co-ordinated satellite tasking, data acquisition and rapid data access.
5. Support diversity of VHR missions (in order to improve temporal resolution).
6. Agency certification of EO products.

Proposed Earthquake Emergency Scenario

Activation:
- Dependent upon issues of vulnerability and exposure *vs* magnitude of event.
- Dependent on level of threat to life and / or property (threshold?).

Obtain background information ***Check if considered***

1.	Location and depth of event (lat, long, km)	
2.	Magnitude: Richter (energy release) and Modified Mercalli Intensity (effects)	
3.	Date and time of event	
4.	Responsible relief agencies	
5.	Contact information for relief agencies (including on-scene commander/coordinator)	
6.	Exposure, i.e. proximity of population centers, structures at risk	
7.	Vulnerability, i.e. information on earthquake resistance (e.g. building design)	
8.	Availability of base maps for logistics and communication	

Map damage and extent (utility for base-mapping also)
- Relevant satellites: SPOT-1/2/4, SPOT 5, IRS, IKONOS-2, QuickBird.
- Pre- and post-event imagery imperative for SPOT-1/2/4 and IRS, but desirable for all listed to improve damage classification accuracy.

1.	Availability of pre-event imagery (all listed satellites)	
2.	Availability of post-event imagery (all listed satellites)	
3.	New acquisitions required (*International Charter* signatories?)	
4.	Order pre- and post-event imagery where already acquired	
5.	Submit programming request for new post-event imagery	
6.	Register data and difference, classify damage, package, courier/ftp results	

Map deformation field
- Relevant satellites: ERS-1/2, ENVISAT and Radarsat-1.
- Relevant techniques dependent on previous strategies: Conventional InSAR, PSInSAR, CRInSAR.

1.	Check ERS/ENVISAT archive for minimum threshold repeat coverage for PSInSAR	
2.	Check ERS/ENVISAT archive for post-event acquisitions for conventional InSAR compliant pre- and post-event pairings, and to update CRInSAR analysis if relevant	
3.	Check Radarsat archive for post-event acquisitions for conventional InSAR compliant pre- and post-event pairings, and to update CRInSAR analysis if relevant	
4.	Submit programming request for new post-event acquisitions	
5.	Process, interpret, package, courier/ftp results	

Priorities for image acquisition planning

1.	Post-event VHR acquisitions for damage and base mapping	
2.	Post-event ERS/Radarsat for InSAR deformation field mapping	

Notes:
- Data delivery channels to be determined, e.g. via space agency or distributor?
- Specifications of finished product to be determined.
- Delivery mechanism and protocols to be determined.

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REFERENCES

Earthquakes

1. Armijo, R; Lyoncaen, H; Papanastassiou, D (1991). *A possible normal-fault rupture for the 464-bc Sparta earthquake*. Nature 351: (6322) 137-139.
2. Bhatia, Sc; Chetty, Trk; Filimonov, Mb; Gorshkov, Ai; Rantsman, Ey; Rao, Mn (1992). *Identification of potential areas for the occurrence of strong earthquakes in Himalayan arc region*. Proceedings of the Indian academy of sciences-earth and planetary sciences 101: (4) 369-385.
3. Bock, Y; Agnew, Dc; Fang, P; Genrich, Jf; Hager, Bh; Herring, Ta; Hudnut, Kw; King, Rw; Larsen, S; Minster, Jb; Stark, K; Wdowinski, S; Wyatt, Fk (1993). Detection of crustal deformation from the Landers earthquake sequence using continuous geodetic measurements. *Nature 361: (6410) 337-340.*
4. Boskova, J; Smilauer, J; Jiricek, F; Triska, P (1993). *Is the ion composition of the outer ionosphere related to seismic activity.* Journal of atmospheric and terrestrial physics 55: (13) 1689-1695.
5. Bossu, R; Grasso, Jr; Plotnikova, Lm; Nurtaev, B; Frechet, J; Moisy, M (1996). *Complexity of intracontinental seismic faultings: the Gazli, Uzbekistan sequence.* Bulletin of the seismological society of America 86: (4) 959-971.
6. Buchbinder, Ggr; Sarria, A (1994). *A satellite-based seismic and volcanic monitoring-system for Colombia*. Bulletin of the seismological society of America 84: (5) 1670-1674.
7. Chiles, R *et al*, NPA (2001*) Satellite image analysis for earthquake damage assessment of Bhuj, Western Gujurat, India*. Document produced for ESA under the *Internatianal Charter: Space & Major Disasters*
8. Das, Jd; Saraf, Ak; Jain, Ak (1996). *A satellite picture reveals seismically potential tectonic structures in north-east India.* International journal of remote sensing 17: (8) 1433-1437.
9. Ferretti, A. Rocca, F. Prati, C. (1999) *Permanent scatterers in SAR interferometry*. Proceedings IGARSS'99, Hamburg, Germany. June 28-Jul 02 1999.

10. Ferretti, A. Rocca, F. Prati, C. (1999) *Non-uniform motion monitoring using the permanent scatterers technique*. FRINGE '99: Second ESA international workshop on ERS SAR interferometry: Advancing ERS SAR interferometry from applications towards operations, 10-12 November 1999, Liège, Belgium.
11. Fuenzalida, H; Dorbath, L; Cisternas, A; Eyidogan, H; Barka, A; Rivera, L; Haessler, H; Philip, H; Lyberis, N (1997). *Mechanism of the 1992 Erzincan earthquake and its aftershocks, tectonics of the Erzincan basin and decoupling on the north anatolian fault*. Geophysical Journal International 129: (1) 1-28.
12. Gaulon, R; Chorowicz, J; Romanowicz, B (1991). *The south Sudan earthquakes of may-July 1990 - evidence of an active intracontinental transform zone*. Comptes Rendus de l Academie des Sciences serie ii 312: (4) 377-384.
13. Gaulon, R; Chorowicz, J; Vidal, G; Romanowicz, B; Roult, G (1992). *Regional geodynamic implications of the May July 1990 earthquake sequence in southern Sudan.* Tectonophysics 209: (1-4) 87-103.
14. Gupta, Rp; Chander, R; Tewari, Ak; Saraf, Ak (1995). *Remote-sensing delineation of zones susceptible to seismically induced liquefaction in the Ganga plains*. Journal of the Geological Society of India 46: (1) 75-82.
15. Harjono, H; Diament, M; Dubois, J; Larue, M; Zen, Mt (1991). *Seismicity of the Sunda strait - evidence for crustal extension and volcanological implications.* Tectonics 10: (1) 17-30.
16. Haynes, M. (1999) *Corner reflector aspects of the SNAP program: Demonstrating the utility of differential SAR interferometry for the assessment of earthquake risk.* FRINGE '99: Second ESA international workshop on ERS SAR interferometry: Advancing ERS SAR interferometry from applications towards operations, 10-12 November 1999, Liège, Belgium.
17. Massonnet, D (1997) *Satellite radar interferometry.* Scientific American, February 1997.
18. Meyer, B; Armijo, R; Massonnet, D; Dechabalier, Jb; Delacourt, C; Ruegg, Jc; Achache, J; Briole, P; Papanastassiou, D (1996). *The 1995 Grevena (northern Greece) earthquake: fault model constrained with tectonic observations and SAR interferometry*. Geophysical research letters 23: (19) 2677-2680.
19. Qiang, Zj; Dian, Cg; Wang, Xj; Zhao, Y (1993*). Using Meteosat to remotely monitor Taiwan earthquakes*. Chinese science bulletin 38: (24) 2062-2066.
20. Schweig, Es; Marple, Rt (1991). *Bootheel lineament - a possible co-seismic fault of the great new Madrid earthquakes*. Geology 19: (10) 1025-1028.
21. Tuttle, M; Barstow, N (1996). *Liquefaction-related ground failure: a case study in the new Madrid seismic zone, central United States*. Bulletin of the seismological society of america86: (3) 636-645.
22. Victor, Lam; Baptista, Mav; Simoes, Jz (1991). *Destructive Earthquakes and Tsunami warning system*. Terra nova 3: (2) 119-121.
23. Werner, C; Rosen, P; Scott, H; Fielding, E; Buckley, S (2000) *Detection of asesimic creep along the San Andreas Fault near Parkfield, CA with ERS-1 radar interferometry.* Jet Propulsion Laboratory.

24. Wright, T; Fielding, E; Parsons, B. (2000) *Triggered slip: observations of the 17 August 1999 Izmit (Turkey) earthquake using radar interferometry.* Geophys. Res. Lett. 2000 (In Press).
25. Zebker, H; Rosen, P; Goldstein, R; Gabriel, A; Werner, C (1994) *On the derivation of coseismic dosplacement fields using differential radar interferometry: The Landers earthquake.* Journal of Geophysical Research, Vol. 99, B10, pp 19,617-19,634, October 1994.

General geology

1. Agarwal, Rp; Bhoj, R (1992). *Evolution of Kosi river fan, India - structural implications and geomorphic significance.* International journal of remote sensing 13: (10) 1891-1901.
2. Ameen, Ms (1991). *Possible forced folding in the Taurus-Zagros belt of northern Iraq.* Geological magazine 128: (6) 561-584.
3. Astaras, T (1994). *The present state of the remote-sensing applications to geological sciences in Greece.* International journal of remote sensing 15: (6) 1251-1258.
4. Berger, Z; Williams, Thl; Anderson, Dw (1992). *Geologic stereo mapping of geologic structures with SPOT satellite data.* AAPG Bulletin-American association of petroleum geologists 76: (1) 101-120.
5. Gladczenko, Tp; Coffin, Mf; Eldholm, O (1997). *Crustal structure of the Ontong Java plateau: modeling of new gravity and existing seismic data*. Journal of geophysical research-solid earth 102: (b10) 22711-22729.
6. Gordon, Rg (1995). *Plate motions, crustal and lithospheric mobility, and paleomagnetism: prospective viewpoint.* Journal of geophysical research-solid earth 100: (b12) 24367-24392.
7. Grimaud, P; Richert, Jp; Rolet, J; Tiercelin, Jj; Xavier, Jp; Morley, Ck; Coussement, C; Karanja, Sw; Renaut, Rw; Guerin, G; Leturdu, C; Michelnoel, G (1994). *Fault geometry and extension mechanisms in the central Kenya rift, East-Africa - a 3d remote-sensing approach*. Bulletin des Centres de Recherches exploration-production Elf Aquitaine 18: (1) 59-92.
8. Huamanrodrigo, D; Chorowicz, J; Defontaines, B; Guillande, R; Rudant, Jp (1993). *Structural geology from space images of a zone submitted to natural hazards - the Colca area (southern Peru).* Bulletin de la Societe Geologique de France 164: (6) 807-818.
9. Karnieli, A; Meisels, A; Fisher, L; Arkin, Y (1996). *Automatic extraction and evaluation of geological linear features from digital remote sensing data using a Hough transform*. Photogrammetric engineering and remote sensing 62: (5) 525-531.
10. Karpuz, Mr; Roberts, D; Olesen, O; Gabrielsen, Rh; Herrevold, T (1993). *Application of multiple data sets to structural studies on Varanger peninsula, northern Norway*. International journal of remote sensing 14: (5) 979-1003.
11. Leturdu, C; Coussement, C; Tiercelin, Jj; Renaut, Rw; Rolet, J; Richert, Jp; Xavier, Jp; Coquelet, D (1995). *Rift basin structure and depositional patterns interpreted using a 3d remote-sensing approach - the Baringo and Bogoria basins, central Kenya rift, East-Africa*. Bulletin des Centres de Recherches exploration-production elf aquitaine19: (1) 1-37.

12. Nash, Cr; Rankin, Lr; Leeming, Pm; Harris, Lb (1996). *Delineation of lithostructural domains in northern Orissa (India) from Landsat Thematic Mapper imagery.* Tectonophysics 260: (4) 245-257.
13. Noomen, R; Springer, Ta; Ambrosius, Bac; Herzberger, K; Kuijper, Dc; Mets, Gj; Overgaauw, B; Wakker, Kf (1996). *Crustal deformations in the Mediterranean area computed from SLR and GPS observations.* Journal of geodynamics 21: (1) 73-96.

Ground networks

1. Fejes, I; Borza, T; Busics, I; Kenyeres, A (1993). *Realization of the Hungarian geodynamic GPS reference network.* Journal of geodynamics. 18: (1-4) 145-152.
2. Gendzwill, D; Unrau, J (1996). *Ground control and seismicity at international minerals and chemical (Canada) global limited.* Cim bulletin 89: (1000) 52-61.
3. Jackson, J; Haines, J; Holt, W (1994). A comparison of satellite laser ranging and seismicity data in the Aegean region. *Geophysical research letters 21: (25) 2849-2852.*
4. Kahle, Hg; Muller, Mv; Veis, G (1996). *Trajectories of crustal deformation of western Greece from GPS observations 1989-1994.* Geophysical research letters 23: (6) 677-680.
5. Reilinger, Re; Mcclusky, Sc; Oral, Mb; King, Rw; Toksoz, Mn; Barka, Aa; Kinik, I; Lenk, O; Sanli, I (1997). *Global positioning system measurements of present-day crustal movements in the Arabia-Africa-Eurasia plate collision zone*. Journal of geophysical research-solid earth 102: (b5) 9983-9999.
6. Robaudo, S; Harrison, Cga (1993). *Measurements of strain at plate boundaries using space-based geodetic techniques.* Geophysical research letters 20: (17) 1811-1814.

Miscellaneous

1. Bernard, En; Milburn, Hb (1991). *Improved satellite-based emergency alerting system*. Journal of atmospheric and oceanic technology 8: (6) 879-883.
2. Evans, Dl; Plaut, Jj; Stofan, Er (1997). *Overview of the spaceborne imaging radar-c/x-band synthetic aperture radar (SIR-C/X-SAR) missions.* Remote sensing of environment 59: (2) 135-140.
3. Grigorev, Aa; Kondratev, Ky (1997). *Satellite monitoring of natural and anthropogenic disasters*. Earth observation and remote sensing 14: (3) 433-448.
4. Marple, Rt; Schweig, Es (1992). *Remote-sensing of alluvial terrain in a humid, tectonically active setting - the new Madrid seismic zone*. Photogrammetric engineering and remote sensing 58: (2) 209-219.
5. Massonnet, D (1996). *Tracking the earth's surface at the centimetre level: an introduction to radar interferometry*. Nature & resources 32: (4) 20-29.
6. Mccarthy, Ts; Franey, Nj; Ellery, Wn; Ellery, K (1993). *The use of spot imagery in the study of environmental processes of the Okavango delta, Botswana*. South African journal of science 89: (9) 432-436.
7. Ramasamy, Sm; Bakliwal, Pc; Verma, Rp (1991). *Remote-sensing and river migration in western India*. International journal of remote sensing 12: (12) 2597-2609.

Other techniques

1. Dea, Jy; Hansen, Pm; Boerner, Wm (1993). *Long-term Elf background-noise measurements, the existence of window regions, and applications to earthquake precursor emission studies.* Physics of the earth and planetary interiors 77: (1-2) 109-125.
2. Galperin, Yi; Hayakawa, M (1996). *On the magnetospheric effects of experimental ground explosions observed from aureol-3.* Journal of geomagnetism and geoelectricity 48: (10) 1241-1263.
3. Henderson, Tr; Sonwalkar, Vs; Helliwell, Ra; Inan, Us; Frasersmith, Ac (1993). *A search for Elf VLF emissions induced by earthquakes as observed in the ionosphere by the de-2 satellite.* Journal of geophysical research-space physics 98: (a6) 9503-9514.
4. Johnston, Mjs; Mueller, Rj; Sasai, Y (1994). *Magnetic-field observations in the near-field the 28 June 1992 m(w) 7.3 Landers, California, earthquake.* Bulletin of the Seismological Society of America 84: (3) 792-798.
5. Molchanov, Oa; Hayakawa, M; Rafalsky, Va (1995). *Penetration characteristics of electromagnetic emissions from an underground seismic source into the atmosphere, ionosphere, and magnetosphere*. Journal of geophysical research-space physics 100: (a2) 1691-1712.
6. Molchanov, Oa; Mazhaeva, Oa; Goliavin, An; Hayakawa, M (1993). *Observation by the intercosmos-24 satellite of Elf-VLF electromagnetic emissions associated with earthquakes.* Annales Geophysicae-Atmospheres Hydrospheres and space sciences 11: (5) 431-440.
7. Molchanov, Oa; Mazhaeva, Oa; Protopopov, Ml (1992). *Electromagnetic VLF radiation of seismic origin observed on the interkosmos-24 satellite*. Geomagnetizm I Aeronomiya 32: (6) 128-137.
8. Mouthereau, F; Angelier, J; Deffontaines, B; Lacombe, O; Chu, Ht; Colletta, B; Deramond, J; Yu, Ms; Lee, Jf (1996). *Present and recent kinematics of the Taiwan collision front*. Comptes rendus de l academie des sciences serie ii fascicule a-sciences de la terre et des planetes 323: (8) 713-719.
9. Parrot, M (1995). *Use of satellites to detect seismo-electromagnetic effects*. Natural hazards: monitoring and assessment using remote sensing technique 15: (11) 27-35.
10. Parrot, M (1994). *Statistical study of Elf/VLF emissions recorded by a low-altitude satellite during seismic events.* Journal of geophysical research-space physics 99: (a12) 23339-23347.
11. Rodger, Cj; Thomson, Nr; Dowden, Rl (1996). *A search for Elf/VLF activity associated with earthquakes using ISIS satellite data*. Journal of geophysical research-space physics 101: (a6) 13369-13378.

Tectonics and faulting

1. Alwash, Ma; Zakir, Far (1992). *Tectonic analysis of the Jeddah Taif area on the basis of Landsat satellite data.* Journal of African earth sciences 15: (2) 293-301.
2. Bellier, O; Sebrier, M (1994). *Relationship between tectonism and volcanism along the great Sumatran fault zone deduced by spot image analyses.* Tectonophysics 233: (3-4) 215-231.

3. Biancale, R; Cazenave, A; Dominh, K (1991). *Tectonic plate motions derived from Lagos*. Earth and planetary science letters 103: (1-4) 379-394.
4. Chetty, Trk; Murthy, Dsn (1994). *Collision tectonics in the late Precambrian Eastern Ghats mobile belt - Mesoscopic to satellite-scale structural observations*. Terra nova 6: (1) 72-81.
5. Cianetti, S; Gasperini,P; Boccaletti, M; Giunchi, C (1997). *Reproducing the velocity and stress fields in the Aegean region.* Geophysical research letters 24: (16) 2087-2090.
6. Corsini, M; Vauchez, A; Archanjo, C; Desa, Efj (1991). *Strain transfer at continental scale from a transcurrent shear zone to a transpressional fold belt - the Patos-Serido system, northeastern Brazil.* Geology 19: (6) 586-589.
7. Cunningham, Wd (1993). *Strike-slip faults in the southernmost Andes and the development of the Patagonian Orocline.* Tectonics12: (1) 169-186.
8. Das, Jd; Saraf, Ak; Jain, Ak (1995). *Fault tectonics of the Shillong plateau and adjoining regions, northeast India using remote-sensing data*. International journal of remote sensing 16: (9) 1633-1646.
9. Deurreiztieta, M; Gapais, D; Lecorre, C; Cobbold, Pr; Rossello E (1996). *Cenozoic dextral transpression and basin development at the southern edge of the Puna plateau, northwestern Argentina.* Tectonophysics 254: (1-2) 17-39.
10. Dunn, Pj; Robbins, Jw; Bosworth, Jm; Kolenkiewicz, R (1996). *Crustal deformation around the Gulf of California.* Geophysical research letters 23: (2) 193-196.
11. Galindozaldivar, J; Jabaloy, A; Maldonado, A; Degaldeano, Cs (1996). *Continental fragmentation along the south Scotia ridge transcurrent plate boundary (NE Antarctic peninsula).* Tectonophysics 258: (1-4) 275-301.
12. Gaudemer, Y; Tapponnier, P; Meyer, B; Peltzer, G; Guo, Sm; Chen, Zt; Dai, Hg; Cifuentes, I (1995). *Partitioning of crustal slip between linked, active faults in the eastern Qilian Shan, and evidence for a major seismic gap, the Tianzhu gap, on the western Haiyuan fault, Gansu (China).* Geophysical journal international 120: (3) 599-645.
13. Ge, Br; Yang, Ky (1990). *Mesozoic-Cenozoic tectonic features in Panzhihua-Xichang area.* Acta geophysica sinica 33: (1) 64-69.
14. Gordon, Rg; Stein, S (1992). *Global tectonics and space geodesy*. Science 256: (5055) 333-342.
15. Hooft, E; Kleinrock, M; Ruppel, C (1995). *Rifting of oceanic-crust at endeavor-deep on the Juan-Fernandez microplate*. Marine geophysical researches17: (3) 251-273.
16. Jordahl, Ka; Mcnutt, Mk; Webb, Hf; Kruse, Se; Kuykendall, Mg (1995). *Why there are no earthquakes on the Marquesas fracture zone*. Journal of geophysical research-solid earth 100: (b12) 24431-24447.
17. Lodolo, E; Coren, F (1997). *A late Miocene plate boundary reorganization along the westernmost pacific-Antarctic ridge*. Tectonophysics 274: (4) 295-305.
18. Lyberis, N; Yurur, T; Chorowicz, J; Kasapoglu, E; Gundogdu, N (1992). *The east Anatolian fault - an oblique collisional belt*. Tectonophysics 204: (1-2) 1-15.
19. Makarova, Nv; Makarov, Vi (1996). *Transverse tectonic zonality of the Kerch peninsula from space survey data*. Earth observation and remote sensing 13: (5) 799-810.

20. Mann, P; Taylor, Fw; Edwards, Rl; Ku, Tl (1995). *Actively evolving microplate formation by oblique collision and sideways motion along strike-slip faults - an example from the northeastern Caribbean plate margin*. Tectonophysics 246: (1-3).
21. Martelat, Je; Vidal, G; Lardeaux, Jm; Nicollet, C; Rakotondrazafy, R (1995). *Satellite images and tectonics of the lower continental-crust - the example of south-western Madagascar*. Comptes rendus de l academie des sciences serie ii fascicule a-sciences de la terre et des planetes 321: (4) 325-332.
22. Mccarthy, Ts; Green, Rw; Franey, Nj (1993). *The influence of neo-tectonics on water dispersal in the northeastern regions of the Okavango swamps, Botswana*. Journal of African earth sciences 17: (1) *23-32.*
23. *Mcintyre, Mc (1991). Sea floor positioning - current needs and a recent advance*. Marine technology society journal 25: (2) 34-42.
24. Ramasamy, Sm; Balaji, S (1995*). Remote sensing and Pleistocene tectonics of southern Indian peninsula*. International journal of remote sensing 16: (13) 2375-2391.
25. Ravat, Dn; Hinze, Wj; Taylor, Pt (1993). *European tectonic features observed by MAGSAT*. Tectonophysics 220: (1-4) 157-173.
26. Raymond, D; Deffontaines, B; Ferhi, A; Dorioz, Jm; Rudant, Jp (1996). *Neotectonic of the south Lemanic area (e-France): a multisource approach (optical images and radar, morphologic analysis*). Eclogae geologicae helvetiae 89: (3) 949-973.
27. Roques, D; Rangin, C; Huchon, P (1997). *Geometry and sense of motion along the Vietnam continental margin: onshore/offshore Da Nang area.* Bulletin de la Societe Geologique de France 168: (4) 413-422.
28. Royden, Lh; Burchfiel, Bc; King, Rw; Wang, E; Chen, Zl; Shen, F; Liu, Yp (1997). *Surface deformation and lower crustal flow in eastern Tibet*. Science 276: (5313) 788-790.
29. Royer, Jy; Rollet (1997). *Plate-tectonic setting of the Tasmanian region*. Australian journal of earth sciences 44: (5) 543-560.
30. Sabadini, R; Vermeersen, Lla (1997). *Influence of lithospheric and mantle stratification on global post-seismic deformation*. Geophysical research letters 24: (16) 2075-2078.
31. Sauvage, Jf; Sauvage, M (1992). *Tectonics, neotectonics and igneous phenomena at the eastern edge of the Nara graben*. Journal of African earth sciences 15: (1) 11-33.
32. Scholz, Ch; Small, C (1997). *The effect of seamount subduction on seismic coupling*. Geology 25: (6) 487-490.
33. Searle, Mp (1996). *Geological evidence against large-scale pre-Holocene offsets along the Karakoram fault: implications for the limited extrusion of the Tibetan plateau*. Tectonics15: (1) 171-186.
34. Spitzak, S; Demets, C (1996). *Constraints on present-day plate motions south of 30 degrees s from satellite altimetry*. Tectonophysics 253: (3-4) 167-208.
35. Taylor, Pt (1991). *Investigation of plate boundaries in the eastern Indian-ocean using MAGSAT data*. Tectonophysics 192: (1-2) 153-158.
36. Tebbens, Sf; Cande, Sc; Kovacs, L; Parra, Jc; Labrecque, Jl; Vergara, H (1997). *The Chile ridge: a tectonic framework*. Journal of geophysical research-solid earth 102: (b6) 12035-12059.

37. Thoue, F; Vidal, G; Gratier (1997). Finite deformation and displacement fields on the southern Yemen margin using satellite images, topographic data and a restoration method. Tectonophysics 281: (3-4) 173-193.
38. Tramutoli, V; Di Bello, G.; Pergola, N.; Piscitelli, S 2001, Robust Satellite Techniques for Remote Sensing of Seismically Active Areas. “Annali di Geofisica” 44:(2), pp. 295-312
39. Wood, R; Lamarche, G; Herzer, R; Delteil, J; Davy, B (1996). *Paleogene seafloor spreading in the southeast Tasman Sea*. Tectonics15: (5) 966-975.
40. Xie, Gl (1991). *Analysis of some characteristics of the fault activities in eastern China by satellite images.* Acta geologica sinica-English edition 4: (4) 357.
41. Zhao, Ls; Helmberger, Dv; Harkrider, Dg (1991). *Shear-velocity structure of the crust and upper mantle beneath the Tibetan plateau and southeastern China*. Geophysical journal international 105: (3) 713-730.
42. Zhu, Wy; Zhang, H; Feng, Cg (1990). *Determination of parameters of present global plate motion using SLR technique*. Science in China series a-mathematics physics astronomy & technological sciences 33: (12) *1477-1487*.
43. *Zikov, Ds; Filimonov, Yl (1994). Remote-sensing of the Neotectonics and young tectonic activity of the geological structures in the Bestube ore fields in the north Kazakhstan.* Soviet journal of remote sensing 11: (5) 863-871.

T E A M   R E P O R T

Fire

FIRE HAZARD TEAM REPORT

CEOS DISASTER MANAGEMENT SUPPORT GROUP

SUMMARY

The purpose of this document is to review potential requirements for space-based observations in fire management. This report was developed under the auspices of the Disaster Management Support Group (DMSG) of the G-7 Committee on Earth Observation Satellites (CEOS). This document was prepared by an international working group, which has experience in the field of remote sensing as applied to wildland fire management. The fire team identifies, in this paper, seven major requirements. These requirements could substantially improve wildland fire management programs, should CEOS augment existing satellites or develop new Earth observation satellites as recommended. Requirements address the different temporal, spatial, and spectral characteristics needed in different phases of fire management and geographic areas of interest. These requirements include fuels mapping, risk assessment, detection, monitoring, mapping, burned area recovery, and smoke management.

The following 11 recommendations support these requirements:

1. Improve satellite technologies and methods to generate accurate, timely, updateable, global wildland fire fuel maps. Provide high-resolution data sets to validate existing methods and test models in tropical, boreal, and temperate forestry environments.
2. Develop data for meso-scale weather models to facilitate daily and 1-2 day prediction of dead and live fuel moisture to augment or replace requirements for ground weather stations.
3. Provide data for decision support models on prescribed fire smoke management and air quality assessment.
4. In geographic areas where rapid response is required, develop an operational satellite wildland fire detection and monitoring system with an ultimate fire detection time of 5 minutes, a repeat time of 15 minutes, a spatial resolution of 250 meters, a maximum of 5% false alarms. This should also have real time data transmission to local ground stations or information networks.
5. Develop and implement an operational system for timely distribution of high-resolution geospatial products displaying fire location and intensity, with the ability to image through smoke and cloud cover.
6. Provide affordable and rapid access to all high-resolution data streams (30m and higher) for burned area assessment and rehabilitation applications.
7. Institute comprehensive global coverage of wildland fires to assess the scale of biomass burning.
8. Develop sensors to monitor smoke over broad geographic areas to help determine the impacts on lower atmospheric chemistry in term of potential global climate change, human health, and human safety.
9. Ensure the continuity of the current civilian satellite systems to maintain their spectral, temporal, and spatial characteristics for local and global coverage of wildland fires.
10. Examine opportunities to develop and release declassified information products derived from classified intelligence and military satellite data to support wildland fire management requirements.
11. Develop an international agreement to improve access to timely and affordable data for the fire management community. CEOS should facilitate this agreement in cooperation with other international organizations.

The fire team also recommends the development of regional wildland fire remote sensing expertise to provide leadership and direction in the use of remote sensing and geospatial technologies for international wildland fire management.

I. BACKGROUND

Natural boreal and temperate forest, brush, and grassland ecosystems evolved and adapted with wildland fire as an agent of ecological change. Human development has altered many natural landscapes and placed people in direct contact with wildland fire. Wildland fires cause loss of human life and personal property, economic upsets, and disturbances in regional and global atmospheric composition and chemistry, and climate. Wildland fire managers wish to respond appropriately to wildland fires to best protect and preserve the resources at risk within the constraints of local policy objectives.

Wildland fires are caused by human activities or by natural phenomena such as lightning or volcanoes. Wildland fires caused by humans can be characterized as either intentional or accidental. Some intentional wildland fires are the result of arson — those that are set to create havoc and cause damage. Most intentional wildland fires, however, are related to forest or shrub removal to transform land for silvicultural or agricultural purposes. These wildland fires are not viewed simply as a technical problem but also as a complex socioeconomic issue.

The term *fire* in this document refers to any wildland fire in the natural environment, including farmland fires. Wildland fire is any nonstructural fire, other than prescribed fire, that occurs in the wildland (and encompasses previous terms such as "prescribed natural fire" and "wildfire").

Information requirements

Managing wildland fire effectively depends on information (that can vary according to the user of the information) the characteristics of the geographic region, and the current and evolving phase of the wildland fire. Suppression planning and prioritization of areas for surveillance requires assessment of the wildland fire potential (risk and hazard mapping) in the fire-prone areas. During the crisis phase, it is necessary to know the exact position of the wildland fire (detection), how it is developing and spreading (behavior), how it has progressed over time (monitoring), and how it is likely to develop into the future (behavior prediction). After suppression it may be necessary to examine the type and extent of damage and to plan for recovery actions (assessment, mapping, and rehabilitation).

Understanding Wildland Fire and its behavior

In simplified models, the behavior of wildland fire depends on three elements: fuel, weather, and topography. Each element has several characteristic parameters, which create a complex set of different combinations for wildland fire behavior.

The fuel may be characterized by the following parameters: biomass condition (living or dead); biomass quantity; moisture content; and vertical and horizontal structure (continuity). To burn, the fuel needs favorable atmospheric conditions, which can be described in terms of weather. The weather's impact on wildland fire behavior can be characterized by the following parameters: wind velocity, wind direction, relative humidity, precipitation, and temperature. A fire's propagation also depends on topographic factors such as aspect (steepness, orientation and position) of the terrain; elevation; and general shape of the terrain (for example, ridge, canyon, flat terrain).

Ancillary Data Requirements

During wildland fire management and suppression, other types of information are crucial, such as information on human settlements (sometimes referred to as the wildland-urban interface) in the wildland fire area, location of water sources for wildland fire suppression, and road networks for access to the area. This essential information is needed for all phases of managing wildland fire. Examples of frequently used sources of information are Orthophotographic imagery and topographic maps. Fire information, combined with three-dimensional views (composed of high-resolution imagery draped over digital elevation surface models) would also be very useful.

II. *SPECIFIC REQUIREMENTS, DESCRIPTIONS AND RECOMMENDATIONS*

In the following section, wildland fire management is divided into three different phases: preparedness, detection and response, and post-fire assessment. The information requirements are typically different in each phase. The most significant differences relate to the temporal and spatial resolution and accuracy of the required information.

Preparedness

The most important task during the preparedness phase of wildland fire management is to assess the values at risk. Conducting risk assessment studies to identify areas with the greatest potential for protecting human lives, property, and natural resources can help authorities impose greater surveillance and/or restrictions on fire use in these areas. Risk assessment considers variables such as land use and land cover, wildland fire history, demography, infrastructure, and urban interface.

Remote sensing is used to derive vegetation stress variables, which are subsequently related to wildland fire occurrence. The most frequently used data source for this information is NOAA/AVHRR data. Alternative data sources are MODIS, ATSR-2; the VEGETATION onboard SPOT 4, as well as the GLI (Global Imager), which will be launched on-board ADEOS-II. Measurement of vegetation stress is one of the most frequent uses of remote sensing in wildland fire management. Fire authorities of the United States, Spain and Southern France use these data systematically during the fire season to determine fire danger ratings. Indices are frequently based on the estimation of live and dead vegetation moisture content, derived from meteorological variables, some of which can be obtained from meteorological satellite data.

Requirement 1. Fuels mapping

Users: land managers; fire prevention personnel; emergency preparedness managers.

Information needed: fuels, climatological data; terrain; vegetation type and moisture level (live and dead); historic fire regime; digital elevation models (DEMs). Fuels mapping is really a modeling exercise using the inputs listed above. One process to map fuels looks at departures of current vegetation / forest types from potential vegetation types. Additional information is needed for determining structural risk associated with biomass, fuel composition and fuel moisture status. This requires high-spatial resolution data (or imagery) to provide estimations of vegetation structure and biomass.

Earth Observation (EO) data sources available: MODIS, NOAA/AVHRR; LANDSAT; SPOT; Ikonos; ADEOS-II/GLI; ATSR. The data source used should be dependent on the study area size.

Improvements needed: 1) calibrated 5-30m multi-spectral (including SWIR at 1.6um for water content estimation and NIR at 0.9um) imagery on a 16-day or better cycle; 2) development of capability for mapping sub-canopy structure and biomass quantification. High-resolution interferometric radar and lidar techniques would provide reliable estimations from space.

<u>*Requirement 2. Identification of wildland fire risk areas - Fire Danger Assessment*</u>
Users: land managers and forest management personnel; international organizations; concerned Ministries and Departments of Interior and Agriculture; insurance companies; emergency management personnel.
Information needed: Human settlement location and lines of communication; fuels information; ecological unit boundaries; vegetation stress; meteorological data.
EO data sources available: LANDSAT; SPOT; Ikonos; ATSR; MODIS; AVHRR; ADEOS-II.
Improvements needed: 1) DEMs available globally at 1m vertical and 5m horizontal accuracy; 2) calibrated 5-30m multi-spectral IR imagery on a 16 day cycle; 3) continuation of 250m to 1k resolution daily AVHRR and MODIS-like products for greenness mapping and drought prediction; 4) development of capability for mapping sub-canopy structure and biomass quantification; and 5) continuous lighting detection in temperate and boreal forest regions; 6) meteorological data, including temperature, wind direction and velocity, humidity, and precipitation available once a day to cover the vegetated areas of the globe.

Recommendations

Information on wildland fire high-risk areas is pivotal to planning for preparedness and wildland fire prevention. There are tools for mapping the risk areas, based on land cover maps, statistical wildland fire information and daily weather conditions. Information on the actual combustible matter, especially on a global scale, is not available. Currently, the estimation of fuel moisture is based on the information from local ground weather stations. Under-canopy observations, integrated with ground measurements, will be required.

Recommendation 1. Improve satellite technologies and methods to generate accurate, updateable, global wildland fire fuel maps. Provide high-resolution data sets to validate existing methods and test models in tropical, boreal, and temperate forestry environments.

Recommendation 2. Develop data for meso-scale weather models to facilitate daily and 1 to 2 day prediction of dead and live fuel moisture to augment or replace requirements for ground weather stations. Provide data for decision support models on prescribed fire smoke management and air quality assessment.

Wildland fire detection and response

Some satellite borne sensors can detect wildland fires in the visible, thermal, and mid-infrared bands. Active wildland fires can be detected by either sensing their thermal or mid-infrared signature during the day or night, or by detecting the light emitted from the wildland fires at night. The sensors must also have frequent over flights with data available in near real time.

The spectral, spatial, and temporal resolutions of current satellite platforms do not adequately meet the need for real-time detection of wildland fires. However, detection of large wildland fires in remote areas, such as Alaska and the tropical forest belts, has been successful using Earth observation.

Existing satellite sensors with wildland fire detection capabilities are not used to their fullest technical extent. All of the sensors currently used were not designed with wildfire detection as an objective. They are instruments with alternative missions that have been creatively used to detect wildfires (with varying degrees of success). They include NOAA-GOES, NOAA-AVHRR, MODIS, and DMSP-OLS. MODIS is the only instrument that has as one of its mission objectives, the detection of wildfires with a working prototype of a global fire detection system. We believe that technology for generating and distributing daily wildland fire products on regional to global scales from these systems is feasible. This would provide an extremely valuable service for both wildland fire management and prevention. There are also multi-instrument integration algorithms that are currently being developed that would lead to a value added solution, increasing the value of any one system.

It is important to increase the temperature detection range (up to about 700K) of existing sensors on future satellites of these series (for the bands in the range of 3 to 4um). This would eliminate existing difficulties in discriminating seasons, fires from sun glint, and exposed/bare soils (in some cases). It would also help to prevent the present saturation problems, which occur at lower levels of emitted radiation, improve the ability of measuring temperatures of burning biomass, and reduce, at a minimum, the occurrence of false alerts (5% maximum desirable). Also desirable would be an 11um channel for detection of lower temperature fires.

Furthermore, in the case of the NOAA-series, it is imperative that the 3.7um channel continues to be active in the mid-afternoon overpass, and not replaced by other channels (as changed in recent years).

Also, regarding the NOAA series, a mid afternoon overpass that does not change by 30-40 minutes from year to year is also suggested, in order to produce more homogeneous data bases (+-20 min or better, with respect to nominal overpass time is desirable).

The future satellites of the NOAA series should be equipped with the necessary attitude control and measurement system, in order to provide to the ground processing system accurate attitude data to allow earth-location accuracy of 1 pixel.

Requirement 3. Rapid Detection

Users: wildland fire community; civil protection services; forestry departments; concerned Ministries and Departments of Interior and Agriculture.

Information needed: location within 1km; measurements of energy release (intensity); detection size of 0.25 acres (0.1 ha). Merge capability with additional data such as meteorology, topography, and fuel maps. In areas where rapid initial attack is anticipated, reports must be received within 5 minutes, with a subsequent confirmation within 5 minutes.

EO data sources available: MODIS, NOAA/AVHRR; DMSP/OLS; GOES; Meteosat GMS (all solely for approximate location and do not meet requirements for minimum fire size, detection time).

Improvement needed: better resolution and accuracy; less than 5 percent false alarms; shorter revisit time (< 30 minutes); measure energy release rate (kilowatts/meter with 500kw resolution); quick access to data, geolocation accuracy of the imagery to less than 1 pixel.

Requirement 4. Local wildland fire monitoring and mapping

Users: Wildland fire community; forestry departments; emergency management organizations.

Information needed: Active fire perimeters located on large scale topographic maps (1:24,000 scale or better) or high resolution ortho-imagery (ground sample distance of 1m) with areas of intense fire, and indicated direction of movement clearly referenced in relation to ground infrastructure and man made and natural fire breaks; integration of ongoing wildland fire

information to supplement fire behavior models in near real time; delivery of map and image products at least once daily in time for incident management planning sessions (generally 6am) to assist wildland fire fighters with individual fire strategies. Fire maps are also used to support mop-up operations following fire containment.
EO data sources available: none at this time
Improvements needed: ability to provide information needed above for baseline requirements. Optimal requirements would provide 30-minute updates for reports on fire line movement and intensity for strategic planning. Ability to image fire location and intensity through smoke and cloud cover is required.

Requirement 5. Global monitoring of wildland fires
Two purposes of monitoring:
for tactical purposes ("to fight the fire")
for strategic global change monitoring
Users: Relief Agencies; Global Changes Research (UNEP, IPCC, IGBP, US-GCRP, NASA, NOAA, EPA, USGS) NGOs; News media; Aviation community; Ministries and Departments of Interior and Agriculture.
Information needed: location; size; transportation networks; population location and census; amount of smoke; amount of aerosols; type of vegetation.
EO data sources available: MODIS, NOAA/AVHRR; DMSP/OLS; GOES; Meteosat; GMS; SPOT-Vegetation; and IRS-WiFS.
Improvements needed: more comprehensive coverage over boreal and tropical forests; better resolution and accuracy (250 meters); quick access to data.

Recommendations

The end users have very strict requirements for the rapid detection of wildland fires. Public reports, watchtower and patrol flight reports currently achieve the average detection time of 15-30 minutes (maximum). A space-borne system should exceed this baseline performance, in order to improve existing systems, but may provide a meaningful and complementary confirming value if they do not. No current satellite system has such a capability. This demanding requirement calls for further consideration to design a constellation of satellites for this purpose.

Recommendation 3. In geographic areas requiring rapid response, develop an operational satellite wildland fire detection and monitoring system with an ultimate detection time of 5 minutes, repeat time of 15 minutes, spatial resolution of 250 meters, a maximum 5 percent false alarm rate, with real time data transmission to local ground stations or an information distribution system.

Local fire mapping for strategic support and suppression response is the highest priority data product required, as it is needed to save human lives and natural and manmade resources. Currently, there are no satellite Earth observation systems commercially available to support local wildland fire monitoring and mapping. For global monitoring of wildland fires, where the detection time is not so crucial, the main requirement is to have good access to the data flow from several information sources. Geostationary and polar-orbiting weather satellites are currently used successfully for mapping and monitoring of wildland fire on a large scale. There is no operational system able to use existing satellites to provide timely, global information.

Recommendation 4. Develop and implement an operational system for the timely distribution of high-resolution geospatial products displaying fire location and intensity, with the ability to image through smoke and cloud cover.

Post-fire assessment

The most important post-crisis activity in wildland fire management is the assessment of the burned area and protection of watersheds and critical resources. Although remote sensing has already proven its usefulness in this activity, very few authorities use space-borne data operationally for assessment of wildland fire damage. With space-borne remote sensing, the wildland fire damage or the extent of burned area is determined by the single-date or multi-temporal analysis of the images.

On national and international scales, NOAA/AVHRR data have been most commonly used for burned area mapping. MODIS data, which has a similar swath width to AVHRR with sixteen (16) times the resolution and superior geolocation accuracy, is quickly assuming this role. The VEGETATION instrument onboard SPOT4 is a new alternative source of data. Also, recent work has demonstrated that calibrated 1.6 micron data, such as that currently available from ATSR-2, may lead to improved fire scar mapping from low-resolution sensors. Access to the AVHRR 1.6 micron data channel would improve current fire scar mapping capabilities further. Other data types of similar spatial and spectral resolution are not widely used because of the difficulty in data acquisition and/or the lack of adequate data. At regional scales within national boundaries, high-resolution data from LANDSAT Thematic Mapper and SPOT/HRVIR are used to determine the extent of wildland fire damage. Space-borne radar data (mainly from ERS/SAR) has been used experimentally, but is not in operational use, probably because of the intrinsic complexity in computer processing of SAR images and unacceptable spatial resolution. Other suitable optical sensors (IRS-1C) and microwave sensors (JERS, RADARSAT) have not been frequently used.

The new medium spatial resolution data from the Indian and Russian remote sensing satellites in conjunction with the high spectral resolution (and also medium spatial resolution) of MODIS (EOS), MERIS (ENVISAT) and GLI (ADEOS-II) may provide very useful imagery for cartography of burned areas on regional to international scales. Some promising experimental projects have been conducted in order to derive the level of damage and the degree to which vegetation has been burned, from high-resolution optical imagery, such as LANDSAT TM, RESURS MSU-E, and IRS-1C LISS-3. The forthcoming high-spectral and spatial optical imagery may provide a unique data source for these types of analyses.

Requirement 6. Local burned area assessment

Users: land managers; emergency management specialists; public works; scientists; aid organizations; environmental agencies; NGOs; insurance companies; Ministries, Departments of Forestry.

Information Needed: area, location, and intensity of burn; damage to natural resources; damage to manmade resources; amount of smoke; amount of aerosols and particulate matter; type of flora and fauna; type of salvage that can be done.

EO data sources available: high resolution – LANDSAT; Ikonos; SPOT; IRS; ERS; JERS-1, ALOS (planned) for area, location and type of damage; moderate resolution – MODIS (Terra and Aqua), IRS-P4; low resolution — NOAA/AVHRR; SPOT Vegetation; ATSR; ADEOS-II/GLI; IRS-WiFS.

Improvements needed: inexpensive high-resolution 5m multi-spectral imagery on a daily cycle; comprehensive coverage; co-scheduling existing satellites to ensure affordable rapid access. For Burned Area Emergency Rehabilitation (BAER), rapid response would require NIR and SWIR data for post-fire intensity mapping and high-resolution SAR data for cloud penetration. The SWIR provides good discrimination inside burned areas with the added advantage of being able to see through some light smoke and haze.

Requirement 7. Global burned area assessment
Users: UNEP; IPCC; IGBP; Global Change Research; NGOs; FAO; transportation planners; public health officials; tourists; and concerned Ministries and Departments of Tourism.
Information needed: vegetation type; distribution pattern; total area, and intensity of burn.
EO data sources available: high resolution — LANDSAT; SPOT; IRS; ERS; JERS-1; ALOS (planned); GOES; moderate resolution – MODIS; low resolution — NOAA/AVHRR; SPOT Vegetation; ATSR.
Improvements needed: comprehensive global coverage; more affordable access; greenhouse gas emission measurement capability.

Recommendations

Burned area assessment frequently requires acquisition of data from several different sources. Smoke and clouds often obscure the ground for extended periods following large wildland fires. Impediments to supporting the user with this information may be the high cost or slow access to the data streams. When developing new applications, these difficulties present a major hindrance.

Recommendation 5. Provide affordable and rapid access to all high-resolution data streams (30m and higher) for burned area assessment and rehabilitation applications.

Wildland fire scars and burning of biomass are often studied locally. In some regions, the existing satellites cannot provide useful timely coverage. For a global understanding of the scale and impact of biomass burning, there must be an operational worldwide system to determine the area burned and the fuel type for assessing the amount of carbon released.

Recommendation 6. Institute comprehensive global coverage of wildland fires to assess the scale of biomass burning.

In addition to the requirement for prescribed fire decision support on smoke management and air quality monitoring identified in recommendation 2, there is need for broad area monitoring of transboundary smoke movement to help determine its impact on human health and safety. Smoke causes reduced visibility, closing of airports and hazards to air, ground, and sea transportation. Better information on the impact of smoke on lower atmospheric chemistry and potential changes in global climate is also required.

Recommendation 7. Develop sensors to monitor smoke over broad geographic areas to help determine the impacts on lower atmospheric chemistry in terms of potential global climate change, human health, and human safety.

General Recommendations

Currently, wildland fire management requires the use of data from satellites, which were not designed for wildland fire monitoring. The investment in the currently developed applications will be at risk if the currently used data sources are discontinued.

Recommendation 8. Ensure the continuity of the current civilian satellite systems to maintain their spectral, temporal, and spatial characteristics for local and global coverage of wildland fires.

Due to the lack of dedicated systems for wildland fire detection and monitoring, intelligence and military satellite systems are the only sources of timely information. While we acknowledge the difficulty and sensitivity of access to military data, there are opportunities for collaboration with the military to provide information on acute wildland fire situations. Such access would imply the release of declassified information products derived from classified satellite data.

Recommendation 9. Examine opportunities to cooperate with the intelligence and military communities to develop and release declassified information products derived from classified satellite data to support wildland fire management requirements.

Recognizing that there is not currently a satellite system dedicated to wildland fire management, the requirements are dependent on the data from several satellite data sources. When commercial data is used, the cumulative price and access to data becomes a major hurdle in developing the most useful applications. In the event of a crisis situation, several satellites might have to be co-scheduled (tasked) in order to receive proper satellite coverage for the area of interest.

Recommendation 10. Develop an international agreement to improve access to timely and affordable data for the fire management community. CEOS should facilitate this agreement in cooperation with other international organizations.

III. DEVELOPMENT OF REGIONAL EXPERTISE IN REMOTE SENSING FOR WILDLAND FIRE MANAGEMENT.

In addition to the above listed recommendations, there is a need for regional expertise in remote sensing to provide an overall organizational framework of leadership and direction in coordinating international fire prevention and for training, monitoring, suppression, and assessment efforts. CEOS could be instrumental in improving remote sensing expertise in wildland fire management and should initiate discussion with international organizations to address the following activities:

1) Coordinate efforts to monitor fire risks:
    - Monitor and predict drought conditions, which lead to abnormal fire danger.
    - Map risk according to vegetation and fuel types.
    - Report fire risk danger to local fire management and forestry offices responsible for activating land use and fire restrictions based on fire danger rating.
2) Coordinate development of satellite fire detection and reporting systems:
    - Use the combination of MODIS, AVHRR, GOES, DMSP, and future satellite systems to identify fire starts early.
    - Identify communication protocols and requirements to convey fire start information to local fire management offices responsible for fire suppression response.

3) Coordinate development of fire monitoring systems:
    - Develop dedicated space-based fire monitoring system(s) to provide information on fires to the impacted country in near real time. The system would use satellite systems and ancillary data (existing GIS data and available airborne imagery) to prepare daily fire perimeter maps. Local fire management offices would use fire maps to coordinate fire suppression efforts.
    - Use remotely sensed imagery to map fire extent, smoke plumes, and fire intensity to assess environmental impacts.
4) Support fire suppression coordination efforts:
    - Serve as a clearinghouse to distribute information, geospatial data, and international contacts to determine available fire suppression resources.
    - Provide training in fire suppression techniques.
5) Fire prevention:
    - Assist in developing guidelines for regulation of agriculture burning, logging, land clearing, and other land uses that create uncontrolled fires.
    - Establish guidelines for management of combustible fuels.
    - Coordinate development of technology transfer and training methods to raise public awareness of fire danger risks and the benefits of preventing uncontrolled burning.

Team Accomplishments

- The Fire Team has worked with the Global Observation of Forest Cover (GOFC) project, an activity under the International Global Observation Strategy (IGOS) Carbon theme, to coordinate the DMSG Fire working group activity with the GOFC fire component.
- Charles Dull presented a paper on the DMSG Fire Team recommendations and published it in the proceedings of the GOFC-Fire workshop held at the European Commission (EC), Ispra, Italy.
- The Fire Team conducted a Wildland Fire Activity and Information Requirements Review, hosted by the Remote Sensing Applications Group of the Subcommittee on Natural Disaster Reduction (SNDR). Charles Dull of the USDA Forest Service organized the meeting held at NOAA in Silver Springs, MD.
- The Fire Team plans to continue to work on coordination with GOFC, and other disaster-related activities such as the Global Disaster Information Network (GDIN) and the SNDR.

Proposed Wildland Fire Hazard Emergency Scenario

Wildland Fire Rapid Detection and Response		
Obtain current and future status		Check if Considered
1.	Active fire perimeter and location of intense burn at 5m resolution	
2.	Detection size of 0.1 ha; location within 1km; measurement of energy release	
3.	Model predicted fire direction of spread and intensity	
4.	Remedial measures taken by local authorities; man made and natural fire breaks	
5.	Forecast of wind, meteorological conditions, significant weather fronts and predicted movements in proximity to ongoing wildland fires	
Obtain background information		
1.	Fuels; vegetation type; live and dead fuel moisture; vegetation stress	
2.	Land use; land cover	
3.	Location and proximity of inhabited areas and industrial centers; values at risk	
4.	Date of fire start; daily progress and spread	
5.	All geospatial products integrated with 1m orthophotos or 1:25,000 scale or larger topo maps	
Select the imaging payload		
1.	MODIS	
2.	SPOT – MIR channel night acquisitions if SPOT4	
3.	NOAA-GEOS; NOAA-AVHRR; DMSP-OLS;	
4.	Landsat 7; Ikonos; QuickBird	
5.	IR with smoke penetration capability (airborne)	
6.	RADARSAT – choice of beam combined with archive acquisitions. High resolution and high incidence are preferable (F4, F5)	
7.	ERS (possibly with interferometric and recent archive data)	
Data		
1.	Value added information – GIS coverages including: terrain (DEM), infrastructure, lines of communication, cartographic projections, demography, urban interface, ecological unit boundaries, historic fire regime, water sources	
2.	Data delivery mechanism via Internet or FTP (electronic) at least once daily (by 6:00 am locally) – 30 minute updates optimal	

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SELECTED REFERENCES

Ahern, F., J. G. Goldammer, and C. Justice (eds.) 2001. Global and regional vegetation fire monitoring from space: Planning a coordinated international effort. SPB Academic Publishing by, The Hague, The Netherlands, 302p.

Alexander, D., 1991. Information technology in real-time for monitoring and managing natural disasters. Progress in Physical Geography, 15: 238-260.

Axelsson, S.R.J., Eriksson, M. and Halldin, S., 1999. Tree-heights derived from radar profiles over boreal forests. Agricultural and Forest Meteorology, 98-9(SI): 427-435.

