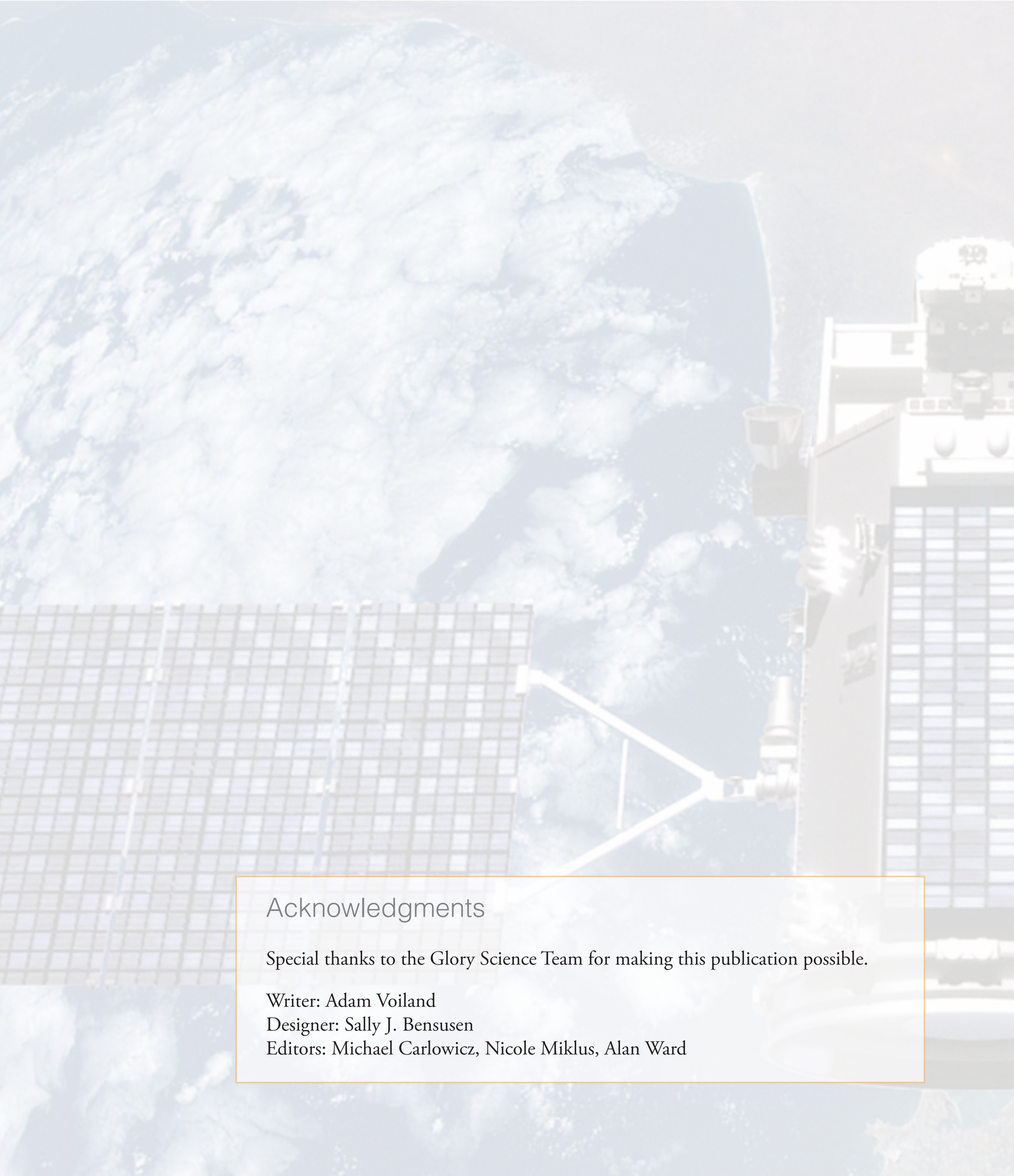
National Aeronautics and Space Administration

Glory

Understanding Earth's Energy Budget



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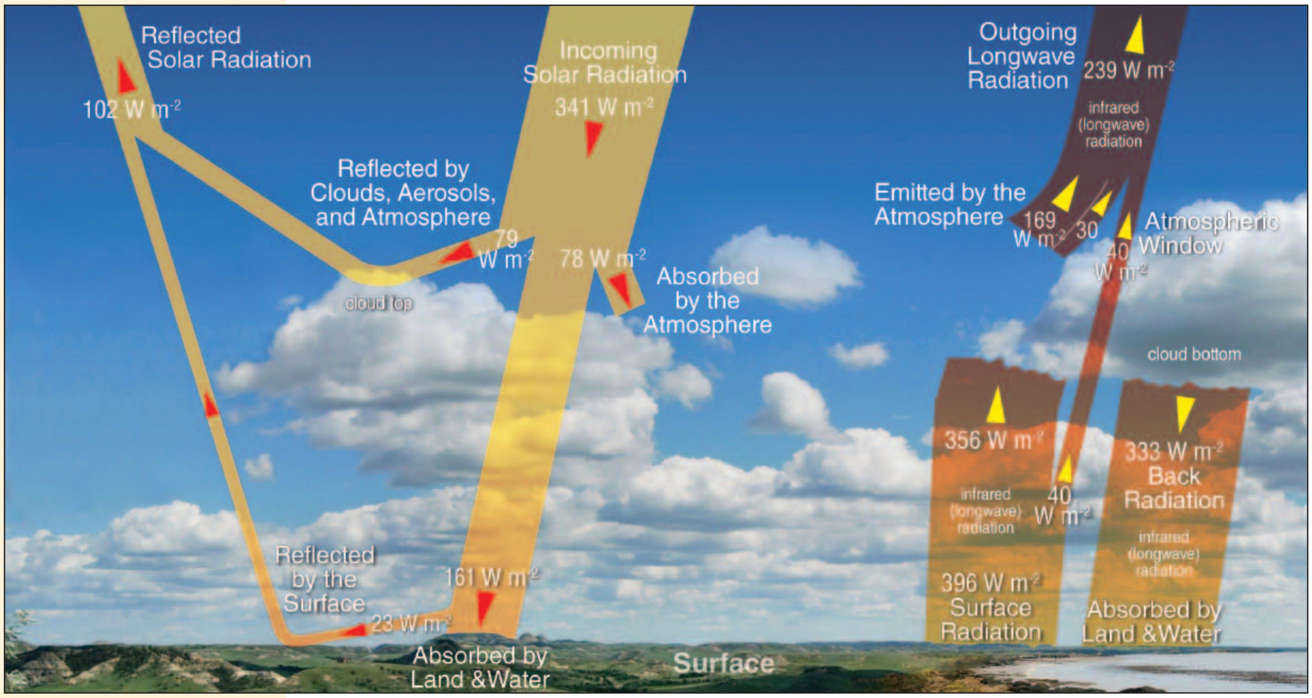
Credit: NASA

The Energy Budget

Energy In, Energy Out



Credit: NASA

Above: About a quarter of incoming solar radiation gets reflected back to space by the atmosphere and a quarter gets absorbed. The rest reaches the surface, where it is absorbed by land and water.

Energy in, energy out: The balance between the two allows life to thrive on Earth. But that balance—between incoming radiation from the sun and outgoing radiation reflected and emitted by Earth—is extraordinarily delicate.

Ramp up the amount of energy trapped in the atmosphere only a small amount, and rising temperatures could evaporate the oceans and leave a scorching Earth that's reminiscent of Venus. Dial it back just a notch and Earth could become a freezing world like Mars.

Earth is a long way from either of these extremes, but our planet's climate is slowly changing. During the last century, global average temperatures at the surface have increased 0.7°C (1.3°F). And climate models estimate that temperatures will increase by another 1.1°C to 6.4°C (2.0°F to 11.5°F) during the twenty-first century.

