A mesoscale data assimilation system for operations : the AROME RUC

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METEO FRANCE
Toujours un temps d'avance

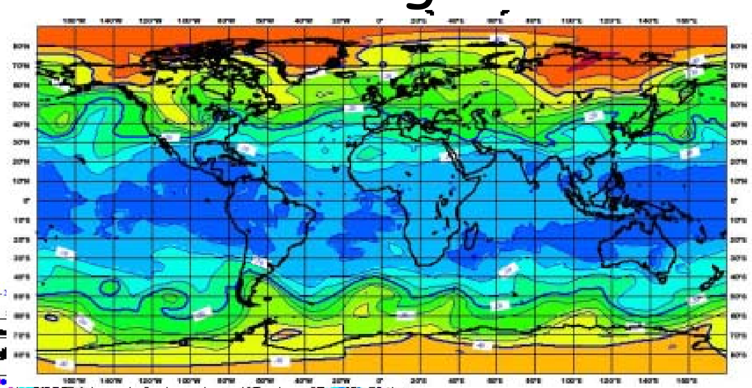
Outlines

- General ideas on data assimilation
- The AROME data assimilation system
- Background-error Statistics
- Assimilation experiments

General ideas : data assimilation in meteorology

- Analysis : production of an accurate image of the true state of the atmosphere at a given time :
  - comprehensive and self-consistent diagnostic of the atmosphere (ex : re-analysis)
  - Initial state for numerical weather forecast
- Using different informations :
  - Observations of the true state
  - A priori estimate of the model state : a short-range forecast, the background

background x^b



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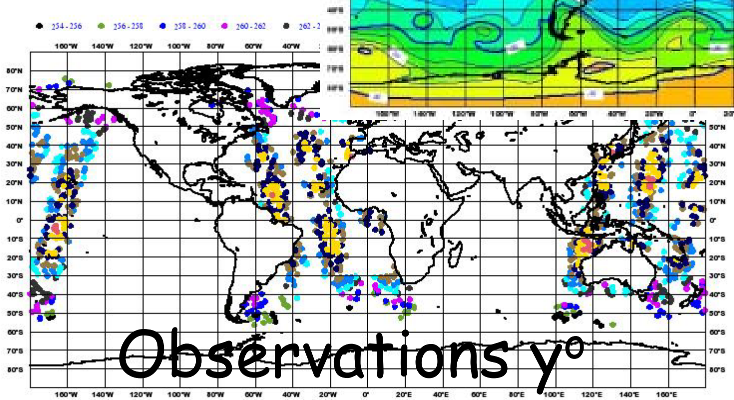
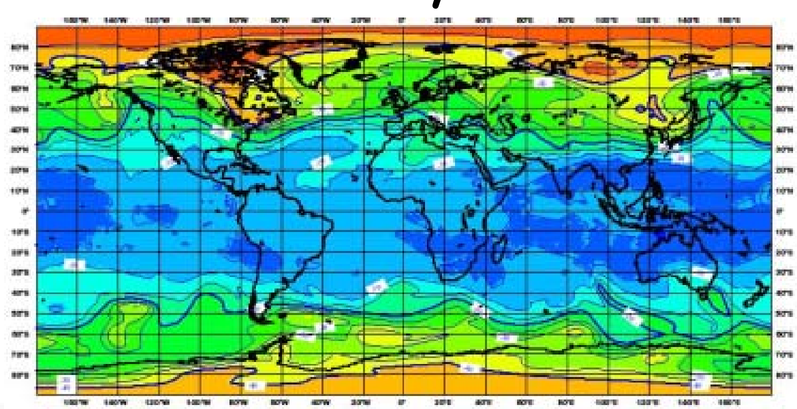
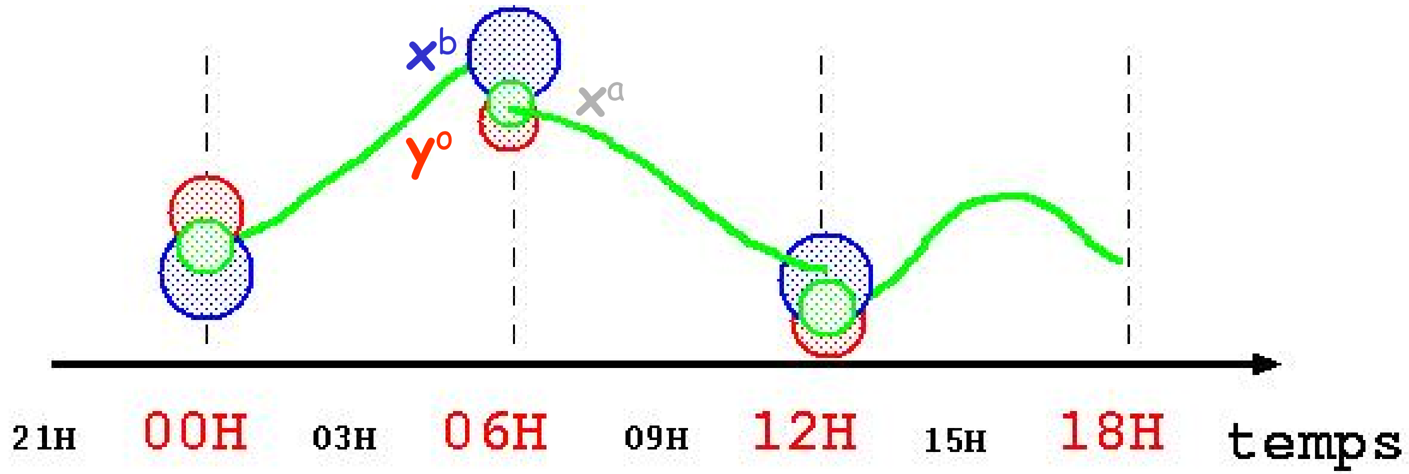


Observations y^o

Analysis x^a



General ideas : the Kalman filter



- Uncertainty in the background x^b and the observations y^o is represented by errors, background errors and observations errors, of covariances noted **B** and **R** respectively.
- The analysis is an optimal combination of the background and observations, also characterised by analysis errors.

General ideas : the BLUE

- The Best Linear Unbiased Estimate :

$$\mathbf{x}^a = \mathbf{x}^b + \mathbf{dx}$$
$$= \mathbf{x}^b + \mathbf{K}\,(\mathbf{y}^o - \mathit{H}(\mathbf{x}^b))$$

with
$\mathbf{d} = \mathbf{y}^o - \mathit{H}(\mathbf{x}^b)$, difference between observations and background called *innovation,*
$\mathbf{K} = \mathbf{BH}^T\,(\mathbf{HBH}^T+\mathbf{R})^{-1}$, optimal weighting between $\mathbf{x}^b$ et $\mathbf{d}$ called *gain matrix.*

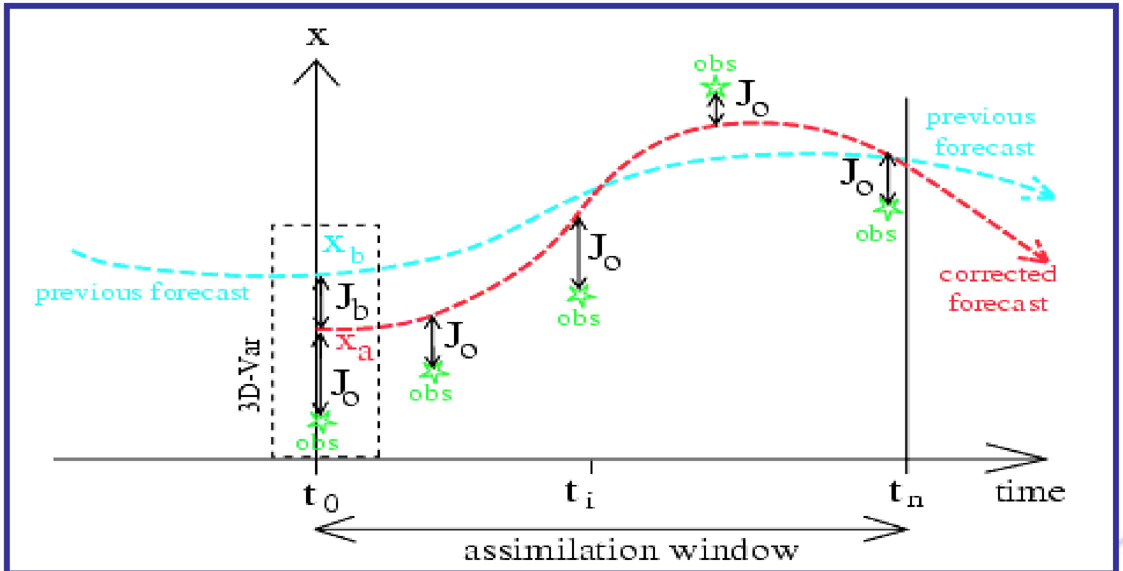
H : observation operator and **H** linear observation operator.

General ideas : variational formulation

- Variational formulation : minimisation of the cost function

$$J(dx) = J_b(dx) + J_o(dx)$$
$$= dx^T B^{-1} dx + (d - H\,dx)^T R^{-1} (d - H\,dx)$$

  - 3D-Var : no temporal dimension in H
  - 4D-Var : *H* generalized to include a forecast model.
  - 3D-FGAT : temporal dimension only in the calculation of **d**



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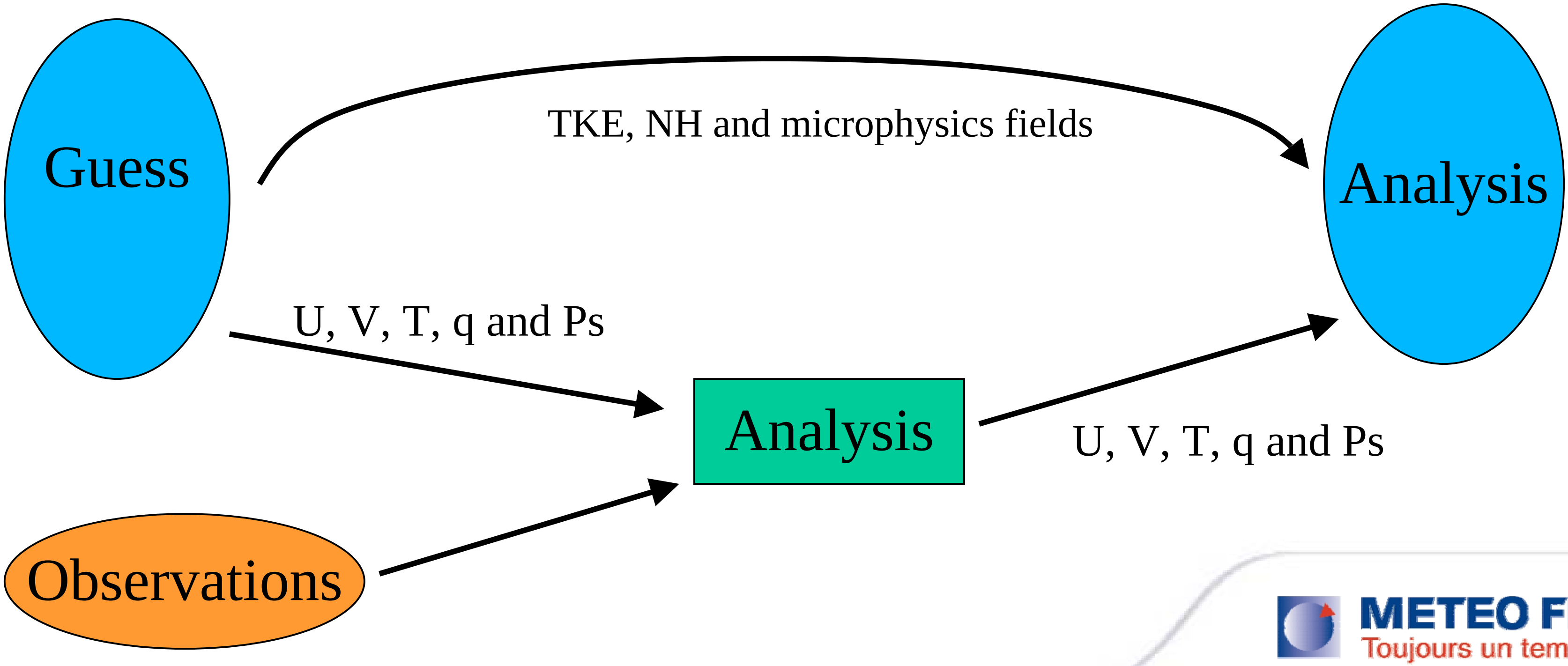
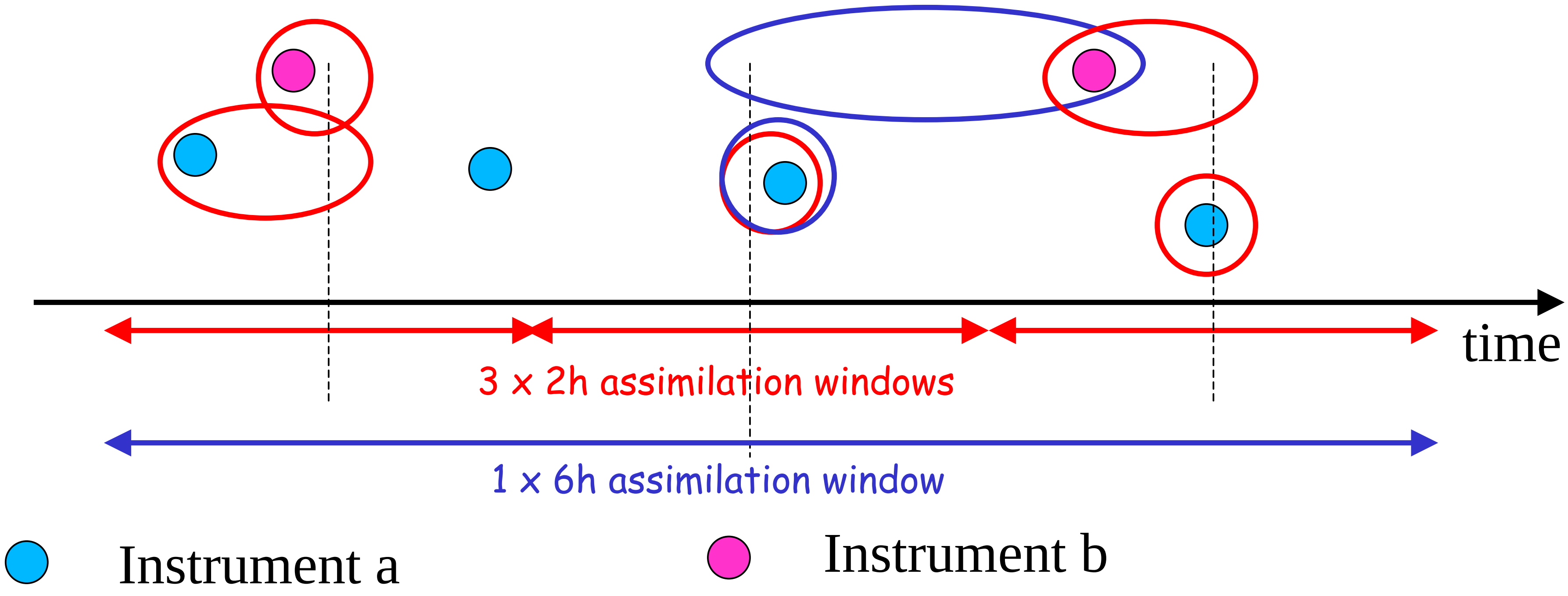
- **The AROME data assimilation system**
- Background-error Statistics
- Daily runs

Assimilation scheme

- Based on the ALADIN-FRANCE 3D-Var scheme (Fisher et al. 2005) :
  - ✓ 2 wind components, temperature, specific humidity and surface pressure are analysed at the model resolution (2.5 km).
  - ✓ Others model fields (TKE, Non-hydrostatic and microphysics fields) are cycled from the previous AROME guess



Assimilation window

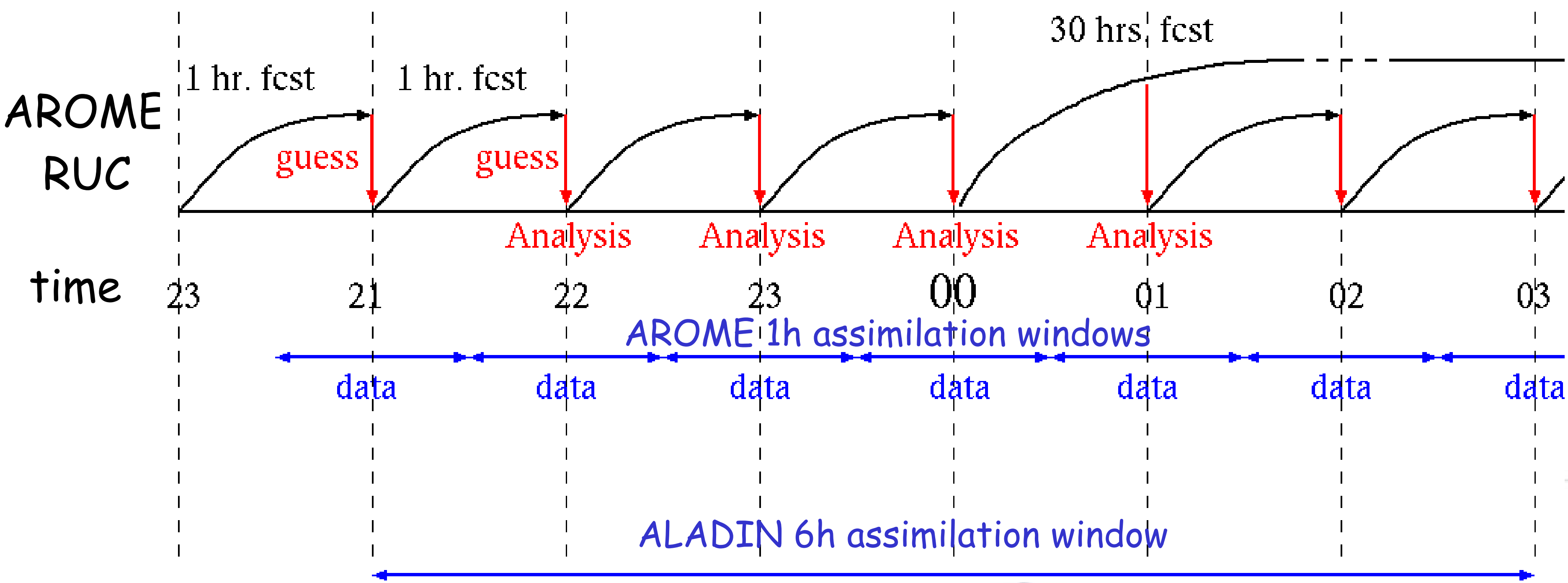


- 3D-Var : short and numerous assimilation windows = more observations assimilated in a more realistic way

