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

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IROWG 2019, Elsinore, 19-25 september 2019

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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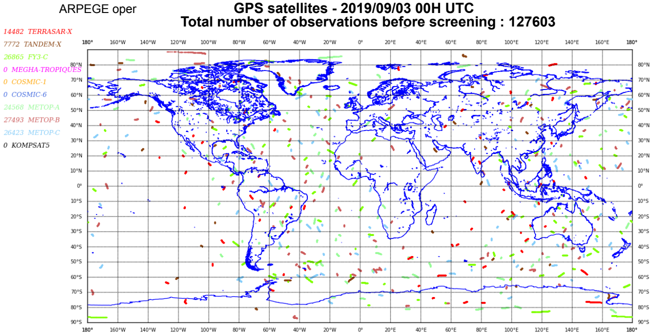
The use of GNSS-RO data at Météo-France

In the global 4D-Var data assimilation system ARPEGE

- $\simeq$ 120.000 data per 6-hour assimilation window ($\sim$ 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

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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

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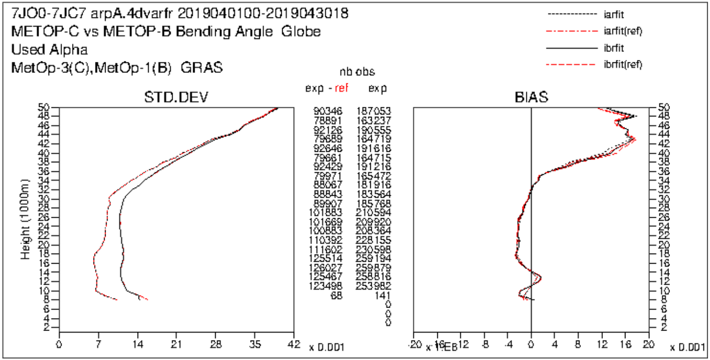
New observations

GRAS on METOP-C

- quality comparable to METOP-A and METOP-B
- O-B and O-A bending angle departure statistics (**Globe**, 2019/04) : METOP-C + METOP-B (experiment, black) compared to METOP-B (reference, red)



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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 :

	Ref.	Radiosondes	IFS analysis
	Range	0H to 96H timestep 12H	0H to 102H timestep 6H
Geopotential	100hPa	▼ ▲ ▼ ▲ = ░ = = =	▲▲▲▲▲▲▲▲▲▲▲▲▲▲░===
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Temperature	100hPa	░ = = = = = = = =	▲▲▲▲=░▲░░░░░======
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	850hPa	= = = = = = = = =	==================
	1000hPa	= = ░ = = = = = =	=░===▼=░======░===
Wind	250hPa	= = = = = = = = =	==================
	500hPa	░ = = ░ = = = = =	==================
	850hPa	= = = = ░ = = = =	=============░░░==
Humidity	400hPa	= = = ░ = = = = ░	============░=====
	700hPa	= ░ = = = = = = ░	=====░░===========
	850hPa	= = = = = = = = =	░=====░===========

	Ref.	Radiosondes	IFS analysis
	Range	0H to 96H timestep 12H	0H to 102H timestep 6H
Geopotential	100hPa	▲ ▲ ▲ ▲ ▲ = = ░ =	▲▲▲▲▲▲▲▲▲▲░=======
	500hPa	▲ ▲ ▲ ▲ ▲ = = = =	▲▲▲▲▲▲▲▲▲▲▲▲░=====
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Temperature	100hPa	= ░ = = = = ░ = =	▲▲▲▲▲▲▲▲▲░░░==░===
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	850hPa	= = = = = = = = =	==========▲▲▲░====
	1000hPa	= = = = = = = = =	==▲░░=░==▲=░======
Wind	250hPa	= ▲ = = ░ = = = =	░▲▲░=▲▲▲▲▲░░▲▲====
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	850hPa	░ = = = = = = = =	=░====░░▲▲▲▲▲░░░==
Humidity	400hPa	= ░ = = = = = = =	=====░==░==░░░░░░=
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- statistically significant improvement for geopotential and temperature for most of the domains at short range

