THE NASA CYGNSS MISSION: OVERVIEW AND STATUS UPDATE

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ABSTRACT

The NASA Earth Venture Cyclone Global Navigation Satellite System (CYGNSS) is a constellation of eight microsatellite observatories that was launched into a low (35°) inclination, low Earth orbit on 15 December 2016. Each observatory carries a 4-channel GNSS-R bistatic radar receiver. The radars are tuned to receive the L1 signals transmitted by GPS satellites, from which near-surface ocean wind speed is estimated. The mission architecture is designed to improve the temporal sampling of winds in tropical cyclones (TCs). The 32 receive channels of the complete CYGNSS constellation, combined with the ~30 GPS satellite transmitters, results in a revisit time for sampling of the wind of 2.8 hr (median) and 7.2 hr (mean) at all locations between 38 ° North and 38 ° South latitude. Operation at the GPS L1 frequency of 1575 MHz allows for wind measurements in the TC inner core that are often obscured from other spaceborne remote sensing instruments by intense precipitation in the eye wall and inner rain bands.

An overview of the CYGNSS mission is presented, followed by early on-orbit status and results.

Index Terms— GNSS-R, Ocean winds, satellites

1. SCIENCE MOTIVATION

Previous spaceborne measurements of ocean surface vector winds have suffered from degradation in highly precipitating regimes, as was the case for QuikScat. As a result, in the absence of reconnaissance aircraft, the accuracy of wind speed estimates in the inner core of the hurricane is often highly compromised. Most current spaceborne active and passive microwave instruments are in polar low earth orbit (LEO). LEO maximizes global coverage but can result in large gaps in the tropics. A comprehensive analysis of the sampling characteristics of conventional polar-orbiting, swath-based imaging systems, including consideration of so-called tandem missions, has been performed [1]. The study demonstrates that a single, wide-swath, high-resolution scatterometer system cannot resolve synoptic scale spatial detail everywhere on the globe, and in particular not in the tropics. The irregular and infrequent revisit times (ca. 11-35 hrs) are likewise not sufficient to resolve synoptic scale temporal variability.

CYGNSS aims to improve extreme weather prediction by measuring ocean surface wind speed in and near a hurricane's inner core, including regions beneath the eyewall and intense inner rainbands. It will study the relationship between ocean surface properties, moist atmospheric thermodynamics, radiation and convective dynamics to determine how a tropical cyclone forms and whether or not it will strengthen, and to what degree. CYGNSS is expected to advance forecasting and tracking methods.

2. MISSION DESIGN

CYGNSS employs a constellation of eight microsatellite observatories in LEO. Each observatory consists of a microsatellite platform hosting a GPS receiver modified to measure surface reflected signals. All eight are shown in Fig. 1 integrated on the launch vehicle prior to fairing encapsulation. Similar GPS-based instruments have been

Fig 1. The "flight stack" of eight observatories are shown concentrically mounted around the central cylindrical deployment module, which is attached to the third stage of the launch vehicle by a tapered adapter cone.

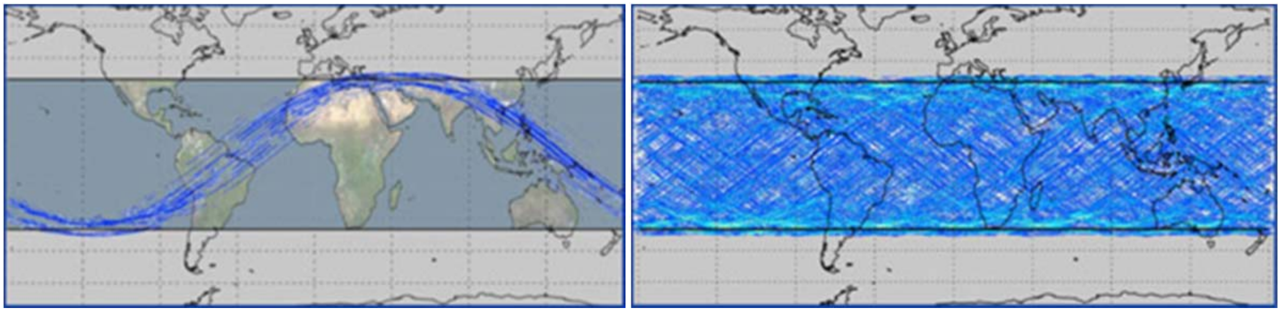

Fig 2. Ground tracks of wind samples by full constellation for one orbit (95 min) (left) and one day (right).

demonstrated on both airborne and spaceborne platforms to retrieve wind speeds as high as 60 meters per second (a Category 4 hurricane) through all levels of precipitation, including the intense levels experienced in a TC eyewall [2].

Each observatory simultaneously tracks scattered signals from up to four independent transmitters in the operational GPS network. The number of observatories and orbit inclination are chosen to optimize the TC sampling properties [3]. The result is a dense cross-hatch of sample points which cover the critical latitude band between ±38 degrees (see Fig. 2).

3. SCIENCE DATA PRODUCTS

The CYGNSS baseline science requirements, defined to meet the mission objectives, are:

1) The baseline science mission shall provide estimates of ocean surface wind speed over a dynamic range of 3 to 70 m/s as determined by a spatially averaged wind field with resolution of 5x5 km.

2) The baseline science mission shall provide estimates of ocean surface wind speed during precipitation rates up through 100 millimeters per hour as determined by a spatially averaged rain field with resolution of 5x5 km.

3) The baseline science mission shall retrieve ocean surface wind speed with a retrieval uncertainty of 2 m/s or 10%, whichever is greater, with a spatial resolution of 25x25 km.