Such amounts may seem small, yet even increases on this scale could have profound consequences for humans. Rising sea levels, changing ocean currents, and fiercer storms, coupled with altered cloudiness, rainfall patterns, and changing growing seasons are real possibilities confronting our home planet as the climate changes.

With such high stakes, understanding Earth's energy budget—the balance of incoming and outgoing radiation—is of critical importance. Indeed, in the last few decades, scientists have gone to great lengths to understand and quantify what happens to the solar radiation that constantly floods Earth's atmosphere and helps drive the climate system. Using satellites, aircraft, ground-based sensors, and a host of other scientific tools, researchers have determined the outlines of Earth's energy budget.

Scientists estimate that on average each square meter of the atmosphere receives 341 watts of radiation from the sun, less than half of what reaches the top of Venus' atmosphere, and about twice as much as Mars receives.

Not all of that radiation will affect Earth's climate. About 23 percent of it reflects off clouds and certain types of airborne particles—called aerosols—and back into space. Another 7 percent of the sun's radiation gets reflected by the surface. The rest gets absorbed by atmospheric gases, aerosols, or Earth's surface and can affect the climate system.

There's a catch behind these numbers. The climate system is stunningly complex, and scientists are still in the process of refining their understanding of the energy budget to better predict how even the most subtle changes in energy might affect the climate.

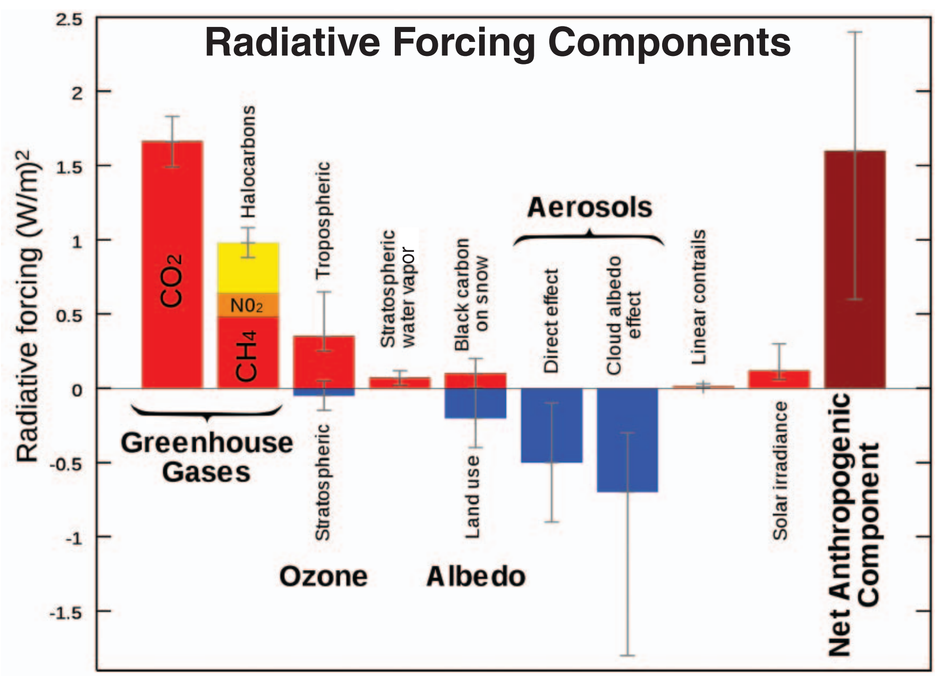
It's well-understood, for example, that greenhouse gases can heat the lower atmosphere and change the balance between incoming and outgoing energy. Indeed, an Intergovernmental Panel on Climate Change (IPCC) report published in 2007 listed the level of scientific understanding about greenhouse gas effects as "high."

Yet to predict how climate change will continue to unfold, scientists need more information about aerosols. These particles tend to cool Earth by reflecting light and changing the behavior of clouds. Like greenhouse gases, aerosols can have a strong impact on climate, but many questions remain about the global distribution of the particles, the degree to which darker aerosols absorb sunlight and heat the atmosphere, and how the particles affect clouds. These uncertainties caused the IPCC to call for more research into aerosols.

Solar variations are also capable of forcing the climate to warm or cool. Overall, scientists believe the sun has brightened slightly in the last 100 years, causing a very small degree of warming. Though they are confident that solar variations are too small to account for the warming seen on Earth since the beginning of the industrial era, questions remain about the sun's long-term variability.

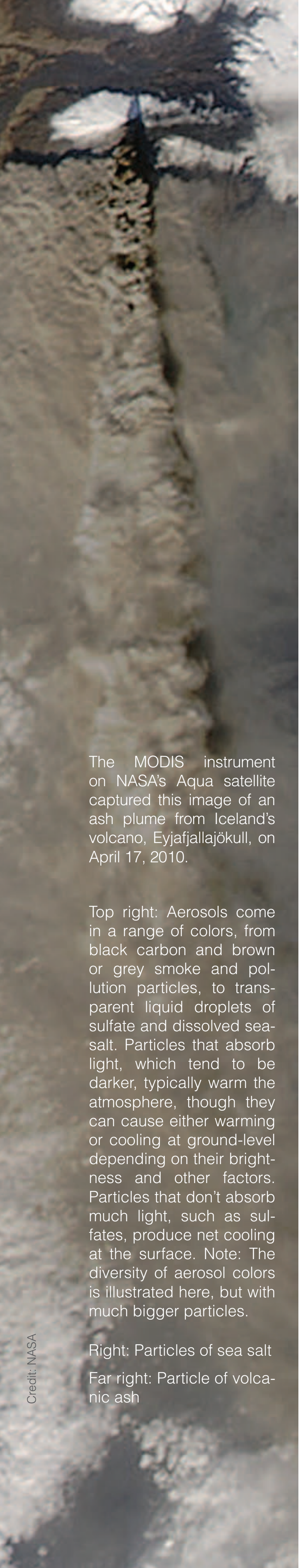
Glory, a climate-observing satellite, will extend and improve measurements of both aerosols and solar variability. In doing so, the mission will refine scientists' understanding of Earth's energy budget and improve our ability to predict how climate change will impact different regions of Earth.

To predict how climate change will proceed, scientists need more information about aerosols, which tend to cool the Earth by reflecting light and changing the behavior of clouds.



Credit: IPCC/Graph adapted by Leland McInnes

Left: Most aerosols have a cooling effect (in blue) on the climate because of the way the particles scatter incoming radiation and change cloud properties. As a result, aerosols tend to counteract the strong warming effect of greenhouse gases (in red) such as carbon dioxide, methane, and ozone. The sun is thought to be responsible for some warming, though the proportion is far less than that caused by human activity (the net anthropogenic component).



Introducing Aerosols

Perplexing Particles that Can Tip the Balance


Photo credit: NASA

Aerosols are tiny liquid and solid particles suspended in the atmosphere. These particles play a critical role in the climate system and are present nearly everywhere from the upper reaches of the atmosphere to the surface air that humans breathe. They range in size from .01 micrometers, about the size of the smallest bacteria, to several tens of micrometers, the diameter of human hair.

The bulk of aerosols—about 90 percent by mass—have natural origins. Volcanoes, for example, can inject huge columns of gases high into the atmosphere that can become sulfate particles. Sandstorms whip small pieces of mineral dust into the air. Forest fires send partially burned black carbon and other smoke particles aloft. The spray from surface waves injects sea salt into marine air. Even certain plants produce gases that react with other substances in the atmosphere to produce aerosols.

The remaining 10 percent of aerosols are anthropogenic, or human-made. Fossil fuel combustion produces large amounts of sulfate aerosols. Biomass burning, a common method of clearing land, yields smoke that's comprised mainly of organic matter and black carbon aerosols. Diesel engines are another especially prolific producer of black carbon. Deforestation, overgrazing, and excessive irrigation change the soil, often leading to higher rates of dust aerosols entering the atmosphere.