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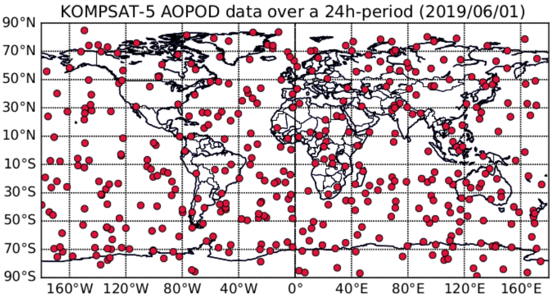
New observations

Testing KOMPSAT-5 (AOPOD)

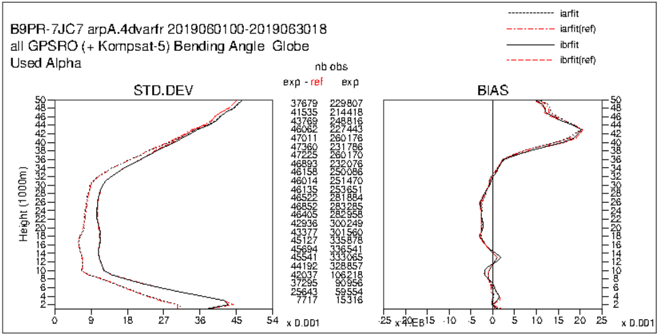
- available since May 2019
- 14% additional GNSS-RO data over globe
- first tests by assimilating the data from 0 up to 50 km



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

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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) :

	Ref.	Radiosondes	IFS analysis
	Range	0H to 96H timestep 12H	0H to 102H timestep 6H
Geopotential	100hPa	░ ░ ▲ ░ ▲ = = = =	▲▲▲▲▲▲▲▲░░========
	500hPa	= = = = = = = = =	▲▲▲▲==============
	850hPa	= = = = = = = ░ =	=░░▲=======░======
	1000hPa	= = ░ = = = = = =	====░==░░=========
Temperature	100hPa	= ░ = = = = = = =	===▲======▲░░=====
	500hPa	= ▲ = = = ░ = = =	▲░░===============
	850hPa	= = = = = = = ░ =	==================
	1000hPa	= = = ░ = = = = =	░===░====░==▲░░===
Wind	250hPa	= ▲ = = = = = = =	░░================
	500hPa	= = = = = = ░ = =	▲▲▲▲░=============
	850hPa	= = ▼ = = = = = =	====░=░=░==░======
Humidity	400hPa	= = ░ = = = = = =	░░=░==============
	700hPa	= = = = = = ░ ░ =	░░==========░=====
	850hPa	= = = = = = = = =	==================

▲ 2D significatively better than 1D (99.5% confidence)

▼ 2D significatively worse than 1D (99.5% confidence)

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

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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 :

$$\alpha(a) = -2a \int_{a}^{\infty} \frac{d\ln(n)/dx}{\sqrt{x^2 - a^2}} dx \quad (1)$$

where *x=nr* *refractive index* $\times$ *radius*

- 1D operator only requires a single profile at a given location

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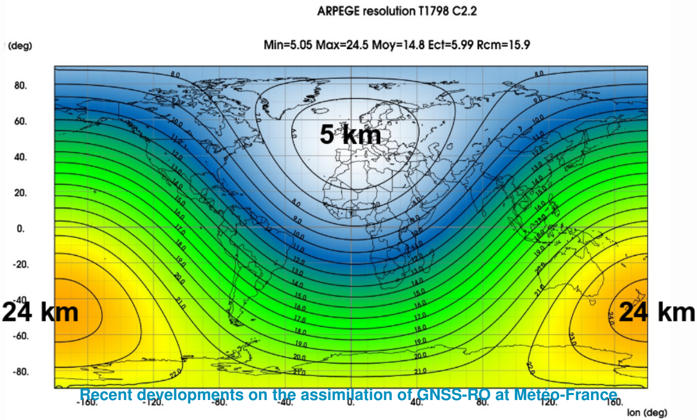
Towards a 2D observation operator in ARPEGE