Rapid Update Cycle

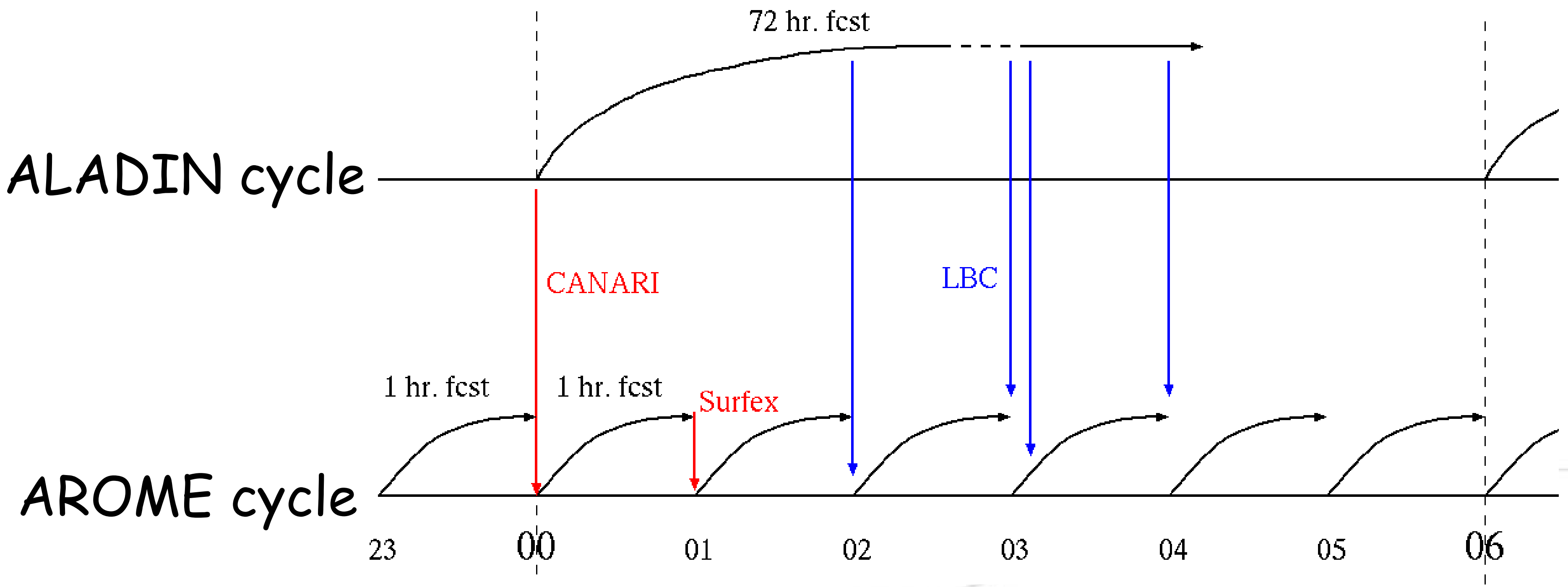
- Idea :
  - ✓ Forecasts initialized with more recent observations will be more accurate
  - ✓ Using high temporal and spatial frequency observations (RADAR measurements for example) to the best possible advantage

Use of a Rapid Update Cycle (Benjamin et al. 2004) in order to compensate the lack of temporal dimension in the 3D-Var



Rapid Update Cycle (2)

- Lateral boundary conditions provided by the ALADIN-FRANCE operational suite.
- Surface conditions provided by :
  - The CANARI analysis (OI) from the ARPEGE operational suite at 00, 06, 12 and 18 UTC
  - Otherwise the previous AROME forecast



Model noise

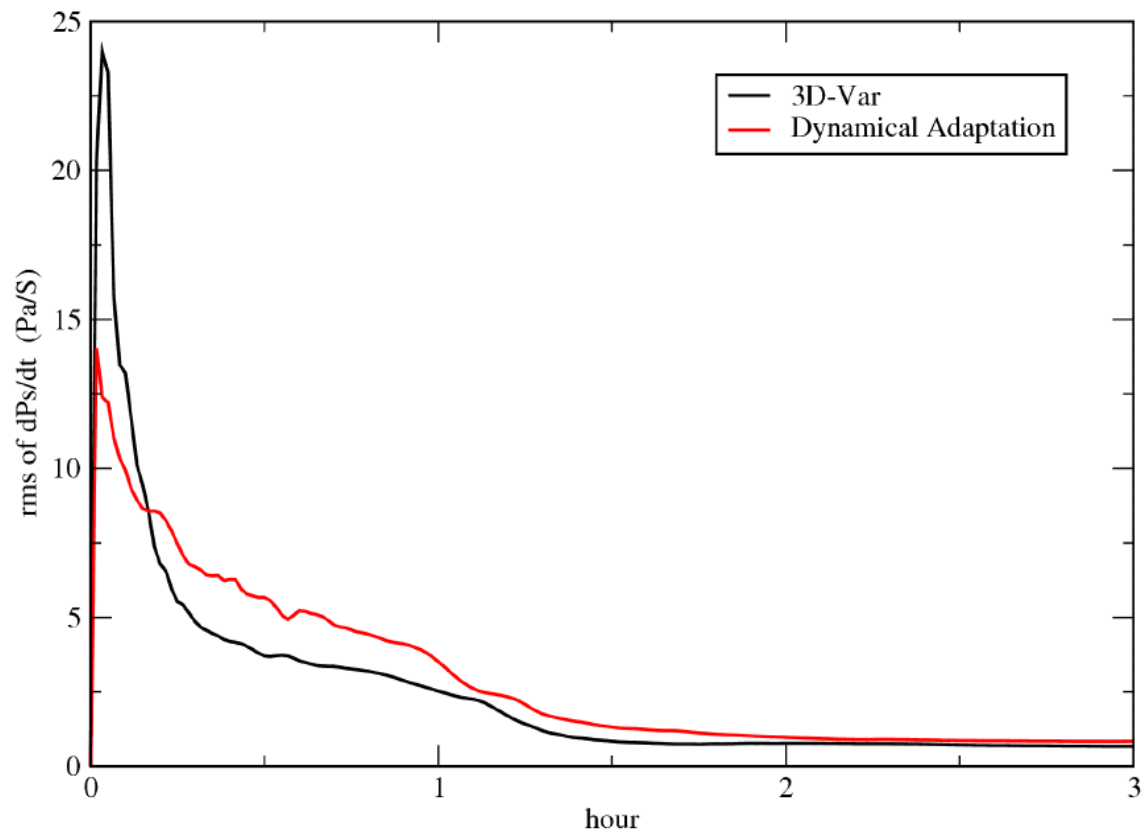
- Risk to accumulate noises and imbalances through cycling.

- model noise is substantially reduced at the 3-h output time but not at 1-h.

- The use of a method (IDFI) to filter those spurious waves has to be considered in a 1-h RUC : not yet implemented

- Only the 3-h RUC is used

Temporal evolution of RMS of surface pressure tendency



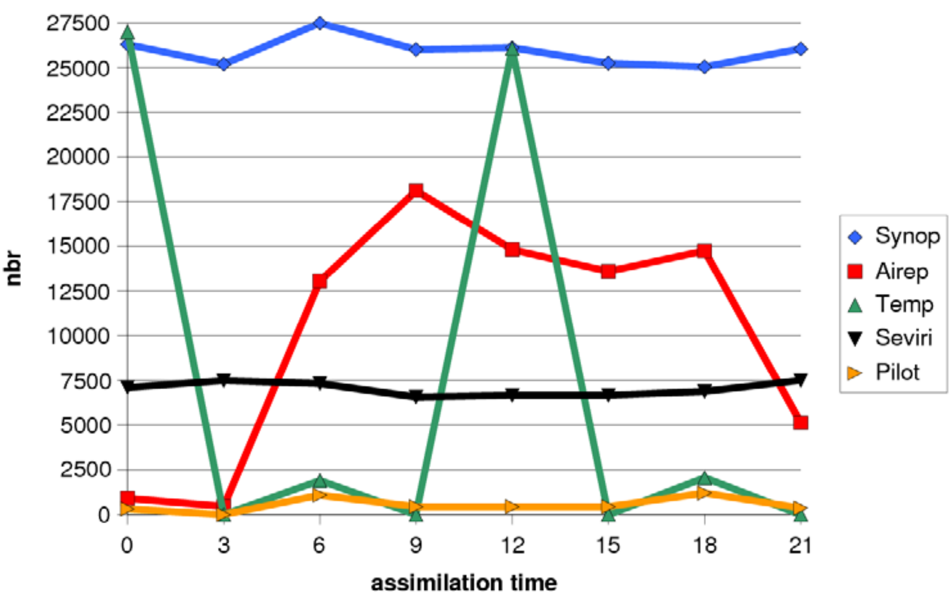
Observations

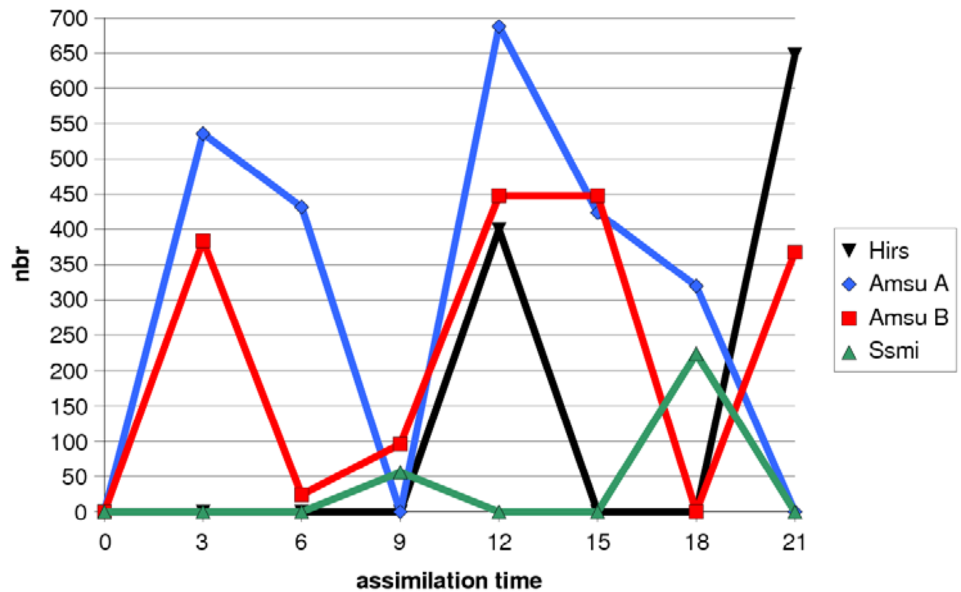
- Same observations as in ALADIN-France operational suite : conventional observations, 2m temperature and humidity, IR radiances from ATOVS and SEVIRI instruments, winds from AMV and scatterometers, ground based GPS among others.
- No specific spatial selection (thining) appropriate to AROME resolution. Studies on this topic still are ongoing (plane measurements, IR radiances…)
- Works are currently in progress about the use of other types of observations with higher spatial and temporal resolutions such as RADAR winds and reflectivities (see also the presentation of E. Wattrelot)

Observation number

- The number of observation depends on the assimilation time (radiosondes,…)
- SYNOP, plane measurements and SEVIRI radiances are of great interest to supply the data assimilation system.

25 november 2007





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Background error statistics

- Background-error statistics determine how observations modify the background to produce the analysis, filtering and propagating innovations.

$$\mathbf{x}^a = \mathbf{x}^b + \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T+\mathbf{R})^{-1}\,\mathbf{d},$$

- **B** should contain some information about the uncertainty of the guess, which depends on the meteorological situation of the day (flow and initial conditions).

- To determinate this uncertainty is a major problem in data assimilation

Documentation of **B**

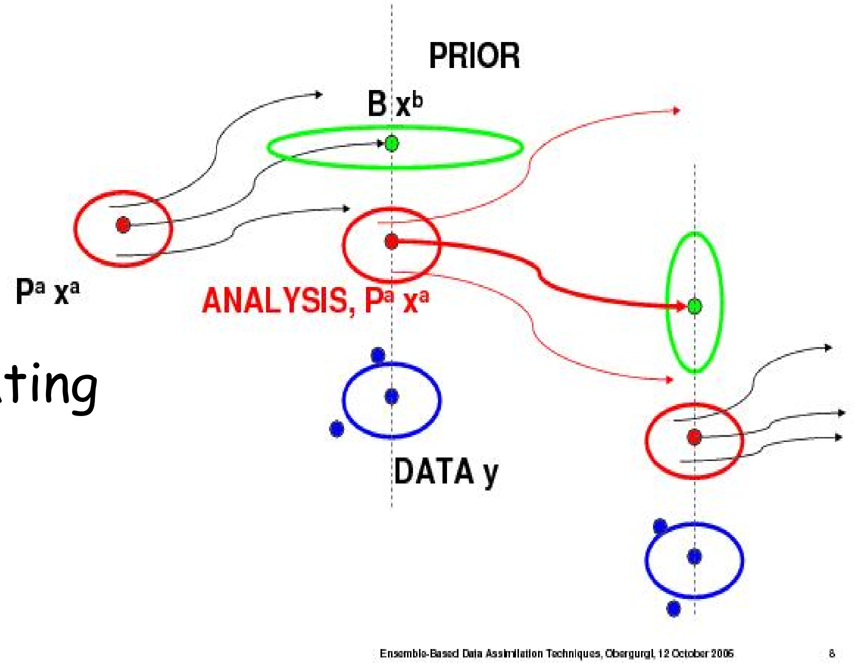
- Statistics on innovations (difference between background and observations)

- ensemble-based assimilation :

Perturbations on observations

-> perturbations on ε^a and ε^b, simulating

background and analysis error.



- Documentation of B

– « climatological » B over a long period,

– B « of the day » ?

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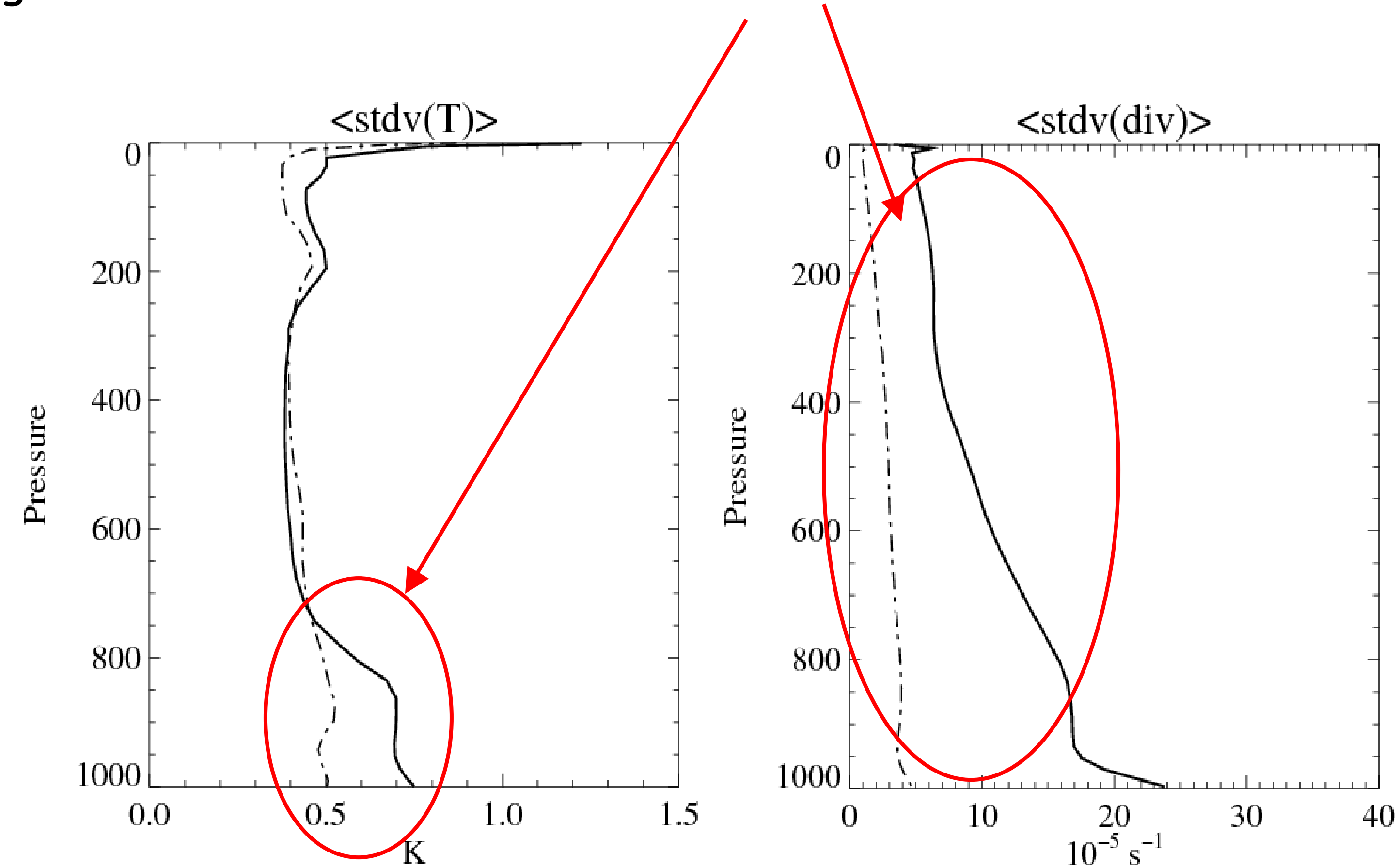
Background-error statistics for AROME

- Background-error statistics for AROME share the same multivariate formulation as in ALADIN-FRANCE (Berre 2000). This formalism uses errors of vorticity, divergence, temperature, surface pressure and humidity, with scale-dependant statistical regressions to represent cross-covariances.
- calculated using an ensemble-based method (Berre et al. 2006), with a six member ensemble of AROME forecasts in spin-up mode carried out over two 15-day periods :
  - Anticyclonic winter
  - Convective summer
- Initial and lateral conditions are provided by a perturbed ARPEGE/ALADIN-FRANCE assimilation ensemble :

