An evaluation of simulated CYGNSS winds in tropical cyclone conditions

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Abstract

The Cyclone Global Navigation Satellite System (CYGNSS) mission has been designed to enable unprecedented spatial and temporal resolution of tropical cyclone wind measurements. Its projected launch date is October 2016. Current pre-launch activities include performance evaluation of simulated CYGNSS winds retrieved from the CYGNSS end-to-end simulator. Hurricane Earl (2010), considered as a well sampled historic hurricane from the Atlantic basin, has been selected for this task. The simulated CYGNSS wind measurements are compared against spatially and temporally collocated aircraft and satellite data including SFMR, GPS dropsondes, Oceansat-2, and ASCAT. Hurricane models such as HWRF and H*WIND, as well as the Best Track data from the NHC are also used to gauge CYGNSS performance. This analysis consists of evaluating maximum winds, wind radii, and storm coverage frequency. These results will help assess CYGNSS's potential in retrieving sea surface winds in tropical cyclone conditions.

CYGNSS End-To-End Simulator Description

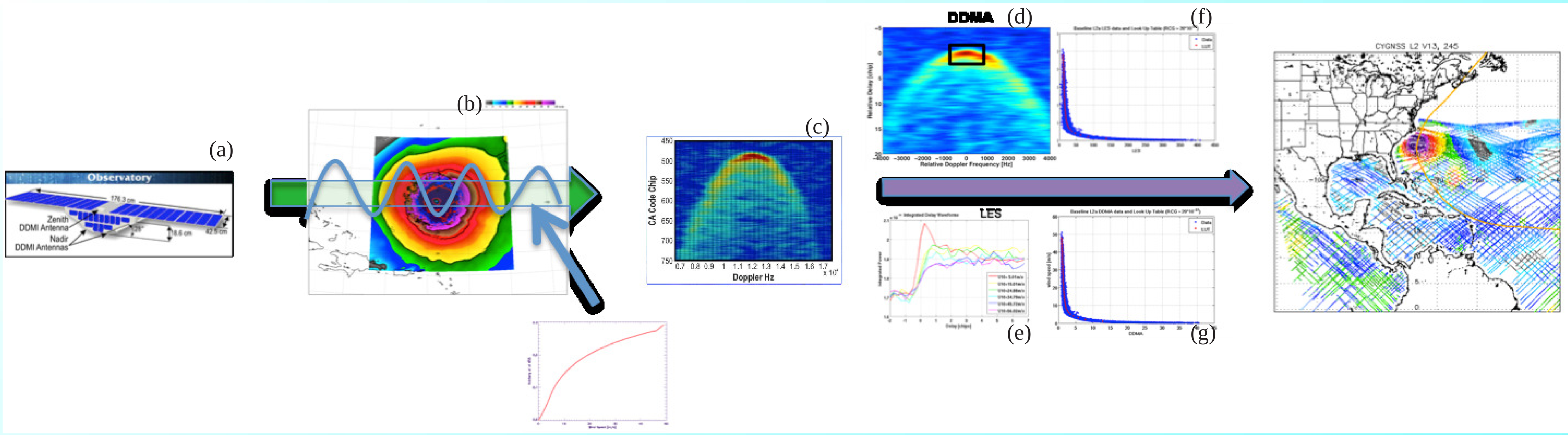


Fig. 1 CYGNSS will use a constellation of eight small satellites receiving both direct and reflected signals from Global Positioning System (GPS) satellites. Each of these instruments carry a Delay Doppler Mapping Instrument (DDMI). Delay Doppler Maps can then be generated from their respective measurements (see plot (c)), from which an averaged DDM value (DDMA) can be computed over a given delay-Doppler window (see plot (d)). The slope of the leading edge (LES) off the Integrated Delay Waveform can also be obtained by integrating (incoherently) the DDM along the Doppler dimension (see plot (e)). The degree of decorrelation present between winds retrieved from DDMA and LES can be exploited to generate a Minimum Variance (MV) Estimator, which delivers optimal performance in terms of RMS error. The MV estimator is a linear combination of winds retrieved from DDMA and LES (see plots (f) and (g)). A 13-day nature run of a hurricane and model data from 3 actual hurricanes have thus far been used with the End-to-End Simulator (E2ES) to generate simulated CYGNSS DDMs and perform wind retrievals. The forward model within the E2ES employs a mean square slope wind speed dependence empirically developed during the NASA GORExperiment [1].

