AN OVERVIEW OF NOAA CYGNSS WIND PRODUCT VERSION 1.0

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ABSTRACT

In November 2019, the Ocean Surface Winds Team at NOAA-NESDIS-STAR released to the public their first version of sea surface winds for the Cyclone Global Navigation Satellite System (v1.0). The reported winds are provided on a 25km grid along each track. A boxcar averaging step is included in order to remove unwanted noise in the signal. Calibration issues are greatly reduced by the use of a track-wise bias correction applied to the normalized bi-static radar cross section. The wind speed is then retrieved on a track-by-track basis where both daily global and storm centered images are provided to the public at https://manati.star.nesdis.noaa.gov/datasets/CYGNSSData.php. For in-depth analyses, NetCDF files are also made available (access instruction provided on the aforementioned link). A comparison with collocated NOAA ASCAT A/B 25km wind product, between July and October 2018, resulted in a -0.13 m/s bias and a 1.23 m/s standard deviation.

Index Terms— Geophysical measurements, Global Positioning System, Microwave reflectometry, Radar measurements, Remote sensing, Scattering, Sea surface, Wind

1. BACKGROUND

Launched on December 15th 2016, the Cyclone Global Navigation Satellite System (CYGNSS) mission constitutes a constellation of eight micro-satellites, with a primary mission to *reliably* provide sea surface wind speed, particularly in the presence of tropical cyclones, with increased revisit time. Each of these micro-satellites is equipped with both a starboard and port side antennas designed such that up to four sea surface specular reflections, from signals transmitted by the GPS constellation, can be processed simultaneously (see Fig. 1). The estimated normalized bi-static radar cross section (NBRCS) can then be used to infer sea surface wind speed via the use of a geophysical model function (GMF).

Since May 2017, CyGNSS wind speed data products have been made available to the public on the PO.DAAC, via a few version iterations (see [1], [2]). A common concern that has been raised, however, is the ever presence of calibration issues affecting the NBRCS quality, which inhibits the ability of producing reliable sea surface winds; intersallites NBRCS biases were originally discovered in the version 2.0 of the data, and reported in [3]. Furthermore, the negative impact of the poor characterization of the GPS effective isotropically radiated power (EIRP) was also assessed. Version 2.1 of the CyGNSS data addressed several of these above mentioned issues to a certain extent [4]. NBRCS calibration issues still remain, where some of them are highlighted in [5] and [6].

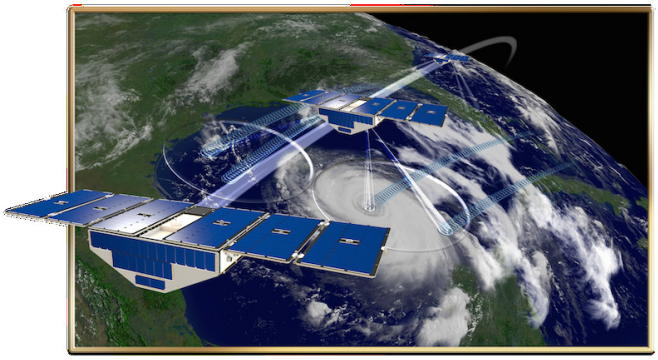

Fig. 1. Graphical representation of the CyGNSS spacecraft. Adapted from [7].

In this paper, we present an overview of our in-house NOAA CyGNSS winds, including a description of the data processing chain. Additionally, since version 1.0 has been made available to the public, a description of the data product content and availability is also provided. Finally, a brief discussion of possible changes to the current version is also included.

2. DATA PROCESSING CHAIN DESCRIPTION

In order to minimize the aforementioned calibration issues currently affecting the CyGNSS mission, our team has developed and implemented a wind retrieval scheme (see [5], [6], and [8]). Figure 2 summarizes the process used to derive the wind speed from the Level 1 CyGNSS NBRCS measurements.

