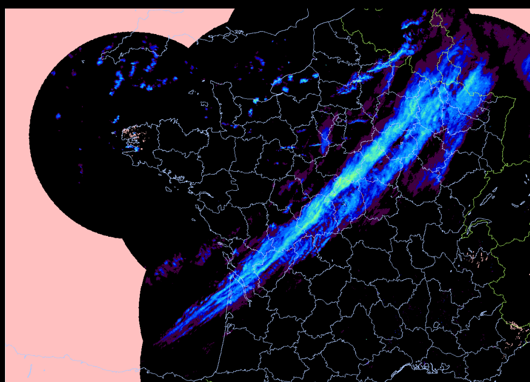
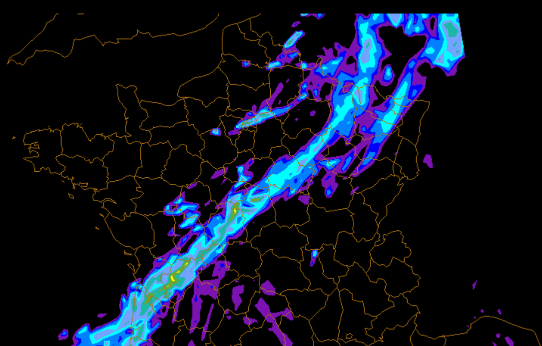
Implementation of the 1D+3DVar assimilation of radar reflectivities in the AROME model at Météo-France





Eric Wattrelot

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Outlines

- Introduction
- Evolution of the radar product for AROME
- Principle of the 1D+3DVar method of reflectivities assimilation
- Illustration of the 1D method, problematic of assimilating the “no-rain” signal
- Evaluation of the 1D method (towards the quality control for the following 3DVar)
- Some few results of the 1D+3DVar through case studies: distinction between stratiform and convective rain cases
- Objective evaluation of two months of cycled assimilations in the 3-hour Rapid Update Cycle AROME
- Conclusions and perspectives

Context and Introduction

Problematic of the assimilation method of reflectivities:

- Reflectivity observation operator needs a complete description of warm and cold hydrometeors : realistic simulation can be obtained with AROME.
- But if reflectivities can provide useful information about the atmosphere water cycle (rain, snow, graupel, primary ice), in the context of variational assimilation, assimilation of rain is very difficult, because:
  - ✓ The direct observation operator involves physical processes which are characterized by discontinuities and nonlinearities, and there is need of simplification in the linearized versions to get some good results…
  - ✓ "rain" is not a variable which is in the "control variable" of the analysis
- But rainfalls have a short shelf life in the atmosphere. Therefore, it's better to try to modify only the humidity field >> need of a 1D method to get some relative humidity retrievals from reflectivities (following ideas of Mahfouf, Marecal …)

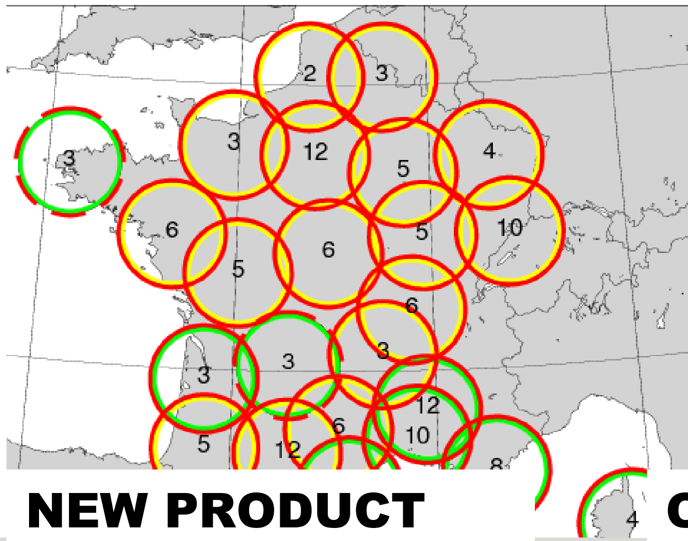
Status of the assimilation of radar reflectivities in AROME:

- Caumont, 2006 has introduced the 1D baysian inversion of reflectivities (offline in Meso-NH)
- In the 3DVar (RUC) AROME, many sensibilities studies, impact studies on specific cases, adjustments and tuning of the 1D+3DVar assimilation method of reflectivities and long period currently being tested in a pre-operational framework (Wattrelot & al., 2008)

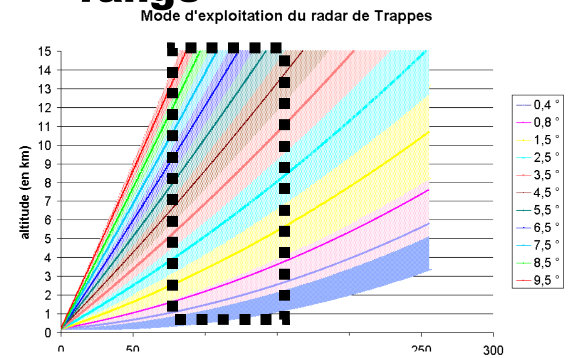
The AROME product from the French Aramis network

24 radars: 16 in C band (yellow circles) + 8 in S band (green circles). Volumes reflectivities (from 2 to 13 elevations).

22 Doppler radars



Optimal vertical sample at medium range



NEW PRODUCT **OLD PRODUCT**

Rain

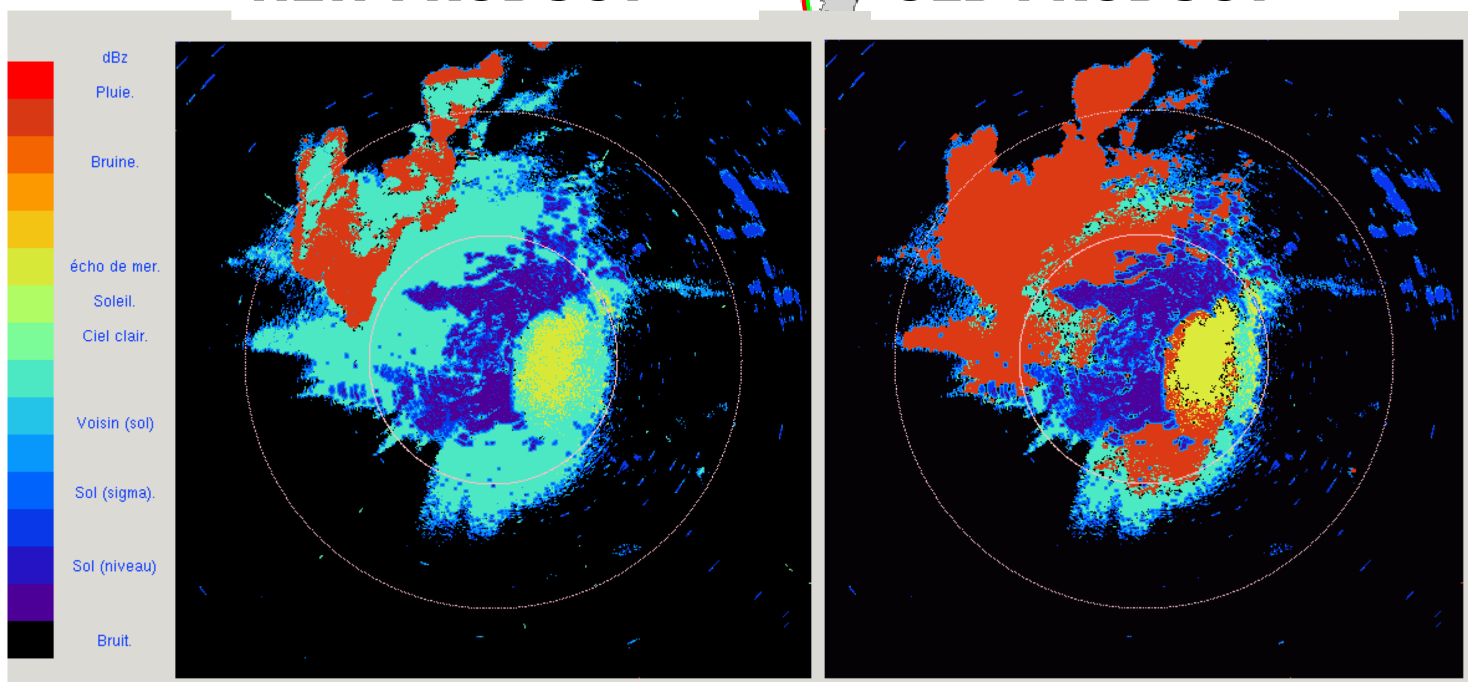
Drizzle

Sea clutter

Clear sky echoe

Ground clutter

Noise



Radar reflectivities assimilation: inversion method

The « best » estimate of atmosphere x given the observation y_0 and using Bayses's theorem (Lorenc, 1986)

$$E(x) = \iiint x.P(x = x_{true} \mid y = y_0)\,dx$$

Bayses's

$$E(x) = \iiint x.P(y = y_0 \mid x = x_{true}).P(x = x_{true})\,dx$$

Olson, 1996 (Gaussian and uncorrelated errors) and x_j database of atmospheric profiles

$$E(x) = \sum_j x_j \frac{\exp \frac{-1}{2} \cdot \| y_0 - y_s(x_j) \|^2}{\sum_j \exp \frac{-1}{2} \cdot \| y_0 - y_s(x_j) \|^2}$$

(with $\| y_0 - y_s(x_j) \|^2 = [y_0 - y_s(x_j)]^T \cdot (O + S)^{-1} \cdot [y_0 - y_s(x_j)]$)

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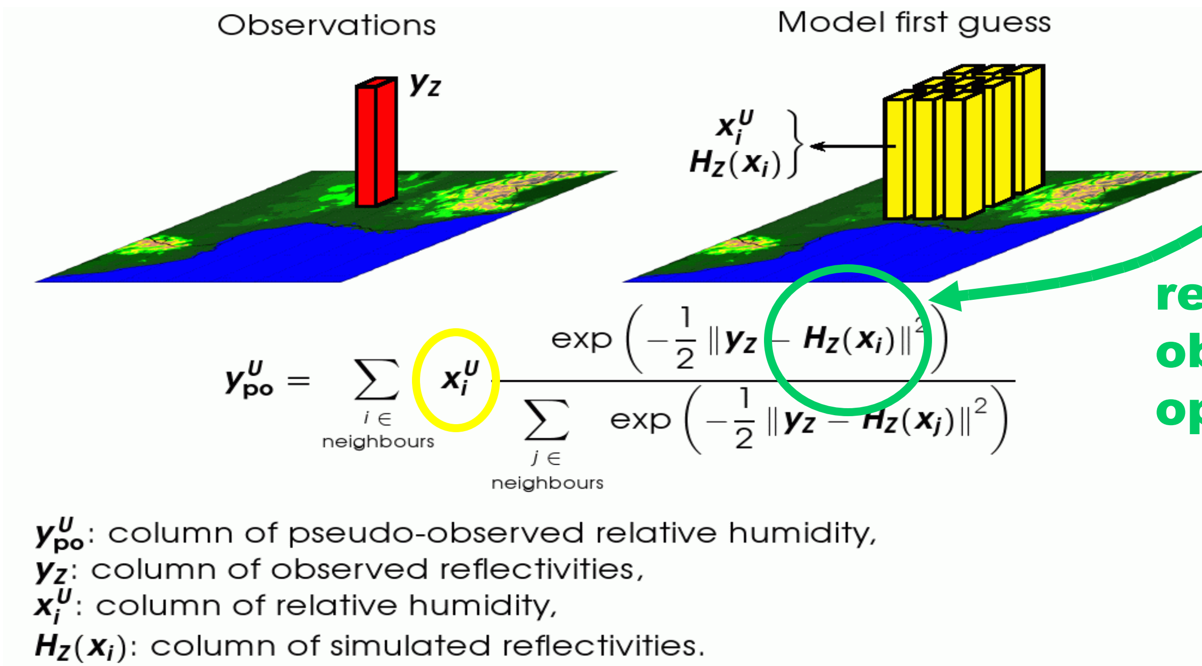
Inversion method of reflectivities profiles

Caumont, 2006: use of model profiles in the vicinity of the observation as representative database

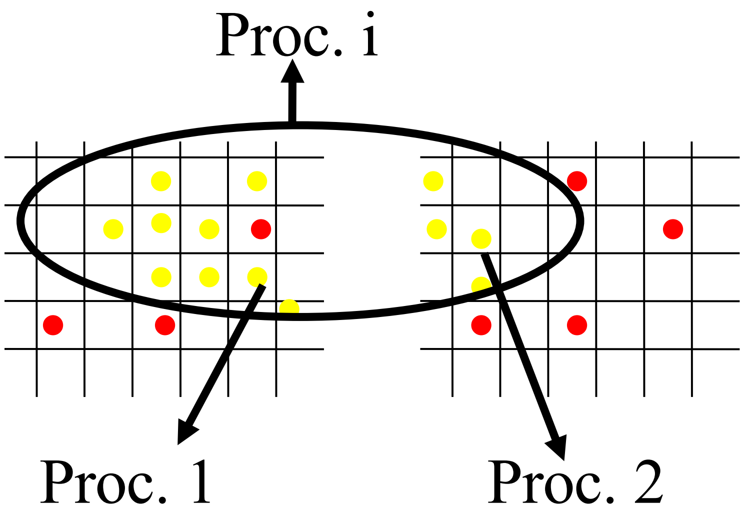
$$E(x) = \sum_j x_j \frac{\exp \frac{-1}{2} \cdot \| y_0 - y_s(x_j) \|^2}{\sum_j \exp \frac{-1}{2} \cdot \| y_0 - y_s(x_j) \|^2}$$

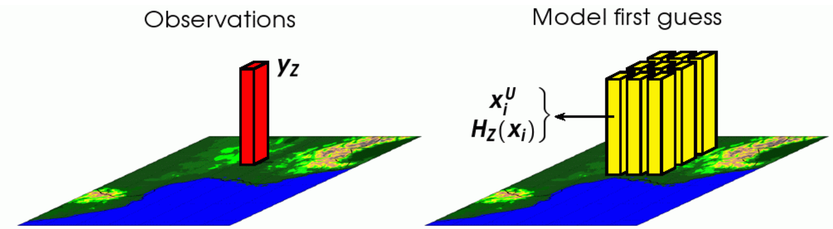


reflectivity observation operator

1. ***Consistency between the retrieved profile and clouds/precipitations that the model is able to provide***
2. ***But, possibility of bad solution if model too far from the reality***

Challenge to implement the 1D inversion: use of the extension of the model/observation interface in 2 dimensions





$$y_{po}^{U} = \sum_{i \in \text{neighbours}} x_i^U \frac{\exp\left(-\frac{1}{2}\|y_Z - H_Z(x_i)\|^2\right)}{\sum_{j \in \text{neighbours}} \exp\left(-\frac{1}{2}\|y_Z - H_Z(x_j)\|^2\right)}$$

y_{po}^U: column of pseudo-observed relative humidity,
y_Z: column of observed reflectivities,
x_i^U: column of relative humidity,
$H_Z(x_i)$: column of simulated reflectivities.

