The impact of CYGNSS Ocean Surface Wind Speeds on Numerical Prediction of Tropical Convection and Hurricanes with NCEP GSI-based ensemble-variational hybrid data assimilation systems

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Outline

PART I: Early OSSE Results: Impact of CYGNSS Level 2 wind speeds on hurricane forecasts

PART II: CYGNSS data assimilation – ongoing work and plan
PART I: OSSE

The impact of CYGNSS data on hurricane analyses and forecasts in regional OSSEs with HWRF model

Objective
Evaluate impact of CYGNSS ocean surface wind speeds on tropical cyclone forecasting with NCEP HWRF model and GSI system

A Regional Observing System Simulation (OSSE) Study with NCEP Hurricane Weather Research and Forecasting (HWRF) model

Observing System Simulation Experiments (OSSEs)

Regional OSSE

Pu et al. 2017 (after Atlas 1985)
Model and Data Assimilation System

- NCEP HWRF Model
- GSI 3DVar data assimilation system

Case, Data and OSSE Configuration

- Hurricane cases during 28 July 2005 and 10 August 2005 in ECMWF nature run
- Regional Nature Run (Nolan et al. 2013), WRF-ARW, (“Truth”)
- ECMWF T511 nature run with 6 to 12h HWRF spin-up (Guess field)
- CYGNSS ocean surface winds (Simulated data)
HWRF data assimilation and model forecast domains

GSI-3DVAR DA scheme

\[ J(x) = x^T B^{-1} x + (Hx - y)^T R^{-1} (Hx - y) + J_c \]

OSSE results to be presented in this talk

- Exp 1: Data Thinning
- Exp 2: Super-obs

- Short assimilation window (12h) [rapid intensification]
- Continuous assimilation window (66 h) [intensity changes]

Model and Data Assimilation System

- HWRF 3.7
- 27km/9km/3km domains, 2-way interaction
- GSI 3DVar data assimilation system

Case, Data and OSSE Configuration

- Hurricane cases during 28 July 2005 and 10 August 2005 in ECMWF nature run
- Regional Nature Run (David Nolan et al. 2013), WRF-ARW, (“Truth”)
- ECMWF T511 nature run with 6 to 12h HWRF spin-up period (Guess field)
- CYGNSS ocean surface winds (Simulated data)
Samples of CYGNSS data distribution for a hurricane case

12-18 UTC 01 August, 2005
Characteristics of CYGNSS Ocean Surface Winds

Before QC

PDF - speeds

After QC

PDF errors
Impact of CYGNSS data on HWRF forecasts

**Track**

- **P_{\text{min}}**
  - 17.3hPa
  - 9hPa
  - 13.1hPa

- **V_{\text{max}}**
  - 13.2m/s
  - 7.8m/s
  - 9.8m/s

Forecasts since 1800 UTC 01 August 2005

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Impact of CYGNSS data (Analysis)

18 UTC 01 August 2005

(a) Surface Wind, P

(b) Tangential Wind

(c) Temperature anomaly and moisture

Nature Run  Ctrl.  Exp.1  Exp.2
Impact of CYGNSS data (24-h forecast)

Surface Wind, P

Tangential Wind

Temperature anomaly and Moisture

Nature Run Ctrl. Exp.1 Exp.2

18 UTC 02 August 2005
Impact of CYGNSS data (Surface fluxes)

Hovmöller diagrams of azimuthally averaged surface latent fluxes (w m⁻²) over inner-core

Nature Run

(b) Ctrl.

(c) Exp.1

(d) Exp.2

(c - b)  

(d - b)  

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Assimilation in a continuous cycle (analysis)

12 UTC 01 Aug to 06 UTC 04 Aug 2005
Assimilation in a continuous cycle: Forecast impact

Track

Track errors

P_{min}

V_{max}

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Summary of Part I

• Assimilation of CYGNSS ocean surface wind speeds can result in positive impacts on tropical cyclone track and intensity forecasting.

• Data thinning and super-obs lead to different assimilation and forecast results. Super-obs method is more beneficial to hurricane track forecasts. Results suggest that it is necessary to develop proper data assimilation methods to enhance data impacts and benefits.
PART II: CYGNSS Data Assimilation

Assimilation of CYGNSS Ocean Surface Wind Speeds into NCEP operational GSI-based 4DEnVAR hybrid data assimilation systems

Model and Data Assimilation System

- NCEP Next-Generation Global Prediction System (NGGPS)
- NCEP Global Forecast System (GFS)
- GSI-based 3dEnVar and 4dEnVar data assimilation systems
Data Assimilation System

• NCEP GSI-based hybrid 3DEnVar (Wang et al. 2013)

\[ J(\delta x, \alpha) = \frac{\beta_1}{2}(\delta x)^T B_1^{-1} (\delta x) + \frac{\beta_2}{2} (\alpha)^T A^{-1} (\alpha) + \frac{1}{2} (H \delta x_1 - y')^T R^{-1} (H \delta x_1 - y') \]

\[ \frac{1}{\beta_1} + \frac{1}{\beta_2} = 1 \quad \delta x_1 = \delta x + \sum_{k=1}^{N} (a_k \circ x_k^e) \]

• 3DEnVar can be extended to use sampled estimates of the background error covariance matrix throughout the length of the window (4DEnVar, Kleist et al., 2015)

\[ J(\delta x, \alpha) = \frac{\beta_1}{2}(\delta x)^T B_1^{-1} (\delta x) + \frac{\beta_2}{2} (\alpha)^T A^{-1} (\alpha) + \frac{1}{2} \sum_{t=1}^{m} (H_t \delta x_t - y_t')^T R_t^{-1} (H_t \delta x_t - y_t') \quad (7) \]

\[ \frac{1}{\beta_1} + \frac{1}{\beta_2} = 1 \quad \delta x_t = \delta x + \sum_{k=1}^{N} [a_k \circ (x^e)_t^k] \]
Distribution of CYGNSS observations: 1-day

2017-04-01

Wind Speed (m/s)

0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45

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Distribution of CYGNSS observations: 1-day

Atlantic Ocean
2017-04-01

Level 2

Level 3
Distribution of CYGNSS observations 6-h window

Atlantic Ocean

Level 2

Level 3
Data quality

Level 2
Sample size=802,834

Level 3
Sample size = 289,629

Time: 04/01/2017
Total: 1 day
Region: global

- The sample size is reduced by ~2/3 from level 2 to level 3
- The CYGNSS wind speeds range in level 2 is [0, 70], while in level 3 is [0, 35]
- In general, level 3 data is less uncertain than level 2 data because of the low wind speeds
Planned work

• Quality control
• Assimilation of Level 2 vs. Level 3
• 3DEnVar vs. 4DEnVar
• Test and evaluation in quasi-operational environment
• Science questions – tropical convection; hurricanes
• GFS/NGGPS transition
Concluding remarks

• CYGNSS mission provides unprecedented data source for studying tropical convection and hurricanes

• For the best utilizing CYGNSS observations, data assimilation is a large research area in the related numerical modeling studies
Thank you very much!

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