Background error statistics for AROME and ALADIN

- Background error standard deviation increase

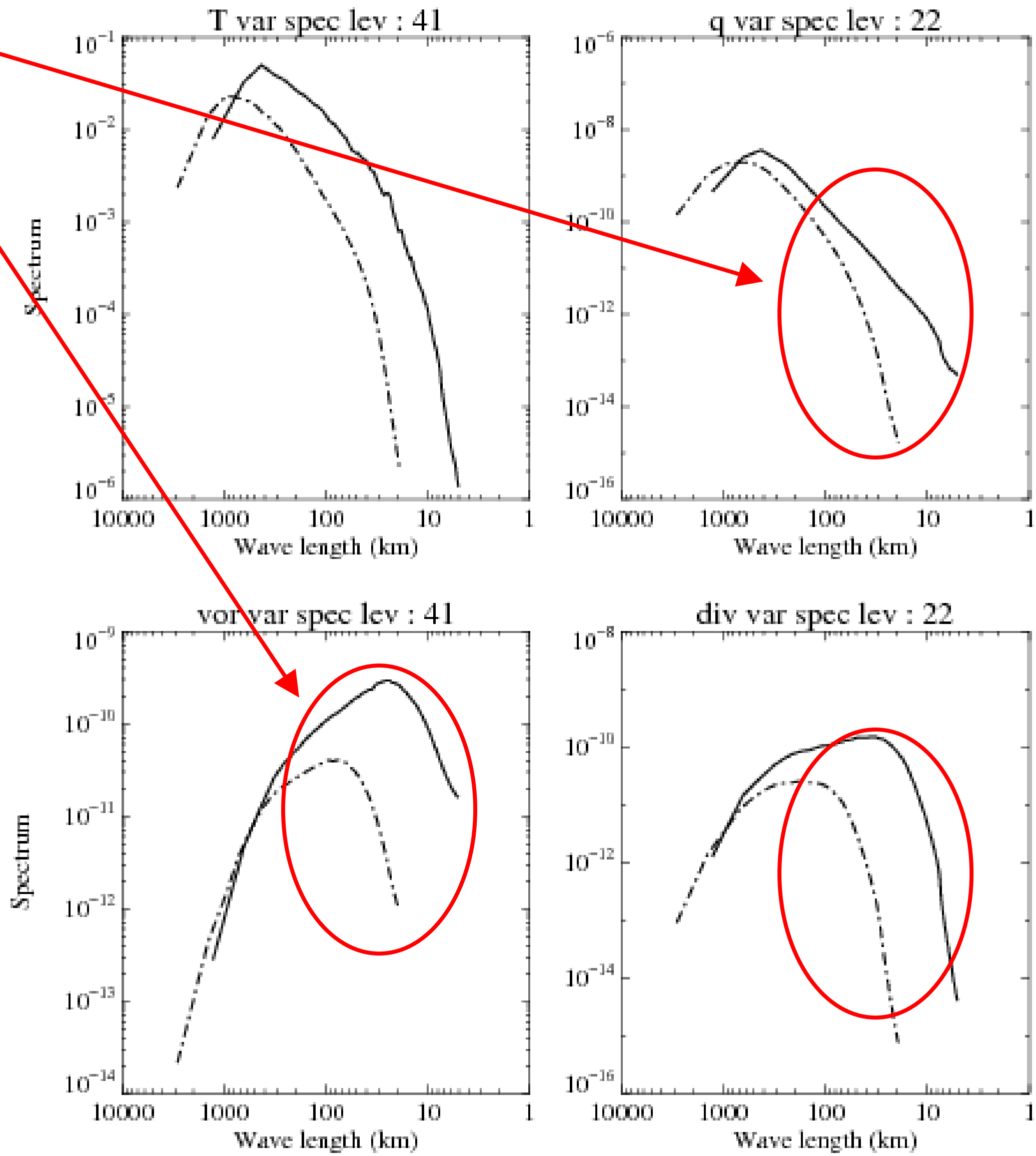


____ Arome

---- Aladin

Variance spectra

- This increase is higher for small scales
- consistent with the explicit representation of small scale structures in AROME, which are either unrepresented or numerically dissipated by ALADIN
- AROME guess will be more strongly modified



____ Arome

---- Aladin

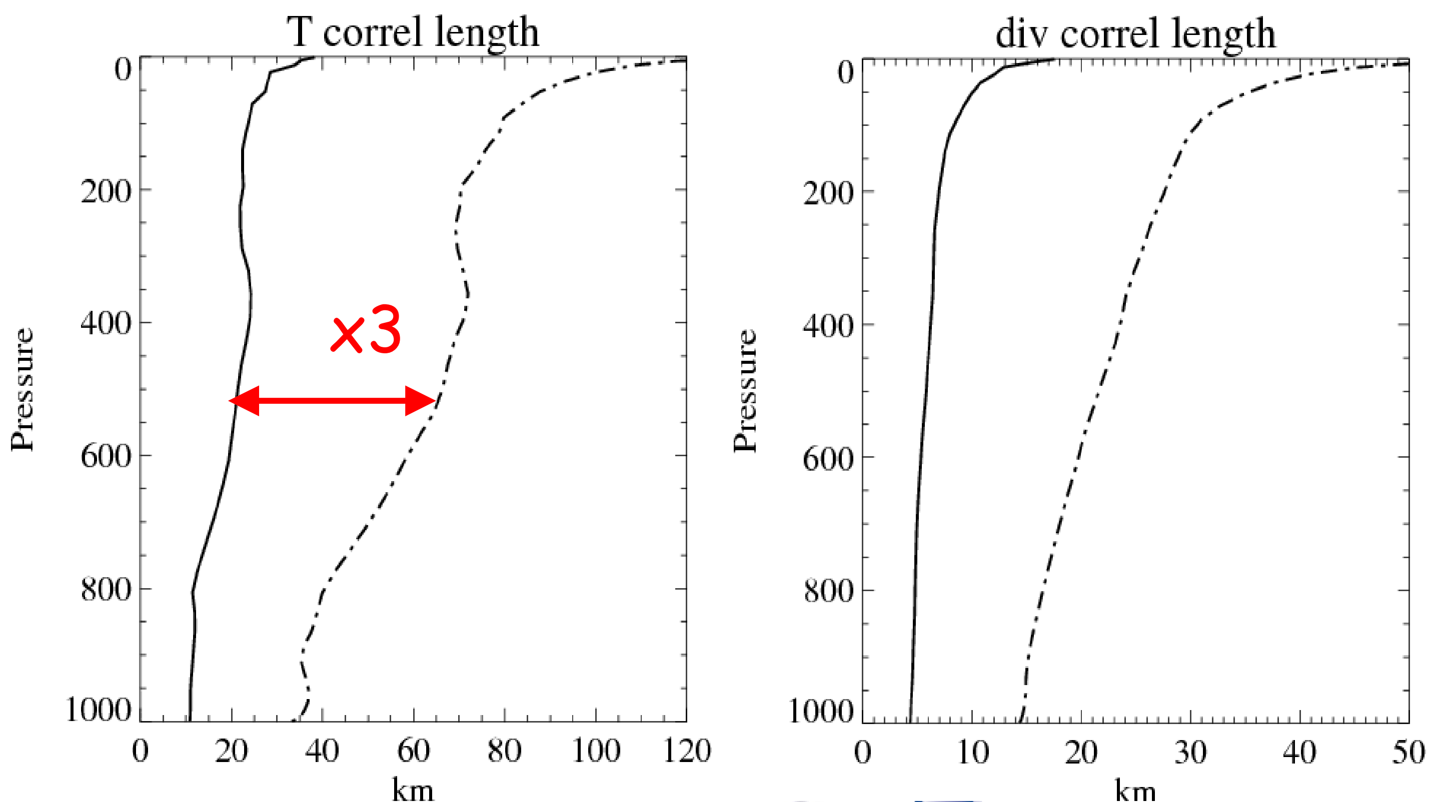
Horizontal correlation lengthscales

- Horizontal correlation lengthscales are smaller than in ALADIN : coherent with the change of domain and of resolution.

- AROME guess will be more locally modified

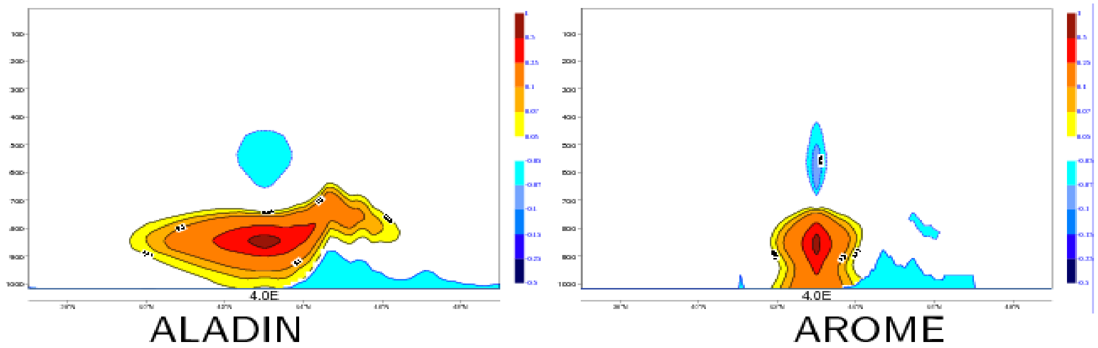
____ Arome

---- Aladin

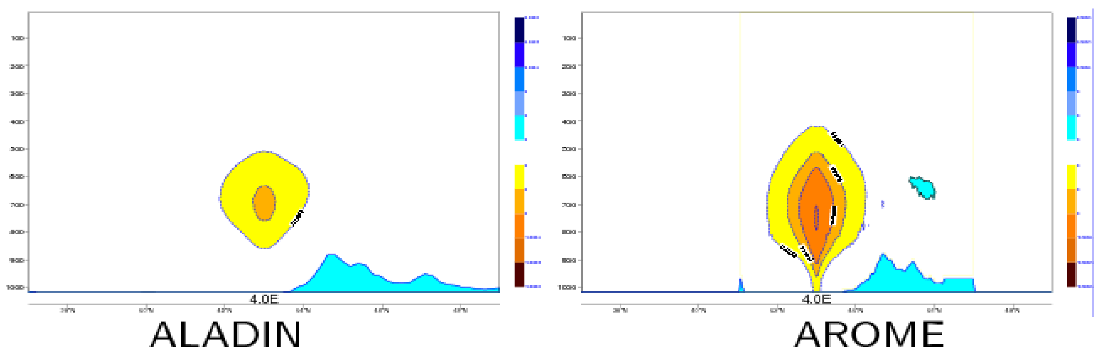


Single observation experiments

Single observation of temperature by radiosonde at 850 Hpa : temperature increment



Single observation of radiance by HIRS channel 15 : humidity increment



- To have an important influence, observation networks must have a good spatial coverage.

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Background error statistics : winter/summer

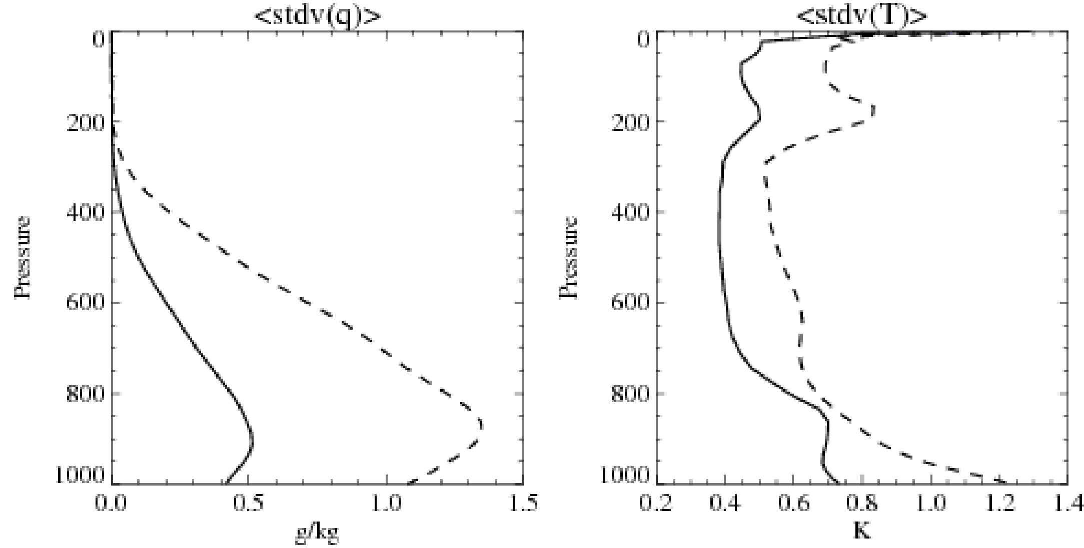
- Background error statistics depend on the meteorological situation: limitation of a “climatological” B matrix

- Use of statistics “of the day” ?

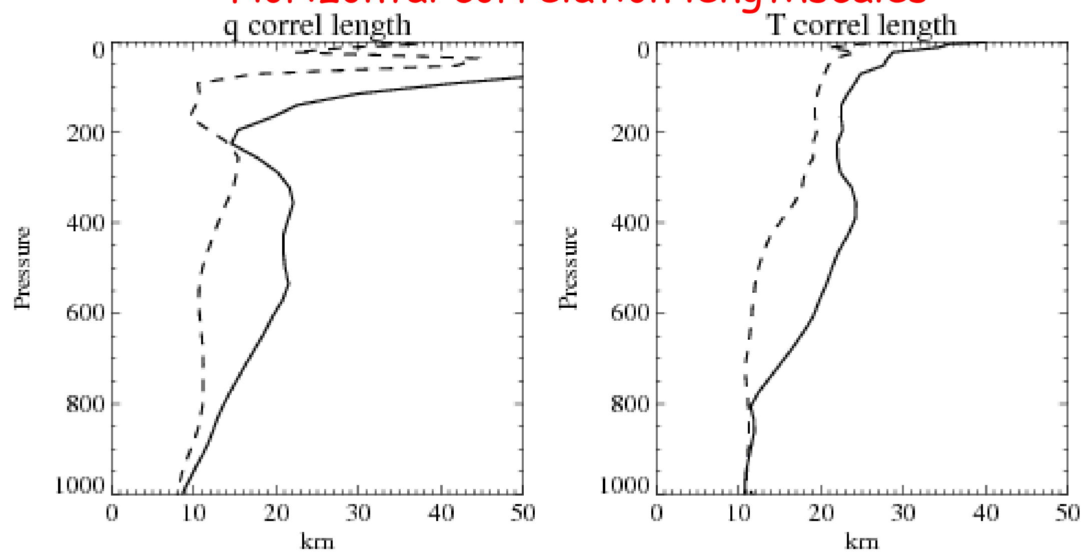
____ winter

---- summer

Background error standart deviation



Horizontal correlation lengthscales



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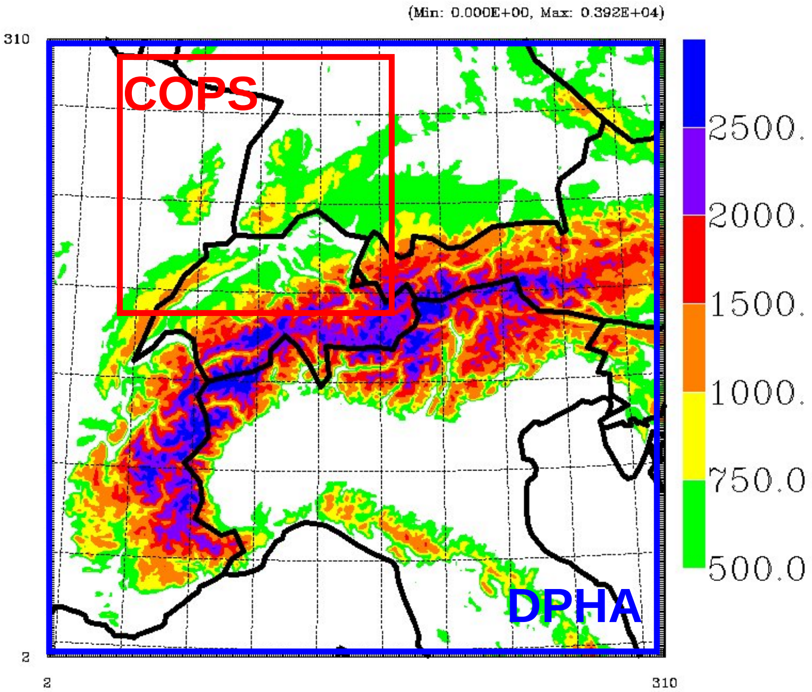
Assimilation experiments

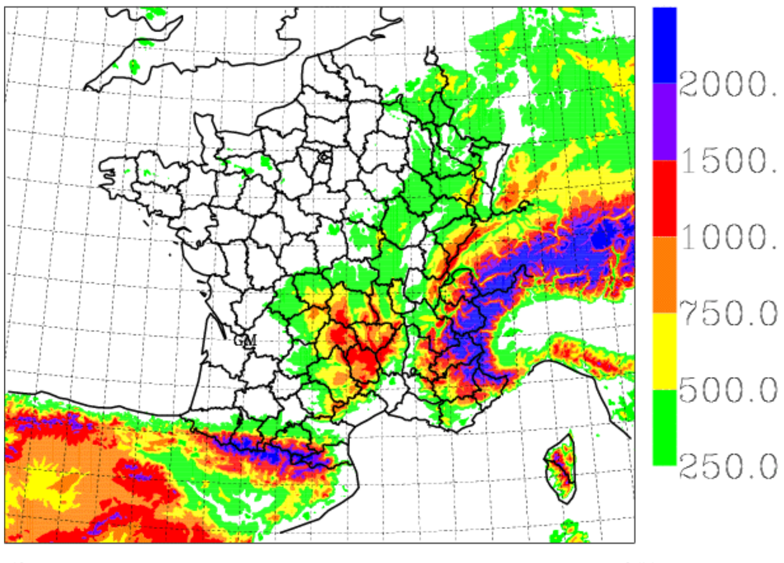
- This prototype of a data assimilation system for AROME has been first evaluated on different case studies (ALADIN newsletter number 30 (P. Brousseau and Y. Seity, 2006)). Encouraging results show its ability to improve analysis and forecasts.



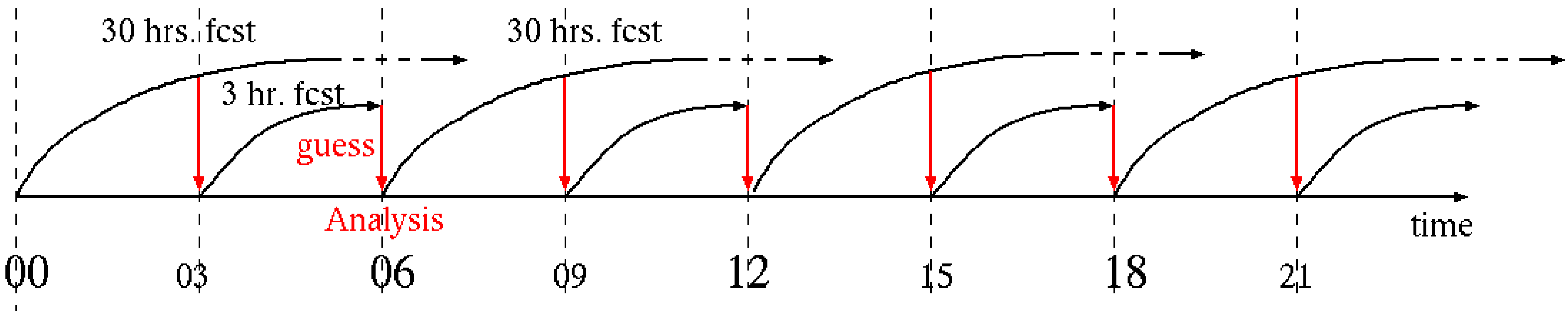
- The technical feasability of a pre-operational use has been also evaluated, simulating long period in a real time approch : daily runs performed in the framework of the MAP-DPHASE/COPS campaign over the alpine regions during summer 2007.

Daily runs

- Since October 2007, daily runs are performed in order to determine and to evaluate a pre-operational configuration.