In context of Arpege/IFS code:

- Difficulty to use model profiles in the observation space: use of the semi-lagrangien interpolation for the profiles in the supporting database as it is done for observations
- and use of the new 2D-interface of model/observation built for 2D observation operator (Grace instrument from METOP).

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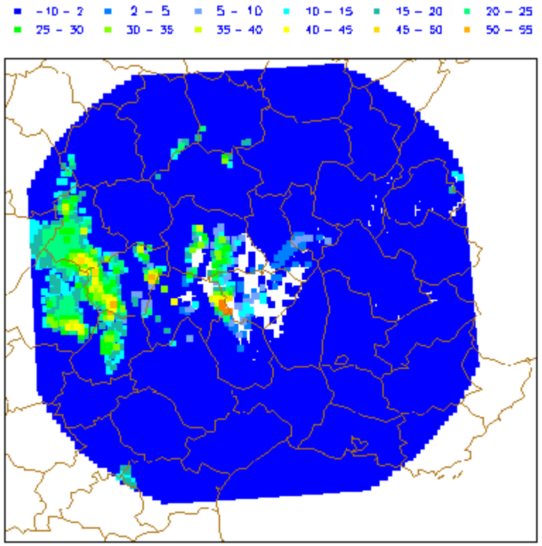
Illustration with one radar assimilated, in the observation space

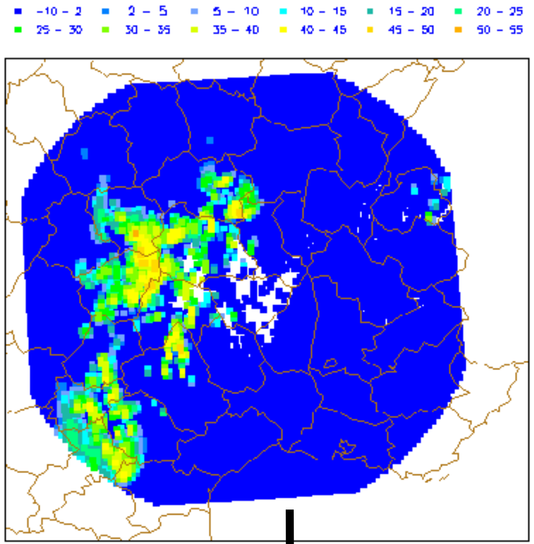
Reflectivities

Elevation 0.44

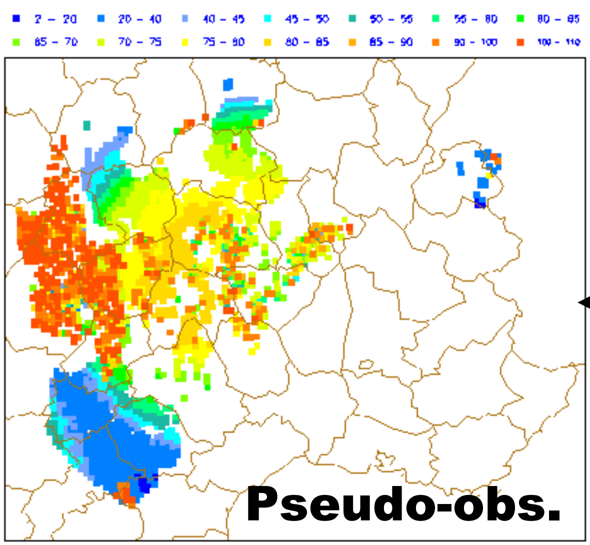
Radar



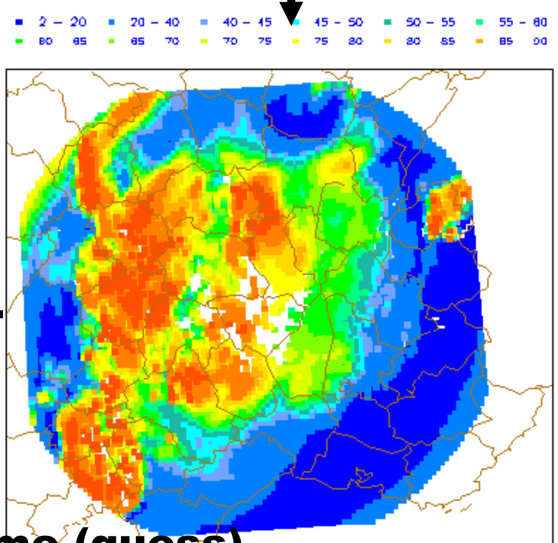
Arome (guess)



Relative humidity



Pseudo-obs.



Arome (guess)

Problematic of « no-rain » signal

Problematic:

- if the SNR (signal-noise-ratio) is very low (bad quality of the radar or very far away from the radar), there is a high probability to dry with pixels below the noise but rainy !!

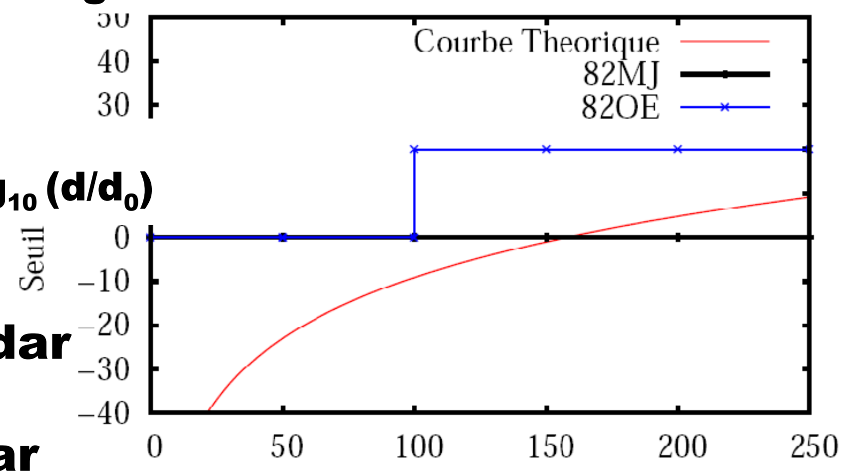
- But we know the noise, so we can … take into account (in the 1D method) the threshold of detection for each pixel of each radar in order to not dry the model below this value : but is it sufficient?

$$\text{Use only } ZZ_{SIM} > ZZ_{THR} \text{ and } (ZZ_{SIM} < ZZ_{THR} \Rightarrow ZZ_{SIM} = ZZ_{THR})$$

- Sensibilities studies have been done by deterioration of the quality of one radar

Threshold of detection, function of range

$$Z\,(dBZ) = +\,20\,\log_{10}(d/d_0)$$

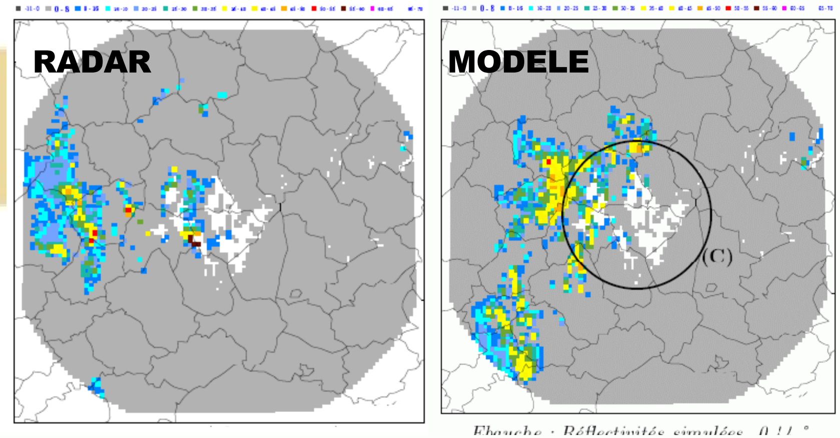


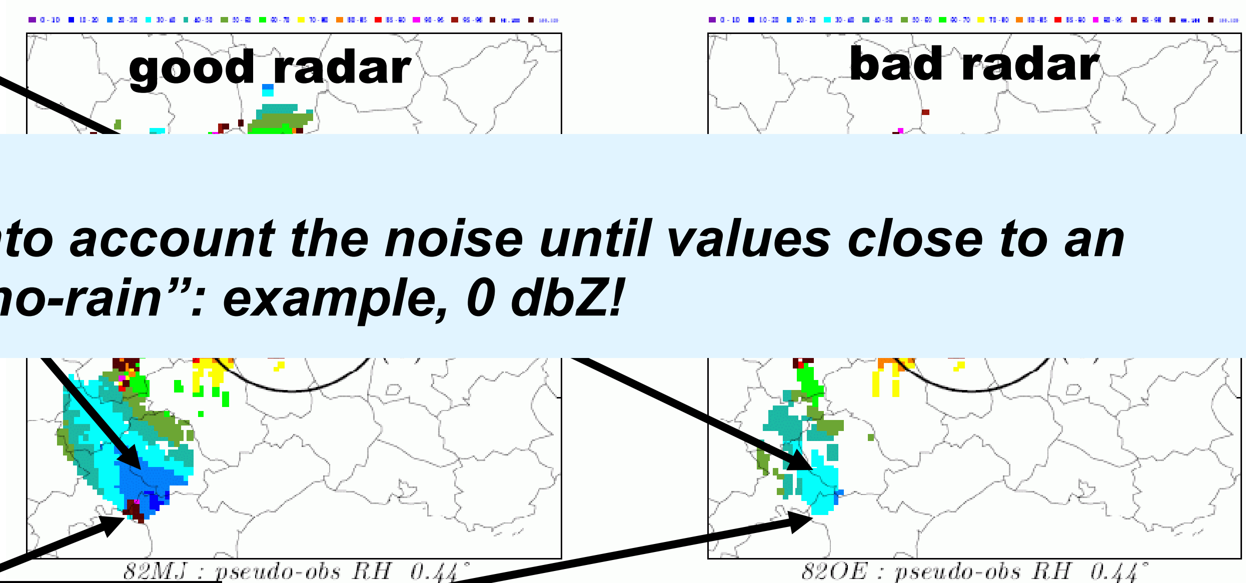
good radar

bad radar

Range from the radar

In dry areas, the inversion dry less with bad radar…expected?

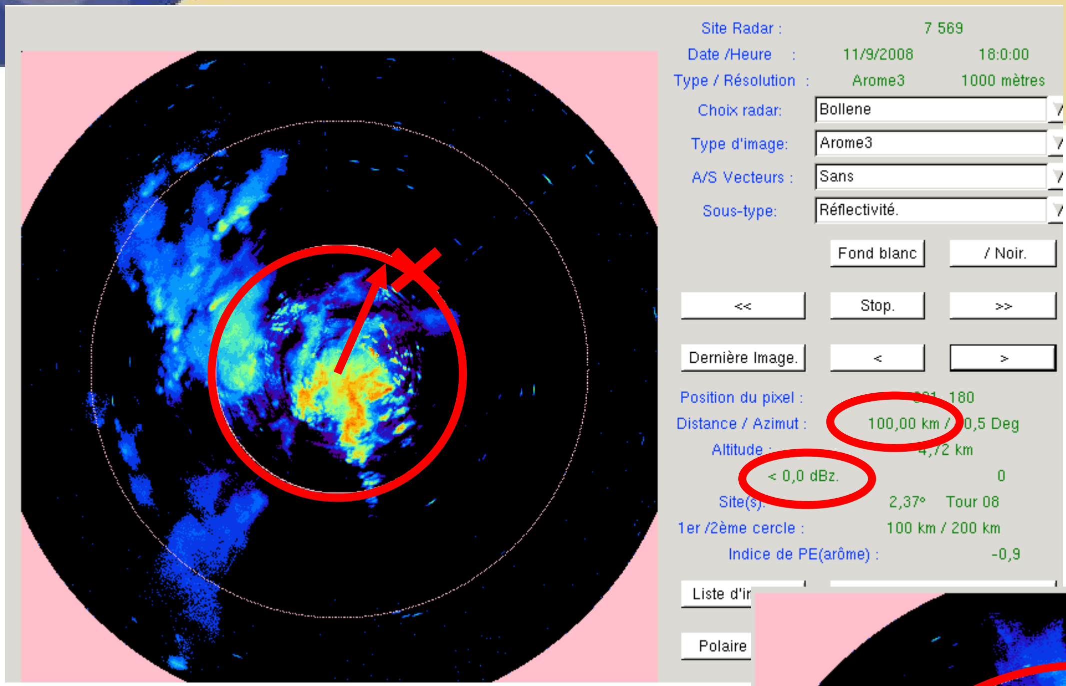




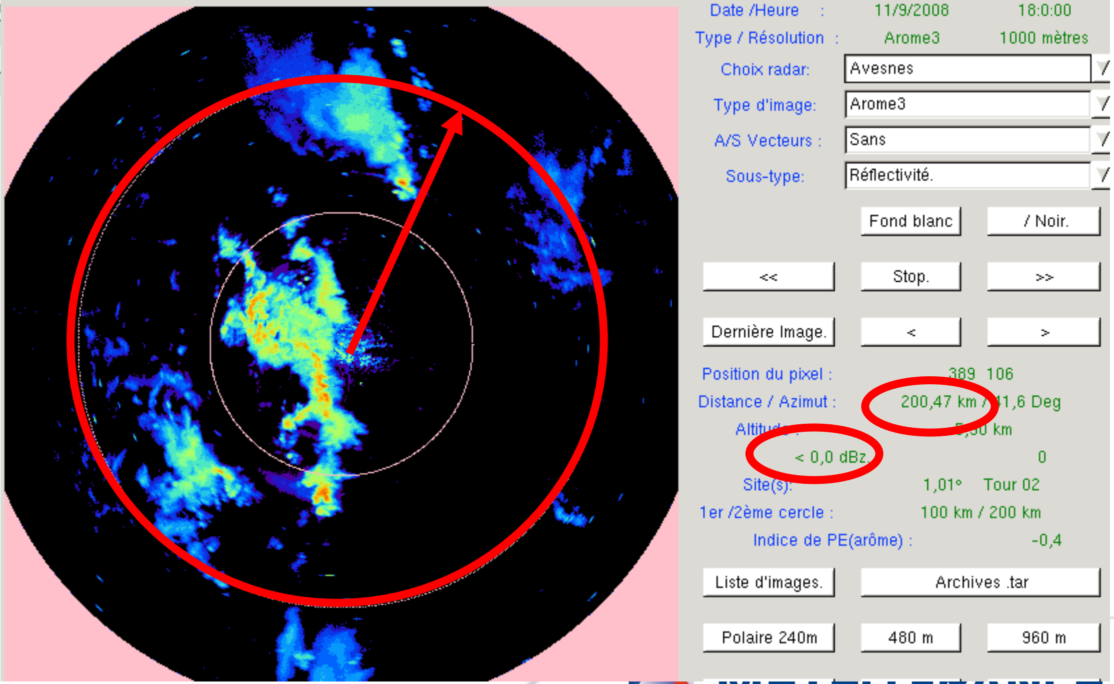
- ***Solution:*** ***take into account the noise until values close to an acceptable value of "no-rain": example, 0 dbZ!***

