Eight Microsatellites, One Mission: CYGNSS

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In December 2016, the Cyclone Global Navigation Satellite System (CYGNSS) will become NASA's first satellite mission to measure ocean surface winds in the inner core of tropical cyclones, including regions beneath the eyewall and the intense inner rainbands that could not previously be measured from space.

Introduction

Tropical cyclones are amongst the most destructive of nature's forces, annually affecting the lives and livelihoods of millions around the globe. Several hazards are associated with tropical cyclones including very heavy rainfall, damaging winds, inland flooding, storm surge, and even tornadoes. The National Oceanic and Atmospheric Administration (NOAA) National Hurricane Center has noted that Hurricane Katrina was the costliest—and one of the deadliest—hurricanes in U.S. history. Much of the catastrophic damage that was caused by the storm has been attributed to the wind-generated storm surge that exceeded 20 ft (6 m) above high tide across parts of the central Gulf Coast as the storm moved onshore. The intensity of Hurricane Katrina's winds varied between Category 1 (winds 74 to 94 mph) and Category 5 (winds >155 mph) as the storm moved through the Gulf of Mexico and toward the Gulf Coast during the period of August 26-29, 2005. The ability to monitor and predict the rapid changes in hurricane intensity such as those observed with Katrina is critical to hurricane forecasters, hydrologists, emergency managers, and other community leaders who together are responsible for protection of the health and welfare of coastal communities.

The accuracy of tropical cyclone track forecasts has improved by approximately 50% since 1990, largely as a result of improved weather forecast models and inclusion of satellite-derived data by these models. By contrast, during that same period, there has been very little improvement in the accuracy of intensity (peak sustained wind speed) forecasts. The limited improvement in intensity forecasts is likely the result of inadequate observations of the storm's inner core, including the eyewall and the intense inner rainbands of the storm.

In December 2016, the Cyclone Global Navigation Satellite System (CYGNSS) will become NASA's first satellite mission to measure ocean surface winds in the inner core of tropical cyclones, including regions beneath the eyewall and the intense inner rainbands that could not previously be measured from space.[1] These measurements will help scientists to obtain a better understanding of what causes variations in tropical cyclone intensity, thereby improving our ability to forecast tropical cyclones[2] such as Hurricane Katrina.

Hurricane Formation

The two key ingredients for hurricane formation are warm ocean surface water and light winds blowing in roughly the same direction at all levels of the atmosphere. The tropical (between the Equator and 5° N and S latitudes) and subtropical latitudes (between 5° and 30° N and S latitudes) of Earth are the most likely areas to offer both of these conditions consistently. In the Northern Hemisphere, most hurricanes form from late August through mid-October, when the ocean water is warmest, providing the warm and humid environment needed to produce clusters of thunderstorms. When *vertical wind shear* is minimal—meaning that winds are light and do not change direction with

[1] *The Earth Observer* first reported on the CYGNSS mission in the May-June 2013 issue [**Volume 25**, **Issue 3**, pp. 12-21], titled "NASA Intensifies Hurricane Studies with CYGNSS."
[2] In the Atlantic, Caribbean, and Central Pacific, tropical cyclones are called hurricanes, while in the Western Pacific they are called typhoons. In the Southern Hemisphere they are simply called cyclones.

height—these thunderstorms begin to grow in height and intensity. The heat released by the formation of these thunderstorms produces conditions which lead to the lowering of atmospheric pressure at the surface. As a result, ocean surface winds begin to blow toward the center of low pressure. In the Northern Hemisphere, hurricane winds rotate counterclockwise around a center of low atmospheric pressure, called the *eye*. Conversely, in the Southern Hemisphere, the rotation is clockwise. The eye of the storm is characterized by *subsiding* (i.e., sinking) air, cloudless skies, and very light winds. Surrounding the eye is a ring of intense thunderstorms that produce heavy rainfall and strong winds, known as the *eyewall*. The eyewall region of the storm is where the tallest and strongest thunderstorms are found, along with the strongest surface winds.

To describe the CYGNSS mission, we will first provide some historical background on how NASA has observed ocean surface winds from space, provide details of the mission, the eight-microsatellite observatories, and planned data acquisition. Finally, we will discuss how the data may be used to benefit of society, given the potentially harmful effects of the storms under study.

A Historical Perspective on Why We Need to Measure Ocean Surface Winds from Space

According to the World Meteorological Organization, over 10,000 weather stations on land provide (at least) three-hourly observations of meteorological conditions at or near Earth's surface, including: cloud cover, atmospheric pressure, temperature, precipitation, and wind direction and speed. Despite the extensive characterization of meteorological conditions over land, relatively limited observations are available to describe meteorological conditions over the ocean—which covers approximately 70% of Earth's surface! While ship- and buoy-based measurement platforms provide some information over the ocean surface, satellite-based measurements play a critical role filling in the gaps and providing a truly global characterization of meteorological conditions, including ocean surface wind direction and speed.

