The Cyclone Global Navigation Satellite System (CYGNSS) – Analysis and Data Assimilation for Tropical Convection

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CYGNSS


Main goal: To monitor surface wind fields of the Tropical Cyclones’ inner core, including regions beneath the intense eye wall and rain bands that could not previously be measured from space; Cover 38°S – 38°N with unprecedented temporal resolution and spatial coverage, under all precipitating conditions

Low flying satellite: Pass over ocean surface more frequently than one large satellite. A median(mean) revisit time of 2.8(7.2) hrs.

Orbits at an inclination of 35°
4 specular acquisitions per second
Ground tracks for 90 minutes from the eight satellites

Sampling capacity: the percentages of TC inner core measurement in 3-hour

Ground tracks for 24 hours from the eight satellites
CYGNSS Instrument Definition

Zenith Antenna: Collect GPS direct signal
Nadir Antennas: Collect GPS scattered signal
DMR: Delay Mapping Receiver – Create Delay Doppler Map (DDM)
Two NASA Projects

Research goals: To analyze and utilize the high spatial coverage and temporal resolution simulated and real CYGNSS data.

NASA Project #1:
Exploring the utility of the planned CYGNSS mission for investigating the initiation and development of the Madden-Julian Oscillation

• Investigate MJO onset using DYNAMO field campaign observations
• Examine how CYGNSS observe tropical convection under heavy precipitation condition
• Assimilate CYGNSS observation with Observing system simulation experiments (OSSEs)
• Eastward propagation of regions of enhanced/suppressed precipitation.
• Distinct patterns in low-level and upper level atmospheric anomalies: OLR, upper level velocity potential, upper and lower level wind, 500-hPa height.
• Planetary-scale over equatorial tropical
• Intraseasonal, a period of 30-90 days.
• Modulation of tropical and extratropical precipitation, monsoon systems, ENSO cycle, tropical cyclone activities, and other meteorological and oceanographic phenomena.

**Challenge:** Lack of high-resolution observations of the many facets of the equatorial tropical atmosphere and ocean

**DYNAMO and CYGNSS:** To characterize the key feature in wind field anomaly during the MJO
DYNAMO Campaign

Dynamics of the Madden-Julian Oscillation (DYNAMO)
• Goal: To observe the cloud population and evaluate the effects of the air-sea interactions, on both the small and large scale, during a MJO event
• 2011 October, November, and December MJO events.

Intensive instruments:
• Indian Ocean - West Pacific
• Sounding array
• Air-sea fluxes
• Ships and buoys
• Satellite and aircraft data
• Radar network
CYGNSS E2ES

CYGNSS End-to-End Simulator (E2ES):
Developed by CYGNSS science team, duplicating the satellites’ path patterns and configurations

Generate DDM's ocean scattering using a fine grid around the specular point

Scattering cross-section, combined with the antenna gains, ranges, and transmitted power are used to compute the total scattered power and mapped into delay-Doppler space

**Input:** Gridded time, location, surface wind, precipitation, ocean conditions (SST, salinity, etc)

**Output:** L1 DDM
L2 retrieved wind speed 25 km grid.

E2ES Case Studies: How CYGNSS Views Convection

9-km resolution WRF simulation
Tropical convection during DYNAMO campaign

1-s sampling
12 – 14 UTC 26 October 2011

Reflectivity and surface wind

1 Specular Point

4 Specular Points
How CYGNSS Views Tropical Convection

4 specular point
12 UTC 21 to 00 UTC 22 December 2011

ASCAT/OSCAT wind
15 – 17 UTC 21 December 2011
CYNSS Observation: WWBs

Westerly Wind Burst (WWB): sustained zonal wind over 5m/s for a few days
MJO: Eastward propagation of convective clusters associated with WWB
CYGNSS vs. WRF truth wind for WWBs

(a) WRF (1300Z) & CYGNSS (Tracks 12, 51, 97)

