PERFORMANCE ASSESSMENT OF CYGNSS HIGH WIND RETRIEVAL FOR THE IMPROVED EIRP CALIBRATION

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ABSTRACT

The CYGNSS Level 2 wind speed retrieval will be updated to a newer version within the next few months. These updates are based on accurate measurements of the Normalised Bistatic Radar Cross-Section (NBRCS) using the improved estimates of the Effective Isotropic Radiated Power (EIRP) of the GPS along the direction of the specular point. This calibration will result in considerable increase in the number of measurement samples (~37% more) by including the block IIF GPS measurements which were previously filtered out due to poor estimation of its antenna gain patterns. In this work the new Level 2 CYGNSS winds will be matched to HWRF hurricane simulated winds for major hurricanes from 2017 and 2018 and their performance will be assessed using different figures of merit. Additional intelligent quality control filters are also planned to be developed that will improve the quality of the CYGNSS data product for reliable operational purposes.

Index Terms—*CYGNSS, GNSS-R, calibration, wind retrieval.*

1. INTRODUCTION

The Cyclone Global Navigation Satellite System (CYGNSS) is NASA's Global Navigation Satellite System reflectometry (GNSS-R) constellation mission. The goal of this mission is to accurately study and model the inner core of hurricanes. It achieves this by increasing the sampling over hurricanes by having a mean revisit period of 7 hrs and by operating at the GPS L-band that can penetrate through clouds and rain. CYGNSS has effectively improved its temporal frequency by utilizing 8 micro satellites that are equally spaced around a 520 km circular orbit inclined at 35 degrees [1]. The spacecrafts carry radar receivers tuned to measure Global Positioning System (GPS) L1 signals at 1.575 GHz scattered from the ocean surface in the forward (specular) direction. These receivers generate Delay Doppler Maps (DDMs) at a rate of 1 Hz within the footprint of its two downward pointing antenna beams that are pointed cross-track to the direction of orbital motion.

The reflected GPS signals captured by the radar receivers onboard the satellites are mapped onto the Delay-Doppler space in order to extract the useful information [2]. The received DDMs then undergo the Level-1 calibration (A&B) [3] to derive the bistatic radar cross section (BRCS) and the normalised areas, which is subsequently used in the retrieval algorithm to extract wind speed information at the specular point.

The CYGNSS constellation was successfully launched on 15 December 2016. The science measurements began in March 2017 and have continued uninterrupted since then. Early science activities focused on development of the wind speed retrieval algorithm and validation of the data products. Non provisional public release of the data products by the NASA PO.DAAC began in November 2017 at the end of the 2017 Atlantic hurricane season [4]. More recently, science activities are focused on refinements to these data products [5].

This paper is organized as follows. Section II gives an overview of the improved calibration of CYGNSS measurements and Section III discusses the planned strategy for performance assessment and quality control.

2. IMPROVED LEVEL 1 CALIBRATION IN CYGNSS

Individual bins of a DDM are measured in raw, uncalibrated units referred to as counts. The power in the total signal is the product of all the input signals (scattered GPS signals, thermal emission from the Earth and the receiver) multiplied by the gain of the receiver and antenna. The Level 1A calibrated DDM represents the received signal power in watts. Level 1B maps DDM of power to DDM of BRCS using the forward model [6]:

$$P_G(\tau,f) = T_i^2 \frac{P_T \lambda^2}{(4\Pi)^3} \iint \frac{G_T(\vec{\rho}) G_R(\vec{\rho}) \Lambda^2(\tau,\vec{\rho}) |S(f,\vec{\rho})|^2 \sigma_0(\vec{\rho})}{R_0^2(\vec{\rho}) R^2(\vec{\rho})} d^2\rho \quad (1)$$

Where $P_G(\tau,f)$ is the coherently processed scattered signal power in watts over the coherent integration timeT_i. P_T, λ and G_T are the GPS transmit power, carrier wavelength and antenna gain respectively. R_0 and R are the transmitter to surface and surface to receiver ranges respectively. G_R is the CYGNSS receiver antenna gain and σ_0 is the Normalized Bistatic Radar Cross Section. Λ and S represent the GPS spreading function and the Doppler zone function of the GPS respectively.

In order to accurately retrieve σ_0 of the surface, accurate information on the GPS EIRP which is the product of the GPS transmit power and antenna gain is needed [7]. The major challenges in the estimate of the GPS EIRP are summarized in [4]: 1) fluctuation in transmit power; 2) limited knowledge of the transmit antenna gain pattern; 3) gain uncertainty due to pattern asymmetry and yaw maneuver.

The real-time EIRP Level 1 calibration algorithm proposed in [8] helps in overcoming these defects and improves the measurement quality of σ_0.