Wrong desaturation in slightly rainy areas (could happen if

$$ZZ_{obs} < ZZ_{THR} < ZZ_{SIM}$$ **)**



bad radar



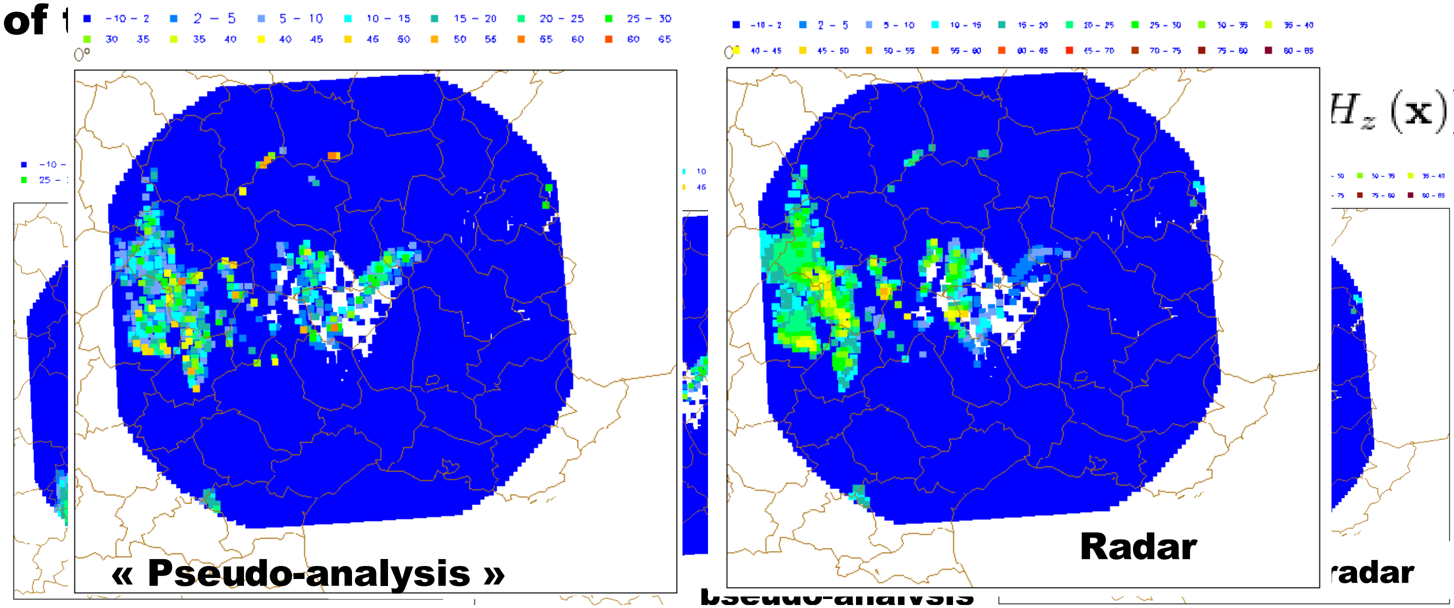
good radar

To evaluate the 1D-method, use of a « pseudo-analysis of reflectivity »

Easy to compute by use of the weights of t

$$Z_{ps} = \sum Z_i \frac{exp(-\frac{1}{2}J_z(x_i))}{\ldots}$$

Reflectivity field



If $||Z_{ps} - Z_{obs}||$ low =>

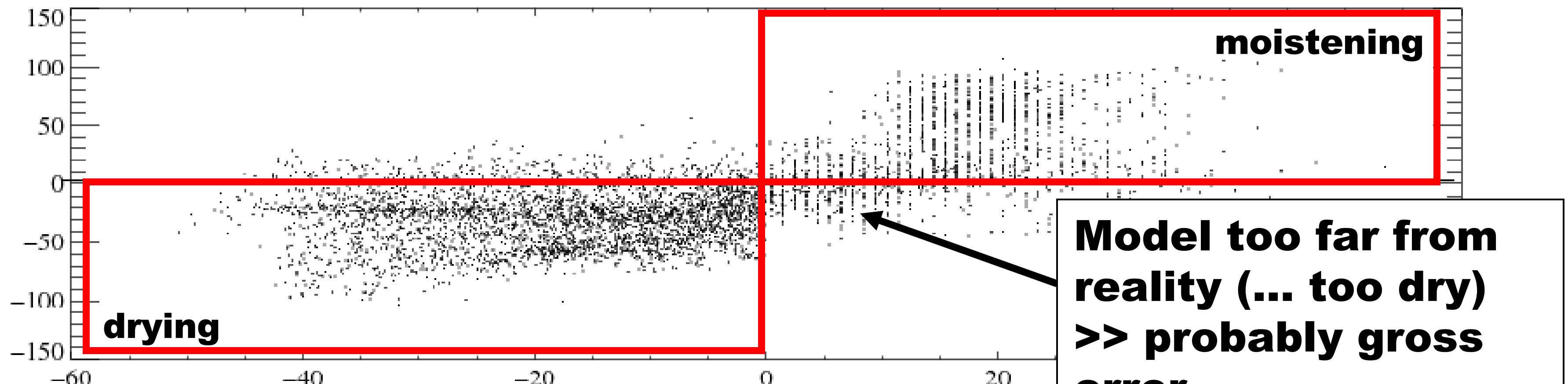
1. good convergence of the 1D method. (RMS deviation can be a measurement of the quality of the retrieved profiles: useful for monitoring)

2. good consistency between the pseudo-observations and the model (because of use of model information in the 1D-inversion). Used for the quality control in the screening

3. Possibility to take into account this value in the choice made in the thinning of the observations (tests are still underway)

Towards the Quality control, thinning and errors…

Another diagnostic: check if drying and moistening are consistent with the negative or positive reflectivity departures: convergence involves that the model has the capability to saturate or desaturate close to the observation.



Scatterplot of relative humidity increments (from 1D m… function of observations minus background reflectivities departures

- **thinning every 15 kms to avoid observation error correlation and representativeness errors (sensibilies studies have shown it is not useful to increase density of obs. with the system now)**
- **specification of pseudo-observation error variance, it depends linearly on the range from the radar until 160 kms, but low sensibility of the results to the observation error specification**

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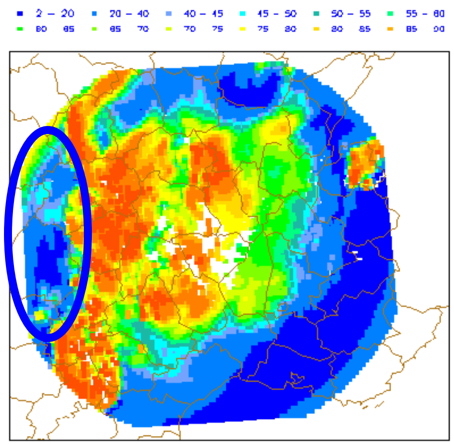
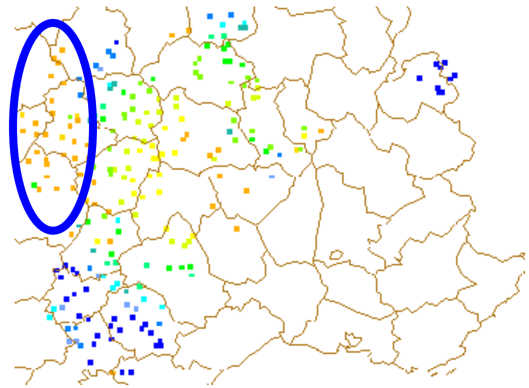
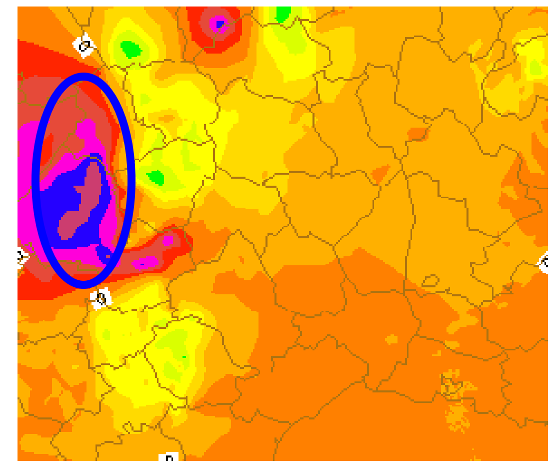
Pre-identification of « gross observation errors » allows to increase the acceptable value « obs minus guess departures »...



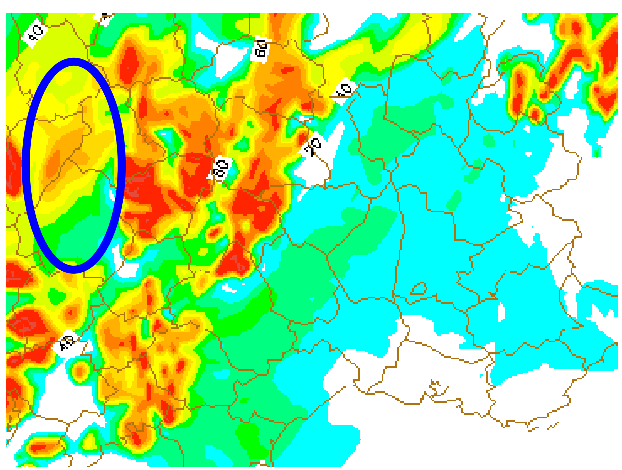
ACTIVE PSEUDO-OBSERVATIONS OF RELATIVE HUMIDITY



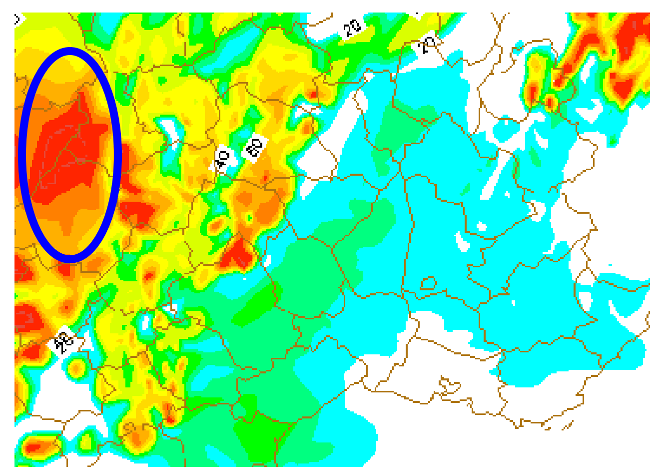
RELATIVE HUMIDITY ANALYSIS DIFFERENCES



ANALYSIS of relative humidity at 500 hpa



~30/50% obs minus guess departures



~50/70% obs minus guess departures

Case of stratiform rain

It works well in stratiform cases: generally because good spatial coverage of precipitation in the model. The method founds sufficient information to converge.

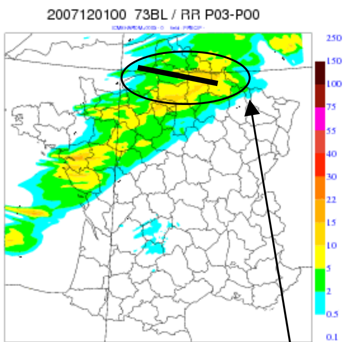
Illustration on one case…

Case of stratiform ra… band of cold fr…

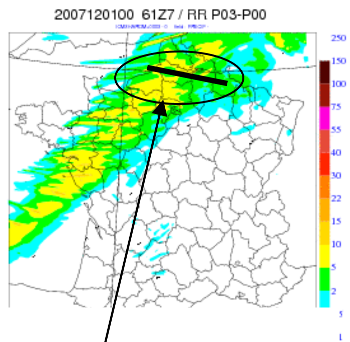
3h - cumulated rain - P3-P0

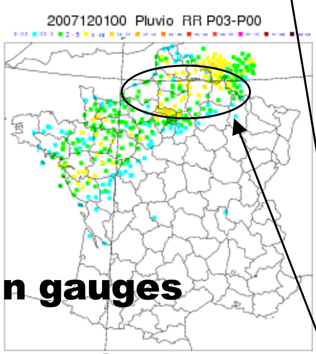
Modification of the divergence field in low layer thanks to the cross-correlations of the B-matrix between humidity and wind field…

