ISS-RapidScat: Measuring Ocean Winds from the International Space Station

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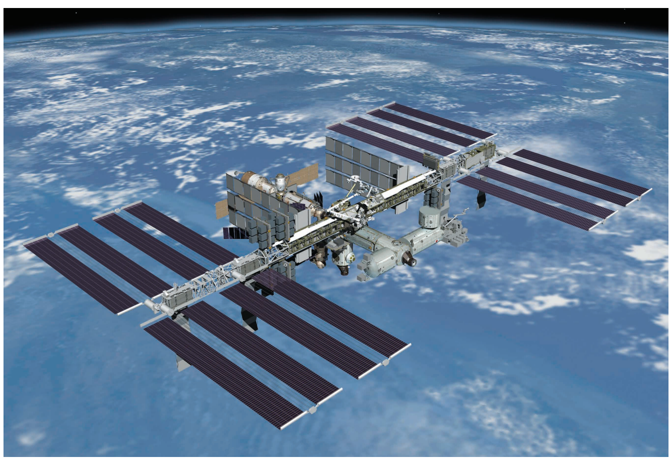
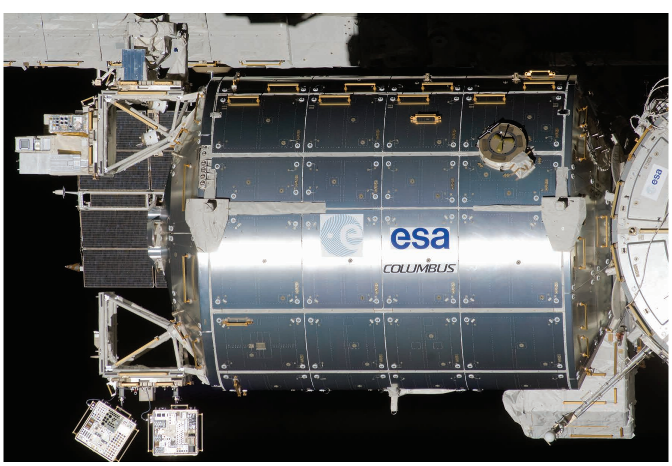
Introduction

NASA and its international partners have used radar scatterometers to measure ocean winds from orbit for several decades—see *History of Scatterometry* on page 5—and scientists have begun to build a continuous, long-term record of this important parameter[1]. That continuity was jeopardized in 2009 when the SeaWinds instrument onboard NASA's Quick Scatterometer (QuikSCAT) satellite malfunctioned, dramatically reducing its scanning capabilities. With no other ocean-wind missions planned for the near future, NASA found itself facing the possibility of a significant gap in the record of this important scientific measurement.

In an effort to mitigate this problem, NASA's International Space Station (ISS) program manager made an offer to a group of scientists and engineers at NASA/Jet Propulsion Laboratory (JPL) in the summer of 2012 that was too good to pass up. If they could have a new scatterometer instrument ready by 2014, it could get a free ride to the ISS onboard a scheduled resupply mission and occupy a vacant berth on the Columbus module for two years—shown in lower photo below.



ISS-RapidScat is the first International Space Station-based Earth-observing science instrument to measure winds. **Image credit:** NASA



The ISS-RapidScat payload will be berthed to the ISS Columbus module—a 7-m (~23-ft) long research laboratory installed in February 2008. **Image credit:** NASA

It was a great offer, but when you consider that most spaceborne missions take many years—if not decades—to prepare, with only two years to put the mission together from start to finish, there was obviously not enough time to design and build a new instrument from scratch. So instead, the engineers made creative use of already available materials: They built the new instrument largely from hardware that had originally been used as an *engineering model*—a copy of an instrument built specifically for testing—for the two SeaWinds instruments that were launched a decade earlier. (Fortuitously, JPL has a track record of doing just this sort of thing—see *History of Scatterometry* for details.) This remarkably fast two-year dash from proposal to launch earned the new radar scatterometer its name: ISS-RapidScat. The RapidScat instrument successfully launched onboard the SpaceX-4 Dragon cargo spacecraft mounted atop a Falcon-9 launch vehicle on Sunday, September 21, 2014 at approximately 1:52 AM EST from Cape Canaveral Air Force Station.