- 1500 km * 1280 km domain
- 30-h forecasts at 00, 06, 12 and 18.
- Initial conditions provided by a 3-h continuous assimilation cycle.
- Lateral conditions provided by ALADIN-France operational suite



configuration

- use of a 4-h (resp. 5:30) cut off time at 00, 06, 12 and 18 (resp. 03,09,15 and 21) : 90 to 95 % of observations over France domain are available

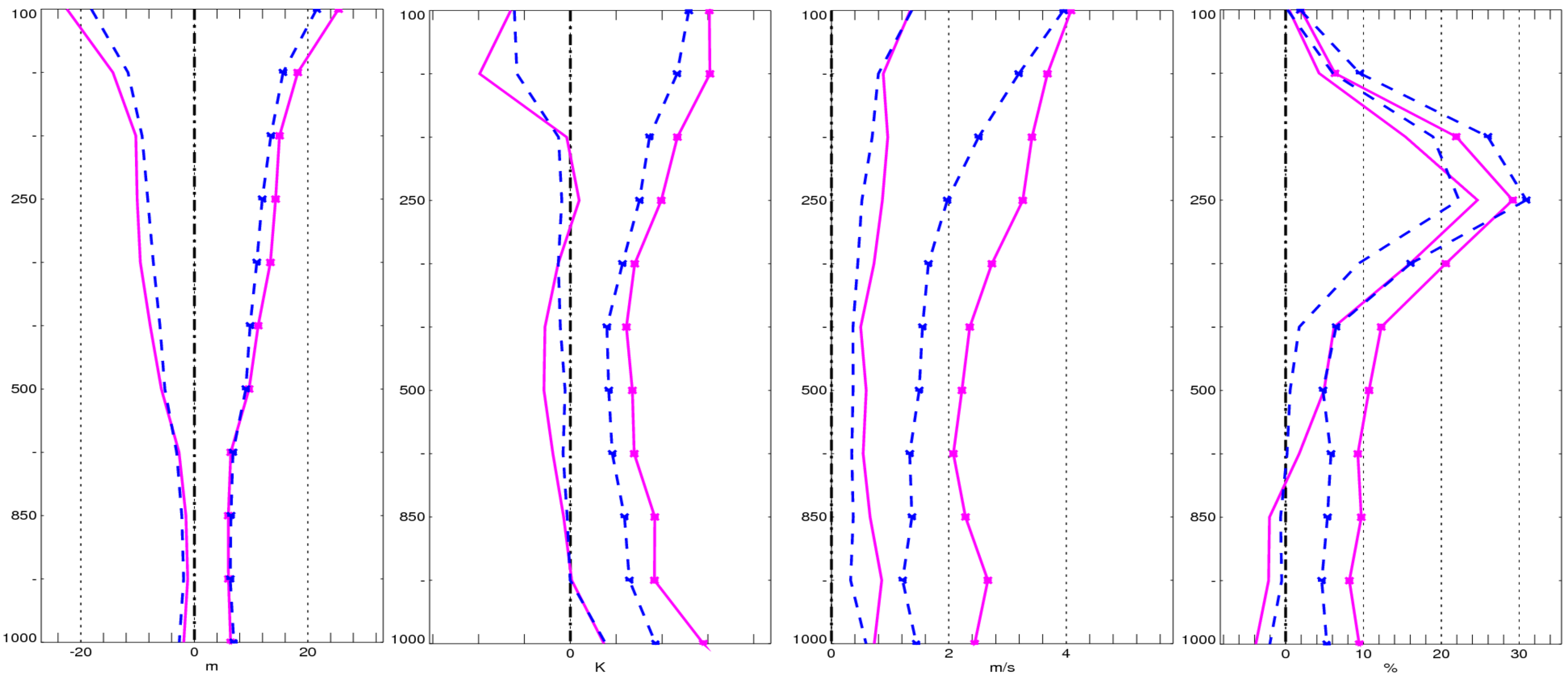
- Numerical cost on NEC sx8 :
  - Analysis : 20 min (elapsed time on 4 processors)
  - Coupling files : 1 min (2 processors) x 30 files
  - 30 hr forecast : 50 min (32 processors)
  - Post processing : 1 min (2 processors) x 30 files

- In order to evaluate AROME assimilation performances, a 30-h range forecast is performed using initial conditions provided by ALADIN analysis (spin-up mode) at 00 UTC.

Objective scores : analysis compared to radiosonde

- Analysis from the AROME RUC compared to ALADIN analysis show an important reduction of Root Mean Square Error for all parameters all over the troposphere except for the humidity field around 200 hPa

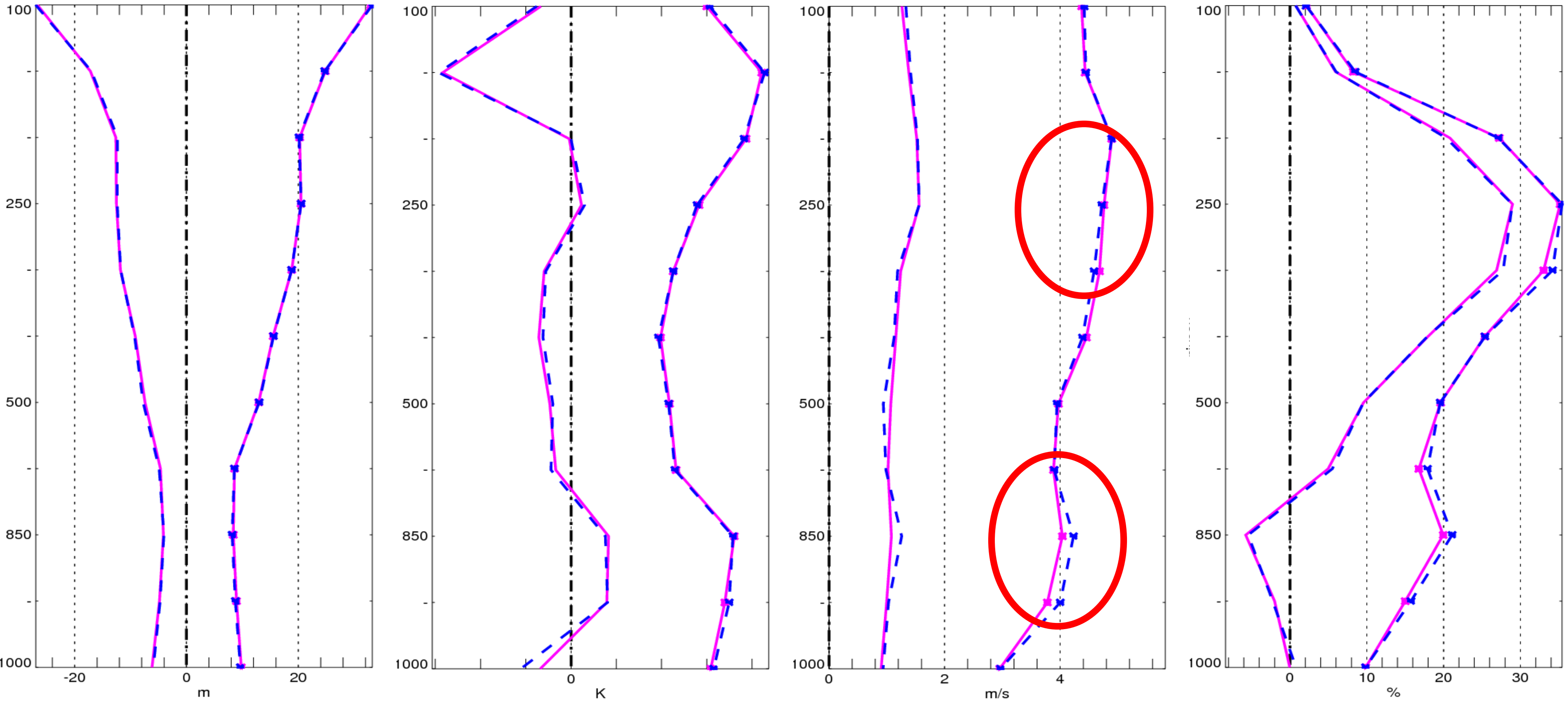
---------- Bias --x---x-- rmse



Geopotential T wind q

Objective scores : 12-h forecast scores compared to radiosonde

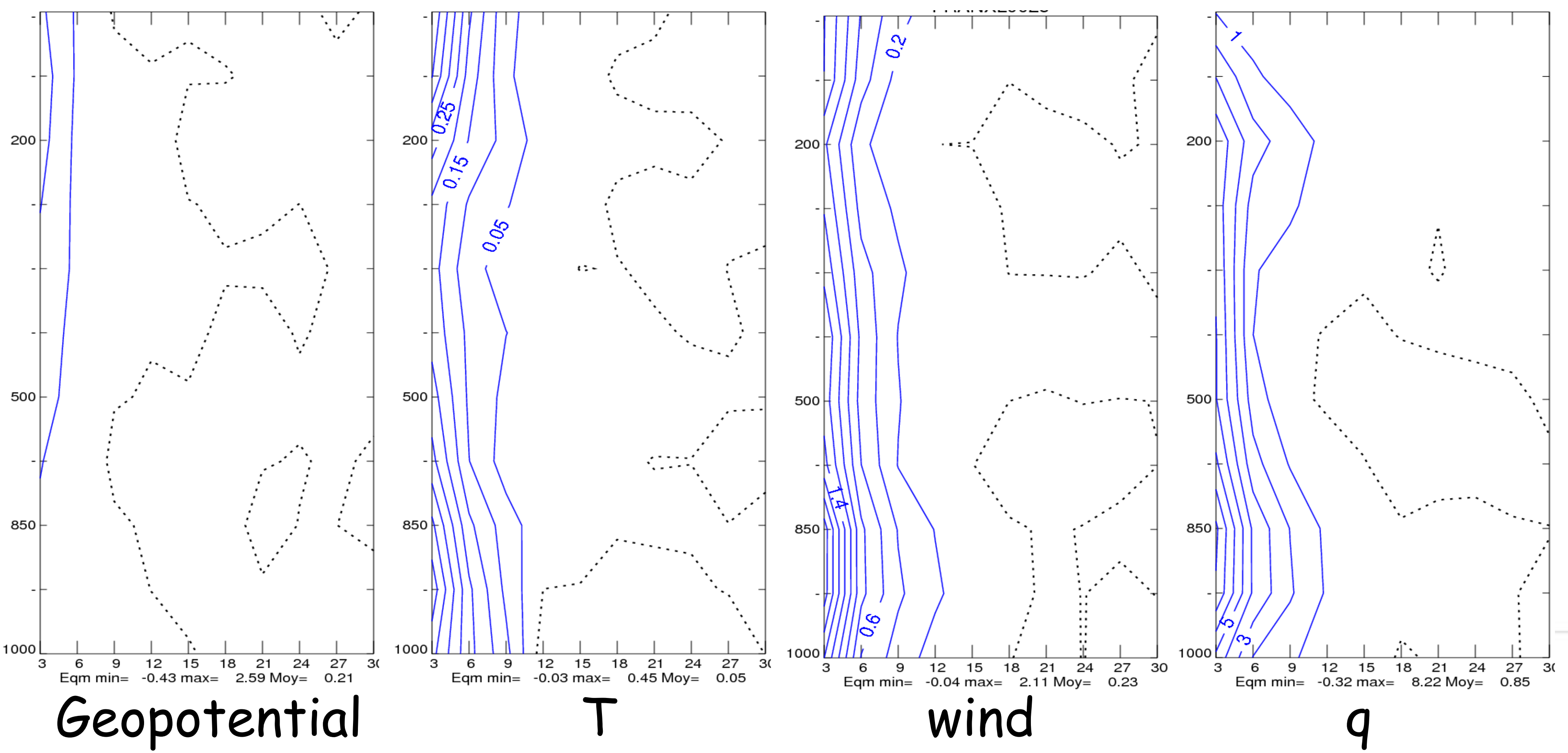
- AROME 12-h forecasts initialized with an analysis from the AROME RUC and an ALADIN analysis (spin-up mode) seem very close compared to radiosonde.



Geopotential T wind q

Objective scores : forecast scores compared to AROME analysis

- Differences of score compared to AROME analysis (spin-up minus assim) show forecast differences up to 12-h forecast. For longer forecast ranges, the two forecasts are very close.

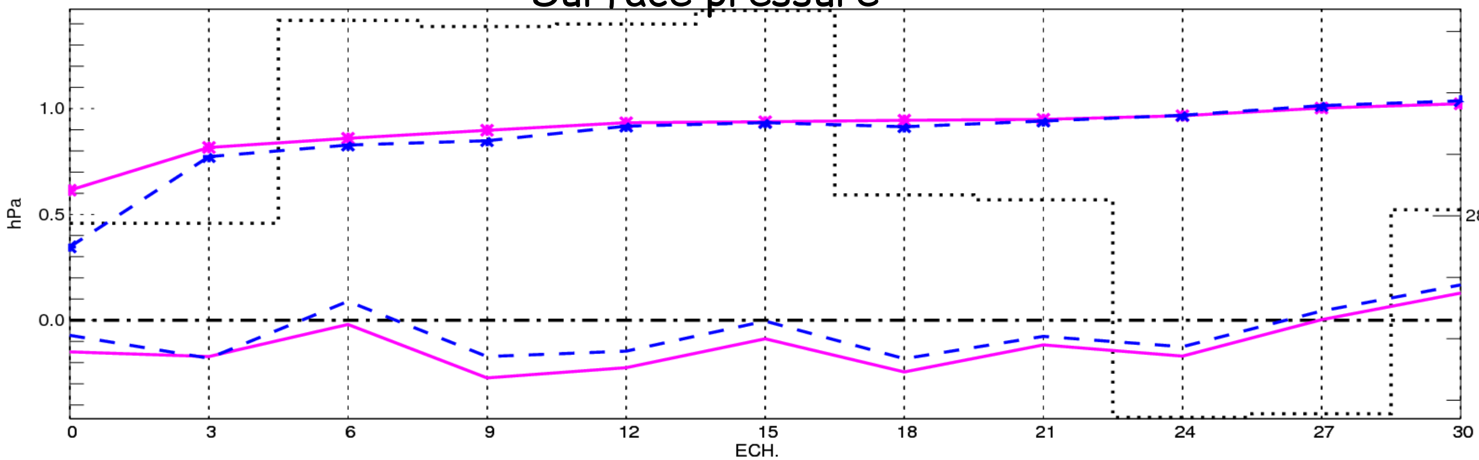


Objective scores : forecast compared to synop

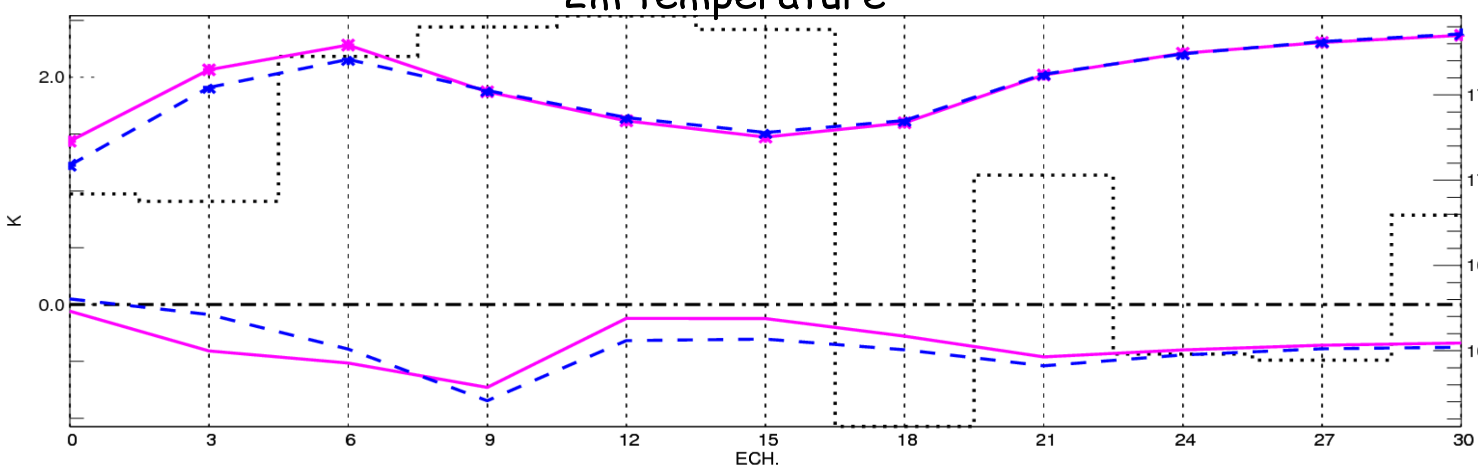
- Same feature is observed regarding scores compared to SYNOP observations

