The Impact of FORMOSAT-3/COSMIC Data on Regional Weather Predictions

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Marine Meteorology Center, Central Weather Bureau, Taiwan\textsuperscript{4}
Introduction


- The GPS RO data also has been applied in several operational centers, e.g. ECMWF, NCEP and Météo France etc. The Center Weather Bureau (CWB) in Taiwan also incorporated the FORMOSAT-3/COSMIC data into its operational system starting in July 2009.

- The error covariance and data quality control are important for the data assimilation. Therefore, we focus on the 1. observational error tuning, 2. vertical data thinning and 3. additional quality control for the GPS RO data in this study.
Model configuration

- **WPS (v3.0.1.1)**
  - D01:222x128x45 (H-resolution=45 km)

- **WRFDA (v3.1)**
  - Cold Start Mode
  - Cycling Mode
    - 6-h updated cycling
    - 6-h assimilated time window

- **WRF_BC**

- **WRF (v3.0.1.1)**

**Options:**
1. microphysics - Goddard GCE scheme
2. planetary boundary layer - YSU scheme
3. cumulus - Grell-Devenyi ensemble scheme

1. GTS (convention + satellite): SYNOP+METAR+SHIP+BUOY+TEMP+AIREP+PILOT+SATEM+SATOB+QSCAT+BOGUS
2. GPS (FOSMOSAT-3/COSMIC): GPSRF
Within the 6h time-window, there are only about 37 GPSRO soundings available in this domain.

CWB domain located in the tropical area of the north hemisphere.

For CWB regional applications, the atmospheric state in the low-mid troposphere, rather than the high troposphere and low stratosphere, is more interested in.
1. Observational Errors and Errors Tuning

Desroziers and Ivanov (2001) method

based on the expectation of observation part of the cost function $J_o$
Through the randomized estimation of the trace $\text{Tr}(HK)$, the expectation of $J_o$ can be computed.

→ Then, the observation tuning factors can be obtained as $(\frac{\text{actual } J_o}{\text{expected } J_o})^{1/2}$. 
For GPSRO refractivity, the observation errors vary with *height and latitude* (Chen and Kuo, 2005).

**Observation tuning factors for GPSRO**
Desroziers and Ivanov (2001) method

<table>
<thead>
<tr>
<th>Observational error tuning</th>
<th>June</th>
<th>December</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS RO (refractivity) error factor</td>
<td>0.63589</td>
<td>0.64422</td>
<td>0.64006</td>
</tr>
</tbody>
</table>
## Experiment Designs

<table>
<thead>
<tr>
<th>Exp Name</th>
<th>OBS Data</th>
<th>Observational Error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2008 Jun.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>6h_NG_OE1</td>
<td>GTS</td>
</tr>
<tr>
<td>2</td>
<td>6h_WG_OE1</td>
<td>GTS+GPS</td>
</tr>
<tr>
<td>3</td>
<td>6h_WG_OE2</td>
<td>GTS+GPS</td>
</tr>
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<td><strong>2008 Dec.</strong></td>
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</table>
Verified against GPS RO at 00 h (2008 June)
The simulations with GPS RO data assimilation did make improvements for both seasons (summer and winter). It would improve the bias around 10%~15% when GPS RO data were assimilated.

- Tuning the observational error factors (case OE2) for GPS RO would further improve the forecasts.
Verified against radiosonde

T-Bias (2008 June)
Verified against radiosonde

q-Bias (2008 June)
## Sensitivity Tests (2008 Jun)

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<tbody>
<tr>
<td>2008 Jun.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 6h_WG_OE1</td>
<td>GST+GPS</td>
<td>Without error tuning</td>
</tr>
<tr>
<td>3 6h_WG_OE2</td>
<td>GST+GPS</td>
<td>With error tuning for GPS RO (Jun)</td>
</tr>
<tr>
<td>4 6h_WG_OE3</td>
<td>GST+GPS</td>
<td>With error tuning for GPS RO (Dec)</td>
</tr>
<tr>
<td>5 6h_WG_OEC</td>
<td>GST+GPS</td>
<td>Use the mean error of Jun and Dec</td>
</tr>
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</table>

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- Similar results for the verifications against GPS RO soundings.
Using an appropriated OE would get a better improvement for the moisture. (1.OE2; 2.OEC; 3.OE1; 4.OE3)

Similar results for the T verification.

It is possible to generate the altitude-dependent GPSRO error tuning factors with Desroziers and Ivanov method in future.
2. Vertical Data Thinning

**Without Obs. Error Tuning**

**With Obs. Error Tuning (not shown)**

Choose the observations closest to the model levels, and set the qc flag of the other observations to be -99.
### Experiment Designs

#### 2008 Jun.

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<td>The same obs. error as in operation</td>
</tr>
<tr>
<td>6h_WG_OE1_Thin1</td>
<td>GTS+GPS</td>
<td>With data thinning (before QC)</td>
</tr>
<tr>
<td>6h_WG_OE1_Thin2</td>
<td>GTS+GPS</td>
<td>With data thinning (after QC)</td>
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#### 2008 Dec.