[1] Katzberg, S.J., Torres, O. and G. Ganoe. Calibration of reflected GPS for tropical storm wind speed retrievals, Geophys. Res. Lett., 33, L18602, doi:10.1029/2006GL026825, 2006.

Validation results

Comparison against Hurricane models

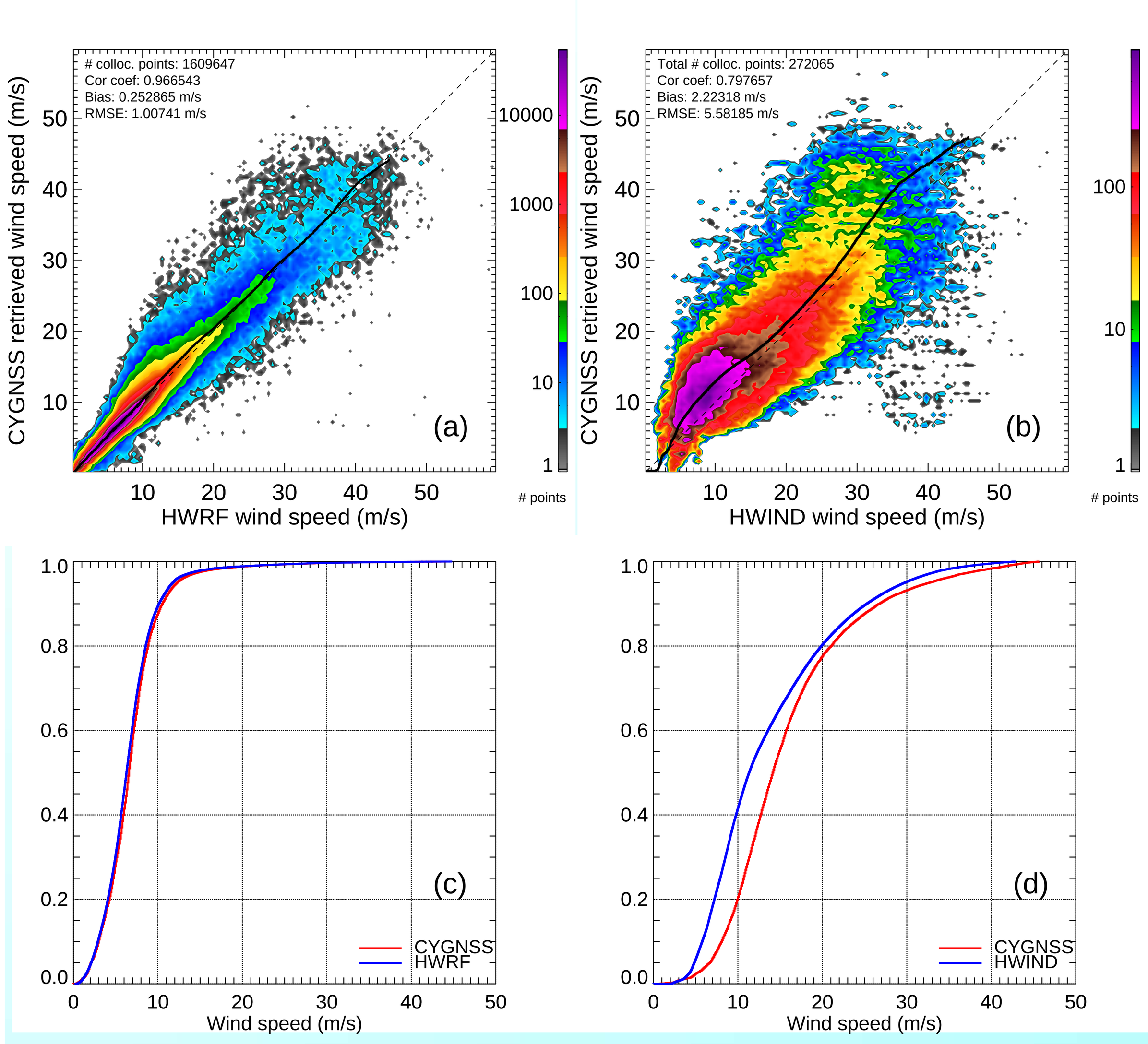


Fig. 2 Spatial and temporal collocations between simulated CYGNSS wind speed data and two hurricane models (HWRF and HWIND) are performed for the period of 08282010 00Z to 09042010 12Z. Temporal and spatial criteria used for the collocations were +/- 3hr and a maximum distance of 25km, respectively. Corresponding scatterplots are provided above (see plots (a) and (b)), with cumulative distribution function plots (see plots (c) and (d)). A noticeable bias overestimation is found between CYGNSS simulated wind speeds and HWIND as shown on plots (b) and (d).