Most aerosol particles tend to cool Earth's surface. Overall, it's thought that aerosols

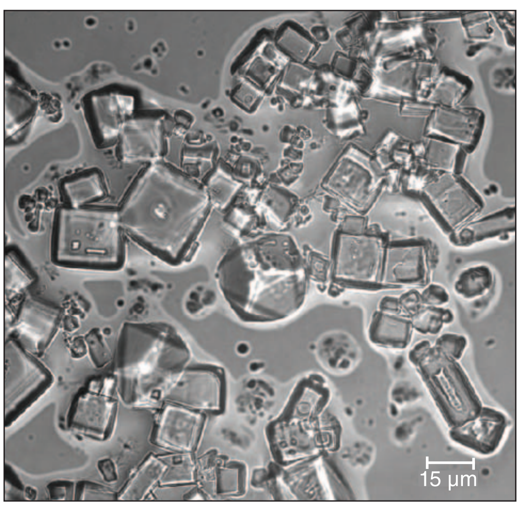


Photo credit: Chere Petty, University of Maryland, Baltimore Campus

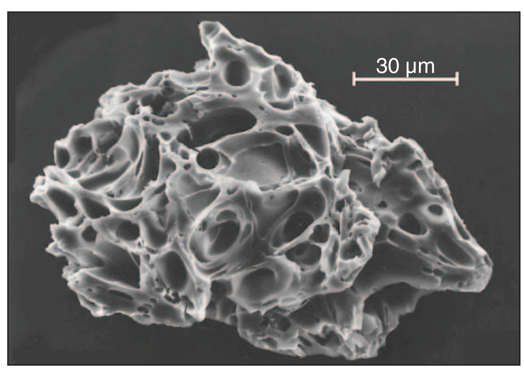


Photo credit: U.S. Geological Survey

The MODIS instrument on NASA's Aqua satellite captured this image of an ash plume from Iceland's volcano, Eyjafjallajökull, on April 17, 2010.

Credit: NASA

Top right: Aerosols come in a range of colors, from black carbon and brown or grey smoke and pollution particles, to transparent liquid droplets of sulfate and dissolved sea-salt. Particles that absorb light, which tend to be darker, typically warm the atmosphere, though they can cause either warming or cooling at ground-level depending on their brightness and other factors. Particles that don't absorb much light, such as sulfates, produce net cooling at the surface. Note: The diversity of aerosol colors is illustrated here, but with much bigger particles.

Right: Particles of sea salt

Far right: Particle of volcanic ash

have a net cooling impact about half that of the warming caused by the build-up of greenhouse gases. But aerosol particles are distributed quite differently, primarily because rains wash them out of the atmosphere after short periods, which causes the particles to be much patchier and less evenly mixed in the atmosphere than greenhouse gases.

As a result, in some areas, the competing effects of greenhouse gases and aerosols don't balance each other out. To predict the impact of climate change on society, scientists need to know precisely how much warming and cooling aerosols produce in different regions of the planet.

In order to do this, researchers require detailed knowledge of certain aerosol properties—their size, shape, and chemical composition. Since existing satellite instruments provide only partial information about aerosol properties, the climate impact of aerosols remains much less certain in comparison to greenhouse gases.

Aerosol emissions fluctuate around the world as economies develop, technologies evolve, and land use changes. Although sulfate aerosol emissions have declined during recent decades in North America and Europe because of clean air regulations, they are increasing in many other regions of the world. Biomass burning remains a major source of aerosols in South America and Africa. And emissions of black carbon are increasing rapidly in parts of Asia.

Although aerosols usually last for just a short time in the atmosphere—typically about a week—they can travel vast distances. Particles traveling a mere 5 meters (16.4 feet) per second can move thousands of kilometers in a week. Satellites have shown that Saharan dust plumes frequently cross the Atlantic and reach the Caribbean and the Amazon.

In recent decades, NASA has launched several missions that provide information about aerosols as part of its ongoing Earth and climate observing effort. The Glory mission will start a new sequence of advanced aerosol studies from orbit by flying an innovative instrument, called the Aerosol Polarimetry Sensor (APS), that will sample rarely measured characteristics of the light scattered by aerosol particles.

The property of light that APS will measure—its polarization state—will reveal new details about aerosol characteristics that should make it easier to distinguish between different aerosol types from space and derive more precise distributions of aerosol size, shape, and abundance. Ultimately, data from Glory's APS instrument, in conjunction with ongoing aircraft and satellite measurements and chemical transport modeling, should provide much needed clarity about how aerosols impact Earth's climate.

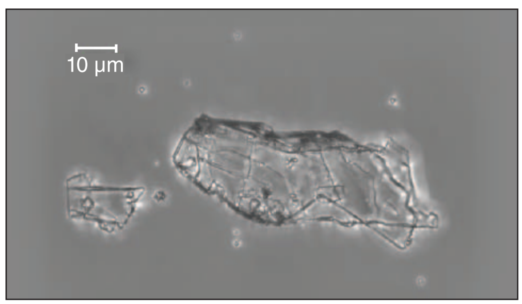


Photo credit: Chere Petty, UMBC

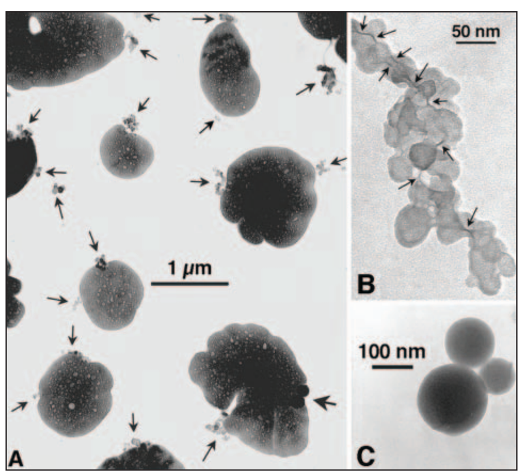


Photo credit: Peter Buseck, Arizona State University

To predict the impact of climate change on society, scientists need to know precisely how much warming and cooling aerosols produce in different regions of the planet.

Black carbon, or soot, is generated from industrial pollution, traffic, outdoor fires, and household burning of coal and biomass fuels.

Top left: Dried potassium aerosol particles imaged by an electron microscope

Lower left: Still image of soot and sulfate particles

Photo credit: wallyir, morguefile.com

The Atmosphere

Where Aerosols and Climate Meet

Above: This astronaut photograph, taken by the *Expedition 17* crew, shows the Piute Fire that was burning in the southern Sierra Nevada Mountains on July 4, 2008.

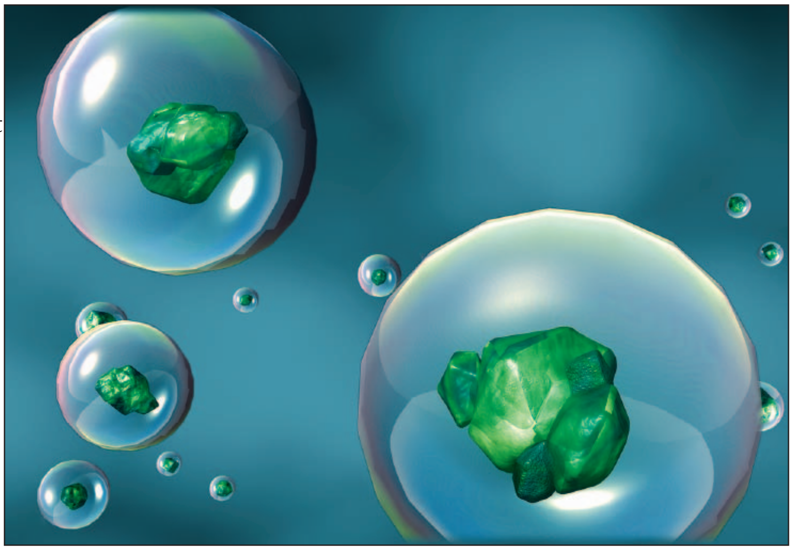
Though it may seem counterintuitive that objects as minute as aerosols influence the climate, it's become clear in recent decades that these airborne particulates have an outsized impact.