Barbosa, P.M., Grégoire, J.M. and Pereira, J.M.C., 1999. An algorithm for extracting burned areas from time series of AVHRR GAC data applied at a continental scale. Remote Sensing of Environment, 69: 253-263.

Blair, J.B., Rabine, D.L. and Hofton, M.A., 1999. The Laser Vegetation Imaging Sensor: a medium-altitude, digitisation-only, airborne laser altimeter for mapping vegetation anfd topography. ISPRS Journal of Photogrammetry & Remote Sensing, 54: 115-122.

Bradshaw L.S., Deeming J.E., Burgan R.E. and Cohen J.D., compilers, 1984. The 1978 national fire-danger rating system: technical documentation, Gen. Tech. Rep. INT-169. Ogden, UT: U.S. Department of Agriculture, Forest Service.

Burgan R.E., Klaver R.W. and Klaver J.M., 2000. Fuel models and fire potential from satellite and surface observations, *International Journal of Wildland Fire*.

Burgan R.E. and Hartford R.A., 1993. *Monitoring vegetation greenness with satellite data*, Gen. Tech. Rep. INT-297. Ogden, UT: U.S. Department of Agriculture, Forest Service.

Cahoon Jr. D.R., Stocks B.J., Levine J.S., Cofer III W.S. and O'Neill K.P., 1992 .Seasonal distribution of African Savanna Fires, *Nature*, vol. 359, pp. 812-815.

Cahoon Jr D. R., Stocks B. J., Alexander M. E., Baum B. A. and Goldammer J. G., 1999. Wildland fire detection from space: Theory and application, *Wengen-98 workshop proceedings on: Biomass burning and its inter-relationships with the climate system,* Wengen, Switzerland, 23 pages.

Castel, T., Martinez, J.M., Beaudoin, A., Wegmuller, U. and Strozzi, T., 2000. ERS INSAR data for remote sensing hilly forested areas. Remote Sensing of Environment, 73(1): 73-86.

Chuvieco E. and Martin M.P., 1994. Global Fire Mapping and Fire Danger Estimation Using AVHRR Images, *Photogrammetric Engineering and Remote Sensing*, vol. 60, 5, pp. 563-570.

Chuvieco, E. (Editor), 1999. Remote Sensing of Large Wildfires in the European Mediterranean Basin. Springer-Verlag, Berlin, 212 pp.

Deeming J.E., Burgan R.E. and Cohen J.D., 1978. *The national fire-danger rating system - 1978*. Gen. Tech. Rep. INT-39. Ogden, UT: U.S. Department of Agriculture, Forest Service.

Dull, C. W. and B. Lee. 2001. Satellite Earth Observation Information Requirements of the Wildland Fire Management Community. In: *Global and Regional Vegetation Fire Monitoring from Space: Planning a Coordinated International Effort*, pp19-33. F.J. Ahern, J. G. Goldammer and C. O. Justice editors. SPB Academic Publishing by The Hague, The Netherlands.

Ehrlich D., Lambin E.F. and Malingreau J., 1997. Biomass Burning and Broad-Scale Land Cover Changes in Western Africa, *Remote Sensing of the Environment,*vol. 61, pp. 201-209.

Elvidge C.D., Baugh K.E., Kihn E.A., Kroehl H.W. and E.R. Davis, 1997a. Mapping City Lights With Nighttime Data from the DMSP Operational Linescan System, *Photogrammetric Engineering and Remote Sensing*, vol. 63, 6, pp. 727-734.

Elvidge C.D., Baugh K. E., Kihn E.A., Kroehl H.W., Davis E.R. and C. Davis, 1997b. Relation between Satellite Observed Visible Near Infrared Emissions, Population, Economic Activity and Electric Power Consumption, *International Journal of Remote Sensing*, vol. 18, 6, pp. 1373-1379.

Elvidge D.E., Pack D., Prins E., Kihn E., Baugh K., Kendall J., Purdom J., Weaver J., Baldwin D. and Emery W., 1997c. Wildfire Detection with Meteorological Satellite Data: Results from New Mexico During June 1996 using GOES, AVHRR and DMSP-OLS, *Report to NOAA-NESDIS*.

Fernández A., Illera P. and Casanova J.L., 1997. Automatic Mapping of Surfaces Affected by Forest Fires in Spain Using AVHRR NDVI Composite Image Data, *Remote Sensing of the Environment*, vol. 60, pp. 153-162.

Fosberg M.A. and Deeming J.E., 1971. *Derivation of the 1- and 10-hour timelag fuel moisture calculations for fire-danger rating*, Research Note RM-207. Fort Collins, CO: U.S. Department of Agriculture, Forest Service.

Fraser, R.H., Li, Z. and Cihlar, J., 2000. Hotspot and NDVI Differencing Synergy (HANDS): a new technique for burned area mapping over Boreal forest. Remote Sensing of Environment, 74: 362-376.

Giglio, L., Kendall, J.D. and Justice, C.O., 1999. Evaluation of global fire detection algorithms using simulated AVHRR infrared data. International Journal of Remote Sensing, 20: 1947-1985.

Goldammer, J. G. 2001. The precursor work of the ECE/FAO/ILO Team of Specialists on Forest Fire and the Global Fire Monitoring Center (GFMC) towards the establishment of the Inter-Agency Task Force Working Group on Wildland Fire within the UN International Strategy for Disaster Reduction (ISDR). Background Paper for the International Strategy for Disaster Reduction (ISDR), 3rd Inter-Agency Task Force Meeting, Geneva, 3-4 May 2001.

Goldammer, J.G. (Editor), *1990. Fire in the Tropical Biota: Ecosystem Processes and Global Challenges*. Springer-Verlag, Berlin, Germany, 497 pages.

Greer, J. D. (Editor), 2000. Crossing the Millennium: Integrating Spatial Technologies and Ecological Principles for a New Age in Fire Management, *Proceedings of The Joint Fire Science Conference and Workshop at Boise Idaho in June 1999*, ASPRS Bethesda, MD.

Hardy, C.C. and Burgan, R.E., 1999. Evaluation of NDVI for monitoring live moisture in three vegetation types of the Western U.S. Photogrammetric Engineering and Remote Sensing, 65: 603-610.

Kasischke E.S., Bourgeau-Chavez L.L. and French N.H.F., 1994. Observations of Variations in ERS-1 SAR Image Intensity Associated with Forest Fires in Alaska," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 32, 1, pp. 206-210.

Kennedy P.J., Belward A.S. and Grégoire J., 1994. An Improved Approach to Fire Monitoring in West Africa Using AVHRR Data," *International Journal of Remote Sensing*, vol. 15, 11, pp. 2235-2255.

Klaver J.M., Fosnight E.A. and Singh A., 1997. Global Forest Fire Watch: Wildfire Potential, Detection Monitoring and Assessment, *First International Conference on Geospatial Information in Agriculture and Forestry*.

Klaver J.M., Klaver R.W. and Burgan R.E., 1997. Using GIS to Assess Forest Fire Hazard in the Mediterranean Region of the United States," *1997 ESRI Users Conference*, http://www.esri.com/base/common/userconf/proc97/HOME.HTM (February 14, 1998), San Diego, CA, July 8-11.

Koutsias, N. and Karteris, M., 2000. Burned area mapping using logistic regression modeling of a single post-fire Landsat-5 Thematic Mapper image. International Journal of Remote Sensing, 21: 673-687.

Koutsias, N., Karteris, M. and Chuvieco, E., 2000. The use of intensity-hue-saturation transformation of Landsat-5 Thematic Mapper data for burned land mapping. Photogrammetric Engineering and Remote Sensing, 66: 829-839.

Langaas S., 1992. Temporal and Spatial Distribution of Savanna Fires in Senegal and The Gambia, West Africa, 1989-90, Derived from Multitemporal AVHRR Night Images, *International Journal of Wildland Fire*, vol. 2, 1, pp. 21-36.

Levine J. S., 1996. Biomass Burning and Global Change, Volume 1: Biomass burning in Africa, *The MIT Press, Inc*., Cambridge, MA, 551 pages.

Levine J. S., 1996. Biomass Burning and Global Change, Volume 2: Biomass Burning in South America, Southeast Asia, and Temperate and Boreal Ecosystems, and the Oil Fires of Kuwait, *The MIT Press, Inc*., Cambridge, MA, 381 pages.

Levine J.S., Bobbe T., Ray N., Sign A. and R.G. Witt, *1999. Wildland Fires and the Environment: A Global Synthesis,* UNEP/DEIAEW/TR.99-1, UNEP.

Liew S., Lim O.K., Kwoh L.K. and Lim H., 1998. A Study of the 1997 Fires in South East Asia Using SPOT Quickly Mosaics, *Paper presented at the 1998 International Geoscience and Remote Sensing Symposium,* July 6-10, Seattle, Washington, 3p.

Lucian A., Baker J., Kuplich T.M., Yanasse C.C.F. and Frery A.C., 1997. A Study of the Relationship between Radar Backscatter and Regenerating Tropical Forest Biomass for Spaceborne SAR Instruments, *Remote Sensing of the Environment*, vol. 60, pp. 1-13.

Malingreau J.P. and Justice C. O., 1997. Definition and Implementation of a Global Fire Product Derived from AVHRR Data, *3rd IGBP-DIS Fire Working Group Meeting Report*, Toulouse, France, 13-15 November 1996: Toulouse, France, IGBP-DIS Office.

Nelson, R. et al., 2000. Canopy height models and airborne lasers to estimate forest biomass: two problems. International Journal of Remote Sensing, 21(11): 2153-2162.

Oertel, D., P.Haschberger, V.Tank, F.Schreier, B.Schimpf, B.Zhukov, K.Briess, H.-P-Röser, E.Lorenz, W.Skrbek, J.G.Goldammer, C.Tobehn, A.Ginati, and U.Christmann. 2000. Two dedicated spaceborne fire missions. In: Proc. Joint Fire Science Conference and Workshop, Boise, Idaho, USA, 15-17 June 1999, Vol.I, p. 254-261. Published by the University of Idaho and the International Association of Wildland Fire.

Pozo D., Olmo F.J. and Alados-Arboledas L., 1997. Fire Detection and Growth Monitoring Using a Multitemporal Technique on AVHRR Midinfrared and Thermal Channels, *Remote Sensing of the Environment,* vol. 60, pp. 111-120.

Robinson J.M., 1991. Fire from Space - Global Fire Evaluation Using Infrared Remote Sensing, *International Journal of Remote Sensing*, vol. 12, 1, pp. 3-24.

Steyaert L.T., Hall F.G. and Loveland T.R., 1997. Land Cover Mapping, Fire Regeneration, and Scaling Studies in the Canadian Boreal Forest with 1-km AVHRR and LANDSAT TM Data, *Journal of Geophysical Research,* vol. 102, d24, pp. 29,581-29,598.

Viedma O., Meliá J., Segarra D. and García-Haro J., 1997. Modeling Rates of Ecosystem Recovery afterFires by Using LANDSAT TM Data, *Remote Sensing of the Environment*, vol. 61, pp. 383-398.

T E A M   R E P O R T

Flood

FLOOD HAZARDS

CEOS DISASTER MANAGEMENT SUPPORT GROUP

SUMMARY

This report addresses the use of Earth Observation satellites for flood managers, flash flood analysis and prediction, and the user community. A remote sensing management cycle is presented that involves: (1) prevention where history, corporate memory and climatology are important (2) mitigation that insulates people or infrastructure from hazards (3) pre-flood, which is the preparation and forecast stage where remote sensing is essential (4) response (during the flood) where actions to be taken is of key importance and weather NOWCASTS (0 - 3 hour prediction of precipitation) using remote sensing is extremely useful, and (5) recovery, (post flood) which is the postmortem stage where damage assessment, procedures, and numerical weather prediction and hydrological models are validated. The potential of high and low resolution polar orbital Earth Resource Satellites have been shown to be an excellent tool for providing hydrological information including the quantification of catchment physical characteristics, such as topography and land use, and catchment variables such as soil moisture and snow cover. There have been many demonstrations of the operational use of these satellites for detailed monitoring and mapping of floods and post-flood damage assessment. A family of satellite-derived products from the operational meteorological satellites (geostationary and polar) for application to general flood and flash flood analysis and prediction is also presented. These products include precipitation estimates and soil wetness indices, both of which can be derived globally. Gaps in remote sensing capabilities are discussed and future improvements and requirements are presented. The ultimate objective is to integrate geostationary data with polar orbital data and to have microwave onboard geostationary satellites early in the next millennium.

Flood Team Recommendations

- Develop methods for the integration of satellite, in-situ and GIS data for input to hydrological models
- Develop multi-sensor/satellite integration methods
- Addition of microwave sensor on GOES
- Estimate soil moisture and snowpack characteristics from high resolution microwave data
- Improve satellite rainfall estimation techniques
- Increase temporal frequency of polar orbiting satellite data acquisitions.
- Decrease time required to acquire and deliver remotely sensed data
- Lower the cost of remotely sensed data
- Develop techniques to generate high resolution DEM
- Education/Training to build local capability
- International coordination of data acquisitions

I. INTRODUCTION

A hazard is defined as a phenomenon that may cause disruption to humans or their infrastructure. A disaster is an event that causes such disruption (one that occurs in the past, present, or future). Disaster management is a set of actions and processes designed to lessen disastrous effects, either before, during, or after a disaster. This report will focus on the use of satellite data for flood management and will include both polar orbital Earth Resource Satellites and operational meteorological satellites. The polar orbital Earth Resource Satellites are of two types: (1) optical sensors that cannot see through clouds, operating at low (AVHRR), medium (LANDSAT, SPOT, IRS) and high resolutions (IKONOS) and (2) microwave sensors that can see through clouds, which include high resolution active sensors such as Synthetic Aperture Radar (SAR) (RADARSAT, ERS, JERS) and low resolution passive sensors (SSMI). These satellites have been used to quantify catchment physical characteristics, such as watershed boundaries, elevation and slope, land cover, as well as catchment variables such as soil moisture, snow pack, temperature, vegetation indices, and evapotranspiration. They have also been used operationally for flood monitoring, mapping and damage assessment (Pultz, et. al., 1991, 1996; and Saper, et. al., 1996). There has been considerable work devoted to developing the approach needed to integrate these remotely sensed estimates and in situ data into hydrological models for flood forecasting.

Meteorological satellites are composed of two types: geostationary and polar orbital. The geostationary satellite (GOES) is a powerful tool to observe the weather on a continuous basis. The orbit is at an altitude of 22,000 miles and picture frequency is normally on a half-hourly basis (currently United States of America GOES 8 and 10 are producing images every 15 minutes). Additional GOES satellites include METEOSAT from the European Space Agency, Japan's Geostationary Meteorological Satellite called GMS, the Indian National Satellite (INSAT) system and the Russian satellite GOMS. These satellites provide images in the visible (VIS) and infrared (IR) wavelengths. Polar orbital satellites (POES) circle the earth twice a day at an altitude of approximately 850km. Two types of polar orbitals are in operation: NOAA (NOAA 15 was successfully launched in May 1998) and the Special Sensor Microwave Imager (SSM/I) onboard the DMSP (Defense Meteorological Satellite Program) satellite; NOAA 15's microwave instrument is called the Advanced Microwave Sensing Unit (AMSU). Both of these satellites provide VIS and IR imagery and microwave data. With respect to precipitation estimates and moisture analysis, GOES offers higher resolution time and space scales, while POES microwave data are more physically related to precipitation and moisture processes. Ideas and concepts for this report were generated from several CEOS (Committee on Earth Observation Satellites) meetings and individual communication that included a comprehensive discussion on Flood Hazard and Remote Sensing (Scofield and Margottini, 1999).

II. GENERAL APPLICATION DESCRIPTION

Floods are among the most devastating natural hazards in the world, claiming more lives and causing more property damage than any other natural phenomena. Within the USA, an average of more than 225 people are killed and more than US$3.5 billion in property is damaged by heavy rain and flooding each year (1993, 1999). As a result, floods are one the greatest challenges to weather prediction. A flood can be defined as: *any relatively high water flow that overtops the natural or artificial banks in any portion of a river or stream -— when a bank is overtopped, the water spreads over the flood plain and generally becomes a hazard to society*. When extreme meteorological events occur in areas characterized by a high degree of urbanization, the flooding can be extensive, resulting in a great amount of damage and loss of life. However, not all hydro-geological events that cause destruction can be classified as floods: in mountainous regions landslides, hyper-concentrated flows, debris flows, etc cause the most damage. Heavy rain, snowmelt, or dam failures cause these hydro geological events.

In the frame of a general analysis, both flood and slope stability phenomena must be considered as different aspects of the same dynamic system, called the drainage basin. The events deriving from slope dynamics (gravitational phenomena) and fluvial dynamics (floods) are commonly triggered by the same factor: heavy rainfall. Especially in mountainous areas, analyzing flood risk is often impossible without considering all of the other phenomena associated with slope dynamics (erosion, slides, sediment transport, etc.). In scientific literature many conceptual models exist where an integrated view between slope instability phenomena and flood events has been provided (Casale and Margottini, 1994). The hydrological cycle influences the evolution of the drainage basin system. Meteorological satellites (both GOES and POES) detect various aspects of the hydrological cycle — precipitation (rate and accumulations), moisture transport, and surface/ soil wetness (Scofield and Achutuni, 1996). The effects of this geomorphologic evolution induce variations of the stream network, which in turn influence the land modeling. This continuous evolution is a long process, but is characterized by accelerated phenomena that develop in the medium or even short time frame (hours to a day). The very short time processes are triggered by extreme meteorological events. The type and magnitude of the ensuing phenomena (floods, landslides, etc) show a great variability, as a function of the considered area and the specific characteristics of the region (climate, land use, geology, slope, etc.).

As a result, different morphological zones need to be identified, in which distinct types of events induce specific kinds of dangers and disasters. These different types of phenomena are a consequence of different interrelations among the hydrologic, hydraulic and geological processes. Two morphological zones are identified:
Plain Areas, where damages are caused by flood phenomena mainly controlled by water flow; floods are caused by heavy precipitation in upstream areas and snowmelt. The duration of effective rainfall necessary to produce floods in rivers (located in the Plain Area) is usually from hours to days. Flash floods can also occur and have a time period of six hours or less (after the rainfall event) and cover areas generally less than ½ x ½ degree. The hazard prediction in these circumstances normally uses hydraulic methods based on Newtonian fluid dynamics.
Mountainous Areas: where landslides cause damages, debris flows and floods that take place almost at the same time as the critical meteorological events. Floods, especially of this variety, are usually classified as flash floods, since the lag time is extremely rapid. In addition, the floods are a result of an over-aggravation phenomenon. Intense erosion often develops on the slopes and along the stream banks increasing the sediment load in the water flow. The abundant water discharge and the frequent slope variation along the streambed causes sediment transport and deposition processes with a consequent over-aggravation phenomenon, especially on the alluvial fans. Landslides triggered by rainfall and by undercutting, can induce direct damage and aggravate the stream danger. Locally, the regular water flow can be obstructed by detritus accumulation that induces destructive peak discharges characteristic of extremely high sediment load. In these cases, hazard prediction must consider the strong interrelation among hydraulic and geological features. Mountainous basins can be subdivided into three main zones: *main valley area* (small slopes within the streambed*); secondary valleys* (high slopes within the streambed); and *slope areas outside the stream network*.

There are several forms of flooding: *River Floods* form from winter and spring rains, coupled with snow melt, and torrential rains from decaying tropical storms and monsoons; *Coastal Floods* are generated by winds from intense off-shore storms and Tsunamis; *Urban Floods*, as discussed above, (urbanization increases runoff two to six times what would occur on natural terrain); *Ice Jams* are generated by natural or man/animal made obstructions; *Flash Floods*, as discussed above, can occur within minutes or hours of excessive rainfall, a dam or levee failure, or a sudden release of water held by an Ice Jam. Flash floods are the number one weather-related killer in the USA.

III. SPECIFIC APPLICATION DESCRIPTION

Regarding the cycle of disaster management, two main fields of interest can be defined for the use of remote sensing data in the flood domain: (1) a detailed mapping approach, that is required for the production of hazard assessment maps and for input to various types of hydrological models. These mapping approaches are used at the regional and local scales; the user requirements are related to detailed mapping for updating (and sometimes creating) risk maps. The maps contribute to the hazard and vulnerability aspects of flooding. The other field of interest is: (2) a larger scale approach that explores the general flood situation within a river catchment or coastal belt, with the aim of identifying areas that have greatest risk and need immediate assistance; in this case, remote sensing may contribute to the initialization of numerical weather prediction models, weather forecasts and to mapping of inundated areas, mainly at the regional level.

Satellite optical observations of floods have been hampered by the presence of clouds that resulted in the lack of near real-time data acquisitions. Synthetic Aperture Radar (SAR) can achieve regular observation of the earth's surface, even in the presence of thick cloud cover. Therefore, applications such as those in hydrology, which require a regularly acquired image for monitoring purposes, are able to meet their data requirements. This presents new opportunities for the observation of hydrological change over time and the quantification, from space, of hydrological variables that are very difficult to measure on the ground.

SAR data are not restricted to flood mapping but can also be useful to the estimation of a number of hydrological parameters (Pultz, et. al., 1991, 1996, 1997). In some cases, such as wet snow mapping, monitoring of wetlands, flood extent delineation and identification of freshwater ice types the capabilities of SAR have been demonstrated and the operational use of such data is becoming a reality. In other areas, such as soil moisture and Snow Water Equivalent (SWE) estimation, the potential of SAR data has also been shown to be useful. However, additional work is required to develop robust quantitative relationships. There is also a need to develop and implement distributed hydrological models, in order to fully exploit remotely sensed data and forecast and simulate stream flow (Leconte and Pultz, 1990 and Jobin and Pultz, 1996). NOAA AHVRR allows for a family of satellites upon which flood monitoring and mapping can almost always be done in near real time. Currently, multi channel and multi sensor data sources from GOES and POES satellites have been used for meteorological evaluation, interpretation, validation, and assimilation (into Numerical Weather Prediction Models) to assess hydrological and hydro geological risks (Barrett, 1996). These data are used to estimate precipitation intensity, amount, and coverage, measure moisture and winds, and to determine ground effects such as the surface (soil) wetness (Scofield and Achutuni, 1996, Scofield, 1987, Borneman, 1988, Vicente and Scofield, 1998; and Achutuni and Scofield, 1998).

Quantitative Precipitation Estimates (QPE) and Forecasts (QPF) use satellite data as one source of information to facilitate flood and flash flood forecasts in order to provide early warnings of flood hazard to communities. New algorithms are being developed that integrate the less direct but higher resolution (space and time) GOES precipitation estimates, with the more physically based but lower resolution (both space and time) POES microwave estimates. An improvement in rainfall spatial distribution measurements is being achieved by integrating radar, rain gauges and remote sensing techniques to improve real time flood forecasting (Vicente and Scofield, 1998).

Table 1 shows a simplified state of art for remote sensing application in the flood disaster management cycle. From this Table, it is possible to notice the strong multi-disciplinary context in which remote sensing has to be considered. It is important also, to mention the possibility of new developments for local topography resolution. This Table has been divided into two main categories:

1) monitored areas in which remote sensing is complementary to direct precipitation and stream flow measurements, and

(2) those areas that are not instrumentally monitored (or the instruments are not working or are in error). In this second category, remote sensing provides an essential tool for flood disaster management. As seen in the Table, each category is further divided into regional and local approaches, depending on the scale of investigation from the adopted methodology and resolution.

Table 1 ***FLOOD DISASTER MANAGEMENT CYCLE***

Instrumentally Monitored Areas		***Not Instrumentally Monitored Areas***	
regional scale	***local scale***	***regional scale***	***local scale***
prevention	yes + other data	yes + other data (new ?)	yes + other data
mitigation			
preparedness/ warning	yes + other data		yes + other data
response	yes + other data	yes + other data	
recovery	yes + other data		
prevention			

The following discusses the above listed disaster management categories in Table 1:

Prevention

The Prevention category involves history, corporate memory and climatology. This is the classical hazard approach in which the individual input data depend on the scale factor. For regional methodologies, the essential input data are geomorphology, hydrological analysis, and historical investigation of past events and climatology. Remote sensing may help in mapping geomorphic elements and land use, providing meteorological data for hydrological modeling and contributing to mapping historical events. For example, GOES and POES weather satellites can provide climatological information on precipitation especially for those areas not instrumentally monitored. In the prevention area, these historical data sets can give managers a “heads up” on what is normally expected (for example, precipitation); hydrological models can use this climatological data to provide decision makers the typical response time for a particular precipitation event. Potential users are land planners (federal or national), hydro meteorologists (including weather forecasters), environmental and agricultural authorities.

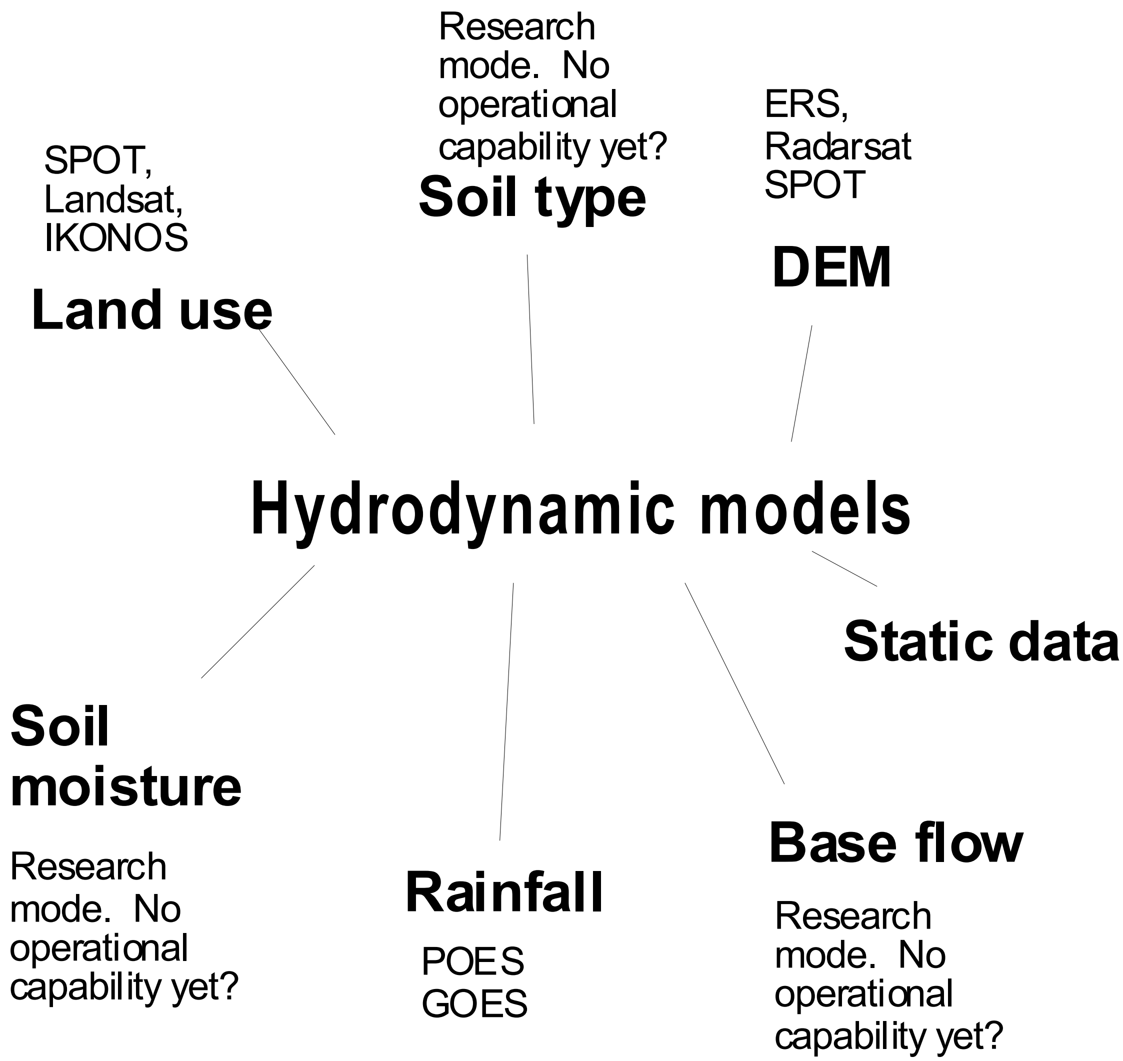
Investigations on the local scale include topography, hydraulic data, riverbed roughness, sediment grain size, hydraulic calculations, land cover, and surface roughness. Remote sensing may contribute to mapping topography (generation of DEMs) and in defining surface roughness and land cover. Potential users are land planners (local municipality), hydro meteorologists, and those in water management. Hazard data obtained on the local scale can be combined with vulnerability data on population, land use, and type of buildings, type of contents, infrastructure and activities to assess the risk. In this case, remote sensing may contribute to updating cartography for land use. Cartographic updates are a critical aspect of remote sensing since there are often delays in public administration for maintaining updated official cartography, as well as illegal construction in some areas that are not reported on official maps.

Mitigation and Prediction

Hydrologic models play a major role in assessing and forecasting flood risk. Model predictions of potential flood extent can help emergency managers develop contingency plans well in advance of an actual event to help facilitate a more efficient and effective response. The hydrologic models require several types of data as input, such as land use, soil type, soil moisture, stream/river base flow, rainfall amount/intensity, snow pack characterization, digital elevation model (DEM) data, and static data (such as drainage basin size). Complex terrain and land use in many areas result in a requirement for very high spatial resolution data over very large areas, which can only be practically obtained by remote sensing systems.

Figure 1 shows the requirements for hydrologic models and indicates potential non-weather satellite platforms that can provide the needed data. Data from satellites such as ERS, RADARSAT and SPOT can provide DEM data at resolutions of about 3 to 10 meters. Land use information can be determined through the use of AVHRR, Landsat and SPOT data. The rainfall component can be determined through the use of existing POES and GOES platforms. Although there are no operational data sources for estimating soil type, soil moisture, snow water equivalent and stream/river base flow there has been considerable research on the extraction of these parameters from existing optical and microwave polar orbiting satellites.

Models can also assist in the mitigation of coastal flooding. Wave run-up simulations can help planners determine the degree of coastal inundation to be expected under different, user-specified storm conditions. These types of models require detailed near-shore bathymetry for accurate wave effect predictions. While airborne sensors provide the best resolution data at present, this data source can be potentially cost-prohibitive when trying to assess large areas of coastline. In addition to DEM data, satellite based SAR can also be used to derive near-shore bathymetry for input into wave run-up models on a more cost-effective basis.



Research mode. No operational capability yet?
Soil type
SPOT, Landsat, IKONOS
Land use
ERS, Radarsat SPOT
DEM
Hydrodynamic models
Static data
Soil moisture
Research mode. No operational capability yet?
Rainfall
POES GOES
Base flow
Research mode. No operational capability yet?

Figure 1

Preparedness Warning (immediately before the flood):
The preparedness/warning category (also called pre flood category) refers to actions taken to insulate people or infrastructure from specific hazard events. In this stage, government agencies, research institutes and hydro power utilities study the cause of floods, plan for possible scenarios to minimize the potential impacts, and subsequently establish the necessary infrastructure to either prevent it or minimize its impacts. In order to establish flood-warning systems, environmental factors and conditions that lead to flooding are monitored and studied. These factors include meteorology, ice and snow conditions (coverage and depth), soil moisture, tidal conditions in coastal areas, water levels and flow, topography, land cover, surface roughness, river bed roughness, soil type, and permeability. GOES and POES weather satellites provide information on precipitation, moisture, temperature, winds, and soil (surface) wetness. Satellite-derived parameters are also used in assimilation techniques to help initialize numerical weather prediction models where outputs are Quantitative Precipitation Forecasts (QPF). Hydrologic models are executed to simulate different situations and policies and systems are implemented to forewarn and evacuate inhabitants living on flood plains.

Remote sensing provides a useful contribution to all of the above listed input data, with the exception of riverbed roughness. Except for the meteorological applications of (NOWCASTING (defined below) and prediction, the benefit from the use of remote sensing techniques may not be essential in well (instrumentally) monitored areas. In these areas, remote sensing can assist in providing better spatial estimates of hydrological parameter, when integrated with the in situ measurement network. As such, more accurate flood predictions are possible and remote sensing is the only cost effective method to monitor the spatial extent of flooding. Remote sensing is essential in those areas not instrumentally monitored. Potential users are civil protection (federal and state), hydro meteorologists, local authorities, water management, and media.

Response (during Flood)
The response category can also be called “relief,” and refers to actions taken during and immediately following a disaster. During floods, timely and detailed situation reports are required by the authorities to locate and identify the affected areas and to implement corresponding damage mitigation. It is essential that information be accurate and timely, in order to address emergency situations (for example, dealing with diversion of flood water, evacuation, rescue, resettlement, water pollution, health hazards, and handling the interruption of utilities etc.).

For remote sensing, this often takes the form of damage assessment. This is the most delicate management category since it involves rescue operations and the safety of people and property. The following lists information used and analyzed in real time: (this includes data from the previous category: *Preparedness*) extent mapping and real time monitoring (satellite, airborne, and direct survey), damage to buildings (remote sensing and direct inspections), damage to infrastructure (remote sensing and direct inspection), meteorological NOWCASTS (important real-time input from remote sensing data to show intensity/estimates, movement, and expected duration of rainfall for the next 0 - 3 hours), and evaluation of secondary disasters , such as waste pollution, to be detected and assessed during the crisis (remote sensing and others). In this category, communication is important to identify which satellite will provide the essential contribution. Potential users are the same as in the preparedness category (civil protection, hydro meteorologists, local authorities, water management, and media) plus insurance companies.

Recovery (after the Flood)
In this stage, re-building destroyed or damaged facilities and adjustments of the existing infrastructure will occur. At the same time, insurance companies require up-to-date information to settle claims. The time factor is not as critical as in the last stage. Nevertheless, both medium and high-resolution remote sensing images, together with an operational geographic information system, can help to plan many tasks. The medium resolution data can establish the extent of the flood damages and can be used to establish new flood boundaries. They can also locate landslides and pollution due to discharge and sediments. High-resolution data is suitable for pinpointing locations and the degree of damages. They can also be used as reference maps to rebuild bridges, washed-out roads, homes and facilities. Finally, these data can be used by agencies to validate and refine their hydrological models that are being used for flood prediction.

Prevention
This category more or less comes back to the top of the disaster cycle. The information (data) and experience (intuition) developed during the flood may help in future events. Validation of models (especially meteorological interpretations) including conceptual and numerical weather prediction models is essential for future improvements. Prevention also involves updating risk assessment maps, identifying lessons learned and developing recommendations. The primary method for enhancing our knowledge of a particular flood event is through flood disaster surveys, where results are documented in a report (see the Natural Disaster Survey Report on “The Great Flood of 1993,” Scofield and Achutuni, 1994).

Mitigation
Mitigation measurements are likely to improve after a flood disaster. Refining the Mitigation process in order to reduce vulnerability to future flood events will hopefully follow.

IV. Products and Services
This section is a NESDIS perspective that emphasizes the use of meteorological satellites for *flash floods.* Nevertheless, most of the satellite-derived information used for flash flood diagnostics and prediction is applicable to the other types of flooding mentioned in Section 2.

Heavy precipitation and flash floods are often a multi scale and concatenating event from the global scale, to the synoptic scale, to the mesoscale and finally to the storm scale. Satellite-derived algorithms, conceptual models, and interpretation techniques are used to provide information on these various scales to monitor, assess, and predict heavy precipitation and flash floods. In the satellite data, global scale connections between the tropics and middle latitudes are observed. These connections are movements, surges, or plumes of water vapor that are often associated with unstable air and prepare the environment for heavy precipitation and flash floods.

On the synoptic scale, the 6.7-micron water vapor is especially useful for detecting jet streaks, vorticity centers and other features that are associated with upward vertical motion and lift the moist, unstable air resulting in the production of clouds and precipitation. Whether or not heavy precipitation and flash floods will occur are generally determined on the mesoscale to storm scale. On the mesoscale, infrared (10.7 micron and 3.9 micron), visible, and water vapor (6.7 micron) are used to locate boundaries (both frontal and thunderstorm-produced) and short waves that may initiate, focus, and maintain the heavy precipitation. Terrain features such as orographic uplift have the same effect of anchoring, intensifying, and prolonging the precipitation.

On the storm scale, the intensity, movement, and propagation of the precipitation system (for example, thunderstorms) is used to determine how much, when, and where the heavy precipitation is going to move during the next zero to three hours (called NOWCASTING). High-resolution infrared (10.7 micron) and visible are the principal data sets used in this diagnosis. The wetness of the soil due to a heavy rainfall event or snowmelt is extremely useful information for flood (flash flood) guidance. SSM/I data from the DMSP are the data sets used in this analysis. SAR, SPOT, and to some extent high resolution NOAA images can be used to determine flood extent and areal coverage.

Satellite derived winds (Nieman, S.J., et. al., 1997 and Velden, C.S., et. al., 1997) and satellite soundings of temperatures and moisture (Hayden, C.M., 1988) are currently being used to initialize some of the numerical weather prediction models. These help to improve QPF, which can then lead to improved output from hydrological models.

Since flash floods are often a multi-scale and concatenating event, the following is a brief discussion of products designed for diagnosing these atmospheric interactions.

Global to Synoptic Scale

Various precipitable water (PW) products have been developed and are available operationally for assessing the state of the atmosphere with respect to the magnitude of the moisture and its transport. These products include satellite derived PW from GOES (Holt, et. al., 1998) and SSM/I (Ferraro, et. al., 1996), and a composite that includes a combination of GOES + SSM/I + model data (Scofield, et. al., 1996, 1995). GOES derived PW are computed over land and water but are limited to cloud free areas. SSM/I derived PW is limited to ocean areas but can be computed where clouds are not producing precipitation. In order to take advantage of the strengths and weaknesses of the SSM/I and GOES derived PW, the above-mentioned composite PW product has been developed. Satellite derived winds are also used in the determination of the moisture transport. The 6.7micron water vapor can detect plumes of upper level moisture and lifting mechanisms (as mentioned above).

Mesoscale to Storm scale

Various satellite derived precipitation algorithms are being employed to determine both the intensity and accumulation of precipitation over short time intervals. The following satellite products have been deemed useful in heavy precipitation estimation: Interactive Flash Flood Analyzer Techniques (IFFA) (Scofield, 1987 and Scofield and Oliver, 1977) for convection, winter storm, tropical storm and lake effect snows: A McIDAS based computer system is used to infer precipitation rates interactively and manually from the GOES infrared and visible data. A principal premise is that colder cloud tops (especially convective) produce heavier rain. NOWCASTS of 3-hour precipitation outlooks are also computed. These outlooks are based on the trends and propagation characteristics of the precipitation system (Spayd and Scofield, 1984; Shi, Jiang and R.A. Scofield, 1987; and Xie, Juying and R.A. Scofield, 1989).

Auto - Estimator (Vicente, Scofield and Menzel, 1998): A GOES 8/9 experimental, quasi-automatic technique based on: (a) 10.7 micron rain rate curve (can be manually adjusted — especially for warm top convection), (b) PW and relative humidity (RH), (c) cloud growth, (d) cloud top gradient, and (e) orography. Trained meteorologists can adjust this algorithm for warm top convection and large-area, cold top, quasi-stationary storms.

GOES Multi-spectral Rainfall Algorithm (Ba and Gruber, 1998): A GOES 8/9 experimental algorithm similar to that listed above, except that it uses the 3.9 and 12.0 micron channels, plus visible, to screen out cirrus and detect precipitation in clouds with warm tops (more stratiform).

SSM/I rainfall algorithms (Ferraro, 1997 and Ferraro, et. al., 1996): This is more physically based, compared to the above listed GOES algorithms, but much less timely. Scattering-based techniques are used over land and a combination of scattering and emission-based is used over water.

Soil (Surface) Wetness Index (Achutuni and Scofield, 1998, Achutuni, et. al., 1996, 1997 and Scofield and Achutuni, 1996, 1994): An experimental product derived from the "85 Ghz - 19 Ghz "horizontally polarized SSM/I data. This product is used to identify surfaces ranging from dry to extremely saturated or flooded. The Soil Wetness Index does not have the resolution capabilities of SAR, SPOT, or LANDSAT but unlike those other sensors, SSM/I is available in real time on a daily (twice a day) basis.

Precipitation Program of NESDIS' Satellite Analysis Branch (SAB):
NESDIS' SAB "flash flood" operation can serve as a prototype operation for centers around the world (Borneman, 1988 and Kuligowski, 1997):

- *Customers*: National Weather Service (NWS) Forecast Offices, and National Center for Environmental Prediction (Hydro meteorological Prediction Center, Tropical Prediction Center, and Storm Prediction Center).
- *Products*: Precipitation (available every 15 - 30 minutes) and NOWCASTS (3 hour precipitation outlooks).
- *Primary*: GOES 8/9: 10.7, 3.9, 6.7, 12 micron, and VIS; GOES sounding derived parameters; DMSP/SSM/I; NOAA K/AMSU.
- *Ancillary*: Numerical Weather Prediction Model derived parameters, radar (WSR-88D), ASOS (Automatic Surface Observation System) and other surface observations.

<u>Soil (surface) Wetness Index (available once or twice a day):</u>

- *Primary*: DMSP/SSM/I (especially 89 and 19 GHz)
- *Ancillary*: ERS (5.3 GHz/ESA), RADARSAT (5.3 GHz/Canadian), JERS - 1 (1.275 GHz/Japan) and ALOS* (1.27 GHz), NOAA high-resolution imagery, rain gauges, soil wetness measurements, SPOT (France) and LANDSAT.
  * PALSAR onboard ALOS is also useful for the observation of soil (surface) wetness.

<u>Composited Precipitable Water (PW) Product (4 times a day):</u>

- GOES derived PW Product available every hour; SSM/I derived PW Product available every 12 hours
- *Primary*: GOES derived PW, SSM/I derived PW, and Numerical Weather Prediction Model - derived PW
- *Ancillary*: Rawinsonde derived PW

Many of the products listed above are available through the NESDIS Flash Flood Home Page: http://orbit-net.nesdis.noaa.gov/ora/ht/ff/

This Home Page includes the global Soil Wetness Index with close-ups of the U.S.A., Canada, South and East Asia, Africa, Europe, South America, Australia, and Indonesia

The following briefly details the data and product resolution requirements for the operational GOES and POES meteorological satellites.

Data and Product Resolution Requirements

Threshold refers to the level below which there is no significant usefulness; *Optimum* refers to the level above which there is no significant improvement in usefulness. The following only addresses the thresholds and optimum levels that can be obtained from the operational meteorological satellites. High-resolution data from the Earth Resource Satellites (RADARSAT, SPOT, etc) are required for mapping and providing parameters for many hydrological models.

Data Resolution Requirements

GOES and POES CHANNELS	***Threshold***		***Optimum***	
	Space	Time	Space	Time
VIS	1 km	1 hr	1 km	5 min
3.9 micron	4 km	1 hr	1 km	5 min
6.7 micron	8 km	1 hr	1 km	5 min
10.7 micron	4 km	1 hr	1 km	5 min
12.0 micron	4 km	1 hr	1 km	5 min
85.5 GHz	15 x 13 km	12 hr	10 x 10 km	15 min
37.0 GHz	37 x 28 km	12 hr	10 x 10 km	15 min
22.2 GHz	50 x 40 km	12 hr	10 x 10 km	15 min
19.3 GHz	69 x 43 km	12 hr	10 x 10 km	15 min

Product Resolution Requirements

Products	***Threshold***		***Optimum***	
	Space	Time	Space	Time
Precipitation:	50km	3 hour	1km	5 min
Soil Wetness Index:	50km	daily	10km	4 times/day
Composited PW	50km	2 times/day	10km	hourly

Polar Orbit Satellite Products and Services

There exists today at least a dozen earth observation satellites currently collecting data that are useful for flood management applications. ***Tables 2 through 4*** include a compilation of specific data requirements for high-resolution satellite data sets related to flood disasters. Three categories of requirements are spatial resolution, temporal resolution, and satellite systems/sensors.

Table 2

<u>Spatial Resolution Requirements (by application)</u>

Application	Phase	Threshold	Optimum
Land use post-flood	pre-flood “ ”	30 meter (MSI) “ ”	4-5 meter (MSI)
Infrastructure status post-flood	pre-flood “ ”	5 meter (pan-vis) “ ”	<= 1 meter (pan-vis)
Vegetation post-flood	pre-flood “ ”	<= 250 meter (M/HSI) “ ”	<= 30 meter (M/HSI)
Soil Moisture Snow Pack	pre-flood pre-flood	1 km 1 km	100 meter 100 meter
DEM (vertical) post-flood	pre-flood “ ”	1-3 meter (INSAR/pan-vis) “ ”	0.10-0.15 meter
Flood development and flood peak	during flood post flood	<= 30 meter (SAR/MSI/ vis-pan/IR)	<= 5 meter
Damage assessment (incl. feedback/lessons learned)	post flood	2-5 meter (MSI/pan-vis/ SAR)	0.3 meter
Bathymetry (near-shore)	pre-flood	< 1 km (SAR/MSI)	90 meter

MSI = multi-spectral imagery (2 to 50 bands)
HSI = hyper-spectral imagery (> 50 bands)
pan-vis = panchromatic visible imagery
SAR = synthetic aperture radar
INSAR = interferometric SAR

Table 3
Temporal resolution requirements (by application)

Application	***Image refresh rate*** (Threshold/Optimum)	***Image delivery time*** (Threshold/Optimum)
Infrastructure status	1-3 yrs / 6 months	months
Land use	1-3 yrs / 6 months	months
Vegetation	3 months / 1 month	months
Soil Moisture	1 week/daily	1 day
Snow Pack	2 month/1 week	1 day
DEM pre- and post-flood	1-3 yrs / months	months
Flood development Flood peak 24-hr from tasking to delivery	hours-days (function of drainage basin)	hours-days (function of drainage basin) /
Damage assessment	n/a	2-3 days / < 1 day
Bathymetry pre- and post-flood	1-3 yrs / months	months

Table 4

Satellite systems to be used for data

System	Status	Capabilities
ALOS	Planned	Radar, optical
DMSP	Existing	Optical, IR
ENVISAT	Planned	Radar, optical, IR
ERS 1 & 2	Existing	Radar, 5-500km swath, 25m resolution
Ikonos 1-2	June 99	Optical 1 and 4m resolution
IRS	Existing	Optical, 150 km swath, 36m resolution
KVR-1000	Existing	Optical 150 km swath, 2 m
LANDSAT 5	Existing	Optical, IR 185 km swath, 30m, 80m
LANDSAT 7	April 99	Optical, IR 185 km swath, 30m, 80m
NOAA-GOES	Existing	Optical, AVHRR
NOAA-POES	Existing	In-situ visible and IR observation
OrbView	Planned	Optical 1, 2 and 4m
QuickBird	Planned	Optical 1 m resolution
RADARSAT 1	Existing	Radar 45-510 km, 9-63m
RADARSAT 2	Planned	Radar 10-500 km, 5-100m
Resurs-01	Existing	160-600 m
SeaWiFS	Existing	Optical, IR 1-4m sea observations
SPOT 1-5	Existing	Optical 60km swath, 10m, 30m

There are several types of data products that are useful for disaster-management decision-making (SAR, 1999). The type and complexity of data products used for disaster monitoring depend on the stage of the disaster, (for mitigation and prevention purposes, early warning, or recovery operations). The most useful type of satellite image products that have recently been exploited for disaster management applications include:

Image maps These products are geocoded and geocorrected satellite images of the disaster area. Image maps do not usually have intensive interpretation and may include place names and general feature identification. These are most useful if they are available during the disaster event to understand the general area affected, and are effective in visualizing a disaster scene “before” and “after” the event.

Image maps with integration of local GIS data When satellite imagery is combined with other GIS data such as land use, slope, aspect, transportation and infrastructure networks, an analysis may be done of the high risk areas that may be subject to damage from disasters. Integration of GIS data with current satellite imagery requires time and effort, but also renders this type of product valuable for disaster mitigation and prevention purposes.

Image maps with cartographic data Map information can be combined with satellite imagery to produce a composite, which is valuable for precise mapping of an affected disaster area.
Digital files Digital products can be produced in various scales and forms. Data providers from satellite companies distribute various types of digital products — some in raw formats, where the user must conduct their own processing techniques, or some in pre-processed form, which greatly enhances the time to produce a final product. These files, depending on their size, can be sent via Internet email, File Transfer Protocols (FTP) or simply by courier to the user.

Digital information for modeling purposes Information derived from satellites is distributed for the purpose of inputting into numerical model data. This data is usually used by academic, research or more sophisticated users.

V. FUTURE IMPROVEMENTS AND REQUIREMENTS

As described previously, remote sensing contributes to the complex problem of flood management. However, gaps remain and remote-sensing data is not being used to its full potential to help alleviate this problem. Improvements can be divided into four categories: (1) methodology, (2) science, (3) technology, and (4) data management. Such improvements can contribute to the cost-effectiveness of EOS (Earth Observation Satellites).

1. Methodology

There is a need for coherent integration with all other disciplines that are operating in regard to flood hazards. In the past, providers of data have been working too often in a vacuum and not interacting enough with the user community. Providers must begin to consider more carefully issues related to data acquisition, data elaboration, scientific interpretation of natural phenomena, and the needs of users. On many occasions, remote sensing techniques have been in competition with the more traditional methods. In the field of floods, where there are many information gaps, integration of both the remote sensing and traditional techniques is strongly recommended for the benefit of the final users.

Regarding flood hazards, the main methodological improvements recommended are:

(a) An integrated approach with other disciplines (data fusion); this includes R&D on integrated approaches of Hydro models, remote sensing, and GIS (Geographic Information System); which can lead to methodologies that improve valorization of remote sensing data;
(b) A differentiated approach according to the typology of the event (flood plain, flash floods, dam breaks, ice jams, storm surges)
(c) An integrated approach between flood and slope instability, as different aspects of the same dynamic system (the drainage basin); and
(d) Improved GIS integration.

2. Science

The scientific gaps are related to improvements in the satellite-derived precipitation algorithms. Currently, most of the satellite rainfall techniques were developed for tropical convective systems. In order to make these algorithms more robust, calibration and validation must be undertaken for various types of precipitation systems (extra-tropical and tropical). Improvements are needed in ground truth precipitation measurements so that the satellite algorithms can become more mature and reliable. Precipitation measurements from TRMM and meso-networks around the world will provide such information. Ba and Gruber (1998) initiated efforts to incorporate GOES multi-channel information into a rainfall algorithm. Turk (1998) and Vicente, (1994) have developed algorithms that combine SSM/I and GOES IR to provide regional scale precipitation analyses. Hopefully, microwave measurements will help to provide a robust methodology in which histograms and probability matching will be used to continuously update GOES precipitation measurements, with respect to both intensity and location. Thus, using multi-spectral and multi-sensor data, combined with ancillary information will help lead to achievement of advanced precipitation algorithms.

The full benefit of remote sensing for applications related to flooding is likely to come from the integration of data from a variety of sensors operating in wavelengths from microwave to visible and infrared. This will pose new challenges in the development of inversion models to quantify the hydrological variable being observed and in the use of geographic information systems to relate these spatial and temporal data sets. In addition, the newly developed physically-based distributed hydrological models will need to be refined to make full use of the high spatial and temporal frequencies of the observations that may be obtained. In addressing these challenges, we will gain a better understanding of hydrologic processes at the local, regional and global scales.

3. Technology

More improvements are needed in the field of technology. These enhancements include:

(a) Increase time and frequency of coverage
(b) Improvement of coverage access and delivery
(c) Increased resolution of DTM for local application — this includes very local (1m) information (town, small watershed, etc) that is very precise and available in the shortest period of time
(d) Achieve the ability to access information from all available data sources
(e) Formulate procedures that affects awareness, access, products and services
(f) Launch meteorological satellites with higher resolution sensors both in time and space
(g) Place microwave onboard operational geostationary meteorological satellites

A good way to improve the utility of the data is to increase its usage. Current prices for high-resolution satellite data sets are often too high to allow for routine use. Perhaps an increase in marketing will increase volume to the point where prices become more affordable for routine and contingency operational use.

4. Data Management

The requirements mentioned earlier in this report state the need for higher spatial and temporal resolution of remote sensor data sets from an increasing number for satellite platforms. Inherent in these requirements is the need for enhanced data management techniques and technologies. The graphical nature of satellite data and associated products means that larger and more efficient data networks are needed along with state-of-the-art data compression capability. Satellite data must also be compatible with GIS software to maximize utility.

There is also a strong need for improving local capacity, education and training, international coordination for response, and international data service to be able to facilitate access to data that is understandable. Few end-users will be experts in the field of remote-sensing techniques. Thus, there is a need for an increase in education and outreach on the increasing number of data types and products that are available and the potential uses for each. Equally important is the need to communicate to the end-users the strengths and limitations of each product so that disaster managers can make decisions based on the appropriate assumptions for their data.