4) The baseline science mission shall collect space-based measurements of ocean surface wind speed at all times during the science mission with the following temporal and spatial sampling: 1) temporal sampling better than 12 hour mean revisit time; and 2) spatial sampling 70% of all storm tracks between 35 degrees north and 35 degrees south latitude to be sampled within 24 hours.

5) The CYGNSS project shall conduct a calibration and validation program to verify data delivered meets the requirements within individual wind speed bins above and below 20 m/s.

6) Support the operational hurricane forecast community assessment of CYGNSS data in retrospective studies of new data sources.

The CYGNSS science data products, generated to support the mission requirements and provided to the NASA PO.DAAC for public distribution, are described below:

Level 0 Data - Unprocessed DDM Data and Metadata
Raw telemetry files and Level 0 data files are transmitted to the PO.DAAC for long term archiving. The Level 0 data files are one of the inputs to Level 1 science data product.

Level 1A Data - Calibrated DDM, Power in Watts
Both the Level 1A and Level 1B data products are contained in a single Level 1 netCDF file. The DDMs in the L0 data file are processed and written to the L1 NetCDF file. L1A processing decompresses the DDMs and converts DDM pixel values from instrument counts to received power in Watts. An instrument gain and noise power model, LNA temperatures and other metadata are used to convert counts to Watts. The initial instrument gain and noise power model is determined through pre-launch testing. It is updated periodically post-launch using black body calibration load DDMs and open ocean DDMs.

Level 1B Data - Calibrated DDM, Bistatic Radar Cross Section, Geolocated
L1B processing converts DDM pixel values in Watts to Bistatic Radar Cross Section (BRCS), in meters2. The L1B processing algorithm is described in [4].

Level 2A Data - Wind Speed, Geolocated
Both the Level 2A and Level 2B data products are contained in a single Level 2 netCDF file. The Level 2 NetCDF files are produced from the Level 1 NetCDF files. Level 2A processing converts each DDM to a single specular point wind speed value. The L2A processing algorithm is described in [5].

Level 2B Data – Mean Square Slope, Geolocated
Level 2B processing converts each DDM to a single specular point mean square slope value. The mean square

slope is a measure of ocean surface roughness. The L2B processing algorithm is described in [6].

Level 3A Data - Wind Speed, Gridded in Space and Time

Level 3A NetCDF files are produced from the L2 NetCDF files. L3A processing uses the geolocated winds speeds in the L2A product to produce wind speeds gridded in space and time (0.2° latitude and longitude, one hour). The L3A processing algorithm is specified in the CYGNSS Level 3A Algorithm Theoretical Basis Document.

4. EARLY ON-ORBIT STATUS

The Cyclone Global Navigation Satellite System (CYGNSS) launched from Cape Canaveral Air Force Station in Florida December 15, 2016 using a rare air-launch approach. An Orbital ATK Stargazer L1011 airliner carried the payload of eight microsatellites aboard a Pegasus XL rocket to approximately 40,000 feet over the Atlantic, where it released the rocket. The Pegasus then traveled to a low-Earth orbit, deploying the constellation in pairs just fifteen minutes later. First telemetry data was received from the first observatory at 11:42 EST on 15 Dec 2016, with telemetry from the rest of the constellation received shortly thereafter. Telemetry from the eighth and final observatory was received at 15:30 EST on 15 Dec 2016.

"First light" measurements by the first science payload on one of the observatories (FM03) were made on 4 January 2017 at 15:48:31 UTC in the South Atlantic Ocean east of Brazil. An example of the Delay Doppler Map (DDM) measured at that time is shown in Fig. 3. The DDM represents the GPS power that is reflected by the ocean in the vicinity of the targeted measurement location. Targeting is done by computing the doppler shift and the time delay of the GPS signal (hence "delay" and "doppler" map) as it travels from the GPS satellite to the ocean surface and from there to the CYGNSS satellite. The vertical axis in the image (from 1 to 20) is the time delay. Each increment is a delay of ~250 nanoseconds. The horizontal axis (from 1 to 128) is the doppler shift. Each increment is a shift of ~250 Hz. The color bar shows the power level of the reflected signal, in uncalibrated units that are proportional to watts.

The targeted location is the "bull's eye" at doppler=64 and delay=11. The high reflected power near the center of the DDM (the red part) is the strong specular component of ocean scattering. The lower reflected power away from the center (yellow, green, light blue) is the diffuse component of ocean scattering. Of particular note in the figure are the fact that Specular point is well centered; indicating excellent on-board open loop tracking of spacecraft altitude variations, a high SNR at the specular point, and a uniform noise floor in the region of the DDM away from the specular point. These features indicate good receiver performance.

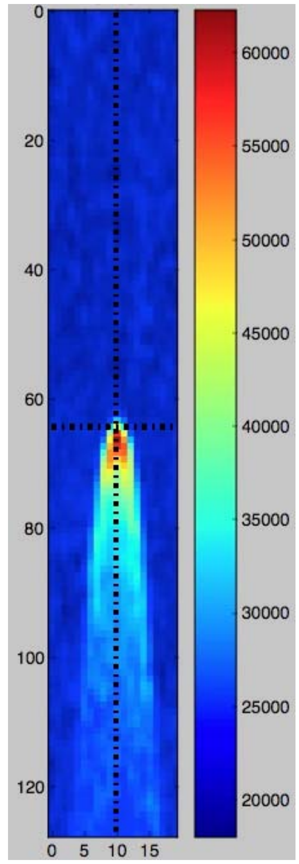

Figure 3. "First light" CYGNSS data in the form of a Delay Doppler Map measured on Jan. 4, 2017. The peak in the center of the image represents scattered GPS signal from the ocean surface, from which near-surface wind speed can be derived.

5. REFERENCES

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