Aerosols can affect climate directly by scattering and absorbing incoming sunlight—or radiation reflected by the surface of Earth—as it passes through the atmosphere. The bulk of aerosols, particularly sulfates, scatter incoming sunlight, some of it back toward space, thus cooling Earth's surface immediately below. Other aerosols, especially black carbon, absorb some of the incoming radiation and can warm the atmosphere. However, accurate quantitative knowledge of direct aerosol effects, and especially the role of human-made aerosols, remains elusive.

Aerosols can also have indirect effects by changing how clouds behave. Clouds are a critical component of the climate system; they cool Earth's surface by shading about 60 percent of the planet at any one time

Right: As shown in these illustrations, forest fires emit particles that both scatter and absorb sunlight, whereas non-absorbing particles (lower left) such as sulfates scatter light in all directions.

and by increasing the reflectivity of the atmosphere. Researchers have estimated that a 5 percent increase in clouds' cooling impact, for example, could entirely compensate for the increase in greenhouse gases that Earth's atmosphere has experienced during the industrial era.

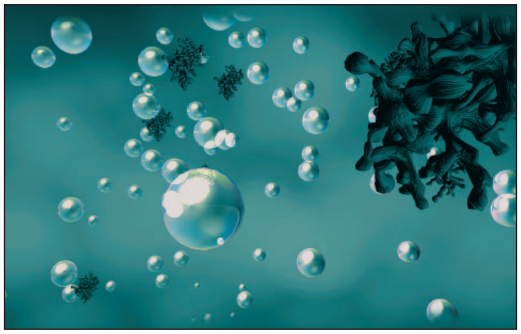

Credit: NASA

Left: An artist's illustration shows water droplets condensing around ocean salt particles.

Any process that influences where and how clouds develop, how they behave, and how long they last can impact Earth's climate. And aerosols, it turns out, are masters of meddling with clouds. In fact, certain aerosols provide tiny "seeds" that allow water vapor in the atmosphere to coalesce much easier than it would otherwise. So, in a sense, clouds owe their very existence to aerosols.

Other things being equal, clouds that occur in areas with high numbers of aerosols in the atmosphere tend to have more numerous—but smaller—droplets than those with lower concentrations of the particles. Such droplet-rich clouds are more apt to scatter incoming radiation, which causes them to appear brighter and more reflective. Ultimately, they have a stronger cooling influence.

Since smaller-sized droplets are also less likely to coalesce into raindrops, small cloud droplets also extend the lifetime of clouds, which increases the globe's reflectivity and slows the cycling of water through the atmosphere—all of which causes climate to cool rather than warm.


Credit: NASA

Left: An artist's illustration of a black soot particle and water droplets

Another aerosol effect on clouds, called the semi-direct effect, occurs when high numbers of light-absorbing aerosols, such as black carbon, warm the surrounding atmosphere and cause cloud droplets to evaporate. In contrast to the direct aerosol effect, this results in net warming by replacing clouds with a smoky haze and reducing precipitation.

NASA satellites have revealed much about aerosols in recent decades, yet many questions remain about aerosols' competing climate impacts. Measuring aerosols within clouds remains challenging. Different types of aerosols can clump together to form hybrid particles that are difficult to study, and changes in humidity or temperature can cause drastic changes in how certain aerosols behave and interact with cloud droplets.

Instruments on previous satellite missions have made significant strides in understanding how aerosols impact climate, yet a new instrument aboard Glory will provide unparalleled views into the complex nature of these critical particles and their natural and anthropogenic climate effects.

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The Sun

The Foundation of Earth's Energy Budget

Photo credit: NASA

Above: Profile of the atmosphere and a setting sun as seen from the International Space Station

Every second, 500 million tons of hydrogen within the sun's core fuse into helium as part of a massive chain of thermonuclear reactions. The process yields the energy equivalent to billions of exploding hydrogen bombs. This energy eventually makes its way to the sun's surface and radiates outward in the form of light—some of it on a trajectory toward Earth.

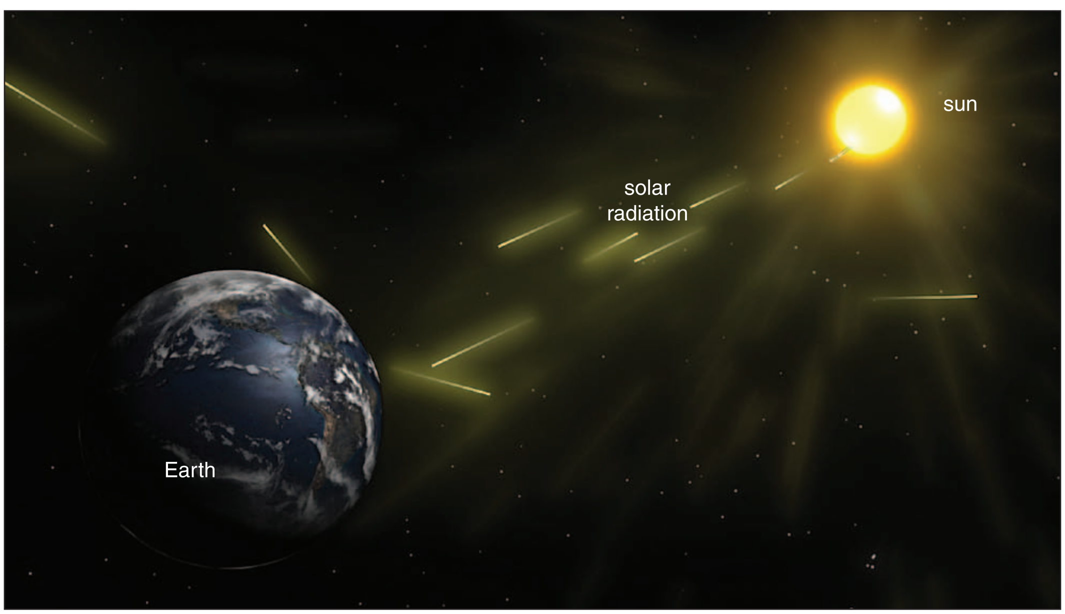
The radiation that eventually reaches the top of Earth's atmosphere—the sun's total solar irradiance (TSI)—is the foundation of Earth's energy budget. On average, approximately 341 watts of radiation reach each square meter of atmosphere per second, about a third as much as a typical house consumes.

Scientists used to describe the amount of incoming energy from the sun as the "solar constant." However, satellite measurements made during the last three decades have revealed that solar radiation actually fluctuates slightly as the sun progresses through periods of more and less intense electromagnetic activity in cycles ranging from a few minutes to decades.

During periods of high solar activity, increases in the number of sunspots (cool dark blotches on the sun's surface) and faculae (hot bright spots adjacent to sunspots) cause the sun's TSI to increase slightly. Overall, TSI varies by approximately 0.1 percent between the most and least active parts of the 11-year solar cycle.