(c) Track 97, 1245 UTC, Median RCG = 64.4

Noise:
Reduced RCG

(b) Track 12, 1233 UTC, Median RCG = 66.0

(d) Track 51, 1335 UTC, Median RCG = 64.1
Convection Along Specular Point Track

Before CYGNSS overpass

Sharp Gradient

CYGNSS overpass

After CYGNSS overpass
WWB event
30 min WRF input
1730 – 1930 UTC 21 December 2011
Strong Wind Gradient

Application of CYGNSS wind: Latent Heat Flux Estimate
<table>
<thead>
<tr>
<th>Track</th>
<th>Simulated</th>
<th>Centered</th>
<th>Fwd-Bk</th>
<th>Mean RCG</th>
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<tr>
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<td>31.2%</td>
<td>16.5%</td>
<td>16.0%</td>
<td>1.5</td>
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<tr>
<td>Track 2</td>
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<td>12.5%</td>
<td>11.4%</td>
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<td>10.3%</td>
<td>9.0%</td>
<td>6.4</td>
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<td>20.0%</td>
<td>17.5%</td>
<td>2.5</td>
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<td>6.1%</td>
<td>5.2%</td>
<td>40.7</td>
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<td>Track 7</td>
<td>24.9%</td>
<td>16.2%</td>
<td>14.4%</td>
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<tr>
<td>RMSE</td>
<td>25.4%</td>
<td>13.9%</td>
<td>12.4%</td>
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</table>

Normalized Root Mean Square Error: 25.4%
Centered Smoothing: 13.9%
Forward-Back Smoothing: 12.4%
Research Result on CYGNSS data for NASA Project #1

1. CYGNSS is able to characterize the mesoscale convective variability, such as WWBs and gust fronts, associated with tropical convection during the MJO.

2. CYGNSS has the ability to observe convectively driven winds in heavy precipitation indicated by the fast-mode E2ES generated data.

3. E2ES was able to produce realistic tracks of CYGNSS specular points using the WRF-based input atmosphere, that demonstrated tradeoffs between RCG and retrieval accuracy.

4. CYGNSS data has natural spatial sparseness in successive specular point tracks do not line up in a spatially contiguous swath like traditional scatterometers. However, counteracting this data sparseness is the more frequent revisit times at a particular location as compared to ASCAT, OSCAT and QuikSCAT.

5. Filtering and/or high RCG (>10 m$^{-4}$), CYGNSS data be used for air-sea flux estimates within and near convection. For low RCG (<10 m$^{-4}$), filtering can reduce wind errors by as much as a factor of 2. In general, aggressive filters (forward-back method) perform better than less aggressive ones (centered method) in low-RCG situations.

Northern Indian Ocean TS 05A:
Vortex formed on 2011-11-25
Severe damage along coast of Sri Lanka
Sustained onshore wind >10m/s
Loss of 33 lives
CYGNSS Data Application: Data Assimilation

OSSE: Cycled Data Assimilation for TS 05A 2011-11-25 – 2011-11-29

3 Experiments:

**Nature run:** WRF model simulation (9-km resolution) starts at 00 UTC 25 Nov 2011, initialized by ERA Interim analysis

**CYGNSS E2ES wind:** Generated from E2ES with WRF nature run files

**CTRL:** WRF model starts at 12 UTC 25 Nov 2011, initialized by GFS analysis

**DA:** Cycled assimilation of E2ES wind using CTRL as first guess
Analysis: 10-m Wind Speed at 15 UTC 2011-11-26

<table>
<thead>
<tr>
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<th>Min</th>
<th>Aver</th>
<th>RMSE</th>
<th>Max</th>
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<tbody>
<tr>
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<td>-19.20</td>
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Analysis: 10-m Wind Speed at 05 UTC 2011-11-27

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Forecast: 10-m Wind Speed at 15 UTC 2011-11-28

<table>
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Analysis: SLP and wind vector at 18 UTC 2011-11-26