VI. SUMMARY AND CONCLUSIONS

The following briefly summarizes the use of, and development required for the use of satellite data for flood monitoring and prediction:

Prediction

- Prediction of floods through Numerical Weather prediction Models that produce Quantitative Precipitation Forecasts (QPF)
- QPF can be inserted into hydrological models to predict river flows and crests
- Precipitable water products for assessing the atmosphere with respect to the magnitude of the moisture and its transport
- Soil (surface) Wetness Index as an antecedent condition as to the wetness of the ground
- Land cover Maps
- Snow cover Maps
- Digital Elevation Models (DEM)
- Flood Risk Maps

Monitoring, Assessment and Prediction

- Estimation of precipitation amounts through Quantitative Precipitation Estimation (QPE) Algorithms
- QPE can be inserted into hydrological models to predict river flows and crests
- NOWCASTS — 3 hour outlooks of precipitation
- Estimation of flood extent using SSM/I, NOAA high-resolution imagery, SAR (RADARSAT, JERS, ERS), SPOT and LANDSAT.
- Damage Assessment

Algorithm and Technique Improvements Required

- Development of methods for the integration of satellite, in-situ and GIS data for input into hydrological models
- Development of multi-sensor/satellite integration methods
- Addition of microwave sensor on GOES
- Estimation of soil moisture and snowpack characteristics from high resolution microwave data
- Improve satellite rainfall estimation techniques
- Increase temporal frequency of polar orbiting satellite data acquisitions
- Decrease time required to acquire and deliver remotely sensed data
- Lower the cost of remotely sensed data
- Develop techniques to generate high resolution DEM
- Education/Training to build local capability
- International coordination of data acquisitions

In closing, satellite-derived precipitation estimates for application to flash floods could be done around the world as, long as GOES data is available and accessible. The potential for such information was discussed in Section IV, along with case studies to illustrate the use of satellite estimates in a heavy rainfall/flash flood event. Soil (surface) Wetness Indices, from SSM/I, are available around the world to determine the wetness of the ground.

Improvements are needed in ground truth measurements so that the satellite algorithms can become more mature and reliable. More robust satellite precipitation algorithms are needed that can better screen non-raining clouds and produce better precipitation estimates from the more stratiform events. These more mature algorithms will provide rapid response with a very low false alarm ratio. The ultimate objective is to integrate the GOES with the SSM/I , radar and in-situ rain gauge measurements to develop a multi-spectral/multi-sensor algorithm for estimating precipitation from all types of cloud systems. Artificial neural network techniques for estimating heavy convective rainfall have shown great potential (Zhang and Scofield, 1994). Finally, the CEOS Flood Team highly recommends that there be microwave "flying" on operational GOES platforms that cover the globe by the 2005 time frame.

Demonstration Project(s)

The Flood Hazard Team proposes that demonstration projects are required to illustrate and educate the end-user community on the capabilities of satellite remotely sensed data to provide information during all of the phases of the disaster cycle. The Team recommends leveraging the opportunities created by the *International Charter* with other ongoing activities such as, but not limited to, the Global Disaster Information Network, the Open-GIS Consortium, the Red River Disaster Information Network and the Canadian GeoConnections initiatives. As developed and developing countries have differing current capabilities with respect to flood forecast, response and recovery it is envisioned that two demonstration projects should be conducted to address the different levels of infrastructure available. Possible demonstration sites identified by the Team include Central America, the Red River (United States/Canada) and the Oder River in Europe.

In order to properly execute the demonstration projects there will be a requirement to gain an understanding of the current operations and requirements of the end users, which may be satisfied wholly, or partly with remotely sensed data. This activity would be a two-way education process conducted in preparation for the demonstration, well in advance of any actual flood event and facilitate a mutual understanding of information/product requirements and the mechanisms to communicate the information at local, regional and national scales. This should not be limited to products derived solely from remotely sensed data but rather should integrate meteorological, in situ and other geospatial data. Lastly, to ensure that there is a high international visibility, the Team recommends that the demonstrations should have a public relations component incorporated into the demonstration.

Scope

In forming emergency scenarios, the team went through a process of re-thinking the flood problem and extracted several critical elements that are important for consideration: timeline, hydrological parameterization, meteorological forecast, in-crisis phase, and flood damage assessment.

<u>Mitigation and Preparedness</u>

1) Hydrologic parameterization

- Land cover
- Infrastructure
- DEM
- Soil Moisture
- Snow pack characterization
- In situ observations – meteorological conditions, water stage and discharge

2) Meteorological forecasting/nowcasting
- Integrate NESDIS QPE/QPF "experimental" global rainfall estimates computed every hour using infrared data from geostationary satellites for flash flood bearing thunderstorms and tropical storms.

3) Flood Forecasting
- Integration of remotely sensed hydrological parameters, meteorological conditions and in situ data in hydrological model for flood forecasting

Response and Recovery
- Flood Extent
- Damage Assessment
- Mitigation Recommendations

Data Requirements
- Temporal and Spatial optimal and minimum requirements specified in this report.

Proposed Flood Hazards Scenarios

Scenario #1

In this scenario, the trigger for a request for assistance would be that there is a potential of severe flooding. This would involve the acquisition of all relevant remotely sensed, geospatial and in situ data to evaluate the current hydrological conditions over a given watershed. Close collaboration with local authorities is essential.

Value added processing of imagery or data

1. Extraction of Hydrological Parameters for modeling purposes
2. Precipitation forecasts
3. Land cover/Infrastructure maps to document conditions before the flood
4. Integration of in situ, geospatial and remotely sensed data
5. Generation of Flood Risk Maps

Scenario #2

The trigger for this kind of request for assistance would be that there is a flood occurring with significant social and economic impacts. Close collaboration with local authorities is essential.

Value added processing of imagery or data

1. Extraction of flood extent
2. Integration of Flood Extend with geospatial data
3. Damage Assessment

The Project Manager will need to ask the end user what will work (ftp, Internet, courier, etc)

Proposed Flood Hazard Scenario

Obtain background information		Check if Considered
1.	Name of River and watershed Boundaries (latitude, longitude)	
2.	Timeframe and location for potential flooding	
3.	Responsible Agency	
4.	Availability of in situ and existing geospatial data (i.e. Landcover, DEM)	
5.	Secondary hazards (landslide potential)	
6.	Location of buildings, roads, airports, hazardous waste sites etc.	
7.	Expected response time of watershed (duration of flood)	
8.	Existing Hydrological Modeling capabilities and data requirements	
Obtain current and future Flood status		
1.	Remotely sensed extent of surface water	
2.	Soil moisture conditions	
3.	Snowpack conditions	
4.	Precipitation Forecast	
7	Current hydro-meteorological conditions	
Priorities for image planning		
1.	SPOT – Preparedness and damage assessment	
2.	Radar sat – Response and Mitigation Choice of beam mode determined by scale of flooding (i.e. Local requires Fine mode, regional requires Standard or ScanSAR modes)	
3.	ERS - Response	
4.	Search all archives for pre-flood imagery.	

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REFERENCES

Achutuni, R., R.A. Scofield, N. Grody, and C. Tsai, 1996, "Global monitoring of large area flooding using the DMSP SSM/I soil wetness index," *Proceedings of the 8th conference on satellite meteorology and oceanography, Atlanta, GA, 29 January - 2 February, 1996*, AMS, Boston, pp. 455-459.

Achutuni, R. and R.A. Scofield, 1997, "The spatial and temporal variability of the DMSP SSM/I global soil wetness index," *Proceedings of the 13th conference on hydrology, 2-7 February 1997, Longbeach, CA,* AMS, Boston, MA, pp. 188-189.

Achutuni, R. and R. A. Scofield, 1998, "Applications of the SSM/I Soil Wetness Index for large area flood monitoring," Submitted for publication in the *Journal of Applied Meteorology American Meteorological Society*, Boston, MA.

Ba, M.B. and A. Gruber, 1998, "GOES multi spectral algorithm for quantitative precipitation estimation (QPE), *Proceedings of the 16th conference on weather analysis and forecasting, 11 - 16 January 1998, Phoenix, AZ,* AMS, Boston, MA, pp. 371 - 376.

Barrett, E.C., 1996, "The storm project: using remote sensing for improved monitoring and prediction of heavy rainfall and related events," *Remote Sensing Reviews,* vol 14, 282 pp.

Borneman, R., 1988, "Satellite rainfall estimating program of the NOAA/NESDIS Satellite Analysis Branch," *National Weather Digest,* 13 (2), pp. 7-15.

Brisco, B., T.J. Pultz, 1998, "Wetland mapping and monitoring with RADARSAT,*" 20thCanadian Symposium on Remote Sensing*, Clagary, Alberta, May 10-23, 1998.

Casale, R. and C. Margottini, 1994, "Meteorological events and natural disasters," EDB and RDB, Roma, Arti Grafiche Tilligraf S.P.A., Roma, Italy, 96pp.

Ferraro, R. R., 1997, "SSM/I derived global rainfall estimates for climatological applications," *J. Geophys. Res., 102, 16*, pp. 715 - 736.

Ferraro, R. R., Weng, F., Grody, N.C. and Basist, A., 1996, "An eight year (1987-94) climatology of rainfall, clouds, water vapor, snowcover, and sea-ice derived from SSM/I measurements," *Bull. Of Amer. Meteor. Soc,* 77, pp. 891-905.

Hayden, C.M., 1988, "GOES VAS simultaneous temperature-moisture retrieval algorithm," *Journal of Applied Meteorology,* 27, pp. 705-733.

Holt, F.C., W. P. Menzel, D. G. Gray, T.J. Schmit, 1998, "Geostationary satellite soundings: new observations for forecasters," *US Department of Commerce, NOAA, NESDIS,* 30pp.

Jobin, D.I., T.J. Pultz, 1996, "Assessment of three distributed hydrological models for use with remotely sensed inputs*," Third International Workshop on Applications of Remote Sensing in Hydrology, Greenbelt, MD, October 16-18*, pp. 100-130.

Kuligowski, R.J., 1997, "An overview of National Weather Service quantitative precipitation estimates (QPE), 1997," *Techniques Development Laboratory Office Note 97-4.* U.S. Department of Commerce, NOAA, NWS, Office of Systems Development, 27pp.

Leconte, R., T.J. Pultz, 1990, "Utilization of SAR data in the monitoring of snowpack, wetlands, and river ice conditions," *Workshop on Applications of Remote Sensing in Hydrology, Saskatoon, Saskatchewan, February 13-14, 1990*, pp. 233-247.

Lu, N, 1997, "Satellite rainfall estimate," *Proceedings of the 1997 meteorological satellite data users' conference. Brussels, Belgium, 29 September - 3 October, 1997, EUMETSAT,* pp. 529 - 533.

Nieman, S.J., W.P. Menzel, C.M. Hayden, D.G. Gray, S.T. Wanzong, C.S. Velden, and L. Daniels, 1997, "Fully automated cloud-drift winds in NESDIS operations," *Bull. Amer. Meteor. Soc., 78,* pp. 1121 - 1133.

Pultz, T.J, R. Leconte, L.St. Laurent, l. Peters, 1991, "Flood mapping with airborne SAR imagery: case of the 1987 St. John River flood," *Canadian Water Resources Journal*, vol 16, 2, 173-189.

Pultz, T.J. and Yves Crevier, 1996, "Early demonstration of RADARSAT for applications in hydrology," *Third International Workshop on Applications of Remote Sensing in Hydrology, Greenbelt, MD, October 16-18*, 1996, pp. 271-282.

Pultz, T.J., Y. Crevier, R.J. Brown, J. Boisvert, 1997, "Monitoring of local environmental conditions with SIR-C/X-SAR," *Remote Sensing of the Environment*, vol 59, 4, pp. 248-255.

Saper, R., T.J. Pultz, Y. Crevier, R. Bowring, and I. McLauren, 1996, "Demonstration of RADARSAT potential for flood monitoring - the 1996 Manitoba spring floods*," Third International Workshop on Applications of Remote Sensing in Hydrology, Greenbelt, MD, October 16-18*, 1996, pp. 313 - 322.

Scofield, R.A. and C. Margottini, 1999, "Earth Observation Satellites for flood management and flash flood analysis and prediction," *Space Forum*, vol 4, pp. 199 - 222.

Scofield, R.A. and V.J. Oliver, 1977, "A scheme for estimating convective rainfall from satellite imagery," *NOAA Technical Memorandum NESS-86, National Oceanic and Atmospheric Administration, U.S. Department of Commerce*, 51pp.

Scofield, R.A., 1987, "The NESDIS operational convective precipitation estimation technique," *Monthly Weather Review,* 115 (8), pp. 1773 - 1792.

Scofield, R.A. and R. Achutuni, 1994, "Use of satellite data during the great flood of 1993," Appendix C of the natural disaster survey report on *The Great Flood of 1993, NOAA/NWS Report, U.S. Department of Commerce*, Silver Spring, MD, C-1 — C-18.

Scofield, R.A., S. Kusselson, D. Olander, and J. Robinson, 1995, "Combining GOES, microwave, and raw insonde moisture data for improving heavy precipitation estimates and forecasts," *Proceedings of the 14th conference on weather analysis and forecasting, Dallas, TX, 15 - 20 January, 1995,* AMS, Boston, MA, (J4) 1 - (J4) 6.

Scofield, R.A., D. Zaras, S. Kusselson, and R. Rabin, 1996, "A remote sensing precipitable water product for use in heavy precipitation forecasting," *Proceedings of the 8th conference on satellite meteorology and oceanography, Atlanta, GA, 29 January - 2 February, 1996,* AMS, Boston, MA, pp. 74 - 78.

Scofield, R.A. and R. Achutuni, 1996, "The satellite forecasting funnel approach for predicting flash floods, *Remote Sensing Reviews,* vol 14, pp. 251-282.

Shi, Jiang and R.A. Scofield, 1987, "Satellite observed mesoscale convective system (MCS) propagation characteristics and a 3 - 12 hour heavy precipitation forecast index," *NOAA Technical Memorandum NESDIS 20, December 1987, Washington, DC,* 43pp.

Spayd,L.E., Jr. and R.A. Scofield, 1984, "An experimental satellite-derived heavy convective rainfall short-range forecasting technique," *Proceedings of the 10th Conference on Weather Analysis and Forecasting, Clearwater Beach, FL*, 25 - 29 June, 1984, AMS, Boston, MA.

U.S. Dept. of Commerce, "The Great Flood of 1993, *1994 Natural disaster survey report," NOAA/National Oceanic and Atmospheric Administration/National Weather Service*, 234pp.

U.S. Dept. of Commerce, "The modernized end-to-end forecast process for quantitative precipitation information hydrometeorological requirements, scientific issues, and service concepts," *1999 U.S. Dept of Commerce, NOAA/National Oceanic and Atmospheric Administration/National Weather Service*, 187pp.

Turk, F.J., F.S. Marzano, and E.A. Smith, 1998, "Combining geostationary and SSM/I data for rapid rain rate estimation and accumulation," *Proceedings of the 9th conference on satellite meteorology and oceanography, Paris, France, May 25 - 29*, 1998, Boston, MA, pp. 462 - 465.

Vicente, G. and R. A. Scofield, 1998, "The operational GOES infrared rainfall estimation technique," Accepted for publication in the *Bulletin of the American Meteorological Society, September 1998.*

Vicente, G.A., 1994, "Hourly retrieval of precipitation rate from the combination of passive microwave and infrared satellite radiometric measurements*," PhD thesis, Department of Atmospheric and Oceanic Sciences, U. of Wisconsin - Madison*, WI, USA, 127pp.

Velden, C.S., C.M. Hayden, S.J. Nieman, W.P. Menzel, S. Wanzong, and J.S. Goerss, 1977:, "Upper-tropospheric winds derived from geostationary satellite water vapor observations," *Bull. Amer. Meteor. Soc., 78*, pp. 74 - 195.

SAR Corporation, 1999, "Spaceborne Remote Sensing and Disaster Management Operations : Current Information Requirements, Delivery Methods and Integration*," Report prepared for the Canada Centre for Remote Sensing. Ottawa, Ontario, Canada*.

Xie, Juying and R.A. Scofield, 1989, "Satellite-derived rainfall estimates and propagation characteristics associated with mesoscale convective systems (MCS), *NOAA Technical Memorandum, NESDIS 25,* May 1989, Washington, DC, 49pp.

Zhang, M. and R.A. Scofield, 1994, "Artificial neural network techniques for estimating heavy convective rainfall and recognizing cloud mergers from satellite data," *International Journal of Remote Sensing,* vol 15, 16, pp. 3241 - 3261.

T E A M   R E P O R T

Ice

ICE HAZARDS

CEOS DISASTER MANAGEMENT SUPPORT GROUP

SUMMARY

The purpose of this report is to identify requirements and review the current and projected utility of earth observation space technology as applied to the detection, mapping and management of ice hazards. Ice hazards include sea ice (ice that is formed from sea water) and icebergs (floating glacial ice). This study was developed under the auspices of the Disaster Management Support Group (DMSG) of the Committee on Earth Observation Satellites (CEOS). This document was prepared by an international working group composed of representatives with experience in remote sensing as applied in the production of operational ice guidance products and services.

It is well known that sea ice and icebergs pose a serious hazard to shipping and other maritime activities in the Polar Regions. The role of EOS data in operational ice monitoring is well documented and has grown in importance over the years. EOS data from visible/infrared sensors are potentially available to all ice services but are useful only under cloud-free conditions. Passive microwave sensors can penetrate cloud cover but their effectiveness in ice monitoring is limited by coarse resolution. Active microwave sensors, such as the Synthetic Aperture Radar (SAR), are ideal for ice mapping because of their high resolution, all weather, wide swath ice detection capability; however it does not always provide unambiguous interpretation. Therefore it is extremely important that all ice centers have access to EOS data in the various spectral ranges (e.g. visible, infrared and microwave) to allow for the most accurate analysis of ice conditions. Investigations have also shown that these data are also valuable in their ability to quantify other ice parameters in addition to ice extent (concentration) and ice type (stage of development), such as ice topography, presence of open water or thin ice openings within the sea ice pack, stages of ice decay and others. Sea ice guidance products derived in real-time from these data are used operationally to ensure safety of navigation by all vessels, maximize time and fuel savings of icebreaker lead convoys, determination of most efficient and safest route, and protect life and property associated with human activities on the ice. In contrast, the utility of EOS observations for iceberg detection is considered limited using presently available sensors. Space-borne SAR sensors can be effective in depicting the location and size of icebergs but only under low surface wind speed conditions.

The following recommendations support these requirements:

1. New and updated EOS sensors provide great promise for improving the applications of sea ice mapping and iceberg detection.
2. Data from multi-spectral visible/infrared radiometers and scatterometers can be used to generate automated sea ice maps.
3. SAR satellites with right/left looking beam steering, multiple polarization modes and enhanced downlink capabilities will provide more valuable data in a shorter period of time to the end user.
4. Coincidental collection of EOS data from multiple instruments, fused with ancillary environmental data can resolve ambiguities and biases in conventional, single sensor algorithms.
5. Affordable data continuity, accessible rapidly for near real time support.
6. Data policies must ease rapid access to EOS data for ice hazard detection & monitoring.

7. Collaborative efforts are needed between all the national ice services to ensure that EOS data are shared, that ice products are issued in standard formats and most importantly that customers are educated on the strengths, weaknesses and value of EOS data and Ice Hazard products.
8. Improved/new sea ice/iceberg detection and classification algorithms.
9. Higher resolution coupled ice/ocean/atmosphere forecasting models to improve sea ice forecasts in the Marginal Ice Zone(MIZ) and iceberg drift and ablation rates.

INTRODUCTION

Eighteen nations, including Australia, Argentina, Canada, China, Denmark, Estonia, Finland, Germany, Iceland, Japan, Latvia, Lithuania, Netherlands, Norway, Poland, the Russian Federation, Sweden and the United States operate national ice services that support shipping and other maritime activities in ice encumbered waters. This support is outlined in the World Meteorological Organization (WMO) publication N0-574. From 1920 to the early 1960's, "in-situ" visual ice observations from coastal stations, transiting ships and aircraft reconnaissance and patrols represented the primary source of data on sea ice conditions and the location of icebergs. The paucity of information made available by these collection methods and the serious hazard posed by glacial ice to vessel operations gained international recognition and notoriety with the sinking of the TITANTIC on April 15, 1912 (struck the iceberg on 14 April, sank in very early morning hours on 15 April). As a result of this accident, the U.S. Coast Guard (USCG) International Ice Patrol (IIP) was formed to provide iceberg detection and warning services to vessels operating in the North Atlantic shipping lanes. Similarly, interest in many nations to develop more accurate methods for the detection, monitoring and forecasting of sea ice did not occur until there were significant incidents that threatened the safety of navigation and life and property at sea.

In winter 1937, which was logistically unexpected and different from the previous mild ones, within the area of the Northern Sea Route (NSR) from Franz-Josef Land to New Siberian Islands 26 cargo ships with approximately 1000 people were beset by ice. That catastrophe led to the establishment of the Russian Ice Service much similar to the present, total duration of ice air reconnaissance being one order greater in 1938 than in 1937. In 1951, operating under the code name *Operation Bluejay,* 30 ships of a 33 U.S. Navy vessel convoy were severely damaged while attempting to navigate along the west coast of Greenland to establish a Distant Early Warning station and air base at Thule, Greenland (McDowell, 1990). In 1952, as a direct result of this accident, the U.S. Navy established a formal sea ice monitoring program. Outside Russia and Denmark, most national ice services at this time were fledgling programs that needed to collect information to build their knowledge on sea ice characteristics and behavior. Beginning in the early 1960's, the capability to collect data was enhanced when the Canadian Ice Service (CIS) introduced the use of search radars on ice reconnaissance aircraft (Bertoia et al 1998). These radars provided, for the first time, a long-range, cloud independent capability to detect ice. Unfortunately, these early instruments were forward-looking, non-imaging sweep radars that were useful only in the accurate measurement of range and bearing to the ice edge.

Due to limited range and expense, aerial reconnaissance was typically flown only in support of specific vessel operations. Knowledge on the overall extent, thickness and behavior of the polar ice cover in both hemispheres was viewed as incomplete, thus posing a continual hazard to vessel operations. It was only during the 1960's that sea ice detection and monitoring entered a new era of remote sensing with the launch of weather satellites by the United States. The usefulness of "pictures" taken by vidicon cameras for gross ice mapping was recognized immediately after the launch of the first TIROS research and development satellite in 1960 (Wark and Popham, 1962). By the late 1960's and 1970's, improvements in satellite technology (ESSA satellites on polar orbits) allowed for the real-time use of these data for operational ice mapping (Strübing 1970). NOAA-2 (launched in October, 1972) carried a dual channel Very High Resolution Radiometer (VHRR) that provided visual and thermal imagery via direct global and local read-out. The NASA research satellite, NIMBUS-5 (launched in December, 1972) included an Electrically Scanning Microwave Radiometer (ESMR) that provided coarse resolution, all-weather, passive microwave data. These data, coupled with traditional data sources, allowed the U.S. National Ice Center (NIC) to initiate weekly global ice mapping program of all Arctic and Antarctic seas.

In the early 1970's, improvements in radar technology resulted in the deployment and use of real aperture Side-Looking Airborne Radar (SLAR) on patrol aircraft. Several national ice services used these SLAR data to extend the range of aircraft providing traditional visual observations and to complement the visual, thermal and passive microwave imagery received from satellites. In June 1978, the benefits of merging rapid advancements in radar technology and satellites were seen in the launch of the NASA research satellite, SEASAT. SEASAT was the first satellite dedicated to using active microwave sensors for ocean observation. Although limited to only 105 days in orbit, SEASAT provided high resolution images which confirmed that a space-borne Synthetic Aperture Radar (SAR) can be a powerful tool in ice detection and mapping (Teleki et. al., 1979).

Today, Earth Observation Satellites (EOS) are used almost exclusively to provide operational information on the extent, concentration, distribution and thickness of sea/lake ice. In demonstration projects, EOS data are now being used to detect, forecast and assess the damage of destructive river ice break-up and ice jams. Additionally, the USCG IIP and CIS are using EOS data for research purposes to detect and map icebergs in the North Atlantic.

General Application Description

The requirement for the detection, mitigation and management of the potential hazards posed by ice originated with early 19th and 20th century polar exploration. Vessel expeditions attempting to find and exploit the Northwest Passage, the Russian Northern Sea Route or the resources found in or beneath the frozen waters of the Arctic and Antarctic were often damaged, beset or destroyed by sea ice. Today, the operational detection of sea ice, icebergs and river/lake ice is vital to ensuring the safety of vessel operations and the commercial viability of associated industries, such as marine transportation, fishing, oil exploration and tourism. National governments are also interested in these data to support components of national defense, scientific research, long-term climate monitoring and environmental programs. Local interest is typically centered on the effect a heavy ice cover has on local economies. For example, native and indigenous people often use unstable shorefast ice as platforms for marine mammal hunts and ice angling. Additionally, severe ice conditions like those observed along the U.S. east coast (e.g. Chesapeake Bay) in the winter of 1976-77 (Foster, 1982) can cause a disruption of maritime fuel oil deliveries, the closure of fishing areas and local navigation as well as extensive infrastructure damage such as loss of coastal navigational aides and docking facilities.

Specific user requirements for ice information can often be quite diverse depending on the user application or the capabilities of a vessel. Non-ice strengthened vessels require timely ice edge and iceberg limit information in order to plan their routes to avoid all known ice. For example, highly vulnerable crab and fishing ships operate directly adjacent to the rapidly changing ice edge in the Bering Sea during the volatile winter weather months. In contrast, vessels with hull strengthening and some degree of ice capability require information detailing ice concentration distribution and associated ice thickness. This information can be used to exploit the ice cover by planning routes more effectively. Even the most capable icebreakers use information on openings in the ice (e.g. leads and polynyas) to choose the path of least resistance in order to achieve greatest fuel economy. Additionally, submarines operating under the ice require ice opening and ice thickness information to assist in surfacing within the ice and in the successful transit of shallow ice-covered waterways.

In the Polar Regions, sea ice varies both spatially and temporally due to high variability in the environmental processes that form, advect and decay the ice. All international ice service organizations produce ice analyses describing current sea ice conditions. The production of these analyses is dependent almost exclusively on the availability and use of EOS data. Although accurate spatial depiction of ice conditions is important to the mariner, temporal accuracy is generally of much greater importance. Ideally, vessels at sea prefer to receive high-resolution satellite images that are less than 6 hours old and have been interpreted to provide the information necessary to avoid or exploit the ice. Sea ice parameters required by users at sea include the location of the ice edge, concentration distribution, stage of development, floe size, amount of pressure ridging or topography, location and orientation of ice openings, degree of ice compaction and divergence and stage of decay during the summer melt season. Additionally, information on the location and size of icebergs is essential in waters located near or downstream of ice shelves and glaciers.

Mitigation and preparedness for hazards posed by ice requires not only accurate ice analyses (describing current ice conditions) but also short (less than 72 hour) to long-term (168 hour to monthly/seasonal) ice forecasts. Most national ice services have developed and are using coupled ice/ocean/atmospheric models to predict short-term changes the movement, formation and ablation of sea ice and icebergs. Long-term monthly and seasonal forecasts are important to mission planning, particularly the prediction of the opening and closing of well-known navigational chokepoints (e.g Bering strait, north slope of Alaska east to Prudhoe Bay and various locations along the Russian Northern Sea Route). Additionally, to effectively describe the sea ice cover, nations with Arctic interests have developed a set of common terminology to describe the nature of sea ice and its behavior. This compendium of internationally accepted ice terminology and symbology was adopted by the World Meteorological Organization (WMO) in 1968. This terminology was compiled into a volume including illustrative sea ice and iceberg photographs and was issued as a publication entitled *WMO Sea-ice Nomenclature* (Publication No. 259) in 1970. This publication, supplemented from time to time, remains the source of accepted terminology and symbology for sea ice mapping and the identification of icebergs.

SPECIFIC APPLICATION DESCRIPTION

a) *Hazard Type*:	Sea Ice/Lake Ice Cover
User Level:	International, Regional, National, State
Disaster Mgmt Category:	Mitigation/Preparedness (surveillance, detection, and warning)
Operational Status:	Operational over all ice-covered seas

The majority of national ice services presently produce sea ice/lake ice guidance products in a digital workstation environment using data from polar orbiting satellites, ship/shore station reports, drifting buoys, meteorological guidance products, ice model predictions and on a limited basis, aerial ice reconnaissance flights. Among the presently available operational data sources, satellite imagery now constitutes the largest percentage of information received and integrated into global ice analysis products. Traditional data collection methods, such as visual aerial ice reconnaissance, require extensive pre-planning, are limited in geographic scope and are generally not cost effective. Real-time satellite data in the visible, infrared and microwave bands of the spectrum are now used extensively, and are an essential requirement for ice services to ensure safety of navigation and protect life and property in ice-covered seas and lakes.

Today's commonly used optical, thermal, passive microwave and active radar satellite systems possess characteristic strengths and weaknesses with respect to spatial resolution, detection capability and classification accuracy of the sea and lake ice cover. Additionally, the orbit of the satellite directly effects the geographical coverage and revisit time. Meteorological satellites fall into two categories based on their orbits: Geostationary or Polar. Orbiting at an altitude of 35,800 km and at the same rate as the earth, geostationary satellites provide superior temporal resolution with images available every 15-30 minutes. Thus, visible and infrared imagery from geostationary (e.g. GOES-8, GOES-10, METEOSAT and GMS) are used by several national ice services to monitor ice in lower latitude seas and lakes. Unlike the Polar Regions, these lower latitudes do not suffer from persistent illumination problems that can restrict the use of visible imagery. In North American areas, this is important because the Geostationary Environmental Satellite (GOES) 8/10 Imager instrument consists of visible and infrared channels that have spatial resolutions of 1 km and 4 km, respectively. The latter does not provide data of sufficient spatial resolution to do detailed ice mapping.

In terms of geographic coverage in the Polar Regions, polar orbiting satellites are the primary source for visible and infrared data for ice monitoring. The National Oceanic Atmospheric Administration (NOAA) and Defense Meteorological Satellite Program (DMSP) Polar Environmental Satellite (POES) operate at an altitude of approximately 830 km with a period of 102 minutes. With multiple satellites operating at any one time, many images are available each day in the Polar Regions. With five or six (NOAA-15) spectral channels and a 1.1 km spatial resolution (at nadir), visible and infrared imagery from the Advanced Very High Resolution Radiometer (AVHRR) is an effective tool for ice mapping. AVHRR imagery can be used to accurately depict the location of the ice edge, ice concentration, ice stage of development and physical surface temperature (Emery et al. 1991, 1994; Massom and Comiso 1994). In contrast, the DMSP Operational Linescan System (OLS) provides visible and thermal data from only two spectral channels but at improved 0.55 km spatial resolution that is consistent across the width of the swath. Additionally, the OLS visible channel often produces images with better sea ice and water contrast than either AVHRR channels 1 or 2. This effect occurs because the broad spectral wavelength of the OLS suppresses optically thin clouds when compared to surface features (Isaacs and Barnes 1987). Creating bispectral composite AVHRR images based on the difference between the visible and near-infrared channels (Lee et al. 1993) can generate a similar but improved effect. Unfortunately, these arithmetic image manipulation functions are limited in their effectiveness when extensive, heavy cloud cover is present.

Climatologically, cloud cover may be present over 80% of the time over the Arctic ice pack and the Marginal Ice Zone (MIZ) during the important summer shipping months (Benner et al. 1992). Visible and infrared data also require considerable expertise in manual image interpretation techniques that use texture, tone, shape and persistence to separate ice from clouds and water. Additionally, due to the fact that thermal contrasts between water and ice are not as large as reflectance (albedo) differences, infrared imagery generally requires image enhancement.

Passive microwave sensors are useful for sea ice mapping because emitted energy in this portion of the electromagnetic spectrum are not limited by clouds or illumination. Additionally, the measured brightness temperature (Tb) is a function that depends more directly upon the geophysical parameters of the sea ice (Comiso 1983; Cavalieri et al. 1984; Kwok et al. 1992; Kwok and Cunningham 1994 and Fung 1994). The Special Sensor Microwave Imager (SSM/I), a multi-channel microwave radiometer onboard the DMSP satellites, can be used to generate global ice concentration and first year/multiyear ice classification products (Cavalieri 1994; Kwok et al. 1996). Many national ice services employ algorithms using some combination of the 19 and 37 GHz channels to produce 25 km gridded mosaic ice maps. These products assist in the general delineation of the ice edge and inner pack concentrations in cloud-covered areas. Unfortunately, the coarse resolution precludes detailed analyses and great care must be taken to account for contamination errors induced by surface meltwater and coastlines.

Similar to passive microwave, SAR satellite systems (Canadian RADARSAT; European ERS-2; Japanese JERS (recently failed) and Russian ALMAZ) are not affected by clouds or darkness. SAR instruments use active microwave pulses to collect high spatial resolution (10-100 meter) data over varying swaths at fixed or selectable incidence angles. ERS-2 is presently being used by some European ice services to routinely map and monitor ice in portions of the Baltic Sea. In general though, the ERS is limited in its effectiveness to accomplish large-scale ice mapping because the single frequency/single polarization SAR has a fixed incidence angle and relatively narrow swath width (100km). In comparison, RADARSAT's C-band SAR has a steerable beam (thus variable incidence angle) and a SCANSAR mode that provides data with a 100 m spatial resolution and a 500 km wide swath. These characteristics back-up the Canadian Space Agency's (CSA) claim that RADARSAT is the world's first radar satellite specifically designed to maximize its usefulness for sea ice monitoring. RADARSAT's wide swath provides high repeat imaging capability that can image every point on the earth's surface north of 65N latitude at least once every day. North of 45N, the entire globe can be covered in 3 days or less. Four Command Data Acquisition (CDA) stations (Fairbanks, Alaska; Gatineau, Canada; West Freugh, Scotland and Tromso, Norway) provide near complete Arctic coverage. Arctic images are typically quick-look processed and transferred via dedicated communications lines or Internet to national ice centers within three hours of acquisition. No SAR imagery are routinely integrated into ice analyses of the Antarctic seas because of tape recorder limitations and data delivery delays associated with communications to/from the McMurdo ground receiving station.

The Russian OKEAN-01 polar orbiting satellite series is unique for ice mapping because it carries three intermediate resolution instruments that have the capability of simultaneously collecting passive microwave, Real Aperture Radar (RAR) and optical imagery. The passive microwave instrument (36 GHz horizontal), X-band RAR and single channel (0.8-1.1um) optical sensor provides imagery with 15km, 1.2km and 1.0km spatial resolution, respectively. Ice maps produced using simultaneously acquired passive and active microwave OKEAN data have compared favorably to concurrent SSM/I and AVHRR ice classifications in several case studies of northern Russian seas (Belchansky G. et al, 2000).

b) *Hazard Type*:	Icebergs
User Level:	International, Regional, and National
Disaster Mgmt Category:	Mitigation/Preparedness (surveillance, detection, and warning)
Operational Status:	Operational in North Atlantic and Antarctic

Icebergs are masses of freshwater ice that have broken off or calved from the edges of glaciers whose termini make contact with the sea or that have resulted from the fragmentation of larger icebergs already afloat (Loset et al. 1993.) The rate of production of icebergs is highly variable, being influenced by glacier velocity, degree of crevassing, ocean waves, swell and tidal variations, temperature and sea ice extent (Loset et al. 1993; Vinje 1989). Maximum production tends to occur in the summer when sea ice extent is at a minimum, temperature (and the glaciers) are at the warmest and wave action is most intense (Vinje 1989). Icebergs are classified on the basis of size and shape. The WMO (1970) system defines three size classes (icebergs, bergy bits and growlers) and six shape classes (tabular, dome, sloping, pinnacled, weathered and glacier). Presently, operational data collection by the International Ice Patrol is limited to visual observations, Side Looking Airborne Radar (SLAR), and Forward Looking Airborne Radar (FLAR) data from planned aerial reconnaissance flights and opportunistic ship reports. Attempts have been made to include EOS data to give synoptic views of large areas. Unfortunately, until recently, the utility of satellite observations (visible, infrared and passive microwave) were considered limited due to an inability to penetrate cloud cover and darkness, inadequate spatial resolution and/or poor revisit times. Research activities are presently evaluating the effectiveness of space-borne SAR's to detect icebergs.

Active microwave systems provide two-dimensional images of variations in backscatter that are difficult to interpret when compared to visible/infrared imagery. First, imaging radars are subject to speckle noise. This noise can be reduced by spatial averaging of the image resulting in a higher signal/noise ratio but at the expense of spatial resolution (Rees 1990). High speckle noise can inhibit the effectiveness of detecting small icebergs and often results in a significant number of false alarms (Willis et al. 1996). Backscatter differences are the result of surface and volume scattering of the target (in this case, an iceberg) and surrounding medium (sea water or sea ice). High wind speeds and resulting rough seas can mask the signal from an iceberg (Steffen et al. 1992a). In calmer conditions, icebergs sometimes give a bright target return with neighboring radar "shadow" that can be used to estimate iceberg volume or size (Larsen et al. 1978).

Iceberg detection algorithms using the ERS-1 SAR (C-band, VV polarized and 23 degree fixed incidence angle) demonstrated that 100 meter data could be used to detect even Arctic and North Atlantic icebergs with great success under "optimal conditions" (Willis et al.1996). Optimal conditions are those with wind speeds below 5 meters/sec and no sea ice or land within the image. At 100 meter spatial resolution, ERS-1 imagery detected 100% of large icebergs (120-200m width), 90% of medium size icebergs (60-120m width) and approximately 40% of small icebergs (15-60m width) (Willis et al. 1996). It is important to note that the less than desirable detection rate of small icebergs is a significant problem since small icebergs, bergy bits and growlers present the greatest danger to maritime shipping in that they are extremely difficult to detect with shipboard surface search radars. It was noted however that the SAR's iceberg detection capabilities decreased significantly with increasing wind speeds. Willis et al (1996) stated that iceberg detection using space-borne SAR's would be most effective with the following preferred radar parameters: as high frequency instrument as possible, horizontal polarization and large incidence angles. With this knowledge, the IIP and CIS are presently conducting research evaluating the utility of Radarsat SAR data for iceberg detection. Radarsat operates a C-band instrument, HH polarization, wide swath widths (up to 500km), variable incidence angles (20-60 degrees) and almost daily coverage in the high latitudes.

As described above, iceberg detection using EOS data is heavily dependent on iceberg size and surrounding environmental conditions. In the southern hemisphere, large tabular icebergs routinely calve from the numerous ice shelves in the Antarctic. Due to the enormous numbers of icebergs in this region and the absence of "in-situ" ground truth information, only very large icebergs (typically exceeding 10 nautical miles along the long axis) are detected and routinely mapped. In most cases, these icebergs are detected and tracked using AVHRR and OLS visible/infrared imagery. Large iceberg calving events are typically detected by significant changes in the ice shelf boundaries. Once within the sea ice pack, albedo similarities between icebergs and sea ice make detection and tracking difficult. Under certain conditions, visible and infrared imagery does show characteristic iceberg signatures. These signatures include leeward open water areas resulting from iceberg movements at a different velocity or direction than that of the surrounding sea ice (Strübing 1974). Surface temperature differences can also distinguish thicker bergs (up to 250m in freeboard) from the surrounding sea ice pack. The former effect is based upon the findings that larger icebergs with deep keel drafts are driven primarily by ocean currents (Gustajtis 1979) vice surface winds for sea ice.

c) *Hazard Type*:	Shorefast, Lake and River Ice Break-up
User Level:	International, Regional, and National
Disaster Mgmt Category:	Mitigation/Preparedness/Relief (surveillance, detection, Warning and damage assessment)
Operational Status:	Operational for navigable areas of the NSR, research with demonstration status in other selected Arctic coastal areas.

As described in the previous sea/lake ice section, data from EO satellites are critical for sea ice/lake ice hazard monitoring. Shorefast ice is defined as sea/freshwater ice that is attached to the coastline. River ice is a type of shorefast ice that forms in many estuarine systems in the polar regions. Human activities, such as Great Lakes ice fishing and whale hunts by Arctic indigenous people, use the stable lake or shorefast ice as a "platform" to conduct these endeavors. In the archipelagoes of the northern part of the Baltic Sea the fast ice in between is used for local car traffic, and also as a protected area (e.g. a 10m navigation channel runs along the southern coast of Finland) against ice pressure at sea. Unpredicted break-up of these ice types can threaten the safety of lives and property. In contrast, river ice break-up poses a hazard but typically only to vessels operating in the river. River break-up is usually an event of short duration but characterized by hazardous destructive forces. Human settlements are typically threatened only by associated flooding resulting from ice jams.

Visible and infrared EOS data are effective in providing general information on the location of shorefast boundaries. The shear zone caused by moving pack ice adjacent the fixed shorefast ice is often quite distinct in AVHRR/OLS imagery. Thickness information must however be obtained from "in-situ" measurements (ice cores) or estimated by freezing degree day (air temperature) models. Space-borne SAR systems are the preferred data source to mitigate and assess the effects of this ice hazard. SAR imagery is high resolution and not affected by clouds and darkness. Thus, these data are ideal for characterizing and monitoring the shorefast, lake and river ice. Unfortunately, what is really needed is a better understanding of the environmental processes that cause the break-up of this ice. Research highlighting case studies that couple EOS data with "in-situ" meteorological/oceanographic observations are needed to enhance the preparedness and capabilities of ice services to issue accurate forecasts. The NOAA Alaskan Demonstration Project is presently making high resolution Radarsat SAR-based products coupled with coincident ancillary environmental data available to state regulatory agencies (Alaska River Forecast Office) responsible for monitoring ice break-up in the Yukon River system (Lunsford 1998). Prototype products such as advisories predicting the break-up of shorefast ice are now being issued by CIS for the Arctic Bay and Pond Inlet areas of the Canadian Arctic. Arctic and Antarctic Research Institute (AARI) operational provides forecasts of fast ice breakup for navigable areas of the Northern Sea Route including estuaries, e.g. March forecast of fast ice breakup in June for Vilkitskii Strait.

PRODUCTS AND SERVICES

a) National Ice Information Services

A detailed description of all eighteen national ice services (Appendix B) can be found in WMO publication No. 574 "Sea Ice Services in the World". This publication is available as hardcopy from the WMO Secretariat or as a softcopy from the WMO/IOC Global Digital Sea Ice Data Bank website (http://www.aari.nw.ru/gdsidb/pub/WMO-574.pdf). In general, national sea ice services provide a diverse suite of digital and analog ice guidance products in support of mission planning, operations and research in the ice-covered seas in the northern and southern hemispheres. In the United States and Canada, this service is extended to the Great Lakes. Routine ice guidance products include regional and local-scale ice analyses, annotated satellite imagery, short to long-term ice forecasts, legacy ice information, ice climatologies and iceberg reports. Ice analyses typically document the date and time of data used in each analysis in a metadata narrative. Ice product formats include a) paper charts, b) simple electronic charts in GIF or Adobe Acrobat formats and c) Geographic Information System (GIS) compatible (e.g. ESRI ARC/INFO .e00 or SHAPEFILE export format) coverages. International standards for archival include the WMO digital standard for Sea Ice in GRIDed (SIGRID, SIGRID-2) formats. Almost all ice analysis charts are labeled using the World Meteorological Organization (WMO) international sea ice symbology. Additionally, many national organizations provide services available via special request. These services include Optimum Track Ship Routing (OTSR) recommendations, pre-sail ship briefings, aerial ice reconnaissance and ship rider support.

The U.S.Coast Guard IIP and CIS provide information on North Atlantic icebergs daily. The IIP distributes information on the southern and eastern extent of all known icebergs in the North Atlantic/Grand Banks region of Newfoundland. During the iceberg season (Feb-Aug), the IIP distributes information on the southern extent of all known icebergs every 12 hours. Size and time of sighting for all reported icebergs are routinely entered into an iceberg forecast model. Initialized daily with surface wind and ocean current information, the Berg Analysis Prediction Systems (BAPS) model is used to predict iceberg drift and estimated rates of deterioration. Model output is critical in predicting movement and longevity of icebergs in North Atlantic shipping lanes. CIS provides information on icebergs within the Canadian Exclusive Economic Zone year-round and collaborates closely with the IIP. Both use the same BAPS model and exchange information daily.

b) User Types

The table below lists the specific ice hazard applications and subsequent user communities that have been identified for EOS data and resulting ice guidance products.

Application	***User Level***	***Category***	***Status***
Sea and Lake Ice Detection for Avoidance	International, National, Regional, State	Mitigation, Preparedness	Operational
Sea and Lake Ice Characterization for Exploitation (safety, efficiency of mission)	International, National, Regional, State	Mitigation, Preparedness	Operational
Beset Vessel in Sea and Lake Ice	International, National	Mitigation, Preparedness, Response	Operational
Iceberg Detection for Avoidance	International, National	Mitigation, Preparedness	Operational, Research
Landfast, Lake and River Ice Break-up	State, Local	Mitigation, Preparedness, Response, Relief	Operational, Demonstration, Research

<u>Sea Ice Detection for Avoidance</u>

The majority of users interested in real-time EOS data and operational sea ice products have a basic requirement to avoid sea ice. All vessels operating near ice-covered waters are users of these data. Knowledge of the exact position of an ice edge is critical to a submarine patrolling underwater but navigating with a periscope. When under the ice, submarines need information on pressure ridging and associated keel depths. Non-ice strengthened government research vessels conducting ocean surveys will in most cases attempt to totally avoid the ice. Similarly, federal and state interest also exists in non-reinforced vessels that are part of the marine transportation, fishing, oil exploration and tourism industries.

<u>Sea Ice Characterization for Exploitation</u>

Knowledge on the characteristics of the sea ice cover is important to both the operational and scientific research communities. National interest lies in the operation of military vessels (e.g. submarines), Government owned icebreakers (e.g. Argentina, Canada, Finland, Germany, Japan, Russia, Sweden and the United States) and ice strengthened research vessels. Icebreaker led convoys want to know the optimum track through ice to maximize time and fuel savings. Many commercial industries have ice-strengthened cargo vessels with the same need for information to exploit the ice cover. For example, along Russia's Northern Sea Route Norilsk-class cargo vessels are capable of maintaining continuous progress through one meter of first-year ice but must avoid areas of high ice concentration under pressure or those dominated by thicker multiyear ice (Brigham 1991). Although not used specifically for exploitation purposes, other users of sea ice extent and coverage information include the international scientific community interested in long-term climate monitoring. Climate models suggest that the Arctic environment is particularly sensitive to global climate change and that sea ice (extent and thickness) is the one geophysical variable that is most sensitive to climate variability (Wadhams 1994). Accurate and complete EOS-derived records of sea ice are recognized as being extremely important to scientific research (Parkinson et al. 1987). As vessels move to Electronic Chart and Display Systems (ECDIS), ice conditions will be required in near real-time. The development and approval of international formats for display and distribution of ice information to ECDIS will increase the safety of navigation near and in ice-infested waters.

<u>Beset Vessels in Sea Ice</u>
Sea ice information intended to assist in the freeing of beset vessels typically receives international and national attention. Vessels that become beset in ice are typically icebreakers or ice-strengthened research vessels operating in the high Arctic or Antarctic ice packs. In the fall of 1983, for example, 15 cargo vessels and several icebreakers that were part of a Russian convoy transiting the Northern Sea Route were beset for weeks in the Chukchi Sea (Brigham 1991). In mid-February 1979 a heavy snow storm resulted in a wide jammed brash ice barrier along the German coast of the western Baltic Sea. Within hours up to 100 cargo vessels and ferries were beset in the approach to Kiel Canal. To assist these vessels in distress, national ice services are often called upon to assist their own vessels and those of other countries that become stuck in the ice. In 1997, the National Ice Center ordered Radarsat SAR imagery to assist the Argentine icebreaker, the ALMIRANTE IRIZAR whose progress was hindered by ice of the Weddell Sea near the Antarctic continent.

<u>Iceberg Detection for Avoidance</u>
The basic premise and mission of the IIP is to provide information on icebergs to protect vessels by ensuring safety of navigation in the North Atlantic. The IIP was formed by international mandate and is jointly funded by many countries with marine shipping interests. Specific national interest in icebergs is more elevated in those countries whose waters are more populated by icebergs. These countries include Canada (Baffin Bay, Newfoundland areas), Denmark (East and West Greenland waters), Russia (Barents Sea) and the United States (IIP area and Prince William Sound, Alaska). The increasing demand for hydrocarbons and other earth resources have stimulated interest and activity in many of these polar seas. Icebergs of all sizes pose a hazard to shipping, oil exploration and extraction activities. Other users of iceberg information include the international scientific community interested in long-term climate monitoring. Rates of iceberg production and distribution characteristics have been suggested as indicators of variations in the global climate since the polar regions are particularly susceptible to the effects of climate change (Brown et al. 1982).

<u>Shorefast, Lake and River Ice Break-up</u>
Users of these data can be federal or state agencies and local communities. Break-up on most rivers (like the Yukon River in Alaska) is monitored at the state level but is a federal responsibility (Canadian Coast Guard) on the heavily traveled St. Lawrence River. Federal agencies (e.g. USCG) can also become involved when navigation aides for the waterways are threatened. Fishing and hunting expeditions by local communities need information on shorefast and lake ice break-up. The user class in this hazard may also transition when individuals do become stranded on drifting ice. While local governments in some northern communities (like the North Slope Bureau in Pt. Barrow, Alaska) can provide the required coordination and resources for search and rescue efforts (ARCUS 1999), federal Search and Rescue assets are often called upon in other areas (e.g. central Canadian Arctic).

c) End User Requirements
As previously described, the operational detection of sea ice, icebergs and river/lake ice is vital to ensuring the safety of vessel operations and the commercial viability of the growing number of industries with activities in the polar regions. End user requirements for ice hazard information are quite diverse mainly due to the variability of applications. Spatial and temporal resolution of EOS data and associated ice guidance products are important to vessels that wish to avoid or exploit the ice. SAR imagery with its high resolution, wide swath, frequent revisit and all-weather capabilities is now the data of choice for many ice hazard users. Ice parameters of most frequent interest to vessels at sea include the location and size of icebergs, the location of the sea ice edge,

concentration boundaries, stage of development, floe size and location and orientation of openings in the sea ice pack. Other developing applications require information on the extent of landfast, ice motion, amount of sea ice pressure ridging or topography, degree of ice compaction and the stage of decay during the summer melt season.

Generally, a ship's captain prefers to receive detailed, tactical-scale graphics or interpreted imagery rather than raw satellite images. This preference is based on the fact that expert ice analysts are found at the various national ice centers and generally not aboard ships. The greatest challenge to most national ice centers is to process the EOS data, interpret it and deliver an ice hazard product to the customer within at least 3-12 hours of acquisition. Additionally, most users desire short-term ice forecasts detailing expected changes in the ice over the next 24-72 hours.

Specific requirements for ice hazard parameters detailing present day thresholds and future objectives are listed in the table below.

Parameters	***Threshold***	***Objective***
Ice Edge Accuracy (absolute)	750 meters	50-100 meters
Ice Concentration Accuracy Ice Concentration Range	< 20% 1/10 to 10/10	< 5% 0 to 100 % (includes less than 1/10th of ice)
Ice Stage of Development (probability of typing correctly) Ice Stage of Development Range	70% Distinguish new, young, first-year and multi-year ice.	90% Distinguish 11 major gradations as defined in WMO nomenclature, between river, lake and sea ice (fresh and salty water)
Fast Ice Boundary Forms of Floating ice	Same as for ice edge 50-100 meters	Same as for ice edge 9 gradations as defined in WMO nomenclature
Ice Motion Accuracy Ice Motion Range	km/day 0-50 km/day	0.05 km/day 0-50 km/day
Timeliness	3-6 hours	< 3 hours
Sampling Frequency	24 hours	6 hours
Geographic Coverage	Poleward of 34^0 north and south of 50^0 south	Poleward of 34^0 north and south of 50^0 south

d) Observational Requirements

For each ice hazard application, EOS data needs have been identified. These requirements are listed in the table below.

Application	***Spatial Resolution***	***Spatial Coverage (swath width)***	***Temporal Resolution***	***Tasking Time***	***Delivery Time***
Sea and Lake Ice Detection for Avoidance	100m	500km	daily	72-168 hours	< 3 hours
Sea and Lake Ice Characterization for Exploitation (safety and mission effectiveness)	50m	300km	daily	72-168 hours	< 3 hours
Beset Vessel in Sea and Lake Ice	30m	150km	2x/daily	24-72 hours	< 3 hours
Iceberg Detection for Avoidance	10m	300km	daily	72-168 hours	<3 hours
Shorefast, Lake and River Ice Break-up	30m	150km	2x/daily	24-72 hours	< 3 hours

Assessment of Current and Planned Satellite Data

Earth Observation Satellites that provide data presently being used *operationally* for Ice Hazard monitoring fall into three major categories:

- Passive microwave satellites (DMSP SSM/I, OKEAN RM08) providing data used to produce coarse resolution (15-25 km) ice concentration/ice type gridded products. The SSM/I 85 GHz channel is also used to produce ice motion and ice concentration products.
- Visible/infrared satellites (TIROS AVHRR, DMSP OLS, various GOES Imager instruments) providing medium resolution (0.55-4.0 km) data.
- Active microwave satellites with Synthetic Aperture RADAR (SAR) instruments (RADARSAT, ERS-2) providing all-weather, high resolution (10-100 m). ***Note***: The OKEAN Real Aperture Radar (RAR) provides 1.2 km spatial resolution data.