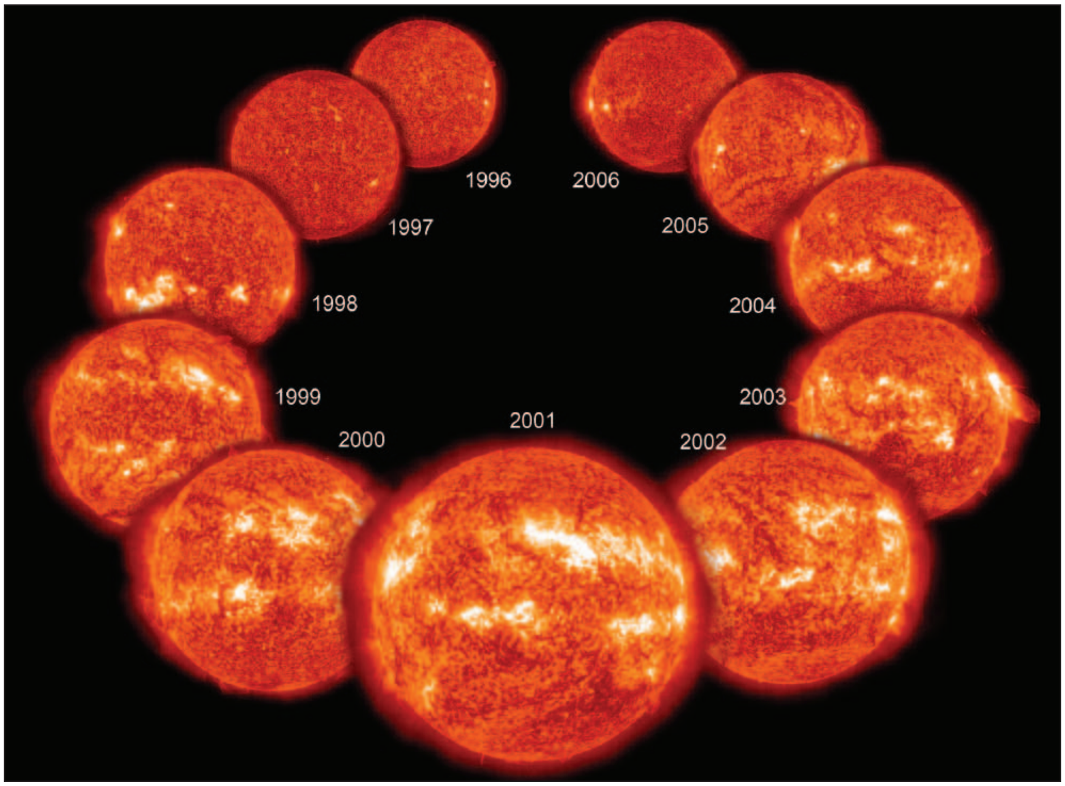
Can such changes in the sunspot levels and total solar irradiance affect Earth's climate in a significant way? This question has been the topic of scientific and public interest over the last few decades, particularly as concerns about Earth's changing climate have intensified.

Some research has suggested that even subtle shifts in the sun's irradiance, on the scale of



Credit: NASA

Right: Total solar irradiance (TSI) is the dominant driver of Earth's climate.



Credit: NASA

Left: This collection of images of the sun shows variations in sunspot and facula activity during a solar cycle.

those seen within one solar cycle, can impact Earth's climate. One theory, for example, is that the amount of ultraviolet radiation the sun emits can impact the formation of ozone, which functions as a greenhouse gas.

Scientists who study the links between solar activity and climate are confident that the small variations in TSI cannot explain the intensity and speed of warming trends seen on Earth during the last century. The 0.1 percent shift in solar irradiance simply isn't enough to have a strong influence, and there's no convincing evidence that suggests TSI has trended upward enough over the last century to affect climate.

However, it's possible—probable, in fact—that the sun experiences sizable shifts in irradiance over much longer time scales that could impact climate. For example, a 70-year period, from 1645 to 1715, called the Maunder Minimum, which featured exceptionally low numbers of sunspots, is thought to be connected to a period of especially low TSI that helped drive Europe's "Little Ice Age."

Since 1978, satellite instruments have allowed solar scientists to make precise measurements of TSI. But on a geological time scale, these thirty years of solar irradiance measurements offer a mere snapshot of the sun. Longer-term, accurate measurements of the sun's total solar irradiance are critical for identifying broader trends that could potentially affect Earth's climate.

Glory carries an instrument called the Total Irradiance Monitor (TIM) that will help maintain and extend the long-term TSI record. The instrument will build upon a similar TIM instrument launched in 2003 as part of the Solar Radiation and Climate Experiment (SORCE) mission.

A key factor for global climate models would be lacking if missions such as Glory did not monitor the sun's irradiance. These models are used to diagnose and predict how climate is changing, and they offer critical information to lawmakers about how societies might react to the changes.

Some research has suggested that even subtle shifts in the sun's irradiance, on the scale of those seen within one solar cycle, can impact Earth's climate.

Glory's Instruments

Measuring Aerosols and Solar Irradiance with Precision

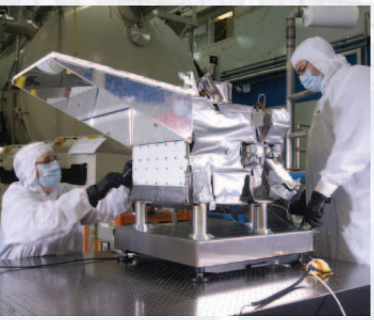


Photo credit: Raytheon

Above: Technicians wear garments—known as *bunny suits*—to protect instruments from dust and other contaminants. Here, engineers prepare Glory's APS for environmental testing.

Credit: NASA

Two instruments aboard Glory—the Aerosol Polarimetery Sensor (APS) and the Total Irradiance Monitor (TIM)—supply information about critical components of Earth's climate system. The APS, a polarimeter mounted on the underside of the Glory spacecraft and facing downward, collects information about aerosol properties. The TIM, which is located on the opposite side of the spacecraft, facing toward the sun, measures the intensity of incoming solar radiation at the top of the atmosphere.

Aerosol Polarimetry Sensor

The design of APS stretches back to the 1970s, when James Hansen, now director of the NASA Goddard Institute for Space Studies, conducted studies on the polarization of light from Venus. By studying polarization—a measure of the physical orientation of light waves as they move and twist through space—Hansen managed to deduce the composition of the clouds in Venus' atmosphere.

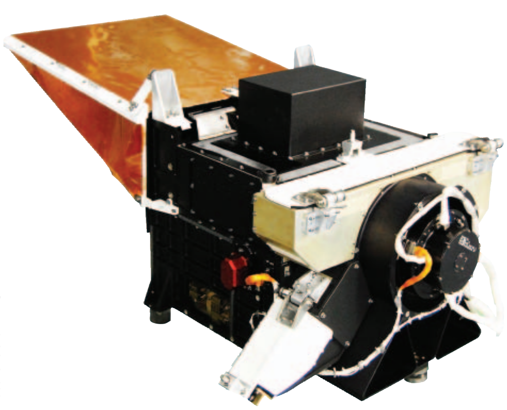
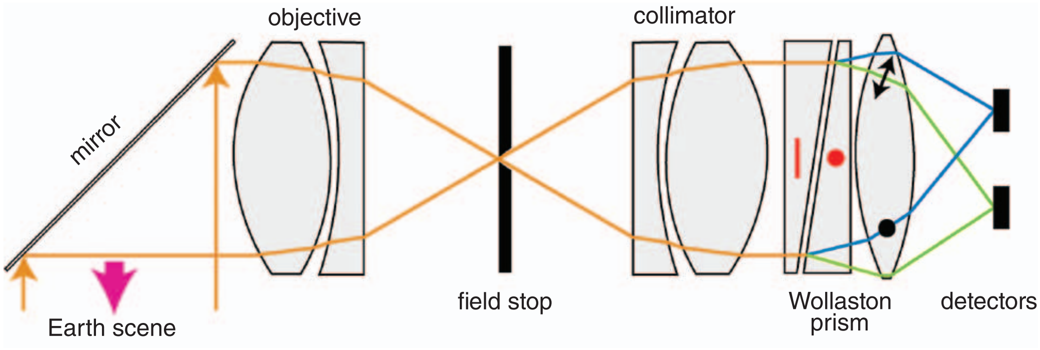


Photo credit: NASA

Right: Glory's Aerosol Polarimetry Sensor (APS) tracks aerosols by measuring the polarization of light scattered by the particles.

