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METEO FRANCE

# Recent developments on the assimilation of GNSS-RO in the Météo-France global and regional NWP models

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**EUMETSAT ROM SAF User Workshop, Reading, 11-13 June 2024**

CNRM

cnrs

# Outline

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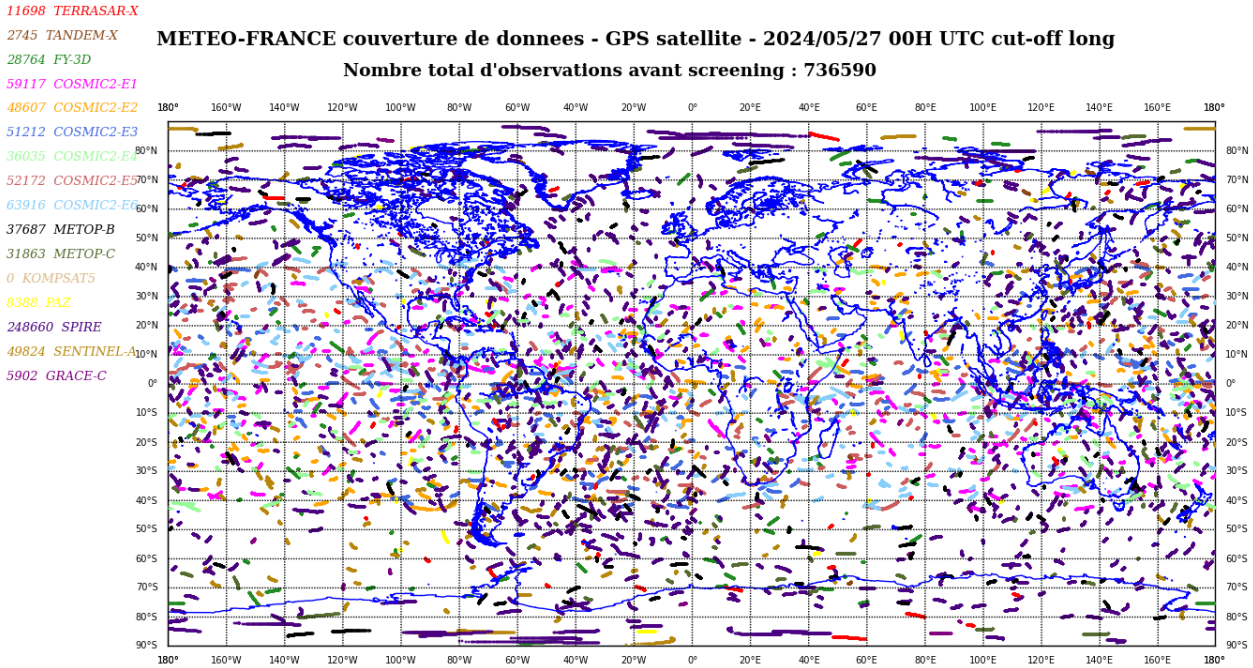
# The use of GNSS-RO data at Météo-France

## In the global 4D-Var data assimilation system ARPEGE

- $\simeq$ 700.000 data per 6-hour assimilation window ($\sim$ 5% of the total observations)




- METOP, TERRASAR-X, TANDEM-X, GRACE-C
- KOMPSAT-5, FY-3D, PAZ
- COSMIC-2, SENTINEL-6
- SPIRE (EUMETSAT + NOAA contracts) processed by ROM SAF

# GNSS-RO operational assimilation at Météo-France

## In the global 4D-Var data assimilation system ARPEGE

- assimilation of bending angles up to 50 km
- use of the observed refractivity for additional QC (super-refraction check)
- rising/setting occultations
- 2D forward operator (since June 2022)
- tangent point drift taken into account
- anchor data for variational bias correction

# Outline

# Use of commercial data

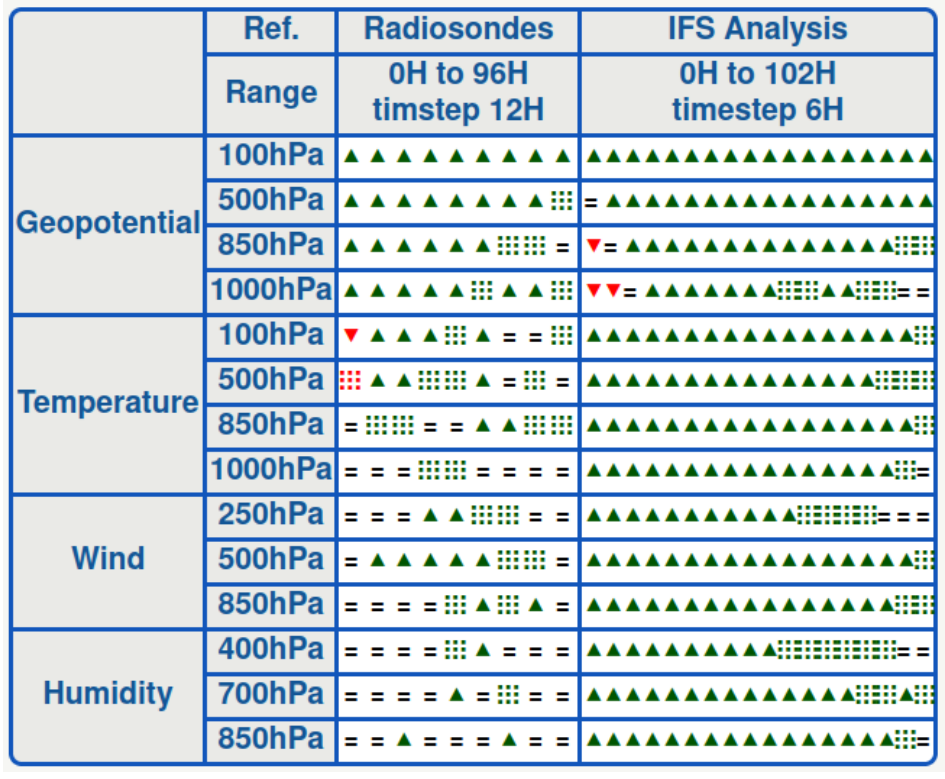
## SPIRE

- EUMETSAT contract : in operational use since 2023-Q1 (from ROM SAF)
  - $\sim$ 15 to 20% additional GNSS-RO data over globe in ARPEGE
  - significant positive impact on the forecast skill
- NOAA contract : in operational use since March 2024 (from ROM SAF)
  - $\sim$ 40% additional GNSS-RO data over globe in ARPEGE
  - significant positive impact on the forecast skill