Planned or recently launched Earth Observation Satellites representing new sources of data (or presently available data in a research or demonstration mode) that are suitable for Ice Hazard monitoring include:

- Passive microwave satellites (DMSP SSM/IS, CORIOLIS, ADEOS-2 AMSR).
- Multi-spectral visible/infrared satellites (TERRA MODIS, ENVISAT MERIS,ADEOS-2 GLI).
- Active microwave satellites with SAR instruments (ENVISAT ASAR, RADARSAT-2 SAR, ALOS PALSAR) and scatterometers (QuikSCAT SEAWINDS, ERS-2, METOP, ADEOS-2)

Passive Microwave Satellites

The DMSP Block 5D-3/F-15 satellite carries an improved Special Sensor Microwave Imager with sounder (SSM/IS). As in previous instruments, SSM/IS measures radiances at 19, 22, 37 and 85 GHz. Most algorithms use the 19 and 37 GHz channels to extract ice concentration and ice type information. The sounder should provide coincident information on attenuation due to water vapor in atmosphere. Additionally, due to the higher spatial resolution (12.5 km) of the 85 GHz channel, some work has demonstrated that sequential SSM/I images can be used to generate ice motion estimates (Kwok et al 1998). The usefulness of the 85 GHz channel is limited by weather. CORIOLIS (United States), planned for launch in 2002 by the U.S. Navy is a passive microwave instrument with 5 bands (6.2, 10.7, 18.7, 23.8 and 37 GHz). ADEOS 2 (Japan), planned for mid-

2001 launch by NASDA, will carry an Advanced Microwave Scanning Radiometer(AMRS), which is expected to provide a spatial resolution of less than 5 km.

Multi-spectral Visible/Infrared Satellites

TERRA (United States), launched in December 1999 by NASA (as part of the Earth Observation System (EOS) program), carries the Moderate Resolution Imaging Spectrometer (MODIS) instrument. MODIS gathers high-quality data in 36 channels covering the visible, shortwave and longwave infrared bands (0.4-14 um). Taking advantage of the high radiometric resolution, NASA's MODIS Instrument Science team has developed the ICEMAP algorithm to produce an automated daily global sea ice extent map (by swath) at a 1 km spatial resolution (Riggs et al, 1999). The ICEMAP algorithm is based on the normalized difference between surface reflectance in the visible band and a shortwave-infrared band. Sea ice will also be mapped using emitted longwave thermal radiation. The Ice Surface Temperature (IST) algorithm is calculated using a split window technique method developed with AVHRR data (Key et al, 1997). Daytime gridded sea ice products will be produced using the ICEMAP/IST techniques while night-time products will be produced using only the IST technique. Data are presently being produced in the research mode with plans for operational use by national ice centers in late 2000/early 2001.

ADEOS-2 (Japan), planned for a mid-2001 launch by NASDA, will carry a multi-spectral Global Imager (GLI) instrument. The GLI, like MODIS, will have 36 channels that can be exploited to produce an automated sea ice product. ENVISAT is planned for a fall 2001 launch date by ESA and will carry a multi-spectral MERIS instrument.

Active Microwave Satellites

a) Synthetic Aperture Radar Satellites

- ENVISAT (Europe), planned for end-2001 launch by ESA, will carry an Advanced Synthetic Aperture Radar (ASAR) instrument. ASAR is a C-band, dual polarized instrument with beam steering (15-45^0 incidence angle) that allows collection of data in several different modes. Data collected in the standard mode will have a 100 km swath and 30 m spatial resolution, while the wide mode will have a swath of 405 km and 100 m spatial resolution. The latter mode is ideal for sea ice monitoring. It is also believed that alternating polarization will give improved ice edge/water discrimination over earlier single polarization SAR's (ERS-1/2 VV polarization; Radarsat-1 HH polarization). Cross polarization data are expected to be particularly useful in estimating topography and ice type discrimination (ESA, 1998).
- RADARSAT-2 (Canada), planned for mid-2003 launch by CSA, will carry an advanced C-band SAR characterized by quad polarization, beam steering in right and left directions, an increased downlink capability and a fine resolution (3 meter) mode in addition to all the same operating modes as Radarsat-1.
- ALOS (Japan), planned for a mid-2003 launch by NASDA, will carry a Phased Array type L-band SAR (PALSAR) with a cross-track pointing capability from 18-55^0 incidence angle and a ScanSAR mode with a 350 km swath and 100 m spatial resolution. ALOS will depend on two Data Relay Transmission Satellites (DRTS) and X-band downlink to ground stations for real-time data delivery to operational users.

b) Scatterometer Satellites

- QuikSCAT (United States), launched in June of 1999 by NASA, carries the SEAWINDS scatterometer. SEAWINDS is a specialized Ku band (13.4 GHZ) microwave radar that was designed to measure ocean-surface winds but can also be used to monitor ice over its 1,800 km swath. Using data from the NASA Scatterometer (NSCAT) mission, Long and Drinkwater (1999) have demonstrated that ice images with spatial resolutions of 8-10 km can be created using the Scatterometer Image Reconstruction with Filtering (SIRF) algorithm. Although the nominal resolution of the QuikSCAT SEAWINDS sensor is 30x50 km it is believed that similar resolution images can be created from QuikSCAT data.

- ERS-2 (Europe), launched in 1995 by ESA, carries a C-band scatterometer that can be exploited to map sea ice. Research and development by the Norwegian Meteorological Institute for the proposed EUMETSAT Ocean and Sea Ice Application Facility (O&SI SAF) is using the ERS-2 scatterometer data to map sea ice on a demonstration basis (Breivik et al, 1999). These data are combined with AVHRR and SSM/I data to produce ice maps with 10 km spatial resolution. METOP (Europe), planned for launch in 2003, will carry a C-band Advanced Scatterometer (ASCAT).
- ADEOS-2 (Japan), planned for a mid-2001 launch by NASDA, will carry SEAWINDS-2, a Ku band scatterometer that also can be used to generate ice all-weather, moderate resolution ice images. Like QuikSCAT, these data would serve as complimentary data sets to the coarser resolution passive microwave and high resolution SAR data to produce more accurate global-scale ice maps ideal for mission planning and climate research.

Future Improvements to Consider

As previously described, EOS data play an important and critical role in the mature application of operational sea ice mapping. The role of EOS data in iceberg detection and monitoring remains in the research and evaluation phase. Possible areas for improvement in sea ice mapping can be divided into four categories: *methodology, science, technology and data/product management.*

Methodology:

- International Collaboration: While the WMO/IOC Joint Technical Commission on Oceanography and Marine Meteorology (JCOMM) has a Sea Ice Expert Panel that provides good international collaboration on standards for sea ice services, there is a need for increased cooperation with other national ice services on a more operational basis. The International Ice Chart Working Group (IICWG) was formed for this purpose and had its 1st meeting in October 1999 in Copenhagen, Denmark, and continues to meet annually. This group will focus on improving the exchange of satellite data and products and initiating cooperative training activities. On a regional basis these activities have existed such as the Baltic Sea Ice Meeting (BSIM) since 1925 and the Joint Ice Working Group (U.S./Canada) since 1986.
- Access to EOS Data: New and updated mechanisms to improve access to satellite data should include satellite acquisition tools (and policies) that shorten time to schedule satellite acquisition of data and a shorter payload planning process for future satellites.
- Data Fusion Techniques: Recent studies indicate that substantial improvements in the quality of ice information derived from algorithms using EOS data can be achieved by using ancillary data and data fusion techniques. For example, Steffen (et. al., 1992b) stated that data assimilation and artificial intelligence (AI) methods offer the greatest promise for resolving ambiguities in passive microwave ice algorithms.
- Standard Product Formats: All national ice centers should produce standard digital formatted products (ice analysis graphics; annotated (interpreted) imagery and ice forecasts) that are user-friendly and GIS-compatible. This standardization effort should be directed at *operational customers* and separate from WMO-approved data archival formats (SIGRID-1/2). FGDC SDTS and IHO S-57 formats show promise but have gained little acceptance by the user community.

Additionally, common digital coastlines are important for seamless exchange of information between national ice centers.

Science:

- EOS Data Algorithms: New or improved sea ice/iceberg detection and sea ice classification algorithms are needed. Possibilities include developing an "expert" or AI system that classifies SAR data into ice types, SSM/I hybrid algorithms that account for natural variations in brightness temperatures associated with regional inhomogeneities of sea ice, SSM/I 85 GHz ice motion products, an ice/no ice cloud-masked visible/infrared product and a SAR-based iceberg detection algorithm.
- Ice Forecasting Models: Develop and implement regional (higher resolution) coupled ice/ocean/atmosphere forecasting models to improve sea ice forecasts in the Marginal Ice Zone (MIZ) and iceberg drift and ablation rates.

Technology:

- New and Improved Satellite Sensors: Use data from new sensors, such as multi-spectral radiometers and scatterometers. Improve ice mapping capabilities by taking advantage of improved sensors like SAR instruments with dual/quad polarization.
- Satellites with Multiple Instrument Payloads: Improve ice mapping capabilities through use of simultaneous data collection (for example, ENVISAT ASAR and MERIS; ALOS AVNIR-2 and PALSAR; satellite with multiple frequency SAR (L-, C- and X- bands).
- Satellite Revisit Time: Design right/left looking beam steering capability and optimum orbits to maximize revisit time and geographic coverage in ice-covered seas.
- Temporal Resolution of EOS Data: Improve delivery of processed imagery by requiring minimum real-time data processing and throughput standards at all participating ground stations. Consider use of onboard satellite data processors.
- Electronic Charts: Improve utility of ice information by producing ice analyses in electronic chart formats that can be integrated into ship chart display systems. The development and approval of international formats for display and distribution of the ice information to ECDIS will significantly increase safety of ice navigation.

Data/Product Management:

- Special EOS Data Policy: Request EOS data providers implement special data policies that allow for preferred and affordable access for national ice services and the production of ice hazard products.
- Outreach Programs: Establish outreach programs to educate customers on EOS data types, products available and the potential uses of each. Communicate to end-users the strengths and weaknesses of EOS data and ice guidance products.
- New and Improved Ice Guidance Products: Survey customer requirements to develop and implement new ice hazard products such as maps indicating state of ice decay and color-coded ice warning charts based on ship classes.
- Data/Product Dissemination: Improve efficiency of data networks through the use of state-of-the-art compression software.

The ice services are extremely dependent on the ground segment provided by satellite operators and receiving stations - e.g. the distribution of receiving stations. Likewise, affordable data continuity (e.g. SAR) is very important. Any gaps in the data between successive launches of SAR satellites could reduce the capability of many ice services.

Summary and Conclusions

It is well known that sea ice and icebergs pose a serious hazard to shipping and other maritime activities. The role of EOS data in operational ice monitoring is well documented and has grown in importance over the years. EOS data from visible/infrared sensors are readily available to all ice services but are useful only under cloud-free conditions. Passive microwave sensors can penetrate cloud cover but their effectiveness in ice monitoring is limited by coarse resolution. Active microwave sensors such as SAR's are ideal for ice mapping because of their high resolution, all-weather, wide swath ice detection capability. Investigations have also shown that these data are also valuable in their ability to quantify other ice parameters such as ice type (stage of development), ice topography and presence of open water or thin ice openings within the sea ice pack. Sea ice guidance products derived in real-time from these data are used operationally to ensure safety of navigation of non-ice strengthened vessels, maximize time and fuel savings of icebreaker lead convoys and to protect life and property associated with human activities on the ice.

In the future, new and updated EOS sensors provide great promise for improving the applications of sea ice mapping and iceberg detection. Data from multi-spectral visible/infrared radiometers and scatterometers will be used to generate automated sea ice maps. SAR satellites with right/left looking beam steering, multiple polarization modes and enhanced downlink capabilities will provide more valuable data in a shorter period of time to the end user. The coincident collection of EOS data from multiple instruments "fused" with ancillary environmental data can be used to resolve ambiguities and eliminate biases in conventional, single sensor algorithms. Data policies must exist for easy and rapid access to EOS data for ice hazard detection and monitoring. Lastly, collaborative efforts are needed between all the national ice services to ensure that EOS data are shared, that ice products are issued in standard formats and most importantly that customers are educated on the strengths, weaknesses and value of EOS data and Ice Hazard products.

Proposed Sea Ice Hazard Emergency Scenario

The trigger for a request for assistance would be:

1) A threat to life, safety and property at sea due to a vessel being beset or incapacitated in sea or lake ice; or people being stranded or incapacitated on the ice for any reason.
2) A threat to the environment due to a hazardous or contaminant spill in ice covered areas

	Obtain background information	Check if Considered
1.	Location of the incident (latitude, longitude)	
2.	Date and Time of the incident	
3.	Responsible Search and Rescue Agency (s)	
4.	Contact information for all involved agencies (RCC, support agencies, on-scene commander, etc.)	
4.	Location of nearby population centers, camps, vessels and other assets	
5.	Navigation, geological or other charts/maps of the area	
6.	Ice, Meteorological and Oceanographic Climatology of the Area	
7.	Availability of information from responsible national ice service(s)	
	Obtain ice information relevant to extraction or search and rescue	
1.	Current Ice Analysis for Concentration and Stage of Development	
2.	Current Ice Analysis for Navigable Features or Impediments to Navigation	
3.	Current Ice Analysis for generating a route recommendation or location for search and rescue access and egress	
4.	Current Meteorological Conditions. Especially current and forecast surface winds.	
5.	Current Oceanographic Conditions. Especially Sea Surface Temperature and Currents.	
6.	Forecast ice conditions (chart or text) if available	
	* Current Ice Analyses done using available radar, visual and infrared imagery of the target area.	
	Priorities for image planning	
1.	RADARSAT Beam mode ScanSAR Wide is optimal for broad area Ice analysis and for access and egress or operations context. RADARSAT Beam mode Standard is useful for Feature Analysis. RADARSAT Beam mode Fine is useful for high resolution targeting.	
2.	ENVISAT Beam mode Wide Swath is optimal for Ice Analysis. ENVISAT Beam mode Image Mode is optimal for site specific Feature Analysis. ENVISAT Beam mode Wave Mode is optimal for high resolution targeting.	
3.	ERS	
4.	DMSP Operational Line Scan (OLS) Visible and Infrared	
5.	NOAA TIROS AVHRR LAC or HRPT Visible and Infrared	

Value added processing of imagery or data?

1) Ice Analysis: Ice Concentration; Ice Stages of Development; Partial Concentration of Stages of Development; and Floe Sizes

2) Special Ice Features: Leads in Ice; Fractures in Ice; Heavy Ridging in Ice; Ice Edge
3) Track Recommendation or Largest Floes in the Area and Their Size
4) Ice Motion: General direction and speed of ice motion, if applicable; measured speed and direction of individual floe motion (from time series images)
5) Feature labeling: North arrow on imagery; Latitude/Longitude Grid; Image type, Date and Resolution; Major Land Features

Data delivery mechanism

Project Manager to ask users what will work. If possible, Internet transfer of Mr. Sid compressed images and other products directly to a vessel are preferable. Alternatively, facsimile transmission of chart and text products via telephone or marine radio is possible in some cases. Should ensure that all appropriate locations are copied including the Rescue Coordination Center, the local on-scene commander and other supporting agencies as appropriate. It is important that everyone involved in the operation have the same set of information.

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REFERENCES

ARCUS, (1999), "The Future of an Arctic Resource –Recommendations from the Barrow Area Research Support Workshop," *Arctic Research Consortium of the United States (ARCUS), Fairbanks, AK*.

Belchansky, G.I. and D.C. Douglas (2000), "Classification Methods for Monitoring Arctic Sea ice Using OKEAN Passive/Active Two Channel Microwave Data. Remote Sensing of the Environment," 73, pp. 307-322.

Benner, D. A. and C. Bertoia, 1992. Operational Satellite Sea Ice Analysis at the Navy/NOAA Joint Ice Center. Proceedings of the Sixth Conference on Satellite Meteorology and Oceanography, Atlanta, Georgia, January 5-10, pp. 395-398.

Bertoia, C., J. Falkingham, F. Fetterer (1998), "Polar SAR for Operational Ice Mapping" in *Analysis of SAR Data of Polar Oceans*, C. Tsatsoulis and R. Kwok, eds, Berlin and Heidelberg:Springer-Verlag.

Brigham, L. (1991), "Technical Developments and the Future of Soviet Arctic Marine Transportation" in *The Soviet Maritime Arctic*, L.W. Brigham, ed. Naval Institute Press.

Brown, C.S., M.F. Meier and A. Post (1982), "Calving Speed of Tidewater Glaciers, with Application to the Columbia Glacier," *U.S. Geological Survey Professional Paper 1258-C, Washington DC Government Printing Office*.

Cavalieri, D.J., P. Gloerson and W.J. Campbell (1984), "Determination of Sea Ice Parameters with NIMBU-7 SMMR," *J. Geophys. Res*., 89, pp. 5355-5369.

Cavalieri, D.J. (1994), "A Microwave Technique for Mapping Thin Ice," *J. Geophys. Res*., 99(C6), pp. 12561-12572.

Comiso, J.C. (1983), "Sea Ice Effective Emissivities from Satellite Passive Microwave and Infrared Observations," *J. Geophys. Res*. 88(C12), pp. 7686-7704.

Emery,W.J., M. Radebaugh, C.W. Fowler, D.J Cavalieri and K. Steffen (1991), "A Comparison of Sea ice Parameters Computed from AVHRR, LANDSAT imagery and Airborne Passive Microwave Radiometer," *J. Geophys. Res*. 96(C12), pp. 22075-22085.

Emery, W.J., C. Fowler and J.K. Maslanik (1994), "Arctic Sea Ice Concentrations from SSMI and AVHRR Data," *J. Geophys. Res.* 99(C9), pp. 18329-18342.

European Space Agency, (1998), "ASAR Science and Applications," SP-1225*, ESA Publications Division, The Netherlands*.

Foster, J. (1982), "Ice Observations in the Chesapeake Bay 1977-1981*," Mariners Weather Log, NOAA/NESDIS/NODC*, vol 26, 2, pp. 66-71.

Fung, A.K. (1994), "Microwave Scattering and Emission Models and their Applications," Artech House, Boston MA.

Gustajtis, K.A. (1979), "Iceberg population distribution study in the Labrador Sea*," C-Core Publication, July Data Report* (79-8), Centre for Cold Ocean Resources Engineering, Memorial University of Newfoundland, St. John's Newfoundland.

Isaacs, R. G. and J.C. Barnes (1987), "Intercomparison of cloud imagery from DMSP OLS, NOAA AVHRR, GOES VISSR and LANDSAT MSS," *J. Atmos Oceanic Technol*., 4, pp. 647-667.

Kern, S., G Heygster and J. Miao (1999), "Towards Retrieval ofAntarctic Sea Ice Using the SSM/I 85 GHz Polarization Difference," *IGARSS-99 Meeting, Hamburg, Germany.*

Key, J., J.B. Collins, C. Fowler and R.S. Stone (1997), "High-latitude surface temperature estimates from thermal satellite data," *Rem. Sens. Of Environ*., 68(2) pp. 152-163**.**

Kwok, R., E. Rignot, B. Holt and R. Onstott (1992), "Identification of Sea Ice Types in Space Borne SAR Data," *J. Geophys. Res*. 97(C2) pp. 2391-2402.

Kwok, R. and G.F. Cunnigham (1994), "Backscatter Characteristics of the Winter Ice Cover in the Beaufort Sea," *J. Geophys. Res*. 99(C4), pp. 7787-7802.

Kwok, R., J.C. Comiso and G. F. Cunnigham (1996), "Seasonal Characteristics of the Perennial Ice Cover of the Beaufort Sea," *J. Geophys. Res*. 101(C12) pp. 28417-28439.

Lee, T.F., S. Atwater and C. Samuels (1993), "Sea Ice Edge Enhancement using Polar-Orbiting Environmental Satellite Data," *American Meteorological Society Notes*, Sept, pp.369-377.

Larsen, R.W., R.A. Shuchman, R.F. Rawson and R.D. Worsford, (1978), "The use of SAR Systems for Iceberg Detection and Characterization," *12th International Symposium on Remote Sensing on the Environment, Ann Arbor, Michigan*; *20-26 April, 1978*, pp.1127-1147.

Lomax, A.S., D. Lubin and R.H. Whritner (1995), "The Potential of Interpreting Total and Multiyear Ice Concentration in SSM/I 85.5 GHz Imagery," *Rem. Sens. Env*., vol. 54, pp. 13-26.

Loset S. and T. Carstens (1993), "Production of icebergs and observed extreme drift speeds in the Barents Sea*," The 12th Conference on Port and Ocean Engineering under Arctic Conditions-POAC 93, Hamberg, Germany; 17-20 August 1993*; pp.425-438.

Lubin, D., C. Garrity, R. Ramseier and R. H. Whritner, (1997), "Total Sea Ice concentration Retrieval from the SSM/I 85.5 GHz channels During the Arctic Summer," *Rem. Sens. Env.,* vol. 62, pp. 63-76.

Lunsford, A.C. (1998), "Use of SAR Data at the Alaska River Forecast Center" *in Proc. 14th Int. Symp. On Ice in surface Waters, Clarkson Univ., Potsdam, N.Y*. pp. 25-30.

Massom, R. and J.C. Comiso (1994), "The Classification of Arctic Sea Ice Types and the

Determination of Surface Temperature using AVHRR data," *J. Geophys. Res*. 99(C3) pp. 5201-5218.

McDowell, J. (1990), "The Other Cold War," *Mariners Weather Log, NOAA/NESDIS/ NODC*, vol 34, 1, pp. 3-7.

Parkinson, C.L.,J.C. Comiso, H.J. Zwally, D. Cavalieri, P. Gloersen and W.J. Campbell (1987), "Arctic Sea Ice 1973-1976: Satellite Passive Microwave Observations," Washington D.C.

Rees, W.G. (1990), "Physical Principles of Remote Sensing," Cambridge: Cambridge University Press.

Riggs, G.A., D.K Hall and S.A. Ackerman, (1999), "Sea Ice Extent and Classification using the MODIS Airborne Simulator (MAS)," *Rem. Sens. Of Environ*., 61, pp. 302-309.

Steffen, K., J. Heinrichs, J. Maslanik and J. Key (1992a), "Sea Ice Features and Type Identification in merged ERS-1 SAR and LANDSAT TM Imagery," *Proceeding of the 1st ERS-1 Symposium-Space at the Service of our Environment held in Cannes, France, 4-6 November 1992*; pp.361-365.

Steffen, K., J. Key, D. Cavalieri, J. Comiso, P. Gloersen, K. St. Germain and I. Rubinstein (1992b), "The Estimation of Geophysical Parameters using Passive Microwave Algorithms" in *Microwave Remote Sensing of Sea Ice, Geophysical Monograph*, F.D. Carsey, ed., Washington DC:AGU, vol.68, ch.1, pp.1-6.

Strübing, K. (1970): Satellite Pictures and Sea Ice Reconnaissance – A Methodical Attempt for the Baltic Sea. Deutsche Hydrographische Zeitschrift, 23-5, pp. 193-213 (in German).

Strübing, K. (1974): Use of ERTS-1 in Sea Ice Studies. Proc. f a Symposium held at Frascati, Italy, 28 January – 1 February 1974. European Space Organization ESRO SP-100, pp. 173-178

Teleki, P.G., W.J Campbell, R.O. Ramseier and D. Ross (1979), "The Offshore Environment: A Perspective from SEASAT-1 SAR Data", *Proc. 11th Annual Offshore Technology Conference, Houston, Texas*, pp.215-220.

Vinje, T.E., (1989), "Icebergs in the Barents Sea," In *Proceedings of the 8th International Offshore Mechanics and Arctic Engineering Conference (OMAE)* held in the Hague, Netherlands on 19-23 March 1989; pp.139-145.

Wark D.Q. and R. W. Popham (1962), "First International Symposium on Rocket and Satellite Meteorology," North Holland Publishing Co., Amsterdam, 415 p.

Wadhams, P. 1994, "Sea ice Thickness Changes and their Relation to climate, in Polar oceans and Their Role in Shaping the Global Environment: The Nansen Centennial Volume," *Geophysical Monograph 85*, pp.337-362, AGU, Washington.

Willis, C.J., Jt. Macklin, K.C. Partington, K.A. Teleki, W.G. Rees, and R.G. Williams (1996), "Iceberg Detection Using ERS-1 Synthetic Aperture Radar," *Int. J. Remote Sensing*, vol. 17, 9, Pp. 1777-1795.

World Meteorological Organization, (1970), "Sea Ice Nomenclature," *WMO/OMM/BMO No.* 259.TP 145 Geneva, Switzerland.

World Meteorological Organization, (2000). Sea-Ice Information Services in the World. WMO No. 574 Geneva, Switzerland.

T E A M   R E P O R T
Landslide

LANDSLIDE HAZARDS

CEOS DISASTER MANAGEMENT SUPPORT GROUP

PURPOSE

This report is a summary of current and potential uses of EO data applied to the assessment of landslides. Our main objective is to assess the role of EO data by improving our understanding of the causes of ground failure and suggesting mitigation strategies. This brief working paper represents the combined efforts of the landslide team listed below. This report is listed at (http://disaster.ceos.org/landslide.htm) to invite additional comments from the disaster management communities. Relevant background information is included to inform a very diverse disaster management community.

Summary Landslide Recommendations to the Space Agencies:

1. The future availability of space borne InSAR data for slope motion monitoring is not yet clear. The European ERS SAR is a useful system for repeat-pass SAR interferometry because of the high stability of the sensor, good orbit maintenance and the fixed operation mode. Other orbital SAR systems needed to provide similar orbit parameters of less than +/- 1km. The European follow-on sensor ASAR on board the ENVISAT, as well as other planned SARs, provide many different operation modes, which will reduce the availability of repeat pass interferometric data. On the other hand, the higher spatial resolution of some of these sensors would be of interest for mapping also small slides. The important contributions of InSAR to landslide hazard management and to a range of other environmental monitoring tasks would justify a long-term SAR mission optimized for InSAR applications.

2. There is a requirement for Space agencies to provide archival background SAR images for all future SAR systems to perform repeat pass InSAR analysis to monitor very slow movements of slopes and other areas.

3. A guideline for landslide hazard emergency response scenario is presented at the end of the Landslide report (section 7). This will facilitate the space agencies to acquire appropriate data to meet the timely delivery of image maps to relief agencies. An internet image distribution system will facilitate emergency response in affected areas

Landslide Team Accomplishments: (2000-2001)

1. The Landslide Hazard team concentrate its efforts on 3 test areas: Fraser Valley Landslides, Canadian Cordillera; The Corniglio Landslide, Northern Apennines, Italy;Itaya Landslide, Japan. The choice of the sites is based on (1) geological diversity;(2) the types of landslides, (3) current threat to populated areas and infrastructure, and (4) existing work conducted by the current Landslide team.

2. Earthquakes, excessive rainfall, and volcanic events are the triggers of the landslides, and this allows the CEOS landslide team to work closely with the other working groups on earthquake, volcanic and flood hazards. Because of this, the Landslide team is participating actively in the development of the IGOS Partners Geohazards Theme.

3. The Landslide Hazard team is producing a special issue Journal issue in "Engineering Geology": for May 2002. This special issue is the result of a special session on "EO application to Landslides" at the European Geophysical Congress in Nice, May 2001.

Background

The term landslide denotes “the movement of a mass of rock, debris or earth down the slope”. In addition to this definition it can be stated that the movement occurs when the shear stress exceeds the shear strength of the material. The analysis of a possible increase of the shear stress and/or decrease of the shear strength of the material is integral to fully understanding landslide mechanics and applying the most appropriate remedial measures.

The factors contributing to an increase of the shear stress include:
- removal of lateral and underlying support (erosion, previous slides, road cuts and quarries)
- increase of load (weight of rain/snow/ash, fills, vegetation)
- increase of lateral pressures (hydraulic pressures, roots, crystallization, swelling of clay)
- transitory stresses (earthquakes, vibrations of trucks, machinery, blasting)
- regional tilting (geological movements)

Factors related to the decrease of the material strength include:
- decrease of material strength (weathering, change in state of consistency)
- changes in intergranular forces (pore water pressure, solution, fracture and crack propogation)
- changes in structure (decrease strength in failure plane, fracturing due to unloading)

Globally, landslides cause approximately 1000 deaths per year, causing property damage of approximately US $4 billion (Alexander,1995). Landslides pose serious threats to settlements, and structures that support transportation, natural resources management and tourism. They cause considerable damage to highways, railways, waterways and pipelines. They commonly occur with other major natural disasters such as earthquakes (Keefer, 1984), volcanic activity (Kimura and Yamaguchi 2000), and floods caused by heavy rainfall. Each type of earthquake-induced landslide occurs in various geological environments, ranging from steep rock slopes to gentle slopes with unconsolidated sediments. The area affected by landslide in an earthquake correlates with the magnitude, geological conditions, earthquake focal depth, and specific ground motion characteristics (Keefer 1984, 1994). Damage from landslides and other ground failures have sometimes exceeded damage directly related to earthquakes. In many cases, expanded development and human activities, such as modified slopes and deforestation, can increase the incidence of landslide disasters. Recent development in large metropolitan areas intrudes upon unstable terrain. This has thrown many urban communities into disarray, providing grim examples of the extreme disruption caused by ground failures.

Landslides can be rapid or slow, and occur in a wide variety of geologic environments, including underwater. The secondary effects of landslides can also be very destructive. Waves generated by landslides entering rivers, lakes or other bodies of water have caused substantial damage.[2] Other

[2] Lituya Bay, Alaska, July 10, 1958 a Magnitude 8 earthquake triggered a landslide that caused a water splash wave that reached 1,720 feet up the mountain slope (ref: See Steinbrugge, K.V. in References at the end of this Team report); and Vaoint Reservoir, Italy, October 9, 1963 a massive landslide caused a tremendous water wave that swept 300 feet above and over both dam abutments, causing a major flood that killed an estimated 2,600 people (ref: See Kierch, G. A. in References at the end of this Team report).

secondary effects include upstream and downstream flooding due to landslide dams and dam breaks. (Evans and Savigny, 1994).

Types of Landslides

In general, there are many landslide classifications, but no single classification has universal application. Six distinct types of landslide movements are briefly described:

- A *fall* or rockfall comprises a detachment of soil or rock from a steep slope and the more or less free and extremely rapid descent of the material. Rockfalls usually occur where a steep rock face is well-jointed. The rockmass disintegrates into numerous blocks that fall, bounce, and roll after detachment. Rockfalls are a constant problem along transportation routes through rocky terrain.
- A *topple* is a forward rotation out of the slope of a mass of soil or rock about a point below the centre of gravity of the displaced mass.
- A *landslide*, in the restricted sense of the word, is a generally rapid to very rapid downslope movement of soil or rock bounded by a more or less discrete failure surface, which defines the sliding mass. An essential element of sliding is that the movement takes place as a unit portion of land, which implies that there are no movements within the slipped block (the internal movements). Sliding in rock and soil may occur along a curved, curvilinear, or a multi-planar surface and is usually retrogressive. Landslides are usually slow moving, but can damage or destroy structures founded on the moving mass. The term rockslide is used when a rock mass slides on a detachment surface. The term landslide most used by non–specialists usually refers to slow moving materials that can damage or destroy structures founded on the moving mass
- *Sagging* is defined as large-scale deep seated deformations that are under the influence of gravity and occur in competent rocks and in zones where erosion has created deep valleys and therefore an unstable situation.
- *Spread* is defined here as an extension of a cohesive soil or rock mass combined with a general subsidence of the broken mass of cohesive material into softer underlying materials
- A variety of *flows* exist and they grade into all other types of slope movements. For example, debris flows can be generated from debris slides or by extreme forms of stream flow erosion. Debris flows are smaller and less rapid than rockfalls but can be very destructive. They occur when a saturated mass of surficial deposits moves down a stream channel, and are characterized by significant relief and sharp, well-defined flow boundaries. Heavy rains often trigger initial failure. They can also occur following the bursting of a natural dam formed by landslide debris, glacial moraines, or glacier ice.

EO data uses for landslides

The use of EO data is discussed as follows: mapping landslide related factors; characterization of landslide deposits monitoring; preparedness (monitoring and mitigation); response; research challenges and CEOS demonstration sites. This report also includes the uses of synthetic aperture radar (SAR) and interferometric SAR (InSAR), high spatial-resolution multispectral (IKONOS), and multispectral (Landsat, SPOT, IRS) data for landslide studies. Future satellites, such as the European follow-on sensor ASAR on board of ENVISAT, the Canadian RADARSAT-2 and the Japanese ALOS are also discussed.

Mapping landslide related factors

The main contribution of EO data is to provide the morphological, land use, and geological detail to assist in determining how the landslide failed and what caused the failure. Where failure could occur can be addressed in a more regional geographic information system (GIS) analysis as a necessary first step in risk analysis. This is because the factors contributing to slope failure at a specific site are generally complex and difficult to assess with confidence.

GIS techniques are used increasingly for regional analysis and prediction. Several digital data sets are typically used for such analysis. These can include an inventory of landslides; seismic records; large-scale geological mapping; extensive geotechnical data on rock properties; high-resolution digital elevation data, and suitable high-resolution remote sensing data and aerial photographs. This mapping procedure can be used to produce hazard risk maps that will assist in emergency preparedness planning and in making rational decisions regarding development and construction in areas susceptible to slope failure. Landslide risk studies are still not very common. This is mainly due to the fact that it is very difficult to represent landslide hazard in quantitative terms related to probability over large areas. This is because landslides do not have a clear magnitude/frequency relation, as is the case for floods or earthquakes. Lithologic and vegetation/landuse mapping use Landsat TM and SPOT and IRS and IKONOS images.

Detailed slope information is essential for reliable landslide inventory maps. Currently, topographic maps and digital elevation data are used. Slope affects surface drainage and is an important factor in the stability of the land surface. Current research has shown that airborne and satellite InSAR techniques are being used to produce detailed slope information (Singhroy et al 1998, Singhroy and Mattar 2000, Kimura and Yamaguchi 2000) This allows a more accurate interpretation of slope morphology and regional fracture systems with topographic expressions. However, further research is needed in updating local slope information from suitable InSAR pairs using ERS1& 2 tandem, JERS-1 and RADARSAT-1. The large archive of SRTM data will assist in providing regional slope maps.

Characterization of landslide deposits

Two distinct approaches can be used to determine the characteristics of different landslides from remotely sensed data. The first approach is to determine the number, distribution, type, character, and superposition relations of landslides using available remotely sensed data. The second approach complements the first one by measuring dimensions (length, width, thicknesses and local slope) along and across the landslides using imagery and topographic profiles (e.g. laser altimeter profiles). Where possible these dimensional data should be compared to any previous studies. With these approaches, it is possible to derive qualitative and quantitative parameters on landslides that are necessary for improved understanding of landslide processes.

Distribution and superposition (Approach 1)

There remain significant limitations on the uses of remotely sensed EO data for landslide studies. The majority of landslide research carried out by remote sensing to date falls into the category of inventory mapping. The principle problem is that remote sensing data rarely had a high spatial resolution to be useful in the study of anything but the largest landslides. However, both space-and-airborne remote sensing systems now have resolutions that permit detailed geomorphologic mapping to be conducted. With the advent of repeat-pass interferometry (*see* section 3.2.2) it has become possible to detect subtle changes (at mm scales) in the landscape such as seismic displacement (e.g. *Massonnett et al.,* 1993). However, landslides are difficult to study using radar interferometry (e.g. *Fruneau et al.,* 1996) because they can experience ground deformations in excess of the phase gradient limit (*Carnec et al.,* 1996) and which eliminate interferometric correlation (*Massonnet and Feigl,* 1998). Attempts are being made to better integrate radar interferograms, field measurements, and ancillary remote sensing of landslides to obtain “calibrated” interferograms which will provide useful geologic and geophysical information to the landslide monitoring community (e.g. *Bulmer et al.,* 2001). However, even such improved technologies are, however, rarely utilized to their full potential in hazard assessment.

Data from both the visible (*Brunsden et al.,* 1975; *Doornkamp et al.,* 1979) and microwave (e.g. *Singhroy et al.,* 1998; *Bulmer and Wilson,* 1999) portions of the electromagnetic spectrum can be used to map the geomorphology of landslides. The application of photogeologic mapping techniques (*Varnes,* 1974) provide a framework for developing mapping strategies will assist in the interpretation of these differing data. Geological units can be defined on the basis of morphological, textural, and structural characteristics visible in the images and related to the existing geologic maps.

Where possible, the highest resolution data that is available should be obtained and used to identify a range of geomorphic features and dimensional data on landslides of interest. Tables 1 and 2 provide guidelines for discerning these features in EO data.

Location	L m	W m	T m	A km^2	θ	V km^3	H m	H/L
Headscarp								
Upper track								
Middle track								
Lower track								
Depositional zone								

***Table 1**. Dimensional data to be obtained on landslides using remotely senses data L = length, W = width (min, max), T = thickness, θ = slope, V = volume, H = height from the top of the adjacent scarp to the base of the slope of the landslide, H/L = average friction coefficient given by the tangent of the line connecting the top of the scarp and the toe of the deposit (see Cruden, 1980; Shaller, 1991). In the absence of any high-resolution topographic information a first order volume can be estimated using the aerial extent and an estimated thickness.*

Features	L m	W m	T m	A km^2	θ	V km^3	H m	H/L
Tension cracks								
Ridges								
Levees								
Overtopping								
Superelevation								
Material sizes								
Material type								

***Table 2.** Additional geomorphic parameters to be obtained on landslides using remotely sensed data. Note that determinations of velocity based on climbed and/or overtopped obstacles only give an estimate for one short segment. It assumes conservation of energy for the material that climbed the obstacle, with the energy required to overcome gravity originating in the kinetic energy of the landslide (Shreve, 1966). Estimates of mean velocity can be made by calculating the tilt of the flow surface and the radius of curvature of the flow bend in a channel (Johnson, 1984).*

When selecting and using remotely sensed data the goal should be to determine: 1) the local lithology, 2) aerial extent of landslide deposits at each site, 3) local age relationships, 4) examine evidence for the cause and frequency of emplacement, 5) look for differences in landslide morphologies as keys to the magnitude and types of mass movement events, and 6) measure dimensions, slopes (local and regional), volumes, and material sizes.

Surface topography studies (Approach 2)

Landslide surface structures and roughness provide information on flow emplacement parameters (such as emplacement rate, velocity, and rheology). Using parallax equations measurements of the heights of surface structures can be made from stereo aerial photographs (*Lillesand and Kiefer,* 1987) and radar images (*Plaut,* 1993). Features such as the peak and the trough of folds on landslides can be measured and fold amplitude calculated. In addition, data from newly developing laser altimeter instruments can be used to measure features of landslides such as ridge wavelengths and amplitudes, thickness variations in debris aprons as well as local, regional and underlying slope. Laser altimeters tend to have vertical and radial accuracy of <1 m (e.g. *Krabill et al.,* 2000). The spacing between pulses along each orbital track or flight line varies depending on the instrument, but is typically ≤ 5 m. Across-track spacing depends on the number of available orbits or flight lines. Thus, the inter-track spacing will decrease as more data is obtained. Using laser altimeters it is also possible to calculate surface roughness in two ways: large-scale slopes directly from the topography (*Aharonson* et al., 2001), and sub-footprint scale slopes from data on the returned laser pulse width (*Garvin and Frawley*, 2000; *Smith et al.,* 2001). Roughness is defined as the topographic expression of surfaces at horizontal scales of centimeters to a few hundred meters. Individual topographic profiles from laser altimeters can be used to construct plots of the Allan variance or structure function, versus horizontal step size. A self-affine, or fractal surface, is characterized by a power-law scaling between these parameters (*Shepard et al.,* 1995). For a two-dimensional profile, the Hurst H exponent is related to the fractal dimension D as $D=2-H$. Surfaces with low values of H roughen more slowly with increasing horizontal scale, while surfaces with high H have vertical roughness that increases rapidly with step size. For different landslides the Hurst exponent and the value of the Allan deviation at unit length (equivalent to the RMS slope at unit scale), can be compared with those measured for other geologic surfaces (e.g. *Campbell and Shepard,* 1996; *Bulmer et al.,* 2001). This examination of the statistical roughness of geologic surfaces can be used to greatly improve in the interpretation of remotely sensed data at all wavelengths.

Surface roughness affects the behavior of scattered microwaves. Because the roughness of landslides has not been studied in detail, a quantitative comparison with other geologic surfaces such as lava textures has not been possible. Studies of roughness have mainly focused on basaltic pahoehoe and a'a lava surfaces (e.g. *Campbell and Shepard,* 1996). Only recently has roughness data and radar backscatter (σ^0) for blocky silicic lava flows and a rock avalanche been computed (*Bulmer and Campbell,* 1999; *Bulmer et al.,* 2001). The lack of detailed topographic data for blocky landslides and lava flows has also meant that the link between their roughness and radar backscatter (σ^0) has remained elusive. This has resulted in difficulties in using radar data to distinguish between rock avalanches and lava flows (e.g. *Bulmer and Wilson,* 1999). At C-band wavelengths (ERS and Radarsat) it is not possible to discriminate between a'a lava textures and blocky lava flows or a rock avalanche based upon σ^0 values alone. Geomorphic features such as blocky landslides will only be identified in longer wavelength data or through morphological signatures.

Preparedness (Monitoring Warning, Prediction)

Disaster preparedness involves temporal prediction and warning, and monitoring once a landslide is taking place. Monitoring landslides can either be done from in-situ measurements, with the help of EO data, or a combination of the two. Challenging components of monitoring landslides include characterizing the time of a landslide occurrence, its velocity and its acceleration. These parameters may be quantified by real-time, in-situ monitoring systems, and with EO InSAR data.

In-situ monitoring systems

A real-time monitoring system using instruments selected according to the characteristics of the soil mass, and placed where the earliest movement is estimated to occur, may represent a powerful tool to produce both local and remote alerts (e.g. Angeli et al., 1994) An efficient monitoring system must ensure safe conditions for the operators and provide the greatest amount of data on the dynamics of the sliding mass.

An example of a real-time monitoring system is the "*Early warning monitoring system",* developed by Aquater, Italy. This monitoring system uses National Instrument LabView software and an analogue/digital (A/D) converter with an internal processor to collect data from a laser diastimeter, seismic detectors (geophones), pressure transducer, and rainfall meter. Alerts are automatically activated when a sensor measures variations, which exceed the fixed threshold limits.

The data that the "*Early warning monitoring system*" collects from the instrumented landslide include

- relative movements recorded by a laser diastimeter
- vibrations (intensity and frequency) from geophones
- groundwater pressures changes recorded from pressure transducers
- rainfall (as total amount and intensity) recorded by rainfall meters

In the case of a landslide occurrence, both local and remote warning signals are activated by the system at the same time allowing emergency measures to be taken. Local alarms may consist of lights and sirens; operators can be alerted directly from the local monitoring station modem; and a web site can display real-time data.

InSAR

Interferometric synthetic aperture radar (InSAR) can be applied for measuring displacements at the Earth's surface with very high accuracy and for topographic mapping. Both capabilities are of high relevance for landslide hazard assessment. Possibilities and constraints of spaceborne SAR for these applications are briefly reviewed.

In a SAR image the location of a target is represented in a two-dimensional coordinate system, with one axis in flight direction (along-track) and the other axis cross-track (slant range), in which the target position (distance) is measured by the round trip travel time from the SAR antenna to the target and back. Because the across-track position represents a range measurement, the SAR image is distorted in this direction. Steep slopes facing in direction of the antenna appear shortened or are affected by layover, which often inhibits the interferometric analysis on these slopes.

An interferometric image represents the phase difference between the reflected signal in two SAR images obtained from similar positions in space (Hanssen, 2001; Massonet and Feigl, 1998; Rosen et al., 2000). In case of spaceborne SAR the images are acquired from repeat pass orbits. For the European ERS, for example, the standard orbital repeat interval is 35 days, for the Canadian Radarsat it is 24 days. The phase differences between two repeat-pass images result from topography and from changes in the line-of-sight distance (range) to the radar due to displacement of the surface or change in the atmospheric propagation path length. For a non-moving target the phase differences can be converted into a digital elevation map if very precise satellite orbit data are available. Effects of noise due to changes of atmospheric propagation between various images can be strongly reduced by combined processing of several interferometric image pairs with different baselines (multi-baseline interferometry) (Ferretti et al., 1999).

For motion mapping by means of InSAR it is necessary to separate the motion-related and the topographic phase contributions. This can be done by differential processing using two interferograms of different time periods calculated from two or three images if the motion was constant in time. If the motion is slow, the topographic phase can be taken directly from an interferogram of a short time span (e.g. the one-day time span of the Tandem Phase, when ERS-1 and ERS-2 operated simultaneously).

There are two important constraints for the application of InSAR to slope motion monitoring: (1) InSAR measures only displacements in slant range, the component of the velocity vector in flight direction cannot be measured. (2) InSAR can only map the motion at characteristic temporal and spatial scales (Massonet and Feigl, 1998), related to the spatial resolution of the sensor and the repeat interval of imaging. Typical scales for ERS interferometry application to landslide movements are millimeters to centimeters per month (with 35-day repeat-pass images) down to millimeters to centimeters per year (with approximately annual time spans). Faster landslides could only be studied during special orbital repeat configurations of ERS in previous years (Fruneau and others, 1996), such as the Tandem Phase or the 3-day repeat cycle during the Commissioning Phase and the Ice Phase of ERS-1 during a few months of 1992, 1993 and 1994. With the resolution of ERS (9.6 m in slant range, 6.5 m across track, 5.6 cm wavelength) the minimum horizontal dimension of a landslide for area-extended interferometric analysis, which can be applied with a single image pair, is about two-hundred meters across- and along-track. Future SARs with higher resolution (Radarsat-2) will enable the mapping of smaller slides. With the Permanent Scatterer Technique the movement of small objects (down to about one square meter) can be monitored, as discussed below.

A precondition for the generation of an interferogram is coherence, which means that the phase of the reflected wave at the surface remains the same in the two SAR images. The loss of coherence (decorrelation) is the main problem for interferometric analysis over long time spans, as required for mapping of very slow movements. Whereas the signal of densely vegetated areas decorrelates rapidly, the phase of the radar beam reflected from surfaces, which are sparsely vegetated or unvegetated often remain stable over years. This has been utilized for mapping very slow slope movements in high Alpine terrain (Rott et al., 1999; Rott et al., 2000).

Motion analysis in vegetated areas is only possible if a few stable objects (usually man-made constructions such as houses, roads etc.) are located within these areas. Using long temporal series of interferometric SAR images (typically about 30 or more repeat pass images over several years) objects with stable backscattering phase are determined by statistical analysis. Only some of the man-made objects reveal long-term phase stability. The analysis of the SAR time series with the Permanent Scatterer Technique (Ferretti et al., 2000; 2001) enables the detection of very small movements of individual objects (e.g. single houses). A certain number density of stable objects (at least about 5 per km2) is needed to enable accurate correction of atmospheric phase contributions. This method has been applied to map subsidence in urban and rural areas in various countries.

The future availability of spaceborne InSAR data for slope motion monitoring is not yet clear. The European ERS SAR is a useful system for repeat-pass SAR interferometry because of the high stability of the sensor, good orbit maintenance and the fixed operation mode. However, a system failure that occurred on ERS-2 January 17 2001 has resulted in the orbit deadband being relaxed from +/- 1 km to +/- 5 km. As a result interferometry can only be performed at few random occasions. The European follow-on sensor ASAR on board the ENVISAT, as well as other planned SARs, provide many different operation modes, which will reduce the availability of repeat pass interferometric data. On the other hand, the higher spatial resolution of some of these sensors would be of interest for mapping also small slides. The important contributions of InSAR to hazard management and to a range of other environmental monitoring tasks would justify a long-term SAR mission optimized for InSAR applications.

Due to the typical SAR repeat orbits of the order of 25 to 35 days, InSAR is mainly suitable for monitoring very slow movements of slopes and individual objects, and for mapping of subsidence. Thus it is able to fulfil specific information needs for landslide monitoring, complementary to other information sources. The main advantage over conventional techniques is the possibility of very precise displacement measurements over large areas at reasonable costs, thus being an excellent tool for reconnaissance.

Landslide mitigation

Landslide mitigation comprises the following activities: hazard, vulnerability, and risk assessment, restrictive zoning, and protective engineering solutions. Slope instability hazard zonation or assessment is defined as the mapping of areas with an equal probability of occurrence of landslides within a specified period of time. A landslide hazard zonation consists of two different aspects, the assessment of the susceptibility of the terrain for a slope failure and the determination of the probability that a triggering even occurs.

The essential steps to be followed in landslide hazard zonation are:

- Mapping the landslide distribution based on type, activity, dimensions, etc.
- Mapping and analyzing the most relevant terrain parameters related to the occurrence of landslides.
- Assigning weights to the individual causative factors, the formulation of decision rules and the designation of landslide susceptibility class.

The development of a clear hierarchical methodology in hazard zonation is a necessary condition to obtain an acceptable cost/benefit ratio and to ensure its practical applicability. The working scale for a slope instability analysis is determined by the requirements of the user for whom the survey is executed. Planners and engineers use the following examples of scales:

- National scale (< 1:1000000) provides a general inventory of problem areas for an entire country, which can be used to inform national policy makers and the general public.
- Regional scale (1:100000 - 1:500000) is used in the early phases of regional development projects to evaluate possible constraints, due to instability, in the development of large engineering projects and regional development plans.
- Medium scale (1:25000 - 1:50000) is used for the determination of hazard zones in areas affected by large engineering structures, roads and urbanization plans.
- Large scale (1:5000 - 1:15000) is used at the level of site investigations prior to the design phase of engineering works.

EO information requirements for landslide mitigation

Potentially unstable slopes and landslides are most often local scale features, even though they can occur in great numbers over a wide area (especially when triggered by a large earthquake or a very intense and/or prolonged storm). This and the limited areal extent of many damaging or socio-economically significant mass movements (often as little as few tens of square meters or less), imply that satellite observation and monitoring will require much greater spatial and vertical resolution with respect to that used in the study of other natural disasters such as floods, earthquakes, volcanic eruptions.

More detailed scales (1:5000 or better) are also required during the site investigations aimed at providing reliable information for designing engineering control works needed to prevent or repair slope failures (Turner and Schuster 1996). In order to be used profitably for slope stability analyses and for planning subsurface investigations, which typically precede the actual engineering construction phase, the acquired detailed information will also need to be quantitative, where possible. In general, the greatest possible (or economically justified) level of detail may be warranted. This will be particularly the case in urban or per-urban settings where public safety is the principal issue, or where the socio-economic consequences of potential landslide damage might be severe. Therefore, the scales required during the design of slopes are often larger than 1:2000, and the most commonly used scales may vary from 1:1000 to 1:500. In some cases, even more detailed scales are utilised. This level of detail would imply a sub-meter pixel spatial resolution of remotely sensed data. Similarly, the altimetric resolution would need to be close to 0,5 m. Therefore, the practical or operational use of the currently available EO data in engineering geology site-specific landslide investigations is considerably limited (Wasowski and Gostelow, 1999). The improved resolution of the planned future sensors (3 m or better pixel resolution), however, should provide information sufficiently detailed for assessing the feasibility of slope engineering projects and for defining some preliminary design characteristics. Various methods have been used to produce landslide inventory maps. These maps are produced from the interpretation of stereo aerial photographs, satellite images, ground surveys, and historical occurrences of landslides. The final product gives the spatial distribution of mass movements, represented either at scale or as points. When multi-temporal airborne or satellite image analysis is included the inventory maps show landslide activity.

There are two aspects of EO data that are important for landslide mitigation. First of all, it has been shown that multi-temporal EO data can be used to determine the changes in landslide distribution, and as such are useful to produce landslide inventory maps. Second, EO data can be used to map factors that are related to the occurrence of landslides, such as lithology, faults, slope, vegetation and land use. The temporal changes in these factors can also be mapped, which can be used within a GIS in combination with a landslide inventory map for landslide hazard assessment.

Current landslide inventory maps are not standardized around the world. They are published at different scales with various levels of details. These maps usually include information on the classification of the landslide type, their location, as well as the geomorphic and slope characteristics. In some cases, active and dormant landslides are distinguished. In other cases, the information is included on geological and soil degradation maps.

For the evaluation of the suitability of remote sensing images for landslide inventory mapping the size of individual slope failures in relation to the ground resolution cell is of crucial importance. Although sizes of landslides vary enormously according to the type of slope failure, some useful information can be found in literature. The total map area for a failure of 42000 m^2 corresponds with 20 x 20 pixels on a SPOT Pan image and 10 x 10 pixels on SPOT multispectral images. This would be sufficient to identify a landslide displaying a high contrast, but it is insufficient for a proper analysis of the elements pertaining to the failure to establish characteristics and type of landslide. It is believed that if 1:15.000 is the most appropriate scale, then, 1:25.000 should be considered as the smallest scale to analyze slope instability phenomena on aerial photographs. Using smaller scales a slope failure may be recognized as such, if size and contrast are sufficiently large. However, the amount of analytical information, enabling the interpreter to make conclusions on type and causes of the landslide, will be very limited at scales smaller than 1:25.000. For this reason, 3-meter stereo images will be most useful for detail interpretation.

Currently, air photos are used extensively to produce landslide inventory maps, because they allow features demonstrating slope movement that range from small terracettes, indicating soil creep to large landslides to be resolved. Current research has shown that high-resolution stereo SAR and optical images, combined with topographic and geological information have assisted in the production of landslide inventory maps. The multi-incidence, stereo and high-resolution capabilities of RADARSAT are particularly useful for landslide inventory maps. High-resolution systems such as IKONOS, IRS and the stereo capability of SPOT 4 are useful for landslide recognition and related land use mapping. Other planned high-resolution stereo systems such as ENVISAT and RADARSAT-2, and ALOS will be useful to map landslide features.