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Technical Underpinnings

Around the time of World War II, several nations began to experiment with radar technology as part of their defense systems. The noise observed in the received signals during these early surface-based radar measurements over ocean surfaces was found to be the result of winds over the ocean. This finding opened new avenues of technology and research, and resulted in the development of a number of radar remote sensing systems designed specifically to measure ocean surface winds.

Since the 1970s, NASA has carried out a series of missions that have focused on monitoring winds over the ocean surface from space—see **Figure 1**—based on *scatterometry,* whereby the instrument sends a pulse of microwave energy towards the Earth's surface and measures the intensity of the return pulse that reflects back from the surface, and *microwave radiometry*, whereby the instrument measures natural thermal emission by the wind-driven ocean foam. The first attempt to measure winds from space occurred when NASA built a "technology demonstration" instrument that flew onboard NASA's Skylab—the United States' first space station—from 1973 to 1979. This successful demonstration showed that remotely sensed measurements of ocean surface winds were indeed possible using space-based scatterometers. NASA launched its second scatterometer, the SeaSat-A Scatterometry System (SASS), onboard the SeaSat-A satellite in 1978. SeaSat-A also carried the first ocean wind radiometer, the Scanning Multichannel Microwave Radiometer (SMMR). While the mission lifetime was limited (it only operated from June to October of that year, due to a power system failure), SASS and SMMR were able to confirm that space-based scatterometry and radiometry were effective tools for making accurate ocean surface wind measurements.

Increasing Technological Sophistication

It was not until nearly twenty years later, in August 1996, that NASA would launch its next scatterometry mission, called the NASA Scatterometer (NSCAT), onboard

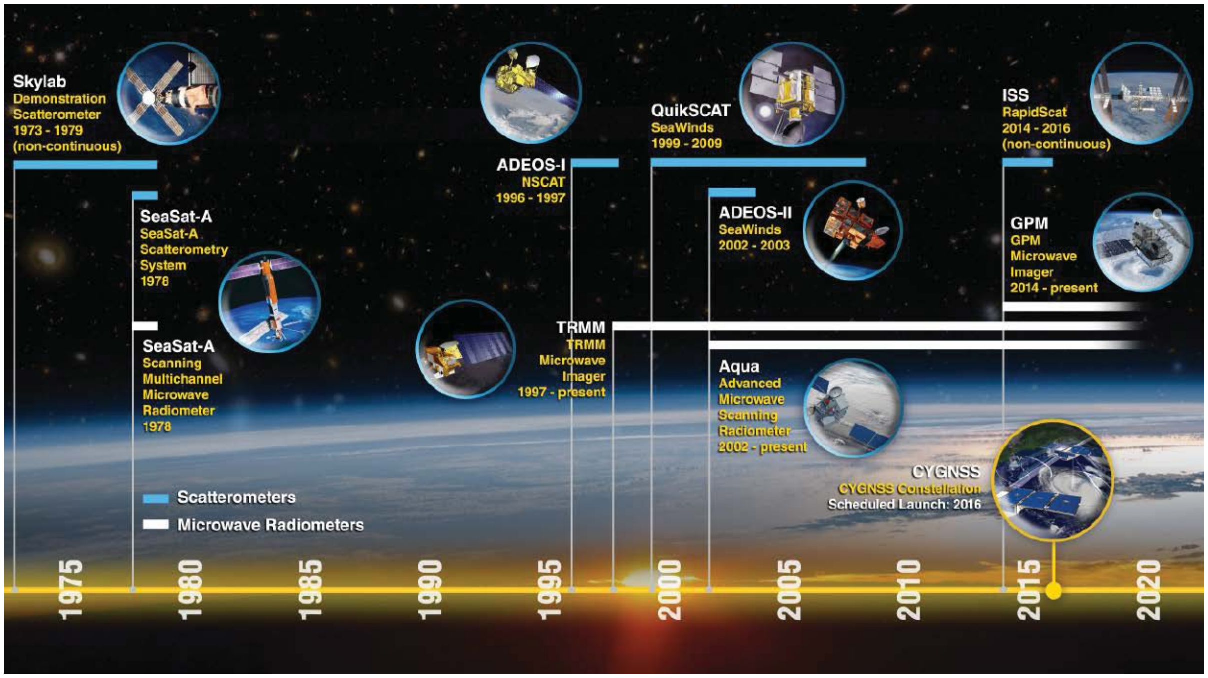

Figure 1. Timeline of NASA scatterometry and microwave radiometry missions. **Image credit:** NASA