REFL

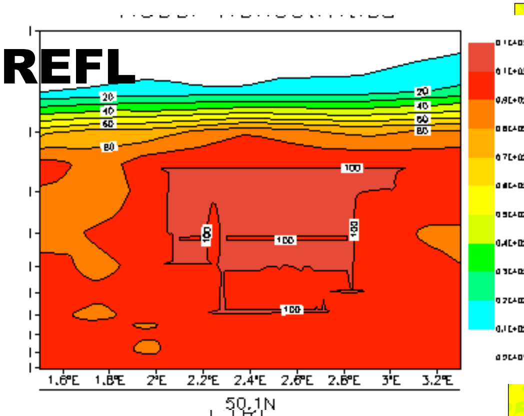


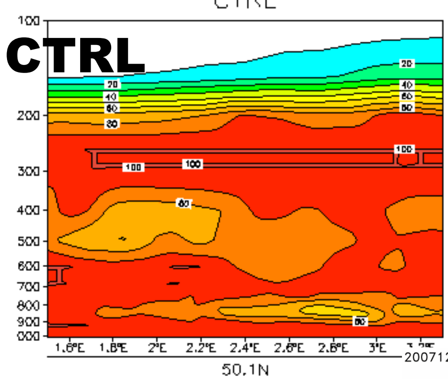
CTRL

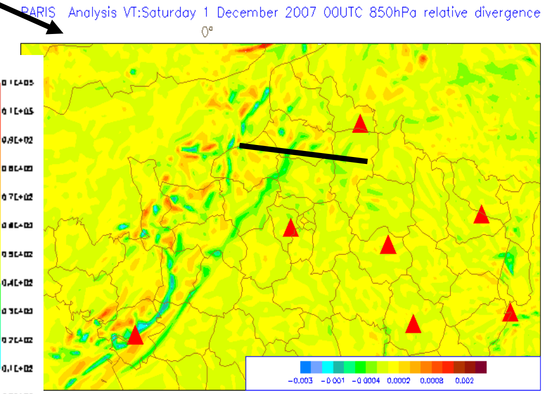


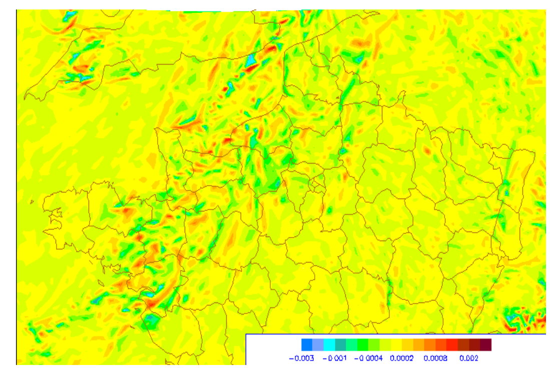


rain gauges



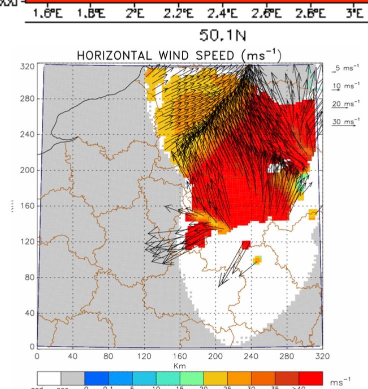


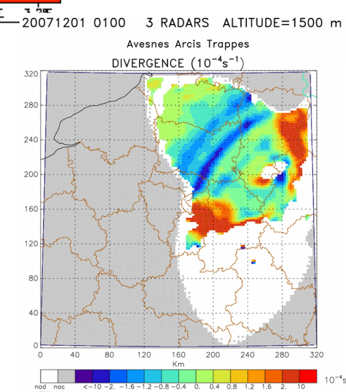




Capability to shift the cold front (well located on the 3-hour forecast from the analysis with reflectivities)

3 cycling

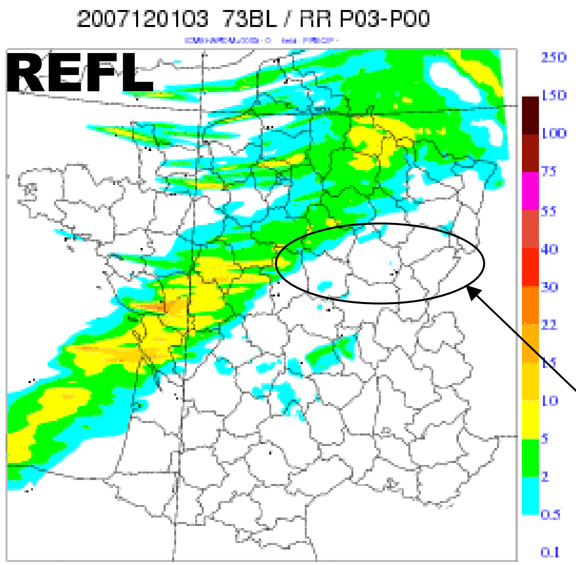


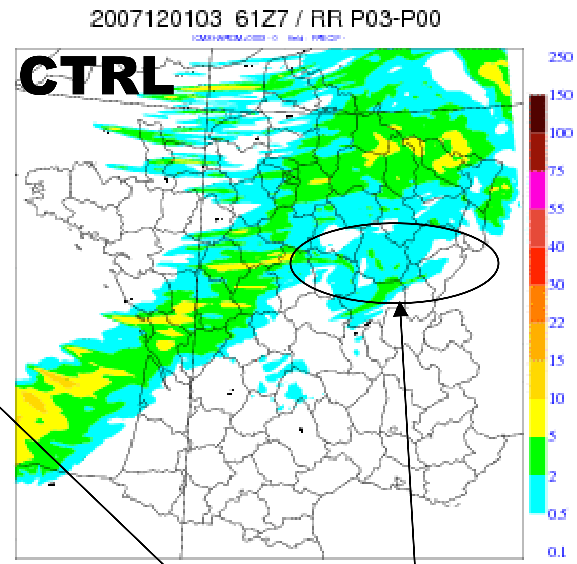


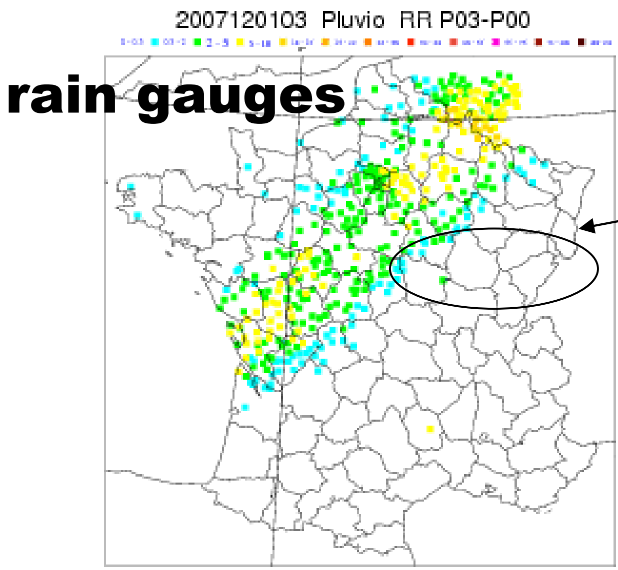
Verification with independant reconstruction of the 3D wind field

One cycling more: r03 – 4 cycling

3h - cumulated rain - P3-P0







Good drying in front of the main rainfalls of the cold front with the run REFL.

And still good impact on 12-hour forecast QPF scores for this case

Case of convective rain: to simplify, what we have learnt…

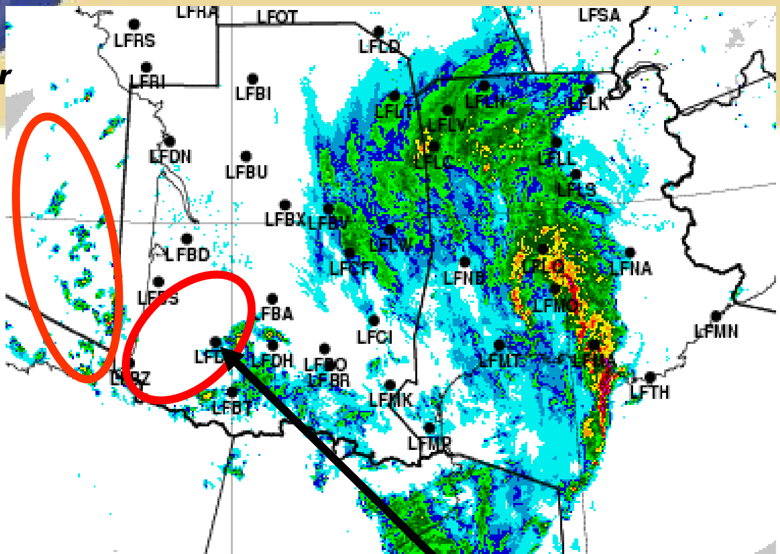
- *No convection triggered in the model (in the vicinity of the observation): difficulty to create precipitation by the 1D method (quality control in order to not introduce gross errors of pseudo-observations).*

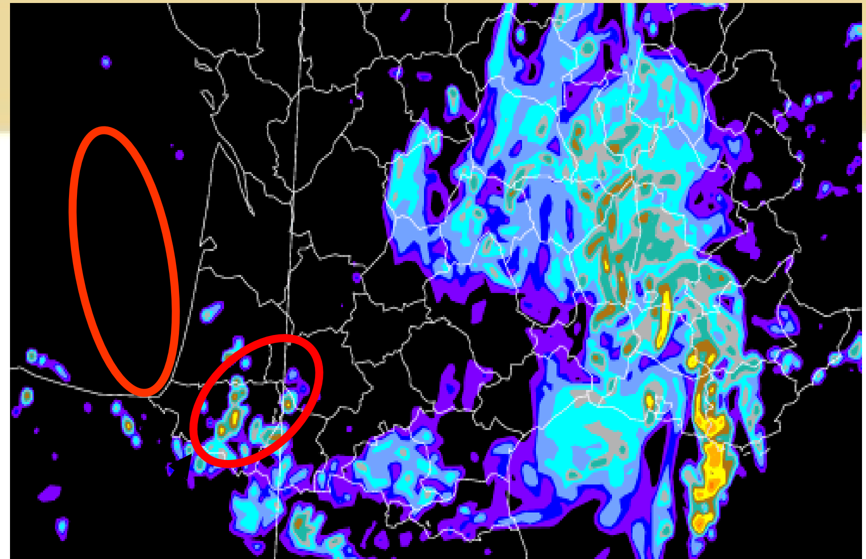
- *If convective cells exist in the model close to the observations: ok but…*
- *To avoid positive biais of humidity: use of observed "no-rain" pixels: ok to remove wrong cells and avoid spreading of positive increments*

- *If convective cells exist but very far from the observations: spreading of positive increments because of too big range length in B matrix… problem needed to be evaluated*

