

# Overview of GNSS data assimilation at Météo-France

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# Outline

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- The operational models at Météo-France
- GNSS ZTD assimilation at Météo-France
- Impact studies
- GNSS ZTD variational bias correction
- Ongoing activities and further works

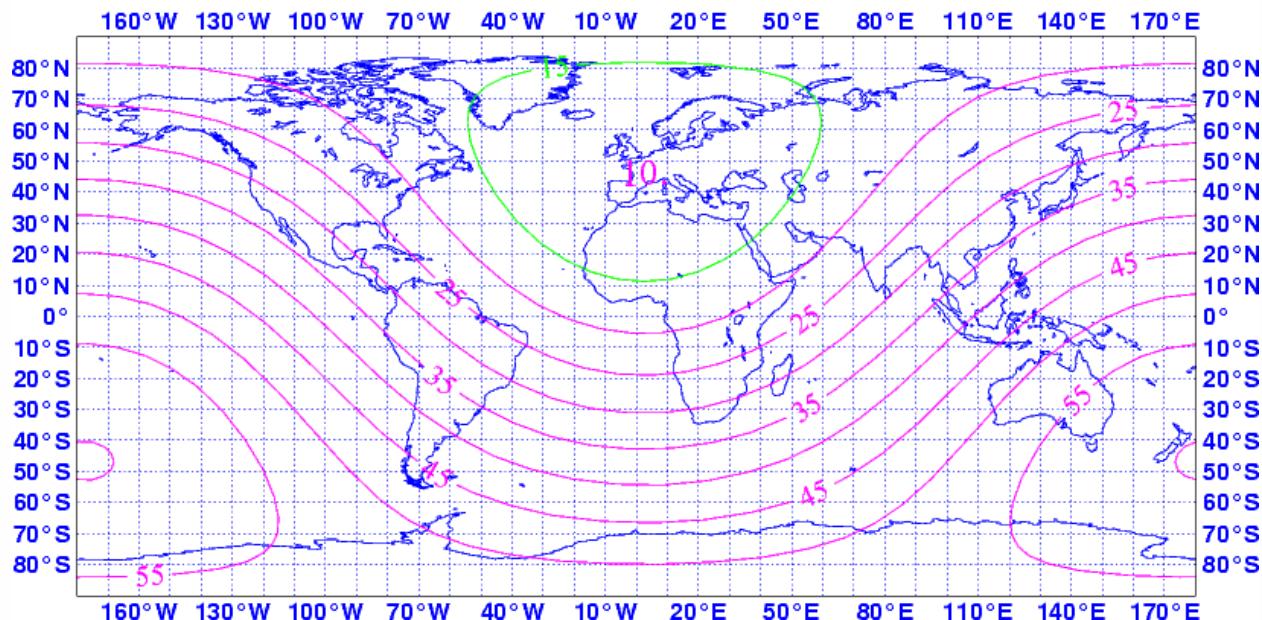
# The operational models at Météo-France



# Global model Arpege

Spectral model with variable resolution : T<sub>L</sub>798C2.4L70 (resolution from 10 km to 60 km, 70 levels from 17m to 0.05 hPa)

## ARPEGE Resolution T798 C2.4 in KM



4D-Var assimilation (6h window and hourly time-slots) :

2 loops of minimization : T107C1L70 (25 iterations) + T323C1L70 (25 iterations)

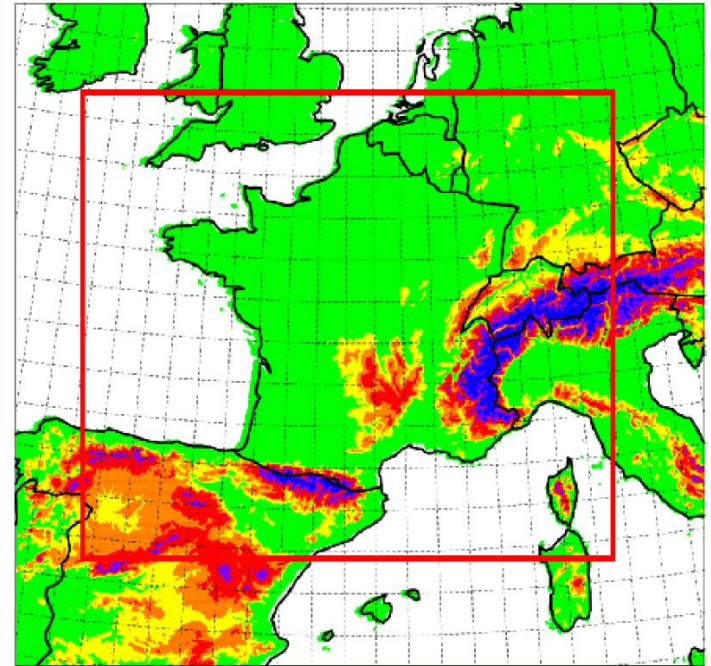
Background error variances from an Ensemble Data Assimilation system (4D-Var at lower resolution) since 2008



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# Regional model Arome

- Spectral limited area non-hydrostatic model with explicit moist convection
- Heritage : Arpege and Aladin NWP models – Meso-NH research model
- Operational at Météo-France since December 2008
- Horizontal resolution : 2.5 km
- 60 vertical levels (up to 1 hPa)
- 3D-Var assimilation (3h window)
- Coupling files : hourly forecasts from global model Arpege
- Forecast range : 30 hours



# GNSS data in the operational models



# A short history

- **2005 - 2008**

- First experiments to evaluate the impact of GPS data in the operational models (Paul Poli)
- Implementation in the operational models : Arpege and Aladin (in 2006) and finally Arome (in 2008) using a white list approach.

- **2008 - 2010**

- No major changes for ZTD data in the operational models, except a new white list for Arome. Experiments in research mode.

- **2010 - 2012**

- After several experiments, big extension of the white list in the mesoscale model Arome.
- Operational suite with an extended white list and a direct BUFR decoding in both Arpege and Arome.

- **2012 - 2014**

- Operational suite with an extended white list (including the GOPG data) and a dynamic selection of the observations inside the screening.
- Evaluation of a variational bias correction of the GNSS data and pre-operational suites.

# ZTD pre-processing

- Statistics of ZTD observations minus model background (OmB) :
  - Creation of a whitelist : list of [station/analysis centre] that can be assimilated (station height, distance with neighbouring stations, OmB statistics, ...)
  - Estimation of a static bias correction :  $\text{mean}(\text{OmB})$
  - Estimation of an observation error from  $\text{Std}(\text{OmB})$
- Data thinning :
  - In 4DVAR: average observations by time-slot (30 minutes or 1 hour)
  - In 3DVAR: retain only the 'most central' obs (closest to analysis time)
- Quality controls :
  - Check that all values are within physical range
  - Check consistency of latitude, longitude, altitude, and time
  - Background check : OmB not too large



# ZTD Pre-processing : next Arpege whitelist

Reading list\_monitor, found : 3534 station/centre

Number of rejections for bad quality : 613

Number of redundant station/centre : 2618

Final number of station/centre kept in the whitelist : 2921

## Summary of the choice by analysis centre

KNM3 :	43	over	45
LPTR :	34	over	43
KNM4 :	28	over	30
GOP1 :	31	over	47
GFZ_ :	265	over	277
ROBH :	335	over	373
LPT_ :	121	over	128
METO :	232	over	243
BKG_ :	84	over	90
SGN_ :	308	over	317
ASI_ :	210	over	244
IGE2 :	289	over	332
IGE_ :	295	over	341
GOPG :	58	over	104
METG :	90	over	124
SGN1 :	401	over	410
NOAA :	97	over	360
SGNC :	0	over	26

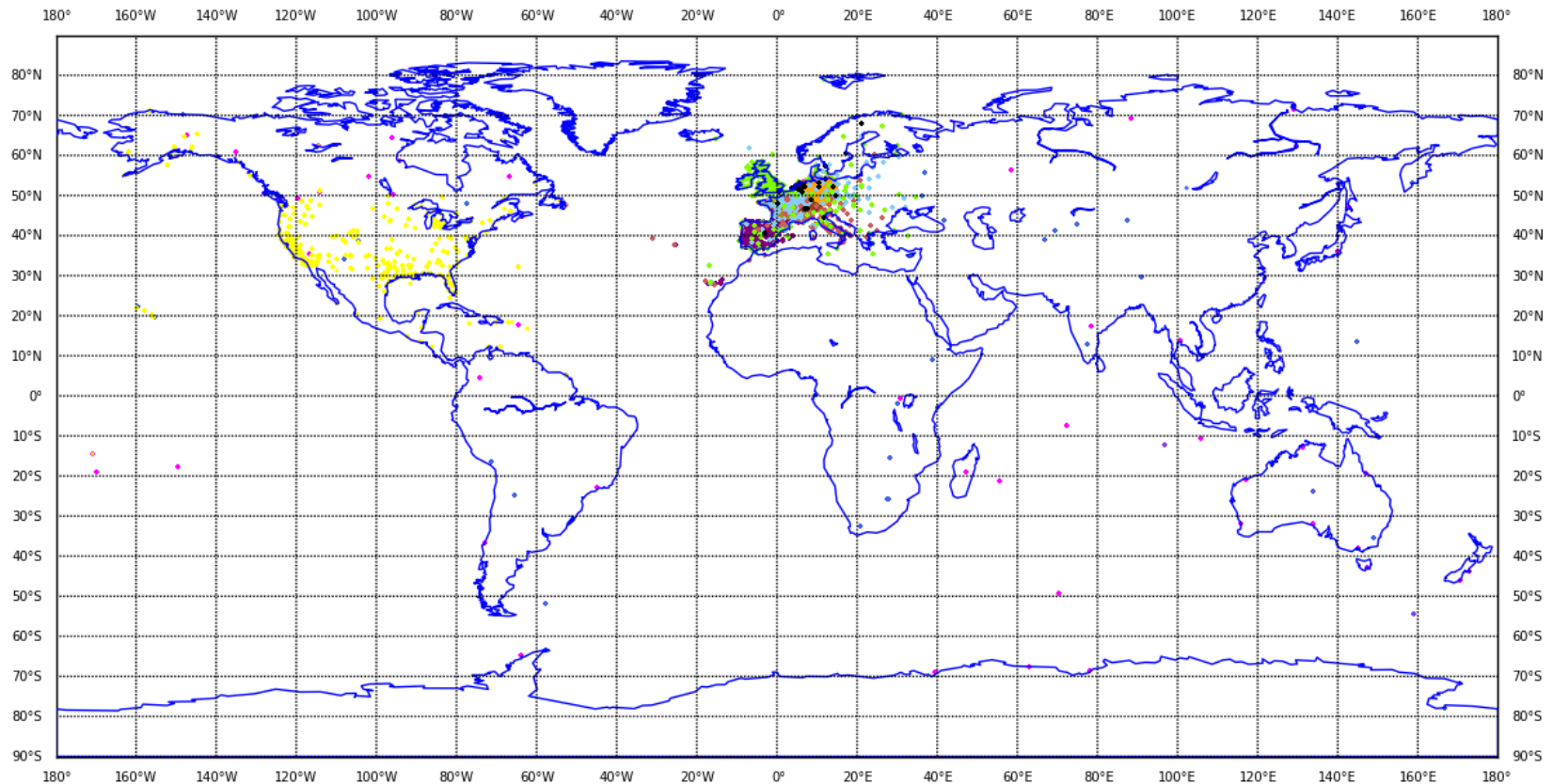
# ZTD observations in Arpege

METEO-FRANCE couverture de donnees - GPS - 2014/10/17 00H UTC cut-off long

87161

Nombre total d'observations avant screening : 87161

2087 LPT  
2848 LPTR  
7879 METO  
3110 METG  
8609 GFZ  
836 GOPG  
339 GOP1  
5142 ASI  
11220 ROBH  
1172 KNM3  
698 KNM4  
970 BKG  
2799 NOAA  
9324 SGN  
11623 SGN1  
9654 IGE  
8649 IGE2