assilimilation
spin-up mode

Surface pressure



2m temperature

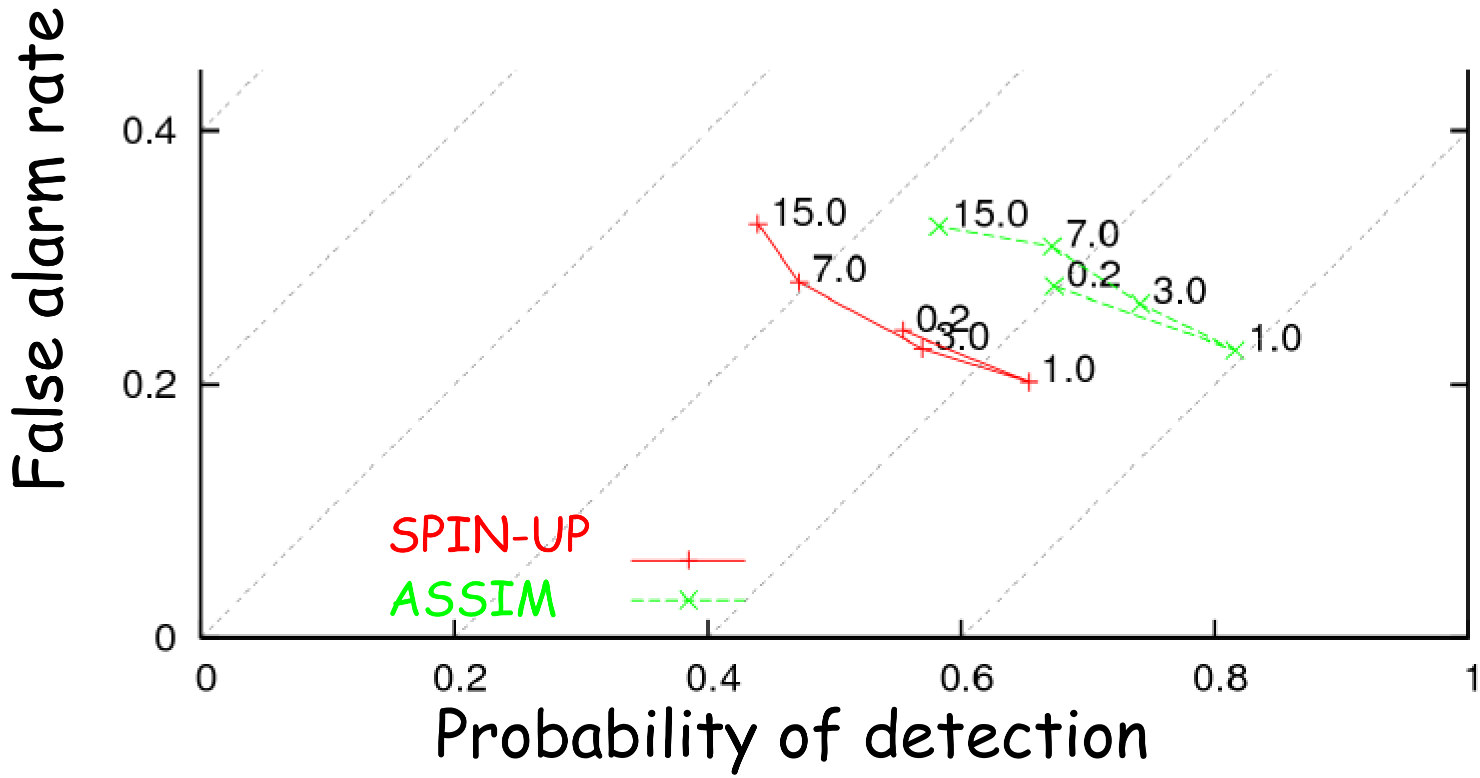


---------- Bias

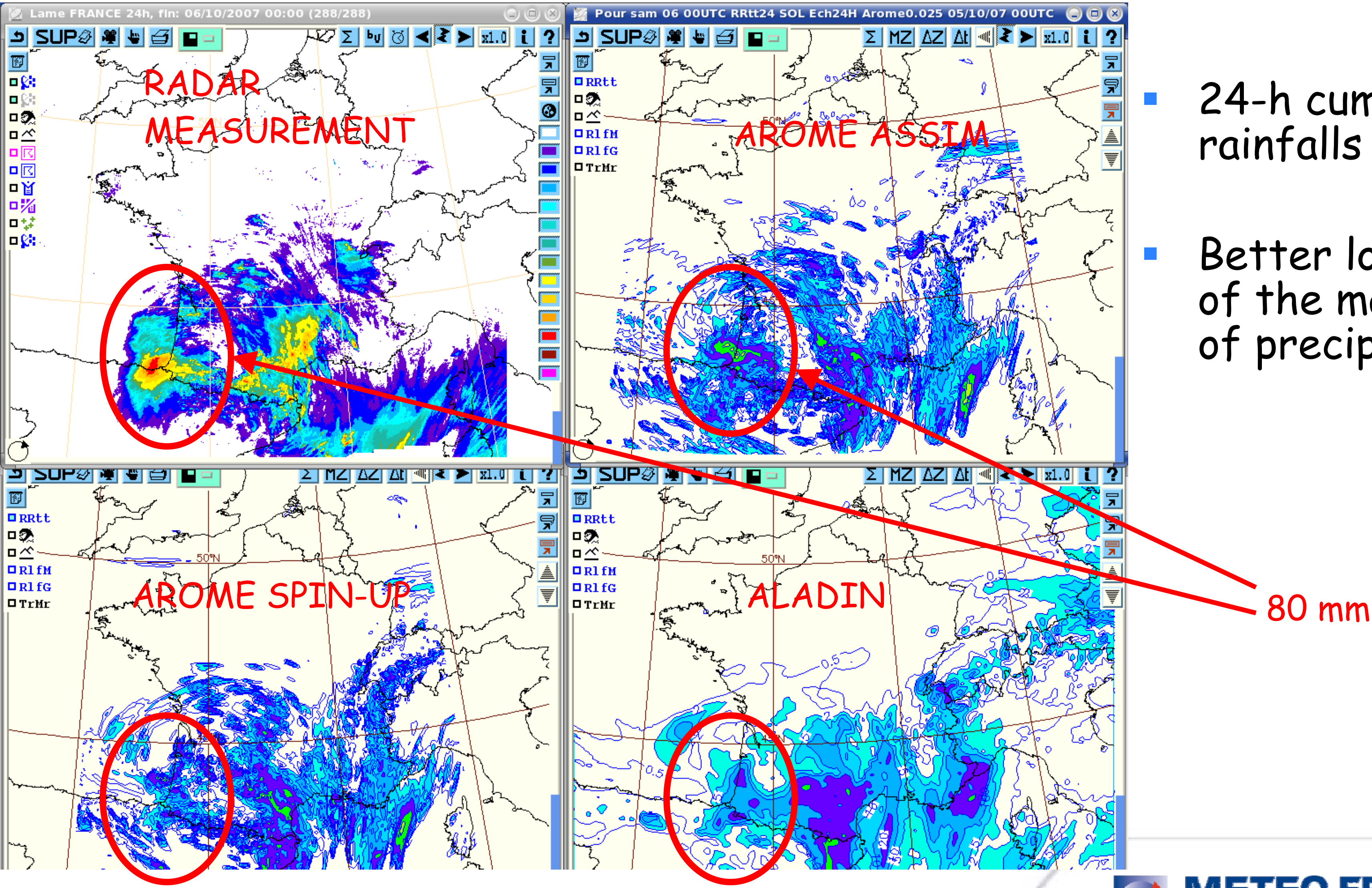
--x---x-- rms

Quantitative Precipitation Forecast scores

- QPF scores for different thresholds for the total rain forecast between 0- and 12-h compared to raingauge measurements in november 2007. With AROME analysis :
  - 20 % Increase of POD for all thresholds
  - 2 % increase of FAR except for the threshold 15mm



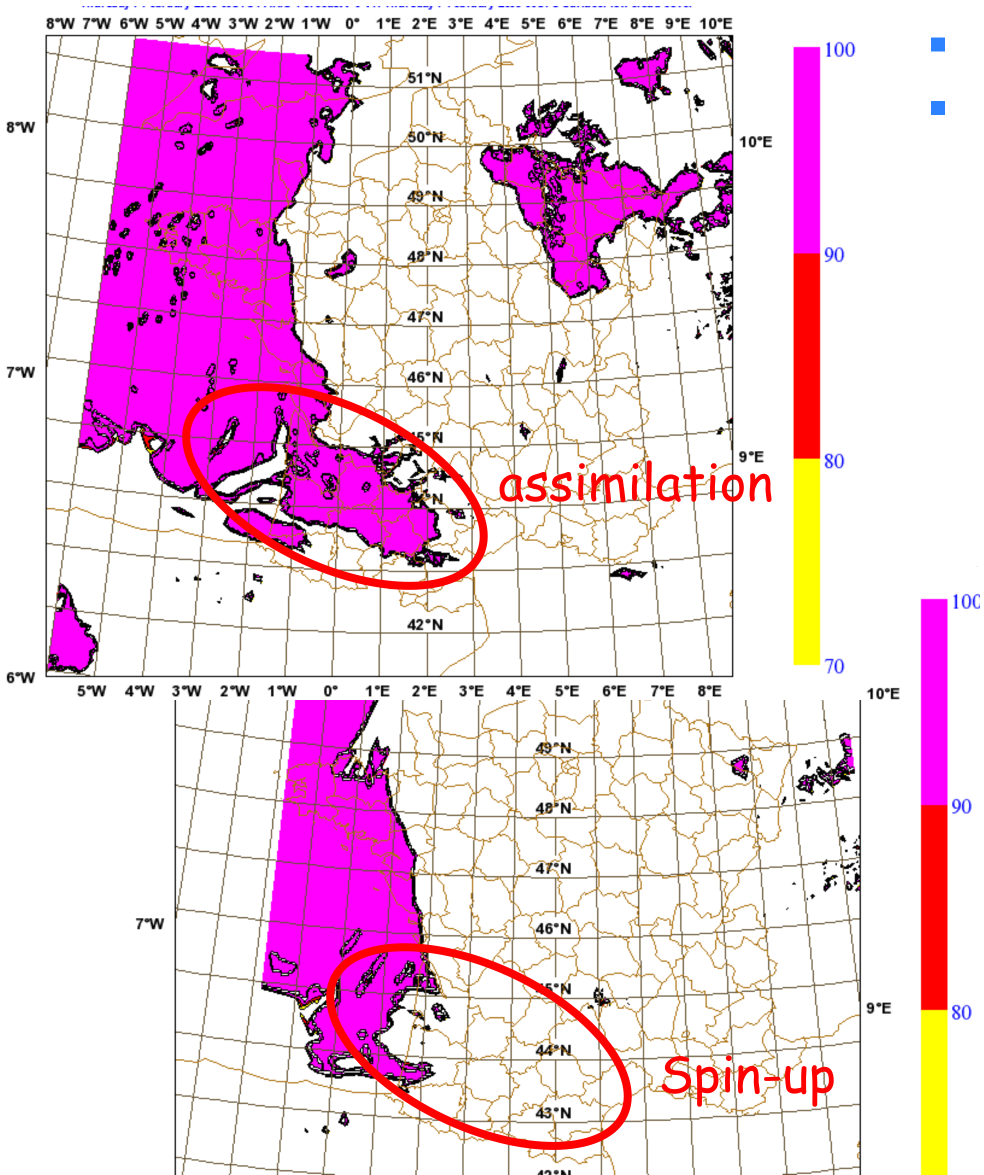
Precipitating event, 5 october 2007



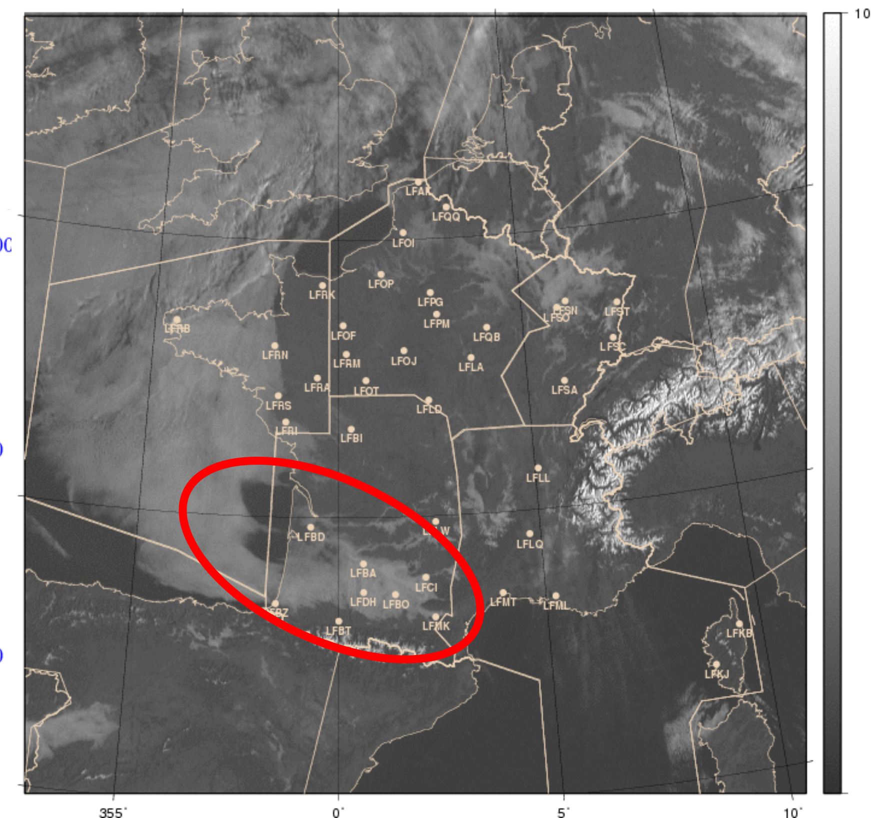
- 24-h cumulative rainfalls
- Better location of the maximum of precipitation

Fog event, 7 february 2008

- AROME low cloud cover at 9-h UTC
- Fog is not simulated in spin-up mode



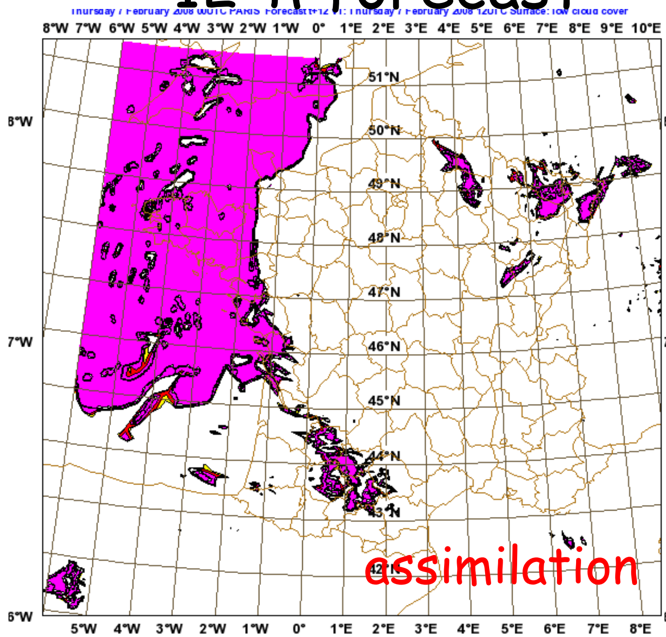
METEOSAT VIS 07 02 2008 09h15Z



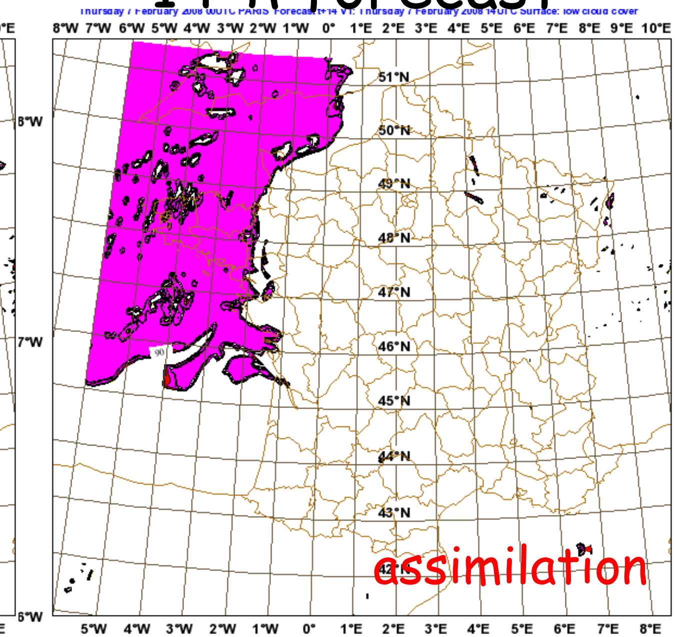
Fog case, 7 february 2008

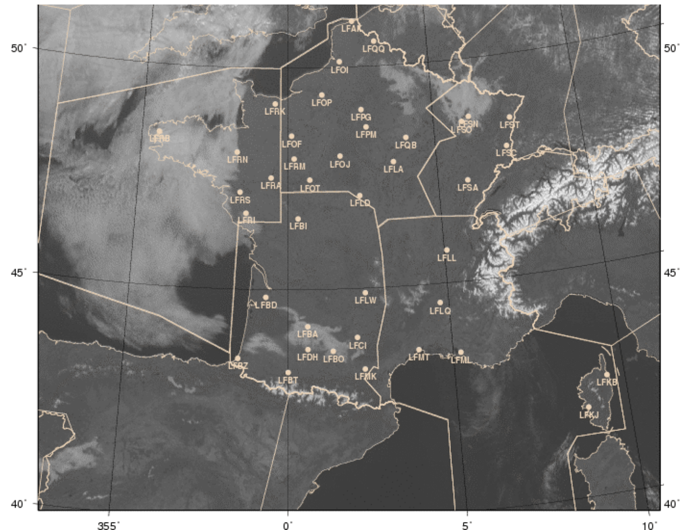
- Lifting is also well simulated
- The use of the AROME analysis allows to have a better depiction of low layer phenomena in this forecast.