How a Scatterometer Works

Radar scatterometers are the only remote-sensing instruments that can provide accurate, frequent, high-resolution measurements of ocean-surface wind speed and direction under most weather

[1] For climate research, NASA seeks to develop data records that are not only long-term but also continuous. Thus, an interruption in continuity of measurements is something scientists hope to avoid.

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History of Scatterometry

NASA deployed its first scatterometer on Skylab, the first U.S. space station, which flew from 1973 to 1979. That experiment proved that sea-surface winds could be accurately measured from orbit.

NASA's Seasat-A Scatterometry System followed in 1978, operating for three months before its power system failed. Another 18 years would pass before NASA flew another scatterometer in space. But during that time, the European Space Agency (ESA) launched two of its own, both called the ESA Scatterometer (ESCAT)—one on its European Remote Sensing-1 (ERS-1) satellite in 1991, and the other on its ERS-2 satellite in 1995.

The NASA Scatterometer (NSCAT) was launched in 1996 on Japan's first Advanced Earth Observing Satellite (ADEOS I). When the satellite suffered a power-system failure less than a year after launch, NASA needed a quick replacement.

There were already plans for a new scatterometer, SeaWinds, to be launched in 2002 onboard Japan's ADEOS II satellite. However, the premature demise of NSCAT prompted NASA to quickly assemble a second SeaWinds instrument from spare parts for the one intended for ADEOS II, and launch it onboard NASA's Quick Scatterometer (QuikSCAT) satellite in 1999. SeaWinds onboard ADEOS II followed as scheduled in 2002 but, like the first ADEOS, the second satellite failed after less than a year in orbit.

The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) followed up in 2006 with two Advanced Scatterometer (ASCAT) instruments on its MetOp-A and MetOp-B satellites.

The SeaWinds instrument onboard QuikSCAT remained fully operational long past the three years the mission was designed to last. But in 2009, the lubricant that coated the antenna's bearings dried up and the radar antenna's spin mechanism failed, preventing the antenna from rotating. Since then, SeaWinds has only been able to observe Earth's surface directly below the instrument. Data from QuikSCAT, however, remain important for calibrating the other orbiting scatterometers.

The Indian Space Research Organization (ISRO) launched its scatterometer, OSCAT, in 2009, which operated until February 2014. China launched the K_u–band Rotating Fan-beam Scatterometer (K_u-RFSCAT) in 2011. This leaves a working constellation of four operational radar scatterometers in orbit: the partially functional SeaWinds onboard QuikSCAT, the two ASCAT instruments, and K_u-RFSCAT. ISS-RapidScat will raise the number to five and, in a sense, bring NASA full-circle as the agency once again flies a scatterometer onboard a space station. Another Indian scatterometer is expected to join the group in 2015.

Key Science Objectives

- ISS-RapidScat will provide ocean vector wind data to scientists and weather forecasters to mitigate the loss of QuikSCAT's SeaWinds data.
- Data from ISS-RapidScat will serve as a calibration standard for the international scatterometer constellation, thereby continuing the SeaWinds data record, and enabling monitoring of climate variability and change over multiple decades.
- ISS-RapidScat will allow scientists to fully sample the diurnal and semidiurnal wind cycles (between 51.6° N and 51.6° S latitude) from space at least once every two months.

and cloud conditions. They do this indirectly, by sensing the wind's effect on the water. As active remote-sensing instruments, they send pulses of microwaves to the ocean surface and measure the intensity of the water-reflected return pulse. In general, stronger return signals represent rougher sea surfaces caused by stronger winds, while weaker return signals indicate smoother surfaces associated with lighter or no winds. Sequential measurements reveal the wind's direction, since waves line up in the direction the wind is blowing.

Instrument Overview

ISS-RapidScat is a pencil-beam, conically scanning radar scatterometer, operating at 13.4 gigahertz. Onboard the space station, ISS-RapidScat will fly in a non-sun-synchronous orbit, which will enable it to sample each location at several different times of day—see *Key Science Objectives* on page 5. It will observe a data swath approximately 900-km- (~552-mi-) wide, covering the majority of Earth's ocean between 51.6° N and 51.6° S latitudes within each 48-hour period, during which it will complete 31 orbits—see **Figure 1**.