ARPEGE oper

Ground based GNSS = 0.16 % of total observations

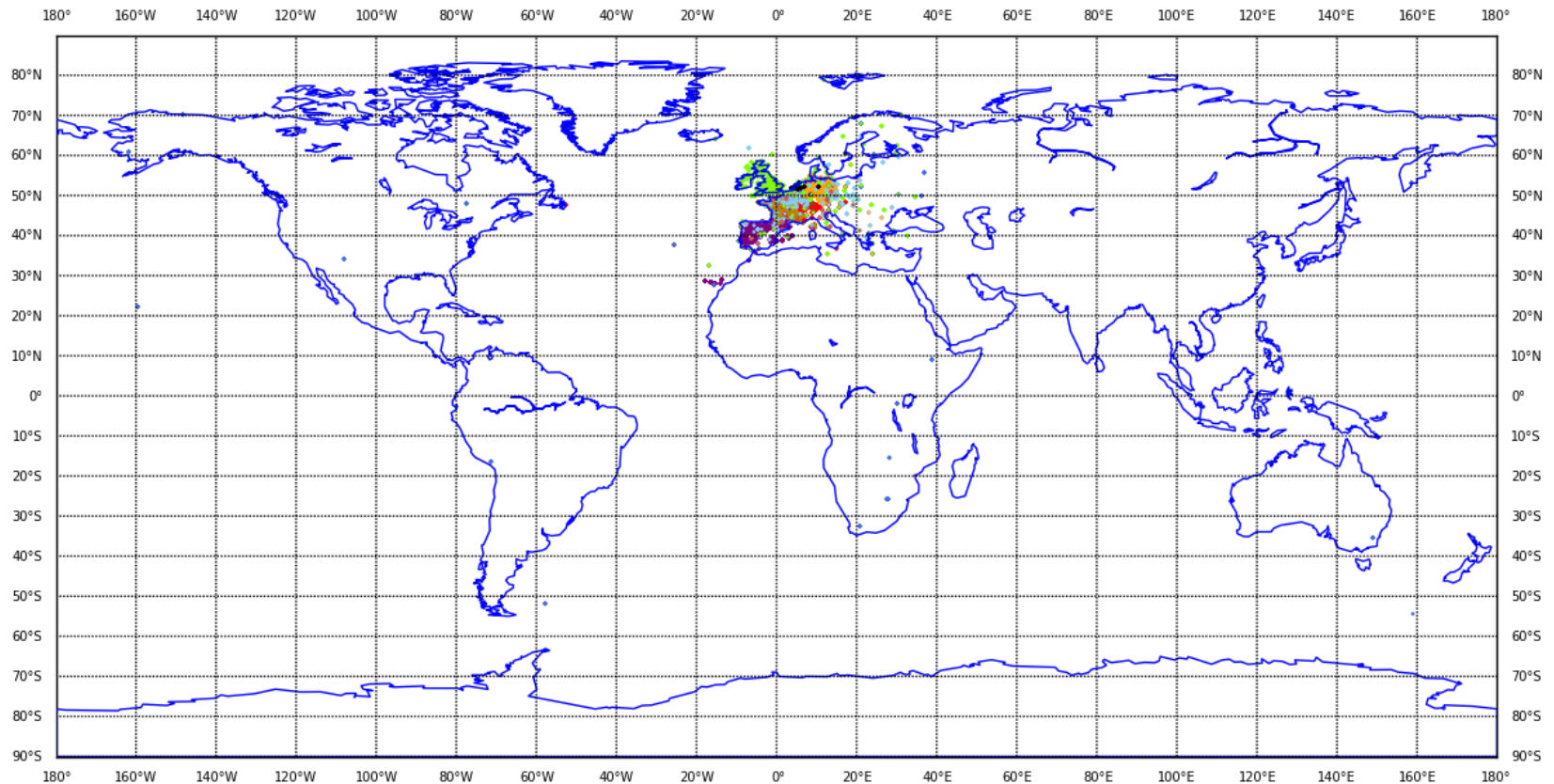
# ZTD observations in Arpege

METEO-FRANCE couverture de donnees - GPS - 2014/10/17 00H UTC cut-off long

6313

Nombre total d'observations apres screening : 6313

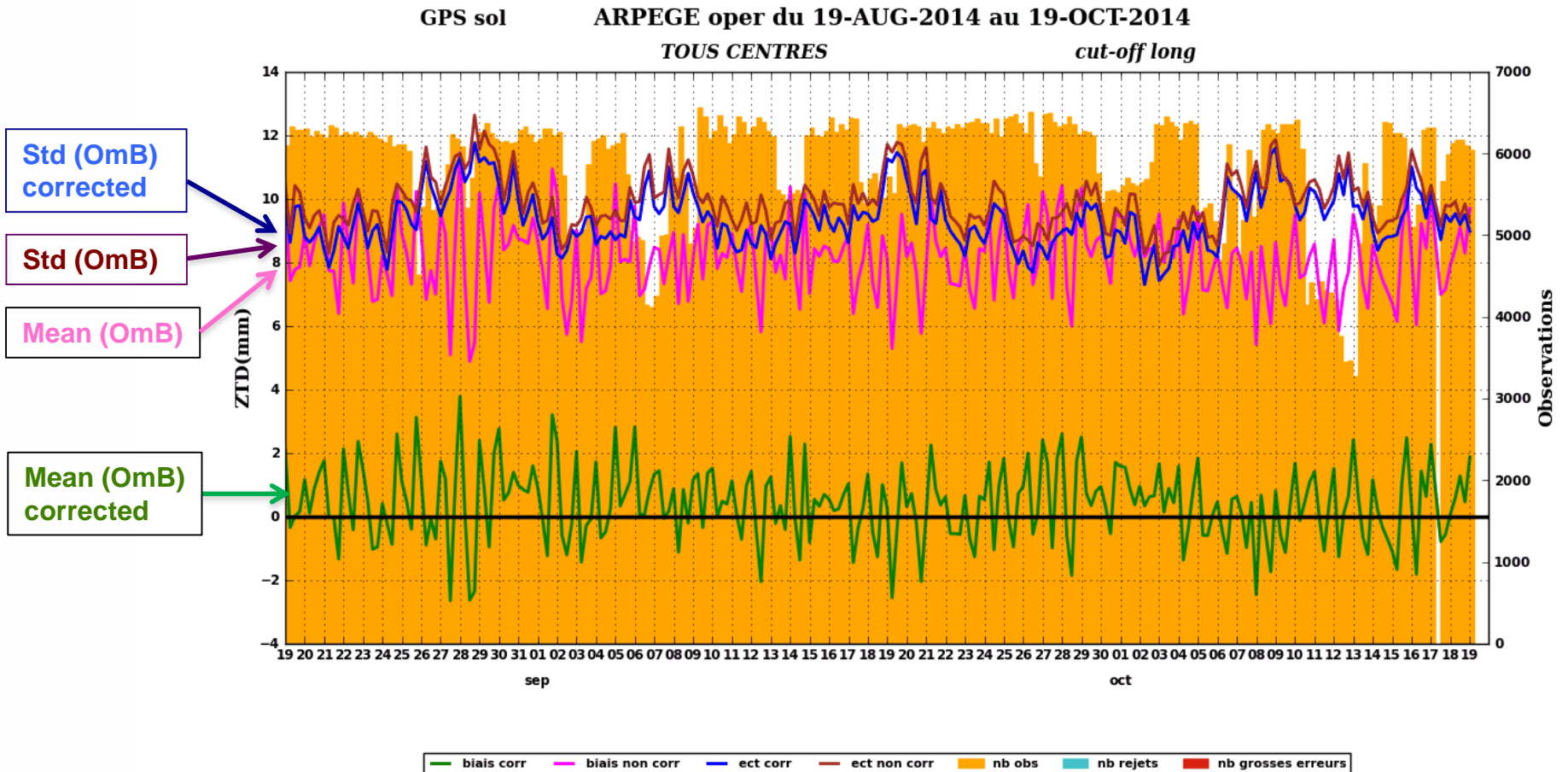
409 LPT  
7 LPTR  
1017 METO  
0 METG  
1383 GFZ  
213 GOPG  
123 GOP1  
95 ASI  
476 ROBH  
81 KNM3  
12 KNM4  
103 BKG  
0 NOAA  
299 SGN  
1086 SGN1  
1009 IGE  
0 IGE2



ARPEGE oper

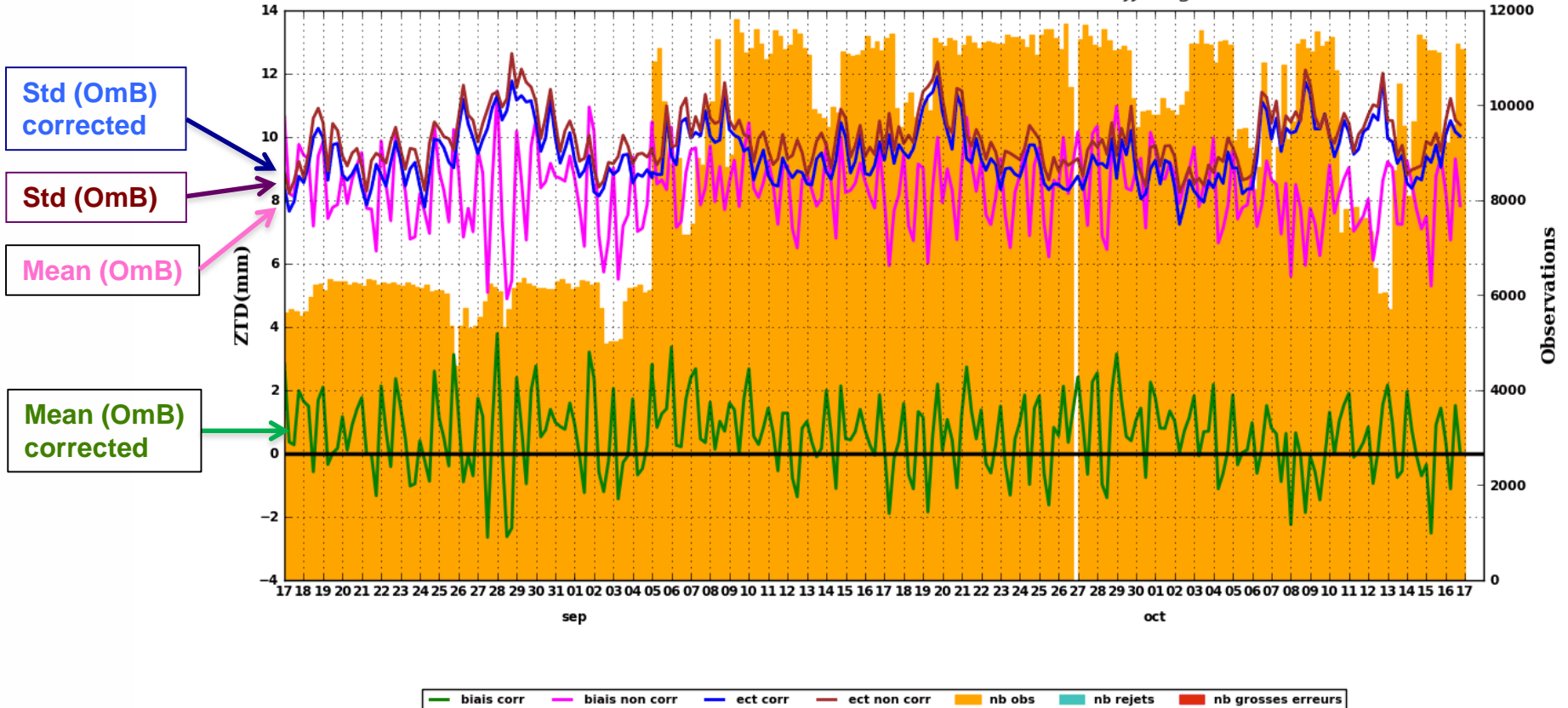
Ground based GNSS = 0.16 % of total observations

# Monitoring in Arpege Oper



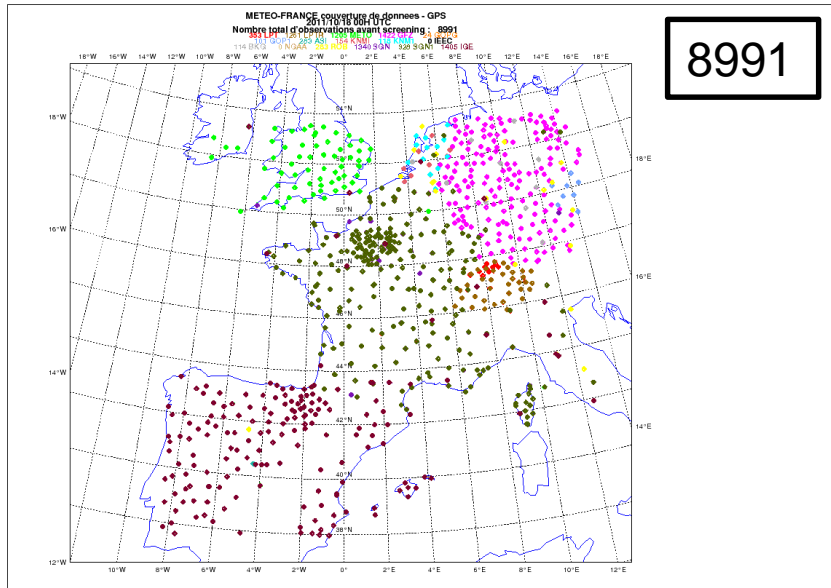
# Monitoring in Arpege Double

GPS sol ARPEGE oper depuis 17-AUG-2014, double depuis 05-SEP-2014  
TOUS CENTRES cut-off long