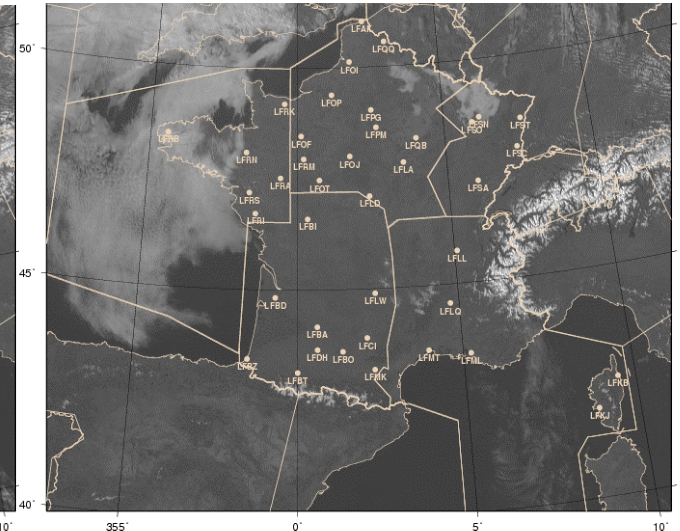
12-h forecast



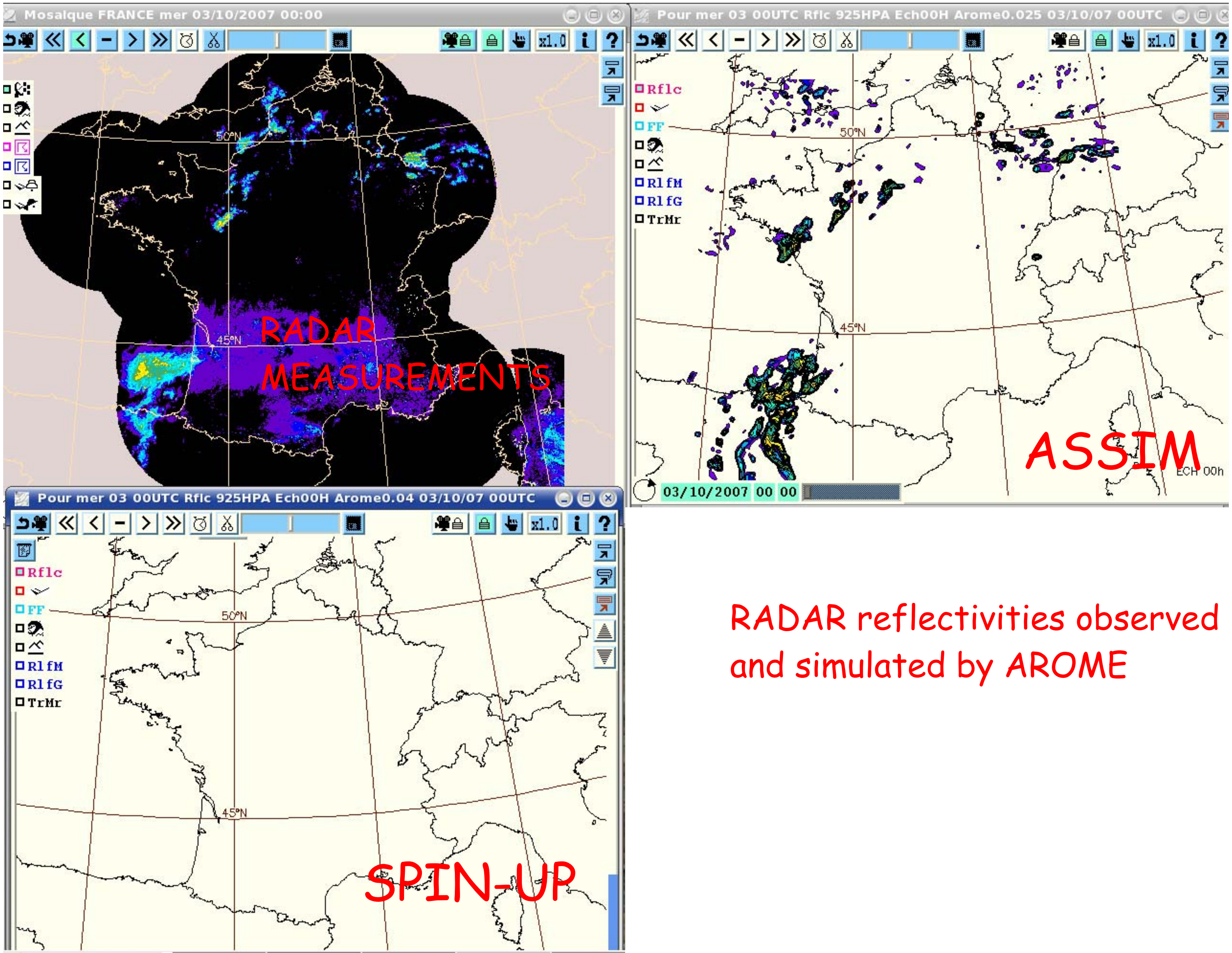
14-h forecast





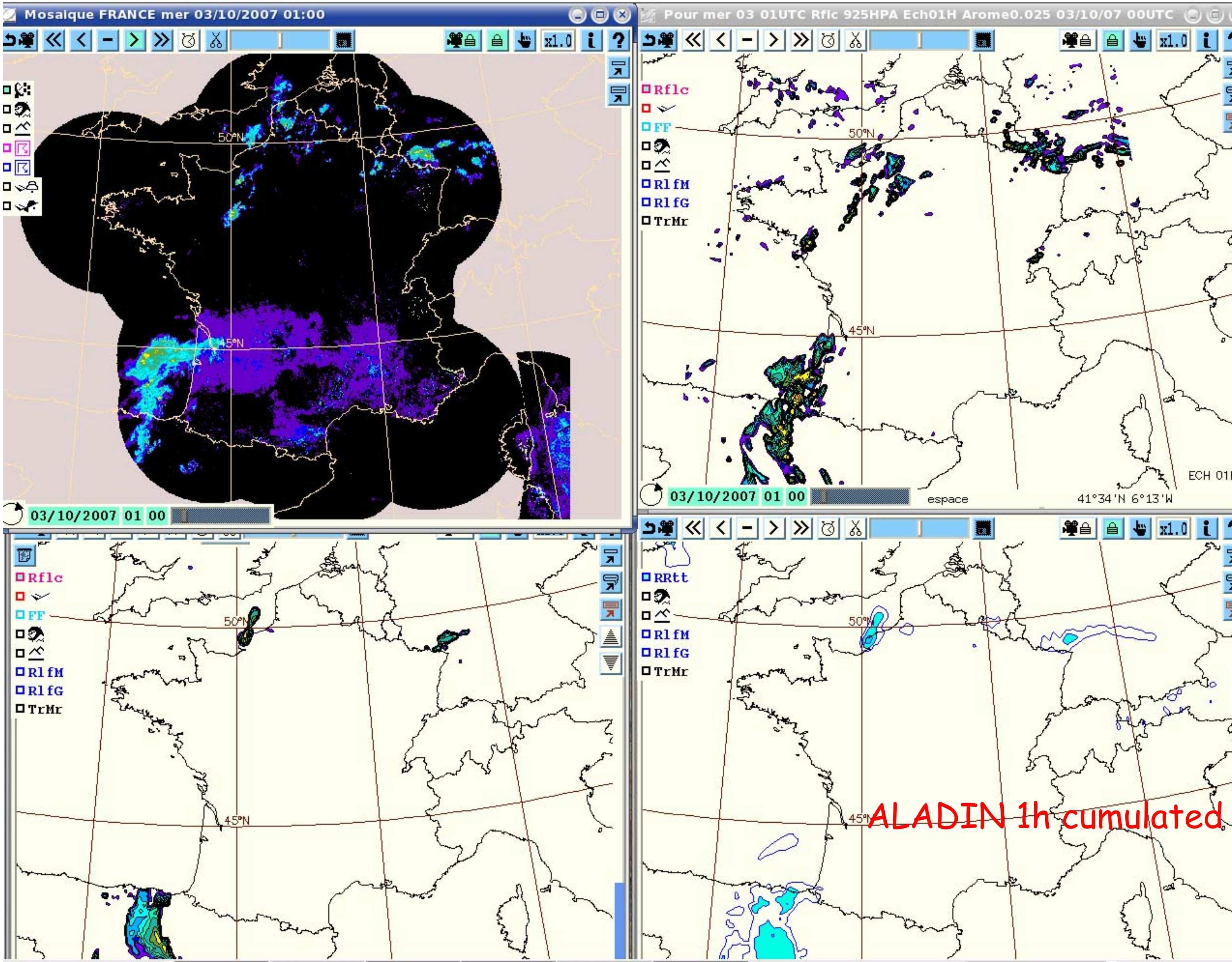


3 october 2007 : 00 UTC

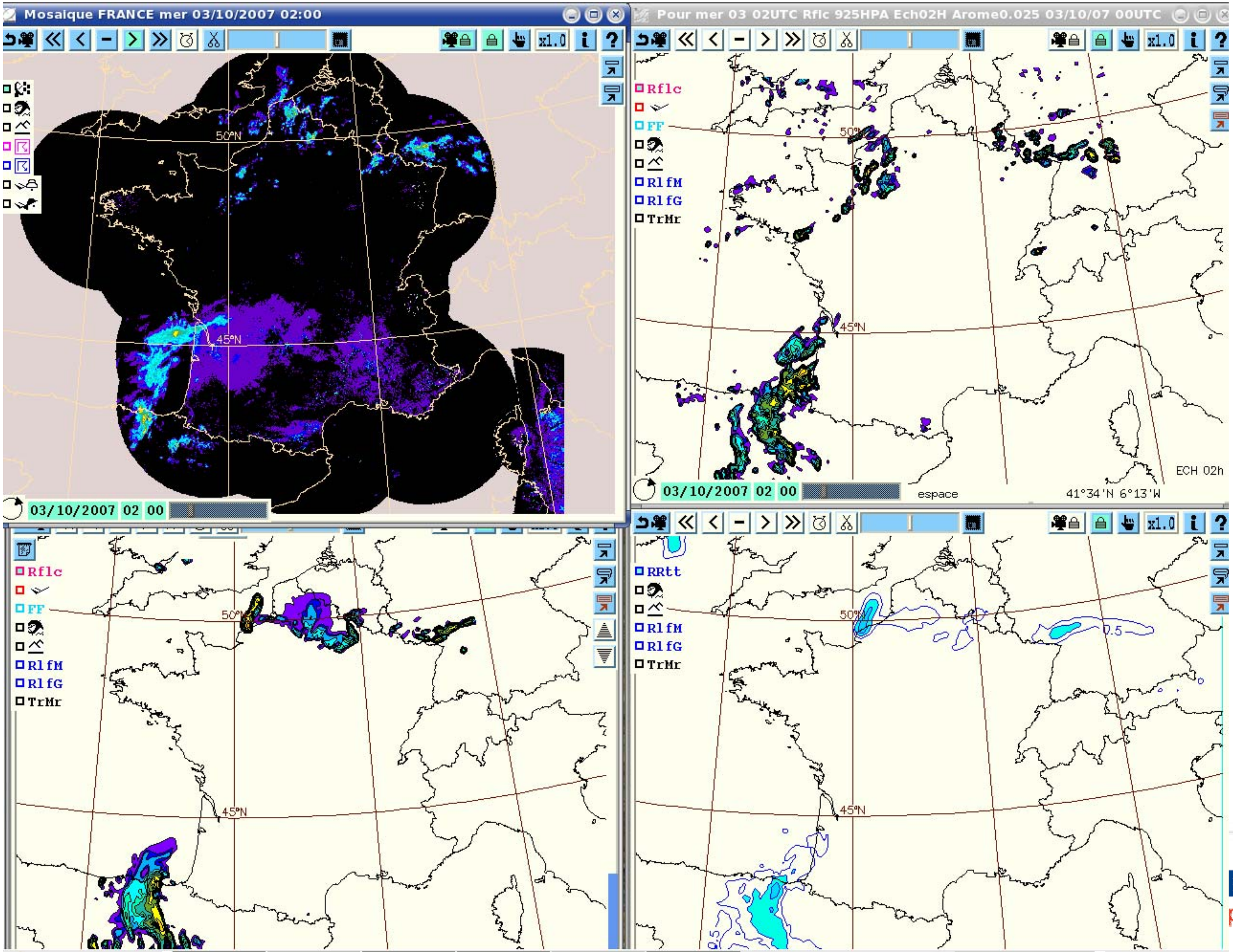


RADAR reflectivities observed and simulated by AROME

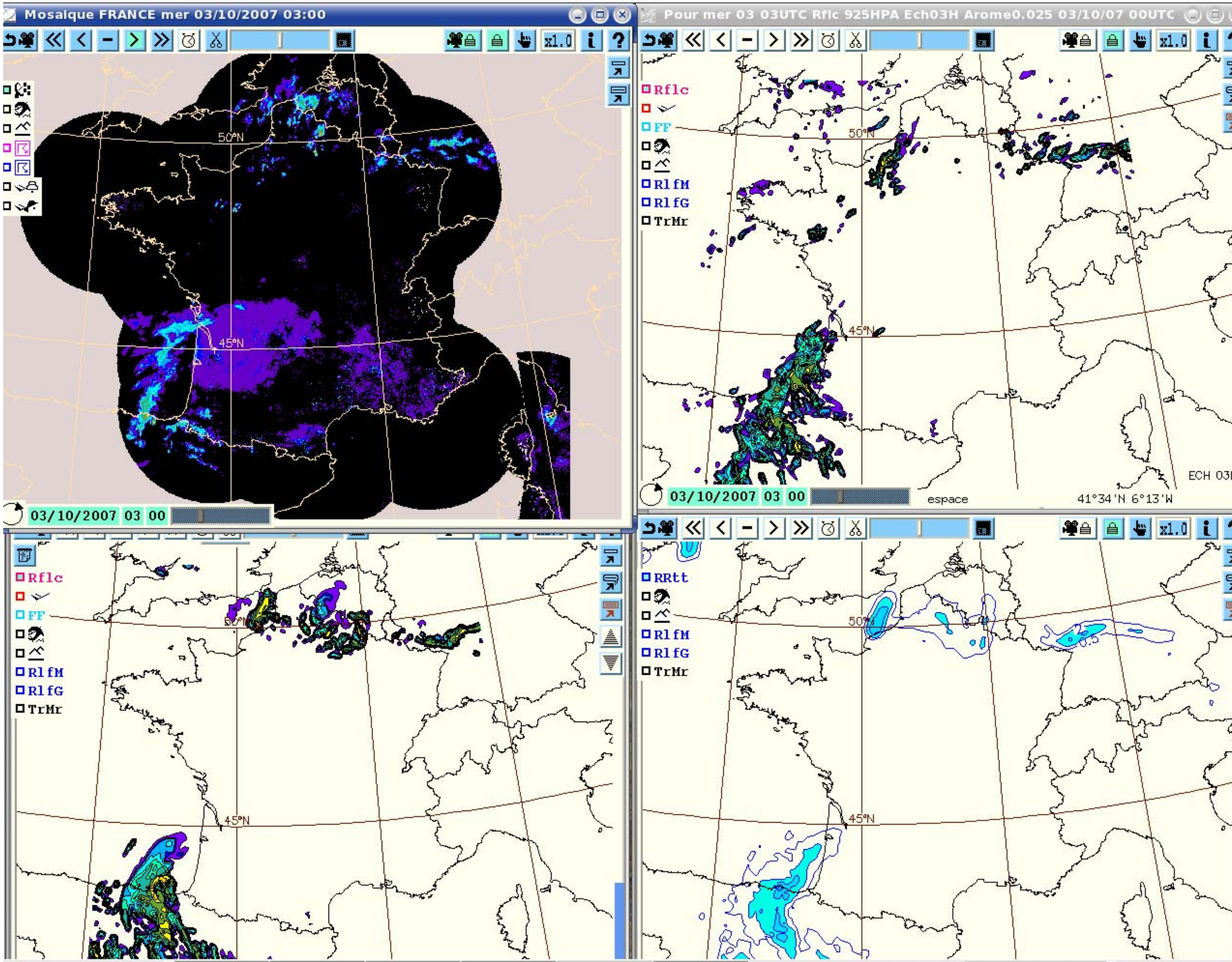
3 october 2007 : 01 UTC



3 october 2007 : 02 UTC

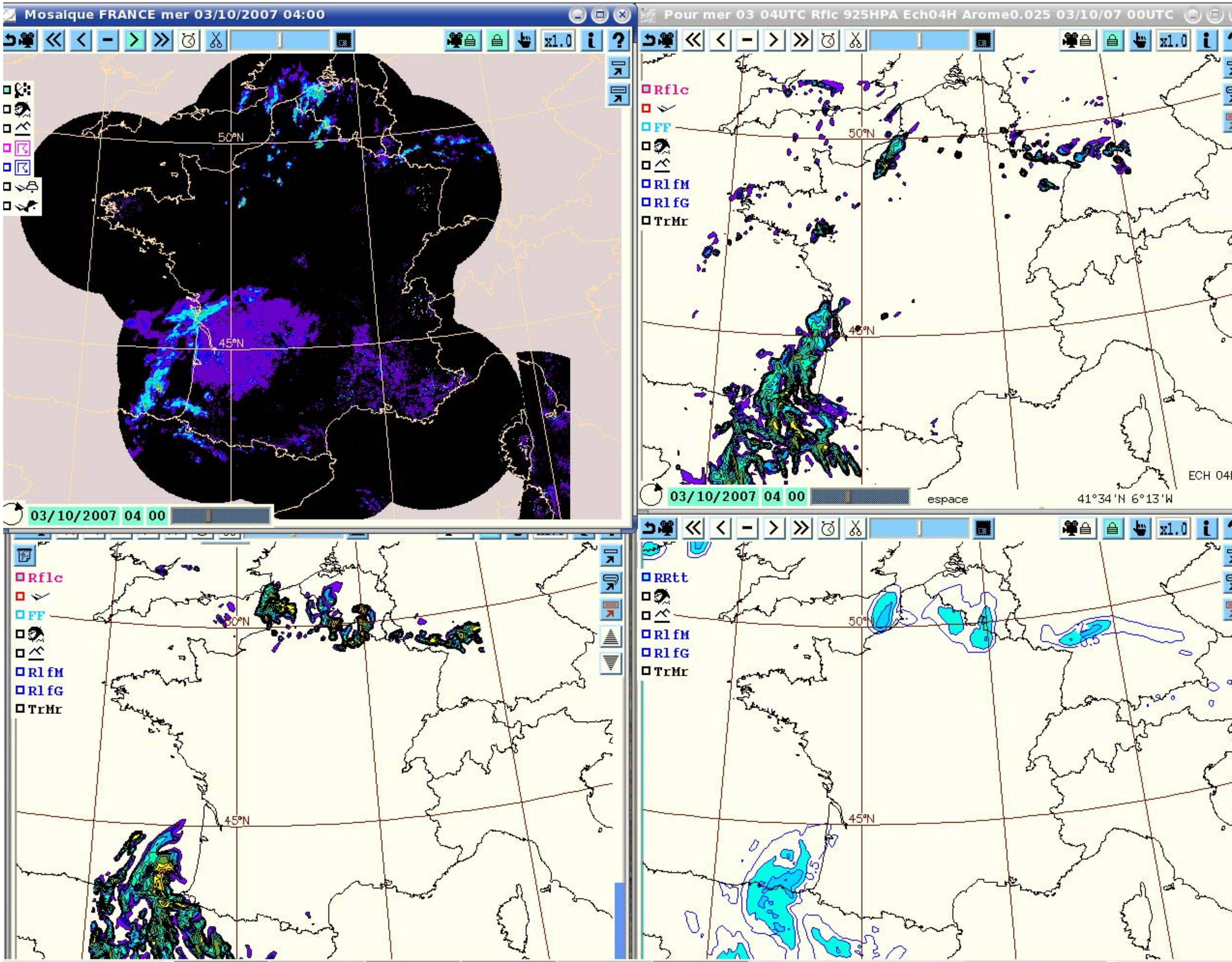


3 october 2007 : 03 UTC

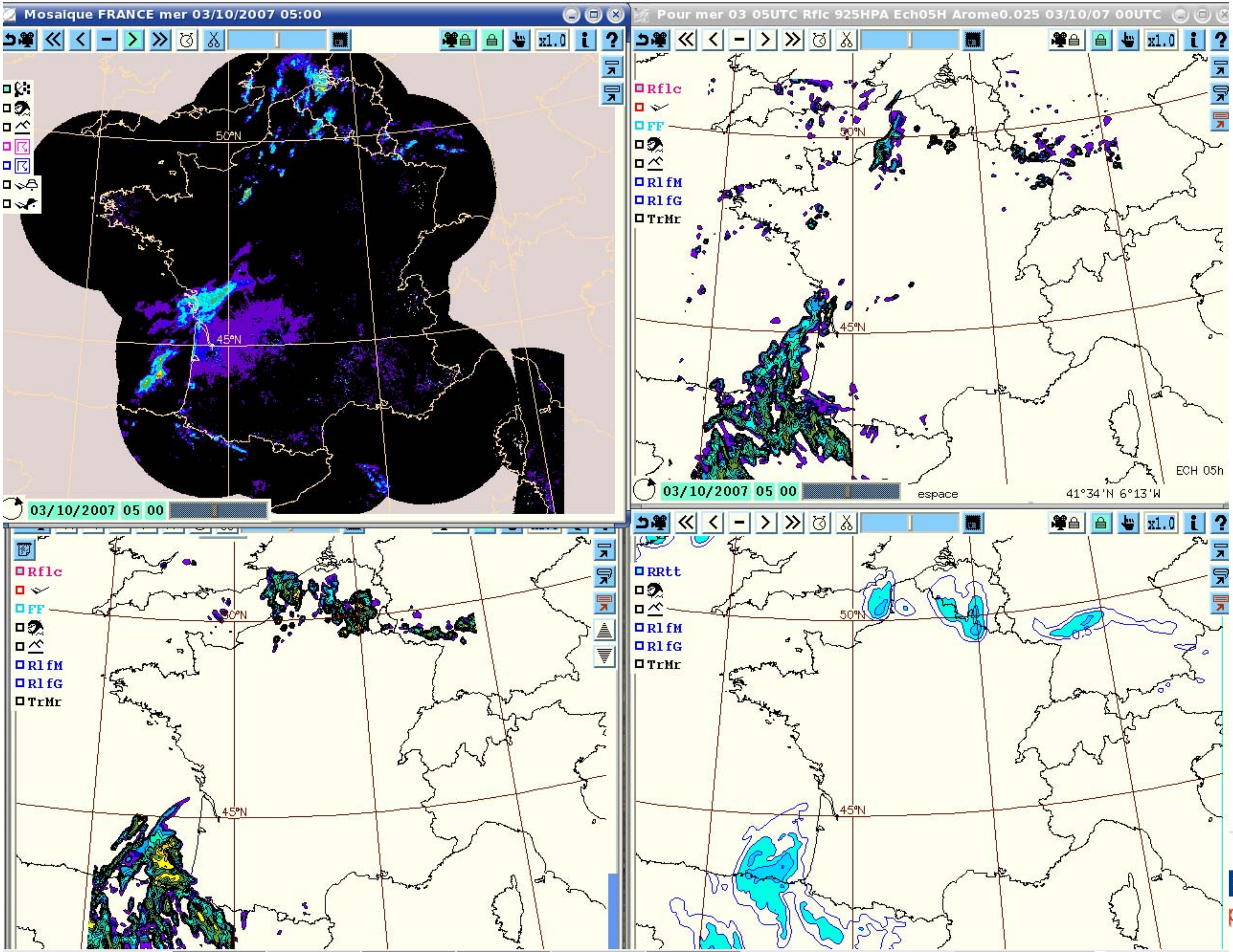


RANCE
ps d'avance