The first step includes a preliminary data quality control

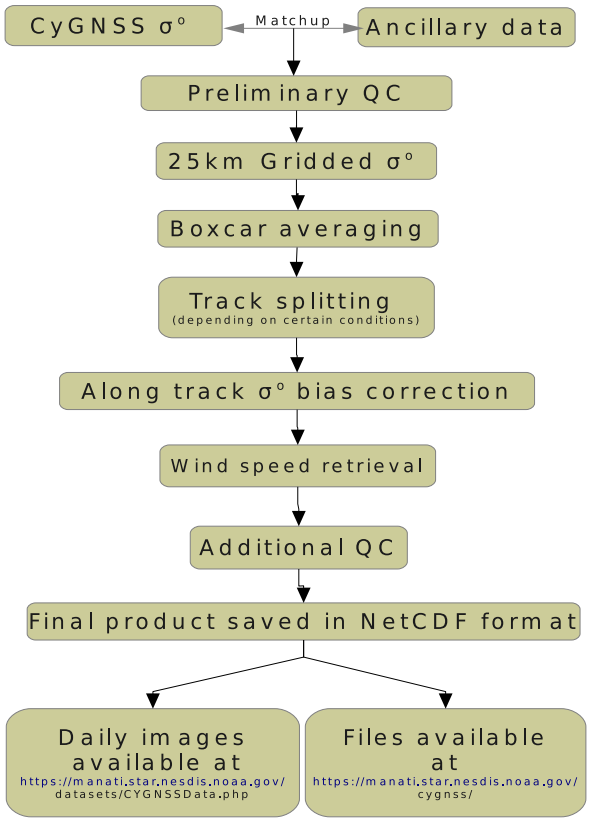

Fig. 2. Diagram describing the data processing chain which produces the Version 1.0 NOAA CyGNSS winds from the v2.1 Level 1 CyGNSS NBRCS measurements available at [9].

Table 1. Variable list from NOAA Level 2 CyGNSS Winds NetCDF files

Variable name	Description
sample	Sample index
spacecraft_num	CyGNSS spacecraft number
prn_code	GPS PRN code
sv_num	GPS space vehicle number
antenna	Receive antenna
sample_time	Sample time
lat	Latitude
lon	Longitude
sc_lat	Subsatellite point latitude
sc_lon	Subsatellite point longitude
incidence_angle	Incidence angle
track_id	Track ID
rx_gain	Rx antenna gain
snr	Signal-to-noise ratio
range_corr_gain	Range corrected gain
sample_flags	Status flags for the sample
num_ddms_utilized	Number of DDM utilized
ddm_sample_index	L1 netCDF sample indices
ddm_channel	L1 DDM channel
nbrcs_mean	Normalized BRCS
nbrcs_mean_corrected	Corrected normalized BRCS
wind_speed	Retrieved wind speed
azimuth_angle	Azimuth angle
sc_roll	Spacecraft attitude roll angle
sc_pitch	Spacecraft attitude pitch angle
sc_yaw	Spacecraft attitude yaw angle
sc_alt	Spacecraft altitude

check which removes poor quality samples, such as data with potentially poor attitude control. This is followed by a data gridding process which averages the NBRCS on a 25km grid along each track. This step is deemed necessary in order to reduce the correlation between adjacent measurements, which are in close proximity to each other (∼3-6km), each of which already spanning a 25 to 40km spatial footprint. A boxcar averaging step is then applied to the gridded data in order to reduce the impact of noisy samples. In some cases, such as very long tracks crossing land or multiple islands, the smoothed gridded data may be further split into subtracks due to some noted inconsistencies in the NBRCS measurements.

Perhaps the most important step of the whole processing is the along track σ^o bias correction which follows. This is made possible by comparing the predicted and measured along track σ^o. The former is estimated using the collocated ancillary data, along with a suitable GMF relating σ^o to geophysical and hardware related parameters (i.e. wind speed, significant wave height, angle of incidence). The overall bias, if any, between predicted and measured σ^o is then used to correct the latter. Note that a single bias correction is applied to all along track measured σ^o, thereby retaining CyGNSS σ^o sensitivity along the whole track. This along track σ^o bias correction step helps reduce intersatellite σ^o biases, starboard vs. port side antenna σ^o biases, and existing σ^o biases between GPS block types.

