CALIBRATION AND VALIDATION PROCESSING FOR THE CYGNSS WIND SPEED RETRIEVAL ALGORITHM

Rajeswari Balasubramaniam, Christopher S. Ruf, Darren McKague, Maria Paola Clarizia and Scott Gleason.*

University of Michigan Ann Arbor, USA
*Southwest Research Institute, USA

ABSTRACT

The processing procedures used for the calibration and validation of Level 2 ocean surface wind speed data product for the CYGNSS mission will be presented in this work. The validation process is planned against a series of ground truth matchups which include buoy measurements, other existing satellite counterparts such as scatterometers, radiometers, altimeters and data from global forecast models.

Index Terms— CYGNSS, calibration, validation, wind speed retrieval.

1. INTRODUCTION

Global Navigation Satellite System (GNSS) is a constellation of satellites primarily designed for precise positioning and timing for military applications. Its usefulness in the field of remote sensing was realised in the early 1990's for two major fields namely, surface sensing and atmospheric sounding [1] [2]. GNSS-Reflectometry (GNSS-R) is the technique of studying the reflected GPS signals to extract useful remote sensing information [3]. The first space based GNSS-R was performed from the NASA space shuttle using the Shuttle Imaging Radar (SIR-C) in 2002. Since then GNSS-R has been a field of active research as it will help reduce the instrumentation required to study a multitude of geophysical surface parameters without the requirement of separate transmitter systems.

The CYclone Global Navigation Satellite System (CYGNSS) is the first of its kind GNSS-R complete orbital mission selected by NASA's earth venture program. The goal of the CYGNSS mission is to study and model the inner core of tropical cyclones (TC's) to accurately forecast its intensification [4]. The existing scatterometer technologies are incapable of accurately modelling TC inner core dynamics primarily because of two reasons. Firstly, the operating frequencies of majority of the current polar orbiting scatterometers fail to penetrate into the inner core of TC's which is characterised by heavy precipitation [5]. Secondly, even if some satellites work at frequencies that can penetrate through the eye walls of a TC, their re-visit period is very large hence fail to capture sufficient data from such fast evolving phenomena.

CYGNSS has overcome these two inadequacies by strategically improving the temporal frequency and by operating at frequencies unaffected by heavy precipitation. CYGNSS works in the all-weather GPS L1 frequency to study the wind speed near the eye wall. It is a well-known fact that L band is sensitive to wind speed and the GPS signals are less affected by heavy precipitation. CYGNSS has effectively improved its temporal frequency by utilising 8 micro satellites that are equally spaced around an orbit inclined at 35° to the equator thereby providing a median re-visit period of around 3 hours and a mean re-visit period of 7 hours. This type of micro-satellite constellation design was achievable due to its bistatic configuration wherein the transmitter is not on the observatory. This is another very important reason to be able to achieve a total power requirement for each of the CYGNSS satellite less than 50 W.

The microsatellites carry a passive instrument called the Delay Doppler Mapping Instrument (DDMI). The received GPS signals need to be resolved in appropriate dimensions to extract useful information [6]. The DDMI resolves these signals into the Delay and Doppler bins by transforming the observed sea surface into iso-delay lines and iso-doppler regions. This forms a 2D representation called the delay-doppler map (DDM) [7] [8], of the forward scattered power signal. The peak of a DDM represents the power coming from the specular point which is neither Delay nor Doppler shifted. Each DDMI outputs 4 DDMs per second which are compressed and sent to the ground resulting in a total of 32 sea-surface measurements produced by the CYGNSS constellation per second.

The received DDMs undergo Level-1 calibration (A& B) [9] to derive the bistatic radar cross section (BRCS) and the effective scattering areas, which is subsequently used in the retrieval algorithm to extract wind speed information in the viewed region. The retrieval algorithm is currently tuned using a population of simulated samples produced by the CYGNSS Project E2ES [10], applied to a 13- day nature run of a tropical cyclone.

