Convective-scale and short-range predictability of high-impact weather events

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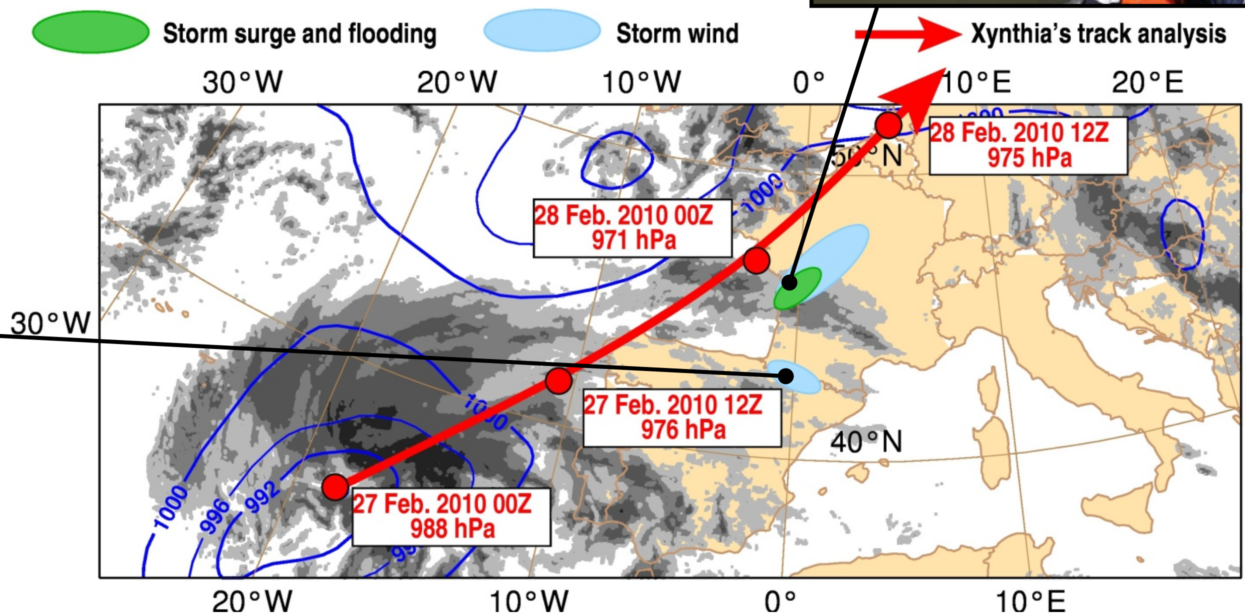
CNRM-GAME (Météo-France & CNRS)

ECMWF Annual Seminar, 9 Sept. 2010, Reading, England

METEO FRANCE
Toujours un temps d'avance

Severe winds (Xynthia storm)

210 km/h were also recorded at Pic du Midi and very strong winds in the Pyrenees valleys



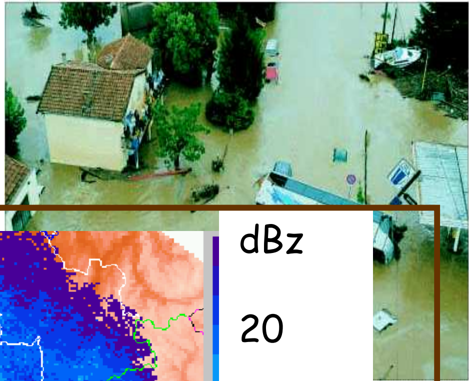
METEOSAT infrared brightness temperatures and ARPEGE analysis in terms of MSLP (blue) 27 Feb. 2010 at 00 UTC

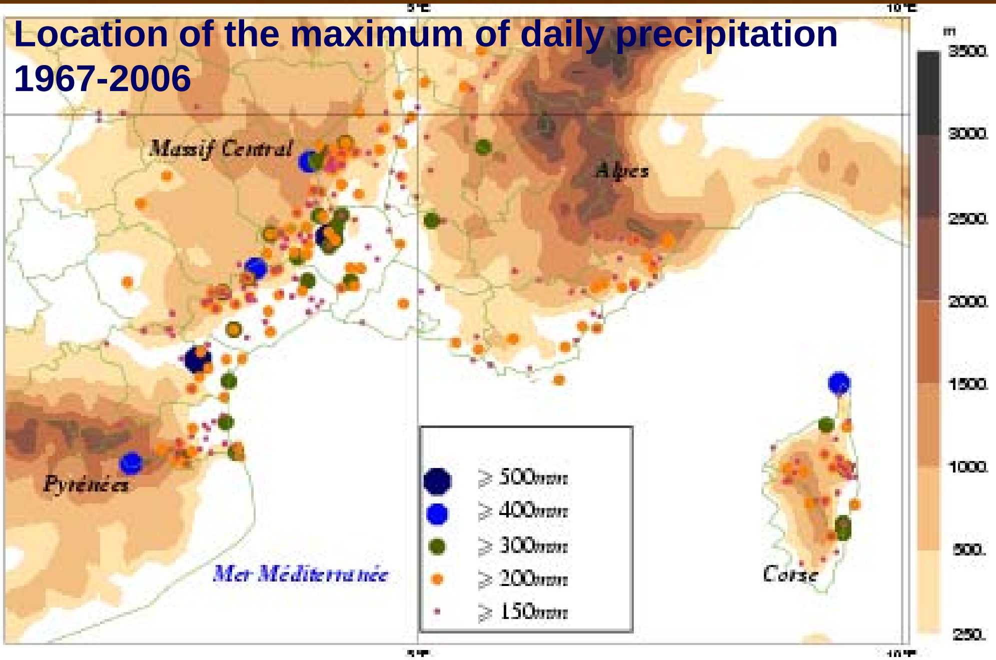
<u>Triggering ingredients for explosive cyclogenesis</u>:
- Strong baroclinicity induced by a strong upper-level jet.
- Existence of a low-level anomaly (PV / Potential temperature) interacting with the upper-level jet .