This path contrasts with the other scatterometers currently flying, which have sun-synchronous orbits that return them to each location at the same local time of day. The space station's orbit will allow ISS-RapidScat to observe—in aggregate—all points within the above-mentioned latitudes at all times of day over a period of roughly two months—see **Figure 2**. Over a period of two years, this will enable estimation of the diurnal (daily) and semidiurnal (twice daily) wind components from ISS-RapidScat data alone—see *Changes Throughout the Day* on page 8.

Though ISS-RapidScat consists mostly of QuikSCAT engineering-model parts, a new, smaller reflector and digital interface were needed in order to comply with ISS interface requirements. The new antenna is about half the area of the SeaWinds antenna to permit it to rotate without obstruction in its ISS berth, a downgrade that is offset by flying at an altitude ranging from about 375 km (230 mi) to about 435 km (270 mi)—about half the altitude of the other orbiting scatterometers. ISS-RapidScat's accuracy will be about the same as that of SeaWinds onboard QuikSCAT, and combining its data with that of the European Space Agency's Advanced Scatterometer (ASCAT) will produce a *temporal resolution*—the time between measurements at the same place—comparable to that of QuikSCAT.

Mounting ISS-RapidScat on the space station presented its engineering team with some other challenges as well. For one thing, the docking point (where the instrument will be mounted) faces outward toward space, not toward Earth. To compensate, NASA engineers designed a downward-pointing mounting device, called a Nadir Adapter, to enable the

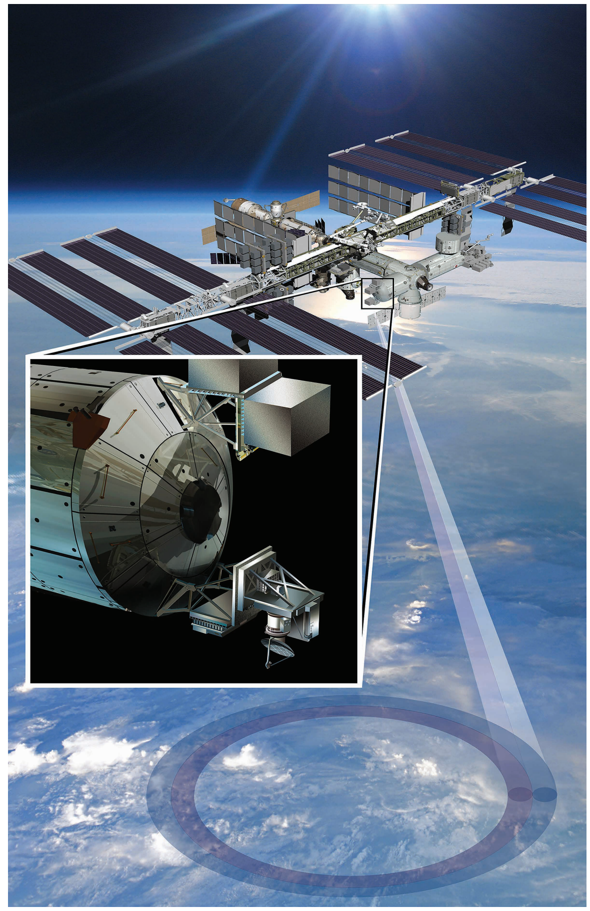

Figure 1. This artist's rendering of NASA's ISS-RapidScat instrument [inset] shows where the payload will be located onboard the ISS, on the end of the station's Columbus module. The conically scanning instrument will collect data across a 900-km- (~552-mi-) wide swath. **Image credit:** NASA/JPL-California Institute of Technology

