PERFORMANCE AND CHARACTERIZATION OF CYGNSS WIND SPEED PRODUCTS

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ABSTRACT

The NASA Cyclone Global Navigation Satellite System (CYGNSS) mission generates several ocean surface wind speed data products. Level 2 products are sampled in time and space as the measurements are made by each individual satellite in the constellation. Due to the nature of GNSS-R measurements, the sampling is essentially a single pixel-wide swath along the specular point (SP) track on the Earth surface. However, the large number of satellites and their low orbit inclination angle result in dense spatial coverage and frequent revisit rates in the tropics when measurements are aggregated together. Standard Level 3 wind products combine measurements by the full constellation which are then gridded in space and averaged over one hour. A new Level 3 storm-centric gridded wind speed product is reported on a finer spatial grid every 6 hours to better resolve storm structure throughout its lifecycle. Spatial and temporal sampling properties, as well as wind speed uncertainties, are presented here for each of the CYGNSS ocean surface wind speed products.

Index Terms— GNSS-R, CYGNSS, ocean wind speed, satellite constellation

1. INTRODUCTION

The Cyclone Global Navigation Satellite System (CYGNSS) constellation of eight satellites was successfully launched in December 2016 into a low inclination (tropical) Earth orbit [1]. Each satellite carries a four-channel bi-static radar receiver which measures signals transmitted by Global Positioning System (GPS) satellites and scattered back into space by the Earth surface [2]. Over the ocean, surface roughness, near-surface wind speed and air-sea latent heat flux are estimated from the direct measurements of surface scattering cross section [3, 4]. Over the land, estimates of near-surface soil moisture and imaging of flood inundation are also possible [5, 6]. The measurements are able to penetrate through all levels of precipitation due to the low microwave frequency at which the GPS operates [7]. The spatial density and revisit time of sampling resulting from the number of satellites in the constellation and from their continuous data-taking operation makes possible the reliable detection of tropical cyclone intensification and the resolving of diurnal cycles of tropical winds and soil moisture variability [8]. Engineering commissioning of the constellation was completed in March 2017 and the mission is currently in its extended science operations phase.

2. CONSTELLATION SAMPLING AND REVISIT

CYGNSS is the first NASA Earth Science mission to use a constellation of SmallSats. The constellation consists of 8 spacecraft distributed around a common circular orbit at 520 km altitude and 35° inclination. The mean revisit time of the full constellation is ~7 hours [9]. An illustration of the coverage provided after one orbit and one full day are shown in Fig. 1. The spacecraft were designed for a 24 month mission duration. The first of the 8 to malfunction was lost in November 2022 after ~6 years of on-orbit operation due to a loss of radio communication. The other 7 continue to operate nominally and produce reliable science data.

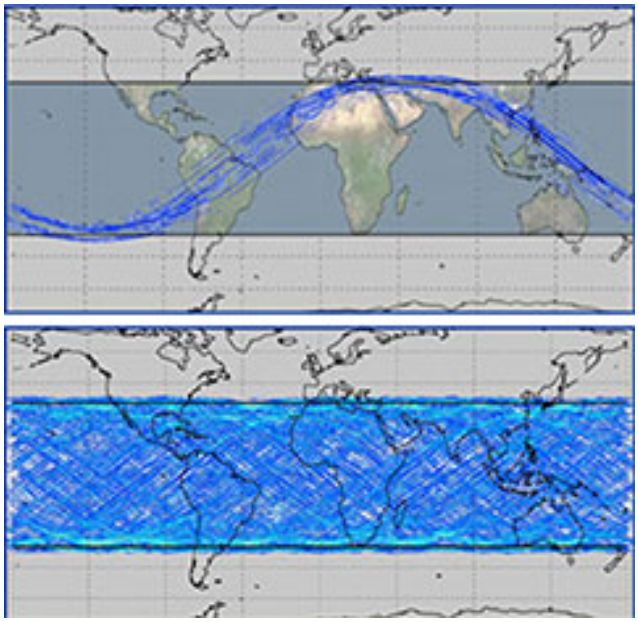


Fig. 1. *Spatial coverage by the CYGNSS constellation after one orbit, or 95 min (top), and after 24 hours (bottom).*

3. DATA PRODUCTS AND LEVELS

The Level 1 engineering data products include scattered signal power and SNR and the bistatic radar cross section of the surface. Level 2 science data products have been developed for near surface (10 m referenced) ocean wind speed, ocean surface roughness (via the mean square slope statistic) and latent heat flux. Level 3 gridded versions of the L2 products are also available [10]. A set of Level 4 products have also been developed specifically for direct tropical cyclone overpasses. These include the storm intensity (peak sustained winds) and size (radius of maximum winds), its extent (34, 50 and 64 knot wind radii), and its integrated kinetic energy. Assimilation of CYGNSS L2 wind speed data into the Hurricane Weather Research Forecast (HWRF) model has also been studied, and their impact on forecast skill demonstrated [11, 12]. Level 2 science data products over land related to near-surface volumetric soil moisture content and flood inundation extent are also in development [5, 6].

