ENABLING SAMPLING PROPERTIES OF THE CYGNSS SATELLITE CONSTELLATION

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ABSTRACT

The CYGNSS constellation of eight smallsats was successfully launched in low Earth orbit on December 15, 2016. Each satellite carries a four channel bistatic radar receiver which measures GPS signals scattered from the Earth surface, from which ocean surface wind speed is determined. The use of a constellation, and the way their orbits are configured relative to one another, enable critical sampling properties. In particular, short time scale physical processes like the rapid intensification phase of a tropical cyclone can be resolved. Results from the 2017 Atlantic hurricane season will be used to demonstrate this.

Index Terms— CYGNSS, GNSS-R, small satellites, tropical cyclones.

1. INTRODUCTION

The Cyclone Global Navigation Satellite System (CYGNSS) mission is designed to enhance our understanding of the coupling between ocean surface properties, moist atmospheric thermodynamics, radiation, and convective dynamics in the inner core of tropical cyclones (TCs). Near-surface winds are major contributors to and indicators of momentum and energy fluxes at the air/sea interface. Understanding the coupling between the surface winds and the moist atmosphere within the TC inner core is key to properly modeling and forecasting its genesis and intensification [1].

Improvements of 50% have been made in TC track forecasting since 1991. Similar improvements have not been made in forecasting intensity, with the cause believed to be in large part because:

- Much of the inner core ocean surface is obscured from conventional remote sensing instruments by intense precipitation in the eye wall and inner rain bands.
- The rapidly evolving genesis and intensification stages of the TC life cycle are poorly sampled by conventional polar-orbiting, wide-swath imagers.

CYGNSS addresses these two limitations by combining the all-weather performance of global positioning system (GPS)-based bistatic scatterometry with the spatial and temporal sampling properties of a constellation of observatories. CYGNSS provides surface winds in the TC inner core, including regions beneath the eyewall and rainbands that could not be measured from space previously due to attenuation and scattering by the rain and ice aloft [2]. The CYGNSS wind fields, when combined with precipitation fields sampled as frequently (e.g., as produced by the Global Precipitation Measurement (GPM) core satellite and its constellation of precipitation imagers), will map the evolution of both the precipitation and underlying wind fields throughout complete TC life cycles. Together, they provide coupled observations of moist atmospheric thermodynamics and ocean surface response, enabling new insights into TC inner-core dynamics and energetics [1].

The CYGNSS flight segment is comprised of eight small satellites in low-earth orbit at an inclination of 35 degrees [3]. An example of one

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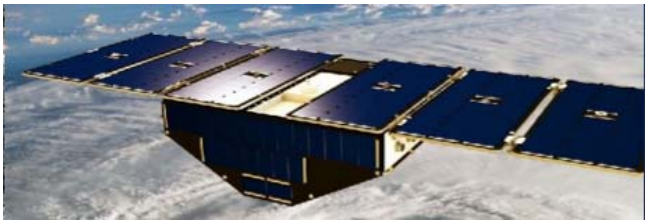

Figure 1. One of 8 CYGNSS satellites in the constellation.

is shown in Fig. 1. Each satellite contains a Delay Doppler Mapping Instrument (DDMI), which receives direct signals from GPS satellites, as well as signals reflected off the ocean surface. The direct signals pinpoint the location of the satellite, while the reflected signals respond to ocean surface roughness, from which wind speed is derived [4,5]. This signal scattering is analogous to the comparison of the moon reflecting off the surface of a smooth vs. wind-roughened lake, as illustrated in Fig. 2.

The CYGNSS constellation was successfully launched on 15 December 2016 into a low inclination (tropical) Earth orbit. The measurements are unique in the frequent sampling of tropical cyclone intensification and of the diurnal cycle of winds, made possible by the large number of satellites. Engineering commissioning of the constellation was successfully completed in March 2017 and the mission is currently in its science operations phase.

Level 2 science data products have been developed for near surface (10 m referenced) ocean wind speed, ocean surface roughness (mean square slope) and latent heat flux [6]. Level 3 gridded versions of the L2 products have also been developed.