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<tr>
<td>Min SLP (hPa)</td>
<td>995</td>
<td>996</td>
<td>998</td>
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<tr>
<td>Max WSPD (m/s)</td>
<td>24.8</td>
<td>22.2</td>
<td>19.2</td>
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</table>
Analysis: SLP and wind vector at 06 UTC 2011-11-27

<table>
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<tbody>
<tr>
<td>Min SLP (hPa)</td>
<td>995</td>
<td>995</td>
<td>996</td>
</tr>
<tr>
<td>Max WSPD (m/s)</td>
<td>25.0</td>
<td>21.5</td>
<td>20.3</td>
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</table>
Forecast: SLP and wind vector at 18 UTC 2011-11-28

<table>
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<tr>
<th></th>
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<tr>
<td>Min SLP (hPa)</td>
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<tr>
<td>Max WSPD (m/s)</td>
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<td>32.8</td>
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Storm Track
00 UTC 2011-11-27 to 00 UTC 2011-11-29

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<tr>
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<th>00UTC 11/27</th>
<th>06UTC 11/27</th>
<th>12UTC 11/27</th>
<th>18UTC 11/27</th>
<th>00UTC 11/28</th>
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<th>12UTC 11/2</th>
<th>18UTC 11/2</th>
<th>00UTC 11/29</th>
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<td>216.2</td>
<td>176.3</td>
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<td>263.3</td>
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<tr>
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<td>360.3</td>
<td>368.5</td>
<td>466.8</td>
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Forecast: 6-h Accumulate Rainfall 18 UTC 2011-11-28

Better Location and Intensity of Rainfall
Forecast: East-West Vertical Cross-section across Storm Center

18 UTC 2011-11-28

T - T0: average over the domain

Water Vapor Mixing Ratio
NASA Project #2:

Demonstrating the value of CYGNSS for investigating relationships between wind-driven surface fluxes and tropical oceanic convection

• Utilize CYGNSS data to study wind-precipitation-evaporation feedbacks
• Improve estimate of surface flux estimates in and near heavy convection
• Study the influence of wind-driven fluxes on convective development with assimilation of CYGNSS observation
Assimilation of Real CYGNSS Wind Speed

**Data:** CYGNSS L3 windspeed data between 00 and 02 UTC 1 May 2017

**Control:** WRF control simulation starts at 12 UTC 30 April 2017
- 2-nested domains (27 + 9 km)
- 20 ensemble members with different physics options and initial conditions

**DA:** Hybrid 3DVAR data assimilation
- analysis time: 01 UTC 1 May 2017
- assimilated into both domains
- observational error: 2 m/s for windspeed < 20 m/s
- 10% for windspeed > 20 m/s
Tropical Convection In Central Indian Ocean
01 UTC 2017-05-01

IMERG rain rate (mm/hr)
CYGNSS L2 wind:
• Baseline product
• Time and location – measurement space (sensor-specific latitude, longitude, and time coordinates)

CYGNSS L3 wind:
• Gridded wind in uniform latitude, longitude, and time
• Combines all 8 observatories x 4 bistatic radar channels = 32 measurements
• Statistics of each bin (number, mean value) and quality flags
10-m Wind Speed at 01 UTC 2017-05-01

Wind Speed Increase
Impact of wind speed assimilation is still apparent in 2 h forecast field
Discussion and Future Works

• Positive Impact has been found with hybrid 3DVAR assimilation of CYGNSS simulated for tropical storm, helping create an improved initial condition and better forecast – intensity, track, and precipitation

• Impact has been found in surface wind field with assimilation of real CYGNSS, which can last 6-12 hours

• Highlight the needs for improved quality of CYGNSS observation: Influence of CYGNSS data is greatly influenced by the data quality.

• CYGNSS DDM (magnitude and shape) is a function of ocean roughness. Further understanding on CYGNSS L1 DDM and its relationship with ocean surface roughness and how to obtain more accurate near-surface wind speed retrievals.