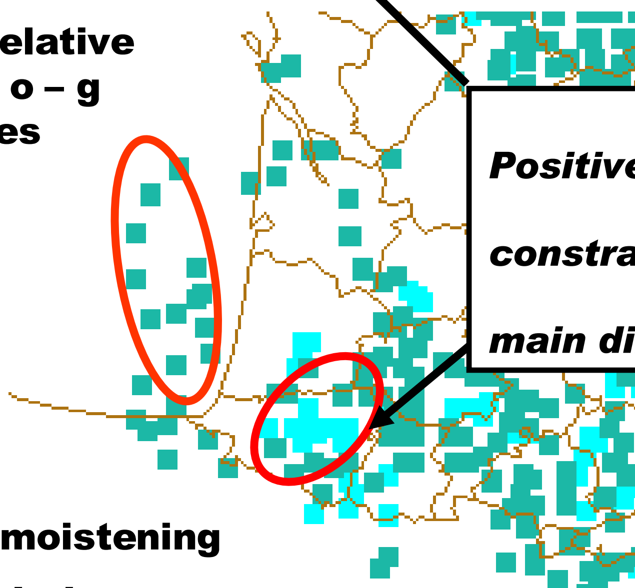
Radar

06h

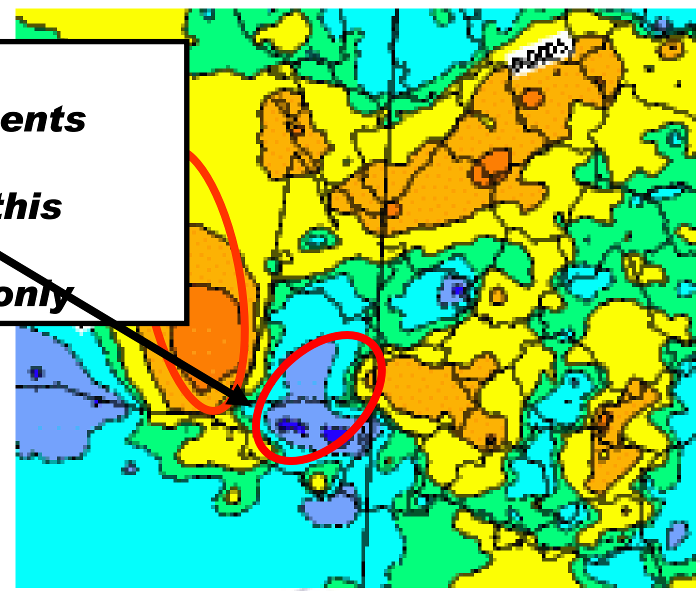




Pseudo-relative humidity o – g departures



Positive increments constrained in this main direction only



moistening

drying

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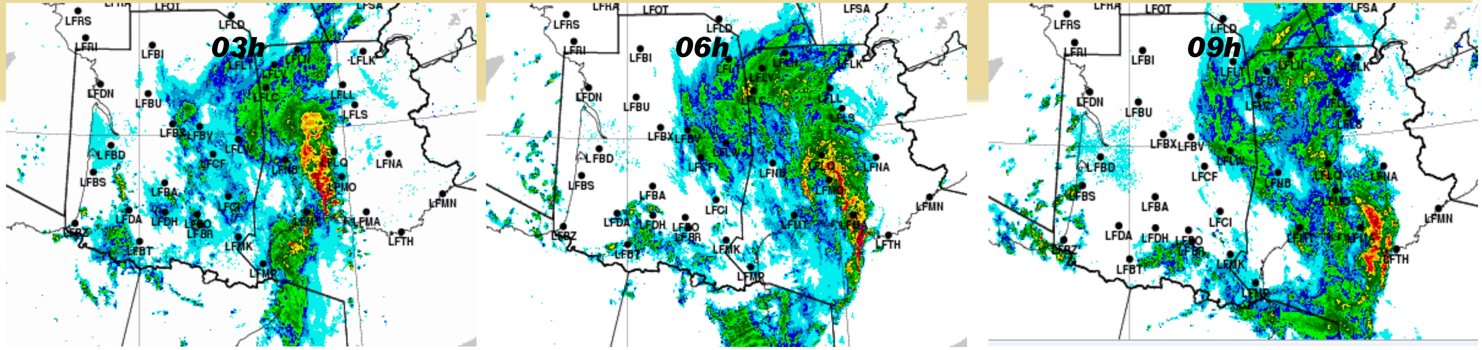
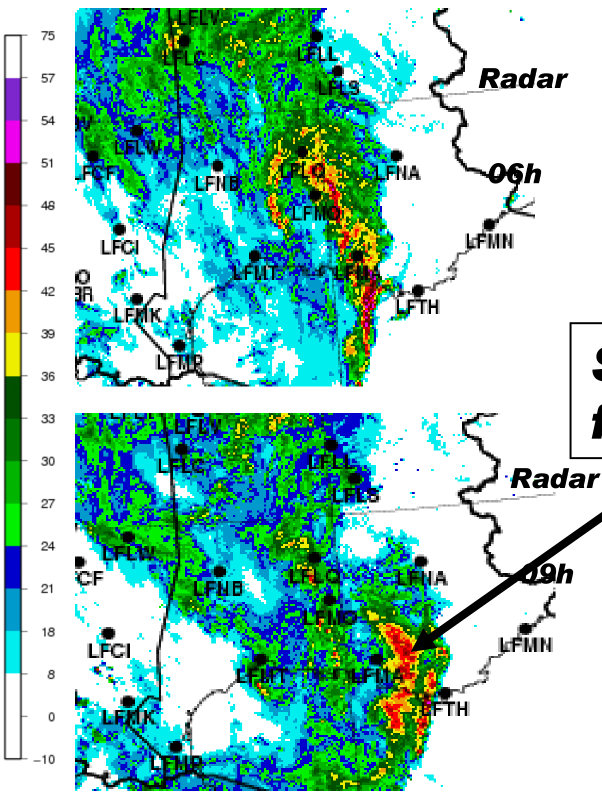
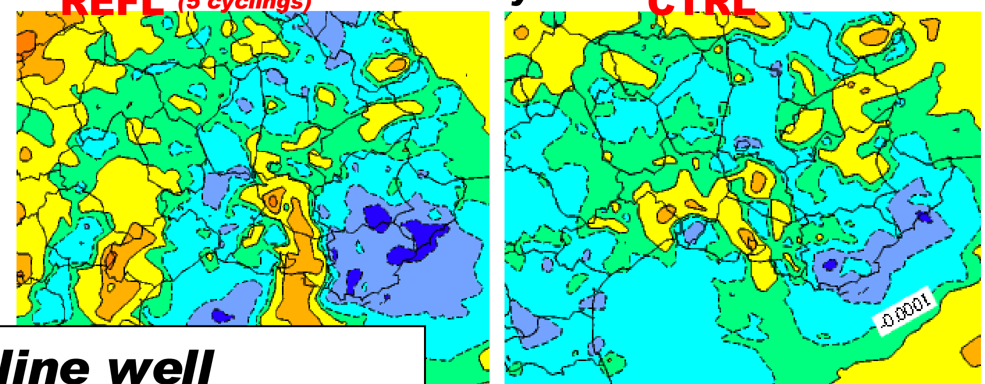
Chronology of the convective event

8 october 2008

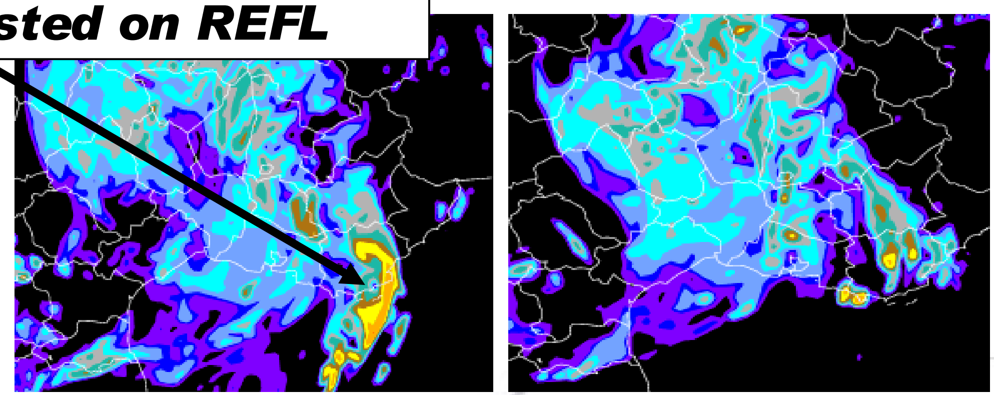




Specific humidity Incr



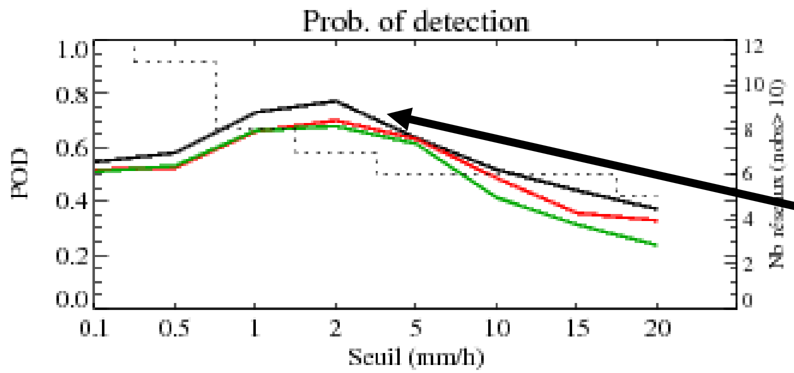
Squall line well forecasted on REFL



Simulated reflectivity field from 3-hour forecast

Average of QPF scores (for 6-hour forecast during the convective event)

7/8 october

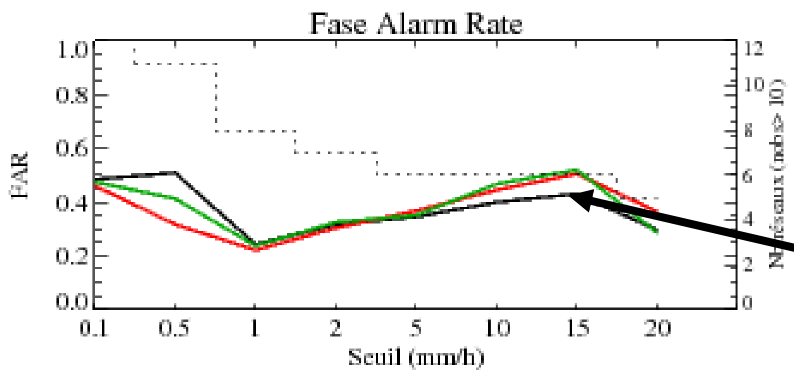


7441

7445

oper

1D+3DVar's detection better for all the thresholds



1D+3DVar's false alarms better for the high thresholds of precipitation

REFL

CTRL (pre-oper without Doppler

Pré-OPER

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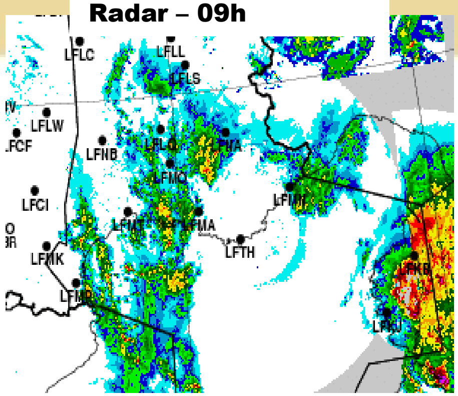
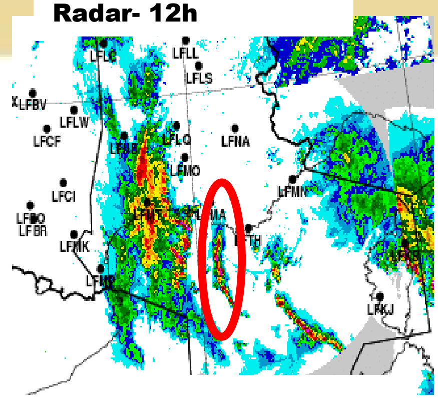
Case of the 04 november 2008: *convection on mediterranean sea*

Chronology of the convective event

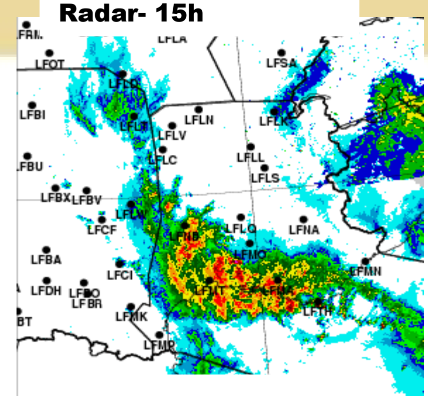
Radar – 09h



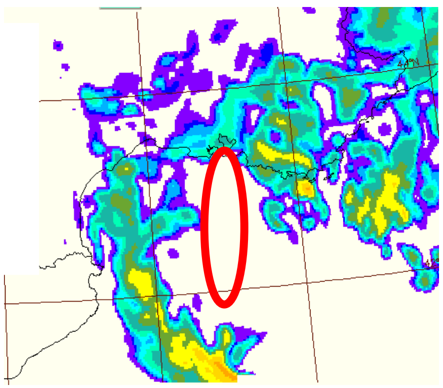
Radar- 12h



Radar- 15h



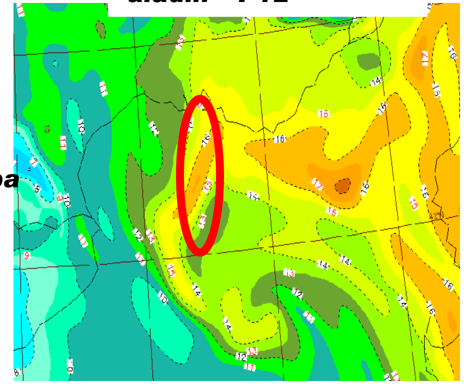
Simulated reflectivities from Arome, 12-hour forecast (850hpa)



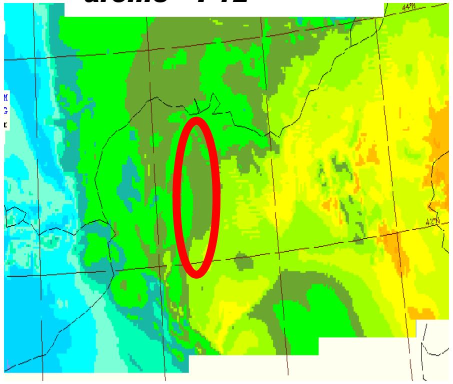
TPW – 850 hpa

(from medit. South)

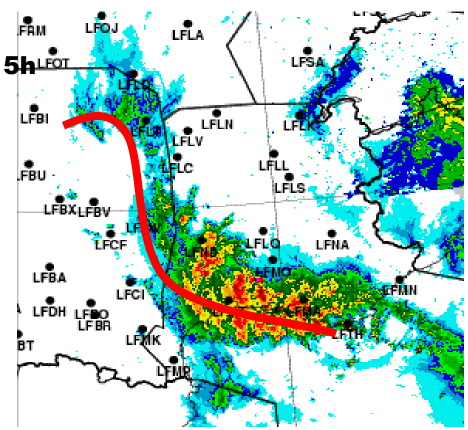
aladin – P12



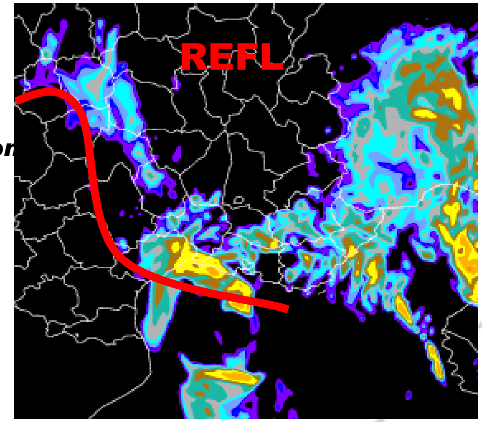
arome – P12

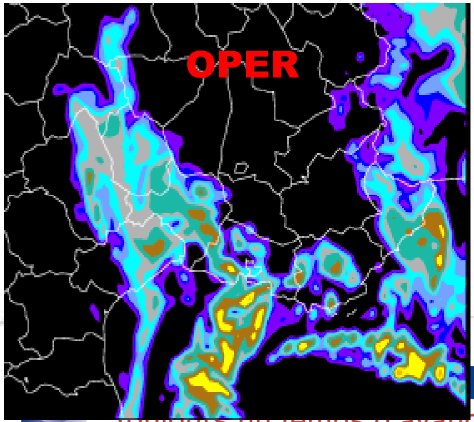


Radar- 15h



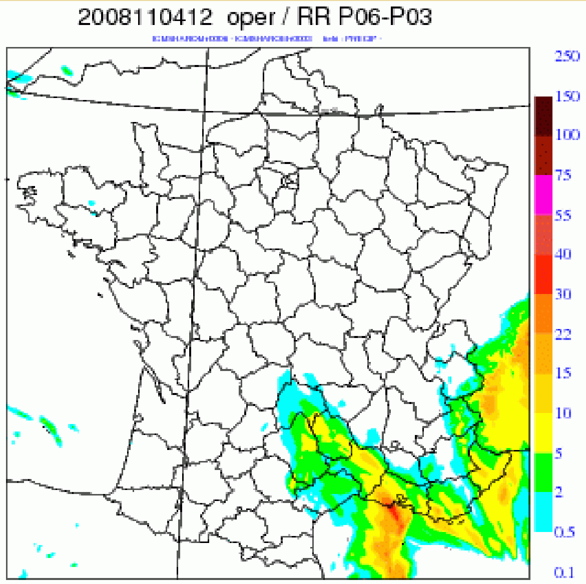
Simulated Reflectivities from Arome, from 3-hour forecast (900hpa) – r12