To facilitate the use EO data for landslide inventory maps more research needs to be done in the following areas in the short term:

- High resolution (<8m) remote sensing data needs to be easily integrated with existing information. This task is particularly challenging in high relief slopes where most landslides occur.
- Current landslide interpretation, data fusion and InSAR techniques needs to be tested in different topographic and geological environments.
- Standardized landslide inventory mapping procedures using high resolution RS data as an image base needs to be developed. This is possible at a scale of 1:50000 using current techniques.
- Low-cost DDTM (= differentiated DTM) can be generated from multi-temporal aerial photographs in order to assess landslide vulnerability.

III. RESPONSE

Disaster response comprises the rapid damage assessment, and relief operations, once the disaster has occurred. Currently, damage assessment is done using aerial photography, videography and ground checks. In order to be able to use EO data for landslide damage assessment, two criteria should be met: High temporal and high spatial resolution (ca 3-10m stereo) is essential for landslide damage assessment and relief efforts. Images taken at the time of disaster or days after the event similar to other geohazards –earthquake and volcanoes – is a requirement to support relief efforts. This will be satisfied, in part, by existing and planned high resolution, stereo optical and SAR systems. In cases where the damage is extensive, either as a single large event, or many small events covering a large area, there is a need for high-resolution images (ca 3-10m), before and after event. This can be used to supplement airborne and ground techniques for local and regional damage assessment. Guidelines for a landslide hazard emergency response scenario are presented at the end of this report. It is intended that this will help to facilitate the efforts of space agencies to acquire appropriate data in order to achieve timely delivery of image maps for relief agencies.

IV. RESEARCH, CHALLENGES AND LIMITATIONS ASSOCIATED WITH EO DATA

The difficulties associated with interpretation of EO data can require a high level of user knowledge in remote sensing systems. Characterizing form, size, causative and triggering factors, pre-monitory signs, mechanisms, post-failure evolution will require both ground-truth knowledge and advanced technical skills in remote sensing processing. Although any InSAR sensed deformation is potentially of interest to an engineering geologist or geotechnical engineer, in the case of landslides or unstable slope areas, a change detection in both vertical and horizontal distances is needed to evaluate landslide mechanisms (the monitoring of a horizontal component of movement is often critical for hazard assessments). Furthermore, some other phenomena such as subsidence (eg. caused by natural processes such as compaction, thawing, or man-made), settlement or subsidence of engineering structures, (eg. caused by compression), shrink and swell of some geological materials, need to be taken into account to correctly interpret the significance of the ground deformation one might be detecting from EO data. The additional specific aspects of the geological context to be considered in the EO data interpretation include (Wasowski and Gostelow (1999):

- three phases of landslide movements (pre-failure, during failure and post-failure)
- importance of gravity or continuous creep distinction
- weathering and shallow seasonal creep

It follows that, in general, the information obtained from InSAR (or other EO) methods will need to be correlated with ground data and detailed survey controls in order to be correctly evaluated and to provide a reliable relevant information to a disaster management community or to engineering geologists and geotechnical engineers. In short, at present the InSAR methods could be viewed as the complementary data source with respect to those acquired through ground based observations and in-situ surveying. They will be especially attractive where no other data sources are available by providing initial (potentially wide-area) assessments of ground deformation susceptibility.

The limitations and benefits of InSAR data processing techniques in terms of the time and cost requirements is very difficult to assess at this time, with respect to in-situ monitoring operations and surveying.

CEOS Demonstration Sites

Given the research gaps outlined above, the Landslide Hazard team plans to concentrate its efforts on 3 test areas with different geological and terrain conditions. The choice of the sites is based on (1) geological diversity; (2) the types of landslides, (3) current threat to populated areas and infrastructure, and (4) existing work conducted by the current Landslide team. Earthquakes, excessive rainfall, and volcanic events are the triggers of the landslides, and this allows the CEOS landslide team to work more closely with the other working groups on earthquake, volcanic and flood hazards. The focus, however, will be to evaluate current and future satellite high-resolution, stereo and interferometric systems, and to develop standardized tools to characterize and monitor unstable slopes in the following areas.

Fraser Valley Landslides: Canadian Cordillera

The Fraser valley in the Canadian Cordillera, is one of the most strategically important transportation corridors in Canada. Almost all the transportation lifelines that link the prairie provinces with metropolitan Vancouver utilize this corridor. Thirty-five large landslides ranging in size from at least 1 million to more than 500 million cubic metres have been identified in the lower Fraser Valley. Recently, landslides have caused serious damage to the major transportation links. In the spring of 1997, landslides have caused the derailment of the CN railway resulting in two deaths and 20 million dollars of damage. In 1965, a large rock avalanche (48 x 10^6 m3) known as the Hope slide, occurred 160 km east of Vancouver. The slide triggered by two small earthquakes (M) 3.2 and 3.1, buried three vehicles and claimed four lives. The causes of landslides in the area include the weakening of failure planes in carbonate rocks, solution erosion, seismic shaking, the presence of clay infilling along discontinuities, steep slopes, excessive precipitation and deforestation. Savigny (1993) identified three types of slides in the lower Fraser Valley. These include (1) slump and earth flow of surficial materials, mainly glacial drift; (2) rock slide with slide scars and multiple scarps and (3) rock slumps with several arcuate scarps. These slides mainly occur along the contact between plutons and metamorphic pendants and are associated with regional north trending thrust and strike slip faults and lineaments. Singhroy et al (1998) used differential airborne interferometry and high resolution (8m) stereo RADARSAT images to map detail slope geomprphology for landslide inventory in the region. Repeat pass interferometry techniques on the vegetation free slopes will be used to monitor motion on unstable slopes.

The Corniglio Landslide: Northern Apennines, Italy

The Corniglio landslide in the Emilia-Romangna Apennine Mts. in northern Italy (44°28' N - 10°05' E) is an active large complex retrogressive landslide (length 3080 m, max. width 1120 m, depth between 30 and 120 m) which underwent recent reactivation in 1994 and 1996 and 2001. Abundant rainfall and minor seismic events accompany reactivation of this type. Field inspections in October 2000 and May 2001 indicate gradual sliding at the head scarp and lower toe regions. The rate of movement during re-activation periods varies from centimeter to several meters per day. Average velocity (1994-96 period) for the middle-lower part of the slide is below 1 m/day. Average daily rates of collateral deformations is < 1mm/day in the town of Corniglio (44.28 N, 10.05 E). The lithology consists of sandstone, limestone, and argillite clasts mixed in fine-grained materials (silty-sandy clay), derived from tectonically deformed "flysch" (turbidite) units. The average slope is <10° in the lower 3/4 of the slide (flow portion); 23° in the upper-most part. The middle-upper part of the slide is bare with grassland, while the lower 1/3 (toe) is sparsely vegetated with trees. Because of the spare vegetation differential InSAR techniques will be used to monitor motion at this site. The buildings of the town will be used as corner reflectors. Continuous monitoring by 15 automated inclinometers, demonstrates that the slide is still moving slowly on a 10 degrees clay slope. Local topographic network and 10 piezometers will provide additional field monitoring data.

Itaya Landslide: Japan

The Itaya landslide is an active silde in Yamagata Prefecture, northern Japan. The landslide is located on the northern slope of Azumayama Volcano. Geologically, the surface of the landslide and its surrounding areas is covered by debris flow deposits composed of andesitic volcanic rocks Interferograms constructed from JERS-1 SAR provided a model of active movement of sub-blocks along slip planes during periods of heavy precipitation (Kimura and Yamaguchi 2000). Stereo RADARSAT images are currently being used to characterize the geomorphic features of the slide. The landslide hazard team will conduct evaluation of future Japanese ALOS data

V. SUMMARY

Our challenge is to recognize and interpret the detailed geomorphic characteristics of large and small landslides, and determine whether or not failure is likely to occur. This has not been fully explored to date from current EO data.

- The role of EO data for landslide hazard assessment will increase as more useful techniques are developed.

- Recent results have shown that more use can be made from current high resolution stereo SAR and optical images to produce more standardized landslide inventory maps which will assist hazard planning.
- The availability of less than 3-meter resolution stereo images from planned SAR and optical systems will increase the geomorphic information on slopes, and therefore produce more reliable landslide inventory and risk maps.
- Landslide prediction will remain complex and difficult even with ground techniques.
- GIS and RS techniques will remain a regional analysis tool.
- Detail slope and motion maps produced from InSAR techniques can assist in more accurate slope stability studies. When the conditions are correct, SAR interferometry is a useful tool for detecting and monitoring mass movement and thus is able to contribute to the assessment and mitigation of landslide hazards.

Guidelines for Landslide Hazard Emergency Response Scenario

Request for assistance would be triggered if a landslide was a threat to life, and or threatened or caused safety or damage to property and infrastructure

Obtain background information		Check if Considered
1.	Location of the landslide (latitude, longitude, possibly GPS info)	
2.	Date and Time of the landslide	
3.	Responsible Search and Rescue Agency (s)	
4.	Contact information for all involved agencies (support agencies, on-scene commander, etc.)	
4.	Location of nearby populated areas and infrastructure such as energy and transportation routes	
5.	Geological (terrain, lithology, structure and seismic), topographic land use/land cover and other risk hazard maps – at scales less than 1: 50,000 if available	
6.	Meteorological data particularly rainfall information before, during and after the event	
7.	Archival, stereo air photos at scale from 1: 5000-50000, and other remote sensing data such as Landsat, SPOT IRS, RADARSAT, ERS , JERS, and Russian high resolution optical data Space agencies should produce " thumbnails of archival images to ensure high quality comparisons and data fusion	
Priorities for image planning		
1.	A. Characterize landslide areas, and assess damage require high to medium resolution (3-10m) cloud free stereo and single images. For example RADARSAT: Fine beam modes F1-5, and RADARSAT Stereo (F1, F5) (F2,F5) (F3, F5) with same look directions – ascending / ascending or descending /descending IKONOS: 4 m. multi spectral: 1m. panchromatic IRS: 5.8m SPOT: 10m stereo and panchromatic B. Monitor motion soon after the slide resulting from seismic aftershocks requires InSAR imagery. For example:- 1 InSAR pair- ERS1&2 ENVISAT, RADARSAT, ALOS) or most ideally 2 InSAR pairs within the first month after the event.	

Value Added Products in support of relief effort (ideally within 2 weeks after the event)

The following value added products should be available for a comprehensive relief effort:

To assess ground/ slope instability:

- Less than 1: 20 000 interpreted image maps (digital and print) with detail geomorphological and geological characterization and interpretation of slide mechanics
- InSAR coherent maps with annotated interpretation for general use

To assess damage:

- Thematic maps at scales less than 1:20000. showing damaged areas such as buildings, infrastructure and resources (forestry etc).
- Change detection image maps using current and archival images with simple legend for general use.

Data delivery :
An Internet transfer system should be established to transfer all images and value added products to relief agencies and participating interpretation agencies. In order for agencies to most effectively work together, all parties should have the same set of state- of art information available as quickly as possible.

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References

Alexander, D. Natural Disasters. Chapman and Hall, New York, pp 621.
Angeli, M-G., P Gasparetto, R.M. Menotti, A. Pasuto, and S. Silvano. 1994.
A system of monitoring and warning in a complex landslide in Northeastern Italy. Landslide News 8: 12-15.
Bulmer, M.H., Murphy, W., Petley, D., Mantovani, F., Keefer, D., and Jibson, R.
Operational use of InSAR for landslide studies: Experiences from Black Ven landslide, Dorset 2001. Submitted to Adv. Space Res.
Bulmer, M.H., B.A., Campbell, and J. Byrnes. 2001. Field Studies and Radar Remote Sensing of Silicic lava flows. Lunar and Planet. Sci. Conf., XXXI, 1850.
Bulmer, M.H., and Wilson J.B., 1999. Comparison of Stellate Volcanoes on Earth's Seafloor with Stellate Domes on Venus using Side Scan Sonar and Magellan Synthetic Aperture Radar, *Earth and Planet. Sci. Lett.* 171, 277-287.
Bulmer, M.H., and B.A., Campbell, 1999. Topographic data for a silicic lava flow – A planetary analog, Lunar and Planet. Sci. Conf., XXX, 1446-1447.
Campbell, B.A. and M.K. Shepard, 1996. Lava flow surface roughness and depolarized radar scattering, J. Geophys. Res., 101:18,941-18,951.
Carnec, C., Massonet, D., and King, C. 1996. Two examples of the use of SAR interferometry on displacement fields of small extent. Geophys. Res. Letts., 23 (24): 3579-3582.
Cruden, D.M. 1980. A large landslide on Mars: Discussion and reply*, G.S.A. Bull.,* 91, 63.
Evans, S. G. and Savigny K.W. 1994. Landslide in the Vancouver –Fraser Valley-Whistler region. (In) *Geology and Geological Hazards of the Vancouver Region, Southwestern British Columbia*. (ed) J.W. H. Monger; Geological Survey of Canada, Bulletin 481, p 251-286
Ferretti, A., C. Prati and F. Rocca, 2001. Permanent scatterers in SAR interferometry. *IEEE Trans. Geosc. Rem. Sens., 39,* 8-20.
Ferretti, A., C. Prati and F. Rocca, 2000. Nonlinear subsidence rate estimation using permanent scatterers in differential SAR interferometry. *IEEE Trans. Geosc. Rem. Sens., 38,* 2202-2212.
Ferretti, A., C. Prati and F. Rocca, 1999. Multibaseline InSAR DEM reconstruction: The wavelet approach. *IEEE Trans. Geosc. Rem. Sens., 37,* 705-715.
Ferretti A, Prati C, Rocca F.1999. Permanent scatteres in SAR interferometry. *Proc. IGARSS'99* Conference, Hamburg 3p.
Ferretti A., C. Prati, F. Rocca, 1999a Monitoring Terrain Deformations Using Multi-Temporal SAR Images *Proc. of FRINGE'99*, Liege, Belgium
Fruneau, B., Achache, J., and Delacourt, C. 1996. Observations and modelling of the Saint-Etienne-de-Tinee landslide using SAR interferometry. Tectonophys. 265: 181-190.
Fruneau, B., Delacourt C., and Achache, J., 1996. Observation and Modelling of the Saint-Etienne-de-Tin´ ee Landslide Using SAR Interferometry, *Proc. of FRINGE'96*, Zurich, Switzerland
Garvin, J. B., and J. J. Frawley, Global vertical roughness of Mars from Mars Orbiter Laser Altimeter pulse-width measurements, *Lunar Planet. Sci.,* 31, abstract, 2000.
Hanssen, R.F., Radar Interferometry, 2001. Kluwer Academic Publ. Dordrecht etc., 308 pp.
Johnson, A.M. 1984. Debris flow, In: Bunsden , D., and Prior, D.B., (eds.) Slope Instability, John Wiley and Sons, New York, 257-361.
Kabill, W.B, Wright, C.W., Swift., R.N and 8 others. 2000. Airborne laser mapping of

Assateague National Seashore Beach. Photogrammetric Engineering and Remote Sensing, 66, 1, 65-71.

Keefer, D.1984. Landslides caused by earthquakes. *Geological Society of America Bulletin* Vol.95, p406-421

Keefer, D.1994 The importance of earthquake-induced landslides to long-term slope erosion and slope failure hazards in seismically active regions. *Geom. Vol* 10 p265-84

Kierch, G. A., 1965, "The Vaiont Reservoir Disaster," California Division of Mines and Geology, Mineral Information Service, Vol. 18, No. 7, p 129-138

Kimura, H., and Y Yamaguchi. 2000.Detection of Landslide areas Using Radar Interferometry. *Photogram Eng. and Remote Sensing* Vol. 66, No.3, p337-344.

Lillesand, T.M., and R.W., Kiefer, 1987. Remote Sensing and Image Interpretation. John Wiley and Sons, New York, p321.

Massonnet, D., Vadon, H., and Rossi, M. 1996. Reduction in the need for phase unwrapping in the radar interferometry. IEEE Trans. Geosci. Rem. Sens., 34 (2): 489-497.

Massonnet, D., and Feigl, K.L. 1998. Radar interferometry and its application to changes in the Earth's surface. Rev. of Geophys., 36 (4): 441-500.

McKean J, Buechel S, Gaydos L. 1991 Remote sensing and landslide hazard assessment. *Photogrammetric Engineering and Remote Sensing*, 57, p1185-1193

Plaut, J., 1993. Stereo Imaging. In. Guide to Magellan Image Interpretation (J.P., Ford and 7 others), NASA JPL Publication 93-24, pp33-43.

Refice, A., Bovenga. F, Wasowski. J, and L. Guerriero. 2000 Use of InSAR Data for Landslide Monitoring: A Case Study from Southern Italy. IGARSS 2000, Hawaii. 3p

Rosen P.A. et al., 2000. Synthetic Aperture Radar Interferometry. *Proceedings of the IEEE, 88(3)*, 333-385.

Rott, H., and A. Siegel, 1999. Analysis of Mass Movements in Alpine Terrain by Means of SAR Interferometry, *Proc. of IGARSS'99*, Hamburg, 3p

Rott H., B. Scheuchl, A. Siegel and B. Grasemann, 1999. Monitoring very slow slope movements by means of SAR interferometry: a case study from a mass waste above a reservoir in the Ötztal Alps, Austria. *Geophysical Res. Letters 26*, 1629-1632.

Rott H., C. Mayer and A. Siegel, 2000. On the operational potential of SAR interferometry for monitoring mass movements in Alpine areas. *Proc. of the 3rd European Conference on Synthetic Aperture Radar (EUSAR 2000)*, Munich, 23-25 May 2000, 43-46.

Savigny, W.K., 1993. Engineering Geology of Large Landslides in the Lower Fraser River Valley Transportation Corridor, Southwestern Canadian Cordillera, *GAC Special Volume,* Landslide Hazard in the Canadian Cordillera. 30p.

Shaller, P.J., 1991. Analysis and implications of large martian and terrestrial landslides, PhD thesis, Calif. Inst. Tech., pp586.

Shepard, M.K., R.A., Brackett, and R.E., Arvidson, 1995. Self-affine (fractal) topography: Surface parameterization and radar scattering, J. Geophys. Res., 100, 11,709-11,718.

Shreve, R.L. 1966. Sherman landslide, Alaska, Science, 154: 1639-1643.

Singhroy, V., Mattar, K.E., and Gray, A.L., 1998. Landslide characteristics in Canada using interferometric SAR and combined SAR and TM images. Adv. Space Res., 3, 465-476.

Singhroy, V.and K. Mattar. 2000. SAR image techniques for mapping areas of landslides. *ISPRS 2000. Proceedings.* Amsterdam, p1395-1402

Soeters R, van Westen CJ 1996 Slope instability recognition, analysis, and zonation. In Landslides. Investigation and mitigation, ed A. K. Turner, R. L. Schuster.

Transportation Research Board Spec. Rep. 247. Nat. Academy Press, 673p

Steinbrugge, K.V. ,1982, “Earthquakes, Volcanoes, and Tsunamis – An Anatomy of Hazards,” pp. 85-87, Skandia America Group, 280 Park Avenue, New York, N.Y. 10017, USA, 392p.

Turner A. K. and Schuster R. L. (eds.) 1996, “Landslides. Investigation and mitigation”, *Transportation Research Board Special Report 247*, National Academy Press, 673 pp.

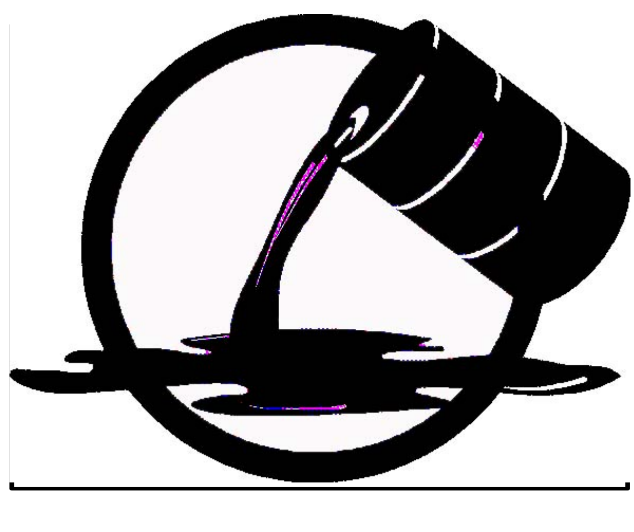
Varnes, D.J. 1974. The logic of geologic maps, with reference to their interpretation for engineering purposes. U.S. Geol. Surv. Prof. Pap., 837.

Wasowski, J. and P. Gostelow, 1999. Engineering geology landslide investigations and SAR interferometry, *Proc. of FRINGE’99*, Liege, Belgium.

Wasowski J. and Gostelow P. 1999, “Engineering geology landslide investigations and SAR Interferometry”, *Proceedings of FRINGE’99*, Liege, Belgium, http://www.esa.int/fringe99

T E A M   R E P O R T

Oil Spill



OIL SPILL HAZARDS

CEOS DISASTER MANAGEMENT SUPPORT GROUP

SUMMARY

Oil is both physically and chemically hazardous, with disastrous consequences in marine environments that are exposed to both chronic and acute pollution. Acute pollution from grounding and breaking-up of tankers, such as the *Torrey Canyon* and the *Erika* has focused public concern, although the total spillage from such incidents is less than that released as illegal discharges attributed to tank cleaning or bilge pumping. Increased public pressure has forced national and international organisations to set up effective legislative protection for the marine and coastal environments over the last 15-20 years. As a result, many countries have signed agreements such as MARPOL and UNCLOS and regional protection agreements, such as the Oslo-Paris and Helsinki conventions in which dumping of waste materials in the marine environment is expressly forbidden. The international legislation allows coastal states to inspect all shipping within territorial waters and also to ensure that national legislation preventing any dumping applies equally to national and foreign owned shipping. At present, penalties are based on fines levied against both the shipmasters and the tanker owners.

In this context, Earth Observation (EO) data has four potential uses based on its ability to provide relatively low cost, large area surveillance. These uses range from prevention to response at local to regional scales and are based on the use of Synthetic Aperture Radar (SAR) instruments. Operational uptake has been slow, complicated both by the need to integrate SAR surveillance information with reconnaissance and vessel identification technologies and by non-technical issues such as legislation, public finance restrictions and political will. Nevertheless, public pressure is increasing the need for EO data integration and this can be facilitated by the actions of space agencies and private sector satellite operators.

At present, satellite SAR data are used within limited areas due to mission constraints on the attainable revisit and spatial coverage. This issue is partially addressed by the next generation of SAR satellites such as the ENVISAT's ASAR and RADARSAT-2 but other issues need to be resolved. Faster information delivery, improved discrimination of oil, increased pricing flexibility and greater redundancy are required before many national pollution control agencies will accept EO data as a reliable tool. Another area where the space agencies can assist the uptake of EO data is in setting up routine (background mission) surveillance of coastal waters. EO surveys provide the only cost effective means to systematically determine the extent and distribution of chronic pollution. As well as allowing pollution control agencies to deploy their existing resources more effectively, surveys advertise the extent of pollution and utility of EO data for monitoring it.

Summary of Recommendations

- Establish routine (background mission) surveillance of coastal waters
- Provide faster information delivery, improved discrimination of oil, increased pricing flexibility and greater redundancy
- Improve levels of dialogue between the service providers — who in most cases are present at the ground station — and the satellite operators
- Optimize airborne-satellite surveillance systems by extending agreements to other areas (for example, the Persian Gulf, the Mediterranean, South East Asia

Means to facilitate filling gaps
- Monitor critical areas (ship routes, oil platforms, national Economic Exclusion Zones)
- Set up a coordinated satellite data ordering system
- Perform oil slick distribution studies. These would provide basic information concerning the scale of the problem (many countries ignore the oil pollution issue, since it is unquantified).
- Increase polarimetric C-band SAR coverage. Current and planned coverage is barely sufficient to run operational services below high latitudes and provides no scope for satellite/instrument failure. The need for excess capacity as redundancy in case of failure should not be ignored. Many national authorities will not commit to operational satellite services that are prone to single point failure

Mechanisms to improve access to satellite data
- Global, unified ordering system valid for many satellites
- Fast payload planning
- Fast data and product dissemination
- Special data policy
- Introduction of products in a standard GIS format (e.g. GeoTIFF), since ingest of EO data using image processing packages (ERDAS Imagine, EASI-PACE, ER-Mapper) is mainly limited to existing EO specialists. Many of the target users are not EO specialists but have GIS packages for spatial databases and/or coastal process modelling.

Expand user outreach
- Spill drifting models that are capable of ingesting satellite data (scatterometer derived surface winds may — with improved resolution — be of practical use with these models to help to determine the direction an oil spill might be going).
- Automated spill detection algorithms
- Standards for products/responsive to user needs
- Mutual training services (towards space info managers and spill response teams)
- Communication means for product delivery
- Flexibility in data pricing (target is < 2.5 US¢ per square km)
- Demonstration projects for multi-satellite usage

General Application Description

Oil is hazardous, both physically and chemically. Physically, oil can coat and clog biological structures (feathers and gills) which are adapted to cope with water. Chemically, oil contains a range of toxins that can either poison living organisms directly in high concentrations or build up slowly in low concentrations, gradually disrupting their biochemistry and increasing their vulnerability to other natural or man-made hazards. Exposure can be both rapid through the massive release of oil associated with the bigger oil tanker accidents or chronic through the build-up of toxins in the marine community after years of oil dumping. Chemical toxins that are not readily broken down become concentrated in ecosystems, rendering those organisms at the top of food chain (including humans) most vulnerable to chronic pollution.

To manage oil spill disasters effectively, national, regional, and international mechanisms are required to support the prevention of spills and the clean up of large-scale accidental spills as well as the prosecution/deterrence of those responsible for deliberate oil dumping. In order for these mechanisms to work, it is necessary to have a legal framework, a clear mandate for operation, and an organization established to carry out the necessary prosecution and clean-up functions (see Figure 1).

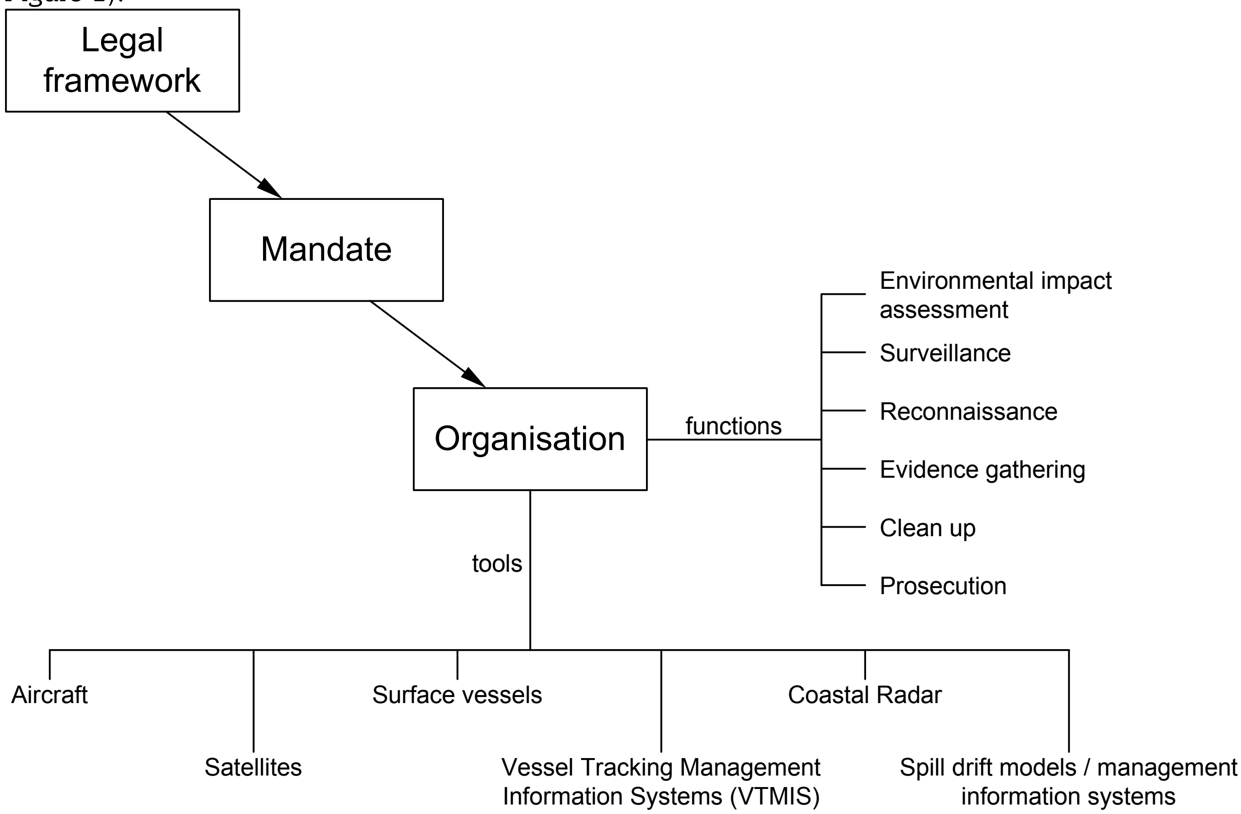


Figure 1*: *Elements of an effective oil spill management system

Increasing levels of public pressure have forced national and international organizations to set up effective legislative frameworks to protect marine and coastal environments. As a result, many countries have signed agreements such as MARPOL, UNCLOS and regional protection agreements such as the Oslo-Paris and Helsinki conventions, in which dumping of waste materials in the marine environment is expressly forbidden. Much of the public concern arose from the grounding and breaking up of tankers such as the *Torrey Canyon,* the *Exxon Valdez*, the *Sea Empress* and the *Erika* (although the total spillage from such incidents in terms of tons of oil released into the marine environment is less than that released as illegal discharges due to tank cleaning activities).

To prevent illegal dumping at sea, legislation has been set up to allow coastal states to inspect all shipping within territorial waters and also to ensure that national legislation preventing any dumping applies equally to national and foreign owned shipping. At present, penalties are based on fines levied against both the shipmasters and the tanker owners. The mandate for enforcement is either divided between government agencies or delegated to a dedicated pollution control agency. Local authorities and non-governmental organisations may also become involved in particular areas of response (beach clean up, sea bird rescue).

Effective prevention, response and deterrence require integration of the tools available to pollution control organisations and it is in this context that satellite remote sensing should be considered. The use of satellite remote sensing is considered in this report in terms of four distinct cases. These ‘use cases’ are summarised in the table below and described in more detail in the following sections.

Each specific application of Earth Observation is considered in terms of the role EO plays and this provides the context for later sections detailing user, observational and baseline data requirements.

Use Case	***User Level***	***Category***	***Action Status***
Enforcement / monitoring	National / regional	Mitigation	Operational
Major coastal spill (accident)	National / regional	Response	Research
Minor coastal spill (dumping)	Local / national	Preparedness	Demonstrator
Spill distribution survey	Regional / national	Mitigation	Research

Table 1: Summary of specific applications of EO to oil spill disaster management

Specific application descriptions

Use Case: Enforcement/monitoring
Hazard Type: Deliberate oil spillage (chronic exposure)
User Level: National, Regional
Disaster Management Category: Mitigation (surveillance and detection)
Operational Status: Operational (over a few areas of the world)

Earth Observation is already used operationally for enforcement/monitoring of national waters, although the uptake has been slow. At present, only the Norwegian Pollution Control Authority (SFT) and the Admiral Danish Fleet (SOK) use operational satellite surveillance services.

National pollution control authorities have the responsibility to maintain some level of monitoring and prosecution to deter shipping operators from illegally discharging material within national and protected international waters. Monitoring and evidence gathering involves three processes: (1) routine surveillance to detect potential oil slicks, (2) detailed reconnaissance of potential slicks to verify the presence of oil and (3) identification of the polluter. Suitably equipped aircraft can accomplish all three tasks but these are expensive to operate for surveillance and are rarely able to reach oil slicks in time to identify the polluter. To understand how Earth Observation satellites can be used in enforcement/monitoring, the oil spill team considered the case of “Molotonia,” a hypothetical country setting up a national marine pollution control agency. Figure 2 illustrates how specialist elements for surveillance, reconnaissance and polluter identification would interact and provides, from the user perspective, the context for the exploitation of EO data.

We do note here that the type of EO for large accidental spills that operational environmental satellite agencies (such as NOAA in the USA) would be involved in is of questionable use. Scatterometry would serve as a source of real wind data (meteorological-modelled is currently used) and could be a useful input for oil drift models. We defer to expert opinion in this area as to whether scatterometer derived surface winds are (or will be with improved resolution) of practical use with these models for helping to determine the direction an oil spill might be going.

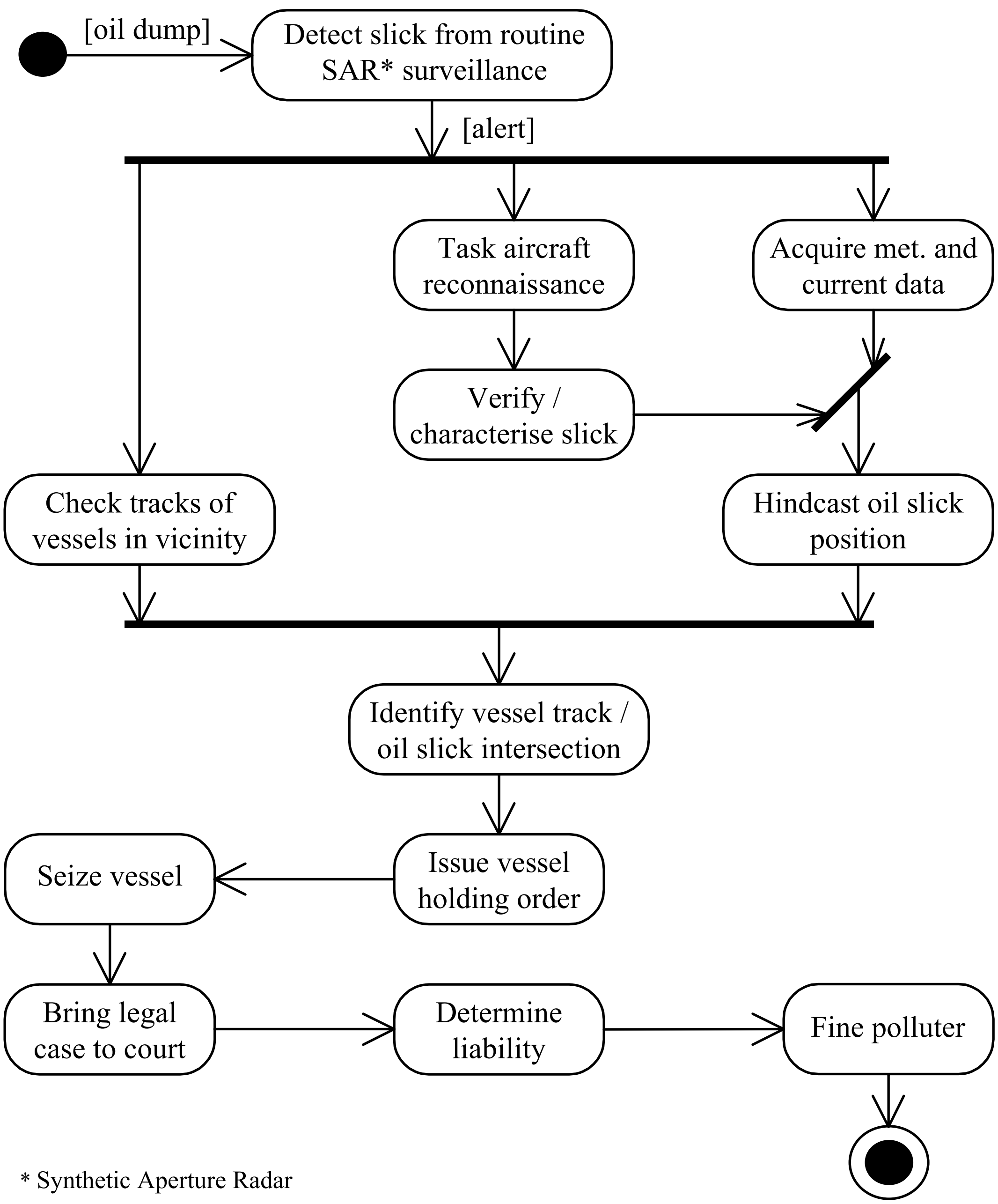


***Figure 2*: Activity diagram showing how the marine pollution control agency of "Molotonia" would respond to an illegal oil spill.**

The principal satellite data source at present is spaceborne Synthetic Aperture Radar (SAR). In some cases, SAR imagery is processed to low resolution (on the order of 100m) within minutes of the satellite overpass and visually analyzed by specially trained operators to identify possible oil slicks. Once a slick is detected, a fax is transmitted to the national pollution control authority, containing the location of possible slicks, classification of the level of certainty in the identification, an estimate of the probable source and the time of observation. In addition, a copy of the SAR image is appended. This information is used by the pollution control authorities to optimize the flight plan of the surveillance aircraft, to confirm possible slicks and to avoid regions known to be free from pollution. The average time elapsed between satellite overpass and reception of an alarm by the pollution control authorities is between 1 and 2 hours.

In some other cases, a better resolution is used (10m with RADARSAT Finebeam) or the processing time may be reduced to less than 1 hour. Use of the satellite data allows significant improvement in the surveillance capability for only a very small additional investment. A preliminary analysis by the Tromso Satellite Station (TSS) indicates that combining one patrol aircraft and a mission such as the ERS SAR (which was not intended to be operational) provides similar performance to a doubling of the available airborne survey resources. Given the cost of aerial surveillance, it is estimated that SAR imagery is competitive at costs below 2.5 US cent per square km.

The provision of this service is dependent on the availability of a suitably fast processor at the point where the data are downloaded, which limits the availability of services to areas within the visibility of suitably equipped ground stations. On-board recording may provide a solution to this issue, by dumping data at a central point, where a fast processor is installed, but the time between acquisition and down-linking can add an extra 1.5 hours between overpass and the alarm being issued. At present, suitable processors are installed in stations in North America, Norway and the UK providing complete coverage of the North Atlantic waters, and in Singapore, covering a large part of the South East Asian coastal seas.

As noted earlier, the Norwegian and Danish agencies responsible for marine pollution control are using satellite surveillance operationally. The surveillance is carried out in tandem with aircraft surveillance to allow aircraft reconnaissance of any detected slicks. The Netherlands' Rijkswaterstaat North Sea Directorate and the German Federal Marine Pollution Control Unit are both evaluating the use of ERS-2 SAR data. A pilot satellite surveillance service is currently being provided to the UK Marine Coastguard Agency. Limited demonstration programs have also been completed in Italian and Greek areas of the Mediterranean Sea, although the processor is not optimized for the application at present. In addition to national pollution control agencies, oil companies operating in areas such as the North Sea, are beginning to use satellite observations to support *in-situ* monitoring infrastructure, although this is not fully operational at this stage.

Use Case:	Major coastal oil spills
Hazard Type:	Massive accidental oil spillage (intense exposure)
User Level:	National, Regional
Disaster Management Category:	Response
Operational Status:	Research (poor results reported to date)

It is tempting for satellite operators to capitalise on the publicity surrounding major oil tanker disasters but experience has shown that the premature release of satellite imagery can be counter productive, confusing the pollution control response. SAR data should be used with caution particularly in the critical coastal areas where response teams need to know the distribution of the spilled oil. Interpretation of oil distribution in coastal areas is particularly difficult because the coastal topography causes wind shadows that, in SAR imagery, are visually indistinguishable from oil. In the cases of the Sea Empress and Aegean Sea oil spills, the well publicised, indiscriminate use of SAR images has given EO a 'bad press'. Under these circumstances, more easily interpreted optical data (such as, SPOT HRV, LANDSAT TM/ETM) may be used.

SAR data has been shown to be useful where analysis has been carried out to take account of local wind effects. In an operational setting, this requires prior acquisition of SAR data under a range of meteorological conditions combined with the simulation of SAR data using a local DEM and wind vector/SAR modelling techniques. This is only practical for areas at high risk either due to their degree of exposure (for example, the approaches to oil terminals) or due to their environmental sensitivity (such as coral reefs, bird sanctuaries).

Use Case:	Minor coastal oil spills
Hazard Type:	Beaching of illegally dumped oil
User Level:	Local, National
Disaster Management Category:	Preparedness
Operational Status:	Demonstration

This use case is similar to the enforcement/monitoring case in that the cause is often deliberate and not reported, so regular monitoring is required to detect spills. The difference is that the interested local/provincial and national authorities are engaged in coastal protection and clean up and need to know where the oil is likely to come ashore. At the very least, they require EO derived spill vector outlines that can be integrated with meteorological and marine current data using coastal Geographic Information Systems or specialist pollution management systems. Ideally, a spill alert service would itself use such information with a drift prediction model to issue alerts targeted to those areas most likely to be affected.

Use Case:	Spill distribution surveys
Hazard Type:	Illegally dumped oil
User Level:	National, Regional
Disaster Management Category:	Mitigation (awareness and resource deployment)
Operational Status:	Research

EO data provides a uniquely cost effective method for wide area, systematic surveillance of national and regional waters to determine the geographic/seasonal patterns of oil dumping. Such surveys, combined with statistical analysis, may be used to determine both the scale and geographic distribution of the pollution problem. The results can be used by marine pollution control agencies in the strategic planning of how their resources should be deployed. Spill distribution surveys require some degree of independent validation to determine the percentage rates of false positives (incorrectly identified oil) and false negatives (oil slicks missed by the survey). A good source of survey data is therefore operational and pilot satellite surveillance services where national pollution control agencies are actively involved. Examples of projects that involved spill distribution surveillance are OilWatch and Clean Seas, which were funded in the late 1990s under EU Fourth Framework R&D contracts.

End user requirements

This section begins with a general discussion of the requirements defined by end users involved in operational and demonstration EO information services. Specific observational requirements for each EO use case are then presented. In the final sub-section, these observational requirements are translated into a set of baseline data requirements, which define the primary and secondary data sources available in the short to medium term. Requirements for the information services can be separated into the level of performance necessary (coverage, update, spatial scale etc.) and the associated quality indicators of the information (probability of false alarm, etc). End users require a subset of priority national waters to be surveyed on a daily basis with coverage sufficient to represent a deterrent against illegal dumping activities. All slicks of importance (greater than 0.01 square km) must be present within the notification service.

With regard to the quality indicators of the information service, the end user must be confident that there are very few false negatives, (that is, that no slicks are present in an area declared "clean"). The false positive rate, the fraction of the slick notifications that turn out to be false alarms, should also be low. A false positive rate of typically less than 10% could be seen as an optimal requirement. Experience with several pollution control authorities suggests that even a large false positive rate is still acceptable. A rate of 50 % could be accepted by some of the end users. False positive rates are difficult to quantify because aircraft confirmation rates drop dramatically as the time between satellite and aircraft observation increases due to slick drift/dispersal and changing wind conditions. The basic methodology of simply validating satellite observations with aircraft observations is fundamentally flawed, since it assumes that the airborne observations are correct. In fact, airborne SLAR is susceptible to the same wind speed constraints and manual interpretation errors as spaceborne SAR. Relating non-synchronous spaceborne-airborne observations compounds this problem.

Observational requirements

For each type of use, information needs have been identified. These needs are listed in the table below:

Use Case	***Spatial resolution***	***Spatial coverage (swath width)***	***Temporal resolution***	***Tasking time***	***Delivery time (hours)***
Enforcement / monitoring	100m 50m	100km 300km	weekly daily	N/A	3 hrs <1 hr
Major coastal spill (accident)	20m 5m	30km >100km	daily hourly	2 days <1 day	2 hrs <1 hr
Minor coastal spill (dumping)	100m 50m	100km 300km	daily hourly	N/A	3 hrs <1 hr
Spill distribution survey	100m 50m	100km 300km	weekly daily	N/A	N/A

Table 2**: **Observational requirements for each specific application (use case) of EO data.

***Note**: Each requirement gives both threshold and optimum values. The data cost requirement (<2.5 US cents per km^2) applies to all the use cases, as this is the cost of using conventional airborne SLAR for surveillance purposes.*

User organizations such as the UK MPCU typically specify the following as the minimum observational requirements necessary from EO data (ESA-ESRIN 1995):

- *Coverage*: national priority waters
- *Update*: daily (for priority national waters)
- *Delivery time*: alarms within 1.5 hours of satellite overpass

The swath width affects the attainable revisit rate. National waters should be surveyed daily (which means daily revisit) although with present systems this is not possible. The delivery time constraint places requirements on the ground segment (users should receive data within 1.5 hours of satellite overpass) which means processing and interpretation of all data over national waters should be completed within this time. There is, however, a constraint regarding the requirement (enforcement/monitoring) for repeat coverage. There are indications that this is not absolute and that it depends on the aircraft resources available to each country. For instance, at least one European monitoring authority is known to fly only 2 flights per week with no flights on weekends and public holidays. They would be incapable of using daily repeat coverage because their aircraft would not be available to respond to satellite-derived oil alerts for at least 5 days each week. For most countries the aircraft reconnaissance capability is the limiting factor, and not the availability of satellite surveillance.

Baseline data requirements

The baseline data requirements (see Table 3) have been derived by mapping the observational requirements to the instruments and imaging modes available from current and planned EO satellites. Table 3 also lists ancillary data types need to support the use of EO data for each use case.

Use Case	***Primary instruments / image modes and other information requirements***	***Secondary instruments / image modes and other information***
Enforcement / monitoring	RADARSAT 1/2 ScanSAR Narrow	ENVISAT ASAR image/alternating polarisation mode ERS-2 SAR; Concurrent wind vector data
Major coastal spill (accident)	ENVISAT ASAR image/alternating polarisation mode RADARSAT 1/2 Standard mode LANDSAT 7 ETM Area specific analysis of SAR response. Concurrent wind / current vector data	ERS-2 SAR ALOS SAR SPOT
Minor coastal spill (dumping)	RADARSAT 1/2 ScanSAR Narrow	ENVISAT ASAR image/alternating polarisation mode RADARSAT 1/2 Wide mode ERS-2 SAR Concurrent wind / current vector data
Spill distribution survey	ENVISAT ASAR image/alternating polarisation mode RADARSAT 1/2 ScanSAR Narrow, Wide or Standard mode ERS-2 SAR	ALOS SAR

Table 3: Baseline data requirements for each specific application (use case) of EO data.

Assessment of current and planned satellite data

Present satellites:	ERS-2, RADARSAT-1. Optical satellites such as SPOT and LANDSAT supplementary (for major spills) under favourable meteorological and light conditions.
Planned satellites:	ENVISAT-1, RADARSAT-2, ALOS, TerraSAR.

- ENVISAT-1 (Europe), launched by ESA, has a C-band ASAR operating at various modes. The ScanSAR mode has a swath width of approximately 400km and a 150-meter resolution, while the standard modes have a swath of 110 km and a 20m resolution. In addition, ENVISAT will operate in a dual polarisation. The capabilities of the ScanSAR and especially the dual polarisation modes for oil spill detection are still to be documented.
- RADARSAT-2 (Canada), to be launched in 2003, has an advanced C-band SAR instrument with 3-meter resolution, quad polarisation and steerable in right and left looking directions. In addition, the various operating modes of RADARSAT-1 will also be available for RADARSAT-2. The capabilities of RADARSAT-2 to detect oil spill are expected at least to be equivalent to those already documented for RADARSAT-1.
- ALOS (Advanced Land Observation Satellite, Japan), to be launched in 2003, has an active phased array, L-band, steerable sensor with a 350km swath and a 46 day repeat cycle (revisit cycle: 5 days for PALSAR/ALOS).
- TerraSAR, a European satellite system is planned for launch in 2004. This system will have an advanced L and X-band SAR. This system is primarily developed for terrestrial applications, but it is expected that it will be applicable within other areas also. The capabilities for detection of oil spill are currently not known.

Each of the satellites enables revisit times to be lowered and greater coverage at any one time to be achieved. Furthermore, if a combination of these satellites were to be used, oil spill detection services could be extremely close to meeting the end user requirements in terms of update times. This would enable even greater savings on the part of the pollution control authorities.

Type of use	***Present***	***Future***
Surveillance	Lacking temporal coverage Large number of false positive alarms Product delivery too slow	Co-ordinated satellite missions Simultaneous cross polarised SAR Improved ground processing Calibrated Radar sensor Information/GIS integration
Marine ecosystem protection	Reference baseline images Contribution to GIS data (e.g. land use)	High resolution optical satellites Dedicated coastal zone missions Information/GIS integration
Response	Meteorological data not adequate for imaging	Revisit time 1 hour with 5m resolution (not planned!) Information/GIS integration
Recreational	Not adequate temporal coverage	Additional/complementary satellites Information/GIS integration

General improvements to consider
Based on experiences in exploiting the ERS and RADARSAT missions in operational services, several issues can be identified that require attention in the development of a global service provision capability.

Joint exploitation of available satellite SAR systems
At present, the joint use of all available C-band SAR systems is not being implemented efficiently due to differences in the data access services provided by the satellite operators. Improved levels of dialogue between the service providers — who in most cases are present at the ground station — and the satellite operators would ensure that acquisitions are scheduled in a manner consistent with the applications requirements (although full compliance with the revisit or coverage constrains would not be met in lower latitudes, such as the Mediterranean).

International co-operation agreements for surveillance
At present, many countries do not have the resources to mount an effective airborne surveillance program. Current capabilities of satellite remote sensing (in particular, the limited revisit time possible) is effectively limited to the optimization of such airborne resources, hence for countries with no airborne surveillance, the contribution of satellite systems is very low. In the North Sea and the Baltic Sea, however, there are agreements among all the states involved to pool airborne surveillance information so that overall monitoring can be implemented in an optimized manner, (that is, respectively within the frame of the BONN and the HELCOM-agreement). If such agreements could be extended to other areas (for example, the Persian Gulf, the Mediterranean, South East Asia), this could result in a more effective basis for deterring illegal spills. Furthermore, such an agreement would allow satellite observations to make a contribution to the monitoring services, enabling each country to obtain an optimized airborne and satellite service for a fixed investment.

Means to facilitate filling gaps
The following methods have been identified:
- Monitor critical areas (ship routes, oil platforms, national Economic Exclusion Zones)
- Set up a coordinated satellite data ordering system
- Perform oil slick distribution studies. These would provide basic information concerning the scale of the problem (many countries ignore the oil pollution issue, since it is unquantified).
- Increase polarimetric C-band SAR coverage. Current and planned coverage is barely sufficient to run operational services below high latitudes and provides no scope for satellite/instrument failure. The need for excess capacity as redundancy in case of failure should not be ignored. Many national authorities will not commit to operational satellite services that are prone to single point failure

Mechanisms to improve access to satellite data
In order to have an appropriate emergency spill response; there is a need for:
- Global, unified ordering system valid for many satellites
- Fast payload planning
- Fast data and product dissemination
- Special data policy
- Introduction of products in a standard GIS format (e.g. GeoTIFF), since ingest of EO data using image processing packages (ERDAS Imagine, EASI-PACE, ER-Mapper) is mainly limited to

existing EO specialists. Many of the target users are not EO specialists but have GIS packages for spatial databases and/or coastal process modelling.

Expand user outreach

The following tools are needed:

- Spill drifting models, that are capable of ingesting satellite data
- Automated spill detection algorithms
- Standards for products/responsive to user needs
- Mutual training services (towards space info managers and spill response teams)
- Communication means for product delivery
- Flexibility in data pricing (target is < 2.5 US¢ per square km)
- Demonstration projects for multi-satellite usage

Concluding remarks

It has been recognised that the satellite operators have the capability to present coverage maps for their planning system. It has also been recognised that no harmonisation has been initiated, giving the user the opportunity, for example, to present jointly the coverage maps from the different missions (ERS and RADARSAT). In practical use, this lack of capability represents a drawback for an operational user. Initiatives should therefore be taken jointly by the satellite operators to develop/implement a multi-mission coverage charting system.

In order to proceed towards a longer term, operational oil spill monitoring service, the main challenge will not relate to the technical portion, but rather to the need to develop more long-term customers. The basic technology exists and the capabilities have been documented. There is hence no need to develop any new image processing systems, but rather to document and inform about the different systems that already exists.

Optical spaceborne systems have been proposed for use in operational services, however, they are dependent upon weather and light conditions, which makes it difficult to establish and operate a reliable monitoring system. Optical systems could, however, be used as a supplementary source of information to radar data. Hyperspectral data, when available, could improve the ability to discriminate and classify oil.

Practical work with pollution control authorities has shown that information about oil spills represent a "sensitive" area. This is especially true for the capability to monitor the territorial waters of neighbouring countries. The fact that such information could be misused represents a key concern. It is therefore inaccurate to assess that such information should generally be made available to the public without prior agreement and acceptance from the customer. Some type of procedure that states ethical principles should therefore be developed. The working group could hence take an initiative to develop a declaration on access to and use of space data in case of disasters.

One of the keys to successful development of the market depends upon a regional engagement. It is strongly recommended that a regional service provider partner become involved from the very beginning of the development work. This could be regional industry and/or any other institution having the capabilities and the interest to invest within this application area. The roles of the international partners, such as space agencies, are preferable during the initial development phases. Such an engagement could, for example, mean that a demonstration service is available to the end-user at favourable cost during the initial phases (since data costs could be covered by the agency during these phases).

Oil spill scenarios for emergency response

The main focus would be to check for and deliver any archived SAR imagery of the affected area together with coincident meteorological data and available digital elevation information. Such background data is needed as a baseline to reveal slick like artifacts caused by interaction of the prevailing winds and coastal topography. Without such background information, visual interpretation of oil extent and distribution can be extremely misleading.