# Impact of SPIRE (NOAA)

## on the forecast skill (NH)

- forecast scorecards against radiosondes and IFS analysis for Geopotential, Temperature, Wind and Humidity over **NH** for 2023/01 :



| | Ref. | Radiosondes | IFS Analysis |
|---|---|---|---|
| | Range | 0H to 96H timstep 12H | 0H to 102H timestep 6H |
| Geopotential | 100hPa | ▲ ▲ ▲ ▲ ▲ ▲ ▲ ▲ ▲ | ▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲ |
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| Temperature | 100hPa | ▼ ▲ ▲ ▲ ⁞ ▲ = = ⁞ | ▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲⁞ |
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| Humidity | 400hPa | = = = = ⁞ ▲ = = = | ▲▲▲▲▲▲▲▲▲▲▲⁞⁞⁞⁞⁞⁞= = |
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**Improvement**

**Degradation**

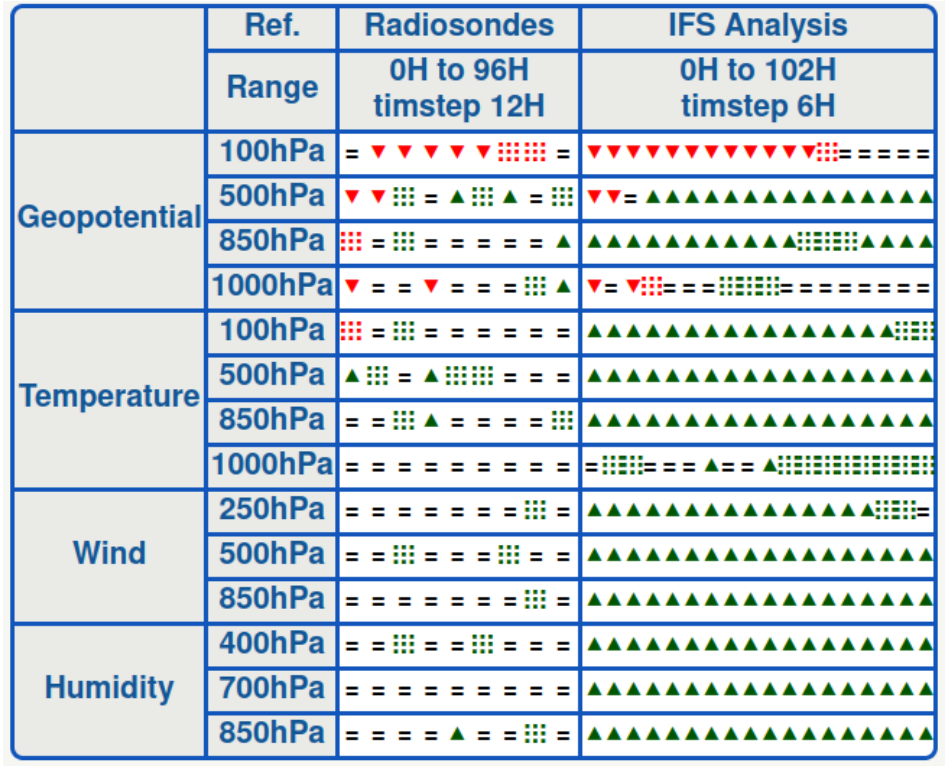
▲ significatively better with new obs. (99.5% confidence)
⁞ significatively better (95% confidence)
= no significant signal (95% confidence)
⁞ significatively worse (95% confidence)
▼ significatively worse (99.5% confidence)

- clear improvement for most parameters

# Impact of SPIRE (NOAA)

## on the forecast skill (SH)

- forecast scorecards against radiosondes and IFS analysis for Geopotential, Temperature, Wind and Humidity over **SH** for 2023/01 :



| | Ref. | Radiosondes | IFS Analysis |
|---|---|---|---|
| | Range | 0H to 96H timstep 12H | 0H to 102H timstep 6H |
| Geopotential | 100hPa | = ▼ ▼ ▼ ▼ ▼ ▒▒ = | ▼▼▼▼▼▼▼▼▼▼▼▒▒= = = = = |
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| Wind | 250hPa | = = = = = = = ▒ = | ▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▒▒▒= |
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| Humidity | 400hPa | = = ▒ = = ▒ = = = | ▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲ |
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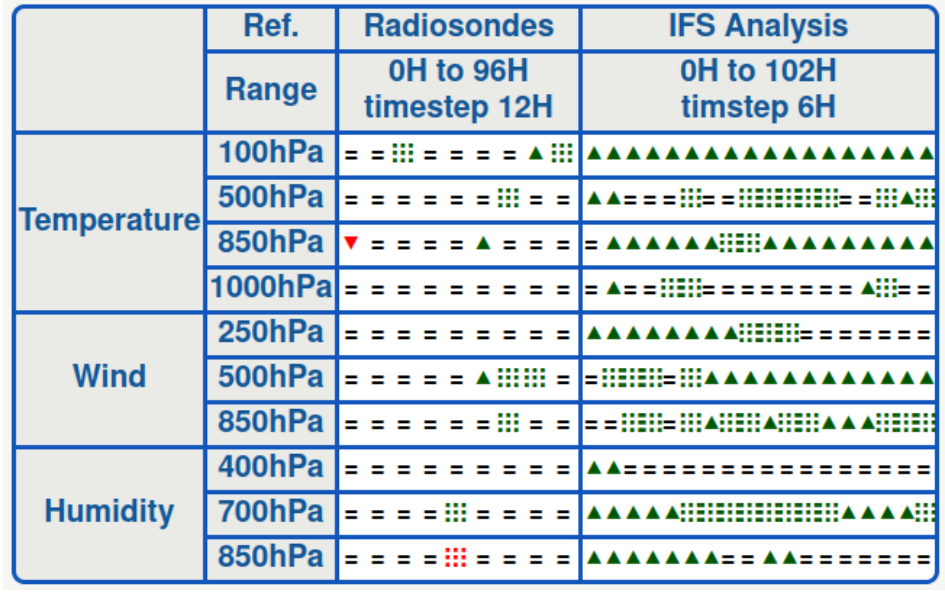
- clear improvement for most parameters (except geopotential above 100hPa)

# Impact of SPIRE (NOAA)

## on the forecast skill (Tropics)

- forecast scorecards against radiosondes and IFS analysis for Geopotential, Temperature, Wind and Humidity over **Tropics** for 2023/01 :



| | Ref. | Radiosondes | IFS Analysis |
|---|---|---|---|
| | Range | 0H to 96H timestep 12H | 0H to 102H timstep 6H |
| Temperature | 100hPa | | |
| | 500hPa | | |
| | 850hPa | | |
| | 1000hPa | | |
| Wind | 250hPa | | |
| | 500hPa | | |
| | 850hPa | | |
| Humidity | 400hPa | | |
| | 700hPa | | |
| | 850hPa | | |