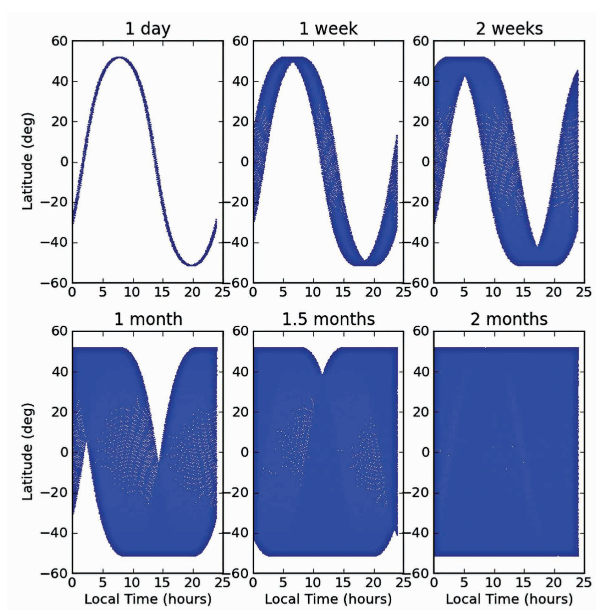

Figure 2. The ISS revisits the same latitude at slightly different local times on each orbit. **Image credit:** NASA/JPL-California Institute of Technology

instrument to view Earth—see **Figure 3**. The adapter also houses new power and digital interface electronics.

Another concern was that one of the space station's docking ports will be within the scatterometer's field of view. To avoid having to turn off the instrument when the docking port is in use, the engineers devised a unique scanning pattern that will avoid the port while still scanning across the vast majority of the instrument's viewing range.

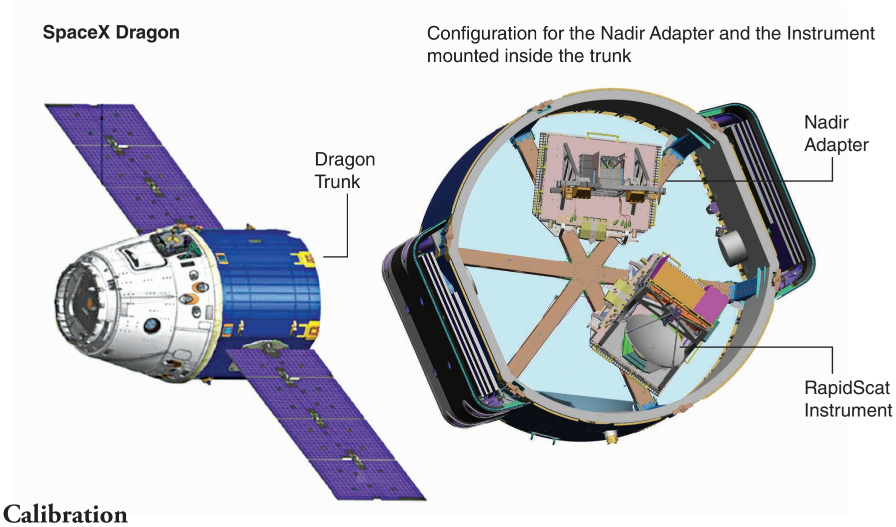

Figure 3. RapidScat was carried to the International Space Station onboard a SpaceX-4 Dragon cargo spacecraft [*shown left*] with the instrument and its Nadir Adapter strategically mounted inside [*shown right*]. Upon arrival, ground controllers at NASA's Johnson Space Center maneuvered the station's Canadarm2 robotic arm to extract both the RapidScat Instrument and the Nadir Adapter from the Dragon Trunk and install them (separately) onto the Columbus Module [shown in bottom photo on page 4]. **Image credit:** SpaceX

Calibration

Instruments need to be calibrated periodically to ensure that they produce accurate and consistent data throughout their lifetimes despite environmental changes, such as fluctuations in electrical power and temperature. Instruments that collect the same kind of data also need to be cross-calibrated with each other so that researchers can combine the different datasets seamlessly. ISS-RapidScat will be used as the "gold standard" to develop bias corrections, thus providing all spaceborne radar scatterometers, current and planned, with a common reference frame. Of particular note is that the resulting data can be used to correct past measurements and validate future observations, thereby creating a consistent, long-term, ocean-wind dataset.

