Data assimilation of GNSS Zenith Total Delays in KMA convective scale model

Eun-Hee Kim, Eunhee Lee, Seungwoo Lee, and Yong Hee Lee
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- **Ground-based GNSS data assimilation in convective scale model**
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KMA Operational NWP system (Feb. 2018)

- KMA’s operational models are based on Unified Model

**Global (GDAPS)**
- Resolution: N768L70(UM) (~17km / top = 80km)
- Target Length: 288hrs (00/12UTC)
- Target Length: 87hrs (06/18UTC)
- Initialization: Hybrid Ensemble 4DVAR

**Global EPS**
- Resolution: N400L70(UM) (~32km / top = 80km)
- Target Length: 288hrs
- Members: 49

**Regional (RDAPPS)**
- Resolution: 12kmL70(UM) (0.11°x0.11° / top=80km)
- Target Length: 87hrs (6 hourly)
- Initialization: 4DVAR

**Local (LDAPS)**
- Resolution: 1.5~4km L70(UM) (1188x1148 / top=39km)
- Target Length: 36hrs
- Initialization: 3DVAR

**Local EPS**
- Resolution: 3km L70(UM) (460x482 / top = 39km)
- Target Length: 72hrs
- Members: 13

KMA’s operational models are based on Unified Model.
KMA convective scale model

- KMA’s operational models are based on Unified Model
- LDAPS (Local Data Assimilation and Prediction System)
  - **Model**
    - UM **vn10.1k** (ENDGame)
  - **Area, resolution**
    - grid number: **1,598** (E-W) X **1,718** (S-N)
    - resolution: 1.5~4 km (Variable grid), DA 3 km, 70 levels
  - **Forecast time (cycle)**
    - **36 hours** (3 hourly)
  - **DA system:** 3DVAR(FGAT, IAU)
    - surface, sonde, radar, aircraft, Scatwind (± 90 min cutoff time)
    - GNSS, AMSU-B, TC Bogus (added ‘18.1)
  - **Operation:** since July 2016
Observation usage in LDAPS

- **Surface** (synop, ship, buoy, metar), **Sonde** (temp, pilot, windprofiler), **Radar** (radial velocity), **Aircraft** (amdar), **Scatwind** (ASCAT) → **Ground-GNSS, AMSU-B**

- 3 hourly cycling 3D-Var: lack of available observation, need more satellite DA

- Adding moisture information to lower and upper layers
What is the GNSS?

- Global Navigation Satellite System
  - GPS (United States), GLONASS (Russian Federation), Galileo (European Union), BeiDou (China)
  - The purpose is to calculate the position of the GPS receiver
  - The signal is delayed due to the amount of water vapor

- Zenith Total Delay
  - \[ ZTD = 10^{-6} \int_{z=0}^{z=\infty} N \, dz \]
  - \( N(\text{refractivity}) = \frac{k_1 p_d}{T} + \frac{k_2 p_v}{T} + \frac{k_3 p_v}{T^2} \)
  - Refractivity exponential decay with height

\( k: \text{constant} \)
\( (Smit, \text{ and W eintraub}, 1953) \)
\( p_d: \text{partial pressure of dry air} \)
\( p_v: \text{partial pressure of water vapor} \)
\( T: \text{absolute temperature} \)

(Bevis et al., 1994)
Current GNSS Usage at the KMA

Purpose

- Ground-based GNSS: **moisture** information in the **lower** level → improved **precipitation**
- GNSS-RO: atmospheric **upper** layer → improved **synoptic field**

Status

- Using ground-based GNSS data and planed GNSS-RO data in local model

<table>
<thead>
<tr>
<th>Data spices</th>
<th>Global</th>
<th>Regional</th>
<th>Local</th>
<th>Very-short</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground based GNSS (ZTD)</td>
<td>1 hourly</td>
<td>O</td>
<td>-</td>
<td>O ('18.1)</td>
</tr>
<tr>
<td></td>
<td>15 minutes</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>GNSS-RO (Bending angle)</td>
<td>COSMIC 1~6</td>
<td>O</td>
<td>O</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Metop-A/B</td>
<td>O</td>
<td>O</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>TanDEM-X</td>
<td>O ('17.10)</td>
<td>-</td>
<td>Planed ('18.5)</td>
</tr>
<tr>
<td></td>
<td>TerraSAR-X</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Grace-B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>KOMPSAT-5</td>
<td>Planed</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

✔ Challenge: global observation speices which covers **local domain** assimilated.
ground-based GNSS operation

- NMSC/KMA receives raw signal data from several domestic GNSS networks of around 100 stations over the Korean Peninsular
- 40 sites operationally used in Jan. 2018 for local model
- **106 sites are testing for quality control and impact of observation error**

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KASI : Korea Astronomy and Space Science Institute  
NGII : National Geographic Information Institute  
NMSC : National Meteorological Satellite Center  
NMPT : National Maritime PNT Office
Quality Control

- Comparison to PWV of ground-based GNSS and Sonde stations
  - Improvement of data quality by improving fixed sites (Courtesy of NMSC)
  - ZTD calculation stability and improvement of O-B
  - Static bias correction (1 month mean of O-B)