**Improvement**

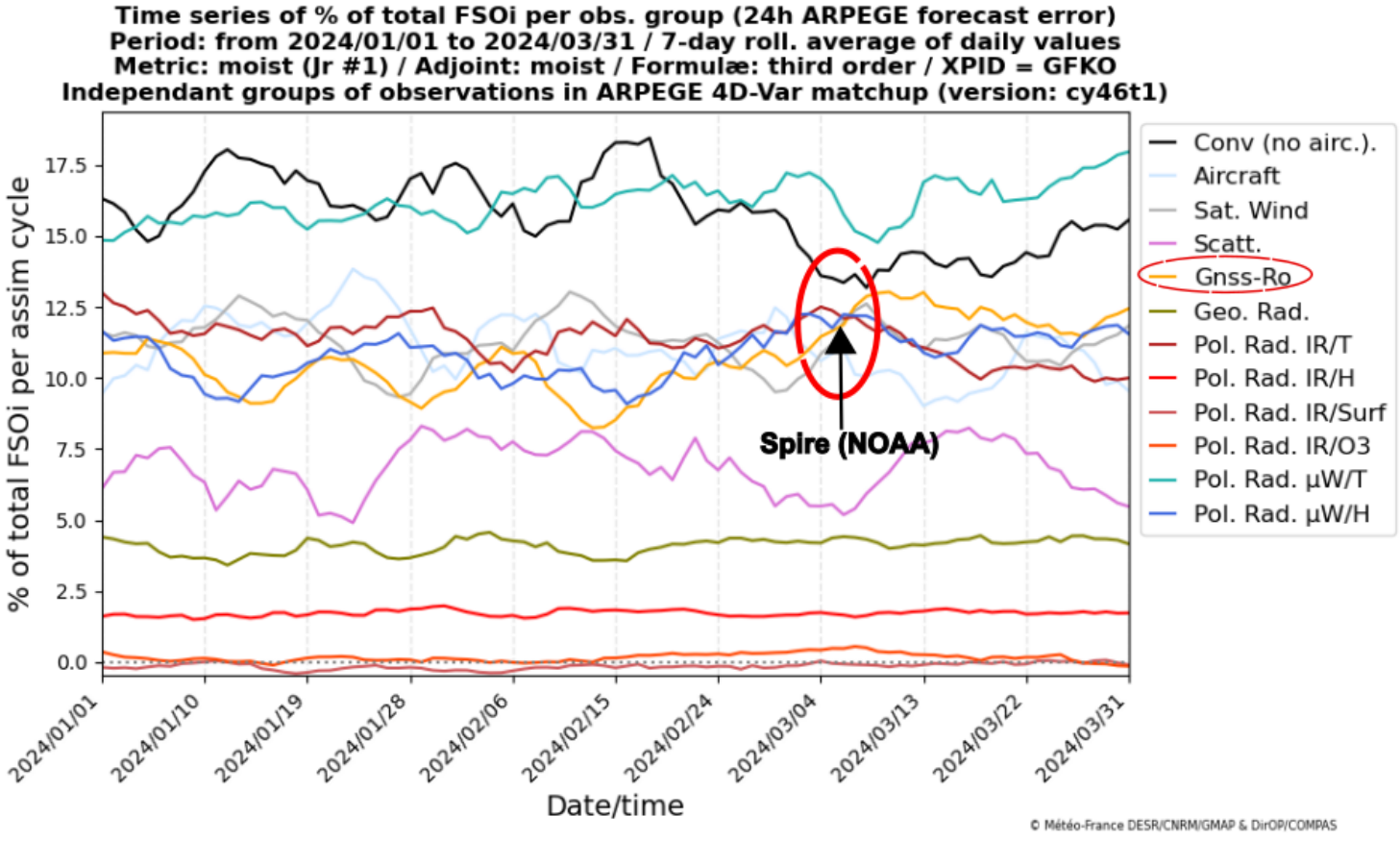
**Degradation**

▲ significatively better with new obs. (99.5% confidence)
significatively better (95% confidence)
= no significant signal (95% confidence)
significatively worse (95% confidence)
▼ significatively worse (99.5% confidence)

- clear improvement for most parameters

# Impact of SPIRE (NOAA)

## on FSOi

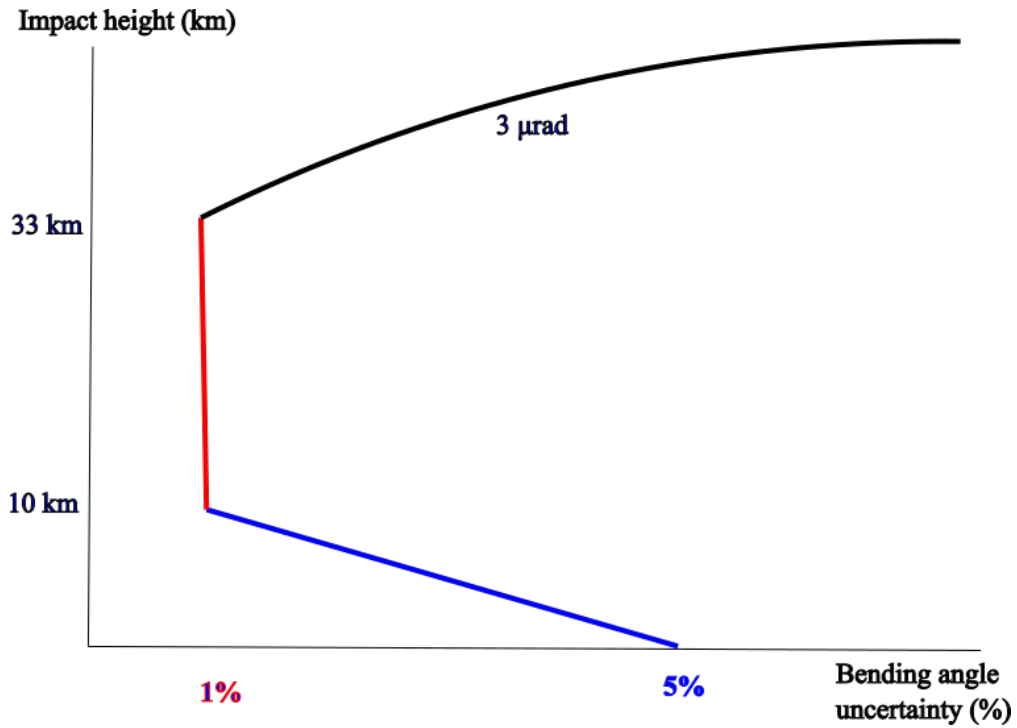



- clear increase of GNSS-RO contribution to FSOi

# Outline

# Current model of GPSRO observation uncertainties

- current uncertainty model as a function of obsvalue (bending angle) and impact height