the Japan Aerospace Exploration Agency's (JAXA) Advanced Earth Observing Satellite (ADEOS-I). NSCAT operated continuously at a microwave frequency of 13.995 GHz, using backscatter data from the instrument's radar to generate 268,000 globally distributed *wind vectors* (i.e., both wind speed and direction) each day. Every two days, NSCAT measured wind speeds and directions over at least 90% of ice-free ocean surfaces at a resolution of 31 mi (50 km). Like some of its predecessors, the mission was short-lived; the solar panels on the ADEOS-I satellite ceased to function properly in July 1997, ending the mission less than a year following its launch.

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Following the end of the ADEOS-I mission, NASA's Jet Propulsion Laboratory built two identical SeaWinds scatterometry instruments. The first launched in 1999 on NASA's Quick Scatterometer (QuikSCAT) satellite. SeaWinds used a rotating dish antenna to send microwave pulses at a frequency of 13.4 gigahertz down to Earth's surface. The characteristics of the returned signal were used to estimate surface wind speed and direction with an accuracy of ±2 m/s (4.5 mph) and ± 20° respectively, at a resolution of 25 km (~15.5 mi). The second SeaWinds instrument launched on JAXA's ADEOS-II satellite in 2002; however, it suffered an eerily similar fate to its predecessor: the spacecraft failed less than a year after launch in October 2003. Meanwhile, the SeaWinds instrument on the earlier QuikSCAT remained fully operational until 2009, when a bearing in the radar antenna's spin mechanism failed. While the instrument performance was not affected by the spin mechanism failure, the scatterometer's coverage area was—and remains—significantly reduced. Data from SeaWinds, however, remain important for calibrating other scatterometers currently in orbit.

To help overcome the loss of functionality of both SeaWinds instruments, NASA refurbished a QuikSCAT *engineering model*—a copy of the instrument built specifically for testing—to fly on the International Space Station (ISS). The ISS Rapid Scatterometer (ISS-RapidScat), which was installed on the station in 2014. Like QuikSCAT, ISS-RapidScat measured both wind speed and direction over the ocean surface at a resolution of approximately 15.5 mi (25 km). On November 28, 2016, NASA announced the end of the ISS-RapidScat mission.[3]

[3] On August 19, 2016, a power distribution unit for the space station's Columbus module failed, resulting in a power loss to ISS-RapidScat. Later that day, as the mission operations team from NASA/Jet Propulsion Laboratory attempted to reactivate the instrument, one of the outlets on the power distribution unit experienced an electrical overload. In the following weeks, multiple attempts to restore ISS-RapidScat to normal operations were not successful, including a final attempt on October 17.

More Data! We Need More Data!

While radar scatterometers have been used to provide high-resolution measurements of ocean-surface wind speed and direction, they cannot observe the inner core of a hurricane because it is obscured by intense precipitation in the eyewall and inner rainbands, for reasons to be discussed later. In addition, the rapidly evolving stages of the tropical cyclone life cycle occur on relatively short timescales (i.e., on the order of hours or days), and are poorly sampled by conventional polar-orbiting, wide-swath satellite imagers such as QuikSCAT and ADEOS-II that generally pass over a particular spot on Earth, at most every other day. It is in response to the lack of such data and the need for consequent understanding of the phenomena being measured, that CYGNSS came into being. How and why this response developed will be discussed in the next section.

CYGNSS will collect the first frequent, space-based measurements of surface wind speeds in the inner core of tropical cyclones using a constellation of eight microsatellites.

CYGNSS Mission Overview

CYGNSS is a NASA Earth System Science Pathfinder Mission. As with many such complex missions, different aspects are addressed by different teams, associated with different organizations—see *CYGNSS:* A *Tightly Knit Partnership* on the next page. CYGNSS will collect the first frequent, space-based measurements of surface wind speeds in the inner core of tropical cyclones using a constellation of eight microsatellites.[4] The microsatellite observatories will provide nearly gap-free Earth coverage owing to an orbital inclination of approximately 35° from the equator, with a mean (i.e., average) revisit time of seven hours and a median revisit time of three hours. These orbital parameters will allow CYGNSS to measure ocean surface winds between 38° N and 38° S latitude, which—notably—includes the critical latitude band for tropical cyclone formation and movement—see **Figure 2**.