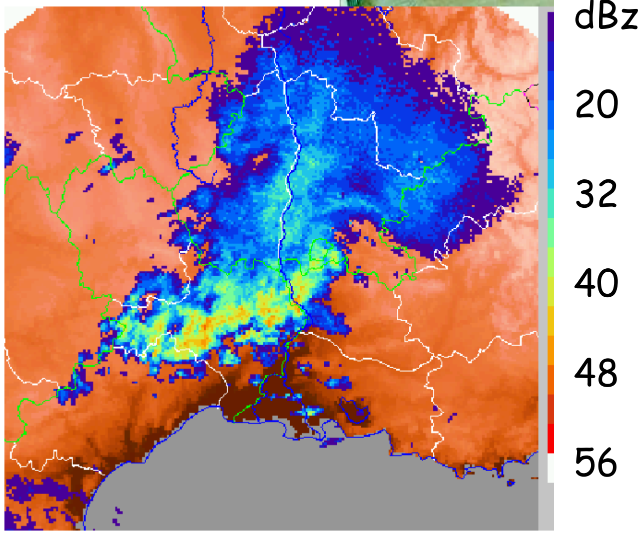
Xynthia caused numerous damages and killed at least 60 people in Europe, with the hardest hit in France

Wernli et al, 2002; Gilet et al., 2009; Rivière et al., 2010

Heavy Precipitation

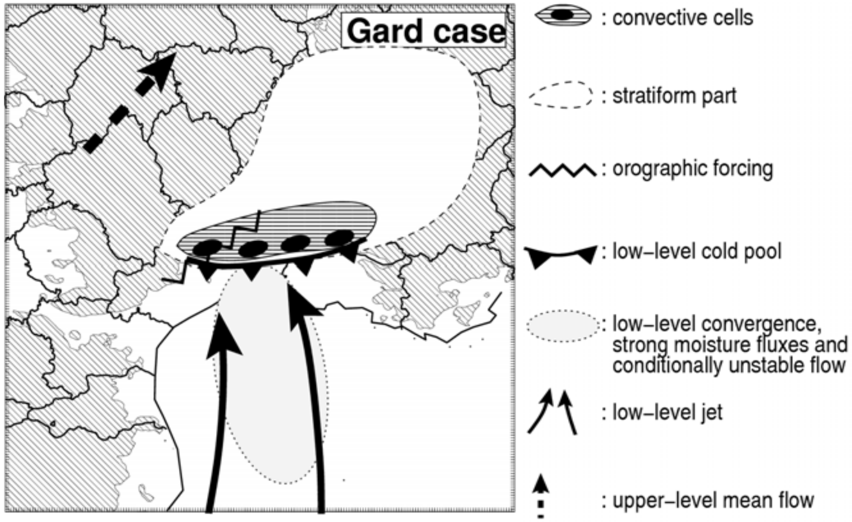






Gard, 8-9 Sept. 2002
~700 mm/ 24h, 1.2 billion € damage

<u>Favoring conditions for "Cevenol" MCS</u>:
-a slow-evolving synoptic environment;
-a mesoscale unstable and moist low-level S-SE flow impinging the Massif Central, sometimes converging over the sea.
Gard'02: in addition, a low-level cold pool produced by the MCS itself, blocked in the Rhône valley and forcing the low-level flow lifting.