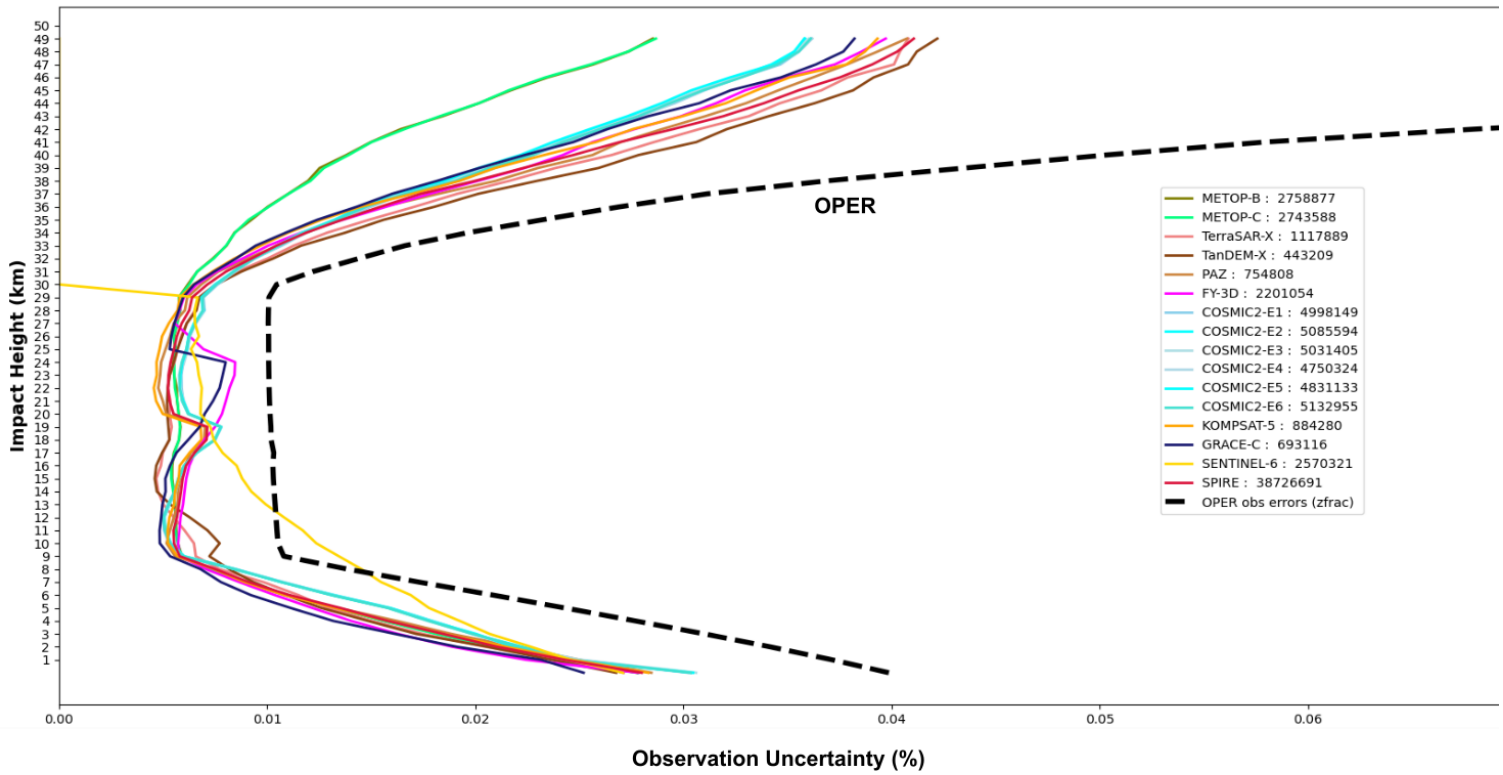
# Review of the GNSS-RO observation uncertainties

## Objectives and plans

- testing the sensitivity of our 4D-Var system to a variation of the GNSS-RO observation uncertainties
- find the optimal value for the $\sigma_o$ in the current uncertainty model
- testing a new model of observation uncertainties depending on additional predictors :
  - satellite receiver
  - latitude
  - transmitting constellation
  - LSW (if available in the BUFR files)
  - synthetic parameter to take account of latitude, seasonal effect and atmospheric characteristics (integrated Temperature or $\theta'_w$ or tropopause height)