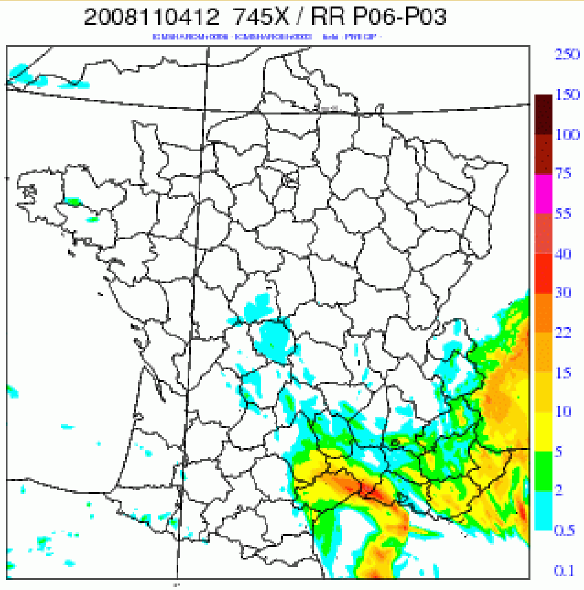




Case of the 04 november 2008: *convection on mediterranean sea*

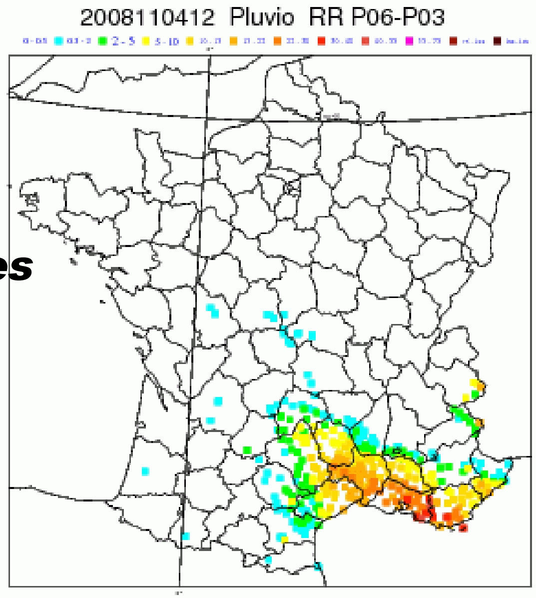
OPER

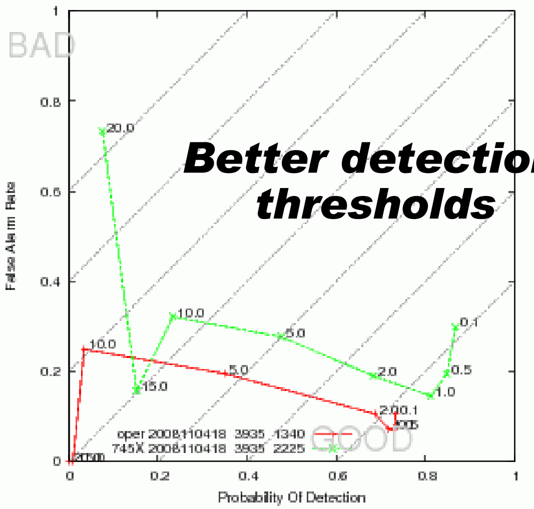




REFL

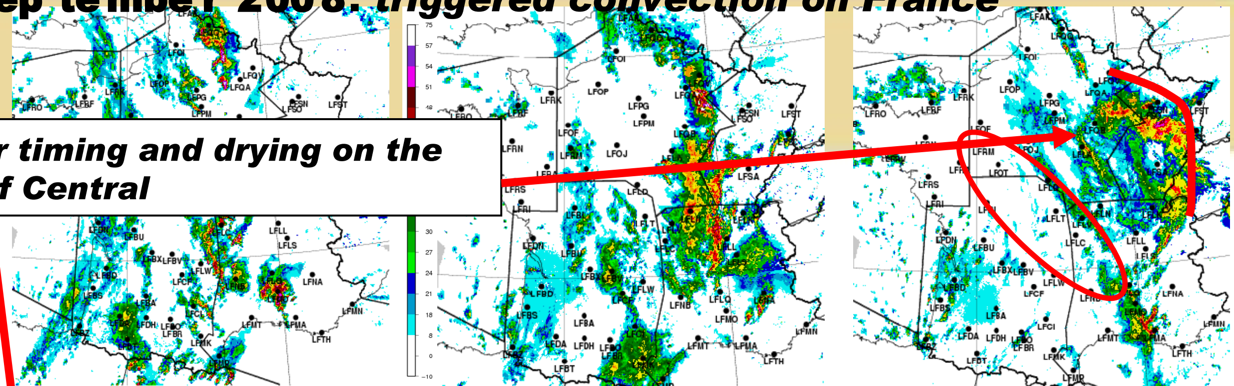
raingauges





Better detection for all the thresholds

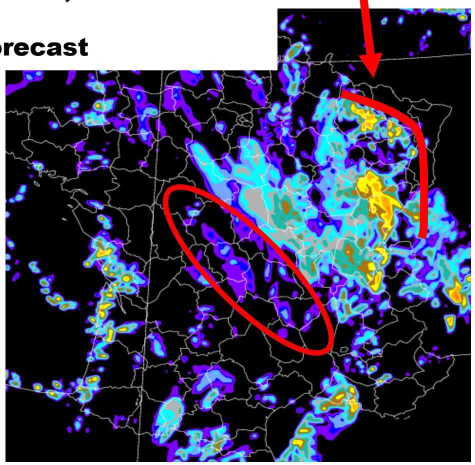
Case of the 11 september 2008: *triggered convection on France*



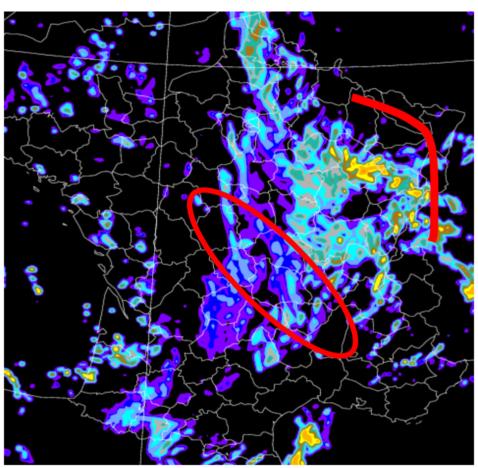
Better timing and drying on the Massif Central

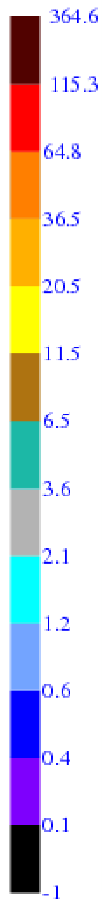
Simulated reflectivities from Arome, 03-hour forecast

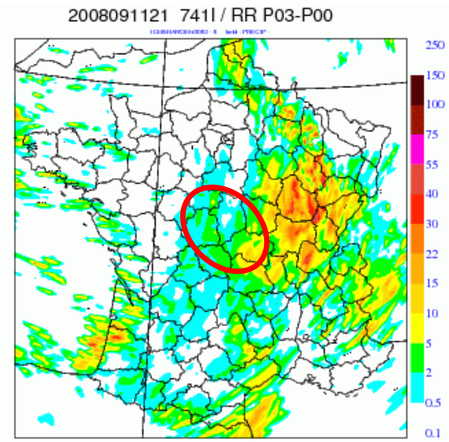
REFL (4 cycling)

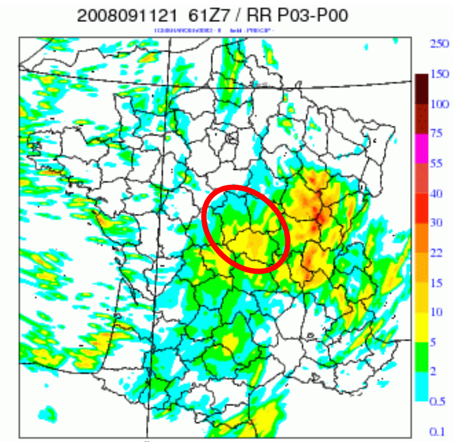


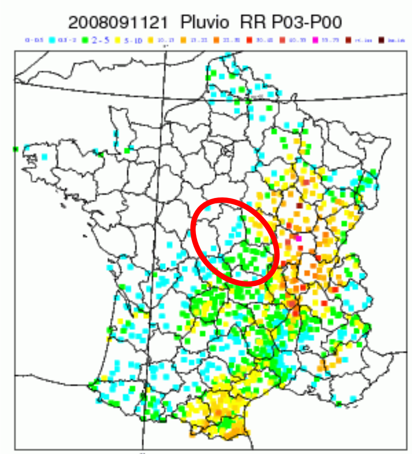
OPER



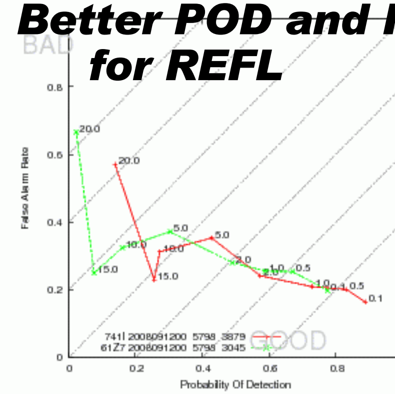




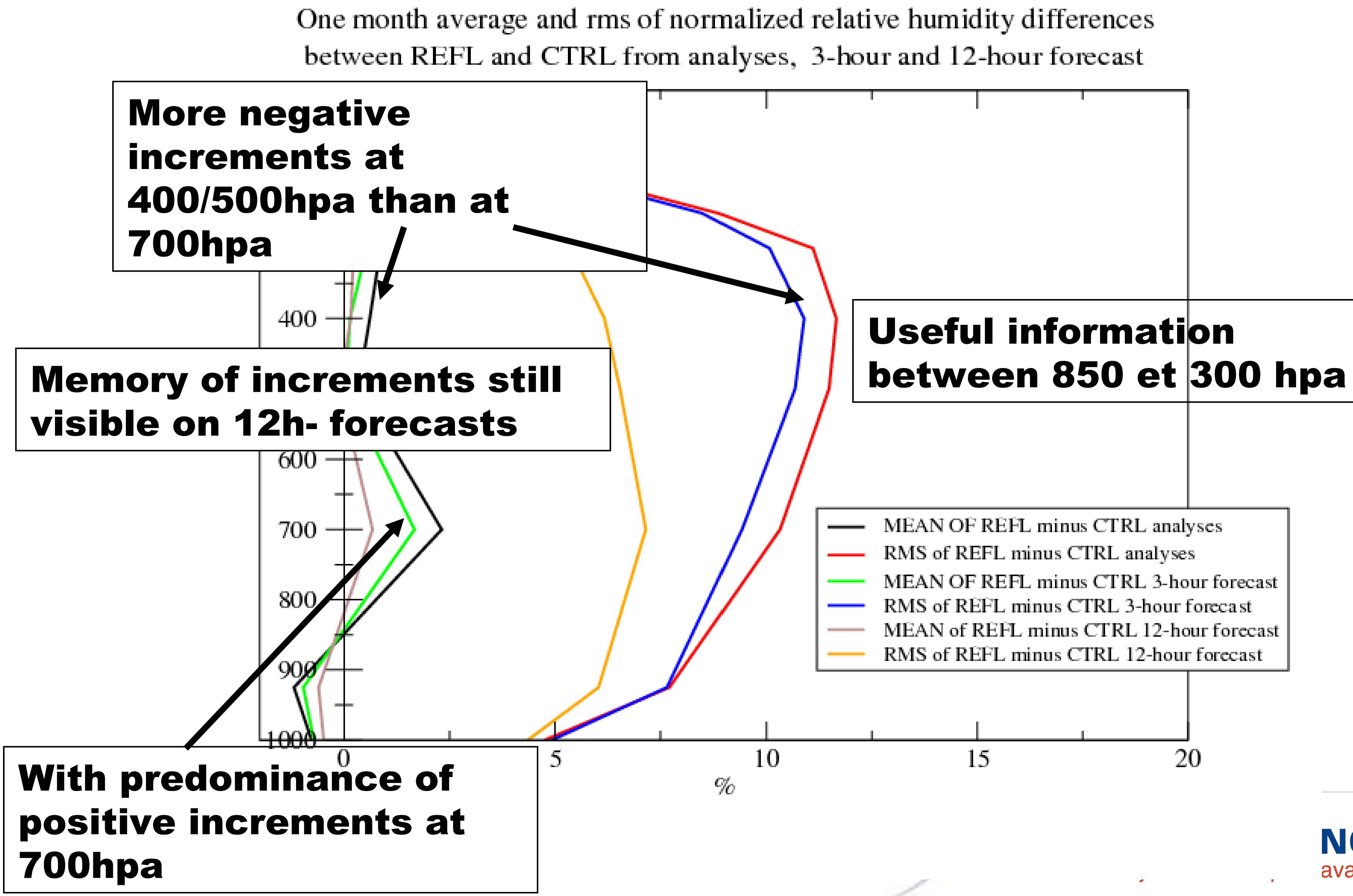




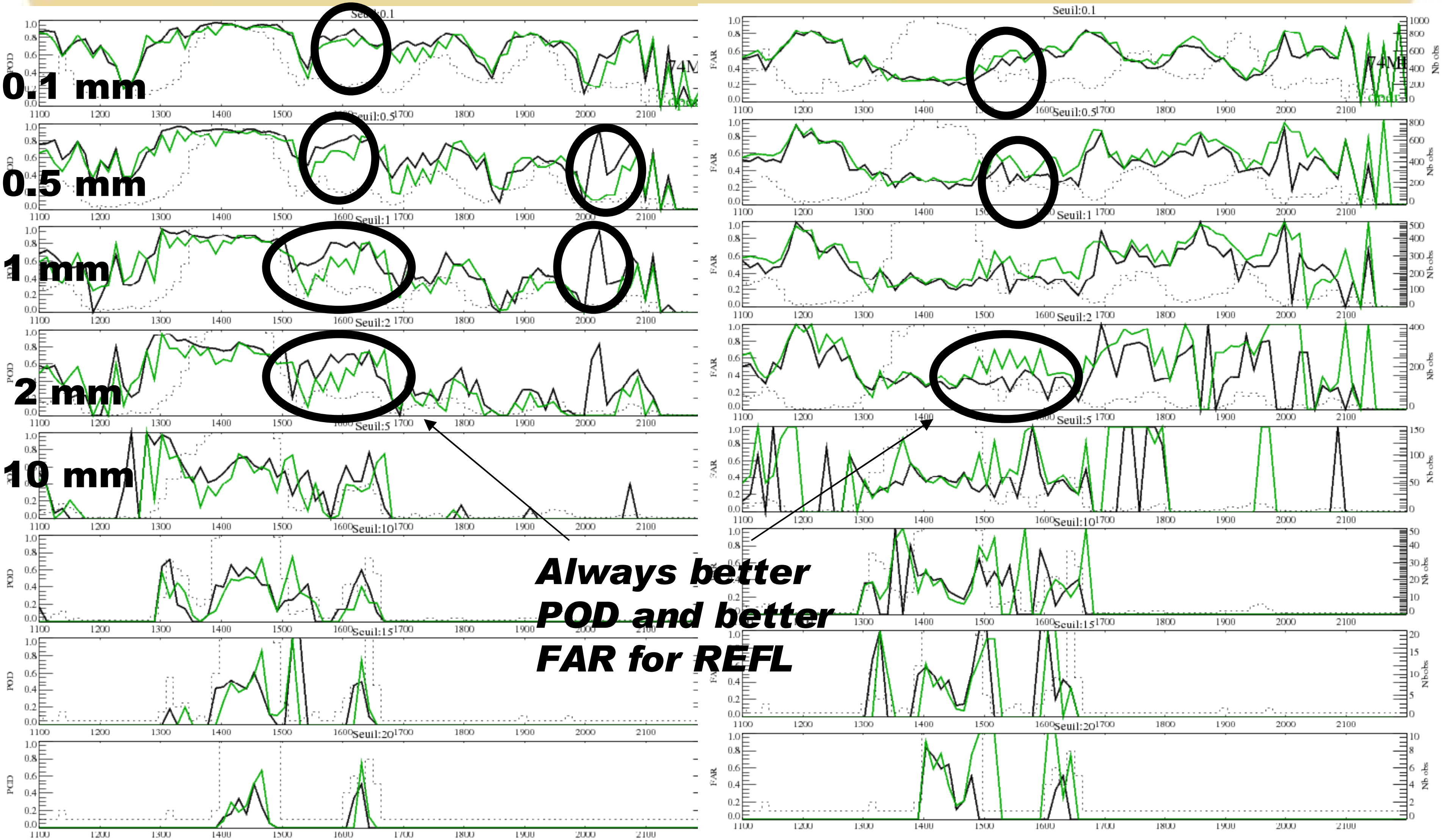
Better POD and FAR for REFL



Analysis increments: behavior through the short-term forecasts (over 1,5 month)