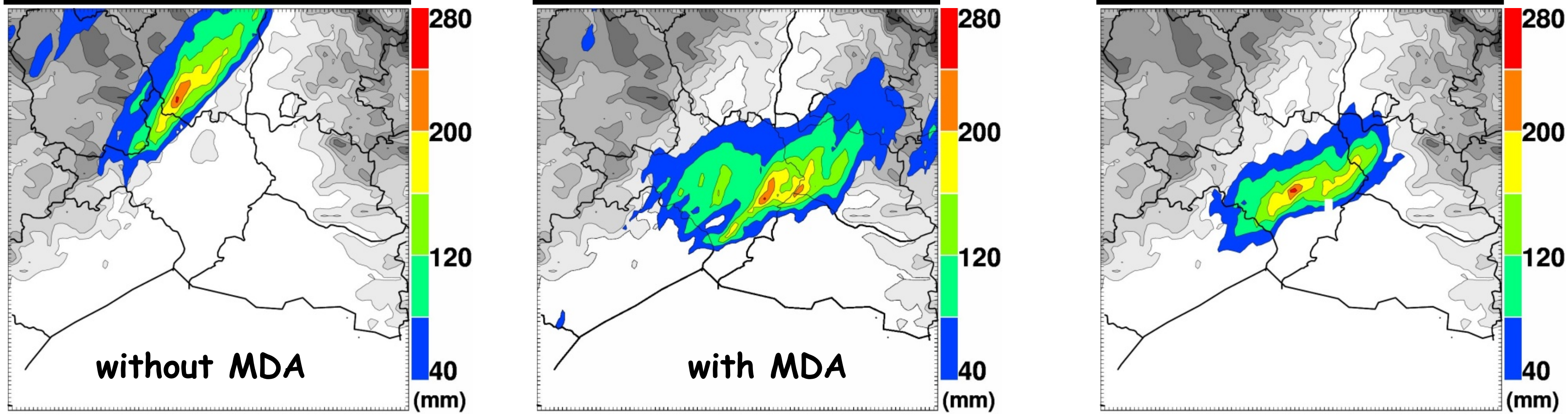


Nuissier et al, 2008; Ducrocq et al, 2008

Sensitivity of high-resolution forecasts

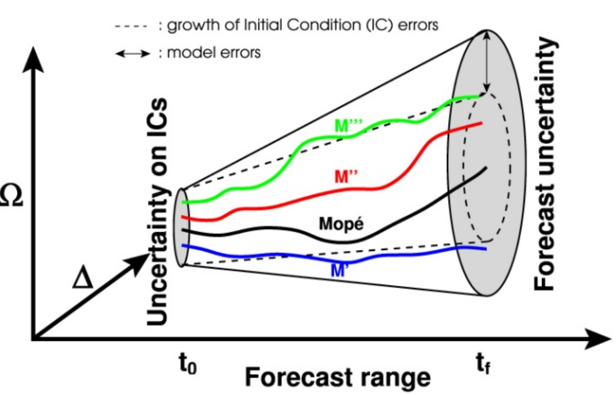
Strong sensitivity in terms of QPFs with non-hydrostatic fine-scale numerical models

MESO-NH simulation | MESO-NH simulation | RADAR observations



Gard flooding, 8-9 sept. 2002 (Ducrocq *et al.* 2008, Nuissier *et al.* 2008)

MDA=Mesoscale Data Assimilation



Lorenz 1963:

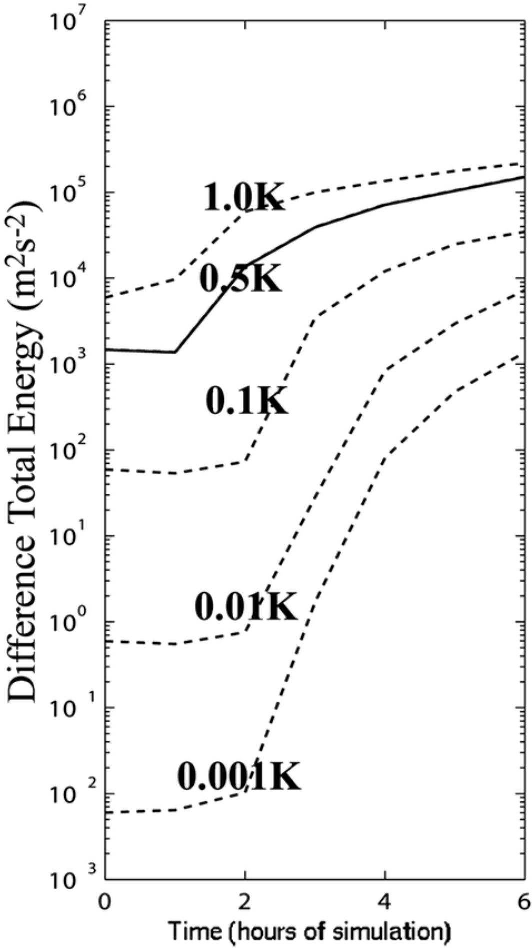
– the chaotic nature of the atmospheric dynamics leads to the unavoidable uncertainty on Numerical Weather Prediction

– forecast error would grow faster at smaller scales when the initial state estimate are improved

– therefore, increasingly rapid error growth → inherent finite limit to the predictability

Convective-scale predictability: scientific issues

- Major results from Hohenegger *et al.*, Zhang, Rotunno, Snyder *et al.*,…
  - small errors grow faster (**non-linear** behaviour).
  - errors amplify faster in high-resolution **convection-resolving simulations.**
  - **moist convection** is the primary mechanism for forecast error growth at small scale.
  - **Mesoscale data assimilation** can lead to improved and more realistic forecasts → however we need to assess the convective-scale predictability
  - **ensemble technique** is well established at synoptic-scale, but suitable for convection-resolving scales?
- Research works and dedicated methods are needed to assess the convective-scale predictability !!
  - Quantify uncertainty sources at convective-scale
  - Initial perturbation generation ?
  - Study the propagation of uncertainties in the hydrometeorological forecasts.