The success of such efforts led engineers to develop similar instruments for use on Earth. In 1999, NASA developed an aircraft-based polarimeter, called the Research Scanning Polarimeter (RSP), for example, that has demonstrated the power of this technique to provide detail about Earth's aerosols. The Glory APS, which has a nearly identical design to RSP, will be NASA's first instrument capable of applying this method to studying aerosols globally from space.

The APS, built by Raytheon Space and Airborne Systems in El Segundo, Calif., measures



Left: A diagram of the inside of Glory's Aerosol Polarimetery Sensor (APS) instrument [*BAMS*, May 2007, © American Meteorological Society. Reprinted with permission]

aerosols from more than 250 angles using nine different spectral channels. The 69-kilogram (152 pound) instrument views Earth's surface in 5.9-kilometer (3.7 mile) bands along a path that repeats every 16 days. Unpolarized light that enters the APS strikes a mirror, passes through a series of lenses that collect and focus the beams, and then gets split by a prism into polarized planes that nearby detectors can measure (see diagram above).

Glory carries secondary instruments called cloud cameras that will support APS by tracking clouds as they pass through APS' sights. These cameras will help scientists remove cloud-contaminated scenes that can hamper analysis of the data.

Total Irradiance Monitor

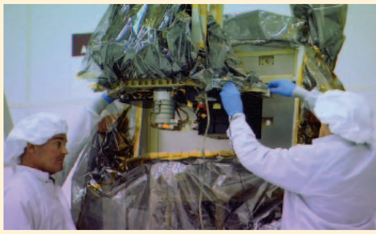
Glory's TIM instrument, a type of radiometer, has an important objective: maintain and improve a decades-long record of total solar irradiance. Though mistakenly considered constant, the amount of incoming solar radiation striking the top of Earth's atmosphere actually fluctuates slightly as the sun cycles through periods of more and less intense electromagnetic activity.

TIM is an improvement of a similar instrument launched in 2003 as part the SORCE mission. The Glory TIM, designed by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado, should be at least three times more accurate than previous instruments.

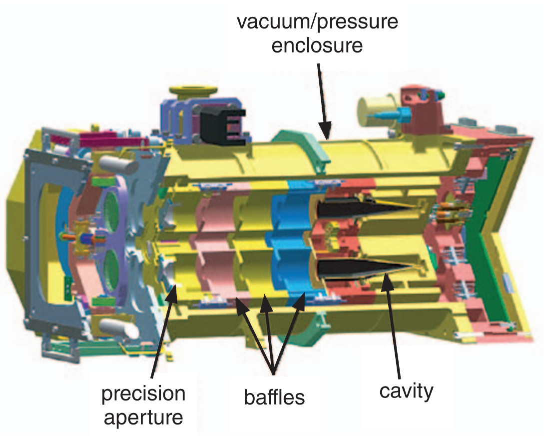
In the past, subtle differences in the design and calibrations of TSI instruments have caused noticeable offsets in the data. In most cases, scientists have had to correct for such discrepancies by matching up data between overlapping missions. While still important, overlapping missions will become somewhat less crucial than they previously were because the Glory TIM has been rigorously calibrated at an innovative ground-based facility at LASP called the TSI Radiometer Facility.

The TIM instrument contains four identical radiometers capable of monitoring the sun during the daylight portion of each orbit. It sits on a gimbaled platform that allows mission controllers to aim it toward the sun independently of the orientation of the spacecraft. Scientists at LASP will process the data TIM gathers, and post it on the web for use in climate and solar science within days of acquisition.

Photo credit: Chris Smith, UMBC



Above: Engineers assist with integration of Glory's Total Irradiance Monitor (TIM).

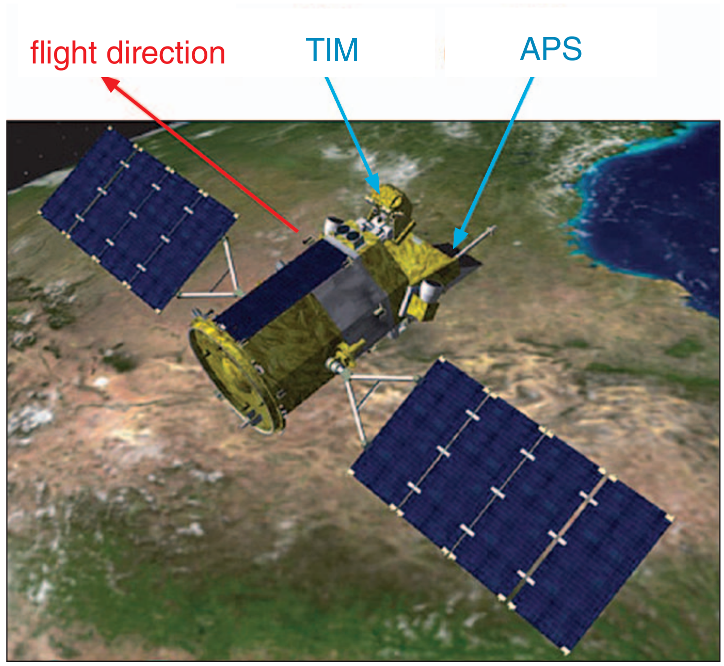


Left: A diagram of the inside of Glory's Total Irradiance Monitor (TIM) instrument [*BAMS*, May 2007, © American Meteorological Society. Reprinted with permission]

The Spacecraft

A Satellite with an Unusual Pedigree

Above: Artist's representation of Glory atop a Taurus XL rocket before launch from Vandenberg Air Force Base in California



Right: APS faces downward toward Earth's surface, whereas TIM looks upward toward the sun. The red arrow shows the direction of Glory's flight, and the two blue arrows point to the two instruments [*BAMS*, May 2007, © American Meteorological Society. Reprinted with permission].

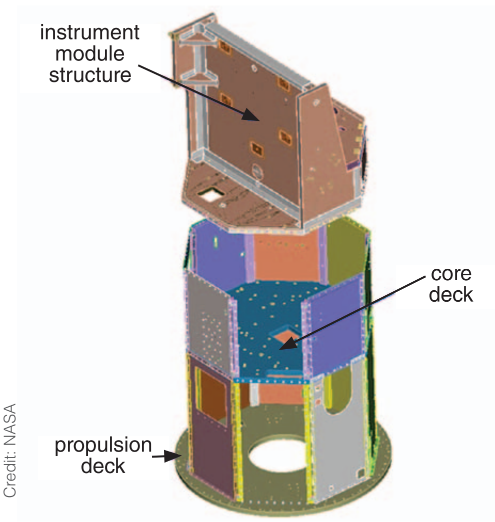
An octagonal aluminum chassis—or bus—serves as the foundation of the Glory spacecraft. The bus is divided into two sections: a propulsion deck at the tail end of the spacecraft and a core deck nearer to the front.

Attached to the core deck, an irregularly-shaped instrument assembly board houses the mission's two milk-crate-sized science instruments, a pair of cloud tracking cameras, a communications antenna, and other supporting components. On the craft's exterior, two rotating solar panels (Glory's means of generating electricity) protrude from the bus like wings.

Stripping away the panels that make up the bus reveal the guts of the spacecraft. On the propulsion deck, a large fuel tank is the most prominent feature. The liquid propellant inside—a clear, pungent substance called hydrazine—gets piped to four adjacent thrusters, which ground-based flight operators use to ease the craft into orbit and make occasional corrections to keep it on course.

The core deck is packed with power control boxes, regulators, and an attitude control subsystem that determines the craft's orientation in respect to Earth. The strategic placement of the spacecraft's battery, in the heart of the core deck facing Earth, protects it from temperature swings. The attitude control system contains four geared reaction wheels that keep the APS pointing directly downward—at nadir—even as aspects of the orbit change.