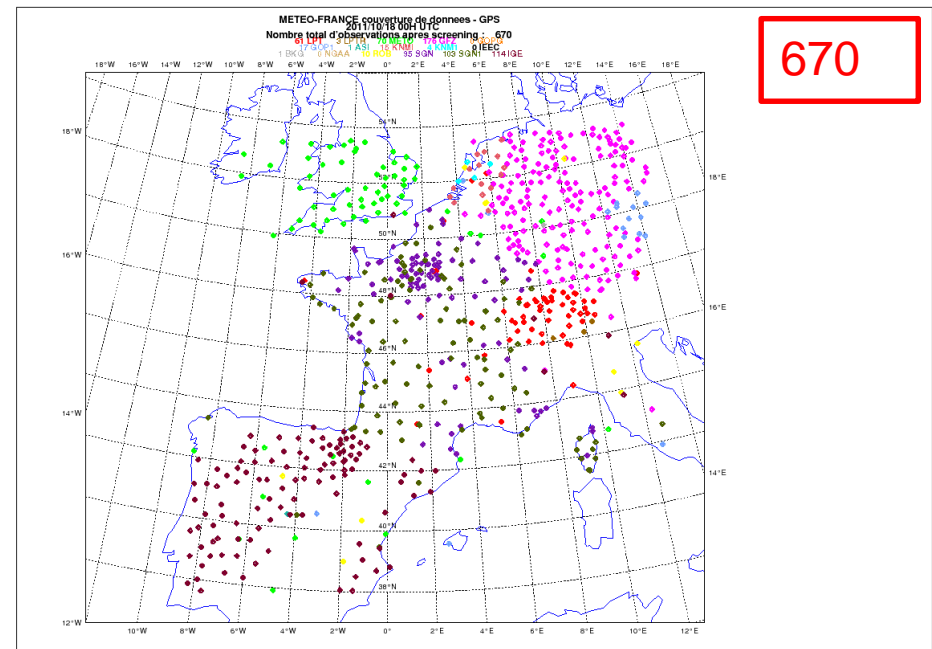


# ZTD observations in Arôme



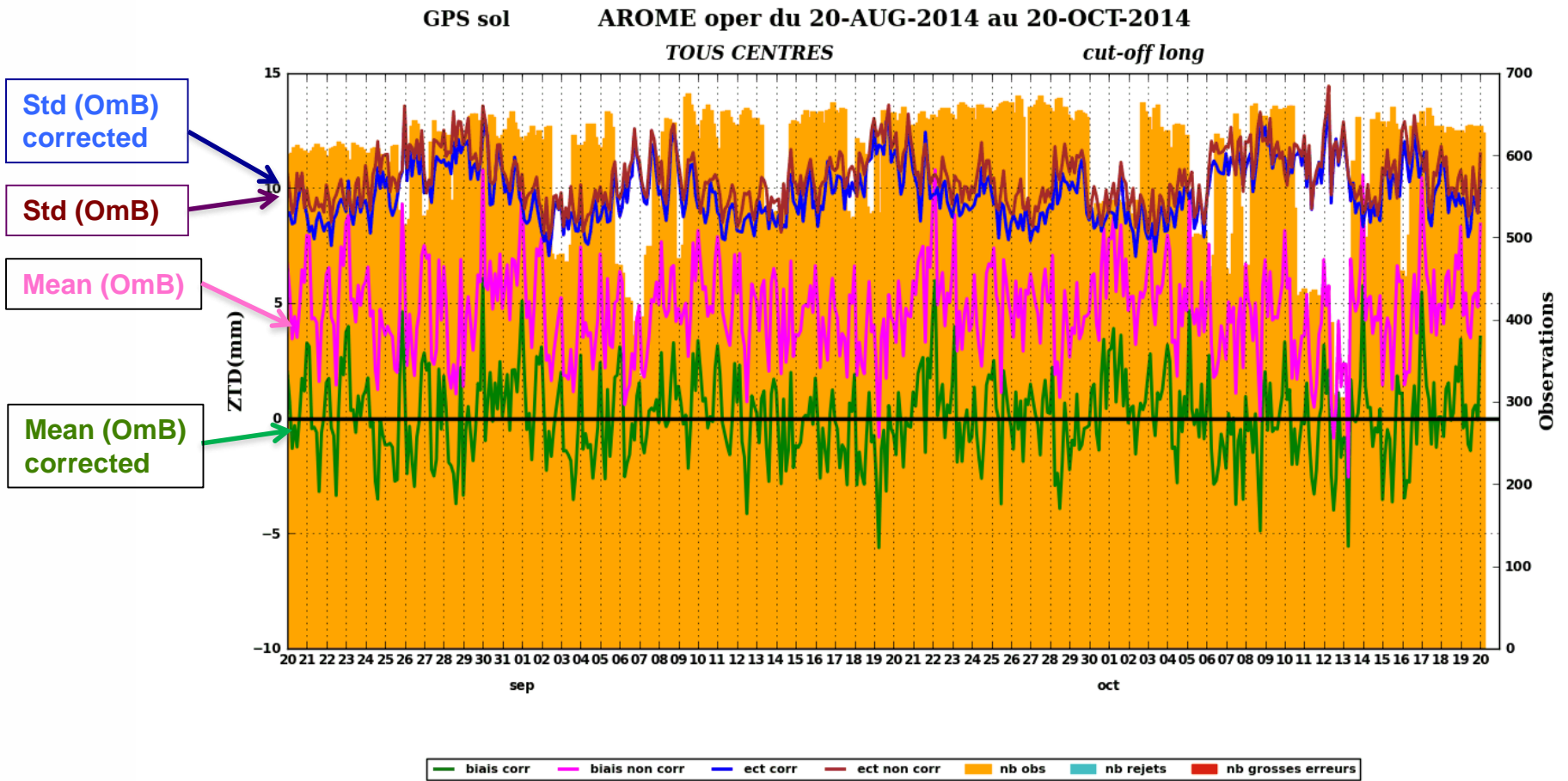
Before  
screening

After  
screening



**Revised white list**

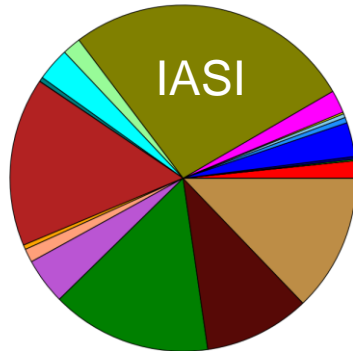
# Monitoring in Arome Oper



# Impact of GNSS ZTD in Arome

## DFS (wet days)

Proportions des nombres d'observations utilisées par type d'obs  
analyses cut-off AROME - AROME France oper  
observations conventionnelles et satellites  
cumul du nombre d'observations utilisées sur la période 2014012600 - 2014012621 : 309393



Number of  
observations  
**GNSS = 1.6 %**

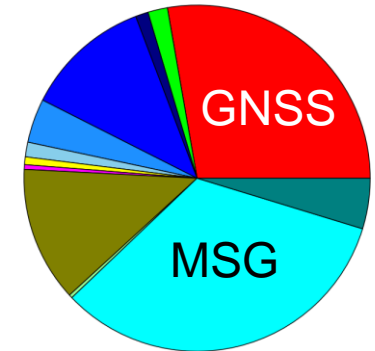
Part des DFS par type d'obs  
analyses cut-off AROME - AROME France oper  
observations conventionnelles et satellites  
cumul du DFS sur la période 2014012600 - 2014012621 : 109693



Information  
content  
**GNSS = 3.4 %**

## DFS (wet days)

Part des DFS par type d'obs  
analyses cut-off AROME - AROME France oper  
observations satellites  
cumul du DFS sur la période 2014012600 - 2014012621 : 13228



Information content  
of remote sensing  
**GNSS = 27.8 %**



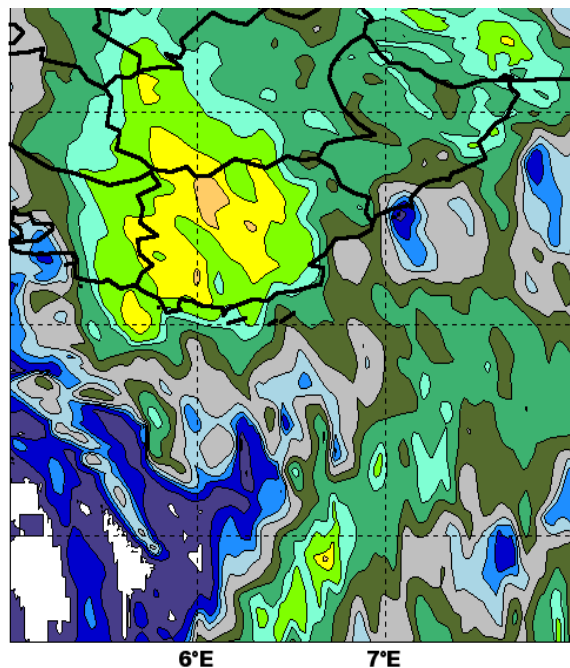
# Impact studies



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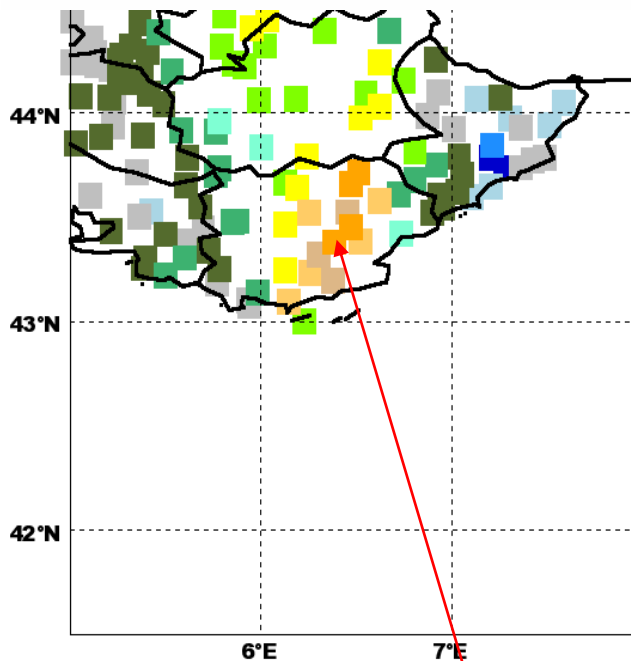
# Case study : Mediterranean flash flood

AROME\_WMED (D031)



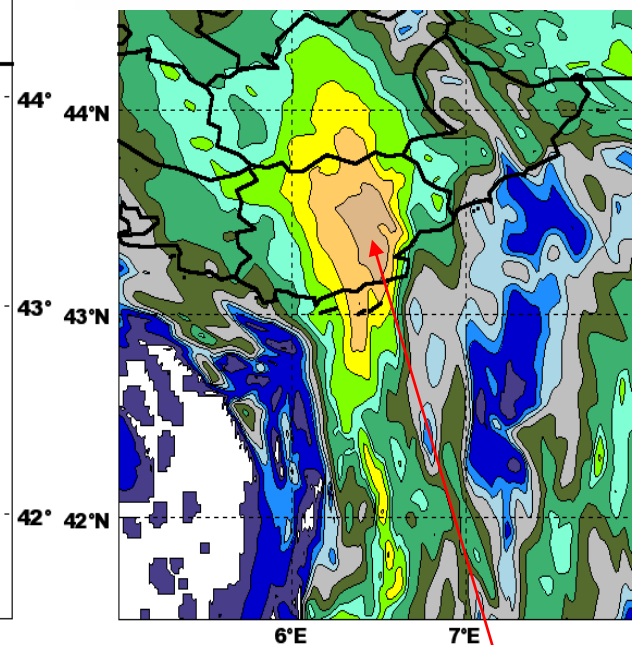
Initial white list

OBS (6h Accumul.)



195mm/6hr

AROME\_WMED (D03Q)



130mm/6hr

Revised white list

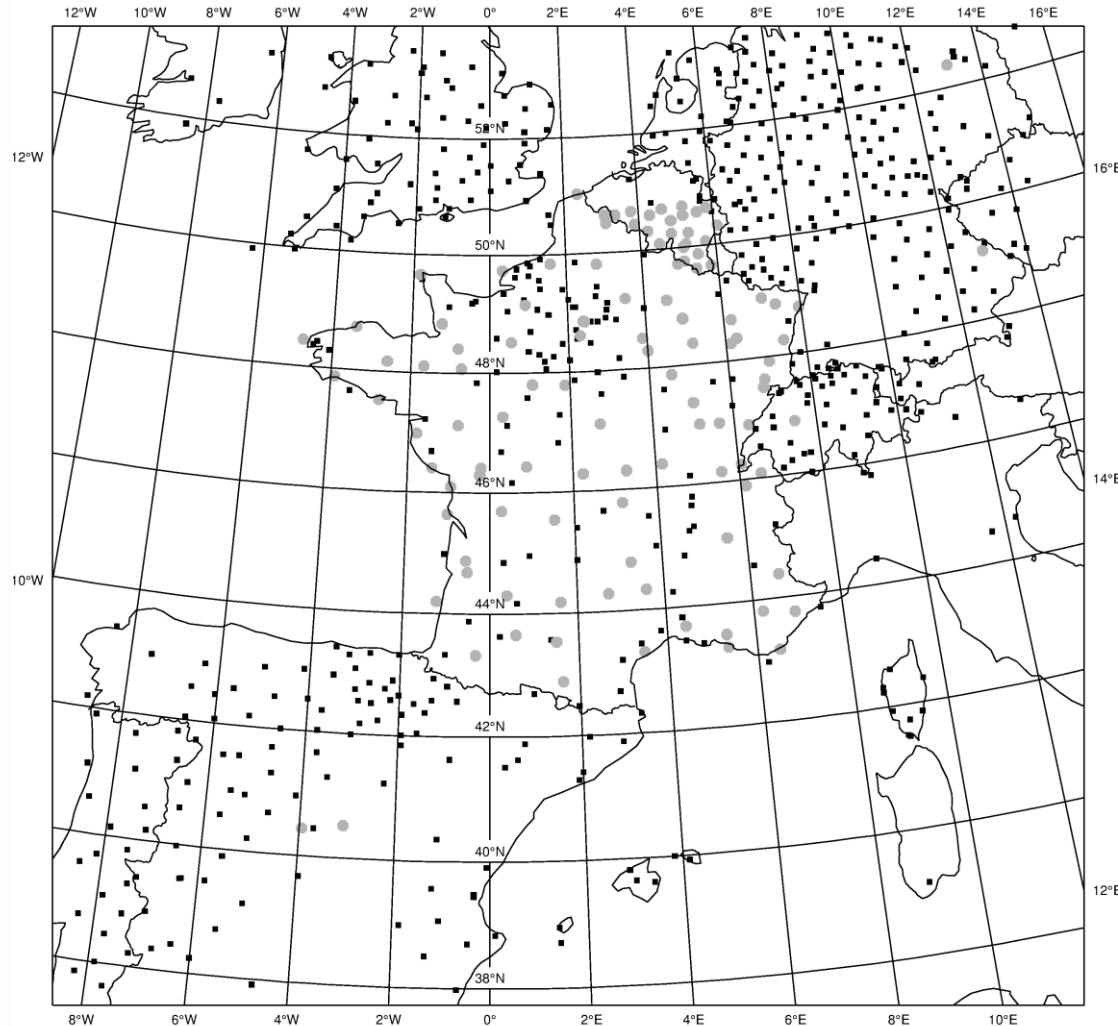


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# UL01 impact study

- 3D-Var Arome operational configuration 15 July 2014 -> 20 August 2014
- NOGPS : All observations except ground based GPS
- GPS : Operational configuration
- UL01 : Operational configuration plus GPS ZTD from UL01
- Examination of impacts on analyses and forecasts
- Activity undertaken within the COST action ES1206 GNSS4SWEC
- Collaboration with Furqan AHMED and Norman TEFERLE (University of Luxembourg)
- Paper submitted to Tellus : « Assimilation of zenith total delays in the Arome France convective scale model : a recent assessment »

# The ground based GPS network



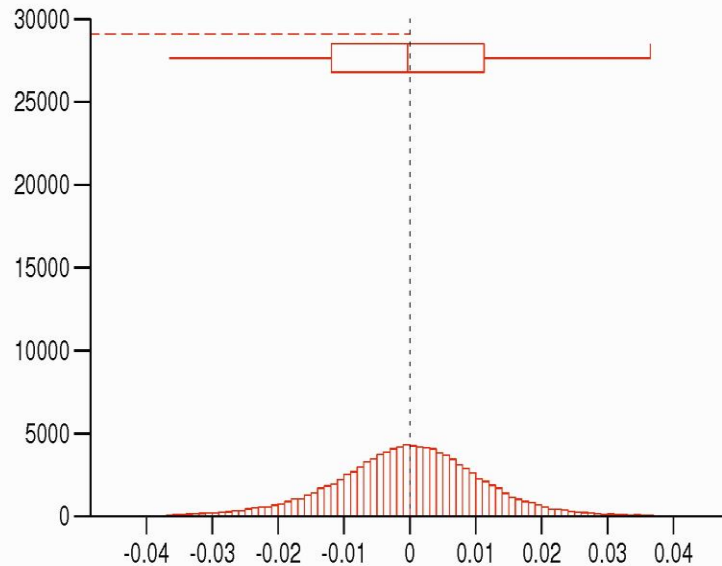
- UL01 stations
- E-GVAP stations

Stations/analysis  
centres retained for  
assimilation in AROME

# Model fit to GNSS data in Arome 3D-Var

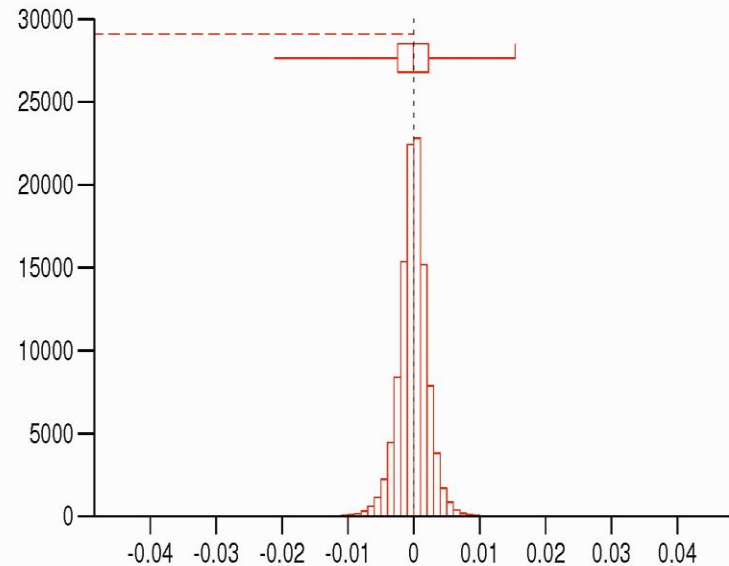
One month statistics : 17/07/2013 -> 17/08/2013  
108399 GNSS observations