Zhang et al, JAS 2003

Outlines

- Motivations and scientific issues
- Impacts of model parameterizations
  - Sensitivity to physical processes and dynamics
  - Case studies with AROME and Meso-NH models
- Impacts of meso-scale initial conditions
  - Assimilation of radar data (Doppler velocities and reflectivities)
  - Case studies with AROME model
- EPS approach for hydrometeorological forecasts
  - Probabilistic evaluation
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- Synthesis and future plans

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The non-hydrostatic numerical tools at Météo-France

- **AROME** and **Meso-NH** are the two non-hydrostatic mesoscale numerical models developped and used at Météo-France, either in a research mode or for operations, or both.

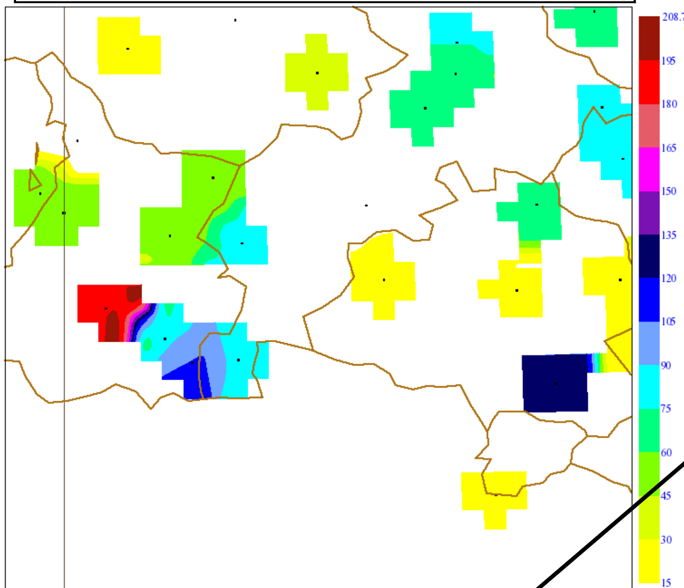
- Some basic characteristics include:

Model	**Resolution / Vertical levels**	**Equations / Temporal scheme**	**Grid**
AROME	2.5 km / 60 lev.	Semi-implicit / **Semi-Lagrangian**	**spectral**
Meso-NH	LES → large-scale	**Eulerian anelastic** / Explicit « leapfrog »	**Grid point**

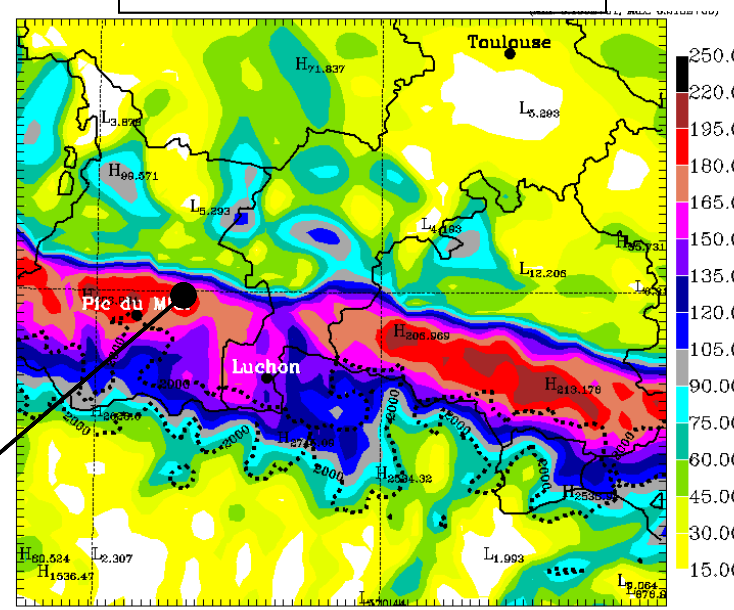
- Both models share the same physics package including among others:
  - a bulk microphysical scheme *(Caniaux et al., 1994 ; Pinty and Jabouille, 1998) governing the equations of 6 prognostic water variables : water vapour, cloud water, rainwater, primary ice, graupel and snow.*
  - The turbulence parameterization modelises the three-dimensional turbulent fluxes based on a 1.5-order closure (*Cuxart et al., 2000*)

