GENERATION OF CYGNSS LEVEL 2 WIND SPEED DATA PRODUCTS

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ABSTRACT

An overview of the wind speed retrieval algorithm used to generate the first CYGNSS Level 2 wind speed products is presented. The algorithm uses two observables derived from Level 1b calibrated Delay/Doppler Maps, and constructs a geophysical model function which maps the observable value and its associated incidence angle into a wind speed value. The wind estimates from the two observables are also combined to form a best-weighted estimator, which represents our final retrieved wind speed. Here the major steps needed to implement the algorithm are reviewed, with a focus on some new aspects, such as the characterization of the dependence of the observables on incidence angle based on real data. An analysis of the algorithm performance is also presented.

Index Terms— GPS-Reflectometry, wind speed, Delay-Doppler Map

1. INTRODUCTION

This paper will present an overview of the generation of Level 2 (L2) wind speed products from Delay/Doppler Maps acquired by the eight observatories of the CYGNSS Mission. CYGNSS was successfully launched on December 15 2016 at 8:37 a. m. from NASA Kennedy Space Center (Florida), and the first ocean DDMs have been successfully measured east of Brazil on January 4 2017. An illustration of these first 4 DDMs representing CYGNSS's "first light" measurements of the GPS ocean surface reflection is shown in Figure 1.

The L2 wind speed products are generated from L1b calibrated DDMs of Normalised Radar Cross Section (NRCS). The overall calibration procedure is described in [1] and in a separate aubmitted paper [2]. The algorithm used here to estimate wind speeds is a version very similar to the baseline L2 algorithm presented in [3], and it is explained in detail in [4].

Here we first illustrate an outline of the steps performed to generate Level 2 wind speed product in its first version (v. 1.1), followed by an analysis of the performance of the algorithm, with some identified improvements to be implemented for the next version. This paper concentrates in particular on the main results of the algorithm and on the performance analysis, while the details of the algorithm implementation are presented in a separate paper [5].

All the CYGNSS v. 1.1 products, including the L2 wind product, will be publicly available on https://podaac.jpl.nasa.gov.

2. CYGNSS LEVEL 2 WIND SPEED RETRIEVAL ALGORITHM

The steps of the wind speed retrieval algorithm used to generate the v. 1.1 L2 wind products are summarized here:

1. Two DDM "observables", the DD Map Average (DDMA) and the Leading Edge Slope (LES), are derived from L1b DDMs of Radar Cross Section (RCS) and DDMs of scattering area, obtained as explained in [1];
2. Time-averaging is applied to the L1b observables obtained in step 1 [3], to reduce the noise in the observables while keeping the requirement on the 25 km x 25 km spatial resolution met;
3. A large enough set of wind speed matchups is gathered for a training dataset. The training dataset is selected as a specified percentage (usually 50%) of the entire CYGNSS dataset;
4. A Geophysical Model Function (GMF) is derived empirically, using a) observables from the training dataset, b) the matchups gathered in step 2 and c) a newly derived dependence of the L1b observables on incidence angle. Wind speeds are estimated from both DDMA and LES observables using the GMF to map each observable value into a wind speed value;
5. Wind estimates from DDMA and LES are linearly combined using a best weighted estimator as described in [3]. The coefficients of the linear

combination are computed using the Adaptive Covariance (AC) method.

6. The performance analysis of the algorithm is carried out for the test dataset, which represents the remaining percentage of the CYGNSS data, and compared against the one illustrated in [3] and the NASA wind speed error requirements originally set for CYGNSS;

2.1 Delay Doppler Map Average and Leading Edge Slope Observables

The two observables used by the retrieval algorithm are the DDMA and the LES, which have been widely introduced in [3], but which are calculated here in a slightly different manner. The DDMA is computed as the integral of the L1b DDM of Radar Cross Section, divided by the associated effective scattering area. Both the numerator and denominator are computed over a delay window around the specular point ranging from -0.25 chips to 0.25 chips, and a Doppler window ranging from -1 kHz to 1 kHz. The choice for such a DD window is widely explained in [3].

Similarly, the LES is calculated as the slope of the leading edge of the Integrated Delay Waveform (IDW). One-dimensional IDWs are derived from the two-dimensional RCS DDMs by integration along their Doppler dimension over the same range of Doppler frequencies as the DDMA. Then, the slope of the IDW leading edge is computed over the same range of delays around the specular point as the DDMA, and divided by the same effective scattering area. The difference with respect to [3] is in the use of the effective scattering area for observable calculation, as opposed to the physical scattering area being used in [3]. The mathematical details of these calculations are illustrated in [4].

2.2 Time Averaging

One extra processing step that improves the performances of the retrieval algorithm is Time Averaging (TA) of the collected data. TA simply consists of averaging a number of consecutive samples in time to reduce the noise in the observables as much as possible, without violating the spatial resolution limit of 25 km x 25 km. The maximum number of samples that can be averaged can be estimated and it is a function of incidence angle [3].

2.3 Wind Speed Matchups

A subset of all the CYGNSS cal/val data called training dataset is used for the subsequent GMF derivation. This derivation requires that winds measured by other sources at roughly the same time and location (i.e. collocated) as the CYGNSS specular points of the training dataset need to be identified. The wind speed dataset collocated in space/time with the CYGNSS acquisition is called wind speed matchup dataset. These winds are gathered using different sources, primarily: a) modeled winds from the NOAA Global Data Assimilation System (GDAS), and b) measured winds from other sensors such as scatterometers (ASCAT A and B, Windsat) and Microwave Radiometers (SSMI, SMAP).