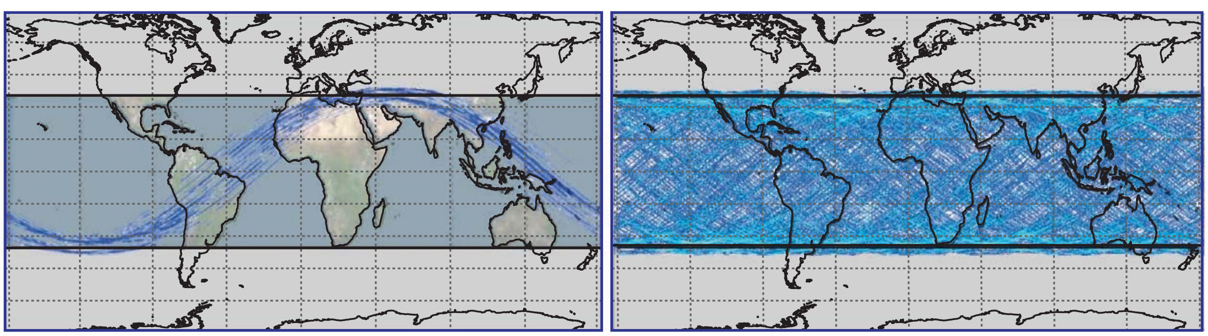

Figure 2. A benefit of using a constellation of microsatellite observatories is that they will pass over the same spot on the ocean more frequently than a single satellite would, resulting in better resolution of changes in the ocean's surface on short time scales. These maps show sample ground tracks between 35° N and 35° S latitude from the CYGNSS microsatellite observatories for 95 minutes [*left*] and a full day [*right*]. **Image credit:** University of Michigan

Technology, Measurements, and Science

The goal of the mission is to study the relationships between ocean surface roughness (from which wind speed is derived), moist atmospheric thermodynamics, radiation, and convective dynamics in the inner core of a tropical cyclone. This will allow scientists to determine how a tropical cyclone forms, whether or not it will strengthen and—if so—by how much. The successful completion of these goals will allow the mission to contribute to the advancement of tropical cyclone forecasting and tracking methods.

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To reach this goal, CYGNSS will measure the ocean surface wind field with unprecedented temporal resolution and spatial coverage, under all precipitating conditions, and over the full dynamic range of wind speeds experienced in a tropical cyclone. The mission will accomplish this through an innovative combination of all-weather performance global positioning system (GPS)-based scatterometry, with the sampling

[4] Microsatellites—also called small satellites, or smallsats—are satellites of low mass and size, usually under 500 kg (1100 lbs). Each of the CYGNSS satellites will weigh 28.9 kg (63.7 lbs).

CYGNSS: A Tightly Knit Partnership

Funded by NASA's Science Mission Directorate and managed by NASA's Langley Research Center, the University of Michigan (UM) has been selected to serve as the lead institution for CYGNSS, while the Southwest Research Institute (SwRI) has primary responsibility for production of the CYGNSS microsatellite observatories. The UM Space Physics Research Laboratory collaborated with SwRI on the design, fabrication, and development of the microsatellite observatories. NASA's Launch Services Program at the agency's Kennedy Space Center is responsible for management and oversight of the Pegasus XL launch services.

The UM Climate and Space Department will house the CYGNSS Science Operations Center (SOC), which is responsible for constellation calibration/validation activities, routine science data acquisition and special requests, and data processing and storage. The CYGNSS Mission Operations Center (MOC) will be located within SwRI's Planetary Science Directorate in Boulder, CO. The MOC will be responsible for mission planning, flight dynamics, and command and control tasks for each of the microsatellite observatories in the constellation. The data from CYGNSS will be made freely available via the NASA/Jet Propulsion Laboratory's Physical Oceanography Distributed Active Archive Center (PODAAC).

Other primary partners include: Sierra Nevada Corporation, which will provide the deployment module for the microsatellite observatories; Surrey Satellite Technology, U.K., which will be responsible for the Delay Doppler Mapping Instrument (described below); and Orbital ATK, which will provide the launch vehicle for the mission (Pegasus XL rocket).

properties of a dense constellation of eight microsatellite observatories. Two aspects of the CYGNSS mission make it unique. One is that it will be NASA's first mission to perform surface remote sensing using an existing Global Navigation Satellite System (GNSS)—a satellite constellation that is used to pinpoint the geographic location of a user's receiver anywhere in the world.[5] The other is that it will be the first ever mission which uses a constellation of small satellites to improve the temporal sampling of the Earth environment.

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Unlike radar scatterometers (e.g., ISS-RapidScat) that emit microwave radar pulses and receive their backscattered signals, CYGNSS's eight microsatellites will only receive scattered GPS signals. Additionally, the microwave radar pulses used by existing radar scatterometers degrade when passing through the intense rainfall typically observed within hurricane eyewalls, thus limiting their utility in measuring the wind speeds in this critical region of the storm. The scattered GPS constellation signals, on the other hand, operate at a much lower microwave frequency, one that is able to penetrate the thick clouds and precipitation around the eyewall; thus, they provide the first opportunity to remotely measure inner-core wind speeds.