Proposed Emergency Scenario Examples:

Oil Spill

Obtain current and future status	***Check if considered***
1. Wind Direction	
2. Weather Conditions	
3. Location of fragile ecological zones that may be in danger	
4. Potential/Expected zone that will be affected (supply map?)	
5. Remedial measures taken by local authorities (containment efforts)	

Obtain background information
1. Location of Oil Spill
2. Cause of Oil Spill
3. Volume of Oil Spill and rate of spillage

Select the imaging payload
1. SPOT
2. RADARSAT - use of radar imagery can facilitate (depending on weather
conditions) locating oil on the sea.
Suggested beams
1. If you have a good idea of where the spill is Wide 1, or if a larger region needs to be covered use
ScanSAR Narrow Fine beams are not suggested due to speckle interference and
inappropriate incidence angles
3. ERS - use of radar imagery can facilitate (depending on weather
conditions) locating oil on the sea

Data
1. Suggested value adding
2. Data delivery mechanism

1) Crisis scenario for the Project Manager (PM)

1. *Context*

The following crisis scenarios are written pursuant to Article IV, Section 4.2 of the *International Charter on Space and Major Disasters.* These scenarios constitute the basis for action, by the PM with initial dialogue with the Emergency On-Call Officer (ECO), in the event of identification of a crisis, and are based on Partner Agencies individual experience, as well as the experience gained through the implementation of the *International Charter*. Consequently the scenarios are subject to regular updates. The number of crises that can be covered and the coverage intensity will also increase as new *International Charter* members are accepted. The applications included here are those that are appropriate for the current constellation of satellites used under the *International Charter*.

2. General Considerations

The tasking of any one satellite to cover a disaster is based primarily on the timeliness of the data acquisition and delivery and the applicability of the sensor in question to the natural or technological event being imaged. The formulation of these scenarios is independent of any consideration of cost, which is already assumed by the each Partner Agency's commitment to deliver data at a defined processing level.

First, general constraints and characteristics of the various sensors to be programmed are described, and then their performance scenarios for each of the major disasters that one or more of the sensors are able to monitor are given.

- SPOT satellites 1, 2 and 4: There are satellite programming conflicts that will be managed by Spot Image and in direct consultation with the ECO and the PM involved. Generally speaking, one image acquisition per day is possible with the intervention of the three satellites. In the case of a volcanic eruption and fires, night imagery (especially with SPOT 4 - MIR channel) can be useful. For temperatures higher than 400 °C, even SPOT1 and SPOT2 might be of use. The 1 km resolution VEGETATION instrument on SPOT 4 does not require programming and provides daily coverage of all the world's landmass with the exception of Antarctica.

- ERS-2: Programming conflicts are managed by ESA in liaison with the ECO and the PM. Depending on the latitude of the disaster occurrence, generally two (2) to four (4) image acquisitions are possible every 35 days on ascending and descending orbits. The previously built ERS-1/ERS-2 tandem mission archives are richer with data acquired on descending rather than ascending orbits.

- RADARSAT-1 has close to 30 imaging modes with regard to the width of the imaging swath, the angle of the incident radar beam, and resolution of the ground target. Given the latitude of the disaster occurrence, the revisit frequency may be no more than 7 days. In view of a large number of imaging modes, there is extensive conflict management in fulfilling a data acquisition request and programming the satellite. The conflict management and data acquisition planning is carried out by CSA. The choice of imaging parameters will be based on the requirement and there will be trade-offs between resolution and the extent of the area that can be covered. Higher resolution is to be preferred generally over the extent of the coverage area; however, there are cases where the choice may be easier to make. This is, for example, the case with Standard and Wide beams of RADARSAT-1, which have similar resolution, though Wide beams have a 150 km wide swath compared to only a 100 km wide swath of Standard beams. The use of On-board tape recorder may introduce some additional constraints in terms data downlink rates and bandwidth.

Radiometric gain issue needs to be addressed. Fixed gain selected by CSA and LUT for data processing chosen by the CDPF are recommended.

- In view of the 'guaranteed' image acquisition with radar sensors, which are not hampered by weather conditions and can image during day or night, the archives of these data may be searched for useful reference imagery, preceding a disaster event. It is preferable to acquire images at identical incidence angles. It is also preferable to compare images acquired during identical periods (seasons), in order to minimise the effects of changes on the ground.

- The purpose for which the remote sensing data are furnished is to monitor the threat of a disaster or to assess its effects. Each data type, radar vs. optical, has its inherent data analysis and interpretation scheme.

3. Disaster Type: Oil Spills

Purpose: Monitoring the disaster - displacement of the oil spill. Several successive data acquisitions will be required. The satellite data acquisition will be combined with wind, sea- state and other meteorological data for complementing the information sources.

- ERS (preferred over RADARSAT because of the vertical VV polarisation, though the dampening effects of the oil surface is strong enough to be picked up equally well with any of the two satellites, regardless of their polarisation. For RADARSAT, shallow-incidence modes (F1, W1, SN1) should be selected. The location of a spill is often only approximately known. In this case the best trade-offs are between Wide and ScanSAR Narrow beam modes (medium-resolution wide swath). The "Fine" mode is only recommended when the location error margin is small.

- SPOT (specular image acquisitions with respect to the Sun : "East-looking acquisitions" or "Sun glint" to be taken into consideration).

Web sites

CCRS http://www.ccrs.nrcan.gc.ca/ccrs

Clean Seas project http://www.satobsys.co.uk/CSeas

ESA-ISIS project http://tempest.esrin.esa.it/isis/osm/OsmStart.hmtl
(user isis password no good)

OilWatch project http://oilwatch.eos.co.uk

RadarSat International http://radarsat.space.gc.ca

Tromso Satellite Station http://www.tss.no/

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REFERENCES

Brown, C.E. and M.F. Fingas, “Oil Spill Surveillance, Monitoring and Remote Sensing: A Global Review”, in *Proceedings of the Twenty-second Arctic and Marine Oil Spill Program Technical Seminar, Environment Canada, Ottawa, Ontario*, pp. 387-402, 1999

G Campbell and G Calabresi, 1995, “Conclusions of the Oil Spill workshop,” *Oil spill special bulletin.* Proceedings of the Oil spill Workshop, ESA-ESRIN

Clemente-Colón, P., X.-H. Yan, and W. Pichel, 1997, “Evolution of Oil Slick Patterns as Observed by SAR off the Coast of Wales,” *Proceedings 3rd ERS Symposium, Florence , March 17-21*, pp. 565-568.

Elliott, A.J. and B. Jones, 1998, “Oceanographic and meteorological conditions,” in *Proceedings of the Sea Empress oil spill international conference, Cardiff*, pp. 379-390.

Jones, B. and E.G. Mitchelson-Jacob, 1998, “On the interpretation of SAR imagery from the Sea Empress oil spill,” *International Journal of Remote Sensing*, 19, pp. 789-795.

J.P. Pedersen, L.G. Seljelv, G. D. Strøm, O.A. Follum, J.H. Andersen, T. Wahl, Å. Skøelv, “Oil Spill detection by use of ERS SAR data,” *Proceedings of the second ERS applications workshop, ESA SP,* p. 361, 1996.

TEAM REPORT

Volcano

VOLCANIC HAZARDS ASSESSMENT

CEOS DISASTER MANAGEMENT SUPPORT GROUP

SUMMARY

Volcanoes pose a serious threat to persons on the ground near erupting volcanoes (due to proximal hazards such as lava flows, mud flows, ash fall, etc). Ash clouds from major eruptions endanger aircraft and airport operations over distances of thousands of kilometers. Remote sensing has become an indispensable part of the global system of detection and tracking of the airborne products of explosive volcanic eruptions via a network of Volcanic Ash Advisory Centers (VAACs) and Meteorological Watch Offices (MWOs). Visible and InfraRed (IR) satellite data provide critical information on current ash cloud coverage, height, movement, and mass as input to aviation SIGnificant METerological (SIGMET) advisories and forecast trajectory dispersion models. Recent research has also shown the potential of remote sensing for monitoring proximal hazards such as hot spots and lava flows using geostationary and polar InfraRed (IR) data. Also, Interferometric Synthetic Aperture Radar (InSAR) imagery has been used to document deformation and topographic changes at volcanoes. However, limited spatial and temporal resolution of available satellite data means that, for most proximal hazards, it is used mainly as supplemental information for current eruptions, and post-disaster assessment in mitigation and prevention of future disasters.

Spectral bands used in detection of volcanic ash and surface-based hazards are identified in this report. They include a variety of IR bands, especially those centered near 4, 7.3, 8.5, 11 and 12 microns. Visible (0.5 - 1.0 micron) and dual ultraviolet (UV) (0.3 - 0.4 micron) channels, although limited to daytime use, are valuable for qualitative assessment of ash and sulfur dioxide (SO_2) plume coverage, and quantitative estimation of ash optical depth, ash cloud top height (through parallax techniques) and total mass of silicate ash and SO_2. The minimum spectral channels needed for effective remote sensing of volcanic hazards are specified in the report and recommendations, as are threshold and optimum spatial resolutions and frequencies. Similar requirements are proposed for some important derived products (ash cloud height, ash column mass, and SO_2 concentration).

Despite the fact that most current meteorological satellite data are being used for an application for which they were not intended, and research into various channel and spacecraft combinations is fairly new, the current remote sensing systems work fairly well for ash cloud detection in some areas. The main limitations of the current systems are: (1) obscuration by clouds or ambient moisture, (2) reduced capability at night, and (3) limited ability to detect small-scale events. As for the detection of the onset of a volcanic eruption, the current system is inadequate in all parts of the world due to poor timeliness (satellite data frequency is typically 30 min to several hours depending on the platform) and precision (false alarm rates are high for existing techniques). While the spatial resolutions of some low earth orbit systems are sufficient for monitoring proximal hazards, timeliness and cost are important issues. For radar, there is an additional need for wider availability of stereo viewing, and for the addition of L-band radar, to expand InSAR applications in vegetated area.

Future geostationary and polar satellite systems will result in overall improvements in our ability to monitor volcanic ash and proximal hazards, except in the Western Hemisphere. The one major weakness in the near term will be the loss of the “split window” (12.0 micron) band, beginning with Geostationary Operational Environmental Satellite (GOES) spacecraft launched in July, 2001, extending to at least 2008. Alternative strategies are being addressed to alleviate this data gap,

including research to utilize the remaining IR and visible bands on GOES, and better use of the GOES sounder and polar spacecraft.

Team Accomplishments:

- Participated in a special session on volcanic clouds at the American Geophysical Union (AGU) Fall Meeting in San Francisco (December 2000).
- Responses from a remote sensing survey sent to volcano observatories were evaluated. The results were presented at the CEOS DMSG meeting in Brussels and are summarized in Appendix B (this report).
- Participated in the CEOS Disaster Management Support Group meeting held in Brussels, Belgium, 26-28 June 2001:
    - Developed a scenario for emergency actions during an ongoing major eruption. That and f further scenarios are presented in Appendix C (this report).
    - Provided NOAA / NESDIS responses to specific CEOS action items
    - Briefed on a demonstration project to provide real-time fire and volcano products to Central American nations
- Helped organize an international volcanic cloud workshop held at Michigan Technological University from 28 July - 3 August 2001 at Houghton, Michigan. As a result of the workshop:
    - There will be increased collaboration on specifying "source terms" in eruption clouds
    - A letter supporting various spectral channels on the future GOES will be drafted
    - An effort will be initiated to allow more widespread access to MODIS data and derived products
    - Another workshop is planned for July, 2003, with greater participation from VAACs desired
    - Communications among participating scientists will be increased by means of a web-based "Volcanic clouds" discussion group

GENERAL APPLICATION DESCRIPTION

Volcanic Ash Plumes

Volcanic ash poses a menace to persons on the ground near erupting volcanoes, and to aircraft over thousands of kilometers for major eruptions. Volcanic eruption clouds containing silicate ash particles, volcanic gases, and acid aerosols can do extensive damage to high altitude jet aircraft. When ingested into jet engines, melted volcanic ash can block air intakes, abrade turbine surfaces and blade tips, and generally cause loss of engine performance that could result in either emergency engine shutdowns or compressor stall failures (flameouts).

Other hazards to aircraft includes pitting and corrosion of leading edge surfaces, abrasion of windshields, and electrical discharges (Casadevall, 1992). Because of their higher operating temperatures, the most modern, fuel-efficient "high bypass" engines are the most susceptible to ash ingestion hazards. Thus, as more and more aircraft are powered by this type of turbine, the consequences of ash ingestion are likely to get worse, rather than better, with time. Since volcanic aerosols (gases and particulates) can be injected at all altitudes from sea level to 150,000 ft (45,000 m) Above Sea Level (ASL) or more, from perennially erupting sources (e.g., Mt. Etna, Italy; Mt. Sakurajima, Japan) or from massive, explosive eruptions (e.g., Mt. Pinatubo 1991), aircraft can be affected at any operational altitude. Thus, ash ingestion and abrasion risks can be experienced by trans-continental and trans-oceanic aircraft at cruising altitudes in the upper troposphere and lower stratosphere, as well as by aircraft operating near the ground in regions affected by local plumes or ashfall. In addition to the hazards of ash to jet engines, the SO_2 and acid aerosols that normally accompany silicate ash pose a separate hazard, although not one that actually stops engines in mid-flight. These components of volcanic plumes etch acrylic windows quickly, and damage exposed metal, plastic and rubber components of aircraft. With the exception of damage to acrylic windows, the damage is difficult to recognize, so that appropriate cleaning and maintenance may not be performed in a timely manner. (Casadevall, op. cit.) The advent of two-engine passenger jet aircraft that are intended for long-distance travel will require (under current safety rules in the United States) that a greater number of airports be clear for emergency landings. For example, along the air routes in the northern Pacific, this means that proximal ash hazards that close an airport (e.g. Adak Island) may require delaying flights through the region, even though that airport would not normally be a destination. Eruptions near airports, as is the case for Popocatepetl near Mexico City, Mexico, or in heavily traveled areas such as the Carribean also pose a problem for arriving and departing jetliners, as well as smaller commuter aircraft.

Due to the worldwide hazard that airborne ash poses to aviation, remote sensing has now become an indispensable part of the global system of detection and tracking of the airborne products of explosive volcanic eruptions. Nine centers of expertise, known as Volcanic Ash Advisory Centers (VAAC), provide updated advisories hazardous ash clouds to Meteorological Watch Offices (MWO), who are responsible for forecasts and official warnings (SIGnificant METeorological (SIGMET) information). VAACs also provide reports of eruptions as received from local or federal geological or volcanological facilities. Areas of responsibility for the VAACs are shown by ***Figure 1***. The Volcanic Ash Advisories (VAAs) are also sent to Area Control Centres (ACCs), who issue NOTices to AirMen (NOTAMs) that describe adverse effects of volcanic ash on air routes and airports. The VAACs are part of the International Airways Volcano Watch (IAVW) program, established by the International Civil Aviation Organization (ICAO).

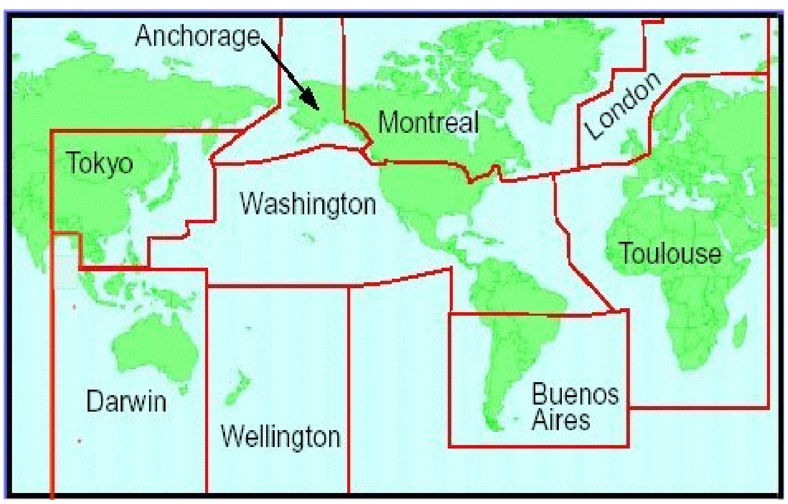


Figure 1. *Areas of monitoring responsibility for the Volcanic Ash Advisory Centers (VAAC) established by ICAO. Shaded areas are unmonitored. (Courtesy of D. Schneider, Alaska Volcano Observatory)*

Government agencies that operate meteorological satellites such as NOAA/NESDIS in the United States, European Organisation for Exploitation of METeorological SATellites (EUMETSAT), and Japan Meteorological Agency (JMA), contribute their data to the VAACs and other volcano monitoring facilities such as the United States Geological Survey (USGS). Once initial conditions regarding the eruption are estimated, parameters are used to initialize a numerical dispersion forecast model that becomes a critical component of the air route planning process.

Proximal Volcanic Hazards

The hazards posed by airborne volcanic ash and acid aerosols to jet aircraft have attracted much attention from the remote sensing community, and understandably so, as the location of these plumes can be monitored by no other means. However, the effects of a volcanic eruption are most intense in the neighborhood of the volcano itself. If satellite-derived information is to make a larger contribution to volcanic hazards mitigation, we must find ways to monitor and quantify the proximal effects of volcanic activity, and to get that information to the locally based communities that are responsible for volcano monitoring and emergency response.

There are two distinct circumstances in which volcanologists monitor activity at volcanoes: (1) unrest at a volcano that has been dormant, but which may be preparing to erupt and (2) activity at a volcano during an eruption, particularly a long-term eruption with spurts of accelerated activity or pauses (as at Kilauea, or Etna, or the slow dome-building eruptions of Montserrat or Unzen). In the first instance, the volcano will erupt only if there is renewed influx of magma from deep within the earth. Magma movement triggers earthquakes and tremor, hence the widespread use of seismic networks as the monitoring method of first resort. Satellite monitoring can come into play only when the magma is near enough to the surface to produce surface deformation, or enhanced heat flow or gas emissions. At this later stage of reawakening, volcanologists need all the information they can get to evaluate the probability of an eruption, and it is here that remote sensing may usefully contribute.

In the second instance, involving long-term eruptions, remote sensing can again be useful in surveying the active area, as it may be too hazardous to survey on the ground, or too time-consuming or expensive (after years or decades) to maintain extensive ground surveillance. In addition, remote sensing data can be used in volcano hazard assessment work at dormant or active volcanoes. Tables 5 and 6 (below) list the various methods for monitoring and assessing volcanic hazards, using both ground-based, and satellite techniques.

Before discussing the potential role of satellite information in detail, it is useful to lay out some differences between dealing with local volcanic hazards vs. the disseminated ash-plume. These differences include:

1. The magnitude of the proximal threat is much larger. There is the potential for many (perhaps thousands) of deaths and of extensive or total destruction of buildings, roads, dams, pipelines, or any other structures in the area. The surface drainage pattern may be disrupted, and arable land or forest temporarily or permanently destroyed.

2. As with the aircraft hazard, the basic means of hazard mitigation is avoidance. However, instead or diverting aircraft for comparatively brief periods, proximal hazards require evacuation of people, livestock, any other movable property, to appreciable distances from their homes, for uncertain lengths of time, often weeks or months.

3. Responsibility for most aspects of volcano monitoring is dispersed and usually quite local. The directory of volcano-monitoring entities issued by the World Organization of Volcano Observatories (WOVO) lists 61 separate observatories. Most of these focus on a single volcano, and the levels of staffing, instrumentation, computer support, and communications links with the outside vary greatly. Their strengths in the event of a volcanic crisis are (1) familiarity with the eruptive history and probable behavior of the local volcano(es), (2) previously established local

credibility based on that knowledge, and (3) established connections with relevant local government officials and emergency responders.

By contrast there are only nine VAACs, all recently established, which are similarly equipped and staffed, and have been designed specifically to communicate with existing formal aviation and meteorological data networks (MWOs and ACCs), and each other. However, remote sensing capabilities vary from VAAC to VAAC (see the next section).

4. The audiences for ash vs. local hazard warnings are very different. For proximal hazards, the entire population is the audience. The experience of that local population with volcanic eruptions is usually limited, often non-existent, as most volcanoes have major eruptions less than once a century. (The best tool for public education found so far is videos of actual eruptions and their consequences.)

By contrast, the audience for warnings about ash clouds consists of dispatchers, flight planners and pilots, who are more technically aware than the general population, and for whom flight diversions (usually because of weather) are almost a daily occurrence.

5. Responsibility for ordering volcano-inspired response (decisions to limit access to, or require evacuation from, certain areas, and for how long) usually rests with local government officials and emergency managers or civil defense personnel. There are enormous social and economic costs to any measures taken, and great resistance from almost all components of the local community is the norm. Even one instance of evacuation that in hindsight comes to be viewed as a "false alarm" can damage the credibility of both the officials and the scientists whose information formed the basis for the action, for many years. (By contrast, a false alarm about a cloud that turns out not to contain ash is a nuisance of short duration, and poses little public safety hazard.)

For all the difficulties involved, the volcanological community has experienced some major successes in working with decision-makers and the general public to mitigate the damage from volcanic eruptions. An excellent discussion of the complexity of the process, and the intrinsic difficulties, can be found in Newhall and Punongbayan (1996), who review the history of response to the 1980 Mt. St. Helens and 1991 Pinatubo eruptions.

In considering how to expand the use of remote sensing information in support of volcanic hazards response and mitigation, it is important to understand that, <u>for volcanoes in populated areas</u>, such information will likely be used only in addition to, not instead of, ground-based information. Attempts by outsiders (no matter how expert or well-intentioned) to preempt the role of the local observatories and local scientists has led to confusion and can delay effective action by decision-makers and the public.

The basic recommendations of this report therefore are:
(1) to take steps to enhance mutual awareness between the space agencies and the volcano observatory community, and
(2) ***to facilitate the task of finding relevant imagery, especially for newcomers to the system, in the event of a major episode of volcanic unrest.***

SPECIFIC APPLICATION DESCRIPTION: Volcanic Ash

Hazard Type:	Volcanic Ash
User Level:	International
Disaster Management Category:	Mitigation/Preparedness
Operational Status:	Operational

Current remote sensing techniques for detection and tracking of volcanic ash clouds vary from VAAC to VAAC, and are very dependent on the availability of satellite data streams and local processing capabilities. In the best case, polar and geostationary single and multi-spectral channel imagery, and polar ultraviolet spectrum data is available in a timely fashion and used together to extract the maximum information. At other VAAC's, only one satellite data stream may be available and that one source may not be adequate for detecting all volcanic ash plumes. In either situation, cloud cover, large amounts of moisture in both the ambient atmosphere and ash cloud, and nighttime conditions may limit the VAAC's ability to detect and track ash.

Current satellite-based data and products:

The following satellite data and products have been deemed useful in volcanic ash detection (spectral channels used in deriving these products are also shown, along with citations):

- Ultraviolet (UV) Backscatter and Absorption (i.e., Total Ozone Mapping Spectrometer (TOMS) 0.3 - 0.4 micron)
  - Sulfur dioxide concentrations (Krueger et al, 1995)
  - Aerosol Index: Sensitive all absorbing aerosols, such as silicate ash, acid aerosols, silicate dust, and smoke (0.34-0.38 micron bands) (Seftor et al. 1997)
- Visible band (0.5-1.0 micron) (Holasek and Self, 1995; Holasek et al. 1996; Pergola et al. 2001)
- Thermal IR band (11 micron) (Holasek and Self, 1995; Holasek et al. 1996)
- "Split-Window" IR (11 micron minus 12 micron temperature difference) (Prata, 1989; Schneider et al. 1995)
- Thermal IR mid-wave band (8.5 micron) (Realmuto et al. 1997)
- Water vapor absorption band (6-7 micron) (Lunnon and McNair, 1999)
- SO_2 absorption (7.3 micron) (Crisp, 1995)
- Reflectivity product (3.9, 11 micron) (Ellrod and Connell, 1999)
- Experimental, three channel IR products (3.9, 11, 12 micron) (Ellrod and Connell, 1999; Di Bello et al. 2002)
- Passive microwave data (85 Ghz) (Delene et al. 1996)

The above list of images or products are derived from both geostationary (GOES, METEOSAT, GMS) and Polar orbiting satellites (NOAA Advanced Very High Resolution Radiometer (AVHRR), NASA's Earth Probe TOMS). The use of some of the above data types or products is currently experimental, and is not available at all VAACs. The "split window" (11 - 12 micron IR) technique is in widespread use at many VAACs, and is especially effective for "aged" ash plumes with low water vapor content. Thus, the technique does not always provide unambiguous identification of the ash cloud. An example of the capability of the split window product for a long-lived eruptive ash cloud is shown by ***Figure 2*** — next page.

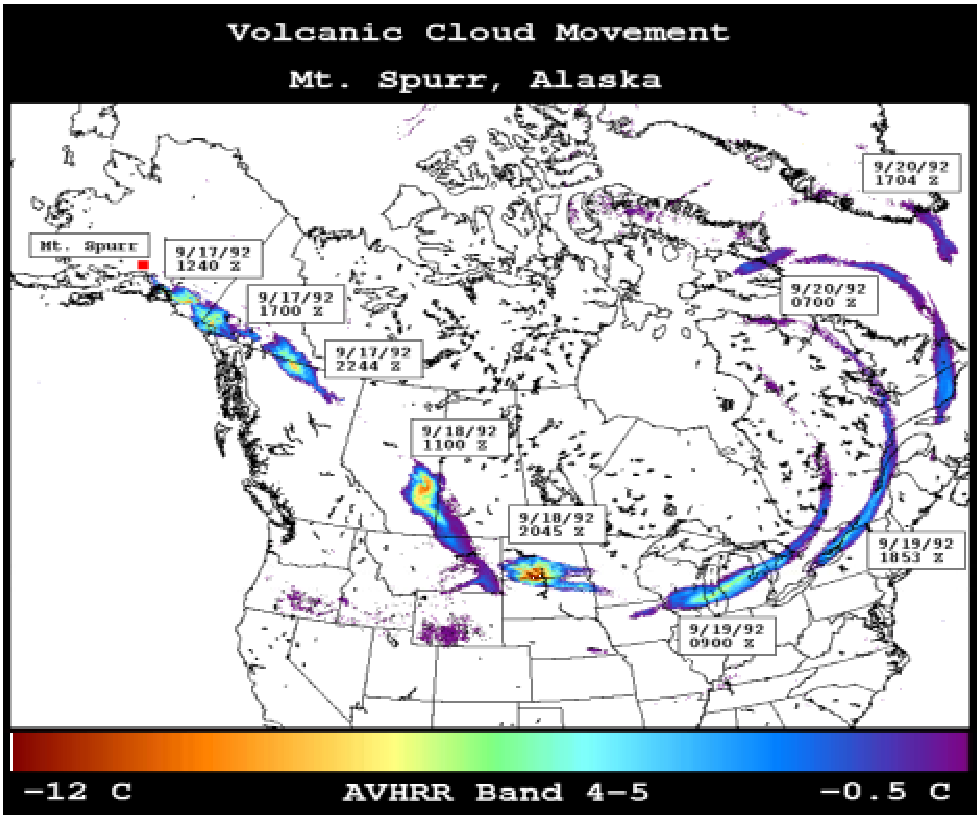


Figure 2. Path of eruption cloud from Mount Spurr eruption of 17 September 1992 from NOAA AVHRR band 4-5 (split window) over a three day period (Schneider et al. 1995)

Routine image product frequency is currently 30-60 minutes for geostationary satellites (except 15 minutes for GOES over the Continental United States), and 2-6 hours for polar products. Product or data resolutions range from 1-8 km. A multi-panel image showing GOES capabilities for an eruption of Popocatepetl near Mexico City (***Figure 3*** – next page) depicts the standard raw images in visible, thermal IR and shortwave IR, plus the split window product, a 3.9 - 11 micron difference image, and the experimental three-band product.

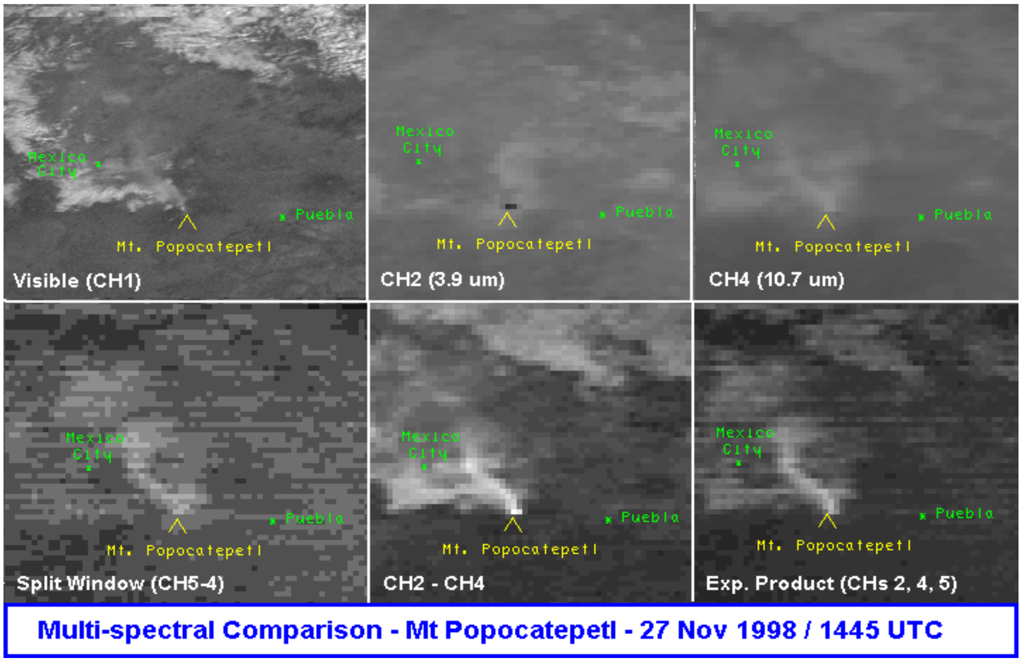


Figure 3. Multi-spectral comparison of GOES-8 data for an eruption of Popocatepetl on 27 November 1998.

Detection of ash further depends on (a) estimating the amount of ambient water vapor assumed in the atmospheric column, and (b) knowing the amount of magmatic or phreatic (ground water source) water vapor in the eruption column. Given a relatively dry atmosphere and volcanic plume, current IR detection algorithms work well (e.g., 1992 Spurr eruption discussed in Schneider et al, 1995). Also, for eruptions where both TOMS and AVHRR data are available, they give similar results for ash retrievals (Krotkov et al., 1999), though the TOMS data is low-resolution and available only during daylight hours.

However, where an eruption incorporates much phreatic water, or under tropical conditions where the water vapor content in the atmospheric column is high, it is more difficult to distinguish volcanic from meteoric clouds (e.g. the 1994 eruption of Rabaul, discussed by Rose et al., 1995, and Prata and Grant, 2001. In regions where only one IR channel is available (i.e., Africa - METEOSAT at present), we cannot distinguish ash from meteorological clouds, except by cloud source and shape. Recently, in order to try to overcome these limitations, a robust approach has been suggested, based on the multi-temporal analysis of historical satellite records, leading to a dynamical determination of local thresholds to be used by the detection algorithms (Pergola et al.2001; Di Bello et al. 2002).

Detection of volcanic hazards at night is more difficult and thus, less adequate, due to the absence of visible band (0.6 micron) imagery or UV data, and the lower resolution of geostationary IR channels. Ash has a distinctive appearance in visible data, and can thus be used to qualitatively verify signatures observed in IR products.

Despite the fact that these meteorological satellite data are being used for an application for which they were not intended, and research into various channel and spacecraft combinations is fairly new, the current remote sensing systems work fairly well for some areas. As for detection of a volcanic eruption, the current system is inadequate for detecting eruptions with a high degree of timeliness in all parts of the world.

Parameters extracted from the satellite data:
An analysis of the horizontal extent of an ash cloud is determined from satellite images, either single channel visible, infrared (IR) or multi-spectral IR, at one of the regional VAACs. The height of the plume is estimated by means of IR satellite imagery, upper level temperatures and winds (derived from radiosondes, satellite cloud motion, or numerical prediction models), aircraft pilot reports, or ground-based observations. The plume location and height (along with eruption time and duration) are then used to initialize a numerical model that forecasts the trajectory of the ash cloud for use by MWOs in developing forecasts and warnings. Model output is also used for air route planning.

Volcanic aerosols and SO_2 are also detected using TOMS UV data, but the availability of TOMS is limited to a few passes per day at present. ***Figure 4*** is an example of ash coverage depicted by TOMS UV on the Japanese ADEOS satellite for an eruption of Bezymianny on May 8, 1997.

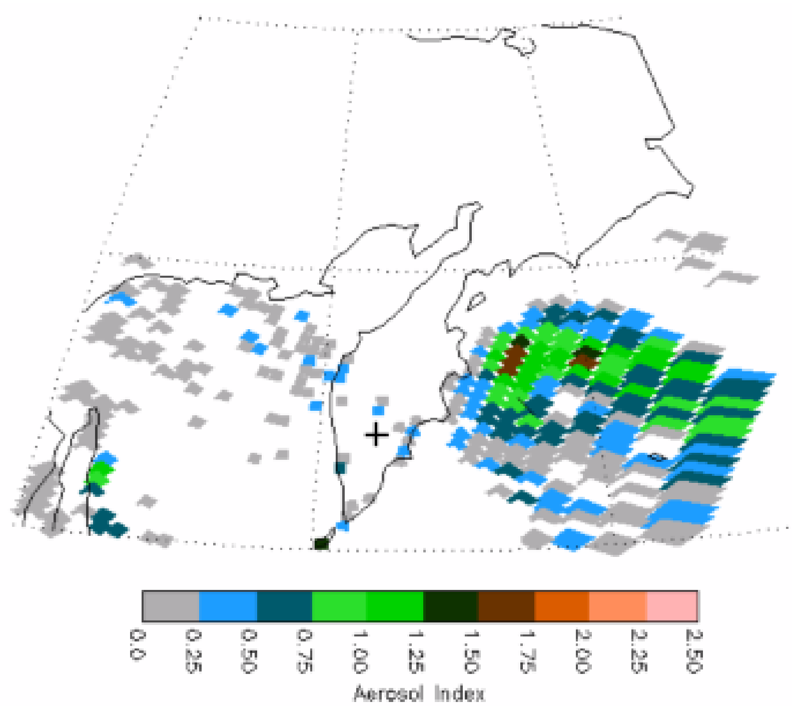


Figure 4. TOMS UV Aerosol Index from the ADEOS satellite on May 8, 1997 showing extent of volcanic ash from an eruption of Bezymianny (at location shown by +). The resolution of TOMS UV is about 40 km at nadir. (NASA)

PRODUCTS AND SERVICES: Volcanic Ash
Principle users of volcanic ash products (satellite data, derived products, warnings, advisories) at the international, national, and local levels are summarized in Table 1 (page 153). Examples of volcanic ash text and graphic products issued to these users include:

- Volcanic Ash Advisory (VAA) issued by all VAACs
- Volcanic Ash graphic analysis (currently issued only by the Washington VAAC)
- Trajectory and dispersion forecast models:
    - Volcanic Ash Forecast Transport and Dispersion (VAFTAD, Washington VAAC)
    - PUFF dispersion model (Anchorage VAAC)
    - CANadian Emergency Response Model (CANERM, Montreal VAAC)
    - Modele Eulerian de DIspersion Atmospherique (MEDIA, Toulouse VAAC)
    - Nuclear Accident Model (NAME, London VAAC)
    - Hysplit Model (Darwin VAAC)
- SIGnificant METeorological information (SIGMET) issued by MWOs
- NOTices to AirMen (NOTAM) issued by ACCs
- Volcanic Eruption Information Release issued by USGS Volcano Observatories

An example of a dispersion forecast of a Mt. Spurr eruption cloud valid at 1200 UTC on 14 February 1996 from the CANERM model (Pudykiewicz, 1988) is shown in ***Figure 5.*** Validation of dispersion trajectory forecast models are usually conducted in-house and involve comparison of forecast ash cloud coverage with visible and IR satellite images. A study by Heffter and Stunder (1993) found that VAFTAD forecasts of several Mt. Spurr eruption clouds in 1992 agreed reasonably well with satellite imagery, considering the inability of satellite data to detect lower concentrations of ash. A recent inter-comparison of VAFTAD and the Alaska PUFF model by the Washington VAAC found that the forecasts from both models provided consistent results.

The ICAO requirement for updates of the VAA, and forecast products (SIGMETs) is a minimum of every six hours during a volcanic ash event. Planned capabilities of future satellite systems (see final section of report) will satisfy the ICAO requirements for remote sensing of volcanic ash, e.g. text messages and/or graphics containing a description of the ash cloud position and its movement every 6 hours, including accurate forecast positions. However, unless suggested research areas are supported and realized, there may be periods where the ash monitoring capability will be degraded, such as during the time frame when GOES will not be carrying the split window channel, at night, or in the critical first few hours of an eruption. It should be noted that this report not only reflects ICAO requirements, but the desires of the aviation community to have accurate ash cloud updates as frequently as possible, as well as the best possible forecast models.

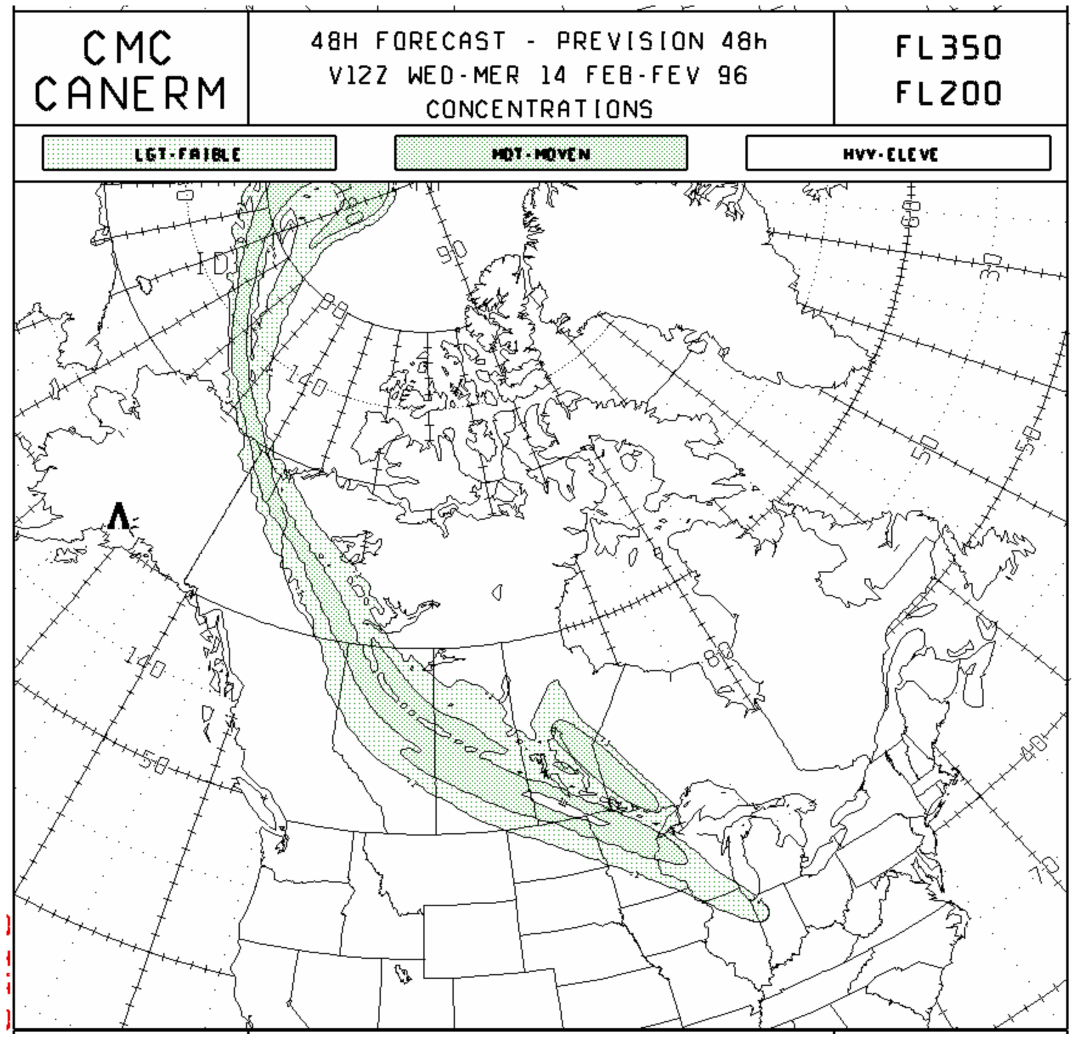


Figure 5. Canada Emergency Response Model (CANERM) 48 hour forecast output valid on 14 February 1996 at 1200 UTC for an eruption of the Mt. Spurr volcano in Alaska (from Servranckx et al. 1996). Ash concentrations are color coded for the altitude range from 20,000 ft (Flight Level 200) to 35,000 ft (FL350) above Mean Sea Level (MSL).

TABLE 1.
Primary Users of Volcanic Ash Products

International	***National***	***State/province/local***
VAACs	Civil aviation agencies	Emergency managers
MWOs	Regional airlines, ACCs	Airport managers
ACCs	All airlines, Military	Police
Major airlines	Geophysical and meteorological agencies	Fire and rescue
International Relief Agencies (Red Cross)	Emergency management agencies	Medical facilities
Geophysical researchers	Medical/relief agencies	
	Volcano observatories	

OBSERVATIONAL REQUIREMENTS: Volcanic Ash Plumes / Eruptions

Remote sensing requirements for adequate volcanic ash and SO_2 detection are listed in the following three tables that describe:

(1) the resolutions of raw image data (***Table 2***),
(2) derived product specifications (***Table 3***), and
(3) data frequency (***Table 4***).

The requirements were developed after consideration of:

(1) the spatial and temporal scales of the phenomena,
(2) current capabilities of the remote sensing system,
(3) user needs, and
(4) ongoing and prior research, including case study simulations with existing sensors.

Data that were considered difficult to obtain or too costly were not considered in the analysis. Threshold requirements determined by current system capabilities and observed performance are listed. Optimum capabilities were those considered achievable in the near future (10-20 years) assuming conservative advances in technology.

The current remote sensing systems need to be augmented to improve existing capabilities. In particular, the resolution of geostationary data needs to approach the polar resolution of 1km from AVHRR. All VAACs should have access to "split window" geostationary data at 30 minute intervals. An IR SO_2 absorption channel is required, and ideally, global UV data should be made available concurrently with high-resolution thermal IR data. To achieve these capabilities, a timely "call up" capability for very high refresh rates is needed, or access to military assets should be provided. Minimum areal coverage of the satellite data is for each VAAC and surrounding VAACs. Optimally, each VAAC would eventually have global satellite data coverage for all VAAC regions.

TABLE 2.
Data Resolution Requirements

Phenomenon	***Data***	***Threshold***	***Optimum***
Ash Cloud	IR	5 km	1 km
" "	Visible	1 km	0.5 km
" "	Sounder	10 km	2 km
SO2 Cloud	UV	20 km	10 km
" "	IR	5 km	1 km
Thermal Anomaly *	IR	1 km	30 m

* Verified (with False Alarm Ratio < 5%)

TABLE 3.
Derived Product Specifications

Product	***Threshold***	***Optimum***
Ash Cloud Top Height	< 2 km	< 1 km
Ash Column Density	1 ton/km2	0.3 ton/km2
SO_2 Precision *	5 DU	0.5 DU

* (SO_2 range = 0 to 700 Dobson Units (DU))

***TABLE 4**.*
Observational frequencies

Phenomenon	***Threshold***	***Optimum***
Ash Cloud	30 min	15 min
SO_2 Cloud	2 hr	15 min
Thermal Anomaly (Persistent)	2 hr	15 min
Thermal Anomaly (Transient)	30 sec	10 sec

RECOMMENDATIONS: Volcanic Ash
The CEOS Volcanic Hazards team makes the following recommendations regarding the remote sensing of volcanic ash and SO_2 clouds:

Space Agencies:
- Incorporate the following spectral channels in planning for all future satellite instruments:
  - Dual longwave (thermal) IR (11-12 micron)
  - Dual shortwave thermal IR (2-4 micron)
  - SO_2 / ash absorption IR (8.5 micron)
  - SO_2 absorption IR (7.3 micron)
- Include both IR and UV (0.3-0.4 micron) sensors on future geostationary satellites for a complementary volcano monitoring system.
- Develop a call up capability to obtain satellite data at the highest frequency possible for emergency situations, and assure transmission to the users.
- The minimum frequency of available multi-spectral data should be 30 minutes for geostationary satellites, with the optimum goal ~5 minutes. The minimum spatial resolution should be 5 km for IR, with an optimum goal of ~1 km.
- Allow VAACs, volcano observatories, and other qualified agencies to have access to multi-spectral satellite data and/or derived products at a frequency of at least 30 minutes. Each VAAC should have access to satellite data coverage for all neighboring VAACs in the event of "handoff" or backup situations.

CEOS
- Support bi-annual international volcanic ash summits such as the one held at Houghton, Michigan in July, 2001.
- Create a standing Science Working Group on Volcanic Hazards Detection.

Operational Hazard Warning Agencies:
While not germane to the responsibilities of the CEOS volcano hazards team, the following recommendations would improve the operational volcanic ash alerting system, provide a better flow of products and services to users, and improve the utilization of remote sensing data:

- Streamline and periodically test the communications system in order to provide timely:
  (1) initial notification of an eruption from VAACs to all interested agencies
  (2) dissemination and display of volcanic ash products from warning agencies to users

- Develop new and/or improved remote sensing tools (i.e. to automatically detect eruptions, discriminate volcanic ash (every 30 minutes), determine height and base of ash clouds, and composition and particle size of ash).
- Increase collaboration and validation efforts between operational agencies and research community, perhaps through regional workshops, WMO, and the World Wide Web.
- Expand education, training, and utilization of remote sensing derived information for all components of the IAVW, through regional workshops, WMO, and the World Wide Web.

Areas for Further Research and Development:

- Develop techniques for automatic detection of volcanic eruptions with as low a false alarm rate as possible (optimally <5%).
- Develop techniques for more accurate estimation of eruption column neutral buoyancy altitude and the top height of the resulting ash cloud ($< \pm 1$ km) (Alternate methods include cloud parallax techniques and UV "ring effects" (Joiner and Bhartia, 1995) and "CO2 slicing" technique (Menzel et al 1983) for optically thin ash clouds)
- Develop techniques for automatic edge detection of ash clouds every 30 minutes
- Develop or improved existing techniques for determining ash column loading, particle size distributions, and total mass.
- Develop alternative sources of 12.0 micron IR data or additional multi-spectral techniques to ameliorate loss of this channel on GOES from 2002 to 2010 or so (Viable alternatives include: the GOES sounder and AVHRR)
- Initiate research on the minimum concentrations of volcanic ash detectable by satellites, and whether or not these concentrations are hazardous to jet aircraft

** In general, an increase in communications among the small group of active researchers in the remote detection of volcanic eruptions and resulting ash clouds, and between the research and operational communities, is fundamentally crucial to the continued success of this effort and the maintenance of safety margins with respect to volcanic ash hazards.

SPECIFIC APPLICATION DESCRIPTION : Proximal Hazards

Introduction

Many volcanic phenomena are detectable and partly quantifiable using remote sensing information. A review of the subject by Francis et al (1996) mentions long-term (baseline) monitoring of deformation or thermal emissions, monitoring of gas emissions, detection of the onset of eruptions, and monitoring of processes during eruptions (especially long eruptions), including topographic changes that influence where lava or pyroclastic flows, lahars, and other gravity-driven materials go during an eruption. Table 5 summarizes important ground-based methods in use vs. currently available satellite techniques.

TABLE 5.
Monitoring Methods for Volcanic Hazards

Ground-based and airborne methods	***Satellite techniques***
Seismic networks to monitor earthquakes, tremor, rockfall	--------
Deformation networks to monitor tilt, expansion or contraction --often in conjunction with GPS	GPS, in conjunction with ground-based networks Radar, particularly InSAR
Monitoring changes in microgravity to detect magma intrusion	----------
Observation of thermal emissions, measurements of temperature, airborne FLIR cameras	Thermal IR
Gas emissions (SO_2, CO_2 levels or changes in gas ratios) via COSPEC, LICOR, FTIR, direct sampling	UV, IR (8.5 micron) can detect SO_2; acid aerosols detectable by various UV, IR methods
Acoustic monitoring for debris flows and lahars	-----------
Mapping, photography to document stages of the eruption, distribution of eruptive products	high-resolution panchromatic or multispectral imagery
Mapping to document topographic changes caused by the eruption, and to determine thickness of eruptive products	high-resolution stereo panchromatic imagery, radar

The techniques are listed in roughly the order in which they can be used to detect movement of magma toward the surface and then in the near-surface environment. Seismicity, deformation and gravity changes provide the earliest assessments; however, volcano-related seismic signals can be quite variable and require much experience in interpretation, for best results. Thermal and gas emissions may also precede activity, but some techniques, such as acoustic flow monitoring require an actual eruption event in progress. Note that there are several types of ground-based monitoring that have no satellite equivalents. However, satellite data provides unique information on (1) broad increases in thermal emissions, especially at temperatures below incandescence in the visible, and (2) broad patterns of deformation over areas, which cannot be done by ground-based networks.

There are two key difficulties in trying to develop satellite systems for better volcano monitoring. The first is that volcanic eruptions are comparatively rare. Thus there are no satellite systems in place that were designed specifically for volcano monitoring: we are working with tools developed for other purposes. However sensors needed for detecting and evaluating other hazards (wildfire detection and tracking, detecting deformation fields associated with earthquakes, landslide imaging and assessment) would also serve to monitor volcanic phenomena.

A second problem is that the time-scale involved is highly variable. Explosive volcanic eruptions are quite brief, while other types can go on for decades. A related problem is that eruptions can happen at night, when many of the higher-resolution sensors do not function. Pieri (et. Al. 1995) gave a good summary of how the brevity of most volcanic eruptions works against using satellite systems for eruption monitoring, comparing two packages that are on the recently launched Terra (formerly EOS AM-1) system (characteristics summarized in ***Appendix A***). The MODIS package has low spatial resolution, hence gives only a rough image of volcanic activity. The high-resolution ASTER system has a revisit time of 16 days at the longer wavelengths, which makes it difficult to capture any but the longest eruptions.