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#### Quality Control (QC) in WRFV AR
1. Relative Error check
2. Low level check
3. Background check
Verified against GPS RO at **00 h (2008 June)**

Bias Profiles 2008 JUN 01_00Z -30_12Z 0h Verification

RMSE Profiles 2008 JUN 01_00Z -30_12Z 0h Verification
With data thinning exhibit improvements on lower levels at 00h in June, but bigger BIAS and RMSE for most forecasts in Jun. and Dec.

Similar results for data thinning with OE tuning

Future, we may consider to use the super-ob, or the vertical covariance for assimilating the GPSRO sounding data.
Quality control in WRFVAR v3.1
1. Relative Error check (qc=-31,-32,-33)
2. Low level check (qc=-31)
3. Background check (qc=-3)

3. Quality Control (QC)
   refer to Poli et al. (2009)

\[
\frac{dN}{dz} < -50 \text{ km}^{-1} \Rightarrow qc = -34
\]
\[
\left| \frac{d^2 N}{dz^2} \right| > 100 \text{ km}^{-2} \Rightarrow qc = -35
\]
Quality Control procedure for Refractivity $N$ implemented in wrfvar:

- **Step 1. Background check:** $|O-B| > 5\sigma_o$, flag = -3

- **Step 2. Relative Error check:**
  
  $R.E. = \frac{|O - B|}{0.5 \times (O + B)}$
  
  - $h \leq 7$ km, $R.E. > 5.0\%$, flag = -31
  - $7$ km < $h$ < 25 km, $R.E. > 4.0\%$, flag = -32
  - $h \geq 25$ km, $R.E. > 10.0\%$, flag = -33

- **Step 3. Low level check:** flag = -31
  
  If the data at certain level fails to pass relative error check, all the data below that level will be discarded.
With QC (arbitrary 5 soundings)

- New QC would impact the data below 4~5 km as mentioned in Poli et al. (2009)
## Experiments

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<th>mean rejection (%)</th>
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<td><strong>2008 Jun.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6h_WG_OE1_QC</td>
<td>With additional QC</td>
<td>1.588</td>
</tr>
<tr>
<td>6h_WG_OEC_QC</td>
<td>With additional QC</td>
<td>1.876</td>
</tr>
<tr>
<td><strong>2008 Dec.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6h_WG_OE1_QC</td>
<td>With additional QC</td>
<td>1.771</td>
</tr>
<tr>
<td>6h_WG_OEC_QC</td>
<td>With additional QC</td>
<td></td>
</tr>
<tr>
<td>6h_WG_OE1_QC_Thin2</td>
<td>With additional QC and data thinning (after QC)</td>
<td></td>
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Bias Profiles 2008 JUN 01_00Z -30_12Z 0h Verification

RMSE Profiles 2008 JUN 01_00Z -30_12Z 0h Verification

2008 Jun.
Bias (Jun.)

Bias Profiles 2008 JUN 01_12Z -30_12Z 12h Verif
Bias Profiles 2008 JUN 02_00Z -30_12Z 24h Verif
Bias Profiles 2008 JUN 03_00Z -30_12Z 48h Verif
Bias Profiles 2008 JUN 04_00Z -30_12Z 72h Verif

Height (km)

Refractivity

Refraction
Bias (Dec.)

Bias Profiles 2008 DEC 01_12Z -31_12Z 12h Verification
Bias Profiles 2008 DEC 02_00Z -31_12Z 24h Verification
Bias Profiles 2008 DEC 03_00Z -31_12Z 48h Verification
Bias Profiles 2008 DEC 04_00Z -31_12Z 72h Verification
Typhoon Period

NAKRI (NAK) : 2008/05/26_06 UTC to 2008/06/06_00 UTC (5 days)
FENGSHEN (FEN) : 2008/06/17_18 UTC to 2008/06/27_00 UTC (9 days)
NTY : 2008-06-06_12 UTC ~2008-06-17_12 UTC (11 days) – no typhoons
JUN : 2008-06-01_00UTC~2008-07-01_00UTC(30 days)
24h verification (RMSE)

RMSE Profiles 2008 JUN 02_00Z -30_12Z 24h Verification

- JUN
- NTY

RMSE Profiles 2008 JUN 06_12Z -17_12Z 24h Verification

- NAK
- FEN

Graphs showing refractivity profiles for different times and locations.
Summary

- Assimilation with GPS data did make a significant improvement on regional weather prediction, and observational error tuning would improve the analysis and forecast when verifying against GPS RO soundings.
- Vertical data thinning only improved the analysis below ~5 km, and got comparable or bigger bias for the forecast.
- Additional quality control got slightly bias improvements for the forecasts.
- Verifications during the typhoon period show bigger errors than the period without typhoon occurred.
Thank you!

The end ~