Fine-scale simulations of Xynthia winds

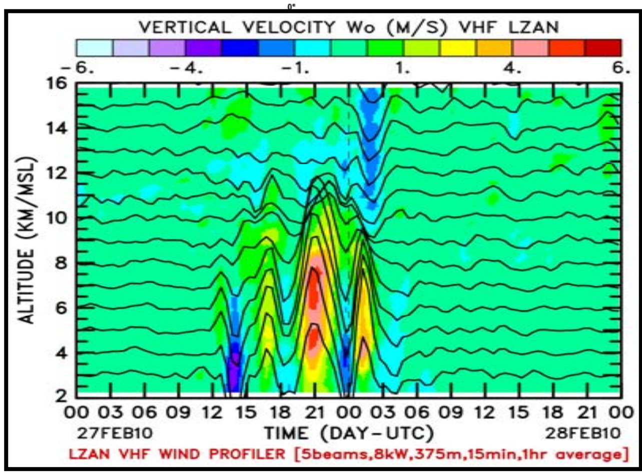
OBSERVATION Max=209km/h



AROME Max=213km/h



10m gust wind (km/h) 28 Feb. 2010 at 21 UTC
(Courtesy of C. Lac)

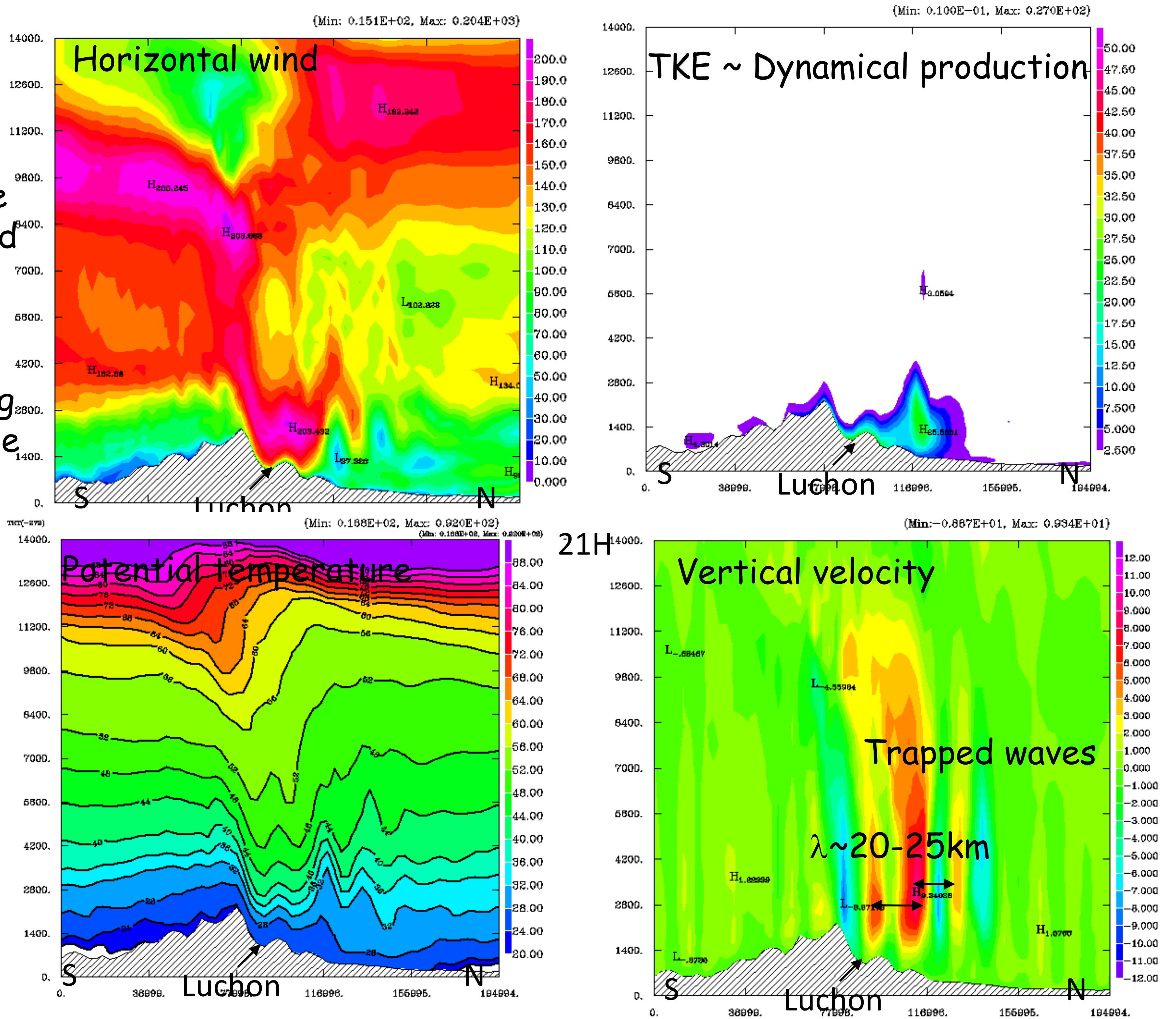


Lannemezan wind profiler shows a structure of trapped gravity waves

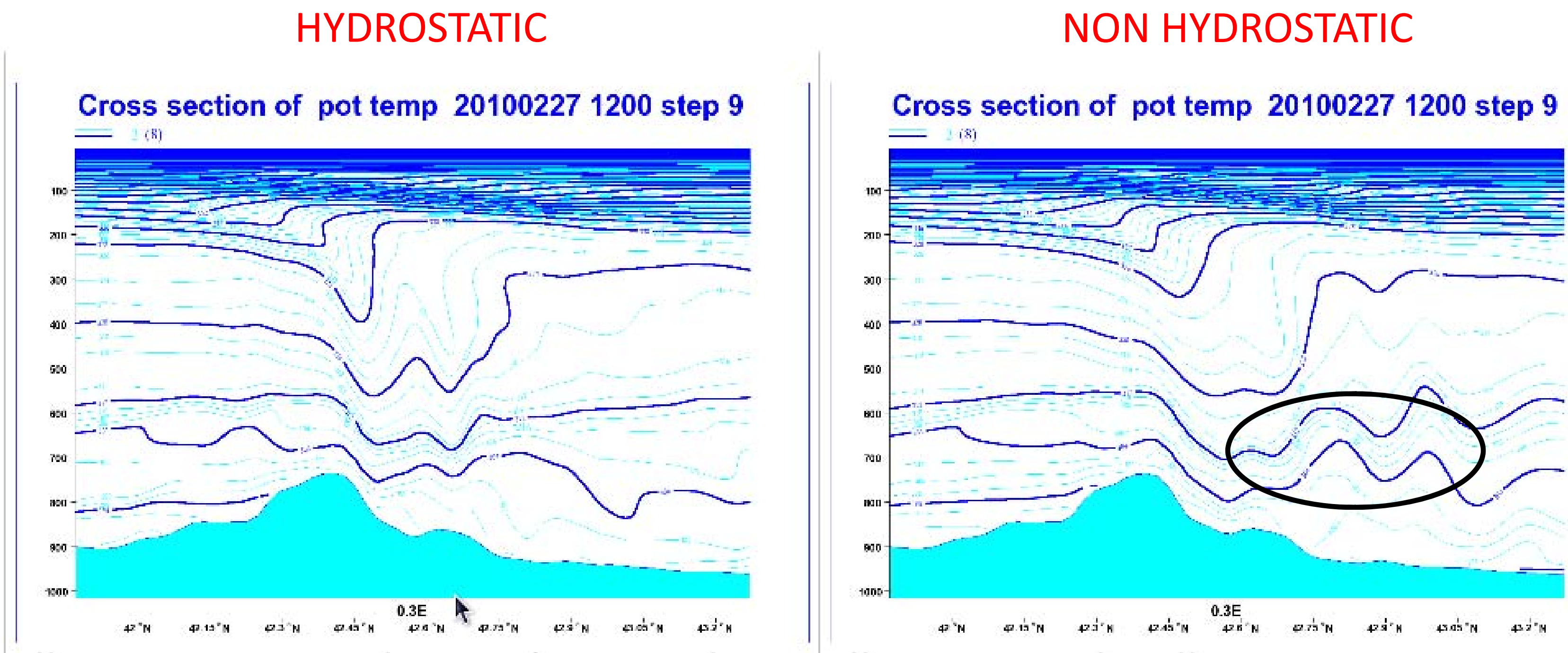
Good forecast on the Pyrenees with AROME, with a band of strong winds on the north of the Pyrenees in the South wind