This paper is organised as follows. Section II describes the L2 wind retrieval algorithm in detail; Section III briefly describes the calibration and validation that is intended to be

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performed using the real time CYGNSS science data after it begins to flow in winter 2017.

2. LEVEL II WIND SPEED RETRIEVAL ALGORITHM

The inputs to the Level 2 wind retrieval algorithm are the observables extracted from the BRCS [11] and the effective scattering area derived from Level 1B calibration algorithm. An observable must be a best representative of the information contained in the input. The observables chosen for this purpose are the Delay Doppler Map Average (DDMA) and the Leading Edge Slope (LES). A regression based Geophysical Model Function (GMF) is statistically inverted over these observables to retrieve the wind speed. The training and testing of the retrieval algorithm is performed over the simulated data from the CYGNSS E2ES odd minute samples and even minute samples respectively. Each section of the retrieval algorithm is briefly described in the following subsections.

2.1. Generating the DDM observables : DDMA and LES

The DDMA observable is the average of the Level 1B DDM of the RCS over a given delay/doppler range window around the specular point [12] [9]. This is normalised by the scattering area included in the DD range to eliminate its dependence on scattering area which again is dependent on the geometry. Notably, the DDMA has the advantage to suppress the noise by averaging the power over the area around the specular point. Fig.1 represents the DDMA observable that can be generated from a DDM.

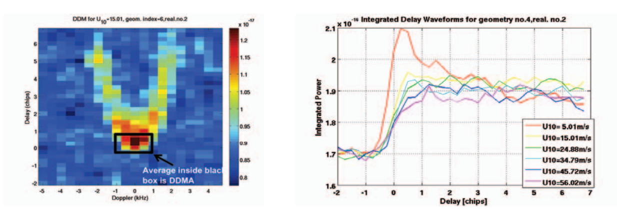

Fig. 1: Left: A simulated DDM and the DDM area where the DDMA is calculated, Right: Integrated Delay Waveforms computed from DDMs simulated using different wind speeds.

LES is the leading edge slope of the Integrated Delay Waveform (IDW) [13]. IDW is generated by an incoherent integration over all possible doppler ranges for every delay unit. As can be observed from Fig.1, the slope of IDW is a function of wind speed. The slope of IDW is obtained from a linear fit at the rising edge of IDW. The choice for the DD ranges over which the observables are extracted is constrained by the baseline spatial requirement of CYGNSS which is $25km \times 25km$. The details about the choice of this range are explained in [14].

2.2. Time Averaging to achieve baseline spatial resolution

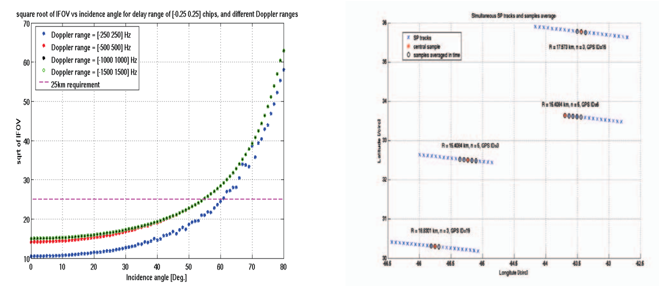

Fig. 2: Graphical illustration of the choice of maximum number of samples for the Time Averaging (TA) algorithm by a single CYGNSS observatory.

The variation of IFOV is simulated for varying incidence angles. It is observed from Fig.2 that, up to an incident angle of $55°$ [14] the square root of IFOV is smaller than the actual requirement of 25 kms. In these cases a number of samples can be averaged to attain the required spatial resolution, also further suppressing the noise. An example illustration of the possible number of samples that can be averaged is shown in Fig.2.