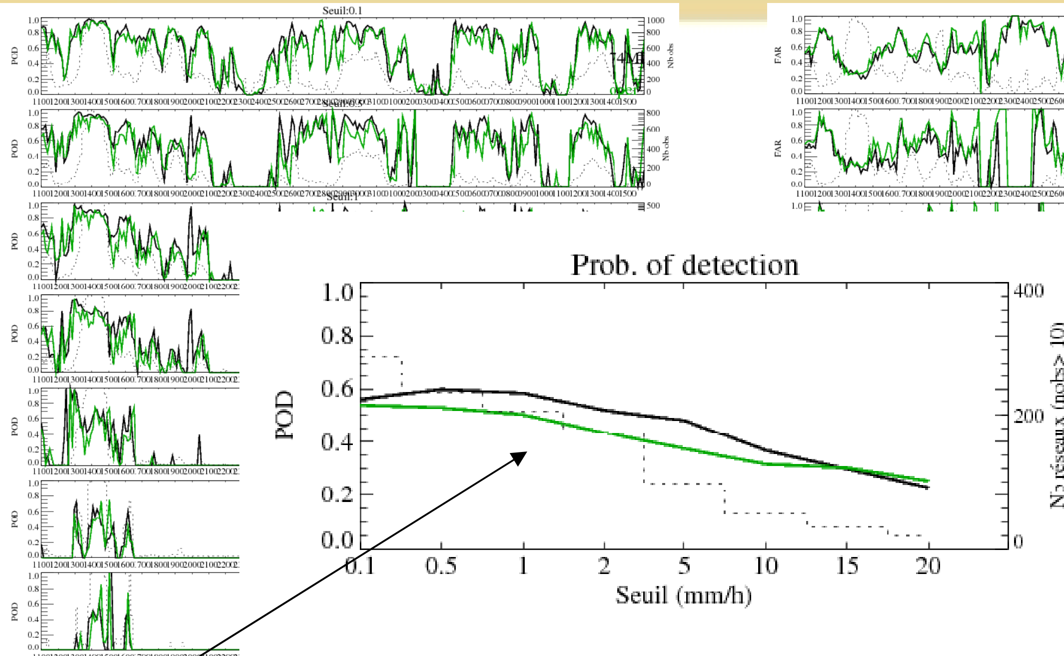
QPF evaluation: Good detection/False Alarme…

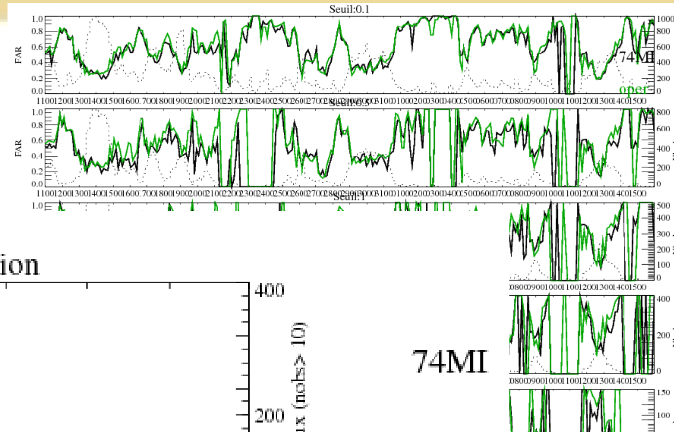


OPER ***REFL***

METEO FRANCE
Toujours un temps d'avance

QPF evaluation: POD/FAR: average on 2 month…





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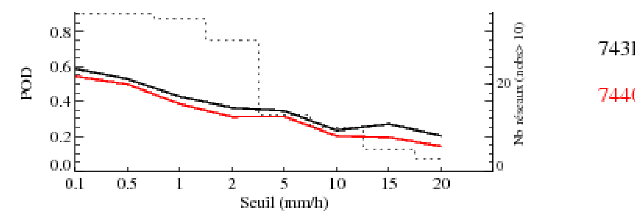
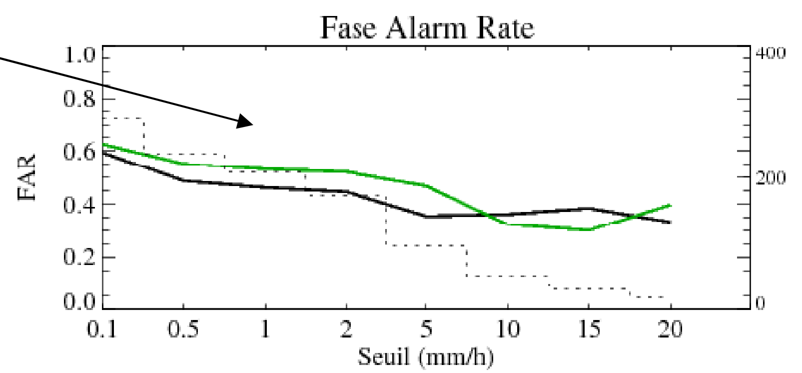
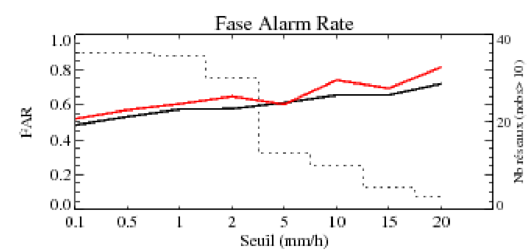
Over august/september 2008 – 6 hour forecast



REFL always better

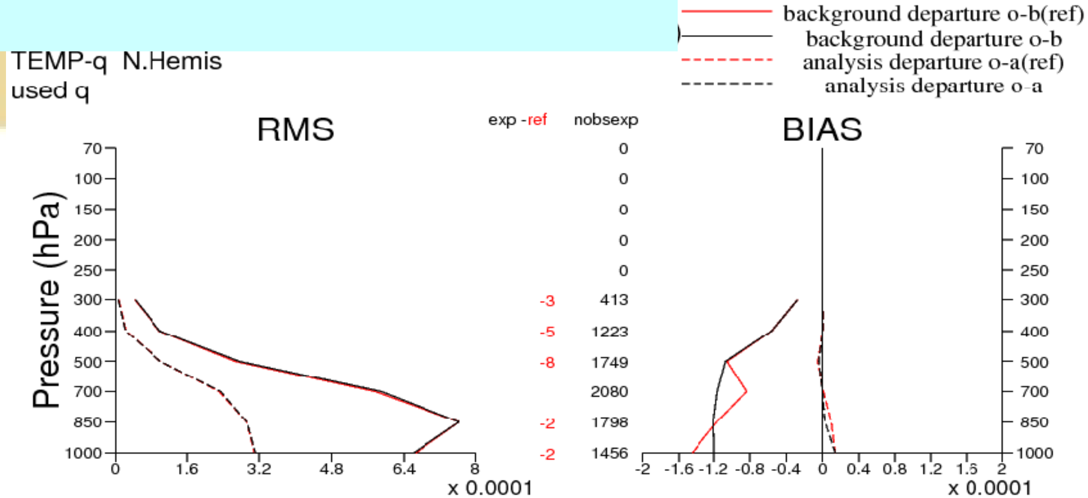




OPER ***REFL***

METEO FRANCE
Toujours un temps d'avance

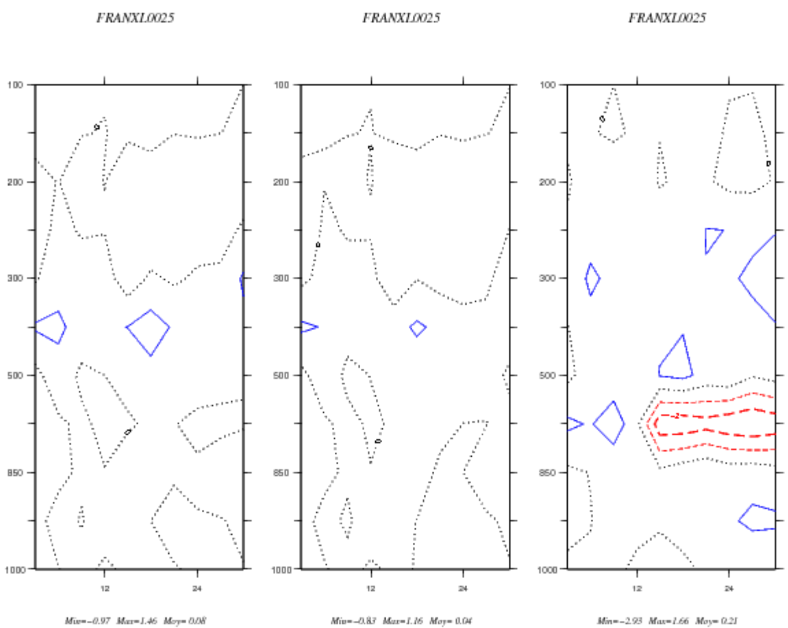
Humidity: difficult to validate with conventional data…



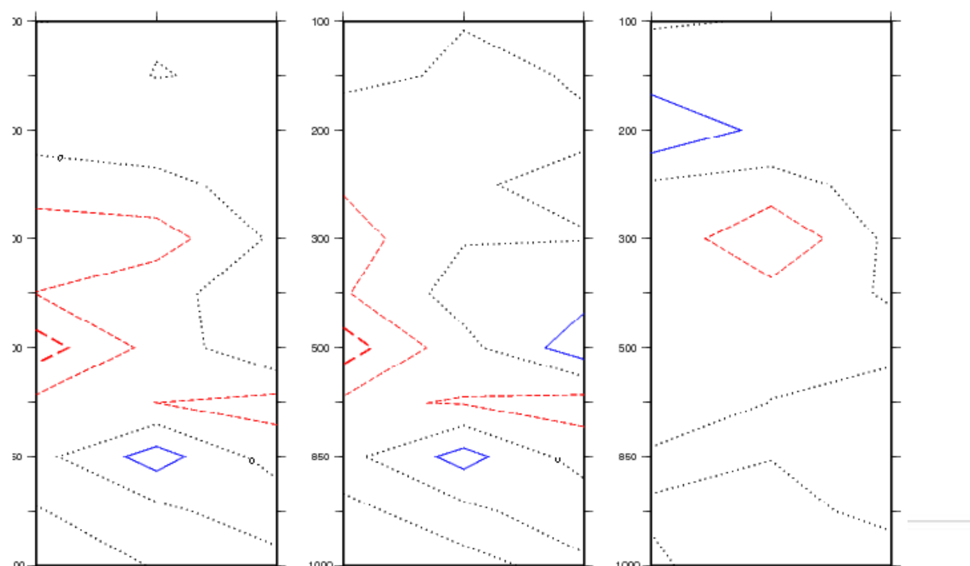
Scores with respect to own analysis, 12h-forecast