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Scientists can calibrate an orbiting scatterometer by pointing it at a large, homogeneous landmass, such as the Amazon rain forest, and watching for inconsistencies in the resulting data over time. However, photosynthesis and evaporation change the amount of water within plants over the course of a day, leading to variations in the radar backscatter signal. When different instruments observe the same location at different times of day, that variation adds uncertainty to the calibration process.

Over the course of its mission, ISS-RapidScat will pass over the same spot on Earth's surface at all times of day. Therefore, scientists will be able to use its data to create a profile of that location's variability throughout the day, which can assist with the calibration of all spaceborne scatterometers—those that conduct their measurements over land as well as those observing the sea.

Four functioning scatterometers are currently in orbit: SeaWinds onboard QuikSCAT, the two ASCAT instruments on the EUMETSAT MetOp-A and MetOp-B satellites, and China's K_u-RFSCAT. However, there have been limited opportunities to cross-calibrate data from SeaWinds with data from the ASCAT instruments, largely because they do not pass over the same regions of Earth at the same time of day. ISS-RapidScat will sometimes fly over the same place at the same time as each of the currently operating instruments and, as currently planned, the scatterometer that the ISRO intends to launch in 2015. Over time, this will reveal any biases connected with wind speed or underlying geography. In particular, NASA will cross-calibrate data from ISS-RapidScat and SeaWinds on QuikSCAT whenever they share the same targeted regions, helping to alleviate any issues that might arise due to ISS-RapidScat's unique environment on the space station.

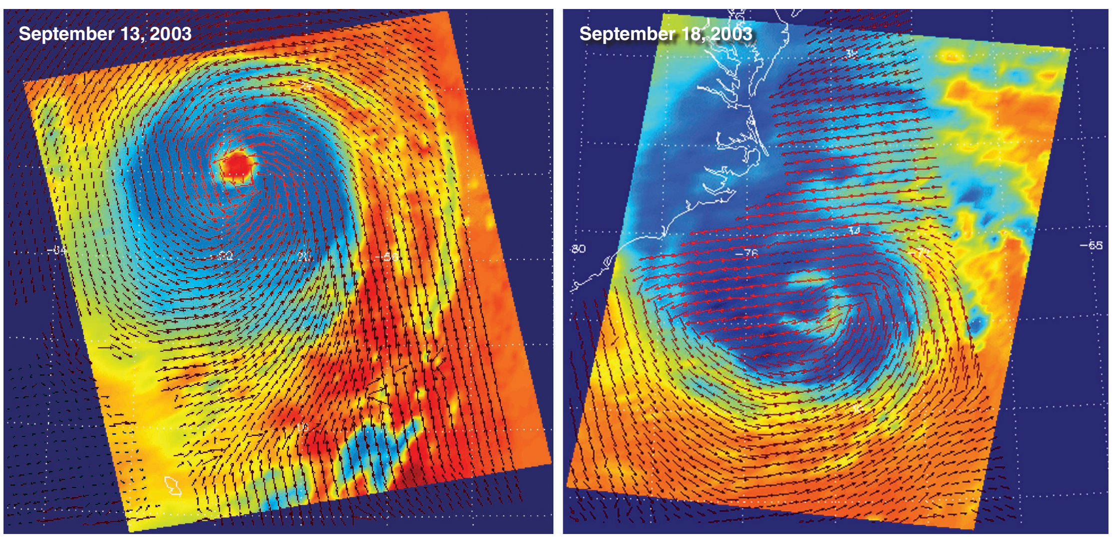
Changes Throughout the Day

In the tropics, sunlight and ocean tides create *diurnal* (daily) and *semidiurnal* (twice daily) cycles in the rise and fall of winds. These wind cycles, in turn, strongly influence the formation of tropical clouds and rain, important components of Earth's water and energy cycles.

To date, all satellite radar scatterometers have flown in sun-synchronous orbits, which means they observe winds over a given location on the ocean only once or twice a day, and at the same local time each day. All the scatterometers flown to date combined have not collected enough observations at enough different times of day for scientists to understand diurnal and semidiurnal wind cycles.