The wind speed is then retrieved from the bias corrected along track σ^o, using a point-wise retrieval approach, a suitable GMF requiring apriori knowledge of the significant wave height and the incidence angle at the specular point. Once a Level 1 CyGNSS file is fully processed, the retrieved wind speed goes through a final quality control step which may or may not remove unwanted samples (e.g. due to poor signal-to-noise ratio and/or low Rx gain levels, tracks going through power flex events [10], high roll angle, etc..).

3. DATA PRODUCT CONTENT AND AVAILABILITY

Once the final QC is applied to the wind speed product, the data is archived in a NetCDF file format, which files are then made available to the user scientific community at https://manati.star.nesdis.noaa.gov/cygnss/. A file is pro-

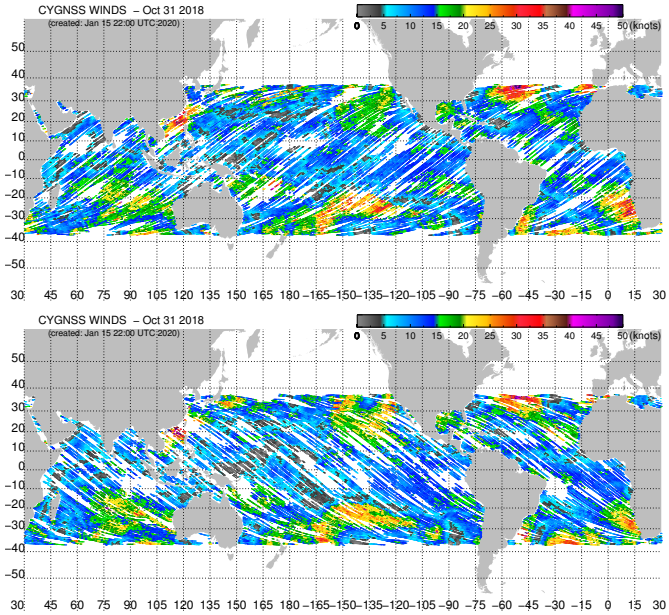

Fig. 3. Example images of daily NOAA CyGNSS global winds available at https://manati.star.nesdis.noaa.gov/datasets/CYGNSSData.php. Images are generated on a daily basis for both ascending and descending passes. In addition, each image includes global winds from all eight CyGNSS observatories.

duced daily and includes global wind coverage from all eight spacecrafts. Table 1 summarizes the list of variables included in these files. As can be seen, a selected list of hardware related variables commonly found in the Level 1 product, are carried over in these files which may simplify the user analysis and troubleshooting work.

In addition to NetCDF files, global and storm centered wind speed images are generated on a daily basis, and made available to the public on https://manati.star.nesdis.noaa.gov /datasets/CYGNSSData.php. Figure 3 illustrates both ascending and descending global wind speed coverage, on October 31 2018, from all eight CyGNSS observatories. Figure 4 includes all CyGNSS wind speeds, +/-3hrs, over Hurricane Dorian on September 01 2019 12:00 UTC. Note the timestamps provided along each track, highlighting the fact that the CyGNSS tracks in each image may span a large time window compared to traditional 'snapshots' from much larger satellites (e.g. the ASCAT A/B scatterometers).

In terms of performance, Fig. 5 shows the NOAA CyGNSS winds against the NOAA 25km ASCAT A/B scatterometer winds [11] for the July-October 2018 period. This comparison was done by collocating both datasets using a +/-90mn time window and 25km temporal and spatial collocation criteria, respectively. As can be seen, there is a good agreement between the two with very little bias (-0.13 m/s) and a standard deviation of 1.23 m/s. Additional validation work was