# Uncertainty estimates

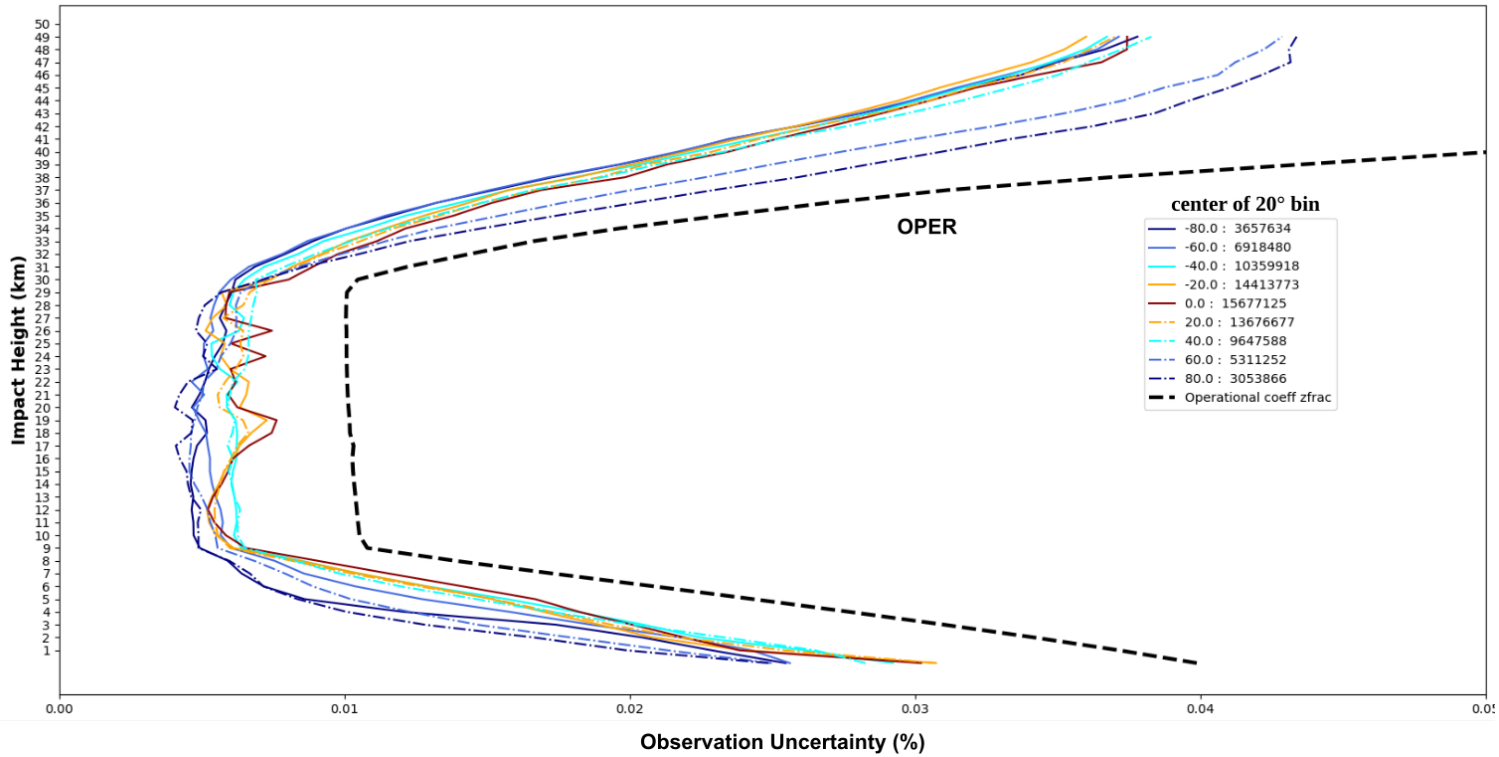
## Desroziers diagnosis by satellite receiver (Dec 2022-Jan 2023)




- suggests to reduce the operational $\sigma_o$
- suggests the $\sigma_o$ depend on satellite receiver

# Uncertainty estimates

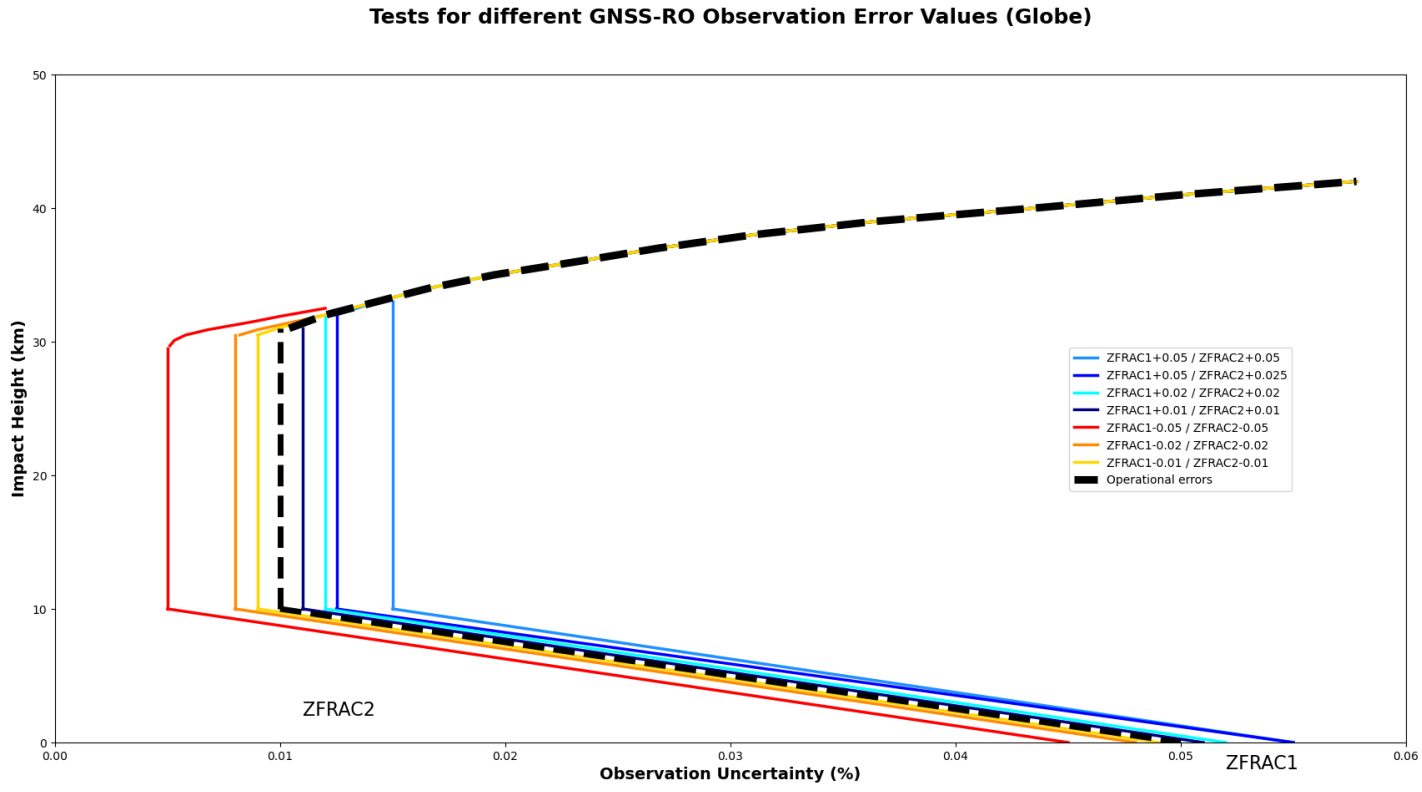
## Desroziers diagnosis by 20° bins of latitude (Dec 2022-Jan 2023)




- suggests the $\sigma_o$ depend on latitude
- high latitudes : diagnosed $\sigma_o$ smaller below 30 km and greater in the stratosphere