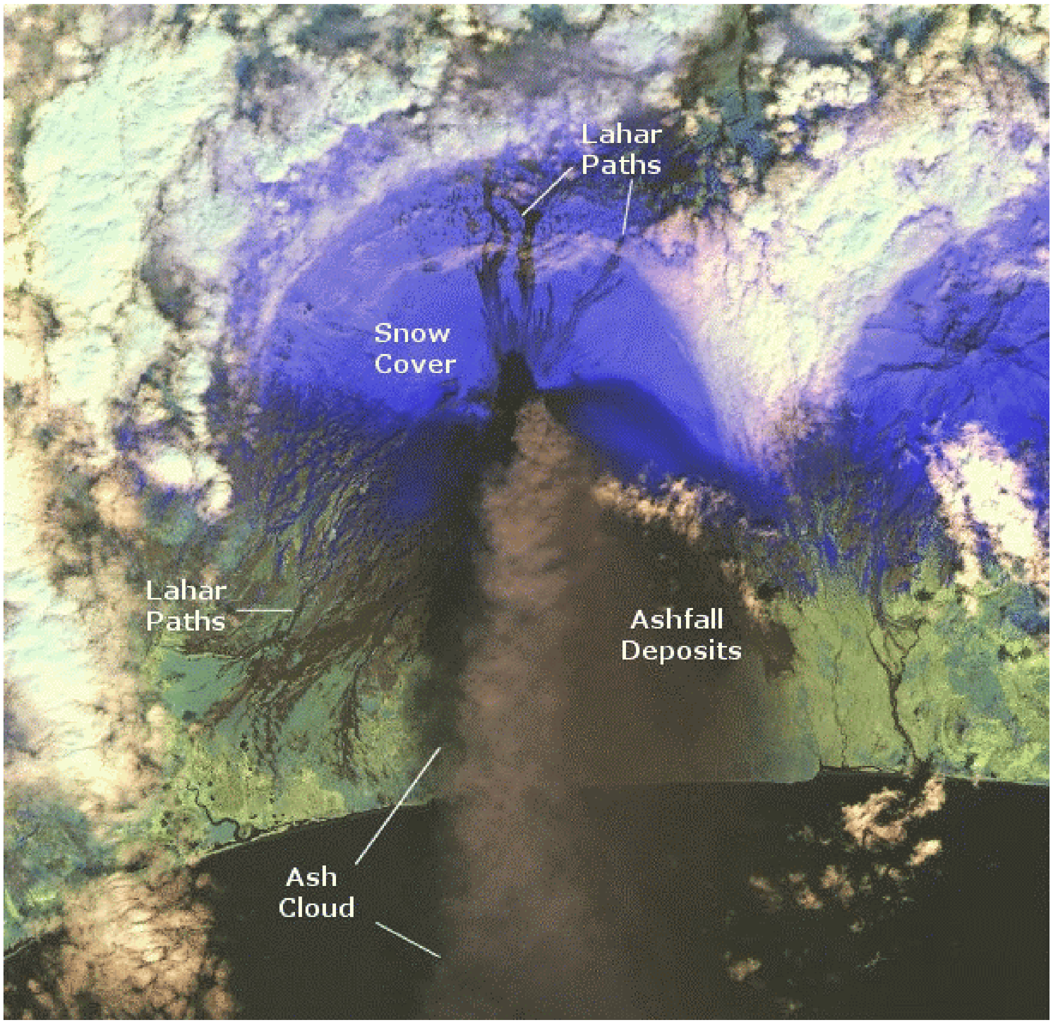
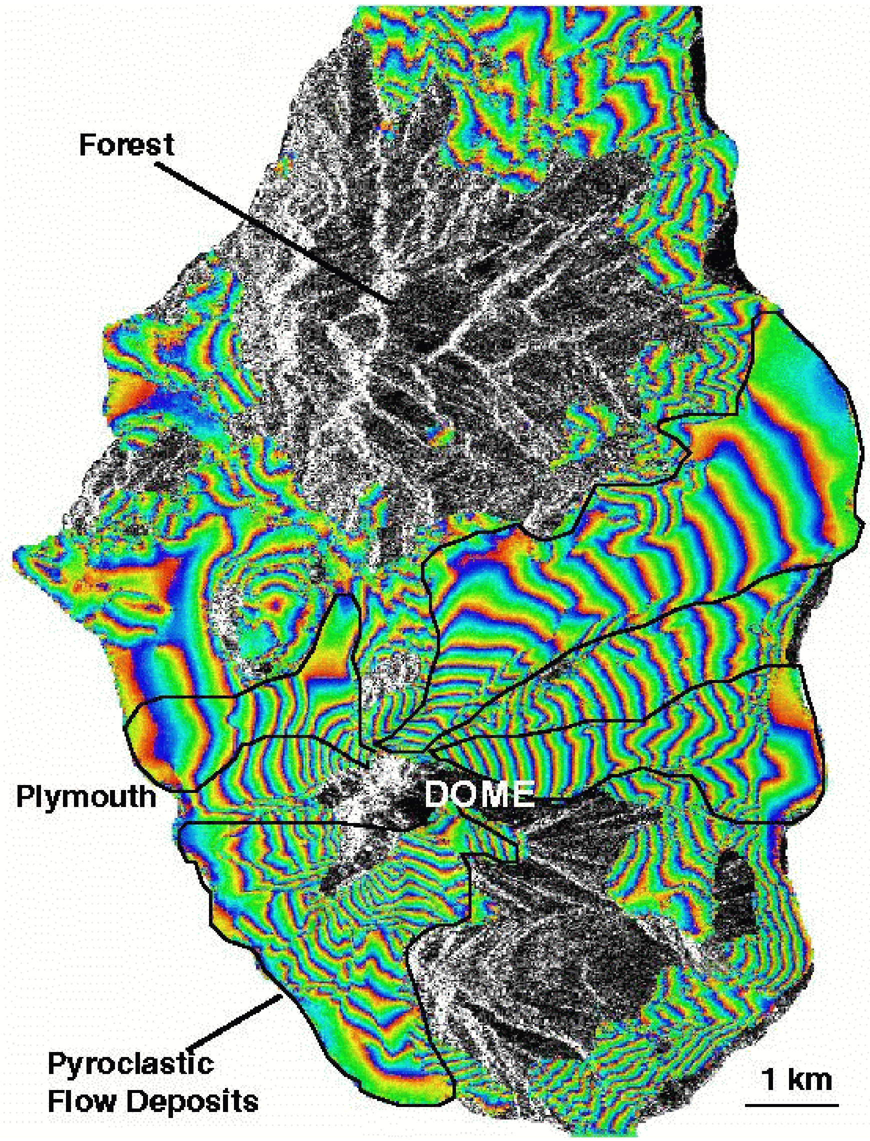


Figure 6. Multi-spectral Landsat image of Shishaldin volcano on May 25, 1999, showing ash-bearing eruption cloud (gray plume at bottom center) and an area of ashfall deposits to the south of the volcano (dark area under gray plume). Lahar pathways in the snow are also visible through light cloud on the north side of the volcano (top center) and to the southwest (lower left). Blue areas indicate snow cover. Image processed and interpreted by D. J. Schneider, USGS. Satellite source: Landsat-7 (false-color image, using bands 7 (2.2 mm), 5 (1.6 mm) and 4 (0.8 mm). North is up.

An example of success in capturing volcanic activity is shown in ***Figure 7*** (next page). This Landsat 7 image of Shishaldin has observed not only an ash plume, but other relatively ephemeral features, such as thin ash deposits and lahar tracks in snow, which can be difficult or impossible to map after the snow melts, or after another season's weather has occurred. The downside of such systems is that, with a 16-day repeat, short events are caught only by chance. Also, at present Landsat 7 and ASTER imagery are not readily available to the relevant volcano observatory in real time.

Figure 7. SAR image (in slant range) of Montserrat during the ongoing eruption of Soufriere Hills Volcano (1995-). The grey tones are amplitude data and the colour is interferometric phase data. In this case the phase has not been corrected for topography so we see the effects of topography as fringes representing about 45m of relief per fringe (blue-green-yellow-red closer to the satellite). The data are from the ERS-1 and -2 C-band SARs (copyright ESA) acquired on 4 and 5 March 1999 respectively. The phase data are lost over this 24 hour period in areas of forest and from part of the growing lava dome. The pyroclastic flow deposits, some of which destroyed Plymouth the main town of Montserrat, are shown in outline. (from Wadge et al 2001)



Data Acquisition Issues

The remotely sensed data used by the VAACs come from operational meteorological satellites, and the data delivery systems needed are already fairly well developed. This is not the case for remote sensing data needed by volcano observatories. The observatories generally need multiple data streams from several satellites, run by different agencies with different data policies, many of which do not have an operational role. Even those observatories that make frequent use of remote sensing imagery acquire their data in an ad hoc fashion, which depends on the initiative of individuals. Academic research groups who are often at some distance from the observatory effort do a considerable proportion of remote sensing work on volcanoes monitored by observatories. For better operational use of remote sensing in volcanology, we will need to get the data to observatories in a more timely and consistent manner. Two possible ways to achieve this would be through either (1) by establishing a global data clearing house system, or (2) by expanded facilities for local data reception.

The role of the clearing house or data center would be to provide a consistent stream of data. There is no "World Volcano Remote Sensing Data Center" that can play this role. However, data delivery could be accomplished via the Internet, or by Internet/communication satellite high-bandwidth routes. A significant advantage to observatories with such a system would be to buffer the observatories from having to deal directly with the individual data providers. The recently established *International Charter for Space and Major Disasters*, co-sponsored by CNES, ESA and CSA, constitutes an alternative approach, but will provide data only under specific, previously defined circumstances (see emergency scenarios in ***Appendix C***).

Local data reception has several aspects that would be attractive to observatories:

- In some locations it is the only way to acquire data (if the observatory is out of range of major ground receiving stations for satellites that do not have substantial on-board storage).
- It maximizes the chance of timely access to data.
- It engenders a sense of local commitment and ownership of the data (equivalent to running a seismic network).

A major inhibitor of local reception is the cost of hardware (e.g. steerable X-band dishes), though this should come down to within the range of observatory budgets in the future. Another factor is that the observatory would have the initial administrative overhead of negotiating bilateral deals with the data providers. Lastly, local reception would in most cases require additional (permanent) staff at the observatory to deal with the data.

Specific monitoring activities:

Hazard Type 1: Thermal monitoring of volcanoes

User level:	Local/National
Disaster management category:	Preparedness/Mitigation
Operational status:	Demonstrated to be useful in restricted circumstances but not in routine operational use.

Volcanic activity introduces heat onto the earth's surface and into the earth's atmosphere, often at temperatures beyond those from other sources, such as wildfires or most human activities. Furthermore, increased surficial heat flow (new steaming cracks, or enhanced activity at existing hot springs and fumaroles) is a recognized precursor to volcanic eruptions. As an example, a thermal anomaly was observed on Mt Etna few days before the opening of one of the new fractures which originated the last strong flank eruption on July 2001 (Di Bello et al. 2002) Accordingly, the potential of satellite-derived thermal imagery of volcanic and geothermal areas has been frequently evaluated (see e.g. Oppenheimer, 1998). Because non-specialists more readily understand thermal images, with appropriate color-coding of pixels, than (for example) most radar imagery, they lend themselves well to public display and discussion. Such products are hence are more likely to be used in disaster response, if freely available, than most other types of satellite-based information currently available.

Volcanic features, which have distinctive thermal characteristics, include: fumarole fields, crater lakes, lava lakes, lava domes, lava flows and pyroclastic flow deposits. However, success in developing remote sensing tools for thermal monitoring of volcanoes has been limited either by inadequate spatial resolution or inadequate temporal resolution of the satellite systems.

<u>Spatial resolution</u> problems arise because extremely hot regions on active volcanoes are usually sub-pixel size for most sensors, even in the visible and SWIR range, but are hot enough to saturate a pixel much larger than the emitting area. Two studies of thermal imagery of Kilauean lava fields

illustrate the problem: Realmuto et al (1992) used airborne TIMS to delineate the thermal anatomy of a lava field at Kilauea, but their success was strongly dependent on the 6m resolution of the imagery, as can be seen by comparing their data with the Landsat image (resolution 30m) of the Kilauean lava field analyzed by Flynn et al (1994).

As for <u>temporal resolution</u>, existing systems with moderate spatial resolution obtain repeat coverage only after many days, a repeat interval which does not permit monitoring of a rapidly developing lava flow or the emplacement of a pyroclastic deposit.

On a more positive note, changes in bulk heat production over large areas, or from a fumarolic field, can be monitored with relatively low resolution, low repeat time, IR imagery. Long-term and emergency monitoring of these targets is possible with AVHRR and the Along Track Scanning Radiometer (ATSR) sensors on the ERS platforms. For example, Wooster and Kaneko (1998) show that combined low (ATSR) and moderately high spatial resolution (TM) SWIR data permit us to monitor the gross heat flux at the surface of an erupting lava dome. The newly available Landsat 7 imagery (resolution 30m and 60m) and ASTER imagery (resolution 30 m and 90m) will be adequate for such broader monitoring, even with the 16-day return time; availability of this imagery may encourage the volcano monitoring community to begin to evaluate it on a more routine basis.

Recently Harris and others (1999) have sought to exploit the high temporal resolution of GOES thermal imagery to monitor rapid-onset hot spots at a selection of volcanoes within the Western Hemisphere. They use bands 1, 2 and 4 of GOES 8 and 10 data to define hot areas on Kilauea, Popcatepetl, Soufriere Hills (Montserrat), and other very active volcanoes. Updated every 15 minutes, the GOES data are processed to give 6 image products per volcano that are posted on the web (http://volcano1.pgd.hawaii.edu/goes/), where they can be picked up by the relevant volcano observatories (the Hawaiian Volcano Observatory for Kilauea; CENAPRED for Popocatepetl and the Montserrat Volcano Observatory for Sourfriere Hills) for detailed inspection, evaluation and use. Sources of noise or data gaps include cloud cover and solar reflection, and the 4km spatial resolution is a major limitation. However, even with these limitations, the data are being used, either to help verify heightened eruptive activity or to disprove an erroneous report.

Hazard type 2: Volcano Topography & Deformation Monitoring with Radar

User level: Local/national
Disaster management Category: Preparedness/mitigation
Operational status: Demonstrated to be useful but not in routine operational use

Radar imagery has great potential for observation and measurement of volcanic activity because of its all-weather and day/night capabilities and its unique ability to measure detailed spatial patterns of surface deformation from space. The principle discouragements from a volcanologist's perspective are the difficulty of processing, expense, and low frequency of radar data. Topography can be supplied by two radar methods: radargrammetry and synthetic aperture radar interferometry (InSAR). Radargrammetry requires two distinctly separate viewpoints. Of the three main SAR satellites available during the 1990's (ERS, Radarsat, JERS) only Radarsat had a steerable angle of view. Unfortunately, the relatively low accuracy (20-30 m rms) and high cost of Radarsat data make this an unattractive option for repeat surveys. A possibility for the future is to use millimetric radar techniques for observing dynamic targets, such as lava domes. These give penetration through clouds to give quantitative ranging information, but can be used to measure temperature as well.

Recent and ongoing experience at trying to monitor the topography and deformation of the eruption at Soufriere Hills Volcano, Montserrat (1995-99) has shown some of the benefits and limits of the currently available data (Wadge et al. 2001). The operational need for mapping the changing topography during dome growth is clear and a frequency of about once a week would be adequate. Equivalent deformation measurement intervals needed are a few weeks. As tested at Montserrat, InSAR proves to be very good at mapping the depth of pyroclastic flow deposits that fill the valleys of a stratovolcano. However, the topographic surface of the lava dome itself, which is a key observational target, is too dynamic to capture using the technique, even with the 1-day separation of ERS-1/-2 interferograms (Wadge et al, 2001).

Space borne differential INSAR has proved to be an excellent new source of deformation information on some volcanoes. Specifically, trans-eruption, hindcast studies of the deformation on basaltic volcanoes or volcanoes at high latitudes have yielded unique results. However, we have as yet no experience in using InSAR to predict anything about a pending eruption. Another difficulty is that the magnitude of the signal can be low, and noise high, particularly where vegetation is abundant. Volcanoes in the tropics are the greatest challenge in this regard. The longer wavelength of L-band radar relative to C-band allows better phase retrievals from forested areas (e.g. Rosen et al., 1996), but there is no L-band satellite currently available. A last problem is that, at present, there is a dearth of any kind of new SAR imagery: only the ERS-2 satellite is still operational, and it is near the end of its life. ENVISAT (to be launched in November 2001) will replace it, but not complement it, as the two have different C-bands.

Recent and ongoing experience at trying to monitor the topography and deformation of the eruption at Soufriere Hills Volcano, Montserrat (1995-99) has shown some of the benefits and limits of the currently available data (Wadge et al. 2001) (Figure 7). The situation will improve as the next generation (2003 -2005) of space borne SAR satellites is launched. These will bring multi-frequency, polarization and angle data to bear on the problem. However, all of these platforms will have long (tens of days) repeat times, giving little direct improvement in the ability to respond rapidly to a new eruption. Also the problem of tropospheric noise from variable water vapor contents (Zebker et al., 1997) has no clear solution in sight. In the longer term (2005 -) the volcanological community should be arguing for (1) space borne single-pass interferometric radar to capture new topography, and (2) repeat-pass L-band radar, to generate a long time series of surface motion data, but with an event response mode with a tasking lead-time of hours to a day or two and complementary tropospheric water vapor mapping.

Hazard Type 3:*   *Gas Plumes

User Level:	Local/national
Disaster Management Category:	Preparedness/mitigation
Operational status:	No appropriate sensors currently operational

The Total Ozone Mapping Spectrometer (TOMS) instrument on Nimbus 7 and now on EarthProbe, even with their very coarse resolution (~40 km at nadir), can measure global scale and distal plume concentrations of SO_2, in conjunction with ozone determinations. At the local scale, many volcano observatories use ground-based remote spectrometry such as COSPEC to measure SO_2 flux, LICOR to measure CO2, and more experimental OP-FTIR instruments to measure other species such as HCl. Space borne measurements at high enough spatial resolution to monitor permanent and evolving SO_2 plumes near the source vents have not been possible, until recently. The value of near-vent monitoring is that (1) it measures primary volcanic flux before broader atmospheric processes complicate the signal, (2) it allows investigation of variations in magmatic gas flux as an eruption precursor, and (3) it documents the spatial and temporal extent of the local air pollution hazard.

The main channel needed for such SO_2 and sulfate mapping is the spectral band centred near 8.5 microns where there is a strong absorption doublet. The first satellite to demonstrate the capability of the 8.5 channel was the OCTS sensor on the short-lived ADEOS platform, which had a spatial resolution of about 700m at nadir. The new MODIS and ASTER sensors on Terra and EO-1 include the 8.5 micron IR band at 1 km (MODIS) and 90 m (ASTER) resolution. These should give us an unprecedented look at tropospheric SO_2 plumes, even at the ASTER revisit interval of 16 days, as data become available and are analyzed by the volcanological community. If these sensors do live up to expectations, they will provide a significant new capability for SO_2 monitoring, allowing evaluation of the effects of long-term (or short-term very high-level) volcanic emissions. These include increased respiratory disease, highly acid rain and vegetation damage from long-lived eruptions and SO2 emissions, such as those at for Kilauea (Sutton et al., 1997). Another strong SO_2 absorption band is centered at 7.3 microns. A 7.3 micron channel is available on MODIS and the GOES Sounder.

Hazard Type 4: ***Mapping for Hazards Assessment***

User Level:	Local/National
Disaster Management Category:	Prevention/preparedness/mitigation
Operational status:	Some sensors newly available; older ones not consistently used

Effective volcanic hazards monitoring and mitigation requires access to high quality topographic data, and easy updating of same. Much can be predicted about where lava or pyroclastic flows and lahars will go, if up-to-date topography can be obtained before an eruption and maintained during an eruption. In the past, topography was normally derived from aerial photography. As satellite systems mature, it may be possible to use stereo satellite imagery, as suggested in the discussion of radar systems above. Stereo viewing is also obtainable from SPOT, at visible wavelengths, and is part of the ASTER package.

Mapping of young volcanic deposits is essential to the evaluation of volcanic hazards at dormant volcanoes. It gives enormous insight into the style of recent activity (even if prehistoric) and offers the best, and often the only, basis for planning for future events. Table 6 summarizes some of the methodology involved, again contrasting ground-based and satellite methods. As with process monitoring, some kinds of information require ground-based studies and actual sampling. However satellite information can help speed the process of mapping the distribution of young volcanic products in rugged terrain.

***TABLE 6**.*
Volcano Proximal Hazard Assessment Methods

Ground-based methods	***Possible satellite sources***
Topographic mapping, traditionally from aerial photography or other airborne sensors	Any high-resolution stereo imagery that can be georegistered accurately enough (SPOT, radar, ASTER panchromatic)
Geologic mapping to determine stratigraphy and character of eruptions, especially prehistoric eruptions	Multi-spectral (e.g. Landsat 7, ASTER) data, which can distinguish units, supplement field work
Radiometric and other dating of young eruptions to establish recent eruptive history of volcano (How young? How frequent?)	-----------

Early work by Kahle et al. (1988) documented that basalt flows of varying ages may be spectrally distinct, depending on the exact condition of the glassy chilled surface, even where there are no compositional differences, but this has not been widely applied to date. The improved resolution of newly available Landsat 7 TM imagery will be extremely important for mapping, and may bring multi-spectral mapping of volcanic rocks into wider use. Lastly, imagery from the experimental Hyperion sensor (resolution 30 m), currently operating on the EO-1 platform, offers an opportunity to evaluate the usefulness of hyperspectral data for mapping in volcanic terrains.

PRODUCTS AND SERVICES: Proximal Hazards

Products for monitoring of proximal volcanic hazards, and for responding to them, are under development in many government agencies and academic institutions. For thermal monitoring the best prototype products available so far are those on the Hawaii Institute of Geophysics (HIG) website. Specific products include images created by subtracting the T4 from T2 in GOES spectral channels (equivalent to T3-T4 for AVHRR data), which show thermal-emitting areas on a selected list of volcanoes. The HIG group also archives integrated radiance data for the hotspots they monitor, which is available by electronic mail to collaborators. The usefulness of the data is limited by the coarse (4km) pixel size of the GOES IR sensor. Other limitations are: (1) only the Western Hemisphere is covered, and (2) data are available only to volcano observatories that have access to the web or electronic mail. However, the simplicity and accessibility of the products has led to their expanding use. Also, the use of a university web site as a prototype public delivery system for volcanic hazards offers a model for distribution of other types of hazard-related satellite data.

Radar studies of dome growth or deformation at volcanoes are still by and large research projects rather than monitoring tools. This reflects limitations of the satellite systems, as well as the high level of computer analysis involved in working with the data. When improved data flow is achieved, however, it is unlikely that interferograms will be the product of choice for presentation to emergency managers and local officials. Shaded relief maps, with areas of inflation or subsidence highlighted in color might have more immediate impact than research-level images. In any case, there is research to be done on how best to communicate these valuable results in a crisis situation.

OBSERVATIONAL REQUIREMENTS: Proximal Hazards

For basic thermal monitoring, the needs in terms of temporal resolution and spatial coverage are well summarized by Harris et al (1999), who recommend:

(1) intervals of 15-30 minutes for image acquisition
(2) multiple IR bands, including the critical mid-IR 3.9 micron band for thermal emission monitoring
(3) more satellite coverage.

They state that five geostationary satellites with the appropriate bands could cover all volcanoes (and wildfire activity) within 55 degrees of the equator. Because several of the next generation geostationary satellites will include the appropriate bands, they anticipate that low-latitude coverage will be achieved. However, to provide equivalent temporal resolution for more northerly regions would require a large number (about 12) of AVHRR-type polar orbiters, which seems less likely to happen.

Beyond more extensive coverage, however, better thermal monitoring of volcanic activity will depend on obtaining better spatial resolution in the IR bands needed: the present 4 km pixel size is too coarse for all but roughest notices of activity. At this resolution we can't unequivocally distinguish between 100 C water and 1100 C lava. Nor can we distinguish between lava flows and wildfires, whether started by volcanic activity or other causes. To really see hot spots, glowing cracks, etc. we need spatial resolution of the order of 10 m, and to track events, we need temporal resolution of the order of 15-30 minutes, as opposed to hours or days. The observational requirements needed for effective monitoring of volcanic thermal signals are very similar to the needs for monitoring the outbreak of wildfires, so sensors that can serve the one hazard will support the other. Dense persistent cloud cover will still thwart our ability to acquire guaranteed regular time-series data.

For radar, the volcanological community should be arguing for (i) a spaceborne single-pass interferometric radar to capture new topography, and (ii) a repeat-pass L-band radar, to generate a long time series of surface motion data — but with a tasking lead-time of hours to a day or two and complementary tropospheric water vapor mapping. InSAR monitoring of deformation associated with earthquakes has much the same observational requirements as that for monitoring deformation at volcanoes, so, as with wildfires, improvements directed at one hazard will support monitoring of another.

RECOMMENDATIONS: Proximal Hazards

Space Agencies:

- Provide information on types of products available, and how to obtain them, on web sites directed at volcano observatories and volcanology researchers. Language protocol as for ICAO.
- Establish mechanisms for expedited access to data and tasking authority for volcanic crises (especially for radar acquisitions), such as the new *Internatianal Charter*.
- Volcanic hotspot monitoring and (and wildfire detection) both need certain IR bands (2.2, 3.9, 11 microns) at high temporal and spatial resolution. These bands should be included on all future geostationary satellites.
- More SAR satellites, with higher resolution, design characteristics optimized for InSAR, plus L-band capability

- Improved SO_2 monitoring, especially SO_2 plumes at low elevations, requires the 7.3 and 8.5 micron band at high (~100 m) spatial resolution.
- Configure orbits for high resolution, low earth orbit (LEO) imaging satellites to reduce revisit times to less than 3 days.

CEOS:

- Assemble information on how to task various satellites and packages (e.g. GOES, ASTER) and post on the CEOS Volcanic Hazards web page, with layout organized for volcanologists.
- Expand education/training in the use of remote sensing information for all components of the volcanological community through workshops (e.g. at IAVCEI meetings).
- Create a standing committee on Volcanic Hazards Detection.
- Establish a liaison with the IAVCEI Remote Sensing Commission, following up on initial contact made at the July 2000 IAVCEI meeting in Bali.

Areas for Further Research and Development:

- Develop delivery systems for products based on remote sensing data that make information available to the volcano monitoring community. The GOES "hotspot" website of the University of Hawaii offers a possible prototype.
- Develop products that communicate information simply and effectively to non-specialists, and standardize those products (e.g. for radar imagery).
- Produce high-resolution DEM's for all active volcanoes in populated areas as data becomes available.
- Investigate, evaluate and link satellite observations for change detection (all kinds) at a volcano over the course of a cycle of volcanic activity.
- Identify means of evaluating edifice stability using remotely sensed data, including evaluation of data from the Hyperion sensor.
- Develop techniques for automatic detection of volcanic eruptions with as low a false alarm rate as possible (optimally <5%).
- Develop techniques for automatic edge detection of ash clouds every 30 minutes.
- Develop alternative sources of 12.0 micron IR data or additional multi-spectral techniques to ameliorate loss of this channel on GOES from 2002 to 2010 (or so) (Viable alternatives include: the GOES sounder and AVHRR).
- Initiate research on the minimum concentrations of volcanic ash detectable by satellites.
- Investigate the utility of new high resolution land surface imagers (e.g., ASTER, Landsat TM7) for providing information on eruption precursors (thermal anomalies), and supplemental information on the characteristics of eruption plumes (as anticipated by Pieri et al., 1995; Andres and Rose, 1995).
- Encourage the development of volcano observing sensors in the millimetric part of the spectrum, where combined topography and thermal signals can be retrieved.

** Last but not least: the most difficult target of investigation, for ground-based observers and remote sensing techniques alike, is the eruption column, that is, the dense, usually opaque, vertical column of a large phreatic or major plinian eruption. Wen and Rose (1994) give an impressive list of aspects of volcanic columns (and plumes) for which further research and technique development (e.g. Doppler radar systems) is needed.

FUTURE SATELLITE SYSTEMS

Meteorological Satellites

Newly-launched and planned geostationary and polar satellite systems will result in overall improvements in our ability to monitor volcanic ash, except in the Western Hemisphere. A summary of these spacecraft, the sponsoring agencies, number of channels, and resolutions are shown in Appendix A.. The replacement for GMS (MTSAT) and the METEOSAT Second Generation (MSG) will both have shortwave IR (3.9 micron), and split window IR (12.0 micron) with a nadir resolution of 4 km and 5 km, respectively. MSG will also have 7.3 and 9.0 micron channels that could be useful for monitoring SO_2 concentrations. An advanced imager is being planned for GOES (circa 2008) that will have as many as twelve spectral bands (including 3.9, 12, and possibly 8.5 micron wavelengths) at higher temporal (5-15 min full disk) and spatial resolutions (2 km IR, 0.5 km visible).

Data from an Advanced Interferometric Radiometric Sounder (AIRS) and MODIS are now available from NASA's Earth Observation System (EOS). MODIS has 36 spectral channels, including the shortwave IR (3.9 micron) and thermal IR bands (7.3, 8.5, 11, 12 micron) needed for volcano monitoring, but will be available at a given location only every 1-2 days. Polar satellite coverage will be enhanced with the European ENVISAT (projected launch date June 2001), which has a near clone of the AVHRR, the European METOP (2002) with SO_2 detection capabilities, and Japan's sophisticated ADEOS-II, a thirty-nine channel, high resolution imager.

One major weakness of the future global satellite network with respect to volcano monitoring is the loss of the "split window" (12.0 micron) channel on all GOES spacecraft launched from 2001 until around 2008. That channel will be replaced by a 13.3 micron CO_2 absorption band at 8 km resolution, to be used for more accurate height assessment of wind vectors and cloud tops by means of a "CO_2 slicing" technique (Menzel et al 1983). Preliminary research has indicated that the 13.3 micron band could have some utility in discriminating volcanic ash from thin cirrus (Ellrod, 2001). The 13.3 mm IR band may also result in more accurate height estimates for thin ash clouds. GOES-11, the replacement for GOES-8, was launched in May, 2000, tested, and is being stored on orbit.

There is a possibility that UV data in several channels (10 km resolution, 15 minute frequency) could be included in a future GOES spacecraft as part of a "Coastal Zone Remote Sensing Instrument" that would also produce "ocean color" imagery for monitoring coastal eco-systems. Alternative sources of appropriate IR data for the Western Hemisphere include the GOES sounder (available only at low and mid latitudes), and AVHRR and similar packages on polar-orbiting satellites (at 2-6 hour intervals depending on latitude). The GOES sounder has lower spatial resolution (10 km) and its temporal frequency is hourly at best, so this is considered a less desirable alternative. A recent study (Ellrod, 1999) describes this capability in more detail, and shows that the area coverage of volcanic ash will be underestimated in some situations.

Regardless of the alternative strategies derived, there will be some degradation of our ash monitoring capabilities in the Western Hemisphere during the period with the loss of the split window IR band on GOES.

Earth Observation Satellites

Monitoring of proximal volcanic hazards depends in part on the meteorological satellites, but also uses a broader range of low-earth-orbit imaging systems. New systems available now include Landsat 7, with 7 bands (resolution 30-60 m nadir) plus a higher-resolution panchromatic sensor. NASA's recently launched TERRA satellite has, in addition to MODIS (discussed above), the ASTER package, developed by Japan, which has 14 channels, including short wave IR (2.2, 3.9 micron) and longwave thermal IR bands (8.5, 11, 12 micron) needed for volcano monitoring. The ASTER package includes stereo panchromatic images for each frame, which can be used to generate a DEM if desired. A limitation of both Landsat and ASTER is that their revisit time is 16 days. The new EO-1 satellite also includes an experimental hyperspectral package (Hyperion).
Panchromatic data with 1-m resolution is currently available from the new IKONOS satellite, but cost and tasking of this commercial system remain problematical even for emergency response, much less monitoring, where a time series of images is usually desirable. Another relatively high resolution system would appear to be CSA's EROS-1.

Important research systems to be launched soon are: AQUA (to be launched in December 2001) as a companion to TERRA, and ENVISAT (projected launch date November 2001). ENVISAT capabilities include C-band radar and the MERIS multispectral package. More radar satellites are planned for somewhat farther in the future, including the Japanese ALOS satellite (L-band radar, to be launched in 2003) and Radarsat II (same C-band as Radarsat I, but intended to have characteristics that will allow production of images suitable for interferometric SAR) which has a planned launch date of April 2003. Additional multispectral packages of some interest include AMSR and GLI on ADEOS II. ALOS will also house a panchromatic stereo imager (PRISM) with a resolution of 2.5 m, and SPOT 5 will have a 3 m resolution pan capability. Lastly, CNES will launch the experimental DEMETER system, to monitor pulses in the earth's electromagnetic field, to see if such phenomena are associated with events such as earthquakes and volcanic activity.

Proposed Volcanic Hazards Scenarios

Hazardous volcanic activity poses a threat to people and property. Unlike most other natural hazards, the damage inflicted by volcanoes can be significantly mitigated if volcanic behavior is assessed rapidly, as dangerous situations develop. Satellite imagery can provide useful information if available to the right people, and in a timely manner. Therefore we propose the following four scenarios. Each is slightly different, as follows:

Scenario #1
In this scenario, the trigger for a request for assistance would be that an eruption has been reported at a volcano where there is some prospective danger to people and infrastructure on the ground. This scenario supposes that only the current assets of member agencies are available. It is further assumed that any danger posed by an ash cloud to aircraft or airport operations will be handled through the existing VAAC/MWO network.

Scenario #2
The trigger for this kind of request for assistance would be that there is major volcanic unrest reported at a volcano which is normally dormant, and where an eruption would pose danger to people and infrastructure on the ground. It is assumed that any of the satellites listed in Appendix A will be available for tasking through the *Internatianal Charter* at some point in the future.

Scenario #3
The trigger for this request for assistance would be that, at a volcano where a long-term eruption has been occurring, there is (1) evidence for a change in behavior to a more dangerous kind of eruption or (2) the build-up of unstable deposits on steep slopes has created a large-scale lahar/debris flow hazard. Again, populated areas or significant infrastructure must be at risk; as in Scenario #2, we assume any satellite listed in Appendix A will be available.

Scenario #4: Volcanic Ash Scenario
The trigger for a request for assistance would be that an eruption has occurred, and has produced a significant ash cloud, resulting in danger to aircraft in flight or in the vicinity of airports. Alerting will be handled through the existing VAAC/MWO network, and the imagery acquired would need to be directed accordingly.

Two other general recommendations for all four scenarios:

Value added processing of imagery or data for scenarios 1-3
Desirable additional processing includes:
1. Feature labeling, north arrow on imagery desirable if user not the responsible volcano observatory, or if there is no observatory with prior experience for the particular volcano
2. DEM from stereo radar or other stereo imagery, if modern topography not available for the volcano
3. Temperature estimate(s) from IR data

Value added processing of imagery or data for scenario 4
Desirable features include:

1. Feature labelling (e.g., edge of visible ash cloud, north arrow) on imagery desirable if user not the responsible volcano observatory or VAAC
2. Cloud top height estimates based on temperatures from IR data, cloud shadow length from visible data

Data delivery mechanism, all scenarios:
The Project Manager will need to ask the end user what will work (ftp, Internet, courier, etc). It may be that derived information FAXed to the observatory may be the fastest means of communication in the absence of adequate electronic connections.

Proposed Volcanic Hazard Emergency Scenario #1:

Obtain background information		***Check if considered***
1.	Name of volcano and its location (latitude, longitude)	
2.	Date(s) of the eruption(s) that have occurred so far	
3.	Responsible volcano observatory, if any; nature of ground-based monitoring being done for the particular volcano, if any	
4.	Location of nearby urban centres if any; otherwise an estimate of population near the volcano (within a radius of 20 km)	
5.	Location of major air routes near the volcano, identity of responsible VAAC	
6.	Location of roads, airports, factories, mines, etc.	
7.	Previous history of this volcano: frequent small eruptions vs. rare large eruptions? Explosive vs. non-explosive?	
8.	Potential role of water: Is there a lake in the crater or caldera? Is the volcano on the coast? Are there major rivers, lakes, reservoirs, etc nearby?	
Obtain current and future status of volcanic eruption		
1.	Location of vent area, if not at summit location given above	
2.	Type of eruption(s) so far: ash column? Lava flow or dome? Ash or pyroclastic flow? Lahar or mudflow?	
3.	Seismicity: are there felt earthquakes? Is seismicity increasing?	
4.	Deformation/ground cracking observed?	
5.	New/enhanced steaming or sulfur emission or hot spring activity?	
6	Weather near the volcano (cloud cover, wind profile, etc)	
7	Potential/Expected/Future affected zone as eruption continues	
Priorities for image planning		
1.	SPOT, standard product, plus especially IR data	
2.	Radarsat (fine mode, 4). Because of steep topography, need high graze angle to reduce shadowing and layover (> 35 degrees)	
3.	ERS, especially to try to duplicate earlier orbital parameters if archival imagery exists, for possible InSAR analysis (otherwise, parameters as for Radarsat)	
4.	Search archives all systems for possible pre-eruption imagery, for visual comparisons, and (for ERS) for potential InSAR	

Proposed Volcanic Hazard Emergency Scenario #2:

Obtain background information		***Check if considered***
1.	Name of volcano and its location (latitude, longitude)	
2.	Date(s) of the beginning of unrest	
3.	Nature of unrest (seismic, ground cracking, increased fumarolic activity, etc.) and how much it deviates from normal (dormant) behavior	
4.	Responsible volcano observatory, if any; nature of ground-based monitoring being done for the particular volcano, if any	
5.	Location of nearby urban centres if any; otherwise an estimate of population near the volcano (within a radius of 20 km)	
6.	Location of major air routes near the volcano, identity of responsible VAAC	
7.	Location of roads, airports, factories, mines, etc.	
8.	Previous history of this volcano: frequent small eruptions vs. rare large eruptions? Explosive vs. non-explosive?	
9.	Potential role of water: Is there a lake in the crater or caldera? Is the volcano on the coast? Are there major rivers, lakes, reservoirs, etc nearby?	
Obtain current status of volcanic unrest and potential for an eruption		
1.	Location of probable vent area, if not at summit location given above	
2.	Any small phreatic explosions? Dirty areas on snow even if no activity directly observed? Landslides or rockfall beyond what is normal?	
3.	Seismicity: are there felt earthquakes? Is seismicity increasing?	
4.	Deformation/ground cracking observed?	
5.	New/enhanced steaming or sulfur emission or hot spring activity? Areas of vegetation kill? Loss of usual snow cover?	
6	Weather near the volcano (cloud cover, wind profile, etc)	
7	Potential/Expected/Future affected zone if eruption occurs	
Priorities for image planning		
1.	Moderate to high-resolution visible imagery, standard product, plus IR data	
2.	Best-resolution C-band SAR imagery. both for visual analysis and for InSAR. If there is steep topography, will need high graze angle to reduce shadowing and layover (> 35 degrees) (ENVISAT, RADARSAT-2)	
3.	If areas of concern are vegetated (especially in tropics) L-band SAR, as available, for InSAR evaluation of deformation patterns	
4.	Search archives all systems for possible pre-eruption imagery, for visual comparisons, and for potential InSAR	

Proposed Volcanic Hazard Emergency Scenario #3:

	Obtain background information	**Check if considered**
1.	Name of volcano and its location (latitude, longitude)	
2.	Date(s) of the eruption(s) that have occurred so far	
3.	Responsible volcano observatory, if any; nature of ground-based monitoring being done for the particular volcano, if any	
4.	Location of nearby urban centres if any; otherwise an estimate of population near the volcano (within a radius of 20 km) . Towns built on lahars?	
5.	Location of major air routes near the volcano, identity of responsible VAAC	
6.	Location of roads, airports, factories, mines, etc.	
7.	Previous history of this volcano: Long eruptions, or multistage eruptions, that become more explosive in the later stages? Does it have deposits of large pyroclastic flows or lahars that have traveled long distances?	
8.	Potential role of water: Is there a lake in the crater or caldera? Is the volcano on the coast? Are there major rivers, lakes, reservoirs, etc nearby?	
	Obtain current and future status of volcanic eruption	
1.	Location of vent area, if not at summit location given above	
2.	Type of eruption(s) so far: Lava flow or dome? Any ash or pyroclastic flows? Thickness of accumulated ash? Any estimates of volume?	
3.	Seismicity: are there felt earthquakes? Is seismicity increasing?	
4.	Any new or increased deformation/ground cracking observed?	
5.	New/enhanced steaming or sulfur emission or hot spring activity?	
6	Weather near the volcano (cloud cover, wind profile, etc). Is there a predictable rainy season that is imminent?	
7	Potential/Expected/Future affected zone for severe eruption? Maximum possible lahar run-out distances?	
	Priorities for image planning	
1.	Moderate to high-resolution visible imagery, standard product, plus IR data	
2.	Best-resolution C-band SAR imagery, both for visual analysis and for InSAR. Because of steep topography, need high graze angle to reduce shadowing and layover (> 35 degrees) (ENVISAT, RADARSAT-2)	
3.	If areas of concern are vegetated or covered by ash or other material unstable on a small scale, L-band SAR, as available, for possible InSAR	
4.	Search archives all systems for possible pre-eruption imagery, for visual comparisons, and for potential InSAR	

Proposed Volcanic Ash Cloud Scenario #4:

	Obtain background information	**Check if considered**
1.	Name of volcano and its location (latitude, longitude)	
2.	Date(s) and time(s) of the eruption(s) that have occurred so far	
3.	Responsible volcano observatory, if any; nature of ground-based monitoring being done for the particular volcano, if any	
4.	Locations of major air routes, identity of responsible VAAC	
5.	Locations of airports	
6.	Potential role of water: Is there a lake in the crater or caldera? Is the volcano on the coast? Are there major rivers, lakes, reservoirs, etc nearby?	
	Obtain current and future status of volcanic ash cloud	
1.	Type of eruption(s) so far: ash column? Lava flow or dome? Ash or pyroclastic flow? Lahar or mudflow? Suspected water/ice content of ash cloud?	
2.	Cloud coverage near the volcano	
3.	Predicted ash movement from trajectory models (VAFTAD, CANERM, PUFF, etc)	
4.	Strength and direction of winds aloft (from radiosonde, profiler, model or aircraft)	
	Priorities for image planning	
1.	Operational geostationary satellite images (visible, IR) and derived products (e.g. split window) (GOES, METEOSAT, GMS) at 30 minute intervals	
2.	Operational polar orbiting satellite images and derived products (AVHRR, FY1-C)	
3.	Research polar orbiting satellite images and derived products (EOS Terra, Aqua, EP-TOMS, etc)	
4.	High resolution images (visible, near-IR, IR) from land use satellites (Landsat, SPOT)	

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CITATIONS

Andres, R. J., and W. I. Rose, 1995: Description of thermal anomalies on two active Guatemalan volcanoes using Landsat Thematic Mapper imagery. *Photogrammetric Engineering and Remote Sensing*, Vol. 61, 775-782.

Casadevall, Thomas J., 1992: Volcanic hazards and aviation safety: Lessons of the past decade. Aviation Safety Journal, Vol. 2, No. 3, Federal Aviation Administration, Washington, DC

Crisp, J., 1995: Volcanic SO2 Alert. EOS IDS Volcanology Team, Data Product Document, Product #3288, Jet Propulsion Laboratory, California Inst. of Tech., Pasadena, California, 13 pp.

Delene, D. J., W. I. Rose, and N. C. Grody, 1996: Remote sensing of volcanic ash clouds using special sensor microwave imager data. *J. Geophysical Research*, Vol. 101, 11,579-11,588.

Ellrod, G. P., 1999: The use of GOES sounder imagery for the detection of hazardous volcanic ash plumes. *National Weather Digest*, Vol. 22, 3-9.

__________ and B. Connell, 1999: Improvements in volcanic ash detection using GOES multi-spectral image data. Preprints, 8th Conf. On Aviation, Range, and Aerospace Meteorology, 10-15 January 1999, Dallas, Texas, 326-329.

__________, 2001: Loss of the 12 micrometer "Split Window" band on GOES-M: Impacts on volcanic ash detection. Preprints, 11th Conference on Satellite Meteorology and Oceanography, 15-18 October 2001, Madison, Wisconsin, American Meteorological Society, Boston.

Flynn, L.P., Mouginis-Mark, P.J., Horton, K.A., 1994, Distribution of thermal areas on an active lava flow field: Landsat observations of Kilauea, Hawaii, July 1991, *Bull. Volcanology*, Vol. 56, p 284-296.

Francis, P.W., Wadge, G., and Mouginis-Mark, P.J., 1996, Satellite monitoring of volcanoes. In Scarpa, R., and Tilling, R.I., eds., <u>Monitoring and Mitigation of Volcano Hazards</u>: Springer-Verlag, New York, pp. 257-298.

G. Di Bello, C. Filizzola, T. Lacava, F. Marchese, N. Pergola, C. Pietrapertosa, S. Piscitelli, I. Scaffidi, V. Tramutoli, 2002, Robust satellite techniques for volcanic and seismic hazards monitoring, Proceedings of the International Workshop on Geo-Electro-Magnetics, September 2001, Lerici – Italy (to appear on Annali di Geofisica, special issue, 2002)

Glaze, L.S., L. Wilson, and P.J. Mouginis-Mark, 1999, Volcanic eruption plume top topography and heights as determined from photoclinometric analysis of satellite data. *J Geophysical Research* Vol. 104, p 2989-3001.

Harris, A.J.L., L. P. Flynn, K. Dean, E. Pilger, M. Wooster, C. Okubo, P.J. Mouginis-Mark, H. Garbeil, C. Thornber, D Rothery, and R. Wright, 1999, Real.-time Monitoring of Volcanic Hot Spots with Satellites, in P.J. Mouginis-Mark, L. Glaze, and J. Fink, eds., <u>Remote Sensing of Volcanoes</u> : AGU Special Monograph, in press.

Heffter, J. L., and J. B. Stunder, 1993: Volcanic Ash Forecast Transport And Dispersion (VAFTAD) Model. Weather and Forecasting, 8, 533-541.

Holasek, R. E., and S. Self, 1995: GOES weather satellite observations and measurements of the May 18, 1980, Mount St. Helens eruption, *J. Geophysical Research*, Vol. 100, 8469-8467.

Holasek, R. E., S. Self, and A. W. Woods, 1996: Satellite observations and interpretation of the 1991 Mount Pinatubo eruption plumes. *J. Geophysical Research*, Vol. 101, 27,635-27,655.

Joiner, J., and P. K. Bhartia, 1995: The determination of cloud pressures from rotational Raman scattering in satellite backscatter ultraviolet measurements. *J. Geophysical Res.*, Vol. 100, 23,019-23,026.

Kahle, A.G., A. R. Gillespie, E.A. Abbott, M.J. Abrams, R. E. Walker, G. Hoover, and J. P.

Lockwood, 1988, Relative Dating of Hawaiian Lava Flows Using Multispectral Thermal Intrared Images: A New Tool for Geologic Mappig of Young Volcanic Terranes, *J. Geophysical Research*, Vol. 93, pp. 15239-15251.

Krotkov, N.A., Torres, O., Seftor, C. Drueger, A.J., Kostinski, A., Rose, W.I. Bluth, G. J. S., Schneider, D. J., and Schaefer, S. J., 1999, Comparison of TOMS and AVHRR volcanic ash retrievals from the August 1992 eruption of Mt. Spurr. *Geophysical Research Letters*, Vol. 26, p 455-458.

Krueger, A.J., L.S. Walter, P.K. Bhartia, C.C. Schnetzler, N.A. Krotkov, and G.J. S. Bluth, 1995, Volcanic sulfur dioxide measurements from the total ozone mapping spectrometer, *J. Geophysical Research*, Vol. 100, 14057-14076.

__________, and A. V. Diaz (Ed.), 1998: VOLCAM - A critical natural hazards research mission. Proposal for NASA Earth Science System Pathfinder Program. Goddard Space Flight Center, Greenbelt, Maryland.

Lunnon, R. W., McNair, I.J., 1999: Development of an Automatic Satellite Volcanic Eruption Detection System, for En-route Aviation, Preprints, Eighth Conference on Aviation, Range, and Aerospace Meteorology, 10-15 January 1999, Dallas TX, pp 318-321.

Menzel, W. P., W. L. Smith, and T. R. Stewart, 1983: Improved cloud motion wind vector and altitude assignment using VAS. J. Climate Appl. Meteor., 22, 377-384.

Newhall, C.G. and Punongbayan,R.S., 1996, The narrow margin of successful volcanic-risk mitigation. In Scarpa, R. And Tilling R.I., eds., Monitoring and Mitigation of Volcano Hazards: Springer-Verlag, New York, pp. 807-838.

Oppenheimer, C., 1998. Volcanological applications of meteorological satellites. *Int.J. Remote Sensing*, 19, 2829-2864.

Pergola, N., Pietrapertosa, C., Lacava, T., Tramutoli, V., 2001, Robust satellite techniques for monitoring volcanic eruptions. Annali di Geofisica, Vol. 44, N. 2, 167-177.

Pieri, D. C., J. Crisp, and A. B. Kahle, 1995: Observing volcanism and other transient events with ASTER. *J. Remote Sensing Soc. Of Japan*, Vol. 15(2), 56-61.

Prata, A. J., 1989: Observations of volcanic ash clouds in the 10-12 micrometer window using AVHRR/2 data. *Int. J. of Remote Sensing*, Vol.10, Nos. 3 and 4, 751-761.

_________, and I. F. Grant, 2001: Determination of mass loadings and plume heights of volcanic clouds from satellite data. CSIRO Technical Paper 48, CSIRO Dept. of Atmospheric Science, Melbourne, Australia, 39 pp. (available only at: http://www.dar.csiro.au/publications/Prata_2001a.pdf)

Pudykiewicz, J., 1988 : Numerical Simulation Of The Transport Of Radioactive Cloud From The Chernobyl Nuclear Accident. *Tellus,* 40B, 241-259

Realmuto, V.J., Sutton, A.J., and Elias, T., 1997, Multispectral thermal infrared mapping of sulfur dioxide plumes: a case study from the East Rift Zone of Kilauea Volcano, Hawaii: J. of Geophy. Res., Vol. 102, no. B7, 15,057-15,072.

_______________, Hon, K., Kahle, A.B., Abbott, E.A., and Pieri, D.C., 1992, Multispectral thermal infrared mapping of the 1 October 1988 Kupaianaha flow field, Kilauea volcano, Hawaii, *Bull. Of Volcanology*, Vol. 55, p 33-44.

Rose, W.I., Delene, D.J., Schneider, D.J., Bluth, G. J. S., Krueger, A. J., Sprod, I., McKee, C., Davies, H.L. and Ernst, G.G. J., 1995, Ice in the 1994 Rabaul eruption coloud: implications for volcano hazard and atmospheric effects. *Nature* Vol. 375, p 477-479.

Rosen, P.A., Hensley, S., Zebker, H.A., Webb, F.H. and Fielding, E.J. 1996. Surface deformation and coherence measurements of Kilauea Volcano, Hawaii, from SIR-C radar interferometry. *J. Geophys. Res.*, Vol. 101, 23109-23125.

Schneider, D.J., W.I. Rose, and L. Kelley, 1995, Tracking of 1992 eruption clouds from Crater Peak vent, Mount Spurr Volcano, Alaska, using AVHRR, in T.E.C. Keith (ed.) The 1992 eruptions of Crater Peak Vent, Mount Spurr Volcano, Alaska. *U.S. Geological Survey Bulletin* 2139, 27-36.

Seftor, C.J., N.C. Hsu, J.R. Herman, P.K. Bhartia, O. Torres, W.I. Rose, D.J. Schneider, and N. Krotkov, 1997, Detection of volcanic ash clouds from Nimbus 7/ total ozone mapping spectrometer. *J. Geophysical Research*, Vol. 102, 16749-16759.

Sutton, J., T. Elias, J.W. Hendley II, and P. H. Stauffer, 1997, Volcanic Air Pollution--A Hazard in Hawaii. U.S. Geological Survey Fact Sheet 74-97.

Wadge, G., Scheuchl, B., and Stevens, N.F. (2002) Space borne radar measurements of the eruption of Soufriere Hills Volcano , Montserrat., In Druitt, T.H. and Kokelaar, B.P. (eds.) The Eruptions of Sourfriere Hills, Volcano, Montserrat from 1995 to 1999. Geological Society, London, Memoir, (in press).

Wen, S. And Rose, W.I., 1994, Retrieval of particle sizes and masses in volcanic clouds using AVHRR bands 4 and 5. *J. Geophys. Research* Vol. 99, pp. 5421-5431.

Wooster,M.J. and Kaneko,T. 1998. Satellite thermal analyses of lava dome effusion rates at Unzen Volcano, Japan. *J. Geophys. Research,* 103, 20935-20947.

WOVO (1997) Directory of Volcano Observatories, 1996-1997, Eds. Netter, C. And Cheminee, J.-L., published by WOVO/IAVCEI/UNESCO, Paris, 268 pages.

Zebker, H.A., Rosen, P.A. and Hensley, S. 1997. Atmospheric effects in interferometric synthetic aperture radar surface deformation and topographic maps. *J. Geophys. Res.*, Vol. 102, 7 547-7563.

Appendix A. Present and Future Satellites and Sensors Useful for Volcanic Hazards

I. ***Satellites currently in operation***	***Agency***	***Channels (m)***	***Resolution (best)***
Geostationary meteorological satellites			
GOES-8,10	NOAA	0.6, 3.9, 6.7,10.7, 12.0	4 km
GMS-5	NASDA	0.7, 6.9, 11.0, 12.0	5 km (1.25 vis)
MeteoSAT	EUMETSAT	0.7, 6.3, 11.5	5 km (2.5 vis)
Polar-orbiting meterological satellites			
NOAA-12, 14, 15, 16, 17 (AVHRR)	NOAA	0.6, 0.9, 3.9, 10.7, 12.0	1 km
Other polar-orbiting satellites			
Earthprobe TOMS	NASA	6 uv bands	39 km
Landsat 7	NASA/USGS	7 vis/IR + pan	15, 30 m
TERRA (MODIS)	NASA (MODIS, MISR)	36 vis/IR bands	1 km
(ASTER)	METI (Japan)/NASA	14 vis//IR	15-90 m
EO-1 (ALI)	NASA	9 vis/IR + pan	10, 30 m
(Hyperion)	NASA	Hyperspectral	30 m
AQUA (MODIS)	NASA	Same as on Terra	1 km
RADARSAT-1	CSA	C band	6-8 m
ERS-2	ESA/CNES	C band (+ ATSR)	30 m (1 km ATSR)
ENVISAT (ASAR)	ESA	C band	30 m
(AATSR)		2 vis, 1.6, 3.7, 10.7, 12	500 m
IRS-P4	ISRO	8 vis/NIR bands	250 m
SPOT 4	CNES	Visible, 0.9,1.6	10-20 m
SPOT 5	CNES	6 vis/NIR + pan	5-10 m (3 m pan)
IKONOS	Space Imaging	panchrmtic., multispctr.	1 m, 4 m
QuickBird2	DigitalGlobe	panchrmtic., multispctr.	61 cm, 2.44 m
EROS-1	CSA	visible panchromatic	1.8 m

II. Satellites to be brought on line/ launched	***Agency (Launch date)***	***Channels***	***Resolution (best)***
Geostationary meteorological satellites			
GOES-11	NOAA (in orbit)	0.6, 3.9, 6.7, 10.7, 12.0	4 km (1 km vis)
GOES-12	NOAA (in orbit)	0.6, 3.9, 6.7, 10.7, 13	4 km (1 km vis)
MeteoSAT Second Generation (SEVIRI)	EUMETSAT (mid-2002)	12 vis/IR bands	5 km (1 km vis)
MTSat-1R	NASDA (early 2003)	0.7, 3.7, 6.7, 10.7, 12	4 km (1 km vis)
Polar-orbiting meteorological satellites			
NOAA-17 (AVHRR) and others	NOAA (in orbit)	same as NOAA-15, 16	1 km
Other polar-orbiting satellites			
ICESat	NASA (Dec. 2002)	Laser altimeter	(532 nm, 1064 nm)
RADARSAT-2	CSA (2003)	C band-radar	3 m
ALOS (PALSAR)	NASDA (FY2003)	L band radar	10-100 m
(PRISM)		Stereo panchromatic	2.5 m
EROS 2-4	CSA	Panchromatic	1.8 m
ADEOS II (AMSR, GLI)	NASDA (Nov. 2002)	39 vis/IR bands	250 m-1 km
DEMETER (electromagnetic pulses)	CNES (early 2003)	Non-imaging	

APPENDIX B: VOLCANIC HAZARDS QUESTIONNAIRE

In early 2000, the Volcanic Hazards group decided it might be informative to send a questionnaire to individual volcano observatories regarding their use of satellite imagery, in response to eruptive activity. The observatories chosen had all seen and responded to volcanic activity in the preceding 2 years, so there were actual, recent events in which satellite imagery or satellite-derived information could have been used. The table below shows the list of volcanoes and summarizes the types of activity they had exhibited.