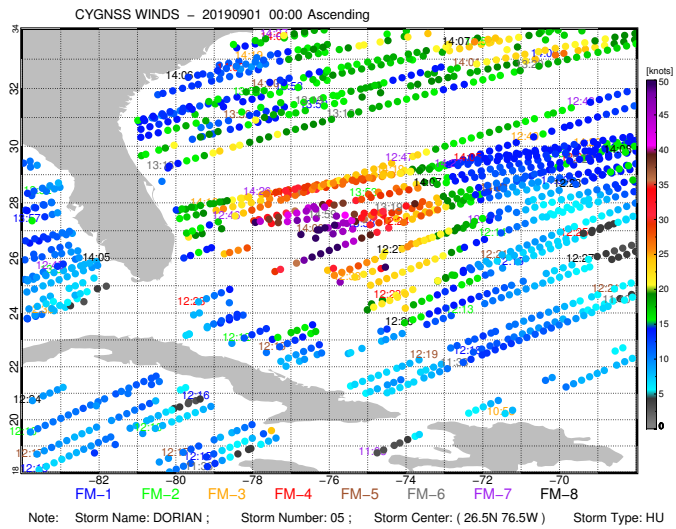

Fig. 4. Example of a storm image over Hurricane Dorian on September 01 2019. Similar images are made available at https://manati.star.nesdis.noaa.gov/datasets/CYGNSSData.php for all tropical cyclones globally.

carried out, showing similar results against other microwave remote sensing devices and numerical weather prediction models [6].

4. PROSPECTIVE CHANGES TO CURRENT VERSION

In order to maximize performance, consistency, and reliability in the generated wind speed, our current wind retrieval algorithm uses a stringent set of QC rules. Current filtering conditions take into consideration the following items:

- the star tracker flag; whenever this flag is set, the reported spacecraft attitude cannot be trusted
- the spacecraft roll angle; throughout the CyGNSS mission, there has been several events where the roll angle was set to $|22.7^o|$ (i.e. nominal roll angle is 0°). Our preliminary analysis showed that the NBRCS cannot be fully trusted in such a scenario
- relatively low SNR (e.g. $< 1dB$) and/or low Rx gain (e.g. $< 3dB$); when either of these occurs, the Delay Doppler Maps are poorly defined, resulting in questionable NBRCS.

Unfortunately, all of these scenarios combined represent a non-negligible amount of data loss (between 40 and 55%). Each of these scenarios will be carefully re-analyzed with the hope of increasing global data coverage in a future version.

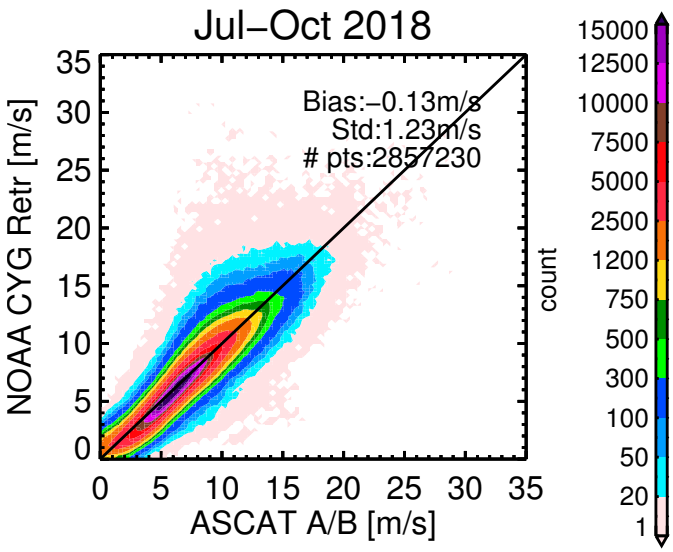

Fig. 5. Two-dimensional histogram comparing NOAA CyGNSS winds with 25km ASCAT A/B winds, collocated between July and October 2018. A +/-90mn time window and 25km collocation criteria were used to generate this figure.

5. CONCLUSION

This paper gives a general overview of v1.0 NOAA CyGNSS winds, including the data processing chain which describes how winds are obtained from the Level 1 CyGNSS NBRCS available on the PO.DAAC. Since the NOAA CyGNSS winds are made available to the public, a description of the data product content and availability has been provided. Images can be viewed and downloaded at https://manati.star.nesdis.noaa.gov/datasets/CYGNSSData.php. The same web page provides instructions on how to access the actual data files for in-depth analysis. Finally, a brief discussion regarding possible future changes to the current version is also provided; the current performance of the v1.0 NOAA CyGNSS winds is very comparable to standard microwave remote sensing devices. However, aggressive QC settings are currently hindering to some extent spatial and temporal coverage. A future version will address this issue.

6. REFERENCES

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