AROME : Structure of trapped gravity waves inducing the strong wind in the North valleys

Courtesy of C. Lac (CNRM)



Sensitivity to dynamics : hydrostatic vs. non-hydrostatic



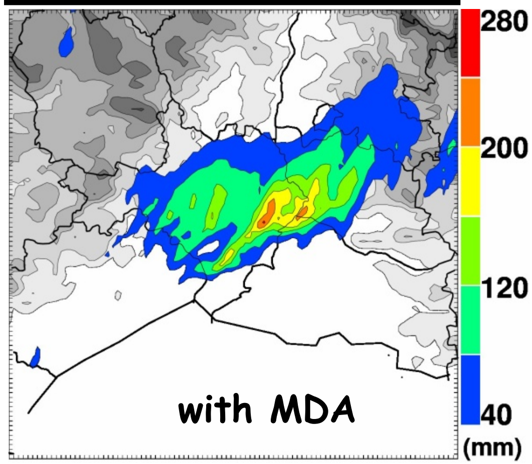
Potential temperature θ 27 Feb. 2010 at 10 UTC (Courtesy of C. Lac)

The structure of low level trapped waves is only reproduced with the non hydrostatic assumption.
In Hydrostatic, wind in the north valleys is weaker (80 km/h instead of 120 km/h) : Positive impact of the NON HYDROSTATISM