3 october 2007 : 04 UTC

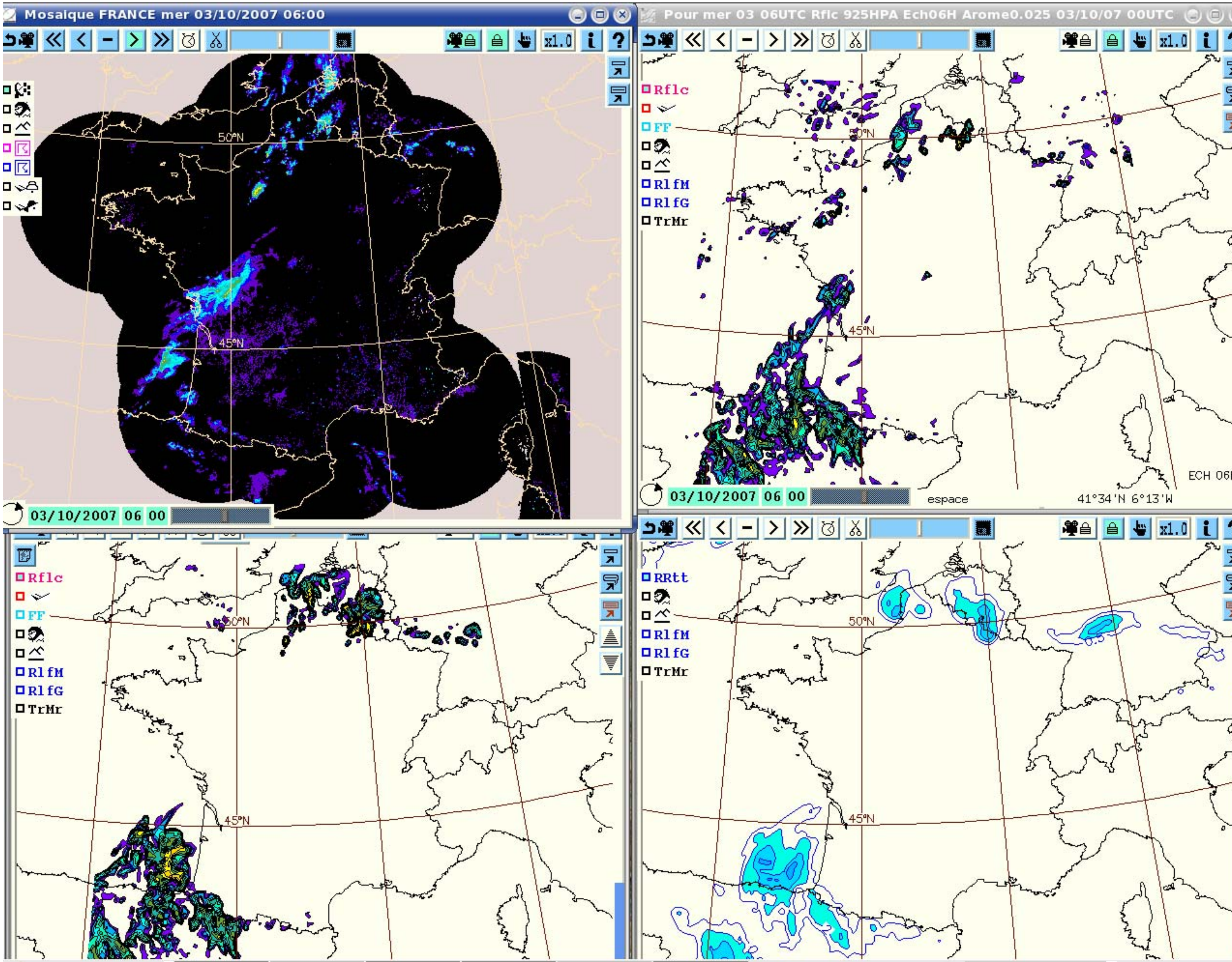


3 october 2007 : 05 UTC



RANCE
ps d'avance

3 october 2007 : 06 UTC



RANCE
ps d'avance

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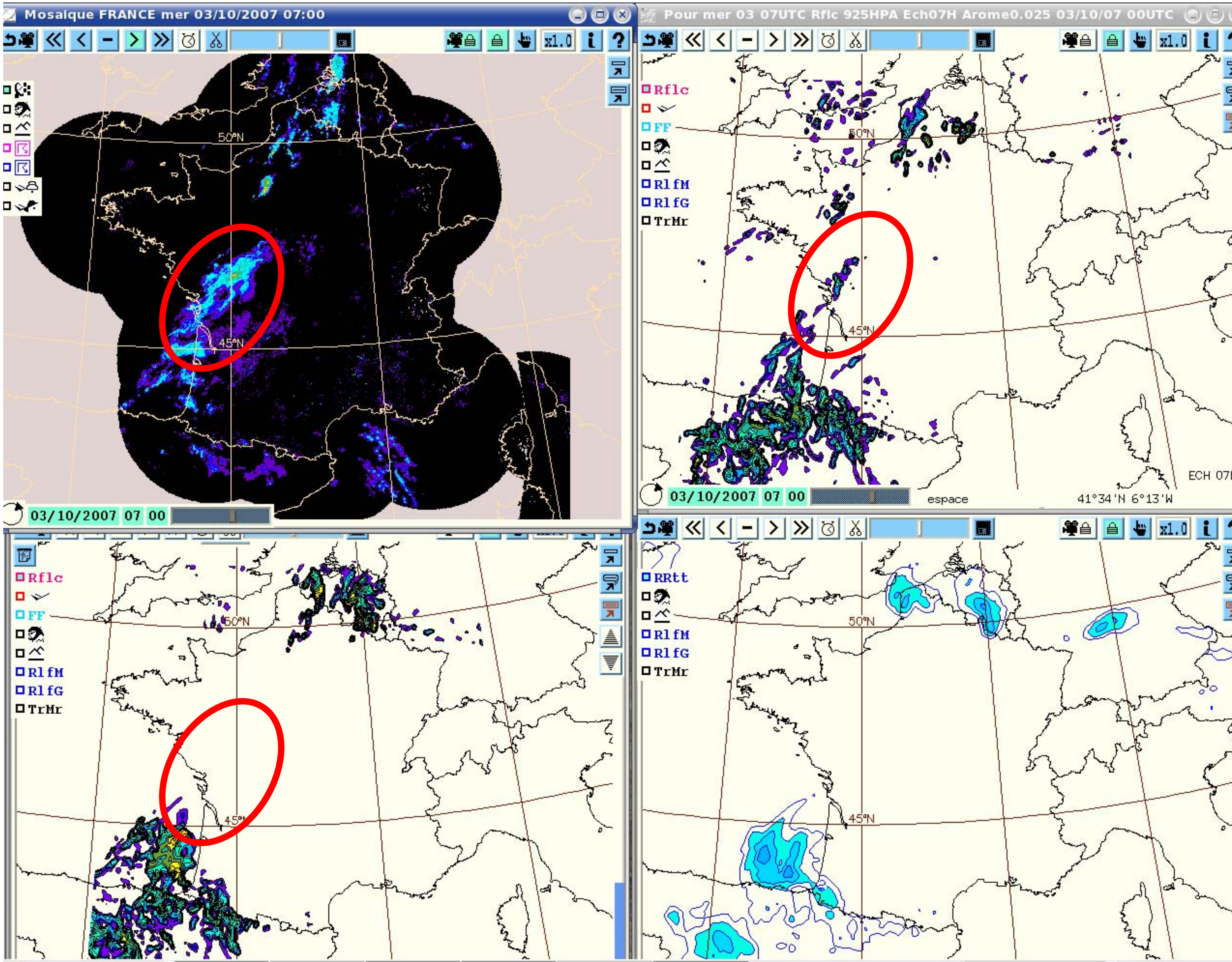
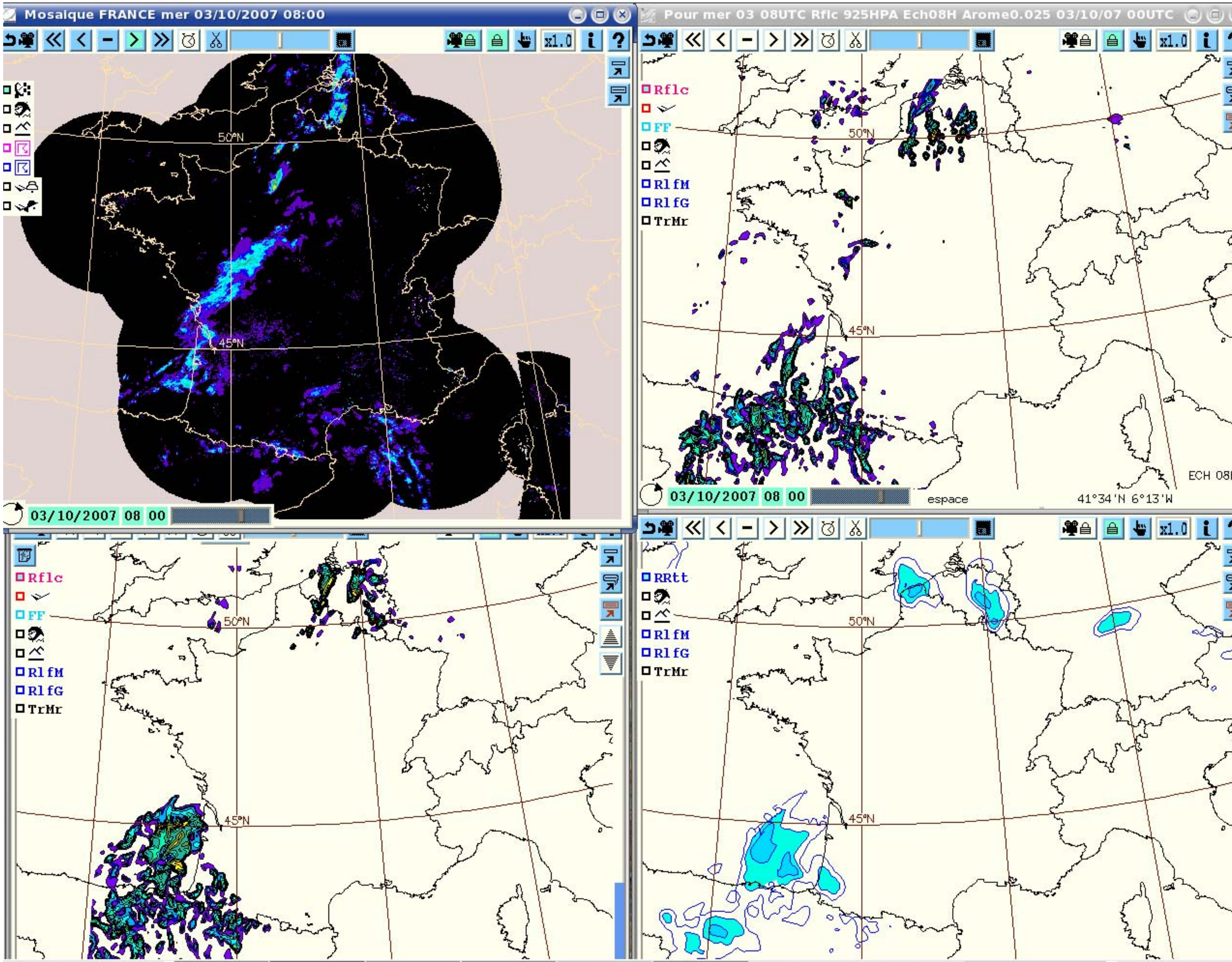


3 october 2007 : 08 UTC



RANCE
ps d'avance

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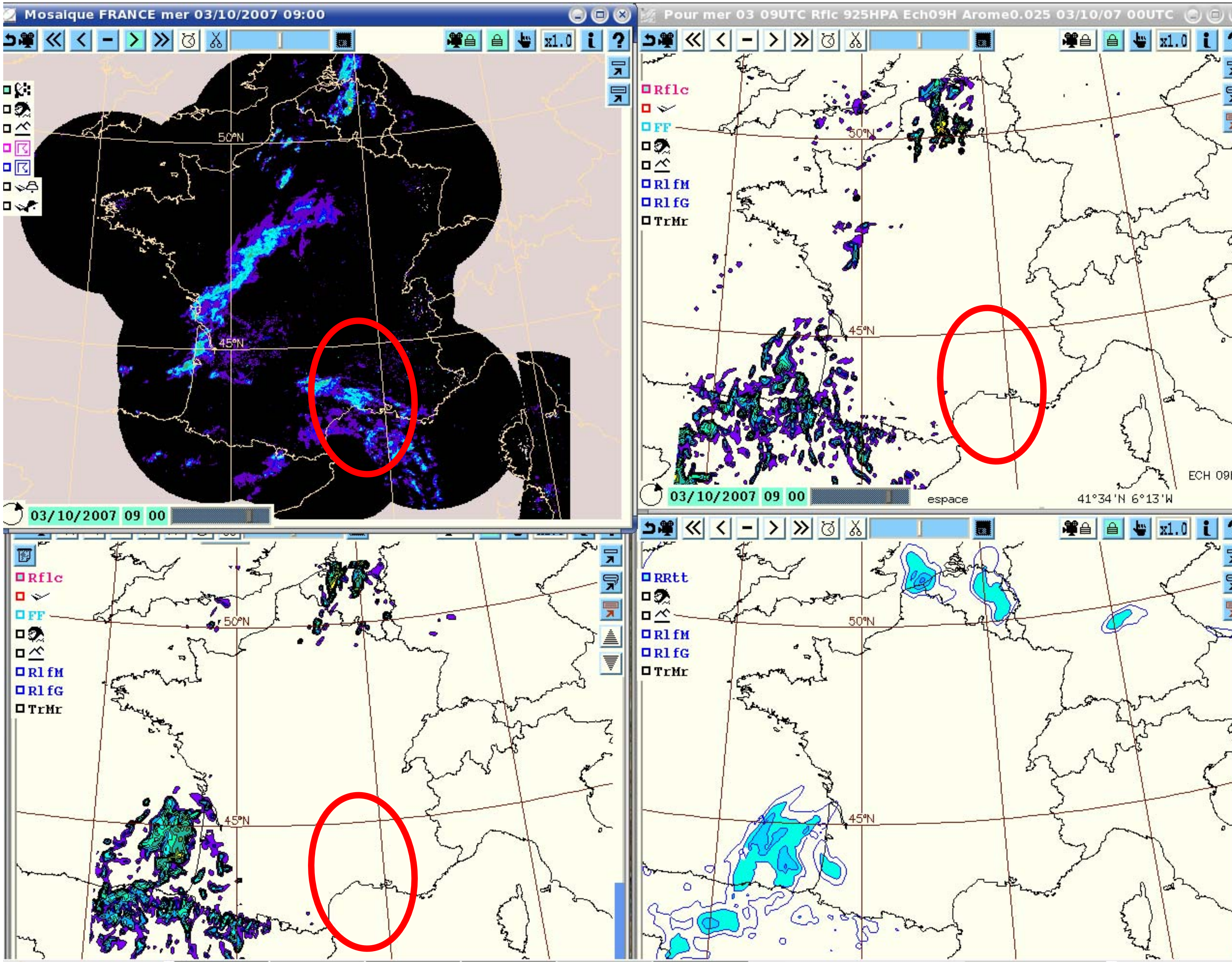
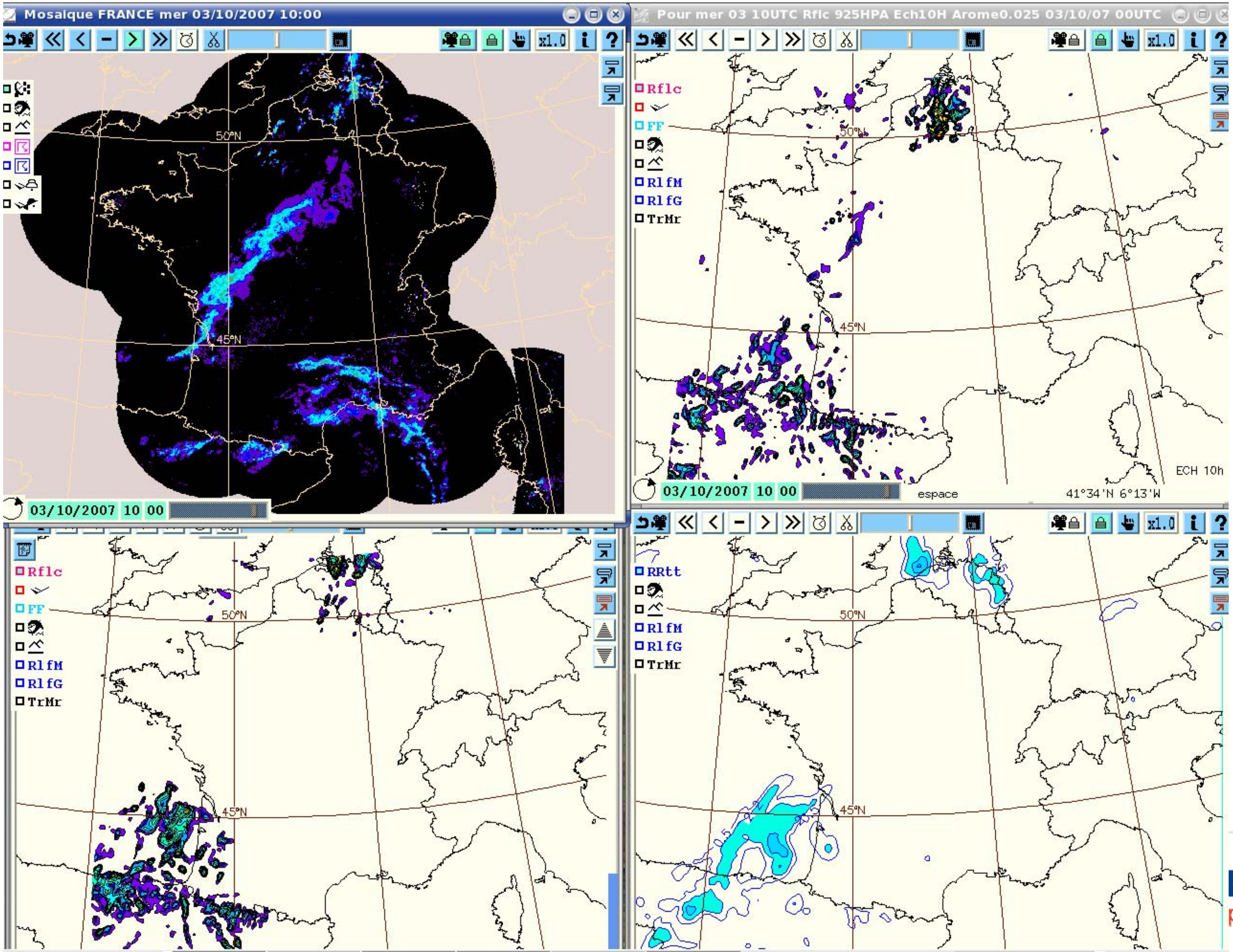
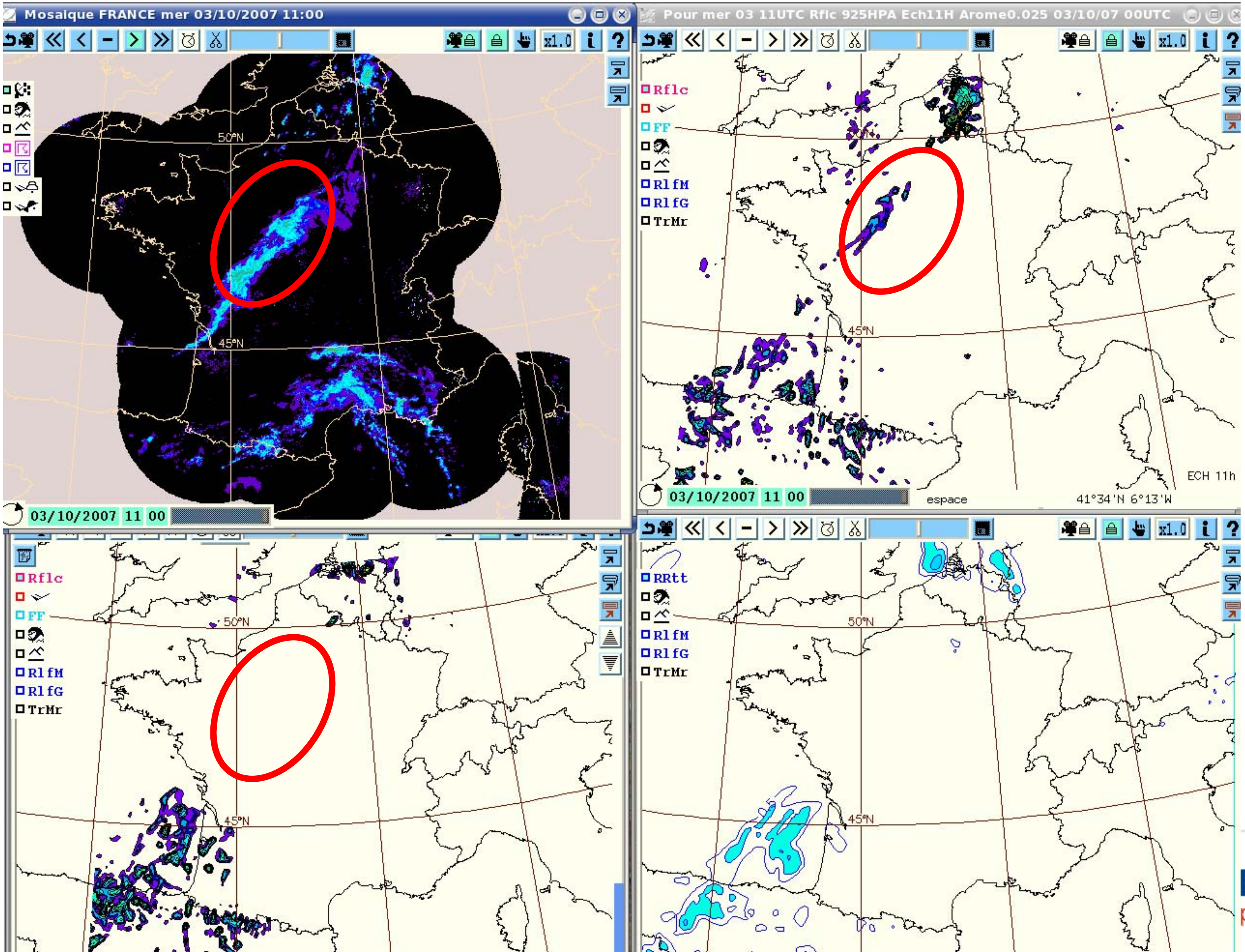


