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

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## 1. Introduction


One of the most distinctive signals of the Madden-Julian Oscillation (MJO) is the upscale development and organization of convection in the Indian Ocean.

Dynamics of the MJO (DYNAMO) campaign occurred in late 2011 – early 2012 to investigate this genesis stage. One of the best non-satellite wind datasets ever obtained over the ocean.

The Cyclone Global Navigation Satellite System (CYGNSS) mission can exploit this dataset to better understand the performance of the satellite constellation in regions of deep convection, in particular for characterizing the MJO.

**Three Scientific Objectives**

1. Produce a high-resolution surface wind dataset for multiple MJO onsets using WRF-assimilated winds and other data from DYNAMO.
2. Use the DYNAMO datasets, along with available scatterometer observations, to study the causes and impacts of wind variability at spatial and temporal scales finer than those planned to be provided by CYGNSS, and the implications of these processes for CYGNSS observations.
3. Using a simulated CYGNSS dataset for the MJO, perform observing system simulation experiments to determine the benefits of CYGNSS for improving scientific understanding and forecasting of the MJO, particularly its genesis over the Indian Ocean.

## 4. Next Steps

De-alias SMART-R/TOGA velocities and correct occasional TOGA azimuthal errors, Prep other DYNAMO data for assimilation

Update WRF 3DVAR framework as needed to handle DYNAMO datastream, Test various assimilation schemes, determine which will be most useful, and execute

NOAA to begin HRDL/scatterometer comparison

**Long-term goal**: Observing System Simulation Experiments (OSSEs) to discover how best to assimilate CYGNSS data into a limited-domain forecast model

**Table 1**. Proposed sample OSSE experiments under Objective 3.

| Experiment | Data Assimilation Focus | Model Domain | Horizontal Resolution |
|---|---|---|---|
| **Background** | N/A | 2- or 3-level nested domains | 12-km, 4-km (also possibly 1.333-km) |
| **CYG** | CYGNSS data | 2-level nested domains | 12-km, 4-km |
| **CYG_NoRain** | CYGNSS data in heavy rain areas eliminated | 2-level nested domains | 12-km, 4-km |
| **CYG_OBS** | CYGNSS data, basic multi-platform obs | 2-level nested domains | 12-km, 4-km |
| **OBS** | Basic multi-platform obs | 2-level nested domains | 12-km, 4-km |
| **OBS_DYN** | Enhanced obs from DYNAMO-style instrument array | 2- or 3-level nested domains | 12-km, 4-km (also possibly 1.333-km) |
| **CYG_HiRes** | Higher-resolution, less accurate CYGNSS data | 2- or 3-level nested domains | 12-km, 4-km (also possibly 1.333-km) |
| **Obs_Err** | Sensitivity exp with different observation error setup | 2-level nested domains | 12-km, 4-km |
| **BG_Err** | Sensitivity exp with different background error setup | 2-level nested domains | 12-km, 4-km |

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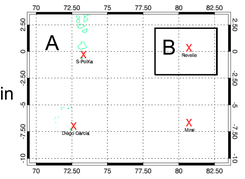
## 2. WRF Model Simulations

### WRF Model Simulation and Assimilation of DYNAMO Data

**WRF model**

- Advanced Research WRF v3.5.1
- A: 3-km resolution DYNAMO domain
- B: 1-km high-resolution smaller domain
- 40 sigma levels (more levels in lower troposphere)
- Separate runs for domains A and B
- Mesoscale features for MJO events




WRF model domain setup

### WRF 3DVAR

Solve for Cost Function:

$$J = \frac{1}{2}(X - X_b)^T B^{-1}(X - X_b) + \frac{1}{2}(Y - H(X))^T R^{-1}(Y - H(X))$$

Background Error Matrix: NMC Method

$$\overline{[X^f(T+24) - X^f(T+12)][X^f(T+24) - X^f(T+12)]^T}$$

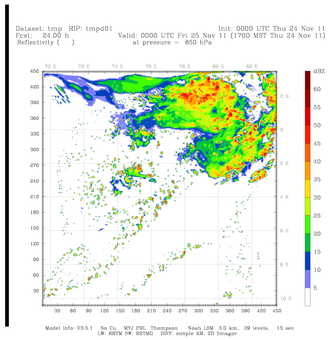
Assimilation Plan:

- Cycled assimilation of available sounding, dropsonde, surface, buoy, radar, lidar, scatterometer data into both domains using WRF 3DVAR

Progress:

- Conducting WRF runs for B matrix generation
- Processing the observational data and prepare for assimilation

### WRF Simulation on 3-km grid (2011-11-24)



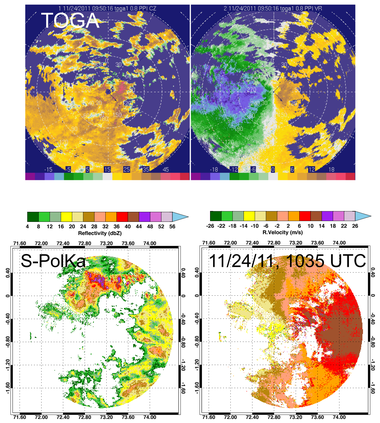
Focusing on roughly last two weeks of each DYNAMO month:

1. November 2011
2. October 2011
3. December 2011

Will produce hi-res wind maps for each of these periods, at least 3-km resolution, 0.5-1 h time steps

Use these maps to study wind variability at time and spatial scales smaller than CYGNSS can provide

## 3. DYNAMO Datasets for Assimilation

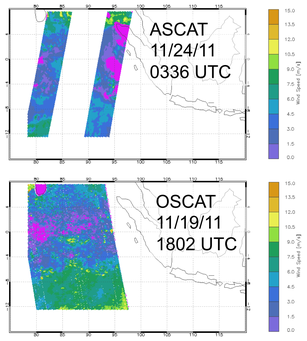



**DYNAMO Radars**

NASA TOGA (Revelle)
Mirai C-band
SMART-R (Gan)
NCAR S-PolKa (Gan)

Assimilate radial velocity into WRF, will also test reflectivity

Most QC done, working with CSU and Texas A&M to de-alias the TOGA and SMART-R velocities, and also fix some azimuthal errors with TOGA



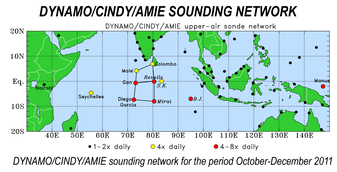

**Scatterometer Vector Winds during DYNAMO**

Assimilate when available, but also produce test dataset without these inputs but with rest of DYNAMO observations

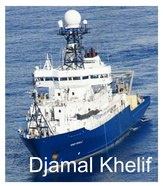
**Other DYNAMO datasets**

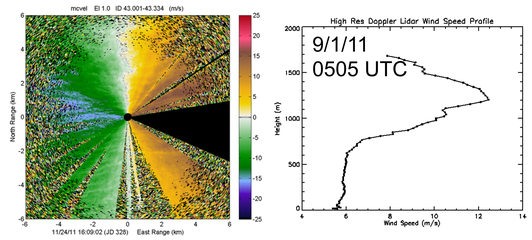
- Radiosondes
- Dropsondes (P-3)
- Surface/buoy/ship-based meteorological observations

Straightforward assimilation process for WRF 3DVAR


Johnson and Ciesielski (2012)




**NOAA High-Resolution Doppler Lidar (HRDL)**

- On Revelle for Cruises 1-3 (1 September - 6 December 2011)
- Produced both vertical profiles (incl. ~15 m winds) and horizontally resolved data
- Test assimilation into WRF – try both polar-coordinate data and vertical profiles

- Our goal is to produce the best possible surface wind dataset for the core DYNAMO region, during MJO onset periods in late 2011
- These wind maps will be ingested into the CYGNSS observational operator to produce simulated CYGNSS observations for DYNAMO
- This will provide an excellent core dataset for understanding how CYGNSS can improve our understanding of convective inflow/outflow structures, wind/precipitation feedbacks, and the initiation and development of the MJO