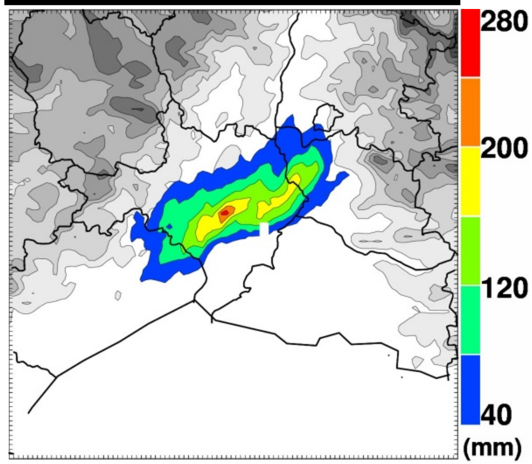
Sensitivity to microphysical processes

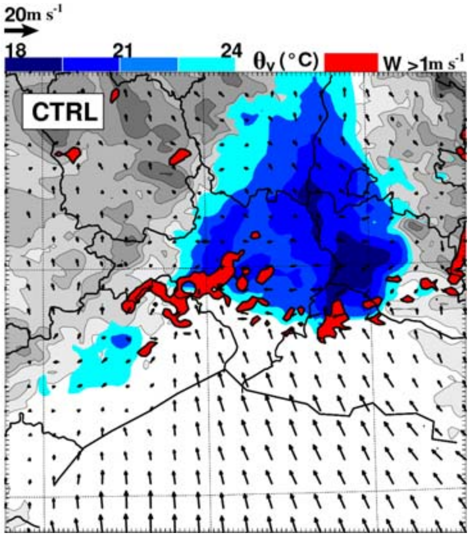
<u>Gard flooding, 8-9 sept. 2002</u> (Ducrocq *et al.* 2008, Nuissier *et al.* 2008)

MESO-NH simulation

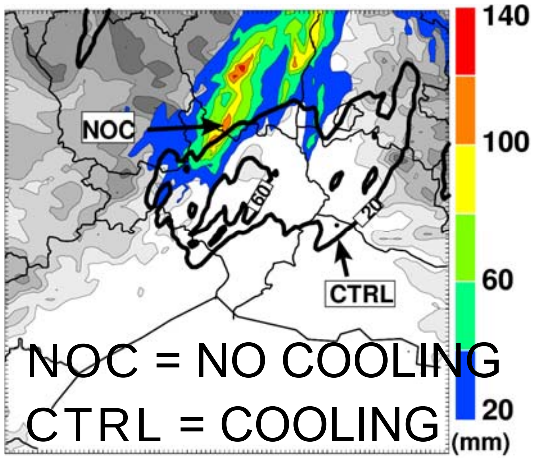


RADAR observations





MDA=Mesoscale Data Assimilation

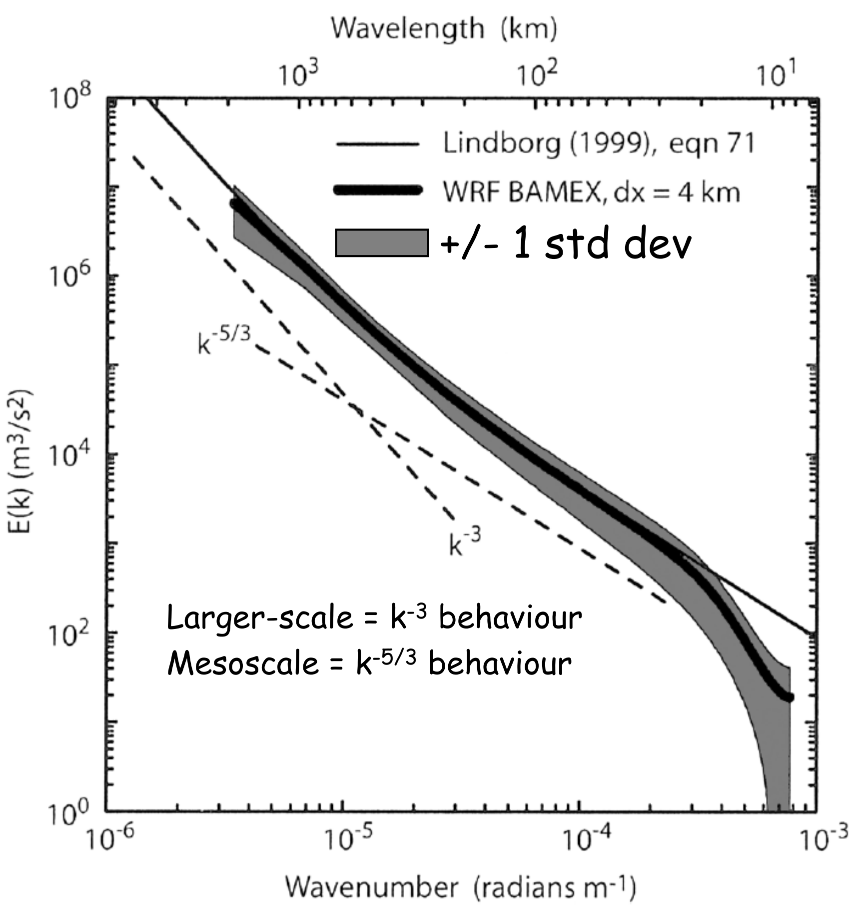


- The low-level cold pool induced by rainfall evaporation play a role in blocking and forcing the warm and moist low-level jet to lift.