2. CONSTELLATION SAMPLING PROPERTIES

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. As shown in Fig. 3, the result is a dense cross-hatch of sample points on the ground that cover the critical latitude band between ±39 degrees.

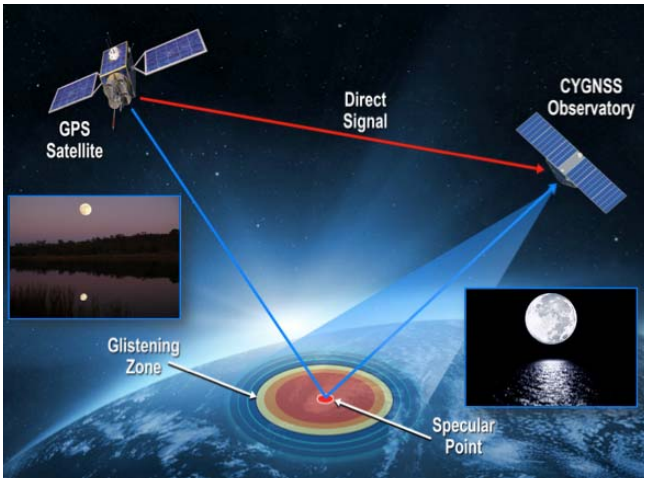

Figure 2. Illustration of specular and diffuse scattering from a smooth (calm wind) or wind-roughened surface, respectively, at optical wavelength, and the extension of that concept to bistatic radar measurements using GPS satellites as transmitters and CYGNSS satellites as receivers.

The CYGNSS constellation began to emerge from commissioning activities in March 2017. The ability of the CYGNSS constellation to track the development of surface winds in a major storm is demonstrated by preliminary measurements made during its flyover of Tropical Cyclone Enawo as the storm approached Madagascar with surface winds in excess of 100 mph. Observations by the

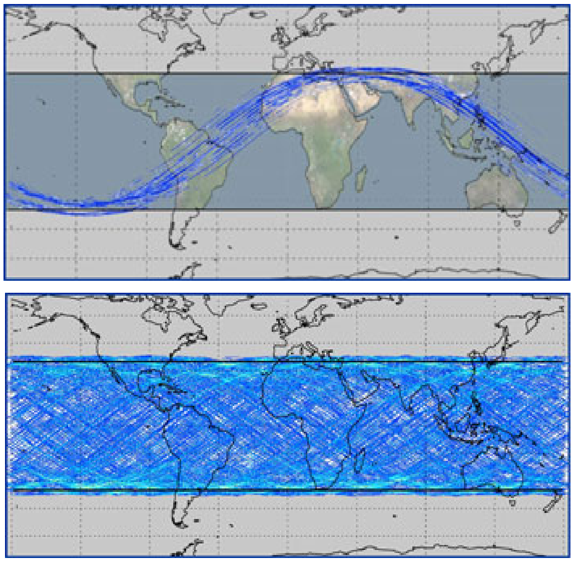

Figure 3. The eight CYGNSS satellites orbit at 35 deg inclination. Ground tracks for 90 minutes (top) and 24 hr (bottom) of wind samples are shown above.