Mean=-0.30 mm  
Std = **11.6 mm**



Observation minus  
Background

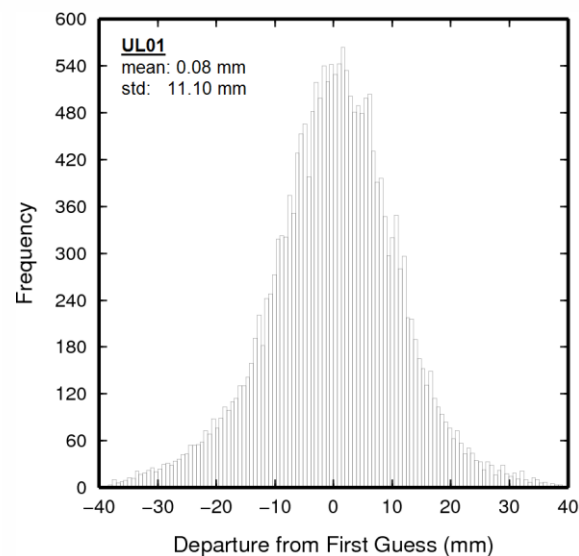
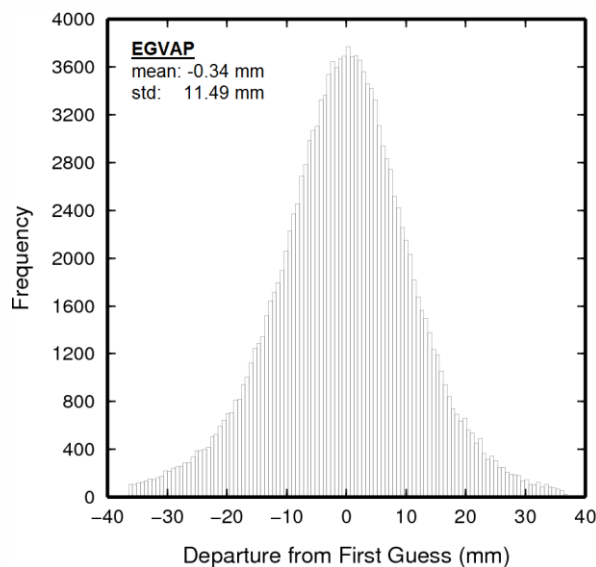
Mean=-0.11 mm  
Std = **2.34 mm**



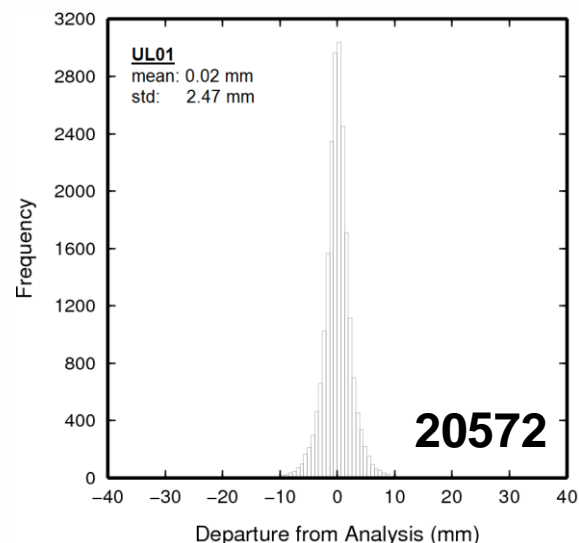
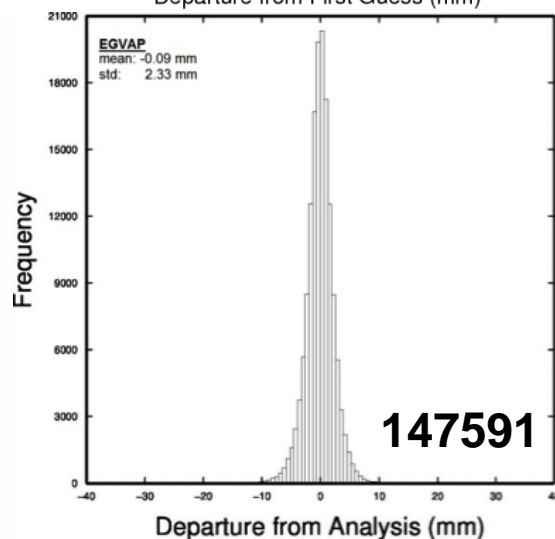
Observation minus  
analysis

# Comparison of EGVAP and UL01 vs. Arôme

Background  
departures

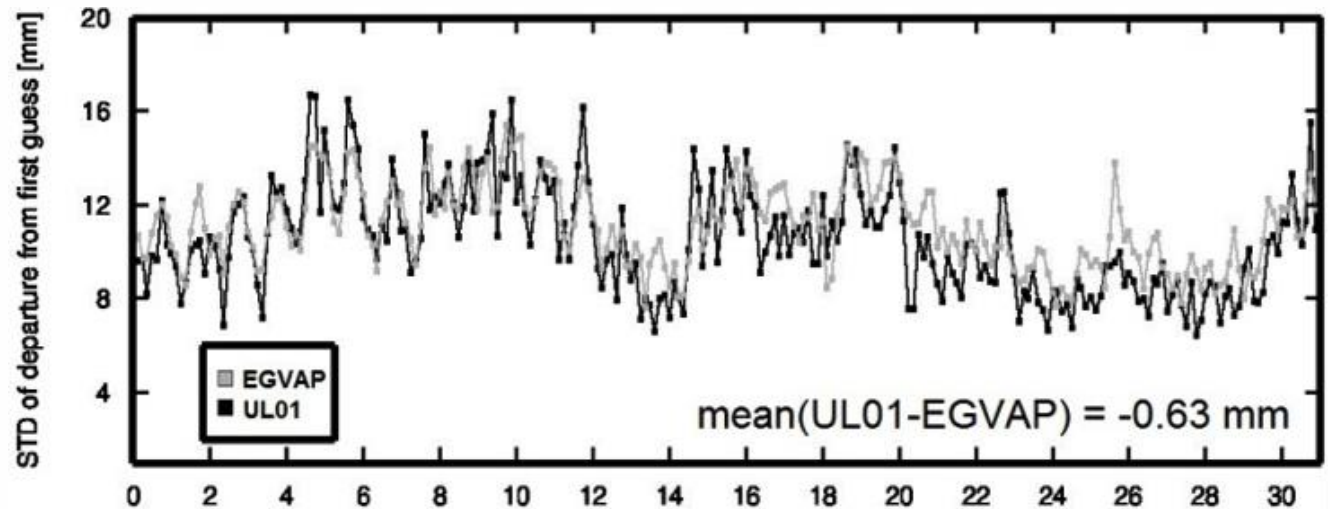


Analysis  
departures

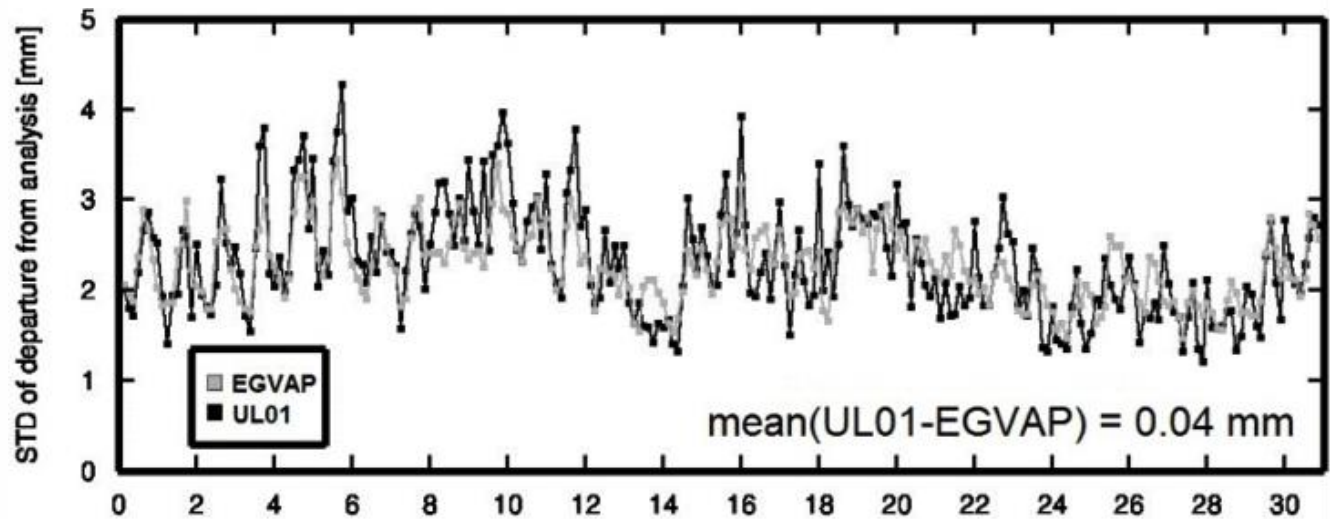


# Comparison of EGVAP and UL01 vs. Arôme

STD  
OmB



STD  
OmA



Days since 2013-07-18 0000UTC

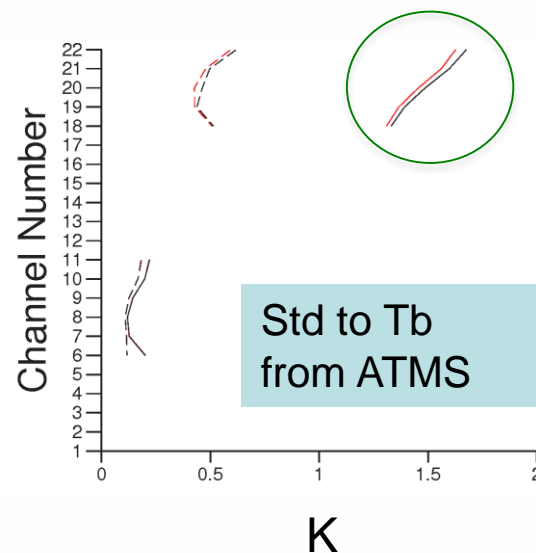
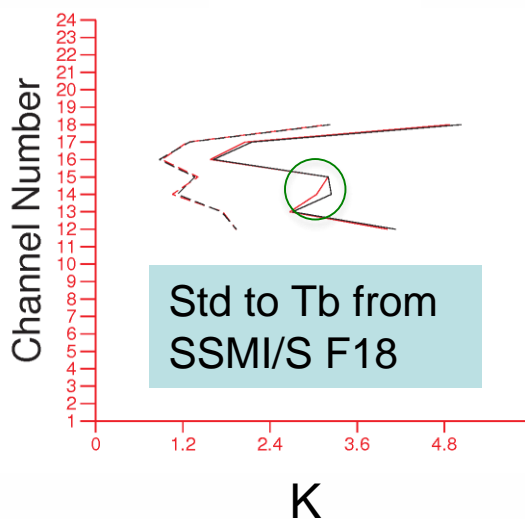
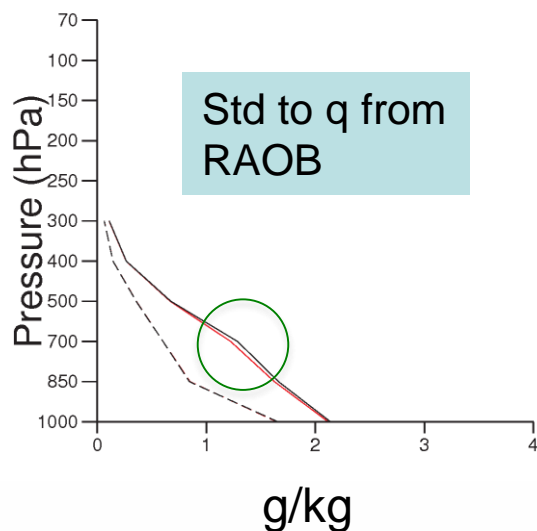


# Model fit to « humidity observations »

One month of 3D-Var assimilation (15/07/2013 -> 17/08/2013)

**EGVAP : all data**

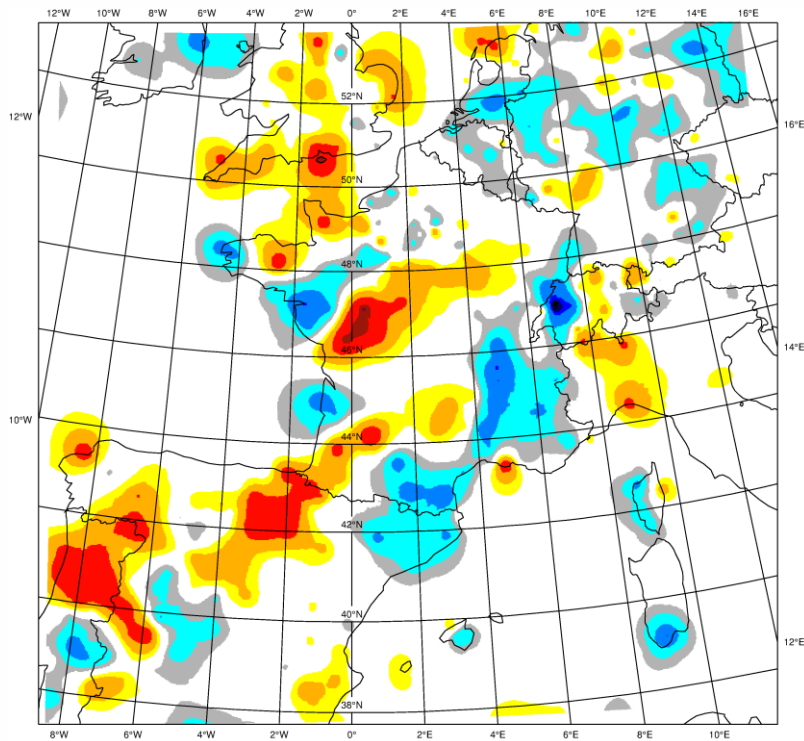
**NOGPS : all data but GNSS**



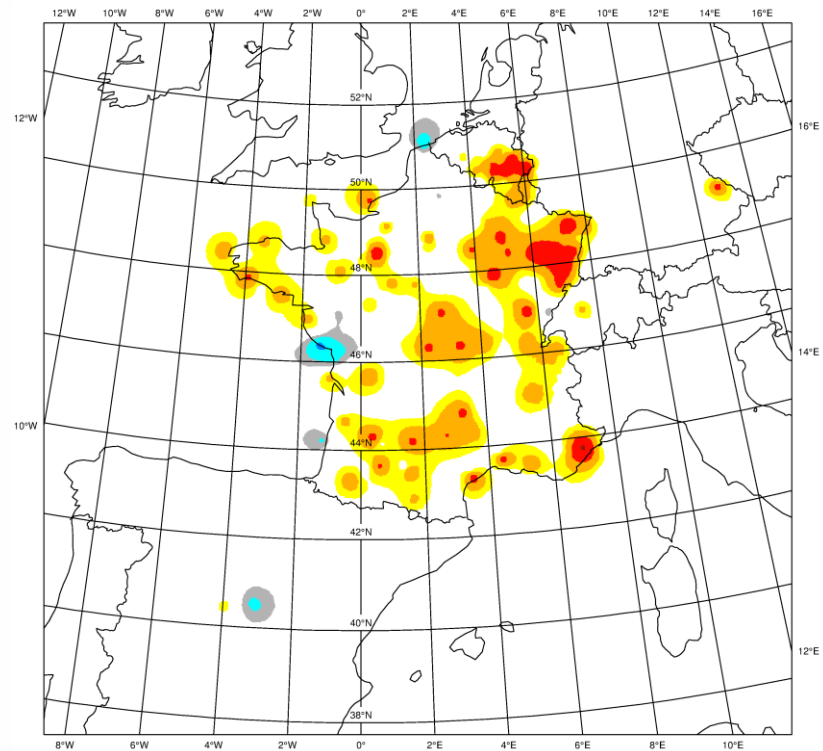
Fit of model background to observations : ———  
Fit of analysis to observations : - - - -



