CALIBRATION AND VALIDATION OF THE CYGNSS LEVEL 1 DATA PRODUCTS

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I. Presentation Overview

This presentation will include an overview of the recently launched NASA CYGNSS mission Level 1 calibration algorithms and their on-orbit validation [1],[2]. The validation of the Level 1 calibration will be performed in several steps, including a) a detailed noise floor analysis to assess the observed on-orbit noise power levels over the open ocean, b) multiple consistency checks using a forward model and co-located ocean wind and wave truth reference data and c) a term by term error analysis of all the non-ocean corrections applied to the final sigma0 estimates. An outline of the Level 1a (calibration from raw Level 0 instrument counts to units of watts for the received power) and the Level 1b (calibration from watts to bistatic scattering cross section) algorithms are each shown below. Three key components of the Level 1a calibration will be presented, namely, an analysis of the instrument (alone) and antenna noise characteristics over the ocean, a study of the range of received power levels from the surface, and comparisons with a forward model. The key components of the Level 1b calibration presented here will include validation of the main corrections applied to arrive at a surface sigma0 estimate, including receiver antenna gain, GPS transmitter and scattering area corrections.

II. CYGNSS Level 0 Data

As of January 2017, the CYGNSS spacecraft have started to produce Level 0 data. An example of CYGNSS Level 0 data over the southern Atlantic ocean is shown in Figure 4. By the end of February the next version of the Level 1 calibration algorithm will be finalized based on the analysis of several weeks of continuous Level 0 from all eight satellites. This new version of the algorithm will be used to produce sigma0 measurements for the generation of the first geophysical model function for L2 wind speed retrievals.

III. CYGNSS Level 1 Calibration Algorithms

Individual bins of the DDM generated by the DDMI are measured in raw, uncalibrated units referred to as "counts". These counts are linearly related to the total signal power processed by the DDMI. The Level 1a calibration converts each bin in the Level 0 DDM from raw counts to units of watts. In addition to the ocean surface scattered Global Positioning System (GPS) signal, the total signal includes contributions

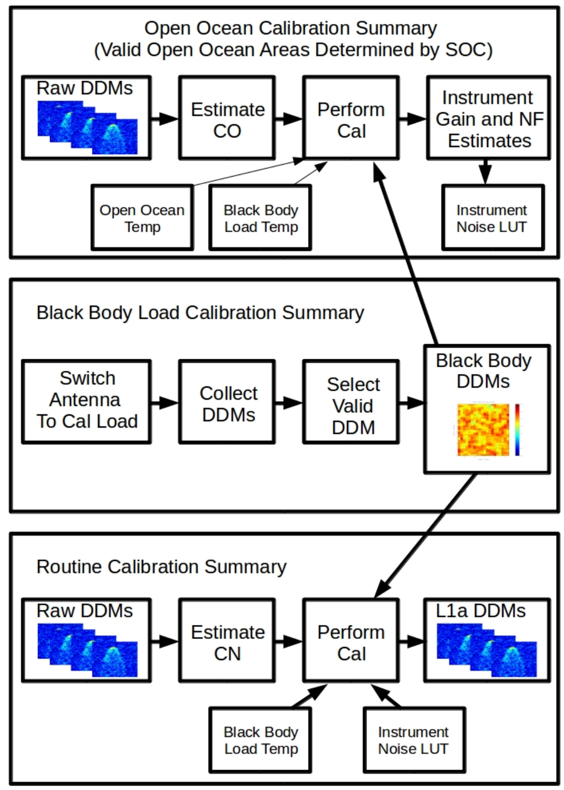

Fig. 1. Outline of the CYGNSS Level 1a Calibration algorithm (counts to watts), from [2]

from the thermal emission by the Earth and noise generated by the DDMI itself. The power in the total signal is the sum of all the input signals, multiplied by the total gain of the DDMI receiver. A block representation of the L1a calibration procedure is shown in Figure 1. The top box describes the open ocean calibration used to update the instrument noise look-up-tables after launch. The middle box shows the periodic generation of black body calibration DDMs (which are used during both the open ocean and routine calibrations). The third box shows the routine calibration performed on every DDM, 4 times per second. Where C_N are the normal DDM noise floors and C_O are open ocean noise floors.

An overview of the CYGNSS Level 1b Calibration is shown in Figure 2. The above left box shows a summary of the meta-data collected by the spacecraft and sent to the ground. The

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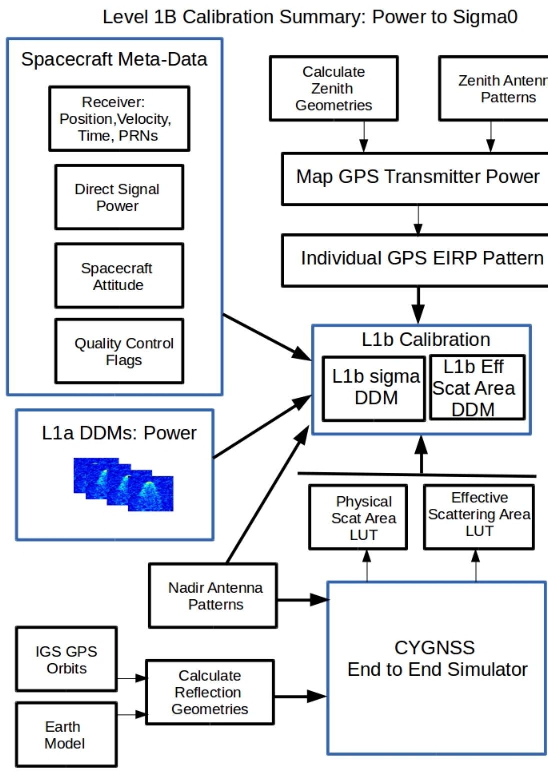