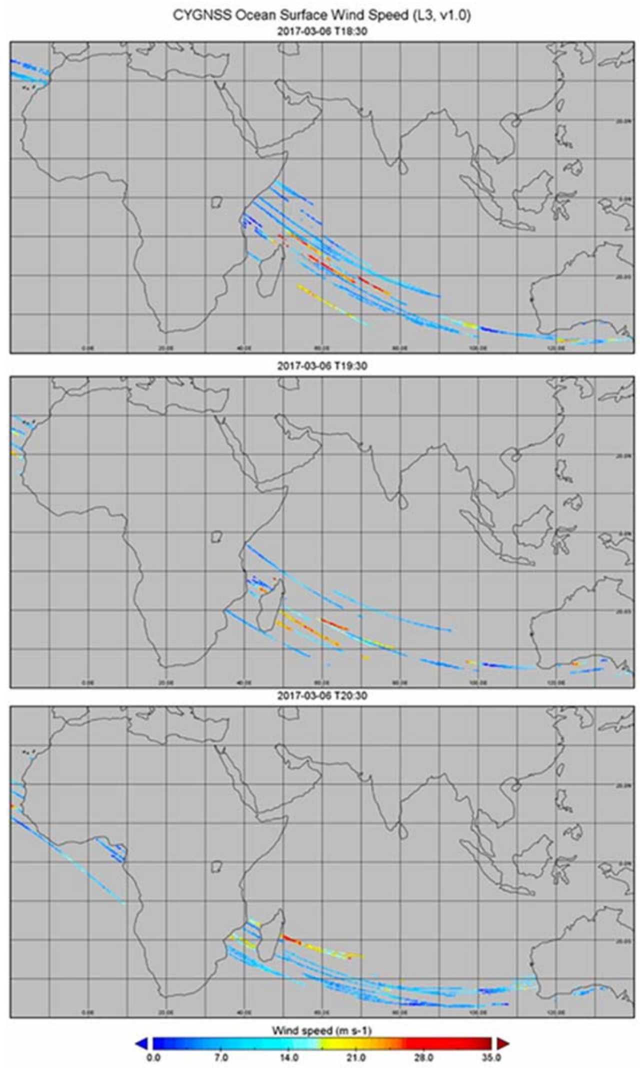

Figure 4. Hourly gridded measurements of ocean surface wind speed made by four of the eight CYGNSS spacecraft on March 6, 2017, as Tropical Cyclone Enawo approaches landfall on Madagascar. The times of the measurements, from top to bottom, are centered at 1830, 1930, and 2030 UTC.

constellation on March 6, 2017, are shown in Fig. 4. During the flyover, four of the eight spacecraft were operating in science mode and captured important elements of the size and structure of the storm. The other four spacecraft were completing engineering commissioning activities at the time. Those activities are now complete and all eight spacecraft are available for science operations.

During the 2017 Atlantic hurricane season, the full 8-satellite constellation was operated continuously in science data-taking mode, providing frequent measurements of wind speed structure over the complete life cycles of Hurricanes Harvey, Irma, Jose, and Maria. An example of wind speed measurements of Harvey made by the constellation over two successive hours on August 25, 2017, shortly before landfall, are shown in Fig. 5. The location of the storm center can be estimated in the figure to be in the general vicinity of the strongest winds. However, it is clear in this and the Fig. 4 images that, by the nature of the GNSS-R technique, there will be gaps in spatial coverage between the long tracks of specular point locations at which the GPS scattered signal is measured. As such, uses and interpretation of the wind (and other) data products will need to account for those gaps. One approach to doing so that is especially well suited to tropical cyclone investigations is to use the