In some respects, the Glory spacecraft is average in comparison to other NASA Earth-observing satellites. It isn't the largest or the heaviest, nor does it carry the most scientific instruments. At 1.9 meters (6.2 feet) by 1.4 meters (4.6 feet)—Glory isn't much taller than most people or wider than an oil barrel. Glory weighed 525 kilograms (1,158 pounds) at launch, about a tenth the mass of NASA's flagship Earth-observing satellite, Terra.



Credit: NASA

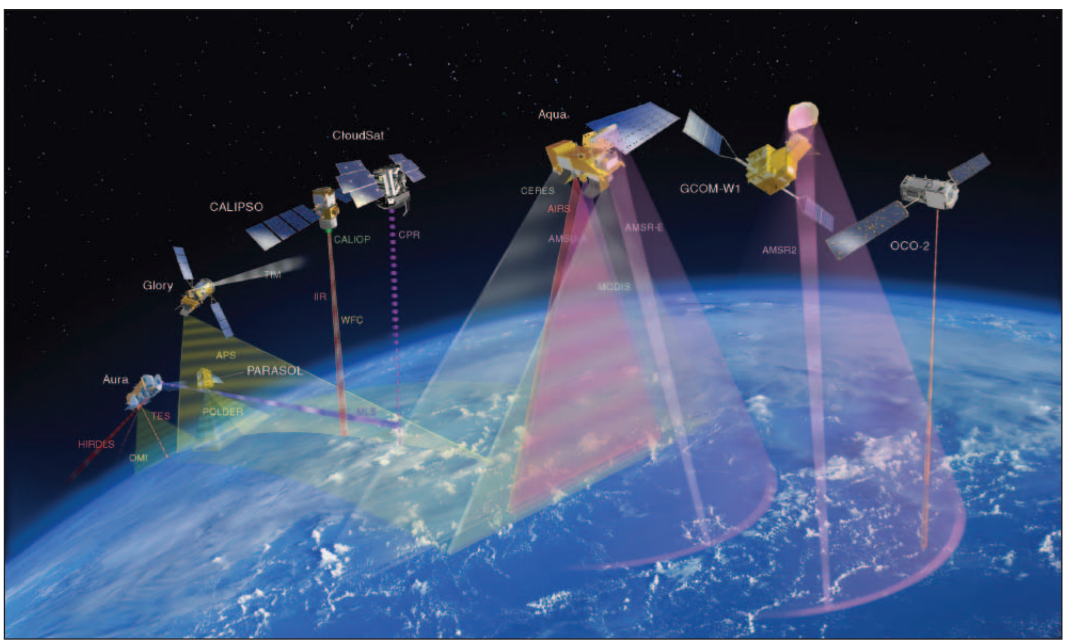
But there's one key detail that makes Glory unusual: the spacecraft's bus was originally designed for the Vegetation Canopy Lidar (VCL), a mission that NASA canceled in 2000 due to a technical glitch in the development of an instrument.

Converting VCL—a spacecraft that would have launched on a larger rocket, flown in a different orbit, and faced slightly different conditions in space—into Glory wasn't always easy. Many of the original VCL bus components had to be replaced; the rest had to be recertified to meet the requirements of the new mission. Many components went through extra rounds of trouble-shooting or unusual environmental testing regimes.

Telltale signs of Glory's unique pedigree still persist. The spacecraft's hydrazine thrusters are significantly larger, for example, than is typical for a mission of its size. And the solar arrays, designed for a different orbit, have an unusual orientation—meaning the spacecraft appears to fly "sideways" in orbit.

A four-stage, solid fuel rocket—a Taurus XL—launches Glory into orbit from Vandenberg Air Force Base in California. The spacecraft flies among a series of Earth-observing satellites, dubbed the A-Train, that tracks the same line over Earth. The A-Train is comprised of a group of U.S. and international satellite missions that have elected to operate in the same orbit for the purposes of making coordinated Earth-science measurements.

Mission operators conduct verification tests for a 30-day period and begin normal data collection for a period of at least three years. Glory moves in a low-Earth orbit of 705 km (438 miles) altitude—about the distance between Boston and Washington, D.C.



Credit: NASA

Left: An engineering diagram illustrates key sections of the Glory spacecraft.

Left: The A-Train, a constellation of satellites, carries sensors with complementary capabilities, offering unprecedented opportunities to study multiple aspects of Earth's climate system at once.

Photo credit: NASA

Post Launch

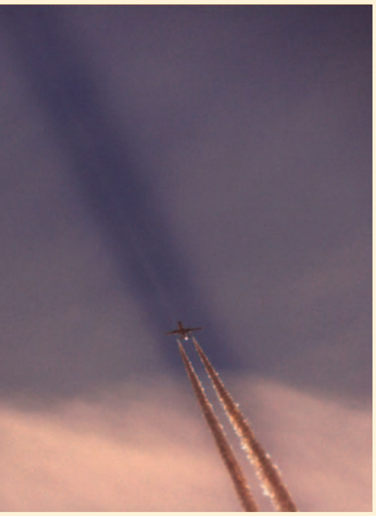


Photo credit: Earth Science Picture of the Day/Jens Hackman

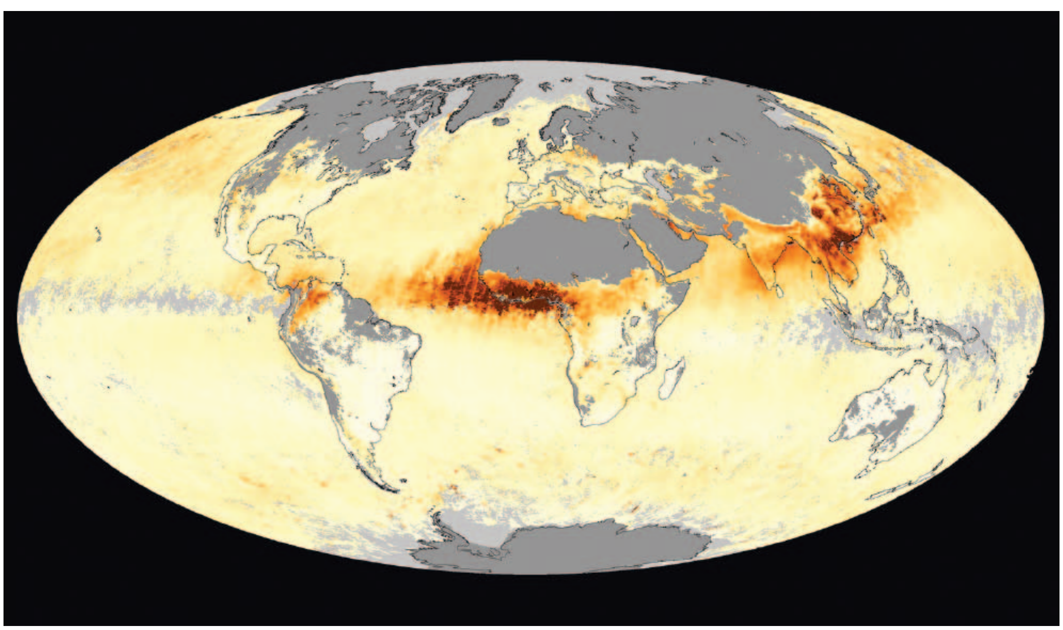
Above: Aircraft engine exhaust can produce condensation trails called contrails.

It might seem like the work should wind down once Glory achieves orbit, but for some, a successful launch means the work is just beginning.

After launch, a team of flight engineers eases Glory into position amidst the other satellites in the A-Train, all of which fly in a similar orbit and within seconds to minutes of each other. After that, engineers confirm that Glory's orbit is correct and that all systems are functioning well. Throughout the mission, flight engineers make periodic thruster burns to correct Glory's orbit when it drifts.