The CYGNSS Microsatellite Observatories

Prior to full deployment, each CYGNSS observatory will be approximately 20L x 23W x 8.6H in (51 x 59 x 22 cm). In orbit, each observatory will deploy solar panels such that its final width will reach a wingspan of 63 in (160 cm), incidentally typical of a full-grown swan. The observatories will use under 60 W of power (less than an average household incandescent light bulb), and weigh 28.9 kg (63.7 lbs). The solar panels will be used to collect incoming radiation from the sun to provide energy to recharge the onboard batteries that power the observatories.

The measurements employed by the CYGNSS observatories will rely on characterizing the signal propagation from the existing GPS constellation, located approximately 12,427 mi (20,000 km) above Earth's surface, as well as on the nature of the scattering

[5] A number of GNSS systems are currently in operation, including: the United States' Global Positioning System (GPS), the European Galileo, the Russian Federation's Global Orbiting Navigation Satellite System (GLONASS), and the Chinese BeiDou system. CYGNSS will use the U.S. GPS constellation.

of these signals by the ocean surface. The observatories will each carry a Delay Doppler Mapping Instrument (DDMI), which consists of a Delay Mapping Receiver (DMR) electronics unit, two nadir- (i.e., downward-) pointing antennas to collect the GPS signals scattered off of the ocean surface, and a single zenith- (i.e., upward-) pointing antenna to collect the GPS signals, directly. The DMR on each observatory consists of a single, traditional, GPS navigation receiver (to support standard GPS geolocation capability, navigation, and timing functions), and four customized GPS receivers to perform the remote sensing signal processing. The scattered GPS signals from the ocean surface received by each of the four GPS receivers will be used to generate Delay Doppler Maps (DDMs), from which ocean surface wind speeds are retrieved—see *Delay Doppler Maps* on page 10. Each observatory will generate four DDMs per second, resulting in 32 simultaneous wind measurements by the complete constellation.

Photo. Pegasus XL expendable rocket affixed to the bottom of the L-1011 Stargazer. **Image credit:** NASA

Getting CYGNSS into Space: Launch and Deployment

The CYGNSS constellation is scheduled for launch on a single vehicle in December 2016 from NASA's Kennedy Space Center at Cape Canaveral, Florida. The launch vehicle will be an Orbital ATK Pegasus XL expendable rocket. Affixed to the bottom of an Orbital ATK L-1011 Stargazer airliner (see **Photo**), the Pegasus rocket will be carried to an altitude of approximately 40,000 ft (12.4 km). Upon reaching this altitude, the aircraft will release the Pegasus rocket, which will then ignite and boost the eight observatories, attached to a Sierra Nevada Corporation deployment module (DM), into low Earth orbit (LEO) approximately 317 mi (510 km) above Earth's surface. The eight observatories will be arranged on the DM in two tiers, with four observatories in each tier—see **Figure 3**. The observatories will be released from the DM in a sequence of four, oppositely positioned microsatellite observatory pairs, which will ensure the stability of the DM during the release sequence.

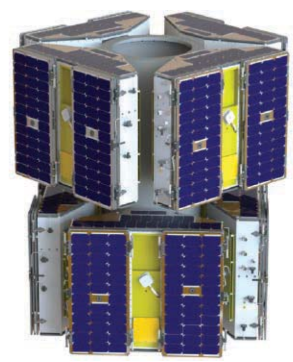


Figure 3. Deployment module that will perform the sequential release of four pairs of microsatellite observatories. **Image credit:** Sierra Nevada Corporation

Ground Segment

To control the observatories and receive and distribute data from the them, the CYGNSS mission ground segment consists of a Mission Operations Center (MOC), located at the Southwest Research Institute's Planetary Science Directorate in Boulder, CO; a Science Operations Center (SOC), located at the University of Michigan's Space Physics Research Laboratory in Ann Arbor, MI; and a Ground Data Network, operated by Swedish Space Corporation (SSC) Space U.S., Inc.'s Universal Space Network, consisting of existing PrioraNet ground stations in South Point, HI; Santiago, Chile; and Western Australia, approximately 248 mi (400 km) south of Perth—see **Figure 4**. Each of these components will be discussed in more detail, later.