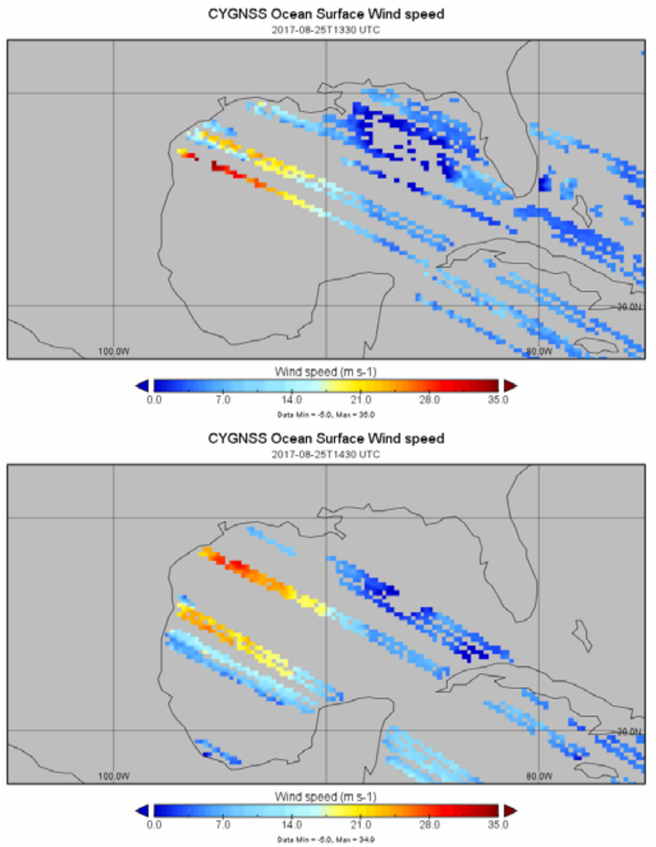

Figure 5. Hourly Level 2 (un-gridded) measurements of ocean surface wind speed in Hurricane Harvey made by the CYGNSS constellation on August 25, 2017 hours before Harvey made landfall in southeast Texas, USA. The times of the measurements are centered at 1330, 1430 UTC.

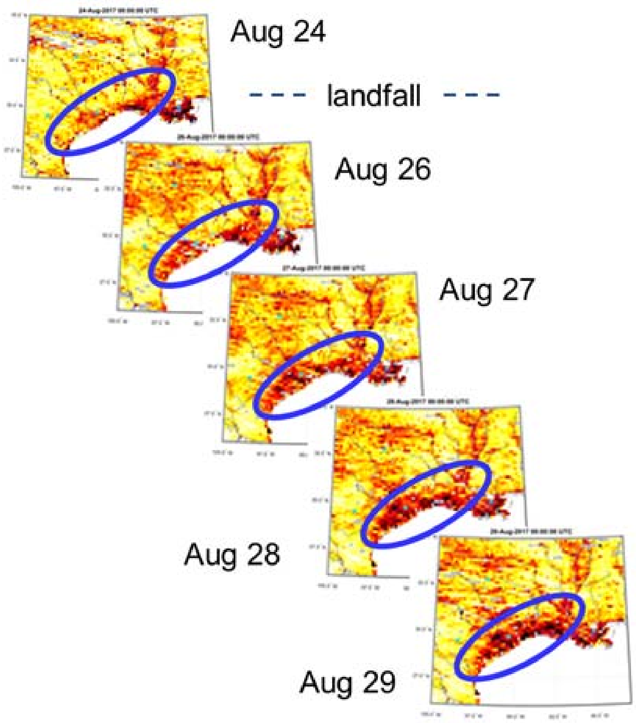

Figure 6. Daily Level 1 (un-gridded) measurements of land surface scattered signal strength just before and in the days after Hurricane Harvey made landfall on August 25, 2017. Note the increase in scattered signal in the (circled) metropolitan region of Houston, TX due to major flooding that occurred as a result of the heavy precipitation associated with Harvey.

measurements as constraints on a parameterized model for the spatial distribution of wind speed in the organized inner-core region [7], [8].

The CYGNSS satellites make continuous measurements of the GPS signal scattered from the Earth surface, over both ocean and land. The ocean measurements, and the wind speeds derived from them, are the primary objective of the mission. However, the land measurements can also be quite useful because they are sensitive to the dielectric properties of the surface and, in particular, to the near-surface moisture content. A limiting case of this is seen in Fig. 6, which shows daily CYGNSS images of southeast Texas, USA in the aftermath of Hurricane Harvey's landfall. Standing water presents a significantly higher scattering cross section to the GPS signal and the measurements clearly resolve the day-to-day development of inland flooding that occurred.

3. CONCLUSIONS

CYGNSS was launched in December 2016 and has been operating in science mode since March 2017. Its spatial and temporal sampling capabilities are significantly enhanced by the eight satellite constellation and by the fact that science data-taking operations are able to be maintained with nearly 100% duty cycle at all times. Wind speed science data products are being produced on a regular basis and are being released to the public via the NASA PO.DAAC data distribution web site at <https://podaac.jpl.nasa.gov/CYGNSS>.

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