3 october 2007 : 10 UTC



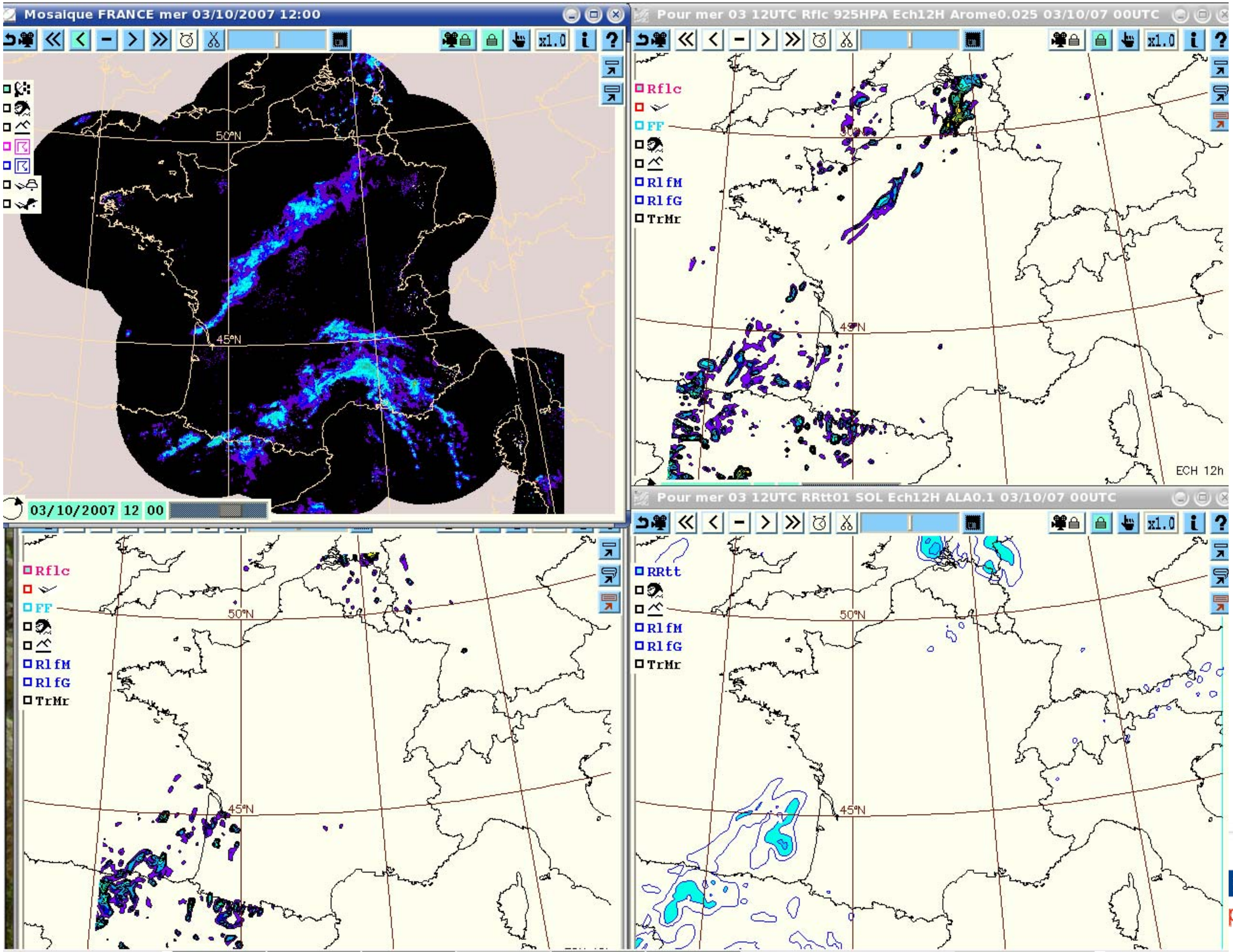
RANCE
ps d'avance

3 october 2007 : 11 UTC



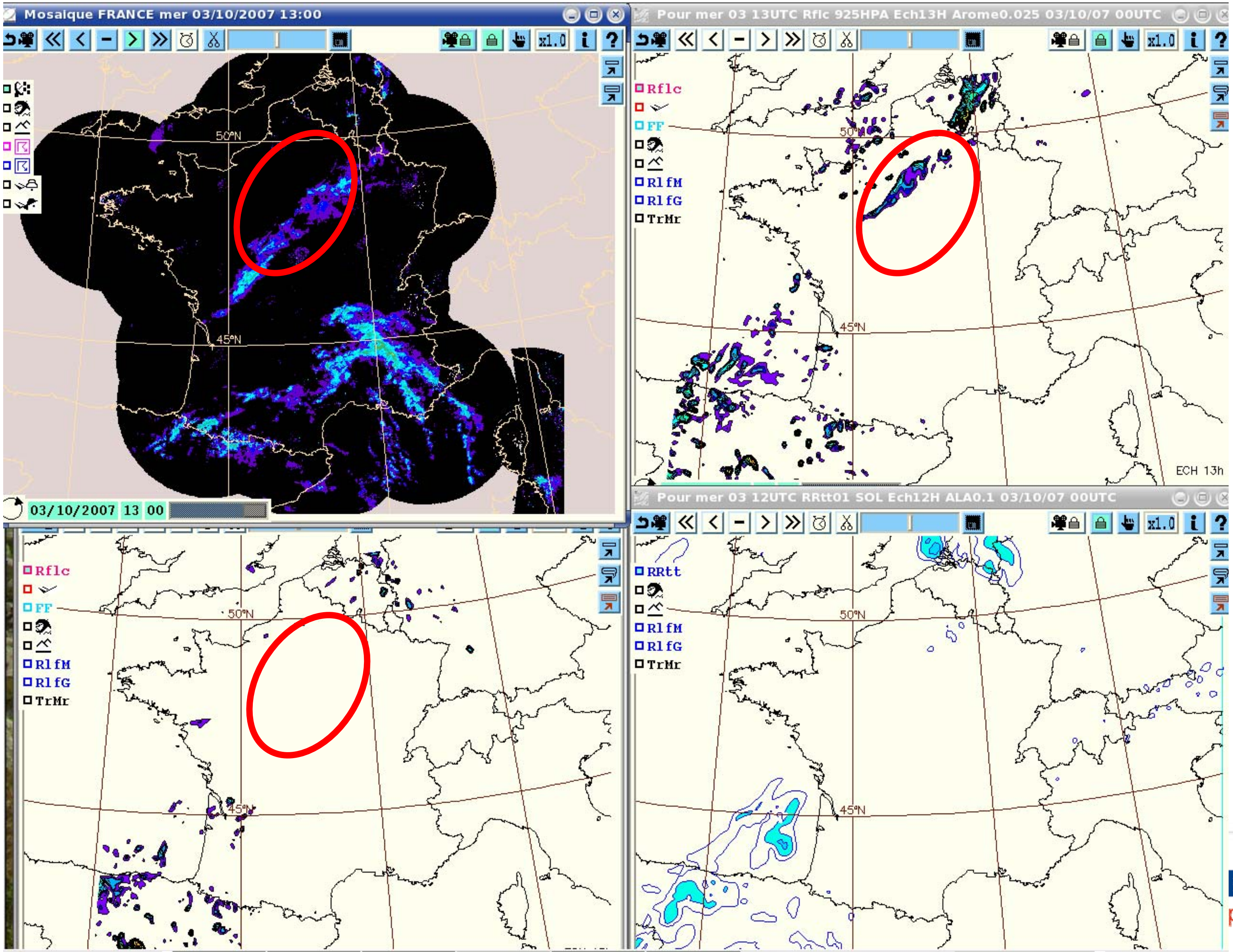
RANCE
ps d'avance

3 october 2007 : 12 UTC



RANCE
ps d'avance

3 october 2007 : 13 UTC

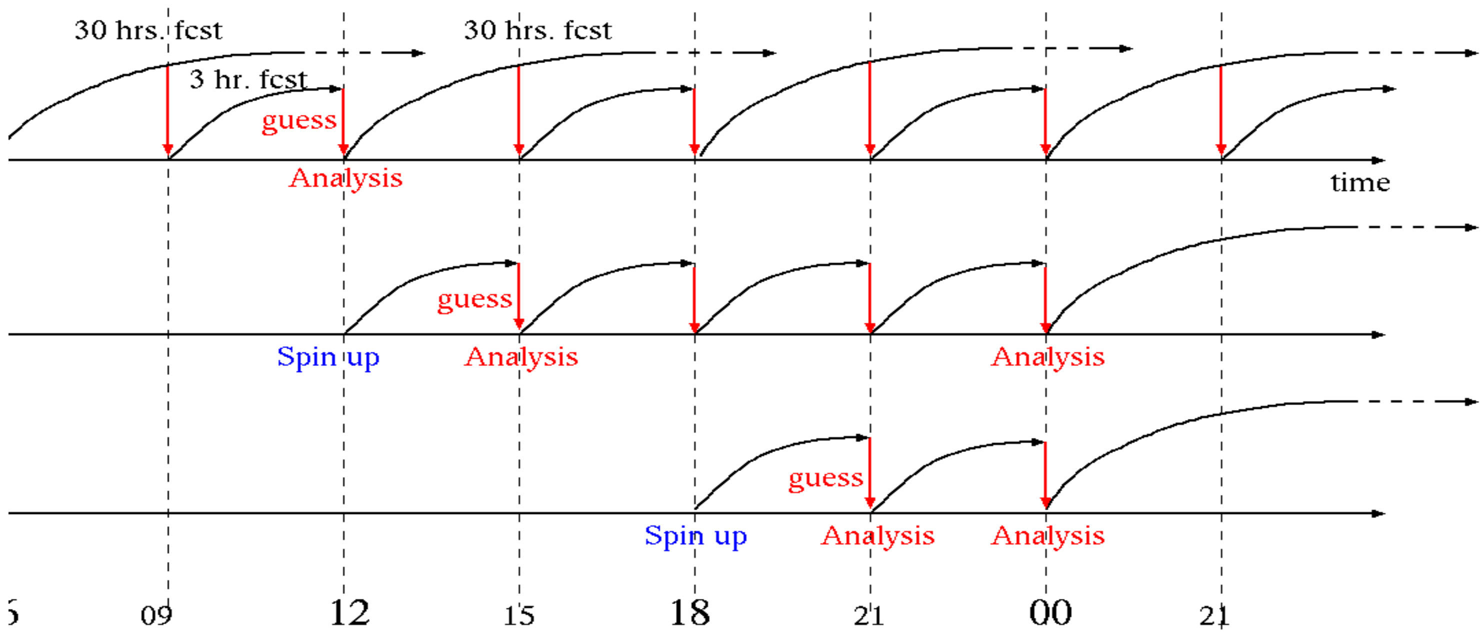


First results

- objective scores show that the general benefit of the AROME analysis appears during the first 12-h forecast ranges, then lateral conditions mostly take over the model solution.
- QPF scores show an improvement for 00-12 cumulative rainfalls. This improvement seems to disappear for longer cumulative precipitation.
- Subjective evaluation confirms many forecast improvement during the first 12-h forecast ranges. In some particular cases, this benefit can also be observed after this range.

Cycling strategy

- Problem: a continuous cycle never sees large scale analysis except trough lateral boundary conditions.
- 2 experiments restarting from ALADIN analysis (spin-up mode) each day

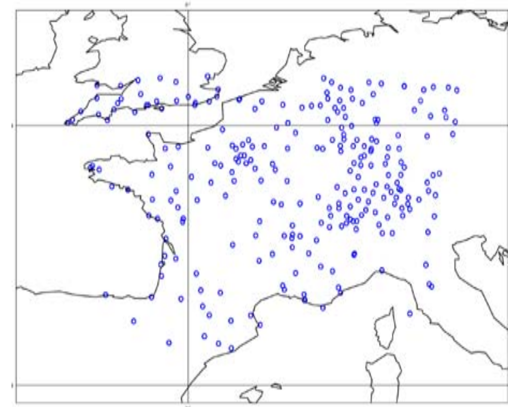


- Objective scores : neutral, slight improvement
- QPF scores and subjective control : deterioration of precipitation and low cloud cover fields

METEO FRANCE
Toujours un temps d'avance

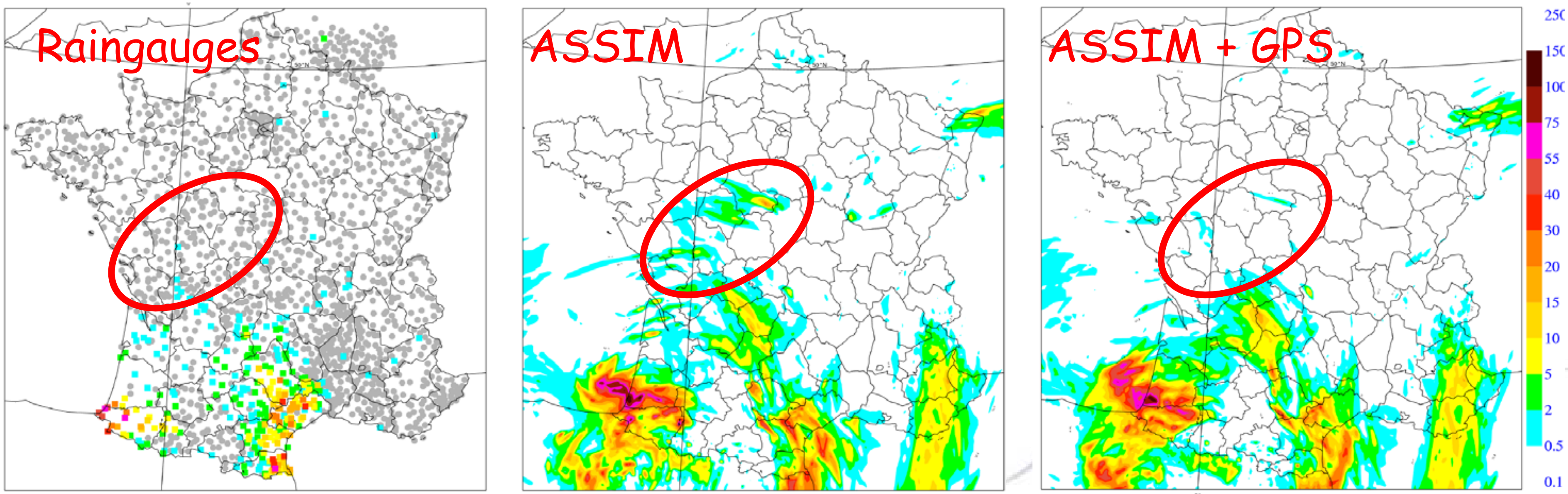
An observation influence study : groundbased GPS

- Aim : to assimilate a new kind of observations in AROME data assimilation system : groundbased GPS.
- To monitor these observations during 2 months: selection of 212 stations
- Experiment in order to evaluate the influence of these observations.
- Objective scores : neutral
- QPF scores and subjective control : decrease of overestimate precipitations



Groundbased GPS stations selected

00-12 cumulative rainfalls



Conclusion

- A prototype for the AROME data assimilation system is currently being tested at Météo-France.
- It is supplied by the same kind of observation as the ALADIN-FRANCE operational suite.
- The background-error statistics for AROME have been calculated by an ensemble methode using the same multivariate formulation as in ALADIN-France. Compared to the ALADIN-FRANCE ones, background-error standard deviations are increased and horizontal correlation lenghtscales are much shorter : Analysis increments are stronger and narrower.
- This prototype shows its ability to improve analysis and forecasts, giving a more realistic depiction of initial conditions.
- The general benefit of the analysis appears during the first 12-hour forecast ranges, then lateral conditions mostly take over the model solution.

Outlook

- Works currently in progress on :
  - the use of observations at a higher spatial resolution (airep, IR radiances,…).
  - the assimilation of observations more representative of mesoscale like RADAR winds and reflectivities (see also the talk of Eric Wattrelot).
  - A surface assimilation for AROME (see also the talk of Rafiq Hamdi).

- Works are planned in order to take a better advantage of high-frequency observations using :
  - 3D-FGAT (First Guess at Appropriate Time) assimilation scheme
  - Incremental Digital Filter Initialization allowing 1-h cycling

- AROME schedule :
  - April 2008 : AROME pre-operational suite managed by operational team (3-h RUC, RADAR winds,…).
  - October 2008 : AROME declared operational at Meteo-France (?)

References

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Thank you for your attention…