10 simulations (500 hPa) de 30 h du 20081211 au 20081221

EQM **StD** **|biais|**

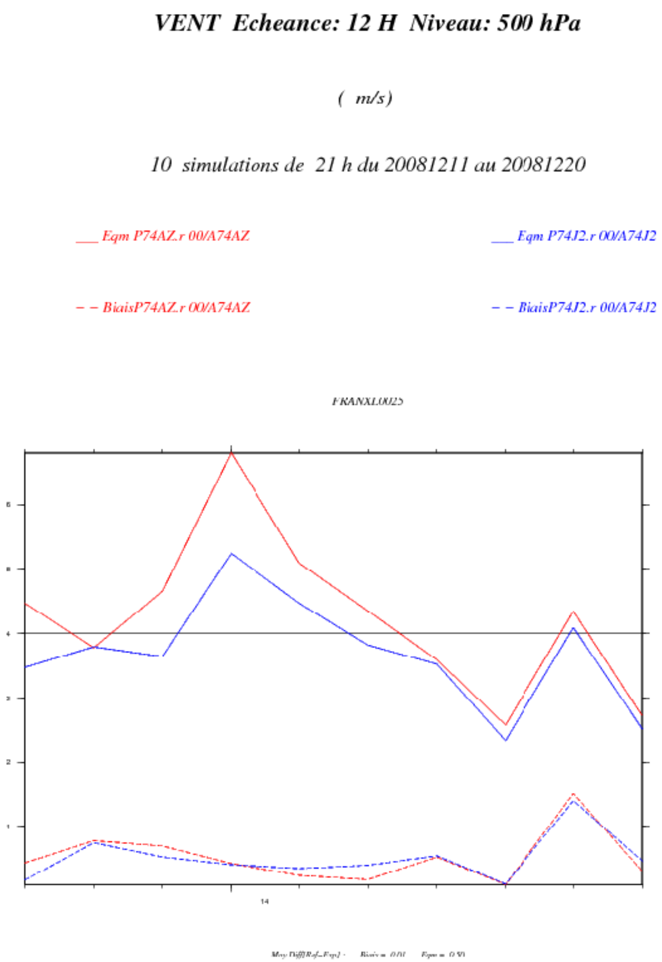


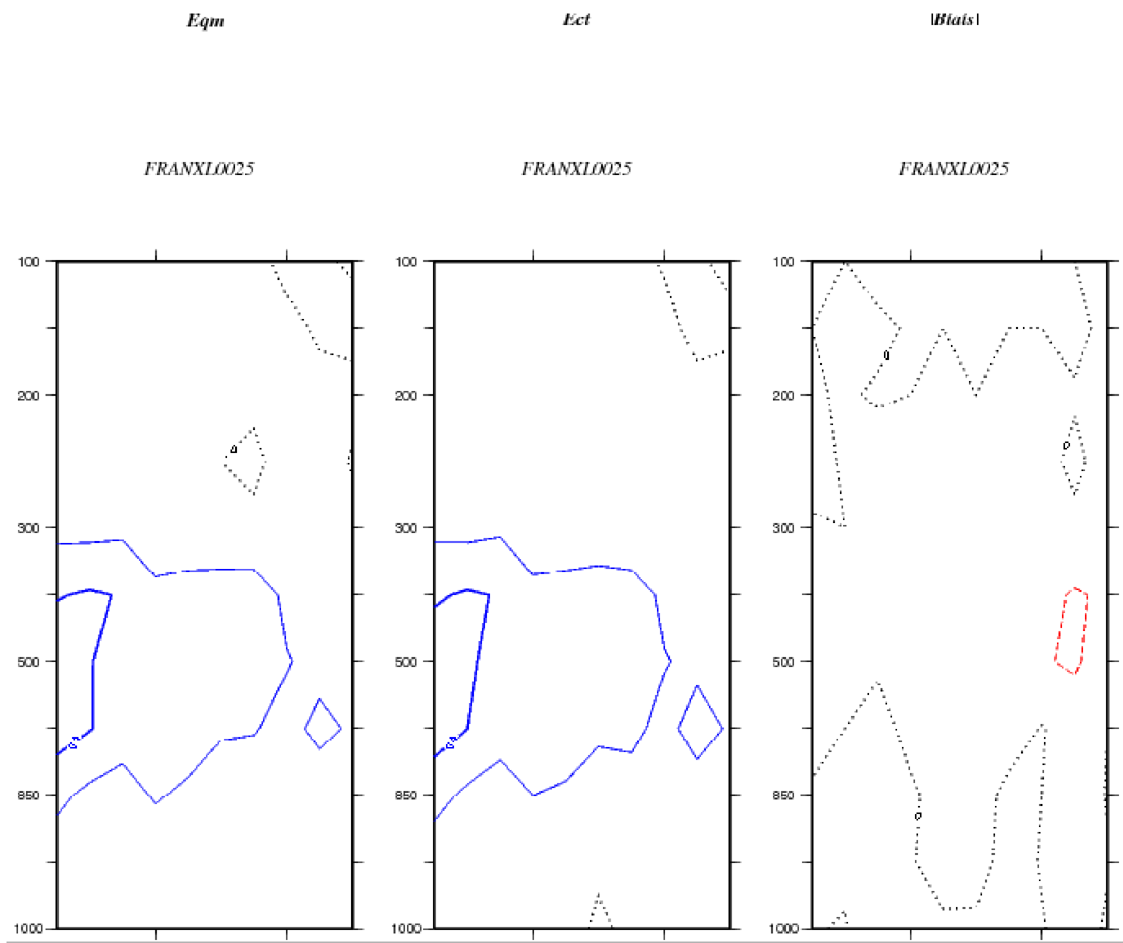
Scores with respect to RS, 12h-forecast



But good impact on wind field

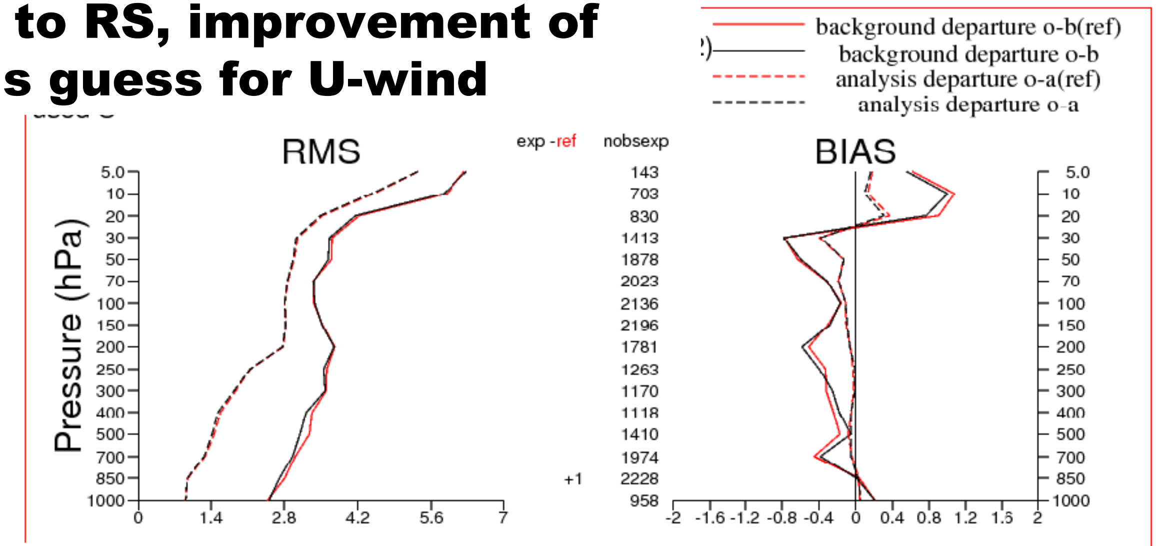
With respect to RS, 24-forecast minus RS difference



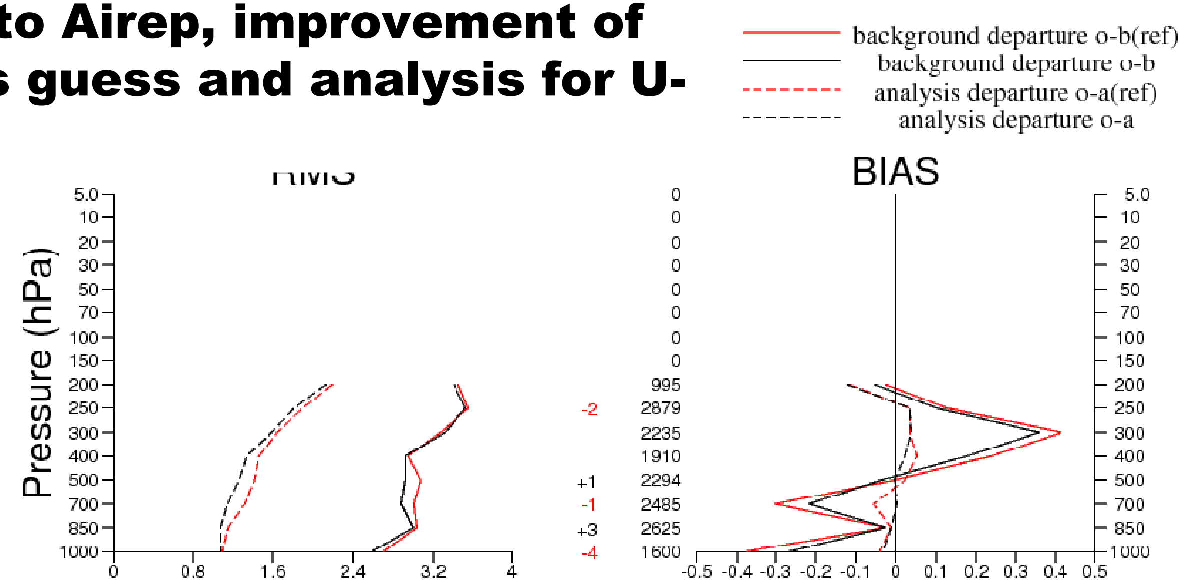


Good impact on wind scores

With respect to RS, improvement of the obs minus guess for U-wind



With respect to Airep, improvement of the obs minus guess and analysis for U-wind



Conclusion

- Sensitivities studies (thinning, observation error…) have shown robust results of the 1D+3DVar method

- But importance of a specific quality control and no-rain signal in particular for convective situations (check of the 1D convergence)

- Assimilation of reflectivities have been tested over two long periods (2 months last winter and 1.5 month last summer): systematic good QPF scores until 12hour forecast, reliable subjective scores on case studies, relatively neutral classical scores (positive impact on wind).

Perspectives of reflectivities assimilation

- work is underway to incorporate reflectivities into the second operational version of AROME

- work to optimize assimilation of both radar winds and reflectivities together (not shown but less fit to radar winds with reflectivities)

- Test of the impact of the use of a flow-dependency B matrix or a clear sky/rainy B matrix

CE
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Bibliography

❑ Caumont O, V. Ducrocq, G. Delrieu, M.Gosset, J-P. Pinty, J. Parent du Châtelet, H. Andrieu, Y. Lemaître, and G. Scialom, 2006: A radar simulator for high resolution Non-hydrostatic Models, *journal of Atmospheric and Oceanic Technology,* Vol. 23, 1049-1067.

❑ Caumont O, E. Wattrelot, V. Ducrocq, G. Jaubert, F. Bouttier: First results of 1D+3DVar assimilation of radar reflectivities: *Proc. ERAD 2006,* Barcelona, 539

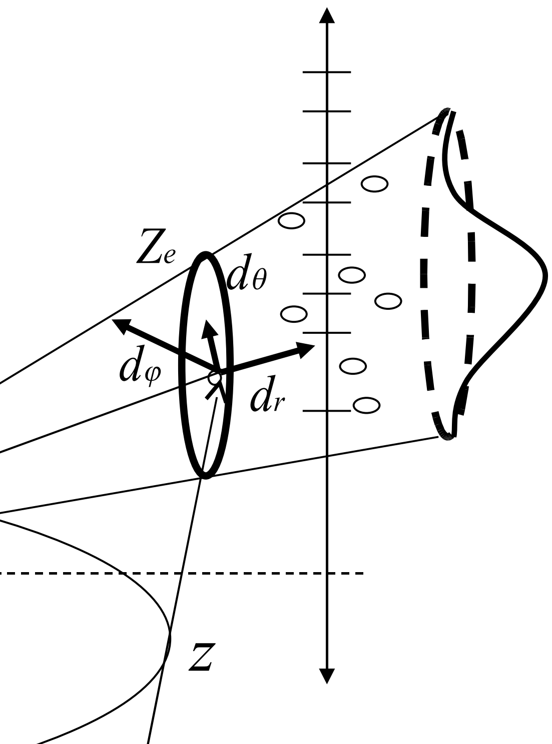
❑ Caumont, O., 2007 : Simulation et assimilation de données radar pour la prévision de la convection profonde à fine échelle. Thèse de l'Université de Toulouse, 252 p

❑ Montmerle, T_and C. Faccani, 2008: Mesoscale assimilation of radial velocities from Doppler radar in a pre-operational framework*. Mon. Wea. Rev, in press*

❑ Wattrelot E., O. Caumont, S. Pradier-Vabre, M. Jurasek and G. Haase, 2008: 1D+3Dvar assimilation of radar reflectivities in the pre-operational AROME model at Météo-France *Erad2008, Helsinki (Finland)*

Reflectivity Observation operator

(Caumont & al. 2006)



- Bi-linear interpolation of the simulated hydrometeors *(T,q, q_r, q_s, q_g)*
- **Compute radar reflectivity** on *each model level*

$$\eta(r) = \sum_{j=rain,snow...} \int_0^{\infty} \sigma j(D,r).Nj(D,r)dD$$

Backscattering cross section: Rayleigh (attenuation neglected)

Microphysic Scheme in AROME

Diameter of particules

- **Simulated Reflectivity factor in « beam volum *bv*»**

$$Z_e = 10\log\left(\int_{bv} \eta(r).f^4(\theta,\varphi).dr.d\theta.d\varphi\right)$$

Resolution volum, ray path: standard refraction (4/3 Earth's radius) and gate length is 250m, smaller than model resolution

Antenna's radiation pattern: gaussian function for main lobe (side lobes neglected)

Problematic of « no-rain » signal : is it sufficient to take into account the threshold of detection to well characterize the « no-rain » signal?

Problematic:

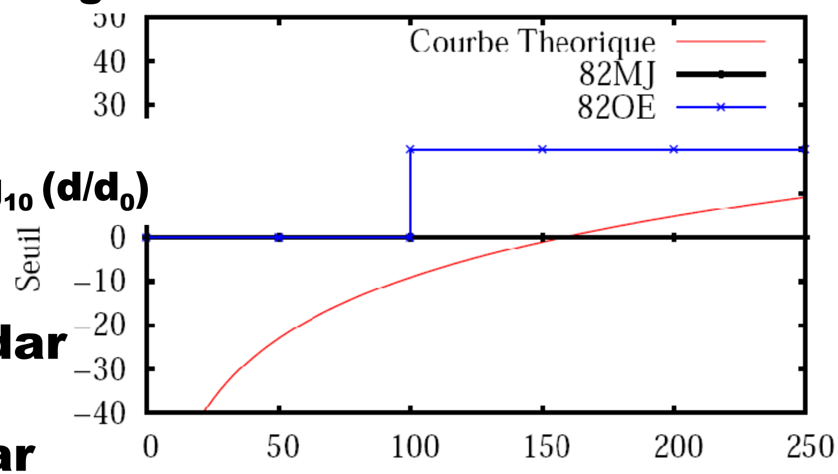
- **if the SNR (signal-noise-ratio) is very low (bad quality of the radar or very far away from the radar), there is a high probability to dry with pixels below the noise but rainy !!**

- **But we know the noise, so we can … take into account (in the 1D method) the threshold of detection for each pixel of each radar in order to not dry the model below this value : but is it sufficient?**

Use only $ZZ_{SIM} > ZZ_{THR}$ and (Z

- **Sensibilities studies have been done by deterioration of one radar**

Threshold of detection, function of range



Range from the radar

$Z\ (dBZ) = +\ 20 \log_{10}(d/d_0)$

good radar

bad radar