# Forecast sensitivity to GNSS-RO uncertainties

## Synthetic scheme of tested $\sigma_o$ within the current uncertainties model

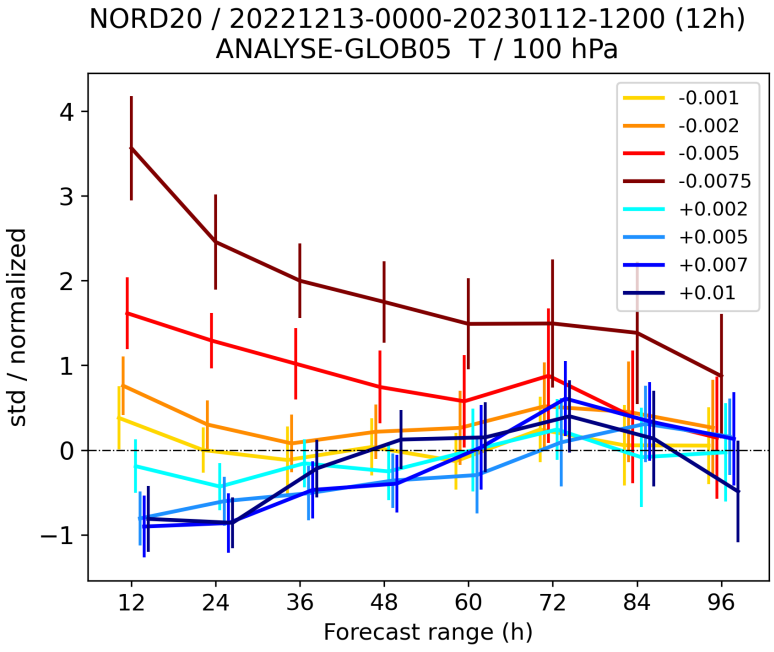



- the same predictors (bending angle and impact height)
- the same breaking levels (0 / 10 / 33 km)

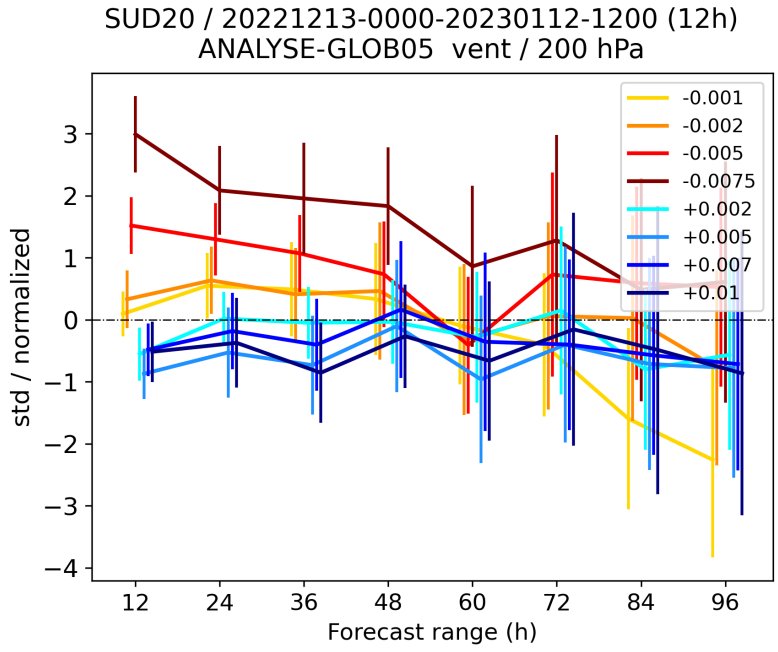
# Tests on tuning the current error statistics

## Synthesis of the results of a series of tests (Dec 2022-Jan 2023)

- normalised difference (exp-oper)/oper of the stdv of the forecast error (vs IFS analysis) for Temperature at 100hPa over NH20 (left) and Wind at 200hPa over SH20 (right)