For one, nine-month period in 2003, oceanographers received data from two scatterometers of the same kind: the twin SeaWinds instruments on the QuikSCAT and ADEOS II spacecraft. QuikSCAT crossed the equator at 6:00 AM and at 6:00 PM local time, while ADEOS II crossed the equator at 10:30 AM and 10:30 PM local time, which allowed scientists to make initial estimates of daily wind cycles in some parts of the ocean. During this brief period, however, scientists also realized how difficult it is to cross-calibrate even two such similar instruments and recognized the advantage of having a single instrument in a non-sun-synchronous orbit—like ISS-RapidScat.

Since the space station revisits the same latitude at slightly different local times on each orbit, ISS-RapidScat will allow scientists to fully sample the diurnal and semidiurnal wind cycles from space (between 51.6° N and 51.6° S latitude) for the first time ever, roughly every two months. It is expected that within the planned two-year life of the mission, scientists will be able to estimate these cycles more accurately than if they were relying on data from multiple instruments.



For a brief period in 2003, oceanographers received data from two scatterometers of the same kind. These two images show ocean-surface wind speed and direction (arrows) associated with Hurricane Isabel as viewed by the two SeaWinds scatterometers: one onboard ADEOS-II [*left*] and the other onboard QuikSCAT [*right*]. The wind data from both SeaWinds instruments is overlaid on data that show the temperatures of clouds and the surface, as viewed by the Atmospheric Infrared Sounder (AIRS) onboard NASA's Aqua satellite. The image on the left was taken on September 13, when Isabel was a Category 5 storm. The image on the right shows Isabel near North Carolina on September 18. Dark shades represent cold cloud tops, while light shades represent warm ocean-surface temperatures. **Image credit:** NASA

Measuring the Wind to Understand the Ocean

The ocean covers about 70% of Earth's surface, and understanding the behavior of winds over the ocean is important to a variety of oceanographic, meteorological, climate, public safety, and commercial interests.

Near-surface ocean-wind data are critical to determining short- and long-term weather forecasts, tracking storms, and analyzing long-term climate trends. For example, ocean-wind datasets are expected to help reveal whether the extent of the tropical and subtropical circulation is changing and, if so, how those changes might affect rainfall patterns over the continents. These datasets could also improve our ability to forecast El Niño and La Niña events.

Our ability to monitor hazardous weather events like hurricanes, typhoons, and other storms at sea suffered a major loss when SeaWinds' functionality became curtailed in 2009 and was further exacerbated by the demise of ISRO's OSCAT scatterometer in February 2014. These losses also limited the ability to improve wind atlases, to which SeaWinds on QuikSCAT had contributed. Such atlases are important to sailors who need to plan their routes over the high seas (and to surfers in their quest to catch the perfect wave).

Even the seafood industry has a stake in ISS-RapidScat. Offshore winds blow warm surface waters away from shorelines, permitting cool, nutrient-rich water to well up from the ocean depths, thereby nourishing marine life. So the question of whether the winds that drive ocean upwelling are changing as climate changes is of great importance to the long-term health of fisheries.

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ISS-RapidScat will restore all those capabilities, helping civil agencies plan their responses and enabling ships to reroute their courses, potentially saving lives and many millions of dollars. The National Hurricane Center of the National Oceanic and Atmospheric Administration (NOAA)'s National Weather Service has endorsed ISS-RapidScat as beneficial to its mission, and forecasters at both NOAA and the European Centre for Medium-Range Weather Forecasts eagerly anticipate using data from ISS-RapidScat in their work.

Conclusion

ISS-RapidScat will once again demonstrate the agile reuse of flight-worthy hardware to build a science-class instrument. During its planned two-year mission, ISS-RapidScat will provide data on near-surface ocean winds that will advance our ability to understand and forecast climate changes, enhance our ability to forecast weather and monitor hazardous storms, and contribute to important research on the interplay of winds, oceans, and sea life.

For more information, visit *winds.jpl.nasa.gov/missions/RapidScat*.

Partners

ISS-RapidScat is a partnership between the following organizations:

- NASA/Jet Propulsion Laboratory;
- The International Space Station Program;
- NASA's Science Mission Directorate;
- NASA's Johnson Space Center;
- NASA's Kennedy Space Center;
- NASA's Marshall Space Flight Center; and
- The European Space Agency. ■