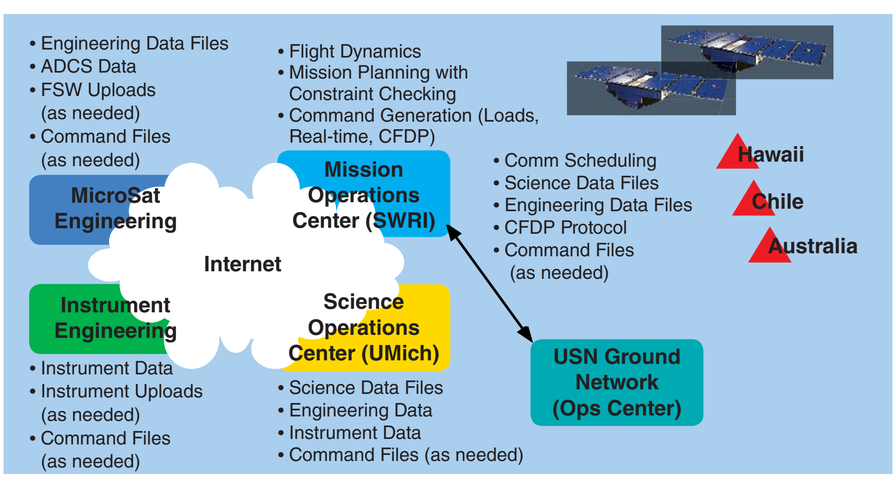
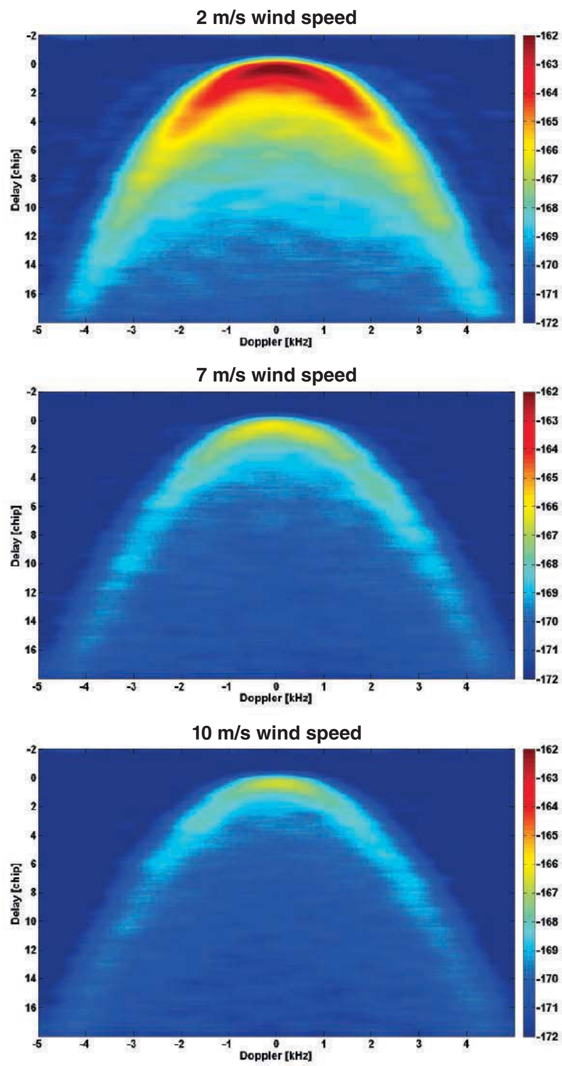


Figure 4. Diagram showing an overview of the components of the CYGNSS ground system. **Image credit:** NASA

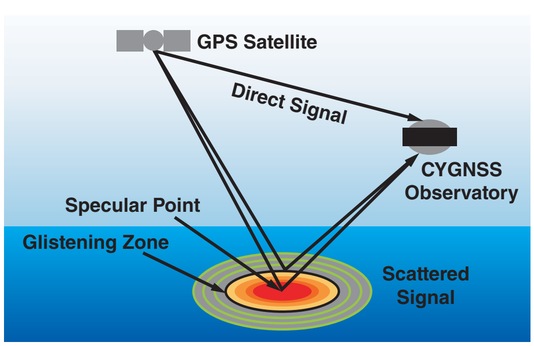
Delay Doppler Maps

The color scale of a DDM denotes the power in the signals scattered by the ocean surface and received by the DDMI (see diagram below), where darkest shades indicate the strongest scattering. The y-axis (see graphs, right) represents the time delay between the direct and scattered received signals (from the GPS and ocean, respectively), while the x-axis represents the shift in frequency between the direct and scattered received signals. The two axes are normalized with respect to the delay and Doppler shift at the *specular point*, the spot on the ocean surface where the scattered signal strength is largest (see three graphs, right).

