# IN A REGIONAL OSSE FRAMEWORK

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# 1. INTRODUCTION

The Cyclone Global Navigation Satellite System, or CYGNSS, is a planned constellation of micro-satellites that utilizes existing GPS satellites to retrieve surface wind speed near the satellites' ground tracks (Figure 1). The orbits are designed such that there is excellent coverage of the tropics and subtropics, resulting in better sampling intervals over tropical cyclones than is possible with current scatterometers. Furthermore, CYGNSS will be able to retrieve winds under all precipitation conditions, and with sensitivity beyond 50 m/s. Spatial and temporal coverage provided by the eight-satellite constellation will be superior to ASCAT and OSCAT combined.

Using model output from a high-resolution tropical cyclone nature run as truth, synthetic CYGNSS surface wind speed data have been created (e.g., Figure 2). The



Figure 1. Geometry of GPS-based, quasi-specular surface scattering. The GPS direct signal provides the location, timing, and frequency references, while the forward scattered signal contains ocean surface information.

tropical cyclone nature run spans 13 days and is based on European Center for Medium range Weather Forecasting's (ECMWF) joint Observing System Simulation Experiment (OSSE) global nature run. The impact of synthetic CYGNSS wind speed data on Gridpoint Statistical Interpolation (GSI) analyses and Hurricane Weather Research and Forecast system forecasts (HWRF) will be shown. With this limited sample, we found it had positive impact on the analyses and short-range forecasts of tropical cyclone track and intensity, as well as the large-scale environment. GSI analyses are very sensitive to the exact location of the observational data, symmetry, and coverage, which affected our results.

# 2. OSSE FRAMEWORK

The regional OSSE framework described here was developed at NOAA-AOML and UM-RSMAS and features a high-resolution regional nature run embedded within a lower-resolution global nature run. Simulated observations are generated and provided to a data assimilation



Figure 2. Example of synthetic CYGNSS data coverage over a 6-hour window. Colors correspond to retrieved wind speed.

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scheme, which provides analyses for a high-resolution regional forecast model (Figure 3).

Our nature run was generated using a high-resolution, 27-km regional domain with 9/3/1 km storm-following nests (WRF-ARW, v3.2.1) embedded in a low-resolution T511 (~40 km) ECMWF global run.

Our Data Assimilation Scheme used GSI, which is a standard three-dimensional variational assimilation scheme (v3.3). The analyses were performed in the parent domain at 9-km resolution.

Our forecast model was the 2014 operational Hurricane-WRF model (v3.5). The parent domain has  $\sim$ 6 km resolution, while the single storm-following nest has  $\sim$ 2 km resolution. Data assimilation and model cycling were performed every 6 hours, with each run producing a 5-day forecast, for a total of 16 cycles.

### 3. METHODOLOGY AND RESULTS

A "Control" data assimilation cycle was performed. This was followed by four experimental assimilations in which CYGNSS data were added to the Control. Fiveday forecasts were generated from both the Control and Experimental assimilations. The analyses and forecasts (from each assimilation) were then verified and compared to determine the impact of each data type being evaluated.

In our experiment, we used two synthetic CYGNSS datasets generated to span the WRF nature run: (a) a low resolution, ~25-km effective footprint (nominal product); and (b) a high resolution, ~12-km effective footprint, an experimental product (much greater noise in the retrieval resulted in many dropped data points after quality control was applied).

The five experiments are described as follows:

- (1) CONTROL: Conventional data minus scatterometers.
- (2) PERFECT\_UV: CONTROL plus all available high-resolution CYGNSS data points; wind speed and direction were interpolated from the WRF nature run and assumed to have zero error.

- (3) PERFECT\_SPD: CONTROL plus all available highresolution CYGNSS data points; only wind speed was interpolated from the WRF nature run and assumed to have zero error.
- (4) REAL\_SPD: CONTROL plus quality-controlled low-resolution CYGNSS data points; synthetic realistic wind speeds and errors were used.
- (5) REAL\_SPD\_HI: CONTROL plus quality-controlled, high-resolution CYGNSS data points; synthetic realistic wind speeds and errors were used.

All experiments listed used identical configurations of GSI for data assimilation and HWRF for forecasts.

We evaluated these experiments by focusing on two scales. In the small scale we looked at storm structure and storm statistics, while in the large scale (parent domain) we looked at the domain-averaged errors.

#### 3.1 Storm Structure

Our experiment showed that the addition of CYGNSS surface wind observations generally improved upon the CONTROL run (brought it closer to NATURE) in terms of symmetry, peak intensity, central pressure, and wind radii (Figure 4). Due to the nature of GSI, however, if observational coverage was not symmetric in a tropical cyclone, the analysis suffered. An example from 36 hours after the previous example is shown in Figure 5.

# 3.2 Average Error Storm Statistics

Figure 6 shows the average errors (experimentnature run) over each forecast lead time for track, maximum 10-m wind speed, and minimum sea level pressure; the x-axis represents time and starts from 2 Aug 06Z through 5 Aug 00Z. From these numbers, we observed that the assimilation of CYGNSS data with GSI almost always improved hurricane intensity and track analyses.

#### 3.3 Large-Scale "Domain-Averaged" Errors

Figure 7 shows the large-scale, domain-averaged errors (experiment-nature run) over each forecast lead time for wind speed (surface and 500 mb). The x-axis



Figure 3. Basic flow chart of the regional OSSE framework.



Figure 4. Examples of the 10-m surface wind and pressure fields from the WRF nature run (a), and analyses from the CONTROL run (b), the PERFECT\_UV run (c), and the REAL\_SPD run (d) at 3 Aug 1200 UTC. Although not ideal, (c) and (d) are better analyses than that from the CONTROL run.



Figure 5. Examples of the 10-m surface wind and pressure fields from the WRF nature run (a), and analyses from the CONTROL run (b), the PERFECT\_UV run (c), and the REAL\_SPD run (d) at 5 Aug 0000 UTC. Asymmetric data coverage in REAL\_SPD results in a very lopsided vortex.

represents time and starts from 2 Aug 06Z through 5 Aug 00Z; the y-axis represents the RMS. The most improvement was observed in the first 24 h, especially in the analyses. Improvements extended far beyond surface wind speed (not all fields are shown here, but include height, pressure, and temperature).

# 4. CONCLUSIONS

The summary is based on a few samples from one storm; therefore, error statistics are not robust and can only provide some guidance. The results of this experiment show the following:

- Assimilation of CYGNSS data with GSI almost always improved hurricane intensity and track analyses.
- Assimilation of CYGNSS data with GSI always improved large-scale analyses of wind, pressure, temperature, height, etc., from the surface through the upper troposphere.
- Assimilation of CYGNSS data can improve hurricane and synoptic field forecasts with HWRF in short lead times.



Figure 6. Average error over 12 cycles (first four cycles are omitted to allow for model adjustment). Storm errors include track (left), peak surface wind (top right), and minimum surface pressure (bottom right).



Figure 7. RMS errors of winds averaged over the entire outer "d01" domain at 10 m (left) and 500 hPa (right). Results are similar for surface pressure, geopotential height, temperature, etc.

- Higher-resolution but noisier data degraded analyses when compared to lower-resolution, higher-quality data.
- Adding directional information to the CYGNSS wind speeds improved hurricane analyses in GSI.
- GSI analyses were very sensitive to the exact location of the observational data, symmetry, and coverage, which affected our results.
- The stronger a storm in an analysis, the more severely the short-range forecast suffered from vortex spindown and adjustment.

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