With the checkout complete, both the APS and TIM begin to collect data on a near-continuous basis. To ensure the accuracy of the TIM data, scientists can compare it to measurements taken by a similar instrument aboard the SORCE satellite. Likewise, scientists can validate APS data by comparing it to information collected by NASA's CALIPSO satellite and instruments aboard other spacecraft called MISR and MODIS, as well as data from aircraft campaigns and ground-based aerosol sensors.

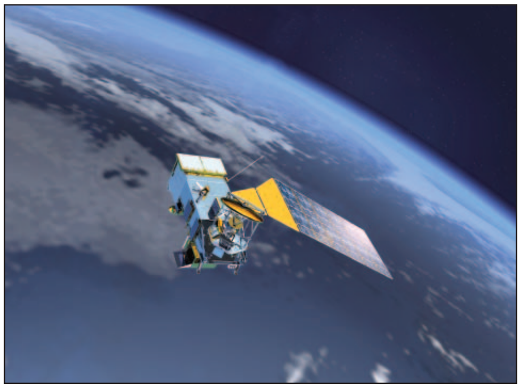
The TIM instrument takes four measurements daily that should be available about a week after acquisition through LASP. APS data yields nine different data products—such as aerosol optical thickness, a measure of aerosol amount. Data from both are freely available to the public. Glory is designed to fly for three years, at the end of which the mission could be granted a two-year extension.



Credit: NASA

Right: This image shows the concentration of particles in the atmosphere (aerosol optical thickness) during March 2010. The dark brown plume extending west from Africa represents smoke and dust blowing westward over the ocean. The dark brown patches over Asia represent a mix of pollutants, smoke, and dust.

Next Generation Climate Satellites



Credit: NOAA

One of the challenging aspects of studying Earth's climate is the need for continuous and long-term measurements. Without them, it's difficult to fully understand how the many interlocking parts of Earth's climate system connect.

The data Glory's instruments provide won't be analyzed in isolation. Data from both instruments contribute to ongoing scientific efforts to understand solar irradiance and aerosols that should continue for decades.

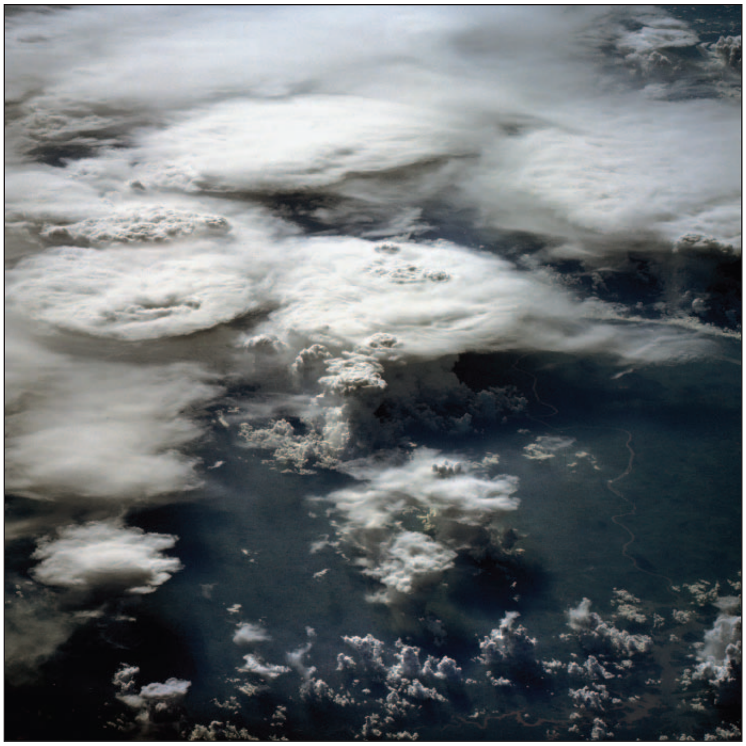


Photo credit: NASA

Prior to Glory's TIM, instruments aboard the numerous satellites—including NASA's SORCE and Active Cavity Radiometer Irradiance Monitor Satellite (ACRIMSat)—have collected information about the sun's total solar irradiance. After Glory, additional instruments, likely quite similar to TIM, will continue measuring solar variations.

Likewise, Glory's Aerosol Polarimetry Sensor is not the first that has collected information about aerosols. MODIS and MISR, instruments aboard other NASA's satellites, are currently making measurements of aerosols.

After Glory's APS completes its mission, satellite measurements of aerosols will continue with a satellite called the NPOESS Preparatory Project (NPP). Following NPP, the next generation of weather and climate satellites, called the Joint Polar Satellite System (JPSS), will continue to make aerosol measurements. These efforts will provide critical answers about Earth's climate as we adapt and respond to our warming world.

Photo credit: NASA

Above: Wildfires release large amounts of black carbon, brown carbon, sulfates, and nitrates, and are another key source of aerosols.

Top left: Artist's concept of the NPOESS satellite in Earth orbit

Left: A series of mature thunderstorms is seen over Brazil, from the Space Shuttle. Introducing anthropogenic aerosols to a cloud typically results in more—and smaller—cloud droplets.

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LASP	Laboratory for Atmospheric and Space Physics
NASA/GISS	NASA Goddard Institute for Space Studies
NASA/GSFC	NASA Goddard Space Flight Center
NASA/UMBC	NASA University of Maryland Baltimore County
NIST	National Institute of Standards and Technology
SIGMA	Sigma Space Corporation
STSI	Stellar Solutions, Inc.

Glossary of Terms

aerosols	Small solid or liquid particles suspended in the atmosphere
Aerosol Polarimetry Sensor (APS)	A scientific instrument aboard Glory that will measure aerosols
black carbon	A type of aerosol formed by partially burned carbon compounds
biomass burning	The burning of living or dead vegetation
cloud cameras	Cameras aboard the Glory satellite that will track clouds and support the Aerosol Polarimetry Sensor
cloud droplets	A small drop of liquid water—formed by condensation of water vapor around an aerosol particle—that is suspended in the atmosphere with other drops to form a cloud
direct aerosol effect	Climate effects related to the fact that aerosols scatter and absorb radiation
energy budget	The balance of Earth's incoming and outgoing radiation
faculae	An irregular, unusually bright patch on the sun's surface
greenhouse gases	Any of the atmospheric gases that contribute to the greenhouse effect by absorbing infrared radiation produced by solar warming of the Earth's surface
indirect aerosol effect	Climate effects related to the fact that aerosols seed cloud droplets
Intergovernmental Panel on Climate Change (IPCC)	A scientific body established by the United Nations and the World Meteorological Organization that reviews and assesses scientific, technical, and socio-economic work relevant to climate change
particulates	Material suspended in the air in the form of minute solid particles or liquid droplets, especially when considered as an air pollutant
polarimeter	An instrument used to measure the state of polarization of a beam of light
radiometer	A device that measures the intensity of radiant energy
Research Scanning Polarimeter	An instrument similar to Glory's Aerosol Polarimetry (APS) sensor that has been flown on airplanes and will be used to validate data from APS
semi-direct effect	A reduction of cloudiness associated with the fact that some aerosols absorb solar radiation and warm the atmosphere, causing cloud droplets to evaporate
solar cycle	Periodic changes in the sun's magnetic field that affect the number of sunspots and other features in 11-year cycles
sulfate aerosol	A type of aerosol that contains sulfate-bearing compounds
sunspots	Any of the relatively cool dark spots appearing periodically in groups on the surface of the sun that are associated with strong magnetic fields
Total Irradiance Monitor (TIM)	An instrument aboard Glory that will measure the sun's total irradiance
total solar irradiance (TSI)	The amount of radiant energy emitted by the sun (over all wavelengths) that falls on 1 square meter at the top of Earth's atmosphere each second

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