2.3. Statistical Inversion of GMF

The regression based statistical inversion of GMF is designed over the 13-day nature run E2ES training data (odd-minute samples). The training data are extracted over a DD range of $[0.25, 0.25]$ chips and $[1000, 1000]Hz$ [14]. Time averaging is applied wherever possible and only data with high enough RCG (lower bound of 20) are chosen. The GMF assumes a

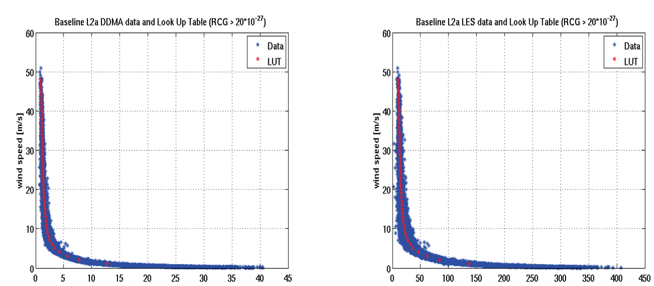

Fig. 3: Simulated ground truth wind speeds versus Level 2A DDMA (a) and Level 2A LES (b) training data, shown as blue points, and selected with $RCG > 20$. The LUT derived from the data is shown as red points.

primary dependence of the observables on wind speed and incidence angle. The inversion algorithm empirically models the wind speed as a function of the individual observables as shown in Fig.3. The performance of the modelled algorithm is tested over the testing dataset (even minute samples) and de-biasing is performed to further improve the performance of the inverse model [14].

2.4. Best Weighed Estimator and EFOV filter

The inversion algorithm attempts to extract wind speed from two different observables. The best weighed estimator linearly combines the DDMA and LES estimates with a weighing function that is derived from minimising the variance of the estimation error (cost function). The details about the implementation of best weighed estimator are described in detail in [12] [14]. To this end an Effective Field Of View (EFOV) filter operation is performed which eliminates all estimates with an incident angle greater than $54.5°$ [14]. As, above that incident angle the baseline spatial requirement is not achieved.

3. CALIBRATION AND VALIDATION OF THE WIND SPEED RETRIEVAL ALGORITHM

The continuous streaming of DDM's from the CYGNSS constellation will begin in winter 2017. The current wind speed retrieval algorithm discussed above has been modelled and tested over the synthetically generated data from CYGNSS E2ES applied to a 13-day nature run of a tropical cyclone. The real time data may significantly deviate from simulated conditions. Hence a thorough validation over the real time data has to be performed. The focus of calibration algorithm spreads across multiple sections of the retrieval algorithm. Most importantly the GMF is modelled over the simulated data, the validity of the same model over the real time data has to be analysed. The dependence of the observables over incident angle and wind speed will need a careful re-calibration with respect to real-time data. Furthermore, modelling of IFOV with respect to incidence angle needs to be fine-tuned as this will determine the changes in the time averaging and the EFOV filtering segments of the retrieval algorithm.
To perform validation of the retrieval algorithm, the ground truth matchups are obtained from a multitude of sources which include buoy measurements, global forecast models and other relevant satellite measurements. The other existing satellites include a wide variety of scatterometers, radiometers and altimeters. ASCAT-A, ASCAT-B, ScatSAT are the scatterometers providing relevant matchups. AMSR-2, GMI, SSMI-F16, SSMI-F17, WINDSAT and SMAP are the matchup providing radiometers. Cryosat-2, Jason-2, Jason-3, Altika and Sentinel-3A are the corresponding altimeters which are considered for providing relevant matchups. The models which we plan to use for generating matchups are GDAS, ECMWF and IFREMER- WW3.

4. CONCLUSION

The first of its kind space based GNSS-R mission CYGNSS, was successfully launched into orbit on 15 Dec 2016. The unprecedented spatial and temporal coverage expected from this mission will provide a deeper insight into the evolution process of tropical cyclones. This paper will be presenting the calibration and validation results of the Level 2 wind speed retrieval algorithm on the real time data. The validation process is planned to be done with respect to a variety of ground truth measurements which include relevant buoy measurements, scatterometers, radiometers, altimeters and the standard global forecast models.

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