# Impact on TCWV analyses



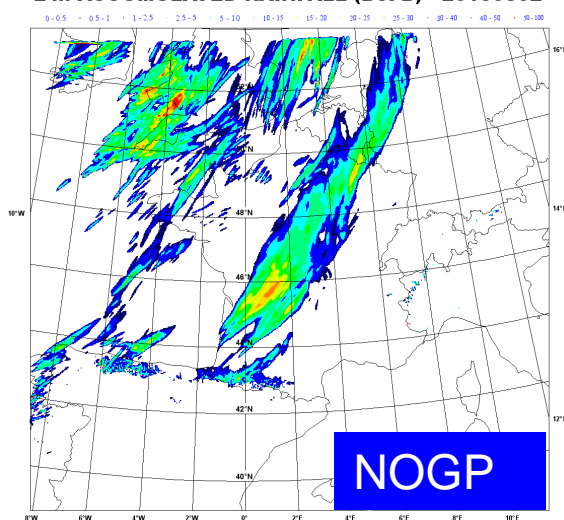
EGVAP - NOGPS



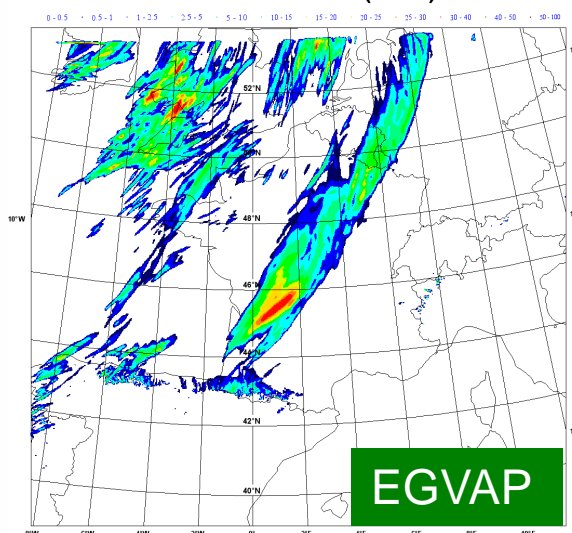
(EGVAP+UL01) - EGVAP

# Impact on 24h accumulated precipitation

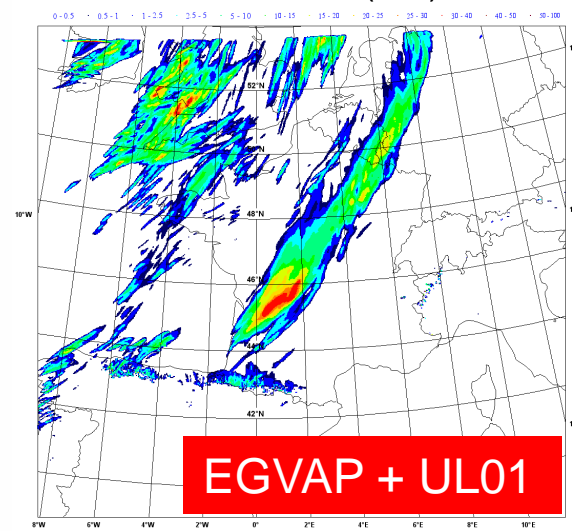
**24h ACCUMULATED RAINFALL (B3FB) - 20130802**



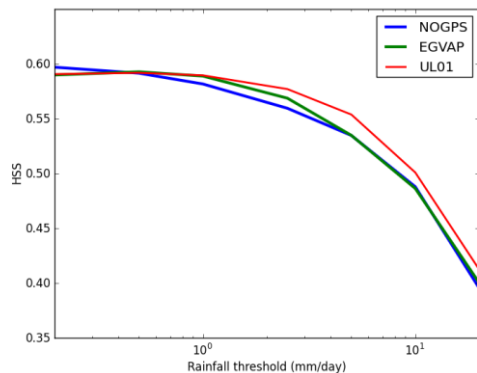
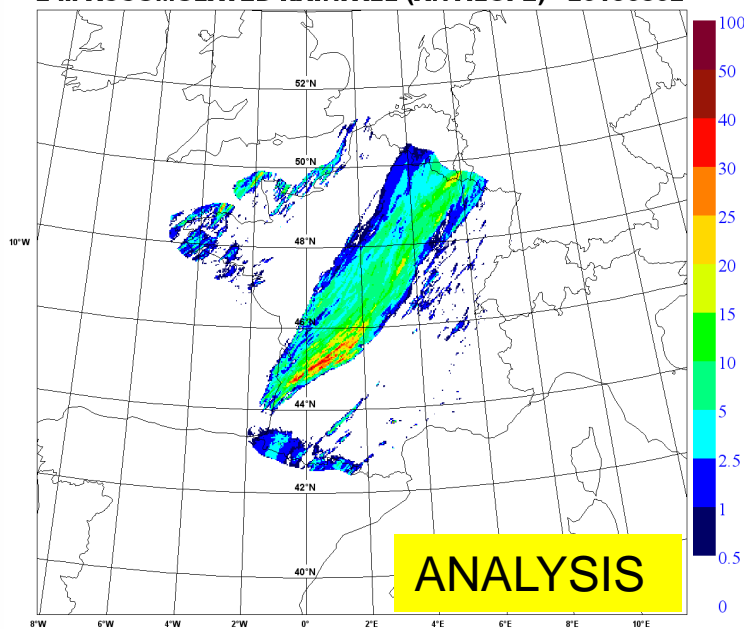
**24h ACCUMULATED RAINFALL (B3CE) - 20130802**



**24h ACCUMULATED RAINFALL (B3DL) - 20130802**



**24h ACCUMULATED RAINFALL (ANTILOPE) - 20130802**



Heidke Skill  
Score (30 days)

02 August 2014



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# Conclusions of UL01 impact study

- Positive impact of GPS ZTD on Arôme forecasts and analyses despite representing a small fraction of the observing system (2 %)
- After an initial station selection, the quality of UL01 is similar to other EGVAP stations : they have been assimilated successfully in Arôme
- Assimilation of ZTD improves the model fit (3h forecast) to other observing systems sensitive to atmospheric moisture (radiosoundings, ATMS and SSMI/S moisture sensitive channels)
- Reduced forecast errors in terms of RH2m
- Improved forecast scores for precipitation (objective categorical scores and subjective case study examination) : UL01 provides significant additional improvement on top of EGVAP
- Recommendation : make UL01 ZTD available through EGVAP

# ZTD variational bias correction



# Theoretical VarBC formulation

The bias is computed following the scheme introduced in Harris and Kelly, 2001. It can be expressed as a linear combination of bias predictors (such as the TCWV, the thickness of given atmospheric layers, ...). For a given observation, the estimated bias can be expressed as follows :

$$b(x, \beta) = \sum_{j=1}^N \beta_j p_j(x)$$

where  $p_j(x)$  are the  $N$  bias predictors and  $\beta_j$  the  $N$  bias prediction coefficients.

An augmented control vector that includes bias prediction coefficients can be defined :  $z^T = [x^T \beta^T]$

The error covariance matrix of  $z$  is defined as :  $Z = \langle \tilde{e}^b (\tilde{e}^b)^T \rangle$  where  $z^b = z^t + \tilde{e}^b$

It is currently assumed that parameter estimations errors and state estimation errors are not correlated, which leads to :

$$Z = \begin{bmatrix} B_x & 0 \\ 0 & B_\beta \end{bmatrix}$$

The extended observation operator that accounts for the bias is defined as follows :

$$\tilde{H}(z) = H(x) + b(x, \beta) = H(x) + \sum_{j=1}^N \beta_j p_j(x)$$

# ZTD VarBC experiment with Aladin-Maroc

Aladin-Maroc : horizontal resolution 7km

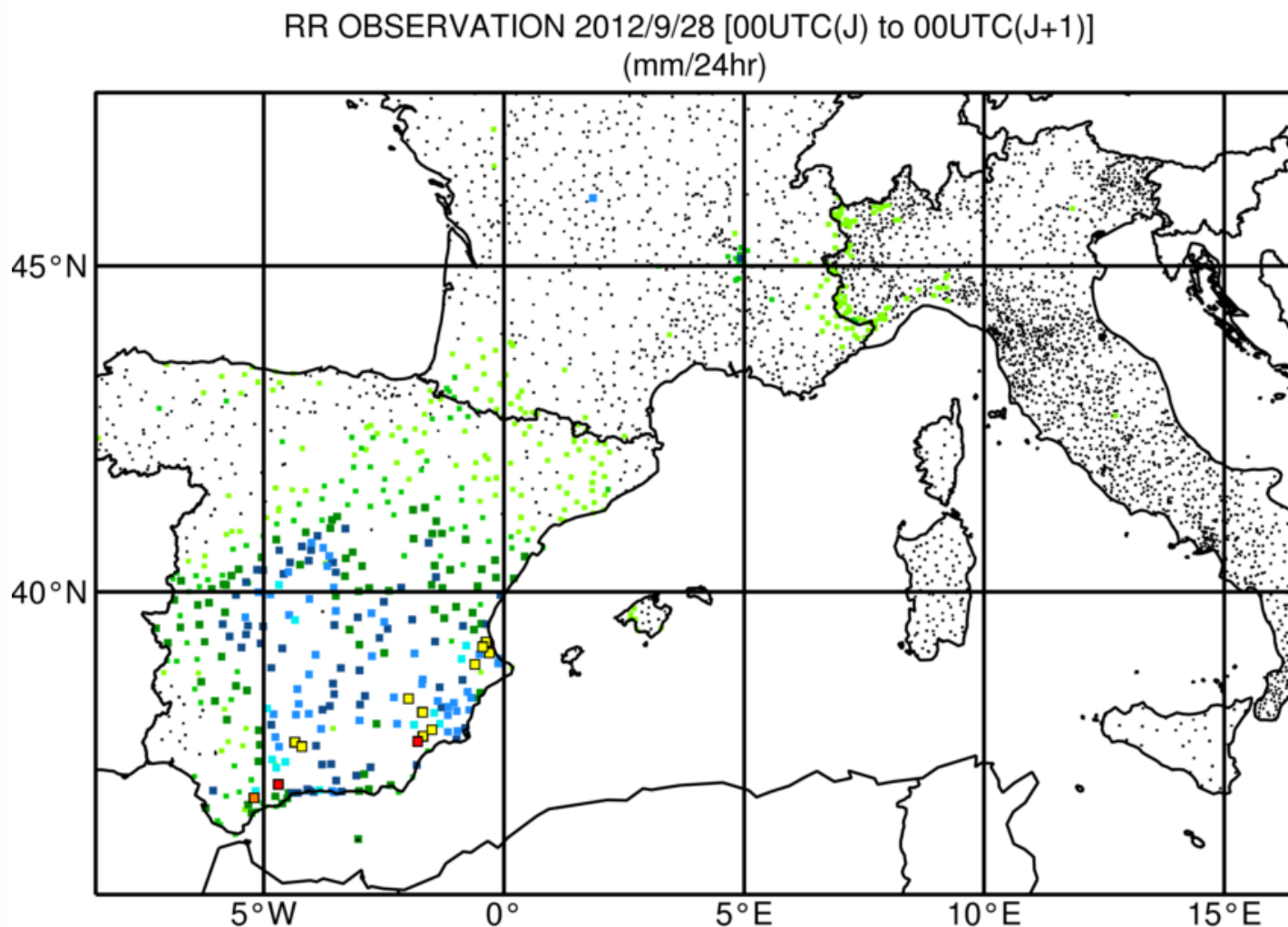
Hymex IOP8

4 assimilation experiments of 45 days :

- B4EU : VarBC with 1 predictor (constant)
- B4ET : VarBC with 2 predictors (constant and TCWV)
- B4EV : VarBC with 2 predictors (constant and thickness 1000-300 hpa)
- B4F8 : VarBC with 3 predictors

Zoom : 28th september 2012, rain (mm/24h)

# ZTD VarBC experiment : Hymex IOP8

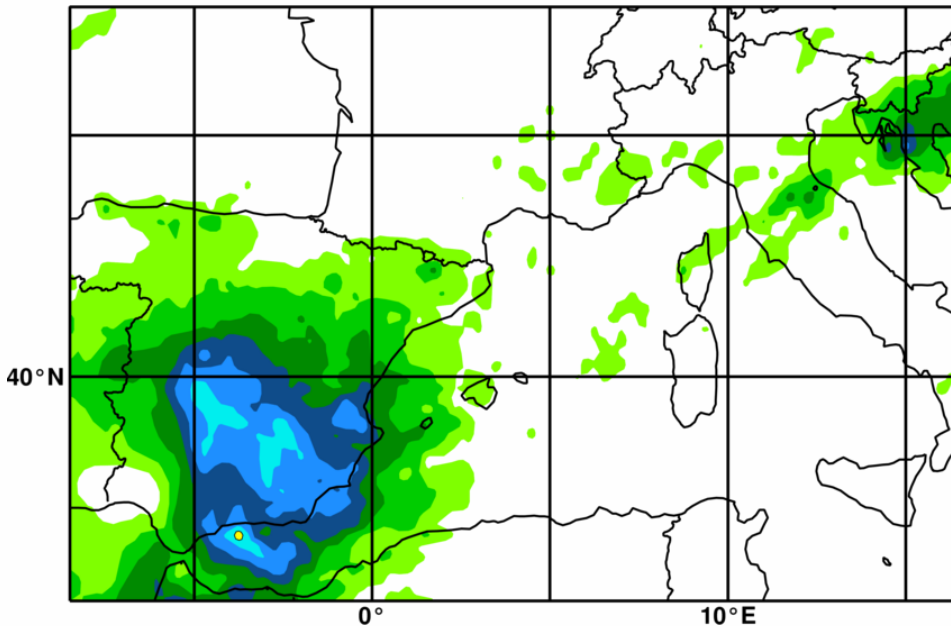


Rain gauges (mm/24h)