Wind speed is estimated from the DDM by relating the region of strongest scattering (the darkest region) to the ocean surface roughness. A smooth ocean surface will reflect a GPS signal directly up toward the CYGNSS observatory, producing a strong received signal. A roughened ocean will result in more diffuse scattering of the signal in all directions (called the *glistening zone*), resulting in a weaker received signal. Therefore, strong signals at the receiver represent a smooth ocean surface and calm wind conditions, while weak received signals represent a rough ocean surface and high wind speeds. The exact relationship between received signal strength and wind speed is provided by the CYGNSS wind speed retrieval algorithm.



[*Above*] Example of Delay Doppler Maps for 2, 7, and 10 m/s (~5, 16, 22 mi/hr) wind speeds [*top to bottom*]. The images show how progressively stronger wind speeds, and therefore progressively rougher sea surfaces, produce a weaker maximum signal (at the top of the "arch") and a scattered signal along the arch that is closer in strength to the maximum. A perfectly smooth surface would produce a single dark spot at the top of the arch. **Image credit:** University of Michigan



[*Left*] This diagram shows the direct signal is transmitted from the orbiting GPS satellite and received by the single zenith-pointing- (i.e., top-side-) antenna, while the scattered GPS signal scattered off the ocean surface is received by the two nadir-pointing- (i.e., bottom-side-) antennas. **Image credit:** University of Michigan

Mission Operations Center

Throughout the mission, the MOC is responsible for mission planning, flight dynamics, and command and control tasks for each of the observatories in the constellation. The MOC also coordinates operational requests from all facilities and develops long-term operations plans. Primary MOC tasks include:

- coordinating activity requests;
- scheduling ground network passes;
- tracking and adjusting the orbital location of each observatory;
- providing trending microsatellite data;
- creating real-time command procedures or command loads required to perform maintenance and calibration activities;
- maintaining configuration of on-board and ground parameters for each observatory;
- maintaining the Consultative Committee for Space Data Systems (CCSDS) File Delivery Protocol [CFDP] ground processing engine; and
- collecting and distributing engineering and science data.

Science Operations Center

The SOC will be responsible for the following items related to calibration/validation activities, routine science data acquisition and special requests, and data processing and storage. Primary SOC tasks include:

- supporting DDMI testing and validation both prelaunch and on-orbit;
- providing science operations planning tools;
- generating instrument command requests for the MOC;
- processing Level-0 through -3 science data; and
- archiving Level-0 through -3 data products (see *Science Data Products*, below), DDMI commands, code, algorithms, and ancillary data at NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC), located at the NASA/Jet Propulsion Laboratory.

Ground Data Network

CYGNSS contracted with SSC Space U.S., Inc.'s Universal Space Network (USN) to handle ground communications because of their extensive previous experience with missions similar to CYGNSS. Each of the observatories in the CYGNSS constellation will be visible to the three ground stations (Hawaii, Chile, Australia) within the USN for periods that average between 470 and 500 seconds of visibility per pass. Each observatory will pass over each of the ground stations six-to-seven times each day, thus providing a large pool of scheduling opportunities for communications passes. MOC personnel will schedule passes as necessary to support commissioning and operational activities. High-priority passes will be scheduled to support solar array deployment for each observatory upon commissioning.

Each of the observatories in the CYGNSS constellation will be visible to the three ground stations (Hawaii, Chile, Australia) within the USN for periods that average between 470 and 500 seconds of visibility per pass. Each observatory will pass over each of the ground stations six-to-seven times each day, thus providing a large pool of scheduling opportunities for communications passes.

For all subsequent stages, the MOC schedules nominal passes for the USN stations for each observatory in the constellation per the USN scheduling process. Each observatory can accommodate gaps in contacts with storage capacity for greater than 10 days worth of data, with no interruption of science activities.

*The CYGNSS mission will produce three levels of science data products for public distribution through PO.DAAC. Data from CYGNSS will be freely available for download at **http://podaac.jpl.nasa.gov**.*

Science Data Products

The CYGNSS mission will produce three levels of science data products for public distribution through PO.DAAC. Data from CYGNSS will be freely available for download at *http://podaac.jpl.nasa.gov*. The maximum data latency from spacecraft downlink to PO.DAAC availability is six days for all three data levels. To learn about the plans for calibration and validation efforts, see *CYGNSS Calibration and Validation Objectives,* below.

Level-1 Products: Delay Doppler Maps

The goal of Level-1 science data processing is to produce DDMs of calibrated bistatic radar crosssections. All Level-1 science data products are provided at a time resolution of 1 Hertz.

Level-2 Products: Wind Speed Retrieval and Mean Squared Slope

The Level-2 wind speed product is the spatially averaged wind speed over a ~9.7 x 9.7 mi^2 (25 x 25 km^2) region centered on the specular point. While the primary objective of the CYGNSS mission is to measure ocean surface winds, Level-1 products can also be related to the mean-square-slope (MSS) of the ocean surface, which is crucial for understanding physical processes at the air-sea interface.