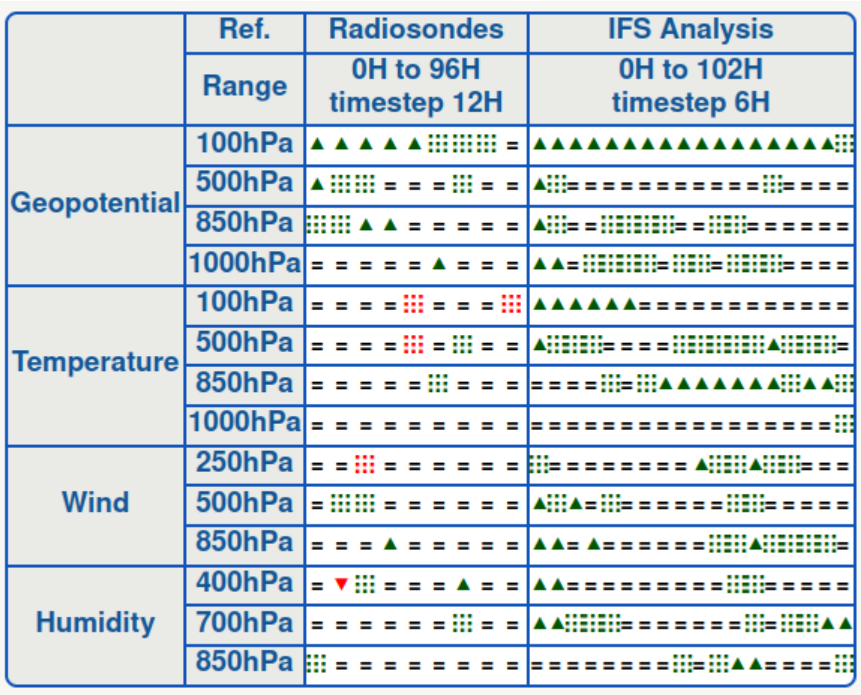


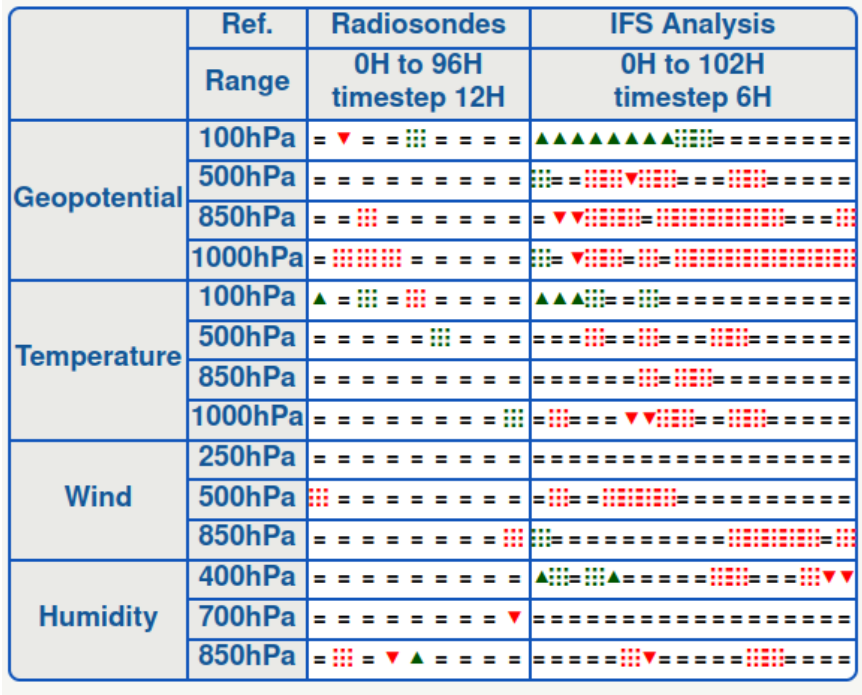

- deterioration of the forecast skill when reducing $\sigma_o$ (short and medium range)
- improvement with increased $\sigma_o$ (0 to 48h)

# Attempts to validate our choice for $\sigma_o$

## More forecast scores on winter and summer periods for a specific setting (ZFRAC1+0.005 / ZFRAC2+0.005)

- forecast scorecards against radiosondes and IFS analysis for Geopotential, Temperature, Wind and Humidity over **NH** for Jan 2023 (left) and July 2023 (right) :



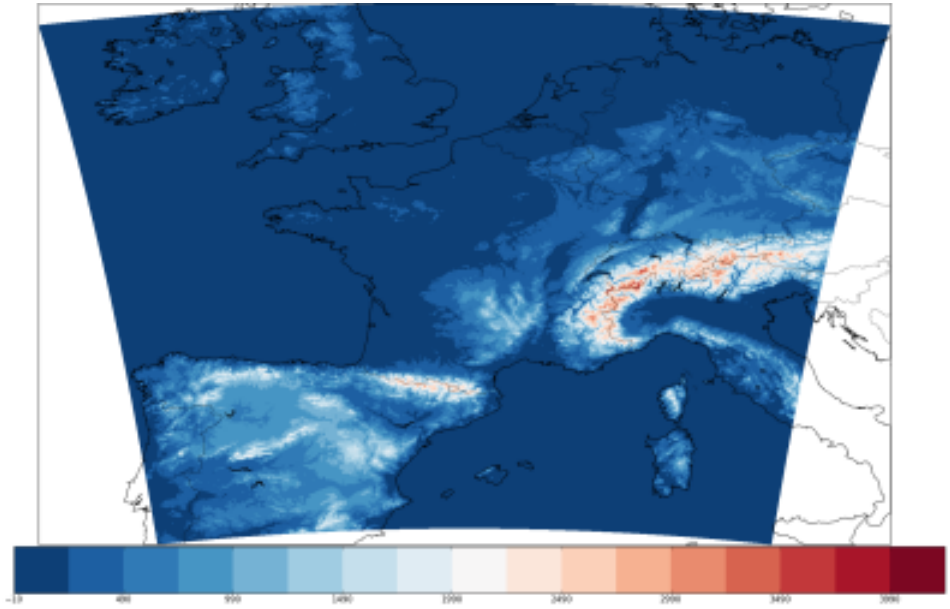




- the improvement obtained in winter is not confirmed during the summer period
- no positive impact from any of the tested settings

# Outline

# The Météo-France high resolution model AROME

- 3D-Var assimilation system
- 1 hour-assimilation window
- 8 runs a day (every 3 hours) up to 51h
- centered over France and Western Europe
- 1.3 km horizontal resolution



# GNSS-RO data in AROME high resolution model

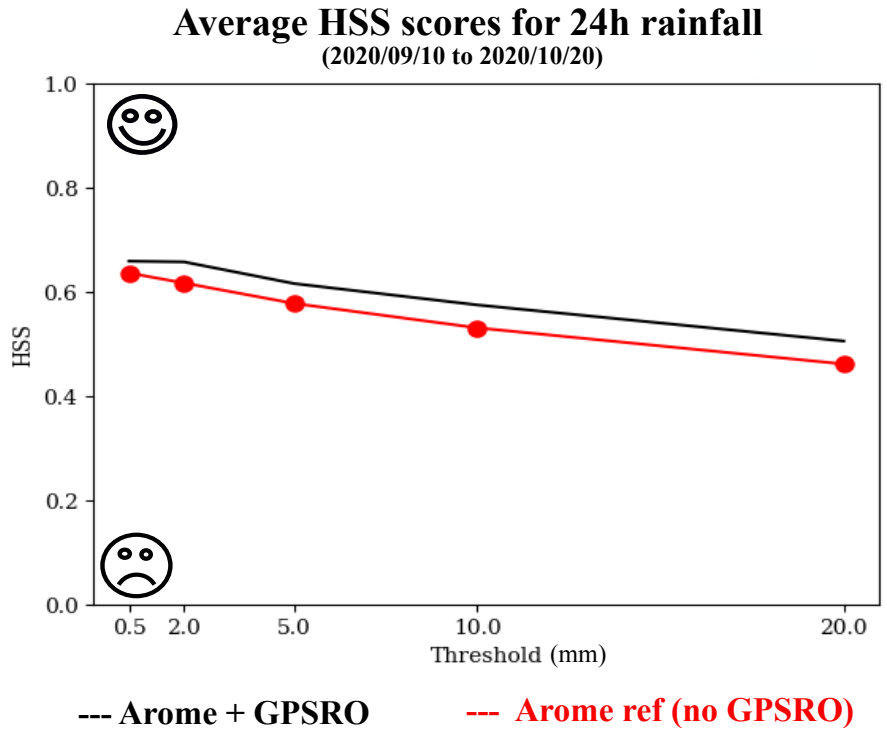
## Assimilation of GNSS-RO in AROME

- operationally used in the high resolution model AROME since June 2022
- assimilation of the bending angles up to 10 hPa (highest level of the model)
- 1D observation operator
- few GNSS-RO data assimilated : $<$ 0.5 % of the total number of observations used
  - GNSS-RO data in $\approx$ 50 % of the networks in average
  - 100 to 200 data by network in average