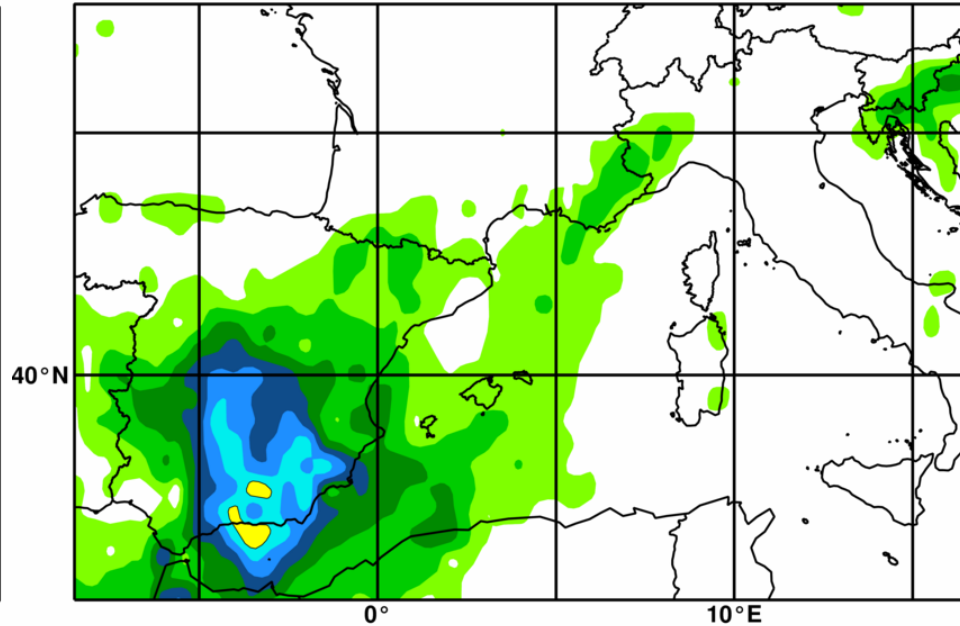
# ZTD VarBC experiment : Hymex IOP8

RAIN (mm/24h)  
ECMWF 20120928\_00 Forecast +24h - +00h



ECMWF

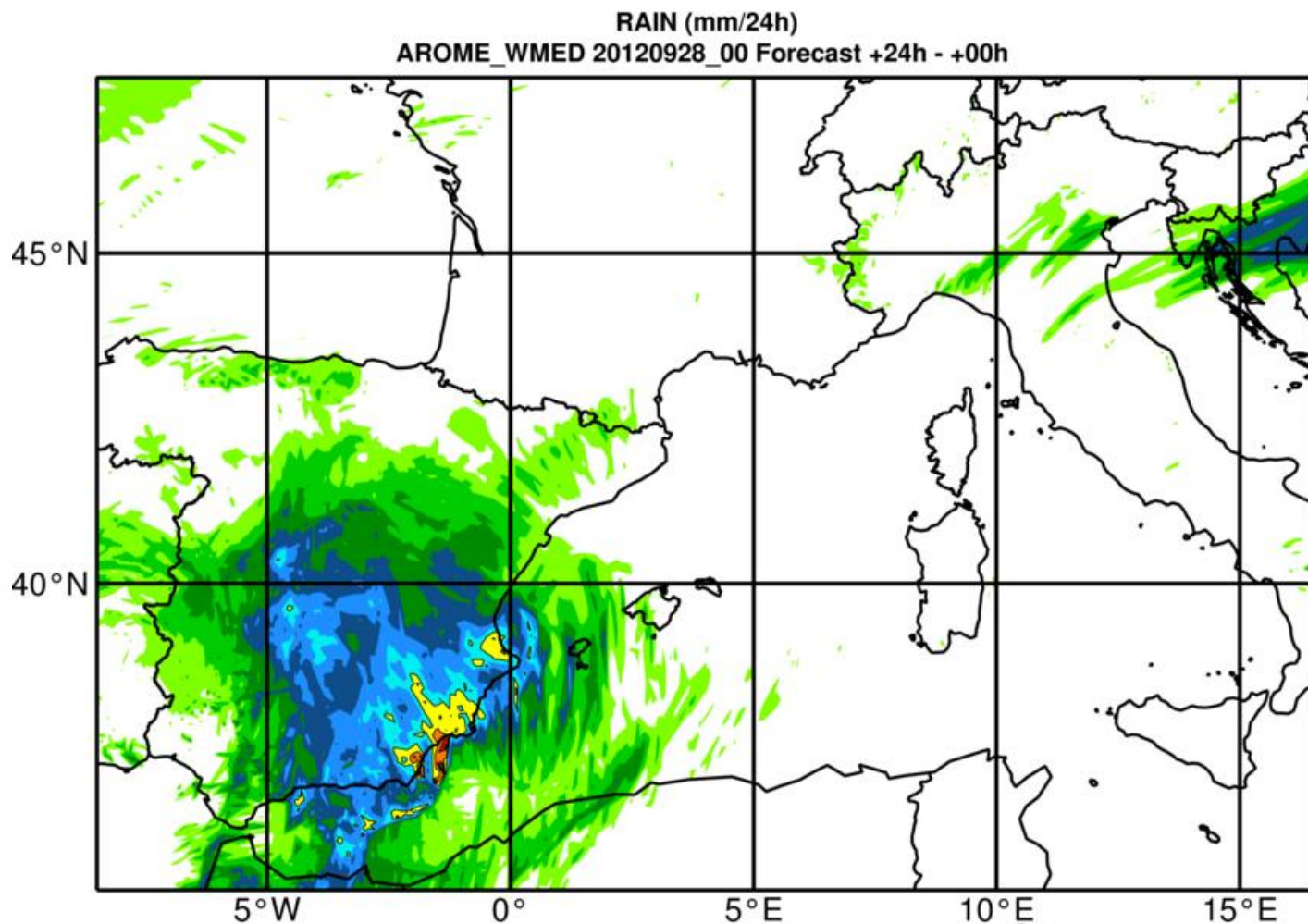
RAIN (mm/24h)  
ARPEGE 20120928\_00 Forecast +24h - +00h



Météo-France



# ZTD VarBC experiment : Hymex IOP8

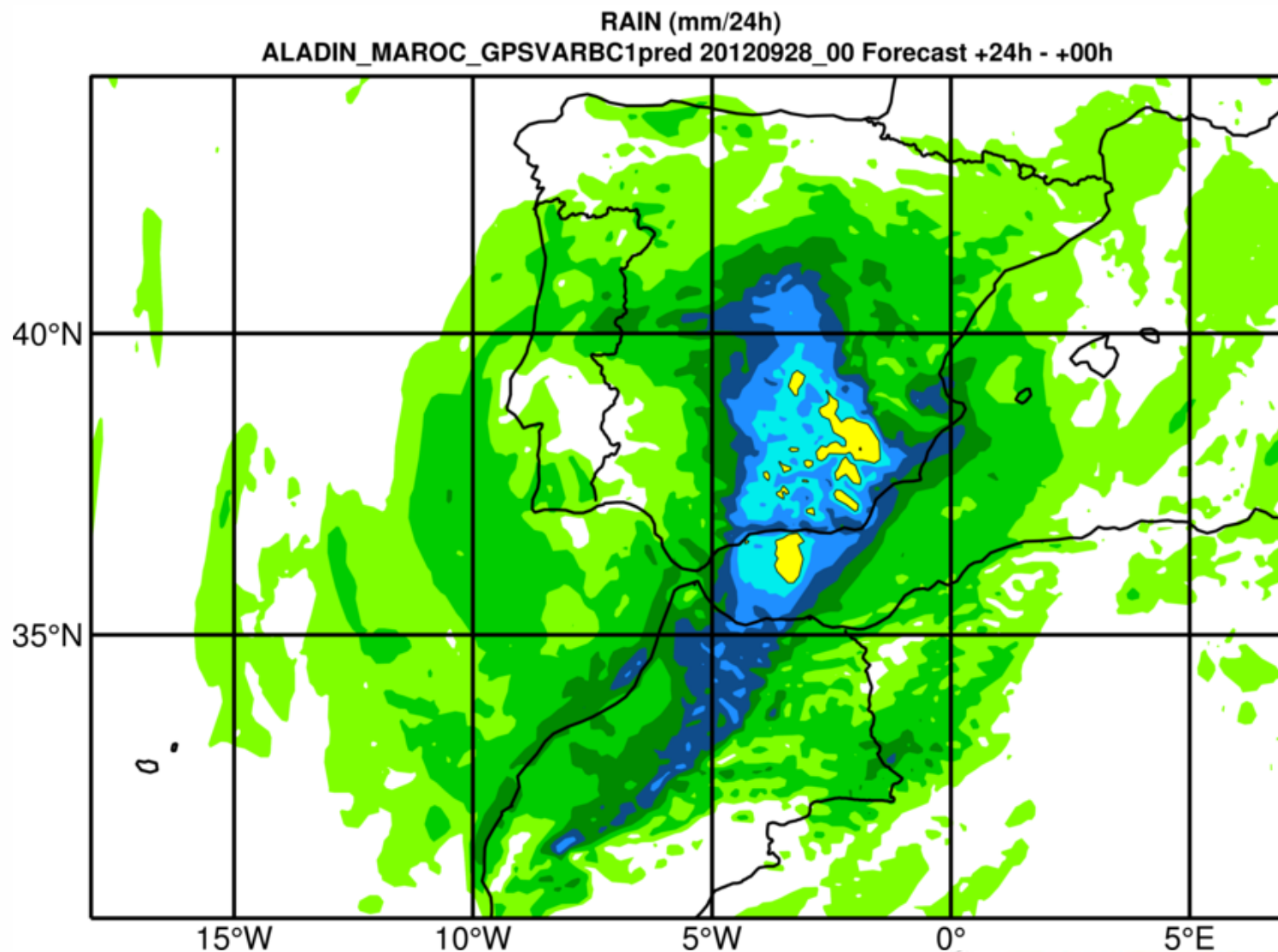


Arome-WMed



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# ZTD VarBC experiment : Hymex IOP8

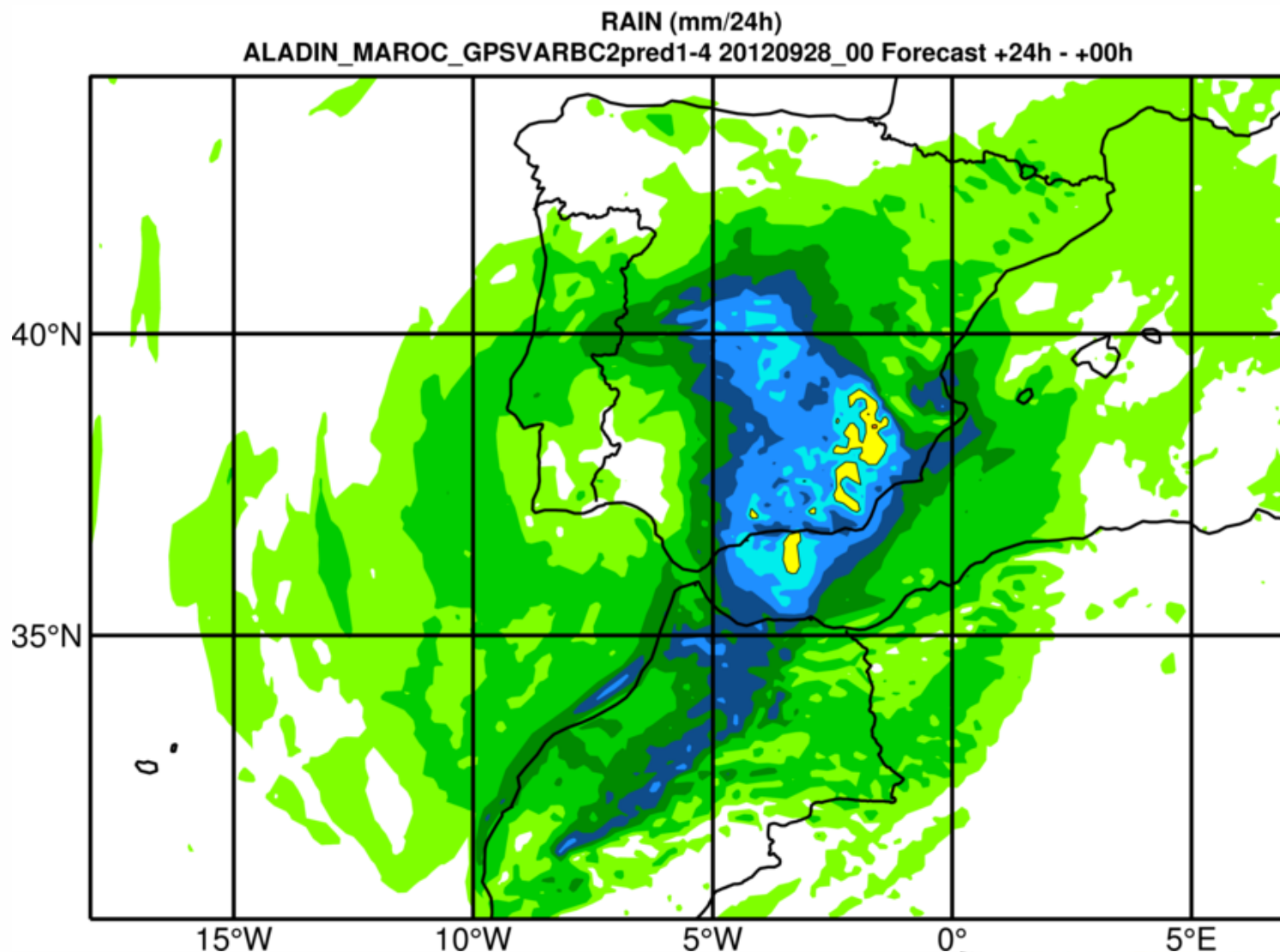


1 pred : constant



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# ZTD VarBC experiment : Hymex IOP8