Fig. 2. Outline of CYGNSS Level 1b algorithm (watts to sigma0), from [2]

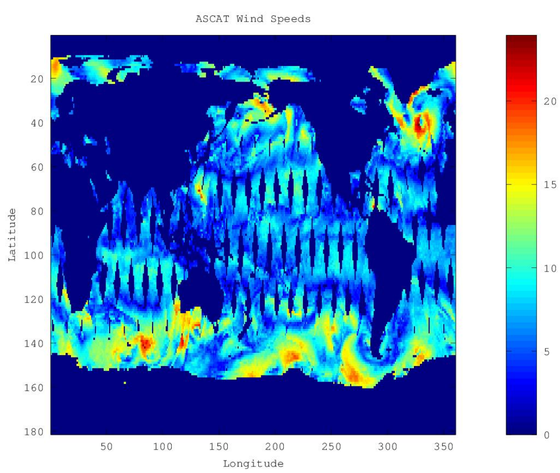

Fig. 3. Example of reference ASCAT estimated wind speeds which will be used with other data sources for providing "truth" wind speed reference input data to the Forward Model during Level 1 Validation.

flow down from the top right is the estimation of the GPS transmitter transmit powers and antenna gains. The bottom right box shows the CYGNSS end-to-end simulator inputs and outputs. All of these elements come together during the L1b calibration.

IV. The CYGNSS Forward Model

A GNSS-R end-to-end simulator (E2ES) was developed as part of the CYGNSS mission. This simulator was intended to act as a science and engineering development tool for the detailed validation of the CYGNSS Level 1 (calibration) and Level 2 (wind retrieval) algorithms. The simulator contains an implementation of the Zavorotny-Voronovich GNSS-R scattering model [3], realistic orbit dynamics and noise models. For the purposes of the Level 1 calibration, reference truth wind speeds and reflection geometry meta data from the instrument itself will be looped back into the E2ES to generate reference Level 1a DDMs and Level 1b sigma0 values for comparison and validation with the performance of the on-orbit instruments.

V. Reference Calibration Wind Fields

A large suite of data will be co-located with the initial CYGNSS measurements. These reference wind speed data will come from active satellites such as ASCATA and ASCATB as well as global models such as GDAS and ECMWF. These estimates of wind speed, surface mean square slope and other parameters will be used to initialize the simulator forward model for generating comparison measurements. An example of an ASCAT global wind field is shown in Figure 3.

VI. Next Steps

This presentation will be based on a set of reference data over areas of the ocean determined to have relatively stable, consistent well developed sea conditions and quality independent estimates of wind and waves over the surface scattering area. By using multiple reference data sets over a full range of surface wind speeds, the conversion of the Level 0 data to Level 1 calibrated measurements will be validated against a forward model and reference surface wind and wave information. This presentation will summarize how raw Level 0 CYGNSS measurements are turned into more useful estimates of surface scattered power and bistatic radar cross sections for use in the Level 2 near surface wind and surface mean square slope estimation [4].

References

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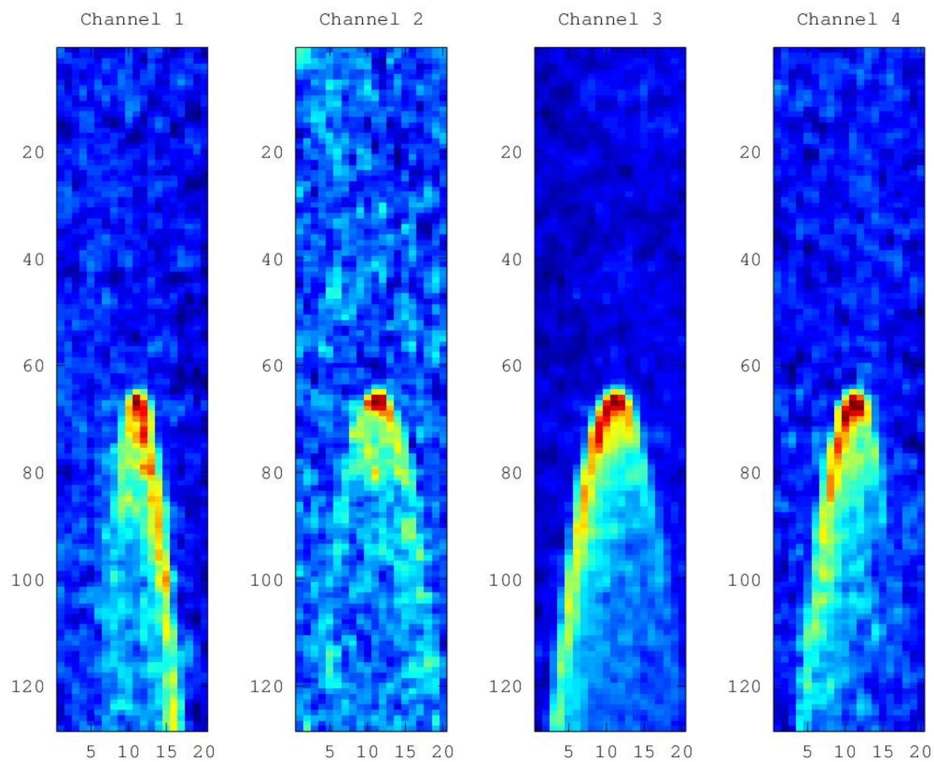

Fig. 4. Example set of 4 CYGNSS ocean DDMs Collected on January 4th 2017. The X-axis for each DDM are Doppler bins at 500 Hz spacing, the Y-axis includes 128 delay bins at 0.25 chip spacing.