4. WIND SPEED PRODUCT DEVELOPMENT

Level 2 retrieval algorithms to estimate geophysical properties of the earth surface from its level 1 electromagnetic scattering properties have been the subject of sustained development, refinement, and validation with respect to alternative estimates of the geophysical conditions (aka "ground truth" references). Science data products have been developed for ocean surface roughness and 10 m referenced wind speed, as well as for latent and sensible heat fluxes at the air-sea boundary. Near surface wind speed over the ocean is estimated from direct measurements of the bistatic radar scattering cross section of the ocean surface. A new Level 3 Merged Storm (MRG) product is also produced throughout the full life cycle of all named storms on a 6-hourly cadence. An example of L3 MRG is shown in Fig. 2, with the global background wind field and an inset highlighting the gridded wind near the storm center.

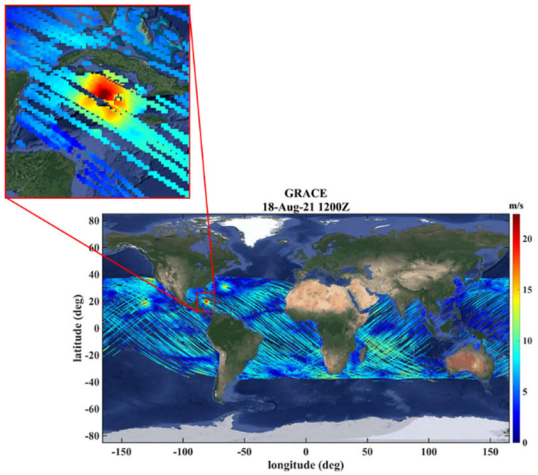


Fig. 2. *Global tropical surface winds on 21 Aug 2022 at 1200Z, with Hurricane Grace insert.*

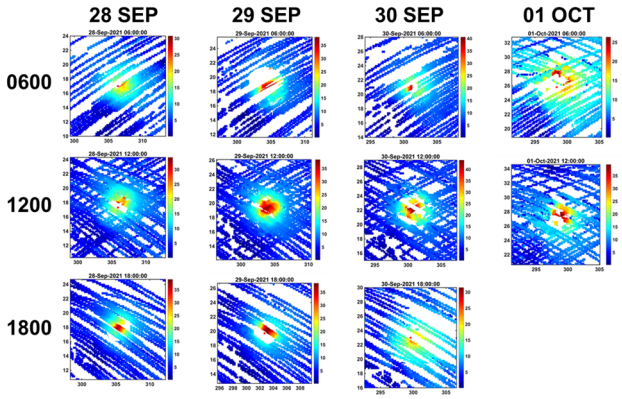


Fig. 3. *Time lapse series of L3 MRG wind speed product reports for Hurricane Sam in 202).*

The L3 MRG product reports every 6 hours provided there are a sufficient number of satellite overpasses of the storm by the full constellation during that time. An example of the resulting reporting frequency is shown in Fig. 3.

5. WIND SPEED PRODUCT CHARACTERIZATION

The CYGNSS engineering team continues to refine and improve upon the calibration of scattering cross section measurements. Similarly, the science algorithm team has been continuously refining and improving the retrieval algorithm that estimates wind speed from the scattering cross section of the ocean surface. An update will be presented of current wind speed retrieval algorithm performance, with an emphasis on performance at moderate to high wind speeds and development of the new merged wind speed data product, L3 MRG. One example of L3 MRG performance is its ability to estimate the 34 knot wind radius of the storm (R34) in each quadrant. R34 matchups with coincident estimates by HWRF are shown if Fig. 4. These and other examples of performance and characterization are presented at IGARSS 2024.

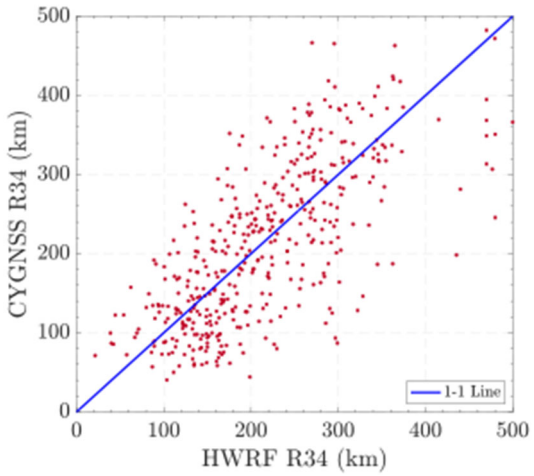


Fig. 4. *R34 retrieval comparisons to HWRF using a CYGNSS data record spanning 436 storms over 2018-2022.*

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