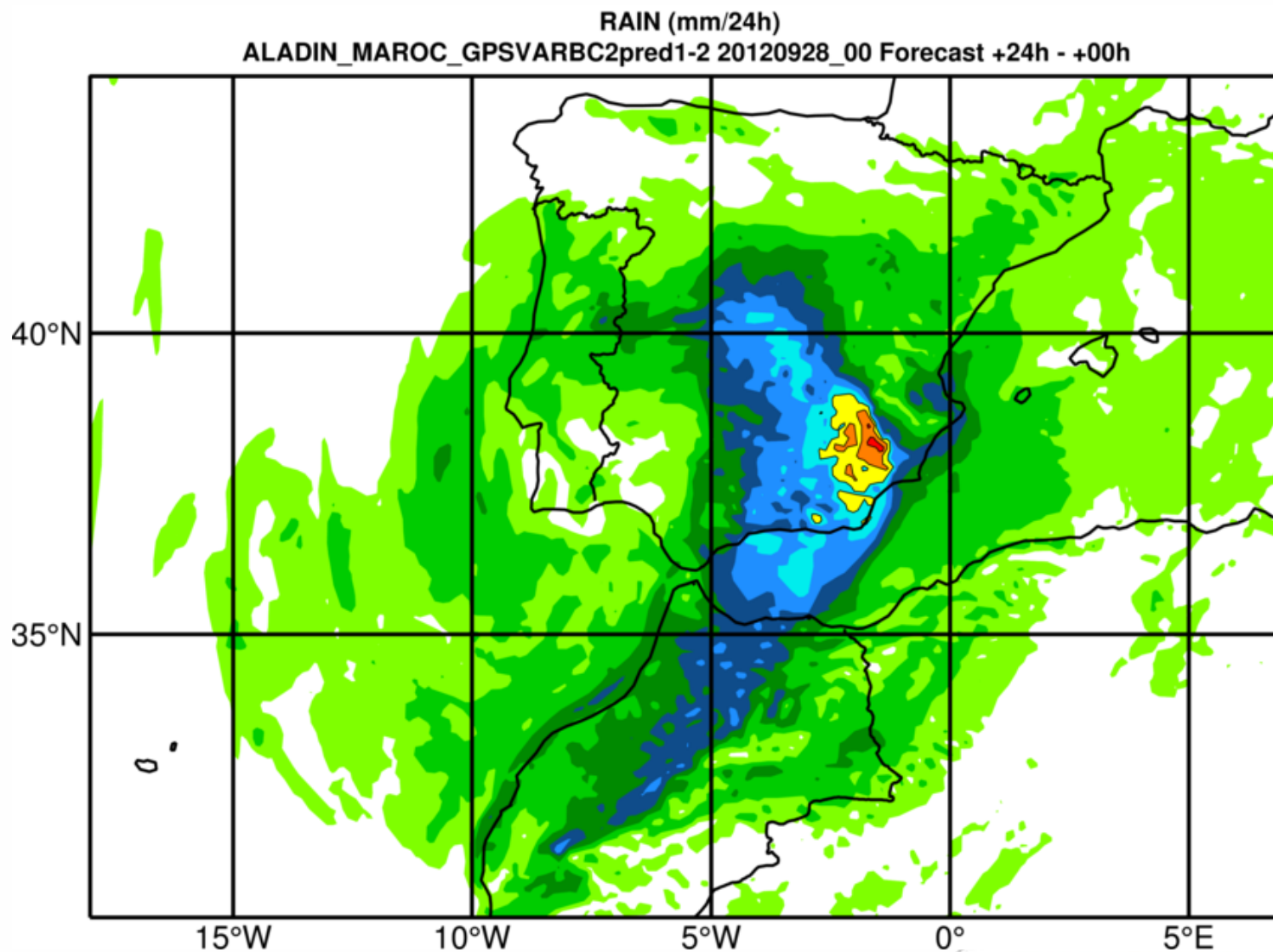


2 pred : constant + TCWV



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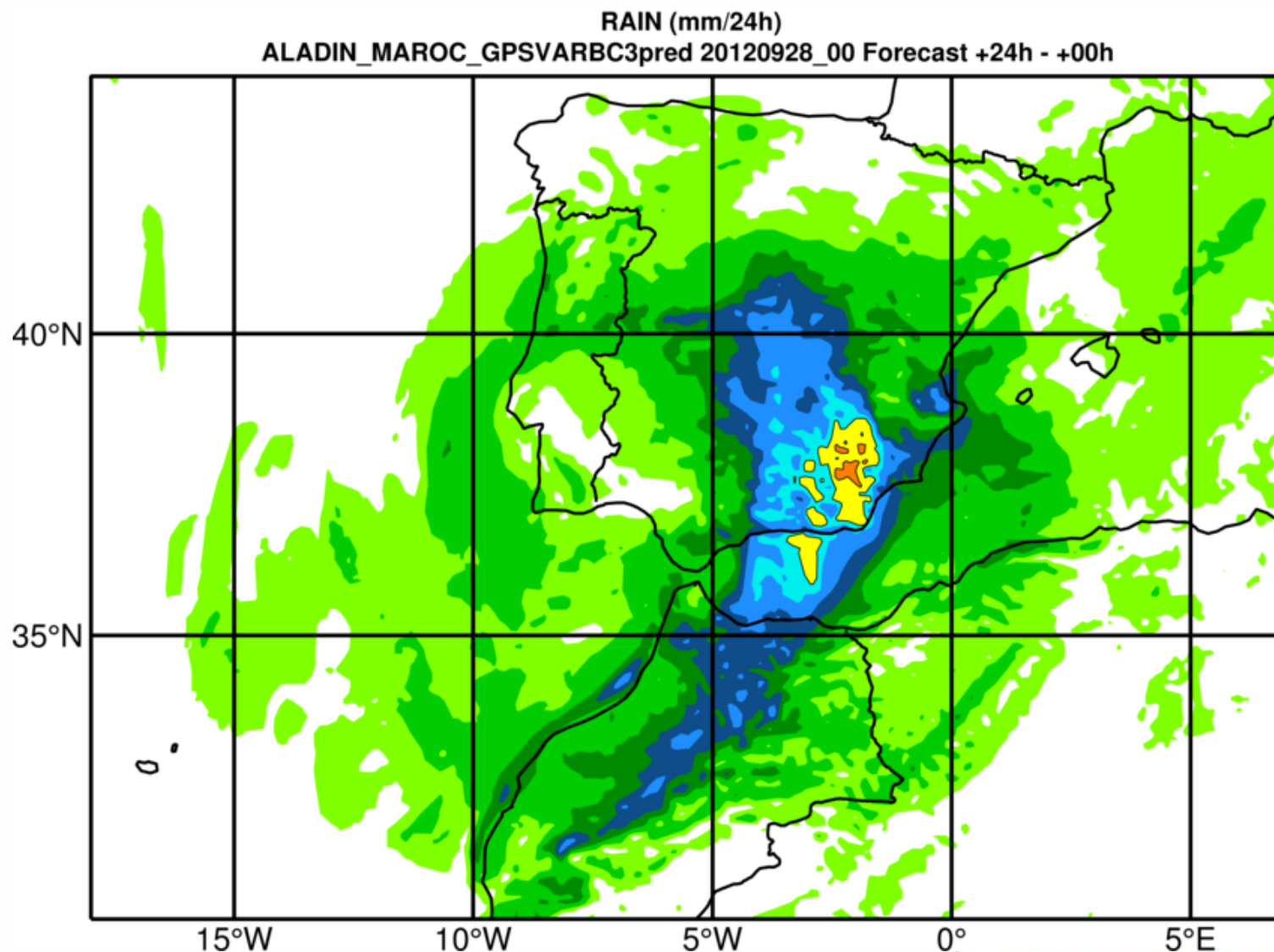
# ZTD VarBC experiment : Hymex IOP8



2 pred : constant +  $T_h(1000-300)$

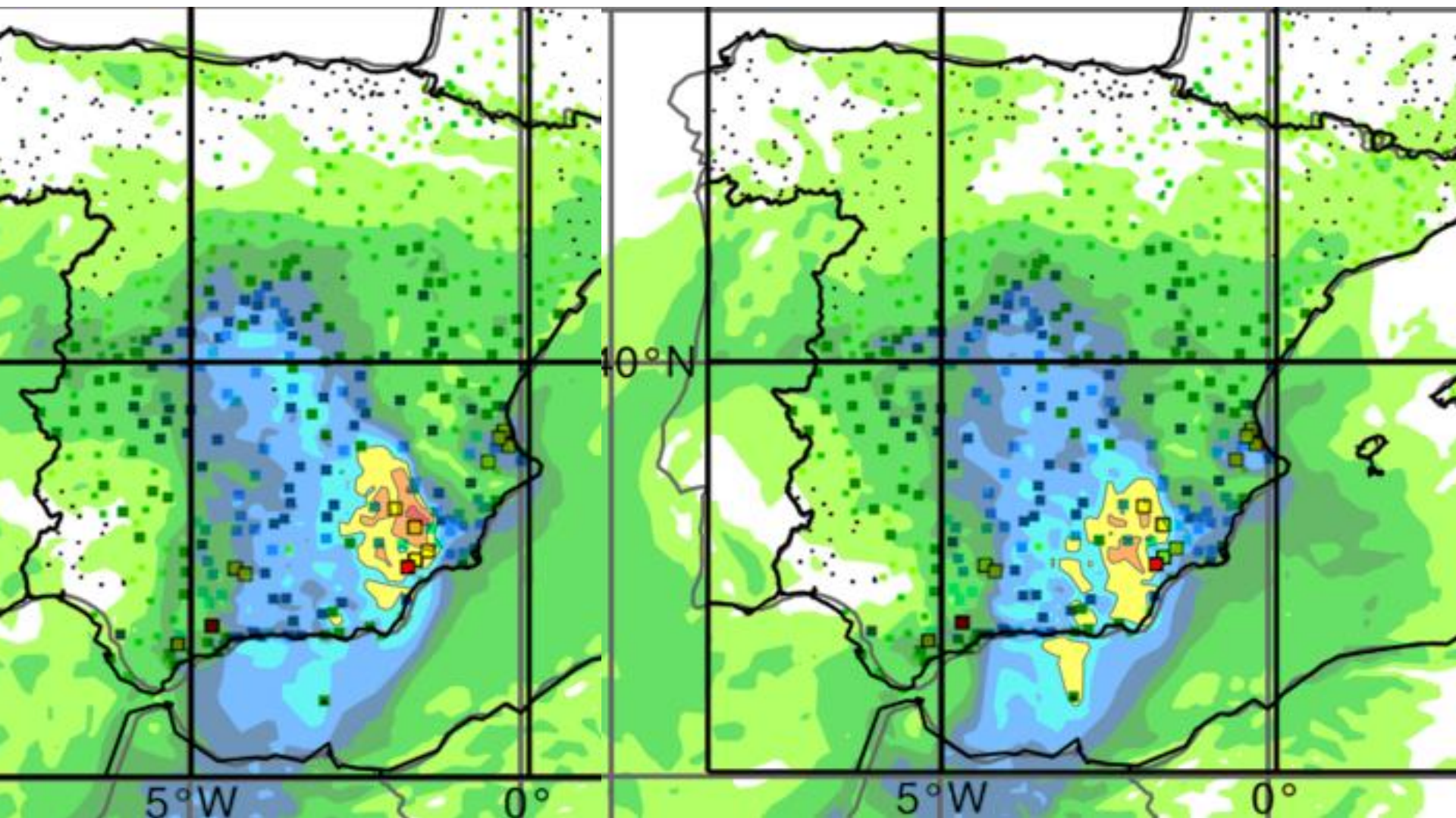


# ZTD VarBC experiment : Hymex IOP8

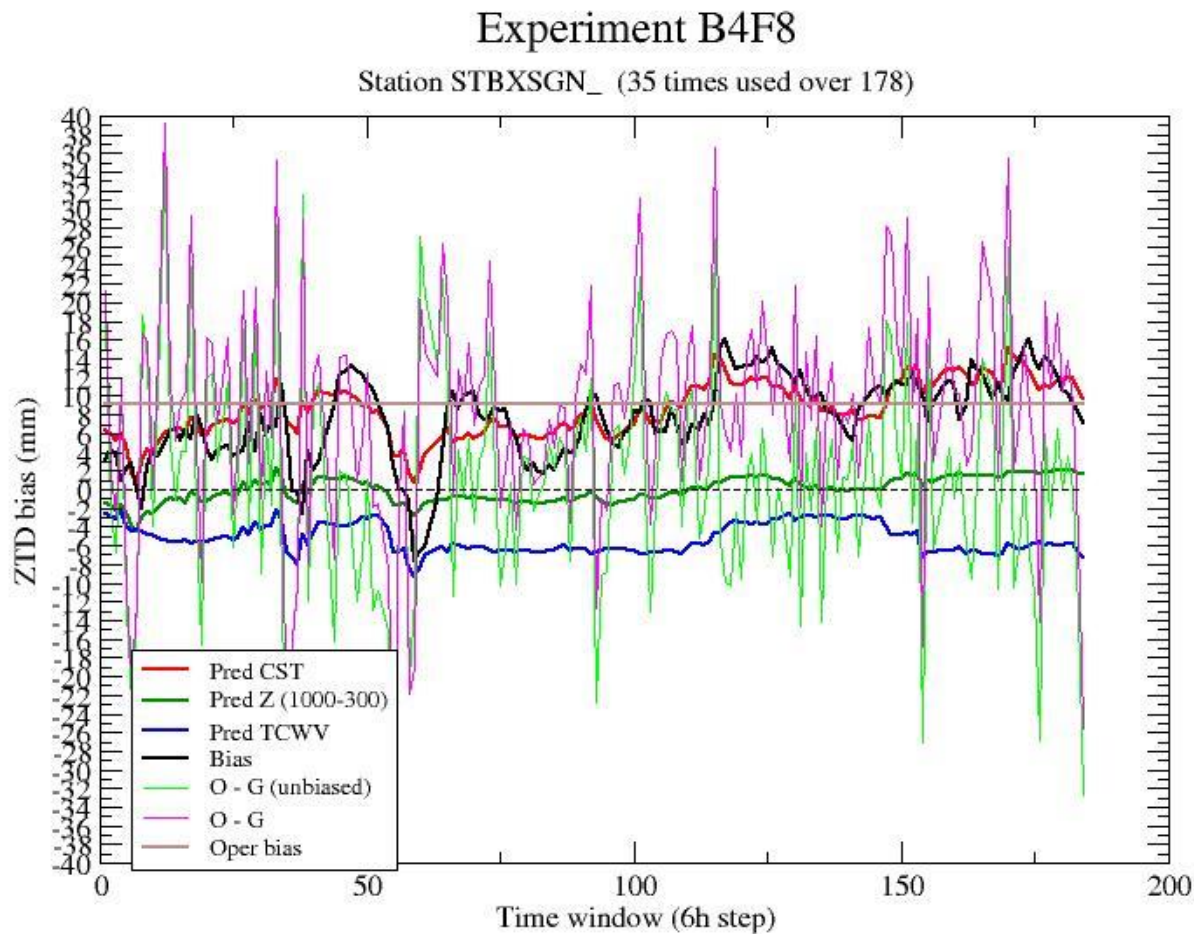


3 pred : constant + TCWV + Th(1000-300)