- 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
- adjustement of the ECMWF code to the stretched and tilted ARPEGE grid



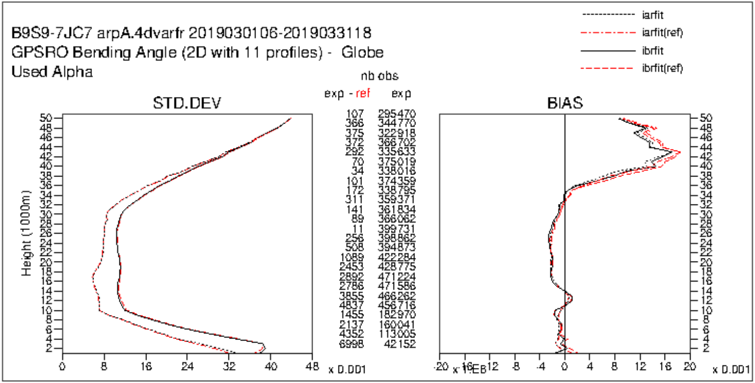
Experiments with 2D operator

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)

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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 :

	Ref	Radiosondes	IFS analysis
	Range	0H to 96H timestep 12H	0H to 102H timestep 6H
Geopotential	100hPa	▲ = = = = = = = ░	▲▲▲▲▲▲▲▲░=========
	500hPa	▲ ░ ░ = = = ░ = ░	▲▲▲▲=░=░==========
	850hPa	▲ = ░ = = = = = =	▲▲▲▲▲▲░░==========
	1000hPa	= = = = = = = = =	=====░░▲==========
Temperature	100hPa	= = = = = = = = =	░==░░=============
	500hPa	= = = = = = = ░ =	▼=▲░==============
	850hPa	= = ░ = = = = = =	==========░=======
	1000hPa	= = ░ ▼ = ▼ = ░ =	======░░=▲========
Wind	250hPa	= ░ = = = = = ▲ =	=░░===░░==========
	500hPa	= = ░ = = = = = =	=░===░░░░=========
	850hPa	= = ░ = ░ = = = =	=====▲▲▲░░░=======
Humidity	400hPa	= = = = = = = = =	====░▲░==░========
	700hPa	= ░ = = = = = = =	===░==░░==========
	850hPa	= = = = = = = = =	======░▲▲▲░=======

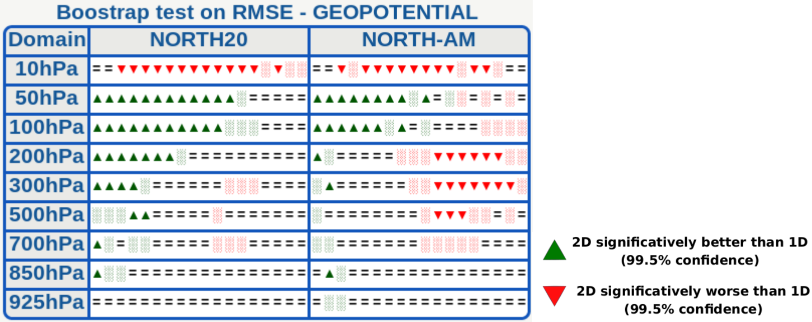
▲ 2D significatively better than 1D (99.5% confidence)

▼ 2D significatively 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) :



- 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).

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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 :

	Number of profiles					
	1	11	21	31	51	101
Mean time (seconds)	538 s	578 s	612 s	647 s	766 s	1066 s

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

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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 ...