- Through comparison of the PWV with Sonde, the quality of GNSS data is reliable

<table>
<thead>
<tr>
<th></th>
<th>KASI vs. RS</th>
<th>NMC vs. RS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bias</td>
<td>0.5</td>
<td>Bias = -0.5</td>
</tr>
<tr>
<td>RMSE</td>
<td>5.8</td>
<td>RMSE = 5.0</td>
</tr>
<tr>
<td>Corr</td>
<td>0.86</td>
<td>Corr = 0.91</td>
</tr>
</tbody>
</table>
Quality Control

- Comparison to PWV of ground-based GNSS and Sonde stations
- Improvement of data quality by improving fixed sites (Courtesy of NMSC)
- ZTD calculation stability and improvement of O-B
- Static bias correction (1 month mean of O-B, remove outlier ±0.1)

<table>
<thead>
<tr>
<th>Fixed sites</th>
<th>Org</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAEJ, SUWN, SHAO, LHAZ, IRKM, AIRA, CHAN, TSKB, USUD</td>
<td>DAEJ, SUWN, SHAO, LHAZ, IRKM, XIAN, URUM</td>
<td></td>
</tr>
</tbody>
</table>

- **DAEJ-KASI**
- **SUWN-NGII**

![Histograms showing distribution of O-B and C-B for DAEJ-KASI and SUWN-NGII between Org and New data.](attachment:histograms.png)

- **SD**
- **Bias**

![Graphs showing SD and Bias for multiple sites including BMAC-KASI, CHUANGII, CNUJ-NGII, DAE-KASI, JIN-NGII, KANR-NGII, KWNJ-NGII, MFCO-KASI, MLYN-KASI, SBAC-KASI, SEOS-NGII, SHAO-KASI, SUWN-NGII, WULJ-NGII.](attachment:graphs.png)
By adding GNSS data, the differences ZTD of between observation and analysis are reduced.

The improvement of 850 hPa Temperature in July 2016

Improved precipitation forecast performance using spatially dense GNSS data

The analyses of GNSS DA match the GNSS ZTD observations better than without GNSS cycle.
By adding GNSS data, the differences ZTD of between observation and analysis are reduced.

The significant improvement of lower tropospheric humidity field and rainfall.

Improved precipitation forecast performance using spatially dense GNSS data.

3% improvement

Positive impact for heavy rainfall than weak rainfall.
Impact of Ground-based GNSS

- By adding GNSS data, the differences ZTD of between observation and analysis are reduced.
- The improvement of precipitation and 850 hPa Temperature in July 2016.
- Improved precipitation forecast performance using spatially dense GNSS data.

Observation

2017.07.15.18UTC

STN #35 (+06h FCST)
STN #80 (+06h FCST)

<1 hour accumulated precipitation>

✓ STN #80 shows better agreement with observation than STN #35.
Observation error calculation for 15 domestic sites (previous LDAPS)

Observation error estimation and sensitivity experiment of GNSS

\[
R = E((y - H(x_a))(y - H(x_b))^T)
\]

(Desroziers et al., 2005)

- **Observation error**

<table>
<thead>
<tr>
<th>OPER</th>
<th>ZTD not assimilated</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXP1</td>
<td>ErrTZD = each station’s R (at least 20mm)</td>
</tr>
<tr>
<td>EXP2</td>
<td>ErrTZD = 15mm</td>
</tr>
<tr>
<td>EXP3</td>
<td>ErrTZD = 6mm (Met Office)</td>
</tr>
</tbody>
</table>

<Configure of sensitivity experiment>

<Observation error by station>

<Averaged RMSE by experiment>
QC for Very-short range forecast model

- Diagnosis of data quality at 50 stations every 15 minutes (± 30 min cutoff time)
- Static bias correction (1 month mean of O-B, remove outlier ±2σ each station)
- Seasonal experiments are in progress

VDAPS (Very-short range Data Assimilation and Prediction System)

<Time series of observation innovation before and after bias correction>
Ongoing activities for CS model

- Estimation of observation error covariance
  - Diagnosis approach (Desrozier et al., 2005, Hollingsworth and Lönnberg, 1986)

- Bias Correction
  - Ground-GNSS (Sánchez arriola et al., 2016), Aircraft, Radiance (IASI)

- Add available data
  - **15 minutes** ZTD → very-short range forecast model (VDAPS)
  - polar-orbiting **satellite** (IASI, ATMS, GNSS-RO, etc)
  - **Intensive observation** data for PyeongChang2018 (Sonde, dropsonde, radar, etc)

Poster(1.5): Hee-Jung Kang
Summary

- KMA has been dedicating to assimilate satellite data to fill gap at sparse area.
- The quality of ground-based GNSS station over the Korean Peninsular was evaluated and it looks good to assimilate for local and very-short range forecast model.
- Ground-based GNSS data gives positive impacts on the lower tropospheric humidity field and improved the skill score of precipitation forecast.

Future Plan

- To optimize use of the ground-based GNSS data, estimation of observation error and new bias correction have been investigated and initial trials show positive results.
- We plan to use the ground-based GNSS data in NEW convective scale model based on KIM(KIAPS Integrated Model system).
Thank you for your attention!