Comparison against sensors

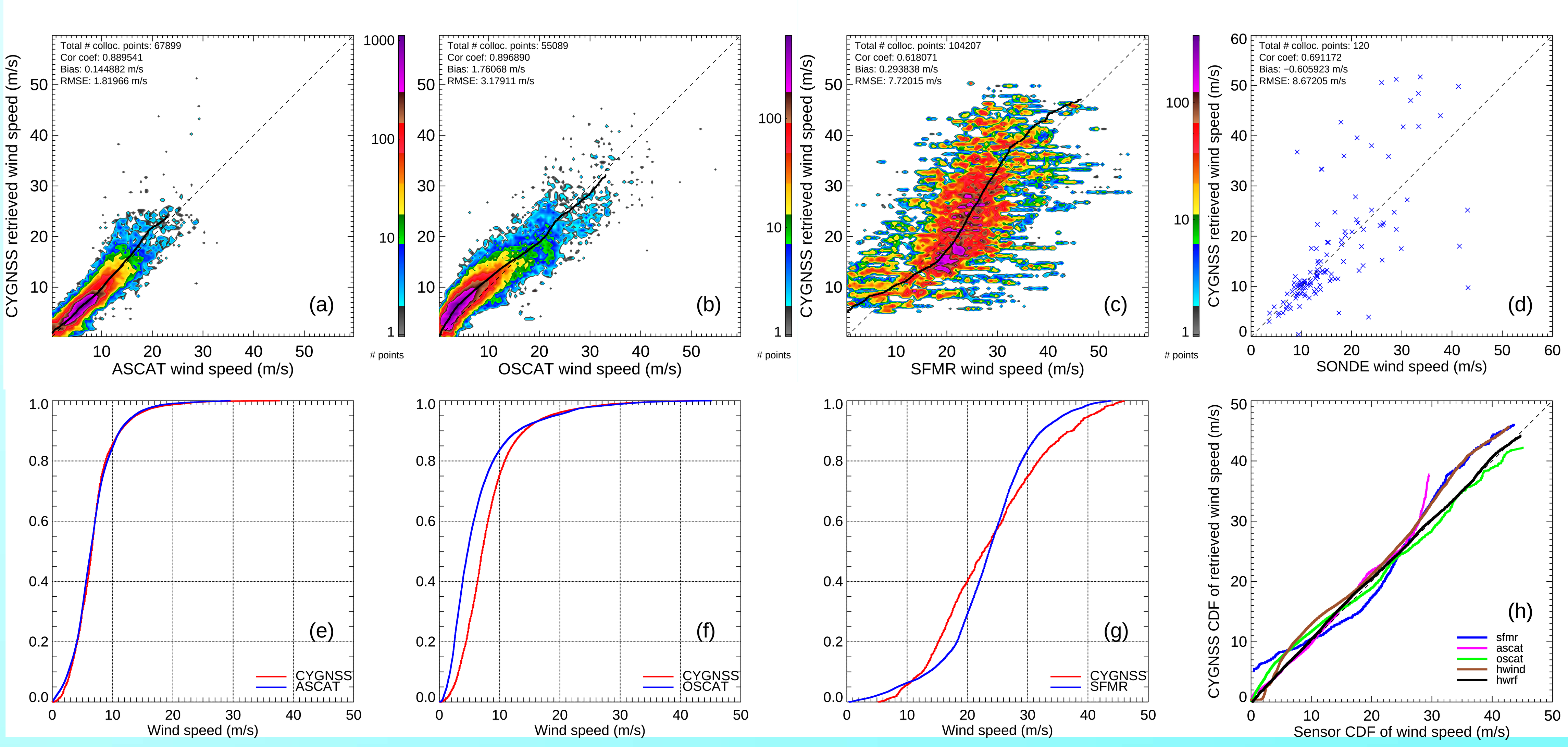


Fig. 3 Just as with the hurricane models HWRF and HWIND on Fig. 2, simulated CYGNSS wind speed data is collocated for the same time period with four different sensors, namely, scaterrometers ASCAT and OceanSAT-2, the Stepped Frequency Microwave Radiometer (SFMR), and GPS dropsondes. Corresponding scatterplots are provided with cumulative distribution function plots. A good match is found between the collocated ASCAT and CYGNSS wind speeds, although high wind speed match-ups are missing (see plots (a) and (e)). When comparing OceanSAT-2 and CYGNSS winds, we note a slight overestimation for winds below 15m/s as shown in plots (b) and (f). Results are mixed when comparing SFMR to CYGNSS winds where the latter underestimate wind speeds between 10 and 25m/s, and overestimate them outside of this interval (see plots (c) and (g)). Finally, up to 120 GPS dropsondes were collocated with simulated CYGNSS winds; plot (d) shows a high correlation between the two dataset, although for higher wind speeds (above 30 m/s), results remain somewhat inconclusive due to a low number of samples.

Plot (h) shows CYGNSS cumulative distribution function (CDF) of retrieved wind speed vs. each available sensor and hurricane models CDF of wind speed. It essentially combines information from all scatterplots from Figs. 2 and 3, thus providing a general overview of CYGNSS sea surface wind retrieval performance against various sensors and hurricane model at a glance.