The format of the questionnaire was as follows:

REMOTE SENSING SURVEY

The following questions concern your observatory's use of remotely sensed data from civilian or commercial sources only:

1. Has your observatory used remotely sensed (satellite/airborne) data to monitor volcanoes? If so, what type of data was used?

2. During the recent activity of (name) volcano, has remotely sensed data been used and if so, of what type (e.g. meteorological satellites, Landsat, radar, aerial photography) and for what purpose?

3. Is your use of remotely sensed data limited by:

   Lack of knowledge/expertise

   Scientific value of the available data/

   Cost?

   Timeliness of reception/processing?

4. What type of remotely sensed data would you like to obtain that you do not now?

5. Other comments:

In each case the questionnaire was sent, not solely to the observatory, but to an individual contact with responsibility either for the entire observatory or specifically for remote sensing. The questionnaire was accompanied by a cover letter introducing CEOS and the Volcanic Hazards group, and asking for their assistance. The letter and questionnaire were sent out in English or Spanish as deemed appropriate.

RESULTS OF THE SURVEY

The response rate, although not 100%, was very high, with responses received from all but three of the original observatories polled. A later follow-up to two observatories and the Indonesian Volcanological Survey netted some additional response.
The responses can be summarized as follows:

1. Most observatories (though not all) do use remotely sensed data. The exceptions are either extremely isolated physically or severely underfunded.

2. The data most commonly accessed and used are from the meteorological satellites (GOES, AVHRR, GMS). They are used to monitor ash clouds and thermal anomalies. In particular, the Hawaii Institute of Geophysics hotspot website is reaching at least part of its intended audience.

Other IR imagery (Landsat, SPOT) is used for thermal monitoring. TOMS is used for SO2, ash and aerosol monitoring. SAR imagery is used for topography and deformation monitoring, though not in real time. High-resolution optical (SPOT, Landsat) is used for topography, location of new lava, ash deposits, etc. Much of this activity occurs at a few observatories, which have better access to imagery, the Web, and funding.

3. Most observatories do aspire to use more remotely sensed data if it could be arranged. There is widespread awareness of its potential.

4. Cost of data and lack of expertise are major inhibitors to wider use, and poor timeliness is also a significant factor for some.

5. Significant use by the research community of remotely sensed data from volcanic activity "off-line" from operational use. Some of this activity is helpful to the observatories, and is shared with them. Some is conducted without communication with the observatories and hence is of relatively little use to them.

We anticipated that the responses would be bi-modal, with some observatories making extensive use of satellite data, and others comparatively little. The most encouraging aspect of the responses is the widespread awareness of the existence and utility of satellite imagery, suggesting that the volcano observatories would be a receptive audience to data sharing programs, such as the *International Charter for Space and Major Disasters*.

VOLCANIC PHENOMENA POTENTIALLY OBSERVABLE

Volcano	*Date of eruption*	*Ash clouds*	*Lava flows, dome, etc.; erosion, deformation*	*Thermal emissions from lava, other*	*Gas emissions (SO2)*
Guagua Pichincha	1999-2000	yes	dome, pyroclastic flows	yes	yes
Tungurahua	1999-2000	yes	ashfall, lahars	yes	very high
Pacaya	2000	yes	lava fountains, flows	yes	minor
Colima	1998-99	yes	dome, pyroclastic flows, ashfall	yes	yes
Popocatepetl	ongoing	yes	dome, minor ashfall	yes	yes
Soufriere Hills	ongoing	yes	dome, pyroclastic flows	yes	yes
Mayon	2000	yes	dome, pyroclastic+lava flow	yes	yes
Rabaul	2000	minor	ashfall	?	minor
Shishaldin	1999	yes	ashfall, bombs	yes	yes
Bezymianny	2000	yes	uncertain	yes	yes?
Piton de la Fournaise	1999-2000	no	lava fountains, flows	yes	minor
Etna	ongoing	yes	lava fountains, flows	yes	yes
Hekla	2000	yes	lava flows	yes	yes
Grimsvotn	1996, 1998	yes	ice cap melted, ashfall, tephra ring	yes?	yes?

TEAM REPORT

INFORMATION SERVER

DMSG Information Tools Development

In general, timely information on the development of hazards as well as general information on risks, hazards, and opportunities remains fragmented and difficult to locate. To begin to address these and other gaps, prototype tools are being developed. NOAA has sponsored a prototype information server for the group. This server was intended to demonstrate timely access to satellite-derived data and information products (i.e., "one stop shopping") to support various facets of disaster management. A number of agencies participated in the development of this service, providing links to their data and information services, and developing additional support tools for the project. A group information server team has supported these efforts. Along with the full DMSG, the tools team is completing its activities. This report provides a summary of team activities, identifies goals that were not achieved, describes why goals were not achieved (lessons learned), and offers ideas on how these goals might be achieved as the work of the DMSG is carried forward in other fora.

Many of the activities, such as hazard theme pages and links to other hazard related web sites have been useful for providing information to a broad range of users and potential users of hazard information. The reports and meeting summaries of the DMSG have been used and referenced by others. Sometimes the "Click here to e-mail us" has been used as a focal point for soliciting help in addressing specific disaster issues. In this way, requests for data, information on what data is useful, or questions regarding scientific phenomena related to specific disasters are received and relayed to members of DMSG. Often an e-mail dialogue ensues that leads to resolving the issue.

Challenges

A key goal of providing a user-friendly Internet search capability to access specific data, derived products and other information for disaster managers has remained elusive. Key problems, such as — lack of consistent, consensus on terminology; the cost and difficulty of achieving the state of the art for search technology; and the need for specific scenarios have limited achieving this goal. Ironically, as the work of the team is winding down, significant progress in solving these problems is emerging. Hopefully, this will encourage others to take up the challenge.

Quite often users are not familiar with the terminology of data providers. In fact, user communities often have their own terminology that is quite different from data providers and other user communities. Within some user communities there is no standardized terminology established. A key goal of the information tools development has been to build a bridge between user and data provider terminology for selected user communities. The goal was to use the hazard team activities to derive appropriate terminology where standardized terminology and specific scenarios were not available. Previous annual hazard team reports did provide useful terminology, but not until this final report have scenarios been defined. Building on the scenarios of the *International Charter for Space and Major Disasters*, hazard teams have defined several additional useful scenarios. This set of scenarios will act as a prototype and template for adding additional scenarios and hazard types in the future. On-going collaboration with activities of UN organizations such as OOSA and ISDR as well as the *Internatianal Charter* will be crucial to maintaining and increasing interaction with a broader user community as well as making this effort more successful. For example, the continuation of user-oriented workshops, co-sponsored by UN organizations and CEOS or CEOS agencies, is strongly encouraged.

Information Access
It has been the goal of the information tools team to have several layers for information access, ranging from a simple list of key data providers, to the hazard specific scenarios discussed in the last paragraph, to an Internet-based search of several Earth observing data and product catalogs. The simple list of data providers should include key contact information including contact person, telephone number, fax number, address, and Internet URL if available. When available, contact information as provided by the CEOS International Directory Network (IDN) and other FGDC compliant catalogs would be used. This list would start as a short list focused primarily on space agencies, and grow from there. Unfortunately, the tools team focused on the more difficult layers, and as a result did not implement the layer that would have been easiest. The lesson learned here is to do the simplest first. A third layer would be a search of existing on-line catalogs including the CEOS IDN and other FGDC compliant catalogs. The key to making this search user-friendlier is to develop a thesaurus of terms to translate from user-friendly terms to catalog terms. To do this properly, a catalog with controlled content such as the IDN is required. The information tools team has begun work with the Working Group on Systems and Services (WGISS) IDN task team to develop this layer. The technology for doing catalog searches on the Internet has progressed to the point that practical implementation methods are possible. With the demise of the DMSG tools team, hopefully others will pick up coordination with catalog activities such as the IDN.

Lessons Learned
Other information tools could provide additional user-friendly features such as visualization tools or orbital tools. Visualization tools will be useful to training in the use of satellite data. Orbital tools would provide a potential user with a list of satellites that has recently or will soon pass over the site of a recent disaster. WGISS task teams could be helpful to those who want to explore and implement capabilities of this type in the future.

A general lesson learned is that the level of effort to maintain the DMSG website properly is much higher than was expected. Even seemingly simple tasks, such as maintaining a current list of upcoming events or hot events, requires constant surveillance of activities. Although simple in nature, they require many hours each week to accomplish.

Although there were problems that kept the information tools team from fulfilling all of its goals, many of these problems are being addressed. User communities are working to develop more consistent, consensus terminology. The cost and state of the art for search technology has progressed to the point that practical Internet implementations are feasible. The work of the Hazard Teams and the on going work of the *Internatianal Charter* have established a baseline for future hazard scenarios. Hopefully, this will encourage others to work toward achieving the identified, but unaccomplished goals that were set under the work of the DMSG.

The information server web site URL is: http://disaster.ceos.org.

INFORMATION SERVER TEAM MEMBERS

1.	Levin Lauritson, Chair	NOAA/NESDIS/OSDPD (USA)
2.	Luc Nguyen, Webmaster	Vista Computer Services, Inc. supporting NOAA (USA)
3.	Susan McLean	NOAA/NESDIS/NGDC (USA)
4.	Hazard Team Chairs	

ANNEX I:

Drought Hazards Team Report
(from 1999 DMSG Annual Report)

The Drought Hazards Team Report was first proposed in the early stages of the work of the DMSG, when it was the CEOS Disaster Management Support Project (DMSP). An interim report on Drought was included in the 1998 DMSG Annual Report and was included as a full submission in the DMSG Annual Report of 1999. The team's original report, included here, contributed well to the early work of the DMSG and is a useful for reference with the other Hazard Team Reports. Key elements of this activity have been and continue to be carried out in other fora elsewhere:

Drought as Natural Hazard
Drought is the single most important weather-related natural disaster. It is often aggravated by human action, since it affects very large areas for months, even years, and thus has a serious impact on regional food production, often reducing life expectancy for entire populations and economic performance of large regions or several countries. During 1967-1991, droughts affected 50 percent of the 2.8 billion people who suffered from all natural disasters and killed 35 percent of the 3.5 million people who lost their lives to natural disasters. In addition, subsidence of buildings, engineering works and relief measures following droughts involve high costs. In the current decade — which was proclaimed the Decade for Natural Disaster Reduction by the United Nations — large-scale intensive droughts have been observed on all continents, leading to***:***
- massive economic losses
- destruction of ecological resources
- food shortages
- starvation for millions of people

Reducing Drought Consequences
To reduce consequences of drought, the main components of a drought preparedness and mitigation plan should include:
- Drought prediction
- Monitoring and early warning
- Assessment of impacts
- Response

Users
Several levels of users can be identified:
- Primary policy makers at the national level and within international organizations; and researchers
- Policy makers at the state and provincial levels; and consultants, relief agencies, researchers and insurers
- Local policy makers; and producers, such as farmers, suppliers, traders, builders and water managers

User Requirements on Drought Information include:

- Early warning of drought onset
- Estimation of area, intensity and duration
- Identification of confidence level for drought event(s)
- Plan for immediate relief and long term management for drought mitigation
- Drought information should be easy to understand and use
- Education of the users on how to interpret the information
- Validation by ground-truth
- Easy access to data sources and documentation
- Easy integration of information into other systems
- Establishment of a parent web site where multiple data are available

CURRENT STATUS (1999)

Drought prediction

Drought prediction can benefit from:

- Climate variability predictions using coupled ocean/atmosphere models
- Survey of snow packs
- Persistent anomalous circulation patterns in the ocean and atmosphere
- Initial soil moisture
- Assimilation of remotely sensed data into numerical prediction models
- Knowledge of stored water available for domestic, stock, and irrigation uses

Present State of knowledge (1999)

Nearly global seasonal climate anomaly predictions are now possible due to the successful combination of new observational networks (for example, the TOGA TAO array in the equatorial Pacific and satellite altimeters) and improved initial and boundary conditions of ocean, atmosphere and land coupled models. Near-real time evaluation of in situ and remote sensing data allows, for the first time, physically-based drought warnings several months in advance — to which a growing number of countries already link policies for agriculture, fisheries and distribution of goods. Therefore, any improvement in operational meteorological, oceanographic and hydrological observations, as well as in coupled ocean/atmosphere/land models, improves the quality of drought warnings. There are a number of satellite-based programs that are providing improved detail relating to expected climatic change. Currently, this topic is a main concern of the insurance industry.

The quality of seasonal predictions of temperature and precipitation anomalies by various centers, such as the National Centers for Environmental Prediction of United States, European Centre for Medium Range Weather Forecasts (ECMWF), National Centre for Medium Range Weather Forecast of India (NCMRWF) is also a function of the quality and amount of satellite data assimilated into the starting fields (for example, SST from AVHRR and profiles from TOVS on NOAA satellites, ERS-2 scatterometer winds, SSM/I on DMSP satellites, and all geostationary weather satellites: GOES-East, GOES-West, Meteosat, GMS of Japan, INSAT of India and so on). New assimilation techniques have produced a stronger impact of space data on the quality of weather and seasonal climate predictions.

To a significant degree, the potential contribution of existing satellites is not fully exploited. The synergy gained by the combination of satellite sensors is not fully used. In addition, all of the satellite data are not distributed internationally. For example, there is a lack of joint evaluation of AVHRR and TOVS for the improvement of temperature and humidity profiles in the lower troposphere.

User requirements on drought predictions:

- Drought predictions should be brought down to larger scales
- Deficiencies in the entire chain, from the raw data to the seasonal prediction of droughts, must be reviewed for a full assessment of potential improvements, given the existing observational networks.
- The improved information flow — i.e., predictions — must get to the user immediately. Better information flow from satellite data producers, to the intermediary services (prediction centers such as ECMWF, NCEP, JMA, NCMRWF etc.) to local services, and ultimately, to end-users. This problem is currently being addressed within the CLIPS (Climate Information and Prediction Services) Project of WMO.

Drought Monitoring and Early Warning

Drought monitoring mechanisms exist in most of the countries that use ground based information on drought related parameters such as rainfall, weather, crop condition and water availability. Earth observations from satellites are highly complementary to those collected by in-situ systems. Satellites are often necessary for the provision of synoptic, wide-area coverage and provision of the frequent information required putting in-situ information into broader spatial monitoring of drought conditions.

Present state of knowledge (1999):

Rainfall, surface wetness and temperature monitoring: Currently, multi-channel and multi-sensor data sources from geostationary platforms (such as GOES, METEOSAT, INSAT, GMS) and polar orbiting satellites (such as NOAA, DMSP SSMI and the recently launched IRS-P4 MSMR) have been used, or are planned to be used, for meteorological parameter evaluation, interpretation, validation and integration. The estimated parameters are precipitation intensity, amount, and coverage, atmospheric moisture and winds, and sometimes surface (soil) wetness. New algorithms are being developed that integrate the less direct but higher resolution (space and time) GOES precipitation estimates with the more physically based but lower resolution (both space and time) polar-orbiting satellite microwave estimates. A further improvement in the spatial distribution of rainfall is being achieved by integrating radar, rain gauges and remote sensing techniques.

Vegetation monitoring: The vegetation condition monitoring is currently possible, ranging from NOAA AVHRR data at 1.1km resolution in a daily revisit, to IRS OCM with 360m resolution in a two day revisit to IRS WiFS with 188m resolution in a 5 day revisit. The normalized difference vegetation index (NDVI) and temperature condition index (TCI) derived from the satellite data is accepted worldwide for regional monitoring.

Ongoing Programs:

- The Africa Real-Time Environmental Monitoring using Imaging Satellites (ARTEMIS) is operational at FAO. It uses METEOSAT rainfall estimates and AVHRR NDVI values for Africa.
- The USDA/NOAA Joint Agricultural Weather Facility (JAWF) uses Global OLR anomaly maps, rainfall maps, vegetation and temperature condition maps from GOES, METEOSAT, GMS and NOAA satellites.
- The Joint Research Centre (JRC) of the European Commission (EC) issues a periodical bulletin on agricultural conditions under the MARS-STAT (Application of Remote sensing to Agricultural

statistics) project which uses vegetation index, thermal based evapotranspiration and microwave based indicators.

- The Agricultural Division of Statistics Canada issues weekly crop condition reports based on NOAA AVHRR NDVI, along with agrometeorological statistics.
- National Remote Sensing Agency, Department of Space issues a biweekly drought bulletin and monthly reports at smaller administrative units for India under National Agricultural Drought Assessment and Monitoring System (NADAMS), which uses NOAA AVHRR and IRS WiFS based NDVI and ground based weather reports.
- Similar programs are followed in many countries worldwide, including some for specific drought prone areas in developing countries.

User Requirements on drought monitoring and early warning

- In developing countries where land holdings are often small and fragmented, agricultural monitoring should be at larger scale, crop specific, at higher frequency (10 to 14 days interval), and should include information on water availability.
- Assessment is required of intensity, areal extent, rate of expansion, and time of drought occurrence.

Assessment of drought impact

The assessment of drought impacts should be carried out following the subsequent ranking:

- Land use type
- Persistence of stressed conditions on an intra-seasonal and inter-seasonal time scale
- Demographics and infrastructure around the impacted area
- Intensity and areal extent
- Agricultural yield
- Impact associated with disease, pests, potable water availability and quality, etc.
- Building subsidence.

Using satellite data as input for crop model yield estimates helps to generally assess the drought impact.

Present state of knowledge (1999):

High-resolution satellite sensors from LANDSAT, SPOT, IRS, (among others) are being used for the assessment of impacts in a few areas, but in most cases this is not a country-wide activity.

Response

- Water management
- Crop management
- Decisions for mitigation and alternative strategies

Present state of knowledge (1999):

High-resolution satellite sensors from LANDSAT, SPOT, IRS, (and others) are being used. For example, in India, drought management action plan maps are being generated at the watershed level for implementation in case of droughts.

However, GIS based decision support systems need to be developed

- GOES, METEOSAT, INSAT, GMS are used for prediction
- NOAA/AVHRR, IRS/WiFS, SPOT4/Vegetation are used for monitoring and early warning
- DMSP/SSMI and IRS-P4 MSMR data should be investigated, together with the existing approaches, as a drought information
- TRMM, RESOURCESAT, MODIS and MERIS need to be evaluated for monitoring
- LANDSAT,IRS,SPOT is used for GIS based drought management system

Future Tasks

- A major task of the drought team is to find the best way for space agencies to prepare more satellite data so that it is properly assimilated into coupled ocean/atmosphere/land models used for drought predictions.
- Requirements for improved space observation, as they have been expressed by the World Climate Research Programme, can be incorporated into the drought team requirements. An example is the need for continuation of altimeter measurements of ocean topography, with the quality of TOPEX/POSEIDON, to be used as a starting field in coupled-model El Nino predictions.
- For cases without the possibility for early warnings, which will be especially frequent when major circulation anomalies like El Nino or La Nina are absent, we still have to work on using satellite information not only to assess the damage but to assess the skill of predictions.

Within the scope of CEOS strategy on using satellite data for drought monitoring, early warning and drought response, the future task of the Drought Team could be formulated as:

Identify the methods for

- Early drought detection;
- Monitoring drought dynamics, delineating drought area and time;
- Assessment of drought impacts and possible consequences;
- Use of satellite and in-situ data;
- Use of multi-sensor/satellite information
- Calibration between satellite platforms and instruments for continuous monitoring

Determine optimal areas for response and mitigation:

- Develop GIS-based models for appropriate action for mitigation
- Improve communications
- Take up demonstration projects

DROUGHT HAZARD TEAM PARTICIPANTS

1. D. P. Rao, Co-leader	National Remote Sensing Agency (India)
2. Hartmut Grassl, Co-leader	Max Planck Institute (Germany)
3. Felix Kogan	NOAA/NESDIS, Office of Research & Applications (USA)
4. Terry Arvidson	NASA LANDSAT 7 Project, Lockheed Martin (USA)
5. Alan Basist	NOAA/NESDIS, National Climatic Data Center (USA)
6. Omar Chafki	Moroccan Weather Service (Morocco)
7. Leona Dittus	US Department of Agriculture, Farm Service Agency (USA)
8. Paul Doraiswamy	Agricultural Research Service, USDA (USA)
9. Jeff Eidenshank	US Geological Survey, EROS Data Center (USA)
10. Vikki French	Famine Early Warning System (USA)
11. Wayne Hall	Resources Science Centre (Australia)
12. Jackie Klaver	US Geological Survey, EROS Data Center (USA)
13. Douglas LeComte	NOAA, National Centers for Climate Prediction & USDA
14. Kevin Marcus	Earthsat (USA)
15. Colin Mitchell	British National Space Centre (UK)
16. Alan O'Neill	University of Reading (UK)
17. Al Peterlin	USDA, Office of the Chief Economist (USA)
18. Alain Podaire	Centre National Etudes Spatiales/Scot Conseil (France)
19. Bruce Ramsay	NOAA/NESDIS, Office of Satellite Data Processing & Distribution
20. Genya Saito	National Institute of Agro-Environmental Sciences (Japan)
21. Macoi Stewart	NOAA Office of Global Programs (USA)
22. Wassila Thiaw	NOAA National Centers for Climate Prediction, Africa Desk (USA)
23. Gue Wei	National Satellite Meteorological Center (China)

ANNEX II:

FINDINGS AND OVERARCHING RECOMMENDATIONS

CEOS DISASTER MANAGEMENT SUPPORT GROUP

- ***Finding***: There is a visible willingness within the disaster management and response community to give due consideration to new space technologies that will improve their operations. This tendency is reflected in the notable participation and interest of the community in the DMSG.
- ***Recommendation***: The space sector should be pro-active in responding to the receptiveness of the disaster management and response community.

- ***Finding***: There is a general reluctance among the disaster management community to assimilate new technologies and information quickly, due to concern for introducing new, unproven technology into operational programs. They also often lack the time, resources, personnel, or technical understanding to do this.
- ***Recommendation***: In order to promote wider acceptance and use of space systems by disaster management users, the space and services communities must create the appropriate tools and continue to perform compelling demonstrations.

- ***Finding***: Space technology has been demonstrated conceptually, however, the viability of operational reliance has generally not been fully demonstrated to the disaster management community. The central challenge relates to the promotion of mutual understanding and dialogue between the disaster management and space sectors.
- ***Recommendation***: The space agencies and applications community should invest in familiarizing themselves with the needs of the disaster management users and work together to the smooth transition from research capabilities to operations.

- ***Recommendation***: Recognizing the reluctance and lack of familiarity of some users to the use of satellite data, effort to be as accurate as possible in describing the capabilities and limitations of space-based observations must also be done. One should not oversell, and at the same time not understate, the true value of remote sensing.

- ***Finding***: Timeliness, cost, accessibility, ease of use, reliability, repeatability, and demonstrated operational capability are all critical factors that affect successful incorporation of space systems and data into disaster management programs.
- ***Recommendation***: Space agencies should address each factor on its own merits, since user acceptance does not necessarily increase by trading one factor off against another.

- ***Finding***: Several teams have identified the need for a broad-based data policy that would improve and assure access, timeliness and affordability of data, including (or especially) high-resolution data streams.
- ***Recommendation***: CEOS agencies should work together to advance common data policies, where possible, to facilitate ready, affordable access to Earth observation satellite data for emergency use. (The data charter, announced at UNISPACE-III by ESA and CNES, may provide a starting point for such a policy.)

- ***Finding***: Timely disaster warning and response, and/or rapid response in support of a disaster situation, is the most important feature in the utility of satellite technology.
- ***Recommendation***: CEOS agencies should work to support rapid satellite tasking of Earth observation missions, to enhance the utility of space for disaster applications.
- ***Recommendation***: CEOS agencies should work to support fast processing and delivery of data, which will also be very important to determining the utility of space data for disaster applications.

- ***Finding***: Typically, users can benefit from satellite data that is provided from more than one agency. Initial project efforts to develop information tools to demonstrate timely access to satellite-derived data and information products received positive reactions. It was recognized that there is merit for moving in a collaborative fashion towards a more integrated approach to mission planning.
- ***Recommendation***: Initial steps should be taken towards sharing technical information and developing tools for satellite tracking and tasking that are more user friendly for disaster management support purposes.

- ***Finding***: While it is not yet a practicality, the goal of mirroring information from agencies in different areas of the world holds promise for providing timely access to essential information on missions, as well as useful educational information.
- ***Recommendation***: Mirroring of information currently contained on the project information server may be a productive operational demonstration of this concept.

- ***Finding***: Disaster management is an area that can greatly benefit from an integrated approach to space technology applications.
- ***Recommendation***: There is a need to integrate non-space information with space imagery and other satellite data, including the use of appropriate geographic information system tools, to facilitate integrating those data quickly and in a seamless fashion.

- ***Recommendation***: It is recognized that each team, and the project in general, must continue to endeavor for broader geographic and disciplinary representation, especially in terms of interacting with specific users, to determine their desired information needs.

RESOLUTION ON THE CEOS DISASTER MANAGEMENT SUPPORT AD HOC WORKING GROUP

THE 13TH CEOS PLENARY:

Recognizing the promise of benefits for natural and technological disaster management support from improved utilization of data from Earth observing satellites;

Noting the strong, positive response to the related, ad hoc pilot project initiated by the CEOS Strategic Implementation Team; and

Noting the outstanding progress of the pilot project in establishing a mechanism for dialogue with international, regional, and national emergency management and other users;

Decides to:

Create a Disaster Management Support Group within the Committee on Earth Observation Satellites (CEOS) as an ad hoc working group, and that it shall report on its activities at the next CEOS Plenary;

Endorse the attached Terms of Reference;

Welcome the offer of NOAA to provide the ad hoc working group's first chair.

TERMS OF REFERENCE FOR THE DISASTER MANAGEMENT SUPPORT AD HOC WORKING GROUP (DMSG)

Membership

Membership in the DMSG is open to all members and associates of CEOS as defined in the CEOS Terms of Reference, as well as to representatives of other organizations who have an interest in the subject.

Objectives

The objective of the DMSG is to support natural and technological disaster management on a worldwide basis by fostering improved utilization of existing and planned Earth observation satellite data.

Specific objectives are to:

1. Provide a forum to promote mutual understanding and dialogue between the wide range of disaster management communities and the space sector;
2. Foster the creation of appropriate information tools and standardized products;
3. Demonstrate and develop suitable response models for coordinated space agency response;
4. Improve identification of and access to useful Earth observation satellite data and products;
5. Investigate and demonstrate possibilities for technical coordination and cooperation for Earth observation satellite systems and their ground systems;
6. Develop and identify specific user requirements for satellite data, derived products, and services in support of disaster management;
7. Develop and refine recommendations for improving the ability of current and planned space systems to meet disaster management user requirements;
8. Work requirements for space segment with SIT; and
9. Participate in the activities of the IGOS Partnership where appropriate.

In particular, the Group will demonstrate the coordination of space agency responses to specific disasters.

Selected Procedures

The DMSG shall meet when appropriate, but at least once per year, rotating venue among members and geographical regions. A Chair shall be designated by the Plenary, and the group will organize itself to carry out its work. The Chair and Secretariat for the DMSG shall prepare and distribute minutes for each meeting. At each meeting of the DMSG, the time, place, and host for the next meeting shall be established.

The DMSG shall coordinate its work with other international groups involved in related activities, as described in the CEOS Terms of Reference. The DMSG shall cooperate with the WGCV and the WGISS on activities that support disaster management, and it shall report on its Activities to the Plenary.

ANNEX III:

International Charter on Space and Major Disasters

C H A R T E R

ON COOPERATION TO ACHIEVE THE COORDINATED USE OF SPACE FACILITIES IN THE EVENT OF NATURAL OR TECHNOLOGICAL DISASTERS

Content

Preamble

RECOGNISING the potential applications of space technologies in the management of disasters caused by natural phenomena or technological accidents, and in particular Earth observation, telecommunications, meteorology and positioning technologies;

RECOGNISING the development of initiatives concerning the use of space facilities for managing natural or technological disasters;

RECOGNISING the interest shown by rescue and civil protection, defence and security bodies and the need to respond to that interest by making space facilities more easily accessible;
DESIROUS to strengthen international cooperation in this humanitarian undertaking;

HAVING REGARD to United Nations Resolution 41/65 of 1986 on remote sensing of the Earth from space;

BELIEVING that by combining their resources and efforts, they can improve the use of available space facilities and increase the efficiency of services that may be provided to crisis victims and to the bodies called upon to help them;

HEREBY AGREE AS FOLLOWS:

Article I – Definitions

For the purposes of this Charter:

The term "natural or technological disaster" means a situation of great distress involving loss of human life or large-scale damage to property, caused by a natural phenomenon, such as a cyclone, tornado, earthquake, volcanic eruption, flood or forest fire, or by a technological accident, such as pollution byhydrocarbons, toxic or radioactive substances;

The term "Charter" means this text;

The term "crisis" means the period immediately before, during or immediately after a natural or technological disaster, in the course of which warning, emergency or rescue operations take place;

The term "space data" means raw data gathered by a space system controlled by one of the parties, or to which that party has access, and transmitted or conveyed to a ground receiving station;

The term "information" means data that have been corrected and processed by the parties using an analysis program, in preparation for use in crisis management by one or more associated bodies in aid of the beneficiaries; it forms the basis for the extraction of specific products for use on location;

The term "space facilities" means space systems for observation, meteorology, positioning, telecommunications and TV broadcasting or elements thereof such as on-board instruments, terminals, beacons, receivers, VSATs and archives;

The term "parties" means the agencies and space system operators that are signatories to the Charter;

The term "associated bodies" means the rescue and civil protection, defence and security bodies or other services referred to in Articles 5.2 and 5.3;

The term "cooperating bodies" refers collectively to the various bodies and institutions, referred to in Article 3.5 of the Charter, with which the parties cooperate;

The term "crisis victims" means any State or community for whose benefit the intervention of the parties is sought by the associated bodies.

The term "beneficiary bodies" means all the bodies benefiting from information intended for crisis management; for example, the authorities and bodies concerned in countries affected by a disaster.

Certain associated bodies may also be beneficiaries at the time of a disaster.

Article II - Purpose of the Charter

In promoting cooperation between space agencies and space system operators in the use of space facilities as a contribution to the management of crises arising from natural or technological disasters, the Charter seeks to pursue the following objectives:

- supply during periods of crisis, to States or communities whose population, activities or property are exposed to an imminent risk, or are already victims, of natural or technological disasters, data providing a basis for critical information for the anticipation and management of potential crises;

- participation, by means of this data and of the information and services resulting from the exploitation of space facilities, in the organisation of emergency assistance or reconstruction and subsequent operations.

Article III - Overall organisation of cooperation

3.1 The parties shall develop their cooperation on a voluntary basis, no funds being exchanged between them.

3.2 The Charter shall be open, in accordance with the provisions of Article VI below, to space agencies and national or international space system operators wishing to cooperate in it.

3.3 The administrative, operational and technical coordination needed to achieve this cooperation shall be provided by a Board on which each party is represented and an executive Secretariat for implementation of the Charter.

3.4 The authorities and bodies concerned in a country affected by a disaster (beneficiary bodies) should request the intervention of the parties either directly through the rescue and civil protection, defence and security bodies of the country to which one of the parties belongs or of a State belonging to international organisations that are parties to the Charter (associated bodies) or where appropriate via a cooperating body acting in partnership with an associated body. The country affected by a disaster may also make a direct approach to the parties' Secretariat but, for the purposes of the intervention itself, the bodies concerned in that country must engage a partnership with one or more associated bodies.
The above provisions in no circumstances prevent parties intervening on their own initiative.

3.5 The European Union, the UN Bureau for the Coordination of Humanitarian Affairs and other recognised national or international organisations, whether governmental or non-governmental, are bodies with which the parties may have cause to cooperate in pursuance of the Charter (cooperating bodies). The Board shall maintain a regularly updated list of cooperating bodies.

Article IV - Contributions by the parties

The parties shall use their best endeavours in the conduct of this cooperation, which shall proceed on the following basis:

4.1 Space facilities available for use
The parties shall undertake to maintain an up-to-date list of the available space facilities under their management and, as far as possible, of such space facilities under the management of private or public operators as may be called upon to supplement the parties' own facilities. In particular, the list shall specify for each space system the following details:
- mission characteristics
- orbital characteristics
- operational condition
- programming procedure
- products and services provided by ground systems.

4.2 Scenario-writing
The parties shall together analyse recent crises for which space facilities could have provided or did provide effective assistance to the authorities and rescue services concerned. A report, structured according to the crises identified and the types of situation encountered, and highlighting possible contributions by existing facilities, shall be prepared by the Secretariat in consultation with the associated bodies described in Article V below and where appropriate with cooperating bodies.

Moreover, the parties shall keep abreast of new methods being developed in applied research for warning of, anticipating and managing disasters. Once these new methods (or technologies) have been identified and validated by the design authorities and associated bodies, they may, with the Board's approval, be subjected to pre-operational implementation testing. A test report and an assessment of the areas of application of the method would then be prepared by the Secretariat. Lastly the Secretariat shall be responsible for designing and proposing, on the basis set out above, scenarios for each type of crisis. Each scenario shall state the conditions under which the parties would coordinate, in the event of a crisis being identified, their action in supplying appropriate information and services, access to the available space facilities being planned accordingly. These scenarios, approved by the Board and regularly updated, shall constitute the basis for action in the event of identification of a crisis.

4.3 Identification of a crisis situation

A crisis situation exists primarily where so identified by a country affected by a disaster and at least one associated body seeking the intervention of the parties underthe terms of the Charter, in accordance with the provisions of Article 3.4 above.
The Secretariat shall handle all associated body requests and shall thus have the authority, once it has identified a crisis situation, to arrange for the appropriate action to be taken.

4.4 Planning of space facility availability in the event of a crisis
In the event of a crisis, the parties shall use their best endeavours to plan the availability of space facilities or arrange for it to be so planned. Such planning shall reflect the provisions described in the corresponding scenarios defined in Article 4.2 above.
In the event of an alert or potential crisis, the parties may, in anticipation, plan the availability of the satellite systems under their control.

4.5 Organisation and assistance on completion of planning arrangements

The parties shall use their best endeavours, in accordance with the identified crisis scenarios, to supply associated bodies and, where appropriate, beneficiary bodies with data, and if necessary associated information and services, gathered by the space facilities.

Implementation of the procedures described in the scenarios implies coordination of tasks between the parties, possibly leading to combining of the available resources:
- access to data archives
- merging of the data to aid understanding of pre-crisis situations
- access to data acquired at the time of the crisis
- merging of those data to report on the crisis
- routing of information to the user
- access to all the technological resources available - telecommunications, data collection, navigation.

The procedures for accessing and integrating data or other services (telecommunications, data collection, navigation) to obtain specific products shall, as far as possible, be stipulated in the scenario descriptions.

Article V - Associated bodies

5.1 The role of associated bodies in intervention by the parties is defined in Article 3.4.
5.2 An associated body shall, for the purposes of this Charter, be an institution or service responsible for rescue and civil protection, defence and security under the authority of a State whose jurisdiction covers an agency or operator that is a party to the Charter, or of a

Member State of ESA or of an international organisation that is a party to the Charter.

5.3 Any entity or service authorised to this effect by the Board may also be considered an associated body.

5.4 The parties shall ensure that associated bodies which, at the request of the country or countries affected by a disaster, call on the assistance of the parties undertake to:

- alert the Secretariat as soon as possible in the event of a crisis and designate their points of contact;
- promptly provide the Secretariat with the necessary details;
- use the supplied information only for the purposes defined with the Secretariat;
- take part as necessary in the relevant meetings organised by the Secretariat;
- report on the use made of the data, information and services supplied and prepare an assessment of each case for which intervention took place;
- confirm that no legal action will be taken against the parties in the event of bodily injury, damage or financial loss arising from the execution or non-execution of activities, services or supplies arising out of the Charter;
- meet any other condition agreed with the Secretariat or Board.

Article VI - Accession

6.1 It is the intent of the parties to encourage the widest possible accession to the Charter by agencies and national or international space system operators.
Requests to adhere to the Charter may be made by any space system operator or space agency with access to space facilities which agrees to contribute to the commitments made by the parties under Article IV above and is willing to assume the responsibilities of a party under the terms of the Charter.

6.2 The Board shall examine accession requests and formulate its recommendations to the parties to the Charter within 180 days of their submission. In doing so, it shall consider that any new accession must, in particular:
- bring a significant contribution by the acceding party to the intervention capacity required for the purposes of the Charter and a commitment to bear its share of the common costs;
- help to achieve the objectives of the parties;
- be such as not to compromise normal deployment of the systems already in place.

On the basis of such recommendations by the Board, any accession shall require the unanimous approval of the parties to the Charter.

Article VII - Entry into force, expiry and withdrawal

7.1 The Charter shall enter into force on the day of its signature by at least two parties. It may be terminated at any time by mutual consent of the parties. Any party may withdraw from the Charter after notifying, with 180 days' notice, the other party or parties in writing of its intention to do so. The possibility of pursuing the mission in a modified form shall be examined by the parties. The party intending to withdraw shall endeavour to maintain continuity of its current contribution.

7.2 Subject to the provisions of Article 7.1 above, the Charter shall remain in force for a period of five years from the date of its entry into force, and shall be automatically extended for subsequent periods of five years.

Article VIII - Implementation

The implementation arrangements for this Charter shall be defined by the parties meeting in the Board.

EN FOI DE QUOI, les Soussignés ont signé la présente Charte en deux originaux, l'un en langue française et l'autre en langue anglaise, chacun des textes faisant également foi.

IN WITNESS WHEREOF, the undersigned have signed the Charter in two originals, one in the French and one in the English language, both texts being equally Authentic.

Fait à Paris le 20 juin 2000
Done in Paris on 20 June 2000
…………………………………
Pour le Centre National d'Etudes Spatiales
Représenté par son Président M. Alain Bensoussan
Et par délégation par son Directeur Général M. Gérard Brachet
For the Centre National d'Etudes Spatiales
Represented by its president, Mr. Alain Bensoussan,
And, by delegation, its Director General, Mr. Gérard Brachet
…………………………………….
Pour l'Agence Spatiale Européenne
représenté par son Directeur Général M. Antonio Rodotà
For the European Space Agency
Represented by its Director General, Mr. Antonio Rodotà

ANNEX IV:

THE 14TH CEOS PLENARY:
RESOLUTION TO SUPPORT THE *INTERNATIONAL CHARTER*

Charter on Cooperation to Achieve the Coordinated Use of Space Facilities in the Event of Natural or Technological Disasters

•***Noting*** *that ESA and CNES initiated the* ***Charter on Cooperation to Achieve the Coordinated Use of Space Facilities in the Event of Natural or Technological Disasters (the "Charter"),*** *announced in Vienna at UNISPACE III, in July 1999;*

•***Recognizing*** *the promise of benefits to be realized through more effective use of data from Earth observing satellites;*

•***Noting*** *that CNES and ESA are encouraging the widest possible accession to the Charter by space system operators, in support of the Public Good;*

•***Noting*** *that CSA has signed the Charter and that a number of other agencies have communicated their intent to do so;*

•***Noting*** *that activities under the Charter will be undertaken on a best efforts basis;*

Decides to

•***Commend*** *ESA and CNES for initiating the Charter;*

•***Endorse*** *the objective of the Charter to coordinate space agency assets for disaster response and the use of satellite data for disaster management support;*

•***Encourages*** *all CEOS agencies to favorably consider joining the Charter; and*

•***Directs*** *the CEOS Disaster Management Support Group to support the promotion and implementation of the Charter through its work plan.*

ANNEX V:

THE 14TH CEOS PLENARY:
RESOLUTION ON UNISPACE III

Resolution on UNISPACE III

CEOS Plenary warmly welcomes the follow-up actions being taken by OOSA in pursuit of decisions taken at UNISPACE III, and re-affirms the intention of CEOS to give its full support to these actions, in particular through the work of its ad hoc groups on Disaster Management Support and Education and Training.

ACTION:

❧*CEOS ad hoc working groups on Disaster Management Support and Education and Training to give full support to the follow-up actions of OOSA in pursuit of decisions taken at UNISPACE III.*

Resolution on CEOS DMSG

Commends the progress achieved by the CEOS Disaster Management Support ad hoc Working Group (DMSG);

❧*Requests all CEOS members and associates to consider and respond to the specific recommendations contained in the Annual Report of the Group.*

ANNEX VI:

ACRONYM LIST

AC	Area Control Centre
ADEOS	ADvanced Earth Observing Satellite
AI	Artificial intelligence
AIRS	Advanced Interferometric Radiometric Sounder
ALOS	Advanced Land Observation Satellite
AMSU	Advanced Microwave Sounding Unit
ARTEMIS	The Africa Real-Time Environmental Monitoring using Imaging Satellites
ASAR	Advanced Synthetic Aperture Radar
ASCAT	Advanced SCATterometer
ASL	Above Sea Level
ASOS	Automated Surface Observing system
ASTER	Advanced Spaceborne Thermal Emissive Radiometer
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AVNIR	Advanced Visible and Near Infrared Radiometer
AVO	Alaska Volcano Observatory
BAER	Burned Area Emergency Rehabilitation
BSH	Federal Maritime and Hydrographic Agency of Germany
CANERM	CANadian Emergency Response Model
CCRS	Canadian Centre for Remote Sensing
CDA	Command Data Acquisition
CENAPRED	El Centro Nacional de Prevencion de Desastres (The geophysical agency of Mexico)
CEOS	Committee for Earth Observation Satellites
CIS	Canadian Ice Service
CLIPS	Climate Information and Prediction Services
CMR	Center of Marine Research
CNES	Centre National d'Etudes Spatiale (French Space Agency)
COSPEC	Correlation Spectrometer
CRInSAR	Corner Reflector InSAR
CSA	Canadian Space Agency
DEM	Digital Elevation Model
DMSG	Disaster Management Support Group
DMSP	Disaster Management Support Project
DTM	Digital Terrain model
DU	Dobson Units
EC	European Commission
ECMWF	European Centre for Medium Range Weather Forecasts
EMHI	Estonian Meteorological and Hydrological Institute
ENVISAT	ENVironmental SATellite
EO	Earth Observation
EOS	Earth Observation System
EPA	Environmental Protection Agency
EROS	Earth Resources Observation Systems
ERS	Earth Resources Satellite
ESA	European Space Agency
ESMR	Electrically Scanning Microwave Radiometer
ETM	Enhanced Thematic Mapper
EU	European Union
EUMETSAT	European Organisation for the Exploitation of METeorological SATellites
FAO	Food and Agricultural Organization
FGDC	Federal Geographic Data Committee
FTP	File Transfer Protocol
GDIN	Global Disaster Information Network
GEC	General Electric Company
GIF	Graphic Interface Format
GIS	Geographic Information System
GLI	Global Imager
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite

GOFC	Global Observation of Forest Cover
GOMS	Geostationary Operational Meteorological Satellite
GPS	Global Positioning System
HAZMAT	HAZardous MATerial
HELCOM	HELsinki COMmmission
HRV	High Resolution Visible
HRVIR	High Resolution Visible and Infrared
HSI	Hyper-Spectral Imagery
IAVCEI	International Association of Volcanology and Chemistry of the Earth's Interior
IAVW	International Airways Volcano Watch
ICAO	International Civil Aviation Organization
IDN	International Directory Network
IFFA	Interactive Flash Flood Analyzer
IGBP	International Geosphere-Biosphere Programme
IGOS	Integrated Global Observing Strategy
IHO	International Hydrographic Organization
IICWG	International Ice Chart Working Group
IIP	USCG International Ice Patrol
INFM	L'Istituto Nazionale per la Fisica della Materia
INSAR	INterferometric Synthetic Aperture Radar
INSAT	Indian National SATellite
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
IR	InfraRed
IRS	Indian Resource Satellite
IST	Ice Surface Temperature
JAWF	Joint Agricultural Weather Facility
JERS	Japanese Earth Resources Satellite
JMA	Japan Meteorological Agency
JNDRD	Japanese Natural Disaster Reference Database
JRC	Joint Research Centre
LANDSAT	LAND SATellite
LEO	Low Earth Orbit
LHMS	Lithuanian Hydrometeorological Service
LISS	Linear Imaging Self-Scanning
MARPOL	MARine POLlution
MARS-STAT	Application of Remote Sensing to Agricultural statistics
McIDAS	Man computer Interactive Data Access System
MEDIA	Modele Eulerian de DIspersion Atmospherique
MERIS	Medium Resolution Imaging Spectrometer
METEOSAT	METeorological SATellite
METOP	Meteorological Operational satellite
MIZ	Marginal Ice Zone
MODIS	Moderate Resolution Infrared Spectrometer
MPCU	Marine Pollution Control Unit
MSG	Meteosat Second Generation
MSI	Multi-Spectral Imagery
MSMR	Multispectral Microwave Scanning Radiometer
MSU-E	Multi-Zonal Scanner
MTSAT	Ministry of Transportation SATellite
MWO	Meteorological Watch Office
NADAMS	National Agricultural Drought Assessment and Monitoring System
NAME	Nuclear Accident Model
NASA	National Aeronautics and Space Administration
NASDA	NAtional Space Development Agency
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NCMRWF	National Centre for Medium Range Weather Forecast of India
NDRD	(NASA) Natural Disaster Reference Database
NDVI	Normalised Difference Vegetation Index
NESDIS	National Environmental Satellite, Data and Information Service
NGDC	National Geophysical Data Center
NGO	Non-government Organization
NIC	U.S. National Ice Center
NIED	National Research Institute for Earth Sciences and Disaster Reduction
NIR	Near InfraRed
NOAA	National Oceanic and Atmospheric Administration

NRSC	National Remote Sensing Centre
NRT	Near Real Time
NSCAT	Nasa SCATterometer
NWS	National Weather Service
O&SI SAF	Ocean and Sea Ice Application Facility
OCM	Ocean Color Monitoring
OCTS	Ocean Color and Temperature Scanner
OKEAN	OCEAN (Russian)
OLR	Outgoing Longwave Radiation
OLS	Optical Line Scanner
OP-FTIR	Open Path Fourier Transform Infra Red Spectrometer
OSDPD	Office of Satellite Data Processing and Distribution
OTSR	Optimum Track Ship Routing
PALSAR	Phased Array L-band Synthetic Aperture Radar
Pan-Vis	Panchromatic Visible Imagery
PIREP	PIlot REPort
POES	Polar Operational Environmental Satellites
PSInSAR	Permanent Scatterer InSAR PW precipitable water
QPE	Quantitative Precipitation Estimates
QPF	Quantitative Precipitation Forecasts
QuikSCAT	QUIcK SCATterometer
RADARSAT	RADAR SATellite
RAR	Real Aperture Radar
SAB	Satellite Analysis Branch
SAR	Synthetic Aperture Radar
SCANSAR	SCAN-mode SAR
SDTS	Spatial Data Transfer System
SEASAT	SEA SATellite
SFT	Norwegian Pollution Control Authority
SIGMET	SIGnificant METeorological information
SIGRID	Sea Ice in GRIDed
SIRF	Scatterometer Image Reconstruction with Filtering
SLAR	Side-Looking Airborne Radars
SLR	Satellite Laser Ranging
SMHI	Swedish Meteorological and Hydrological Institute
SNDR	Subcommittee on Natural Disaster Reduction
SOK	Admiral Danish Fleet
SOLAS	International Convention for the Safety of Life at Sea
SPOT	Système Probatoire d'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
SSM/I	Special Sensor Microwave/Imager
SSM/IS	Special Sensor Microwave Imager with Sounder
SST	Sea Surface Temperature
STSC	Scientific and Technical Subcommittee
SWE	Snow Water Equivalent
SWIR	Short Wave InfraRed
TAO	Tropical Atmosphere Ocean
Tb	brightness Temperature
TIMS	Thermal Infrared Mapping Spectrometer
TIR	Thermal InfraRed
TIROS	Television InfraRed Observing Satellite
TM	Thematic Mapper
TOGA	Tropical Ocean-Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOPEX	TOPology EXperiment (Ocean)
TOVS	TIROS Operational Vertical Sounder
TRMM	Tropical Rainfall Measuring Mission
TSS	Tromso Satellite Station
UK	United Kingdom
UNCLOS	United Nations Convention On The Law Of The Sea
UNEP	United Nations Environmental Programme
USCG	United States Coast Guard
USDA	United States Department of Agriculture
US-GCRP	United States Global Climate Research Program
USGS	United States Geological Survey
UV	Ultra-Violet
VAA	Volcanic Ash Advisory
VAAC	Volcanic Ash Advisory Center
VAFTAD	Volcanic Ash Forecast Transport and Dispersion
VHR	Very High Resolution (1-2m)
VHRR	Very High Resolution Radiometer
VIS	VISible
VLBI	Very Long Baseline Interferometry
VOLCAM	VOLCanic Ash Mapping

VTMIS	Vessel Tracking Management Information System
WCRP	World Climate Research Programme
WGISS	Working Group on Information Systems and Services
WiFS	Wide Field Sensor
WMO	World Meteorological Organization
WOVO	World Organization of Volcanologist Observation
WSR	Weather Surveillance Radar

ANNEX VII:

PARTICIPANTS LIST:

CEOS DISASTER MANAGEMENT SUPPORT GROUP

Note: This list is a snapshot of participants current to the time this report was published. For an up-to-date list, please refer to the on-line participants list at the Group web site: disaster.ceos.org. The on-line list contains addresses, telephone and fax numbers, and e-mail addresses. It is difficult to ensure that this information is the most current. Your assistance is requested. If you are aware of errors, please e-mail Levin.Lauritson@noaa.gov or Richard.Ohlemacher@noaa.gov; noting the errors and provide corrections.

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ANNEX VIII:

CEOS OVERVIEW

CEOS was created in 1984 as a result of the international Economic Summit of Industrialized Nations and serves as the focal point for international coordination of space-related, Earth observation activities. Policy and technical issues of common interest related to the whole spectrum of Earth observation satellite missions and data received from such are addressed. CEOS encourages complementarity and compatibility among space-borne Earth observing systems through coordination in mission planning, promotion of full and non-discriminatory data access, setting of data product standards, and development of compatible data products, services, and applications. The user community benefits directly from this international coordination.

Members are those national and international government agencies with funding and program responsibilities for a satellite Earth observation program currently operating or in the later stages of system development. CEOS members include National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), the European Commission, European Space Agency, EUMETSAT, and counterpart space and Earth observation agencies in Australia, Brazil, Canada, China (Chinese Academy of Space and Technology and National Remote Sensing Centre of China), France, Germany, India, Italy, Japan, Sweden, Russia (Russian Space Agency and Hydromet), Ukraine, and the United Kingdom. Governmental entities with a space-based Earth observation program in the early stages of development or with a significant ground segment activity that supports CEOS member agency programs may be invited to participate as an observer. Current observers are agencies from Belgium, Canada, New Zealand, and Norway. CEOS members approved affiliate status for other international satellite coordination groups and for international scientific and intergovernmental bodies in November 1990. To date, the Food and Agriculture Organization, Global Climate Observing System, Global Ocean Observing System, Global Terrestrial Observing System, Intergovernmental Oceanographic Commission, International Council of Scientific Unions including its International Geosphere Biosphere Program, International Society of Photogrammetry and Remote Sensing, UN Economic and Social Commission for Asia and the Pacific, UN Environment Programme, UN Office of Outer Space Affairs, World Climate Research Program, and World Meteorological Organization have been affiliated with CEOS and participate in CEOS plenary and working group meetings.

CEOS Plenary meets once a year to pursue coordination, receive progress reports and provide direction to its technical working groups. The Calibration and Validation Working Group has developed a dossier providing information on instruments, laboratories, and test sites, and is conducting a number of validation projects. The CEOS Working Group on Information Systems and Services facilitates data and information management and services. Activities include the CEOS International Directory Network, Global Land 1km Base Elevation Project, Global Land 1km AVHRR Project, CD-ROM "Resources in Earth Observation," CEOS Information Locator Service, Catalog Interoperability Protocol, and development of the virtual CEOSnet.

In November 1996 CEOS created a Strategic Implementation Team (SIT) to develop further the concept of an Integrated Global Observing Strategy (IGOS), to examine how CEOS could contribute to the space component of such a strategy, and to begin early implementation activities. The SIT has endorsed six prototype projects to help develop the process by which an IGOS would function. To evolve, IGOS needs input and commitment from non-CEOS organizations contributing to its development as equal partners with CEOS. Dialogue with such organizations led to an IGOS partnership arrangement, which held its first meeting of the Partners in June 1998.

CEOS is a consultative organization — striving for information exchange, coordination, and consensus on policy issues. CEOS deliberations and recommendations help members come to agreement on issues and assures appropriate coordination among national programs and across space-based Earth observation missions and data management activities.