# ZTD VarBC experiment : Hymex IOP8

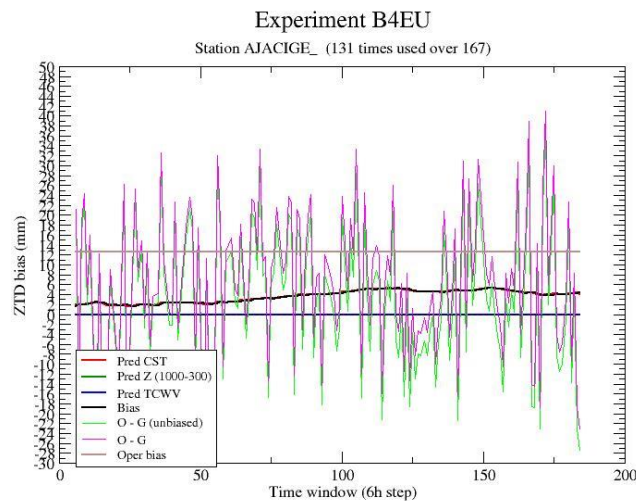


# ZTD VarBC with Aladin : Hymex IOP8

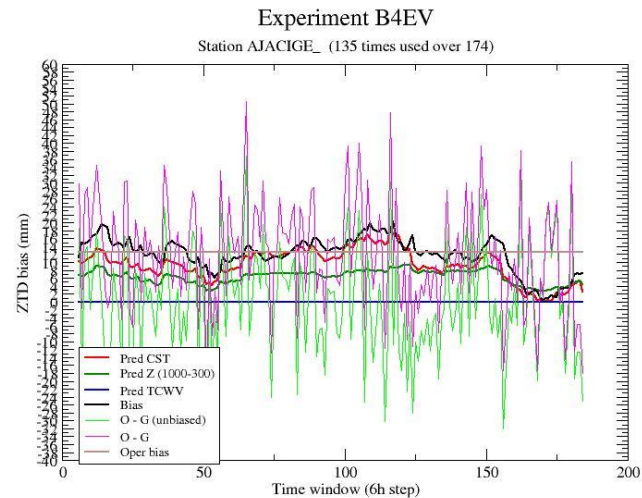




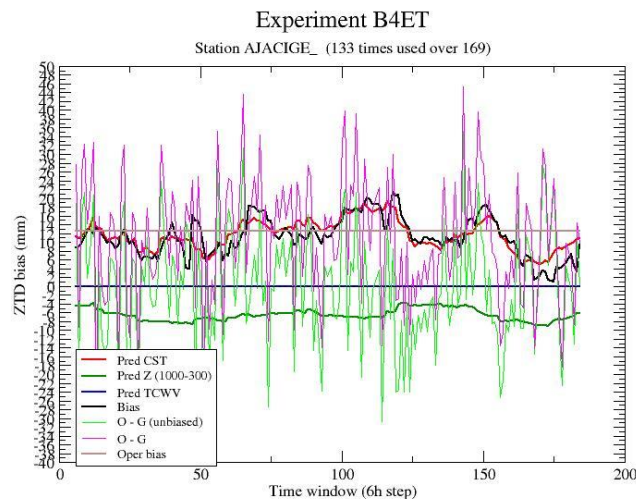
# ZTD VarBC experiment : Hymex IOP8



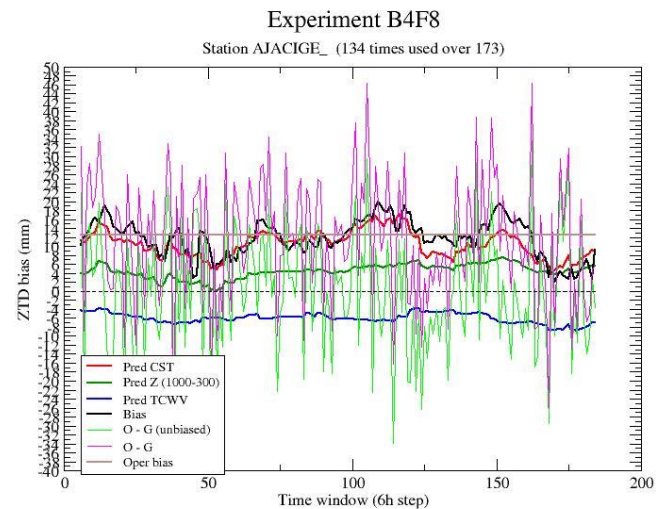
VarBC with 1 predictor (constant)



VarBC with 2 predictors (constant and thickness 1000-300 hpa)



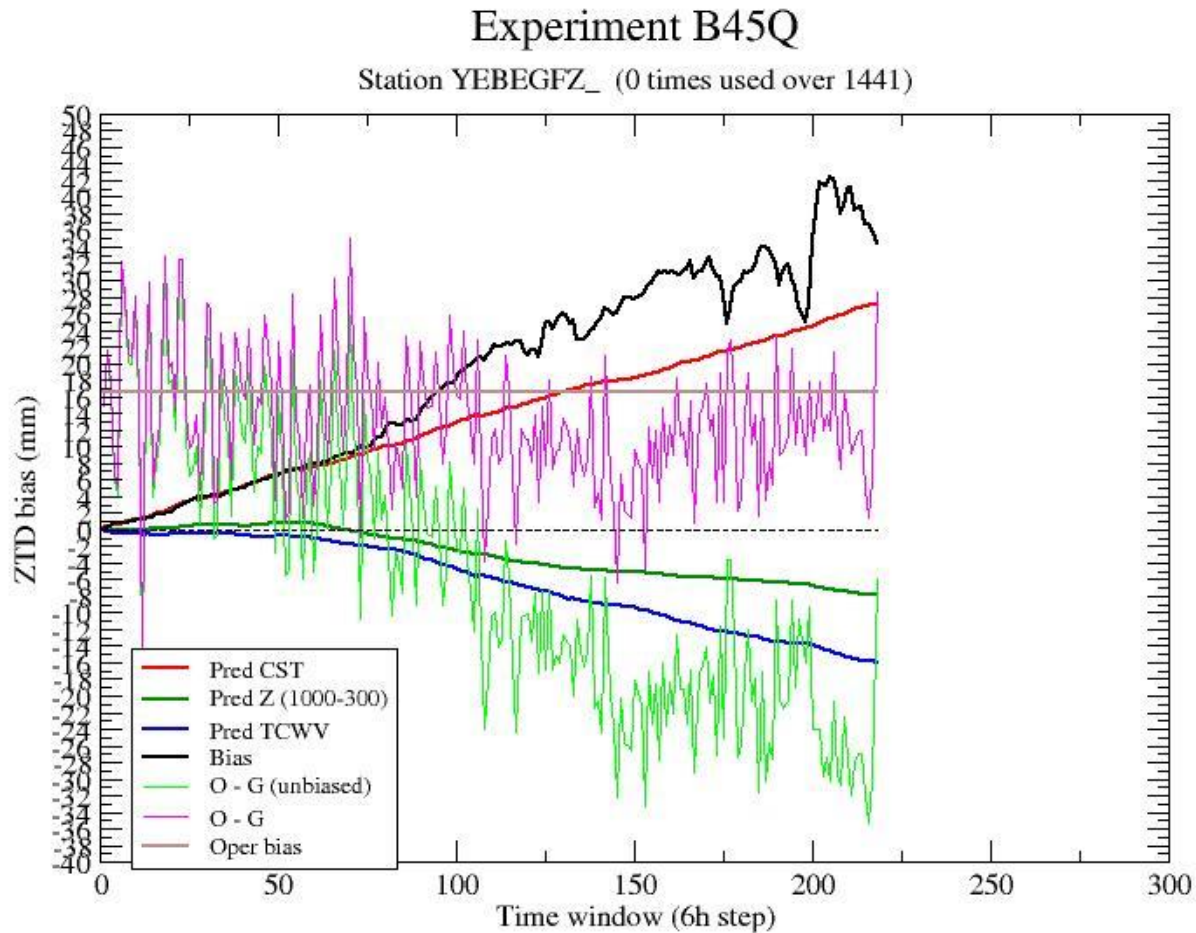
VarBC with 2 predictors (constant and TCWV)



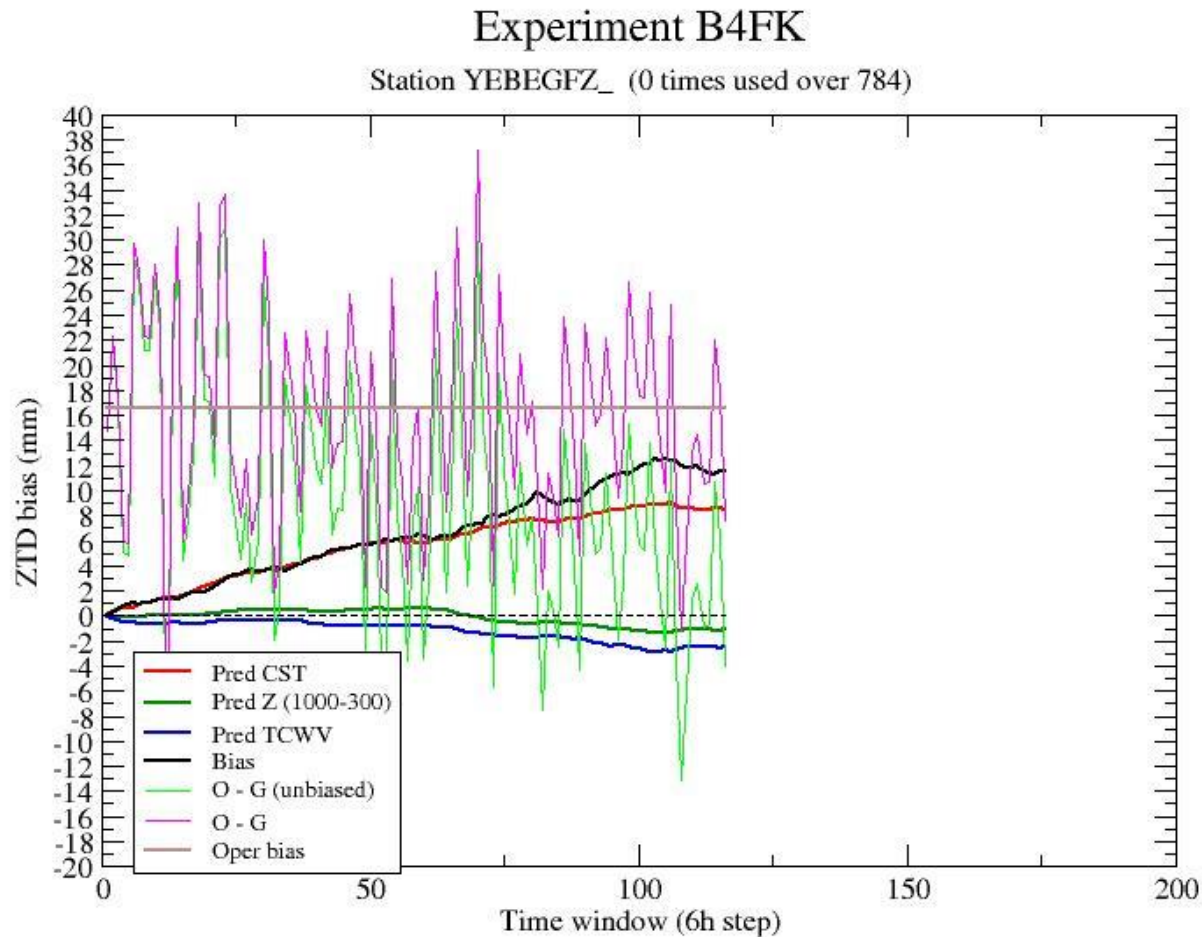
VarBC with 3 predictors



# ZTD VarBC with Arpege : drama...



# ZTD VarBC with Arpege : problem solved...



# ZTD VarBC experiment : conclusion

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- Very interesting impact
- Continuous adjustment of the bias correction
- Possibility to compute the bias of non-used data (adjoint zeroing method)
- Difficult to tune because of too few amount of data
- More studies needed to chose the best predictors (Arome-WMed experiment is currently running on Hymex IOP8, and Arpege experiment is planned)
- Operational implementation planned in 2015 for Arome and Arpege

# Ongoing activities and further work

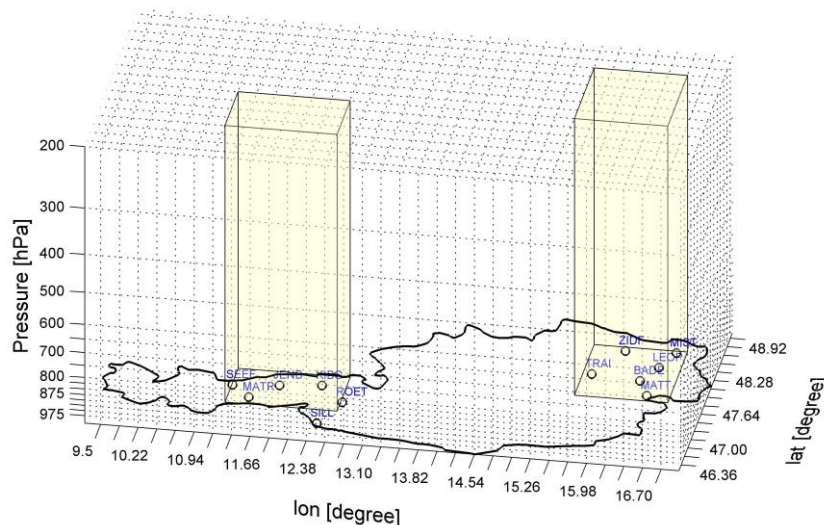


# Ongoing activities

- Finalize the variational bias correction scheme (constant + suitable predictors) : to be implemented in the next operational suite
- Use hourly ZTD in the next 3D-Var Arôme system at 1.3 km (3x more ZTD)
- Use approx. 80% more ZTD in 4D-Var Arpege system (30 mn timeslots instead of 1h)
- Perform an explicit evaluation of the “hydrostatic delay” above model top (set to 10 hPa in the next system)
- Assimilate NOAA GNSS ZTD in Arpege and ALADIN models
- Perform HYMEX re-analyses with Arôme-WMed using E-GVAP data and reprocessed GNSS ZTD (collaboration O. Bock)
- Finalize the study of the impact of ZTD VarBC in Hymex IOP8 with Aladin-Maroc and Arôme-WMed (collaboration M. Raouindi and F. Hdidou)
- Finalize the study on recent assessment of GNSS ZTD data in Arôme using both E-GVAP and UL01 data (collaboration F. Ahmed)

# Requirements and further work

- GNSS ZTD data of interest : processing outside Europe (METG, GOPG and NOAA) for the global model Arpege and for Aladin-Réunion
- Improved timeliness : useful for nowcasting applications
- Future developments : use of asymmetry information available from GNSS receivers (slant delays ? gradients ?) => definition of a new observation operator
- Case studies within two regions in Austria using the GPS tomography refractivity. Work done by Xin Yan in collaboration with ZAMG (Zentralanstalt für Meteorologie und Geodynamik) and Technical University of Vienna



Thank you for your attention !

