Typhoon Predictions with GNSS RO Data Assimilation in the MPAS-GSI System

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Introduction

• To improve a typhoon prediction, an accurate representation of the atmospheric environment would be much helpful. However, sparse observations are available over the ocean.

• The accurate and abundant observations over ocean could be helpful for the NWP, e.g., FORMOSAT-7 data over the tropical region.

• With the global MPAS-GSI system, we conduct data assimilation to assess the RO data impact on the prediction of typhoon events. A preliminary result for two typhoon cases, i.e., Typhoon Nepartak (2016) and Typhoon Lekima (2019), will be shown.
GNSS Radio Occultation

- **GNSS** (Global Navigation Satellite System)
- Global coverage
- High accuracy and high vertical resolution
- All weather-minimally affected by aerosols, clouds or precipitation

![Image of GNSS Radio Occultation with Abel Inversion and 1DVAR](image)

Courtesy of UCAR
cyclogenesis of typhoon Nuri (2008)

Vertical Cross Section of Vorticity and RH

DA – 0h  DA – 24h  DA – 48h  DA – 72h

w/o RO  w/o RO  w/o RO  w/o RO

w RO  w RO  w RO  w RO

600-km averaged cross section  Cyclogenesis after two-day forecast

ChenKuoHuang (2019) has been submitted to Mon. Wea. Rev.

Vor: $2 \times 10^{-5}$ s$^{-1}$

RH: %
Vertical Motion and Water Vapor Mixing Ratio

Statistics for 10 Typhoons over the NW Pacific (2008 – 2010): Probability of detection is increased from 30% (without GPS RO DA) to 70% (with GPS RO DA).

Averaged over a 6° x 6° box following the 500 hPa vorticity center
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• A preliminary result for two typhoon cases, i.e., Typhoon Nepartak (2016) and Typhoon Lekima (2019), will be shown.

• The accurate and abundant observations over ocean could be helpful for the NWP, e.g., FORMOSAT-7/COSMIC-2 data over the tropical region.
MPAS Model Configuration

- Model configuration:
- Variable reso. meshes: 60-15 km
  Vertical levels of 41 and model top of 30 km
- Physics suites: mesoscale reference
  Convection: Tiedtke; Microphysics: WSM6; Land surface: Noah; Boundary layer: YSU; Surface layer: Monin-Obukhov; Radiation, LW/SW: RRTMG

Cycling DA example:
MPAS-GSI system

1. Dual resolution
2. Recenter process

Low resolution (120 km)

High resolution (60-15 km)

36 MPAS members

(extracted from Bresch et al. 2015)
Typhoon Nepartak (2016)

JWTC:
2016/07/03 00UTC: Tropical depression
2016/07/03 12UTC: Tropical storm
2016/07/04 18UTC: Typhoon
Experimental design

TY Nepartak (2016)

<table>
<thead>
<tr>
<th></th>
<th>2016/07/02</th>
<th>2016/07/03</th>
<th>2016/07/04</th>
<th>2016/07/05</th>
<th>2016/07/09</th>
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</table>

- Cycling GSI
- MPAS forecast

With DA (GTS, REF, BND) → Without DA (NODA)

<table>
<thead>
<tr>
<th>CASE</th>
<th>DA obs.</th>
<th>GPS variable</th>
<th>DA strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>NODA</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>GTS</td>
<td>GTS</td>
<td>X</td>
<td>3DVAR / Hybrid</td>
</tr>
<tr>
<td>REF</td>
<td>GTS + GPSRO</td>
<td>Refractivity</td>
<td>3DVAR / Hybrid</td>
</tr>
<tr>
<td>BND</td>
<td>GTS + GPSRO</td>
<td>Bending angle</td>
<td>3DVAR / Hybrid</td>
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</tbody>
</table>

GPS Science and Application Research Center
GNSS RO Data
2016/07/02 0000 UTC ~ 2016/07/04 0000 UTC

~200 RO
Simulated Track and Intensity

3DVAR Nepartak Var case
Typhoon Nepartak intensity with mslp(201607)

Hybrid Nepartak Hybrid case
Typhoon Nepartak intensity with mslp(201607)
After two-day cycling DA (T, Z, and Wind)
### Track Error

#### Typhoon Nepartak track error (201607)

<table>
<thead>
<tr>
<th></th>
<th>3DVAR DA</th>
<th>Hybrid DA</th>
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</thead>
<tbody>
<tr>
<td>EXP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NODA</td>
<td>112.5</td>
<td>112.5</td>
</tr>
<tr>
<td>GTS</td>
<td>98.4</td>
<td>100.0</td>
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<tr>
<td>REF</td>
<td>79.5</td>
<td>71.5</td>
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<tr>
<td>BND</td>
<td>83.0</td>
<td>60.5</td>
</tr>
</tbody>
</table>

#### AVE. TRACK ERROR (07/04-07/07) Before landfall

- **3DVAR DA**: 112.5
- **Hybrid DA**: 112.5
- **GTS**: 98.4
- **REF**: 79.5
- **BND**: 83.0
Verification against ERA-Interim (RMSE) [averaged of 5-day fcst.]
FORMOSAT-7/COSMIC-2 satellites were launched successfully on 25 June 2019.

The first RO profile (2019/07/16 11:44 TST)

http://tacc.cwb.gov.tw
Data Penetration

FS3/C1 (one day data)

~45.7% below 1km

FS7/C2 Data @ 2019/07/16 (first day)

~84.3% below 1km
FS7/C2 NRT Data (30 days)

~78.8% below 1km
Verification against MetOP (30 days)

FORMOSAT-3 $(\pm 45^\circ)$
2018/08/01-2018/08/31

FORMOSAT-7
2019/07/26-2019/08/25

courtesy of TACC
Verification against MetOP (30 days)

atmPrf (Refractivity)

FORMOSAT-3 (±45°)
2018/08/01-2018/08/31

FORMOSAT-7
2019/07/26-2019/08/25

courtesy of TACC
Typhoon Lekima (2019)

Cycling GSI
With DA (GTS, BND)

MPAS forecast

00 06 12
2019/08/06

12
2019/08/07

12
2019/08/11

Courtesy of typhoon2000.com

Courtesy of CWB

GPS Science and Application Research Center
GNSS RO distribution

More than 50% come from FS7
Statistic (bending angle)

\[ O - B \]

\[ O - A \]
<table>
<thead>
<tr>
<th>EXP</th>
<th>GTS</th>
<th>BND</th>
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<tbody>
<tr>
<td>Ave. track error (3 days)</td>
<td>68</td>
<td>45</td>
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</table>
In this study, the simulations with GNSS-RO data assimilation have better predictions in typhoon tracks for both assimilation strategies (3DVAR or Hybrid).

Further, the assimilation with RO bending angle has a better performance than the others (GTS and REF).

From the preliminary comparison, the data quality of FS7 is comparable with FS3, but the FS7 has more data available and further penetrate into the lower troposphere.

With GNSS RO DA (inc. FS7), the simulated track and intensity show a slightly improvement in the early forecast of typhoon Lekima (2019).

Further investigation and more experiments will be conducted in the future.

Thank you ~