Level-3 Products: Gridded Wind Speed and Mean Squared Slope

The Level-3 gridded wind speed product is derived from the Level-2 wind speeds by averaging them in space and time on a 0.2° x 0.2° latitude/longitude grid. Each Level-3 gridded wind file covers a one-hour time period for the entire CYGNSS constellation. The Level-3 MSS product is a similarly gridded version of the Level-2 MSS product.

CYGNSS Calibration and Validation Objectives

The calibration and validation objectives are to:

- verify and improve the performance of the sensor and science algorithms;
- validate the accuracy of the science data products; and
- validate the utility of CYGNSS wind products in the marine forecasting and warning environment.

For satellite ocean wind remote sensing, validation typically involves comparing measurements with numerical weather model wind fields. This allows a relatively large number of collocated comparisons to be obtained in a short amount of time. Since model winds are generally not reliable enough to properly validate very-low or very-high wind speeds, other comparison data are required. Validated wind speed data from satellite sensors, such as scatterometers, can be compared more directly and provide higher wind speed validation. Validation at the highest wind speeds in tropical cyclones will require utilizing data collected from aircraft-based measurements, such as GPS dropsondes, or other remote sensing equipment that might be onboard, such as the Stepped Frequency Microwave Radiometer or the High Altitude Imaging Wind and Rain Airborne Profiler that fly onboard National Oceanic and Atmospheric Administration (NOAA)'s Hurricane Hunter aircraft.

Another facet of the validation effort will include training forecasters at the NOAA National Hurricane Center (NHC) in Miami, FL, to use CYGNSS-derived wind retrievals. At the end of each hurricane season, the retrievals will be provided to the forecasters, so they can evaluate their effectiveness during postseason storm analysis. The objectives of this effort will be to evaluate the value of these data in the operational environment and to get validation feedback from forecasters. Experience has shown that viewing the data from a forecaster's perspective can reveal performance issues that can remain hidden in global statistics.

Conclusion: Definite Benefits to Society

CYGNSS will measure surface winds in the inner core of tropical cyclones, including regions beneath the eyewall and intense inner rainbands that could not previously be measured from space. These measurements will help scientists obtain a better understanding of what causes the intensity variations in tropical cyclones, such as those observed with Hurricane Katrina, as described earlier. The surface wind data collected by the CYGNSS constellation are expected to lead to:

- improved spatial and temporal resolution of the surface wind field within the precipitating core of tropical cyclones;
- improved understanding of the momentum and energy fluxes at the air-sea interface within the core of tropical cyclones and the role of these fluxes in the maintenance and intensification of these storms; and
- improved forecasting capabilities for tropical cyclone intensification.

Combined, these accomplishments will allow scientists and hurricane forecasters to provide improved advanced warning of tropical cyclone intensification, movement, and storm surge location and magnitude, thus aiding in the protection of human life and coastal community preparedness. ■

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Congratulations to AGU and AMS Award Winners!

The Earth Observer is pleased to recognize the following Earth scientists from NASA who will receive awards from the American Geophysical Union (AGU) and American Meteorological Society (AMS) at their annual meetings in December 2016 and January 2017, respectively.

AGU Winners

Kevin Murphy [NASA Headquarters—*Program Executive for Earth Science Data Systems*] has been selected to receive the AGU's 2016 *Charles S. Falkenberg Award*. The award recognizes an early- to middle-career scientist who has contributed to the quality of life, economic opportunities, and stewardship of the planet through the use of Earth science information and to the public awareness of the importance of understanding our planet.

Kevin Murphy **Photo credit:** Karen Michael

In the September–October issue of *The Earth Observer* [**Volume 28**, **Issue 5**, p. 29], we recognized **Brent Holben** and **Claire Parkinson** [both from NASA's Goddard Space Flight Center] as 2016 Fellows of the AGU.

To see the full list of AGU honorees, visit *honors.agu.org*.

AMS Winners

Cynthia Rosenzweig [NASA's Goddard Institute for Space Studies—*Senior Research Scientist*] italicize position title per usual has been selected to receive AMS's *Walter Orr Roberts Lecturer in Interdisciplinary Sciences for 2017* award for her innovative efforts in turning climate knowledge into action in support of environmentally-based decision making in agriculture, urban systems, and assessment.

Cynthia Rosenzweig **Photo credit:** International Food Policy Research Institute

To see the full list of AMS award winners, visit *https://www.ametsoc.org/ams/index.cfm/about-ams/ams-awards-honors/2017-award-winners-and-fellows.*