# GNSS-RO data in AROME high resolution model

## Slight positive impact on the forecast skills

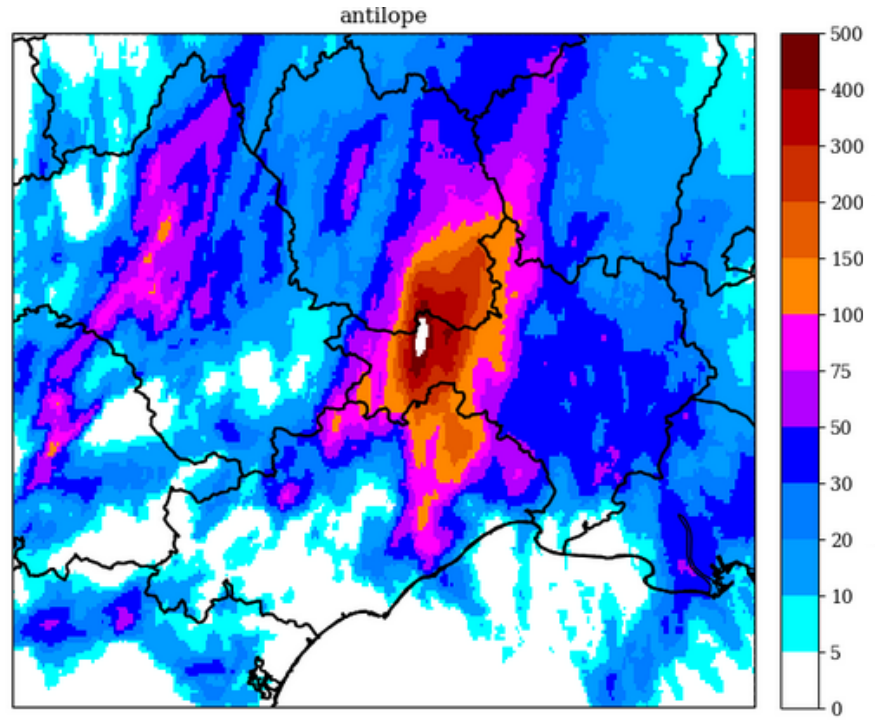
- mainly neutral impact on large-scale parameters but slightly positive on temperature
- slightly positive impact on rainfall scores (summer and winter)



# GNSS-RO data in AROME high resolution model

## High precipitation event over the French Mediterranean area (2020/09/19)

- ≈ 650 mm observed in less than 24 hours

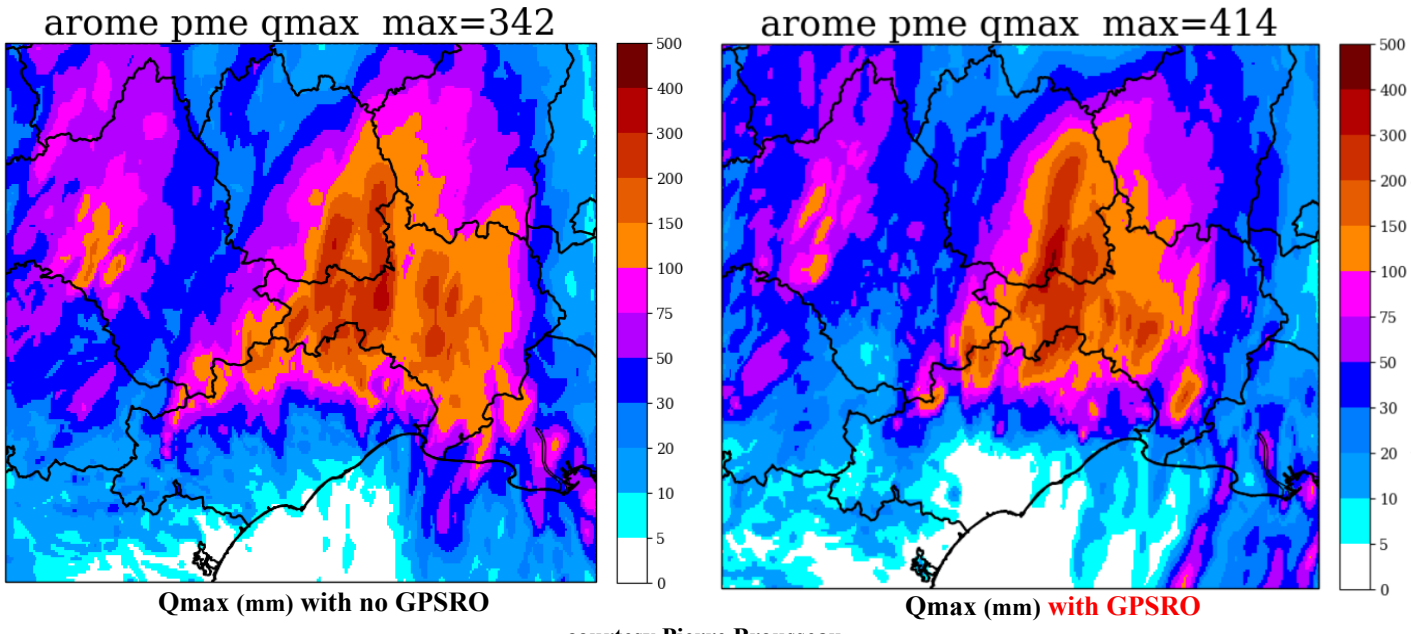



**Observed rainfall (mm) between 2020/09/19 04H and 2020/09/20 00H**

# GNSS-RO data in AROME high resolution model

## High precipitation event over the French Mediterranean area (2020/09/19)

- 268 mm in AROME operational forecast (no GNSS-RO) of 2020-09-19 00h UTC
- ”lagged-ensemble” approach : 2 ensembles with hourly forecasts, 27 runs each
  - 1 ensemble without GNSS-RO
  - 1 ensemble using GNSS-RO
- up to 414 mm with GNSS-RO data




Qmax (mm) with no GPSRO

Qmax (mm) with GPSRO

courtesy Pierre Brousseau

# Outline

# Conclusion and prospect (1/2)

## Use of new observations

- clear beneficial assimilation of SPIRE (NOAA) in the Météo-France operational global model with a significant positive impact on the forecast skills
- in progress : use of FY-3E

## Review of the GNSS-RO observation uncertainties

- first results : current $\sigma_o$ should be increased
- tuning of the current model unsactisfactory till now

## GNSS-RO in high resolution model

- few observations (a bit more with SPIRE)
- but able to provide interesting information on temperature in upper troposphere/lower stratosphere

# Conclusion and prospect (2/2)

## Planned work

- review of super-refraction check in QC : assess the change from a control based on observed refractivity to a control based on refractivity from the model

## Propects on innovative data

- work on PAZ GNSS-Polarimetric RO just began in collaboration with IEEC
- future work for the community : airbone radio-occultations