2.4 Wind Speed Retrieval from DDMA and LES

The GMF is empirically derived as a function that relates each observable value and each incidence angle value to a wind speed value, which would be the retrieved wind for that particular observable. A separate GMF is estimated for DDMA and LES. The GMF estimation requires the matchup dataset, as well as a characterization of the dependence of L1b on incidence angle. This characterization has been derived in [3] using simulated data, and it is here re-derived from CYGNSS real data.

The mathematical details for the GMF derivation will be presented in [5].

2.5 Adaptive Covariance Estimator

The wind speed estimates from DDMA and LES are linearly combined together to produce an optimal final wind speed estimate. This best weighted estimator exploits the degree of decorrelation present between the errors in the individual DDMA and LES estimates to minimize the RMS error in the wind speed estimate [3]. The correlation between DDMA and LES retrieval errors also varies as a function of the SNR of the measurements. For this reason, the covariance matrix assumed by the estimator is also varied accordingly, in a manner referred to as Adaptive Covariance (AC). The AC approach estimates a different covariance matrix, and therefore a different pair of coefficients for the linear combination, for different ranges of the SNR, where the SNR is estimated using the Range Corrected Gain (RCG) parameter [3].

3. ALGORITHM PERFORMANCE ANALYSIS

The performance of the wind speed retrieval algorithm is evaluated using the test dataset. The algorithm performance and error characterization is done in a manner very similar to [3], using the same performance figure-of-merits, and characterizing the errors in terms of different lower bound thresholds and intervals for the RCG. In this case, the EFOV filter, which was used in [3] to exclude the data with incidence angle higher than ~55° due to the violation of the spatial resolution requirements, is not applied. The reason is due to the present algorithm not wanting to exclude a-priori samples that can still give a meaningful and useful wind speed estimation, even though at a slightly worse resolution than the one prescribed.

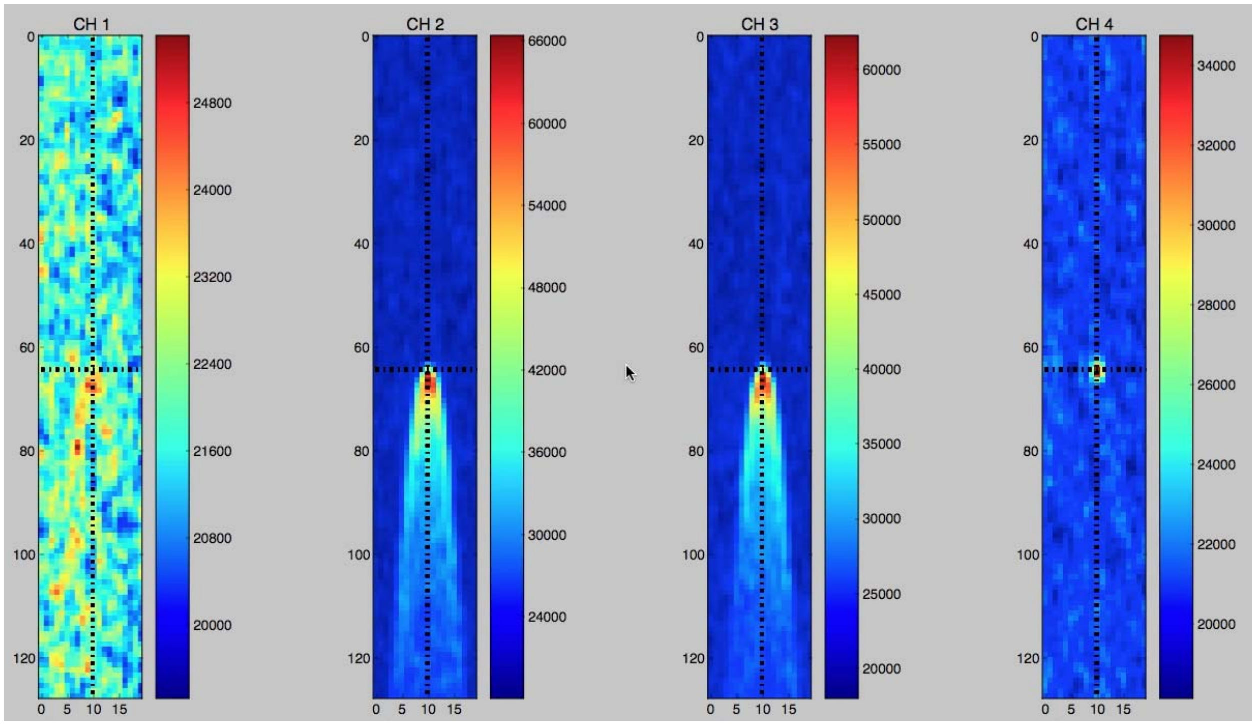

Figure 1. The January 04 2017 four separate acquisitions of the "First Light" DDMs from east Brazil.

4. SUMMARY AND NEXT STEPS

This paper presents the main steps of the wind speed retrieval algorithm used to generate the first CYGNSS L2 wind speed product (v. 1.1), and analyses its performances. The algorithm is very similar to the one presented in [3], which some minor differences implemented (i.e. use of effective scattering area for observable calculation, elimination of the EFOV filter) and with a newly derived dependence of the L1b observables on incidence angle based on real data.

The limitations and issues of the present algorithm will be widely discussed, along with ways forward to reduce or remove such limitations, and to derive the next version of new, improved wind products.

5. REFERENCES

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