Observation analysis

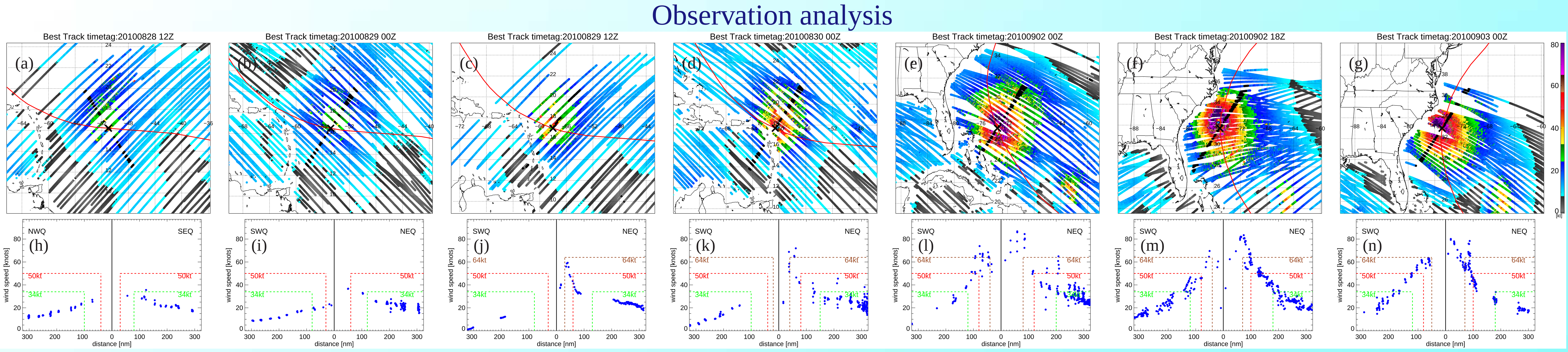
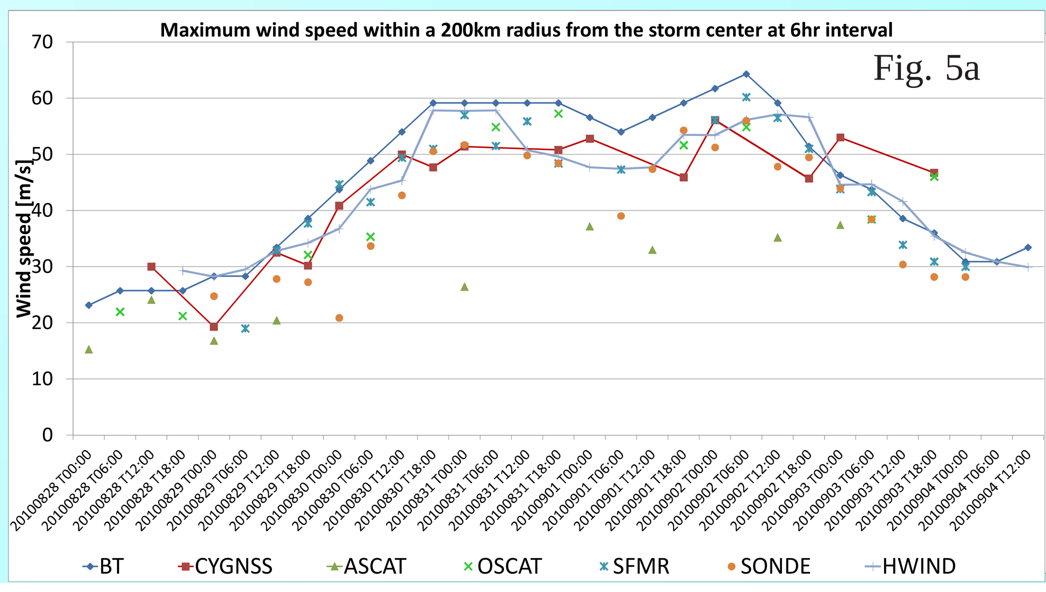


Fig. 4 A preliminary wind radii analysis is shown in the above plots (a) through (n). For each simulated CYGNSS storm pass (a through g), the wind speed is selected along a 45 degree line crossing the storm eye center (shown in black). The selected wind speed is then plotted against the distance from the eye and compared with best track 34-, 50-, and 64-knot wind radii as reported per quadrant (see plots (h) through (n)). These plots show that observed CYGNSS wind radii compare well with best track wind radii, including in the presence of hurricane force winds as shown in plots (k) through (m). CYGNSS spatial data gap can be a potential issue at times however, as shown in plots (a) through (c) where possible high winds close to the eye center may be missed.

