Recent developments on the assimilation of GNSS-RO bending angles in the Météo-France 4D-Var system

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Outline

1. Current assimilation of GNSS-RO data at Météo-France
2. Use of new observations
3. Tests on the 2D bending angle operator
4. Conclusion and prospect
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The use of GNSS-RO data at Météo-France

In the global 4D-Var data assimilation system ARPEGE

- ≃ 120,000 data per 6-hour assimilation window (∼ 1% of the total observations)
- TERRASAR-X, TANDEM-X
- METOP
- COSMIC
GNSS-RO operational assimilation at Météo-France

In the global 4D-Var data assimilation system ARPEGE

- since 2007
- assimilation of bending angles up to 50 km
- rising/setting occultations
- 1D observation operator
- tangent point drift taken into account
- anchor data for variational bias correction
Outline

1. Current assimilation of GNSS-RO data at Météo-France
2. Use of new observations
3. Tests on the 2D bending angle operator
4. Conclusion and prospect
New observations

GRAS on Metop-C

- Metop-C data assimilated in ARPEGE operational system since July 2019
- ROM SAF BUFR files
- Assimilated from 10 km up to 50 km in the tropics, from 8 km elsewhere (as for Metop-A & B)
- 25% additional GNSS-RO data
New observations

**GRAS on METOP-C**

- quality comparable to METOP-A and METOP-B
  METOP-C + METOP-B (experiment, black) compared to METOP-B (reference, red)
### New observations

**GRAS on METOP-C**

- forecast score cards against radiosondes and IFS analysis for Geopotential, Temperature, Wind and Humidity over **NH** (left) and **SH** (right) from 2019/04 to 2019/06:

<table>
<thead>
<tr>
<th>Geopotential</th>
<th>Ref. Range</th>
<th>Radiosondes 0H to 96H timestep 12H</th>
<th>IFS analysis 0H to 102H timestep 6H</th>
</tr>
</thead>
<tbody>
<tr>
<td>100hPa</td>
<td>➤➤➤➤➤➤➤➤➤➤➤➤➤➤➤➤➤➤</td>
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- statistically significant improvement for geopotential and temperature for most of the domains at short range
New observations

Testing KOMPSAT-5 (AOPOD)

- available since May 2019
- 14% additional GNSS-RO data over globe
- first tests by assimilating the data from 0 up to 50 km

KOMPSAT-5 AOPOD data over a 24h-period (2019/06/01)
New observations

Testing KOMPSAT-5 (AOPOD)

- O-B and O-A bending angle departure statistics over Globe for a 1-month period (2019/06): operational GPSRO + KOMPSAT-5 (exp, black) compared to operational GPSRO (reference, red)

- promising results: fit to guess and analysis rather similar to other GPSRO data
New observations

Testing KOMPSAT-5 (AOPOD)

- forecast score cards against radiosondes and IFS analysis for Geopotential, Temperature, Wind and Humidity over SH for a 1-month period (2019/06):

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<td>Geopotential</td>
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<td>100hPa</td>
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</tbody>
</table>

- statistically significant improvement for geopotential for most of the domains at short range, slight positive impact for other parameters in the troposphere.

▲ 2D significatively better than 1D (99.5% confidence)
▼ 2D significatively worse than 1D (99.5% confidence)
1. Current assimilation of GNSS-RO data at Météo-France
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The current 1D observation operator

1D bending angle operator that doesn’t take into account the 2D nature of the measurement and integrates:

$$\alpha(a) = -2a \int_{a}^{\infty} \frac{d\ln(n)/dx}{\sqrt{x^2 - a^2}} dx$$  

(1)

where $x=nr$  

*refractive index* $\times$ *radius*

1D operator only requires a single profile at a given location
Towards a 2D observation operator in ARPEGE

- 2D operator: the NWP information must be available at multiple locations within a 2D slice defined by the 2D occultation plane (Healy et al. 2007)
- existing code for the 2D operator developed and used at ECMWF (Healy et al. 2007)
- implementation in IFS: 31 NWP profiles in the 2D occultation plane separated by 40 km
- adjustment of the ECMWF code to the stretched and tilted ARPEGE grid
Experiments with 2D operator

Implementation of a set of experiments

- 2-month period (March-April 2019)
- operational version of the model (all observations and full resolution)
- reference: 1D operator
- 2D experiments: tests on 5 numbers of NWP profiles in the 2D plane
  - 11 profiles
  - 21 profiles
  - 31 profiles
  - 51 profiles
  - 101 profiles
Impact of 2D

- O-B and O-A bending angle departure statistics over Globe for a 1-month period (2019/03): 2D with 11 profiles (exp, black) compared to 1D (reference, red)

- more observations assimilated with 2D (+2% < 10 km)
- better fit to guess (std dev reduced < 15 km and bias reduced by 10 to 20% > 35 km)
Impact of 2D on the forecast skills

Forecast score cards (31 profiles) over SH for the 2-month period 2019/03/05 to 2019/05/05:

- Statistically significant improvement compared to 1D for geopotential at short range for all domains (SH, NH, tropics). Slight positive impact for other parameters / ranges.

![Table showing forecast scores for different parameters and ranges](image)

- 2D significantly better than 1D (99.5% confidence)
- 2D significantly worse than 1D (99.5% confidence)

Statistically significant improvement compared to 1D for geopotential at short range for all domains (SH, NH, tropics). Slight positive impact for other parameters / ranges.
Impact of 2D on the forecast skills

- Forecast score cards against IFS analysis (2D with **31 profiles**) over NH and **North America** for a 2-month period (2019/03/05 to 2019/05/05):

![Bootstrap test on RMSE - GEOPOTENTIAL](image)

- Improvement with 2D for geopotential at short range in altitude
- BUT clear deterioration in the troposphere over North America at medium range for most parameters (Z, T, wind, Hu).
Computing cost of the 2D operator

- strong impact mainly in the first minimization
- elapsed time for the first minimization in ARPEGE depending on the number of profiles:

<table>
<thead>
<tr>
<th>Number of profiles</th>
<th>1</th>
<th>11</th>
<th>21</th>
<th>31</th>
<th>51</th>
<th>101</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean time (seconds)</td>
<td>538 s</td>
<td>578 s</td>
<td>612 s</td>
<td>647 s</td>
<td>766 s</td>
<td>1066 s</td>
</tr>
</tbody>
</table>

- cost increased by 20% with 31 profiles compared to 1D, nearly 100% with 101 profiles!
Outline

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## Conclusion and prospect

### Use of new observations

- Beneficial assimilation of METOP-C data in the Météo-France operational global model with a significant positive impact on the forecast skills.
- Promising tests on KOMPSAT-5 data with planned tests excluding the data below 10 km in the tropics.

### 2D operator

- Neutral to slightly positive impact in the troposphere.
- Encouraging improvement of the scores for geopotential.
- Troubling degradation of the scores over North America:
  - $\rightarrow$ GPSRO information inconsistent with conventional observations?
  - $\rightarrow$ Influence of the stretched grid?
- Planned tests with a reduced number of profiles in the minimization in order to reduce the computing cost.
- Compromise between slight improvement and increased computational cost ...