3. PERFORMANCE ASSESSMENT OF WIND RETRIEVAL

Two observables are derived from the DDM of NBRCS namely, the Delay Doppler Map Average (DDMA) and the Leading Edge Slope (LES) [9]. A regression based Geophysical Model Function (GMF) is inverted over these observables to retrieve the wind speed. The Young Sea Limited Fetch GMF [10] is developed using the matchups with near co-incident overpasses of CYGNSS and the SFMR onboard the hurricane hunter flights over the major 2017 Atlantic hurricanes. In this work we match up the CYGNSS measurements over major hurricanes from 2017 and 2018 with HWRF forecast hurricane winds [11]. The hurricanes that will be used for the assessment are listed in Table 1. The CYGNSS measurements are matched to HWRF within a temporal separation of 0.25 deg latitude and longitude and less than 60 minutes of temporal separation.

WEST PACIFIC	EAST PACIFIC	ATLANTIC	INDIAN OCEAN
JEBI JELAWAT MANGKHUT MARIA TRAMI WALAKA YUTU	ALETTA WILLA OTIS	FLORENCE HARVEY IRMA MARIA JOSE JOSE MICHAEL OSCAR	MEKUNU TITLI

Table 1: Hurricanes chosen for performance assessment.

The assessment will be based on Root Mean Difference (RMD) between the matchups which is given by:

$$RMD(w) = \sqrt{\langle(\boldsymbol{u}_{CYGNSS} - \boldsymbol{u}_{HWRF})^2\rangle} \qquad (2)$$

Where w is the wind speed bin over which the error is evaluated, $\boldsymbol{u}_{CYGNSS}$ is the set of CYGNSS wind samples in the given wind bin and $\boldsymbol{u}_{HWRF}$ is the set of corresponding HWRF measurements.

We also plan to perform quality control of CYGNSS data based on the ROC curves of different diagnostic filters such as incidence angle, Range Corrected Gain (RCG) etc, to help improve the quality the data product.

4. SUMMARY AND NEXT STEPS

This paper presents the analyses that will performed on CYGNSS L2 wind speed product (v3.0) after the improved calibration of NBRCS at Level 1. The major steps include, creating matchups between CYGNSS and HWRF winds over several hurricanes in 2017 and 2018 and the algorithm performance and error characterization based of different figures of merit such a mean difference and root mean difference of winds. The quality control algorithm is also briefly discussed which will be based on the probability of detection and false alarm rates derived from ROC curves for different diagnostic variables such as incidence angle and RCG. As the next steps, we plan to identify the limitations and issues in the new calibration and along with it discuss possible improvements for future CYGNSS wind speed data products.

5. REFERENCES

[1] C S., Ruf, P Chang, M P., Clarizia, S Gleason, Z Jelenak, J Murray, M Morris, S Musko, D Posselt, D Provost, et al., "CYGNSS handbook," *Ann Arbor, MI, USA: Michigan Publishing*, 2016.

[2] O Germain, Giulio Ruffini, F Soulat, M Caparrini, Bertrand Chapron, and P Silvestrin, "The eddy experiment: GNSS-R speculometry for directional sea-roughness retrieval from low altitude aircraft," *Geophysical Research Letters*, vol. 36(2), 2009.

[3] Scott Gleason, Christopher S., Ruf, Maria P., Clarizia, and Andrew J., O'Brien, "Calibration and unwrapping of the normalized scattering cross section for the cyclone global navigation satellite system," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 54(5), pp. 2495– 2509, 2016.

[4] PO.DAAC, 2018: CYGNSS. NASA Physical Oceanography Distributed Active Archive Center, https://podaac.jpl.nasa.gov/CYGNSS.

[5] Wang, T., C. S. Ruf, B. Block, D. S. McKague, and S. Gleason, 2018: Design and performance of a GPS constellation power monitor system for improved CYGNSS L1B calibration. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, **12**, 26–36, https://doi.org/10.1109/JSTARS.2018.2867773.

[6] Valery U Zavorotny and Alexander G Voronovich, "Scattering of GPS signals from the ocean with wind remote sensing application," *IEEE Transactions on*

Geoscience and Remote Sensing, vol. 38, no. 2, pp. 951–964, 2000.

[7] S. Gleason, C. S. Ruf, A. J. O'Brien and D. S. McKague, "The CYGNSS Level 1 Calibration Algorithm and Error Analysis Based on On-Orbit Measurements," in IEEE J Sel Top Appl Earth Obs Remote Sens. doi: 10.1109/JSTARS.2018.2832981.

[8] Wang, T., Ruf, C., Gleason, S., Block, B., McKague, D., & O'Brien, A. (2019, July). A Real-Time EIRP Level 1 Calibration Algorithm for the CYGNSS Mission Using the Zenith Measurements. In *IGARSS 2019-2019 IEEE International Geoscience and Remote Sensing Symposium* (pp. 8725-8728). IEEE.

[9] Maria P., Clarizia and Christopher S., Ruf, "Wind speed retrieval algorithm for the Cyclone Global Navigation Satellite System (CYGNSS) mission," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 54(8), pp. 4419–4432, 2016.

[10] Ruf, C. S., & Balasubramaniam, R. (2018). Development of the CYGNSS geophysical model function for wind speed. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *12*(1), 66-77.

[11] Gopalakrishnan, S. G., et al. "Hurricane Weather Research and Forecasting (HWRF) model scientific documentation." *Development Testbed Center* (2010).