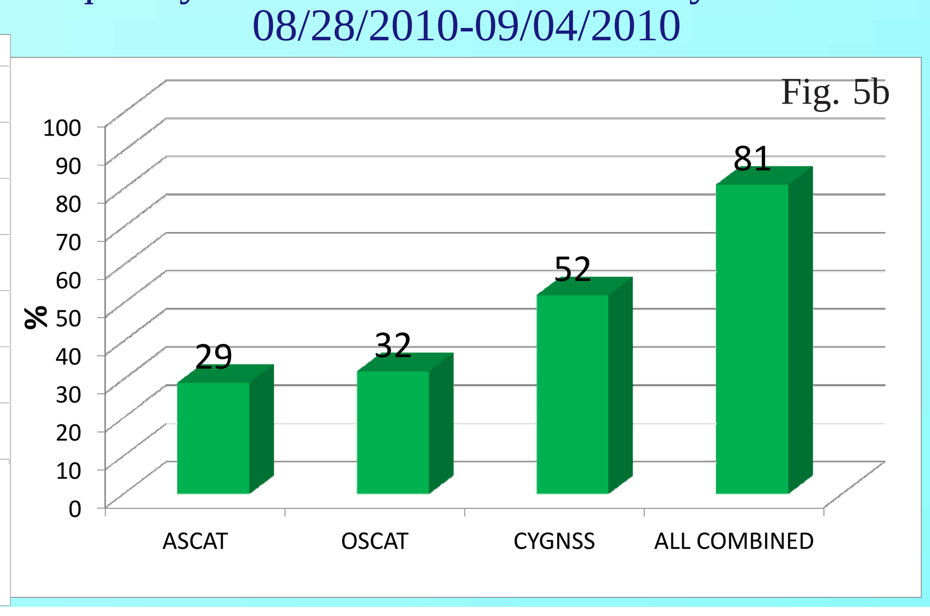
Fig. 5a In order to assess CYGNSS performance in its ability to measure maximum hurricane force winds, we compare simulated CYGNSS maximum winds with those provided by the best track dataset at 6hr interval for hurricane Earl. It is further compared with ASCAT, OSCAT, SFMR, GPS dropsondes, and hurricane model Hwind. Temporal and spatial collocation criteria with best track are +/- 3hr from best track time within a 200km radius from best track eye center location, respectively. Fig. 5a shows that the maximum winds provided by the simulated CYGNSS dataset does provide a good match compared to best track.

Fig. 5b Between the dates 08/28/2010 and 09/04/2010, the number of storm passes from ASCAT, OSCAT, and CYGNSS are recorded on 6 hourly increments for hurricane Earl. Their respective percentage of frequency of observations are shown on Fig. 5b. When combining storm passes from all three sensors, a near complete coverage is obtained for hurricane Earl for the aforementioned time period.

Maximum wind observations



Frequency of Observations in 6 hourly increments 08/28/2010-09/04/2010



Discussion and future work

CYGNSS is the first to provide systematic space-based measurements of winds utilizing GNSS technique, in contrast to traditional use of ocean wind retrieval methods based on scatterometer data. A CYGNSS End-to-End simulator has been developed in order to better understand the expected CYGNSS performance and identify potential trouble areas. Simulated CYGNSS wind measurements are gauged against several sensors and hurricane models, using Hurricane Earl (2010) as a case study. The probability of sampling maximum winds and frequency of observations are explored. The use of simulated CYGNSS data alone noticeably increases the frequency of storm observations (up to 52% for Hurricane Earl). Simulated CYGNSS maximum winds also compare well with best track. One has to keep in mind however that this present study is based on a very limited data set. Statistical results should be interpreted with caution. Actual CYGNSS data is required to gauge CYGNSS hurricane true wind retrieval performance.

To complete preparations for the launch of CYGNSS, future work could include a broadening of the cal/val database to include additional actual hurricane cases; a study of the pros and cons of different CYGNSS measurements and operating configurations may be desired as well. Since CYGNSS wind retrievals depend on a constellation of eight satellite receivers, a performance analysis of each receiver should also be conducted; data from individual receivers could be binned and analyzed to compare receiver characteristics and identify any anomalous behavior. Finally, sensitivity to geophysical parameters, such as sea state, wind direction, sea surface temperature, precipitation, should be evaluated as well.