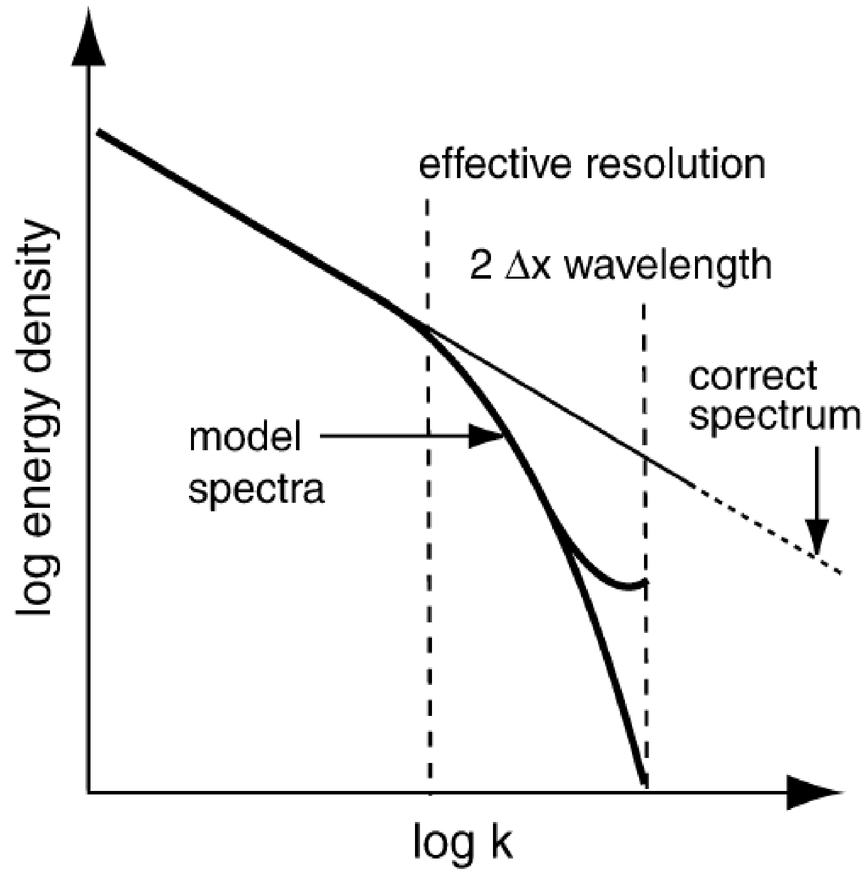
- The NOC experiment clearly shows that the simulated surface rainfall is significantly shifted northwards when cooling is removed.

An other evaluation approach: kinetic energy spectra

- Spectral analysis is a powerful tool to evaluate mesoscale NWP models:
  - ability of non-hydrostatic mesoscale models to reproduce kinetic energy spectra
  - direct assessment of the true resolution (effective) of NWP models



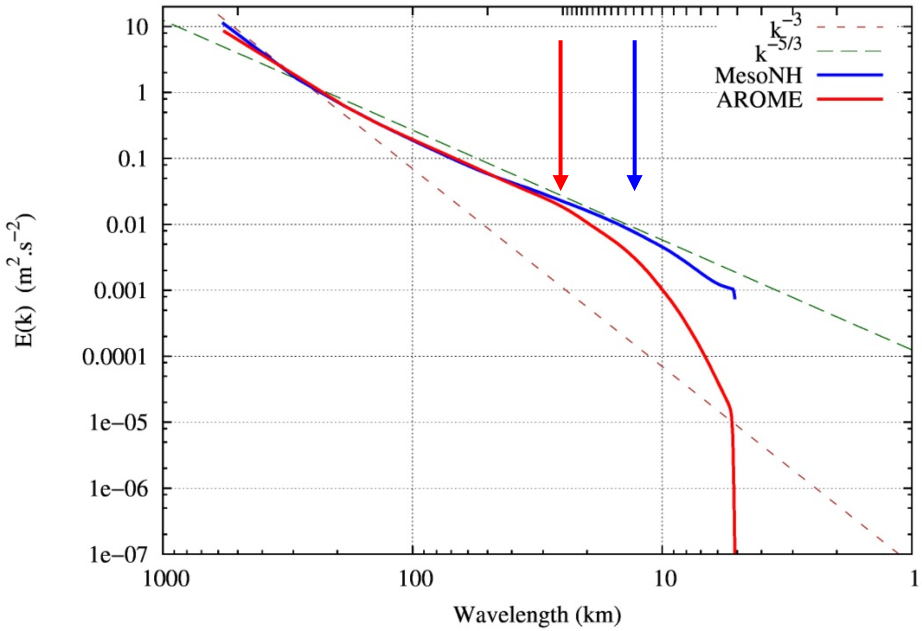
Spectra from the 4-km WRF BAMEX forecasts from 5 May to 14 Jul 2003 (from Skamarock 2004)

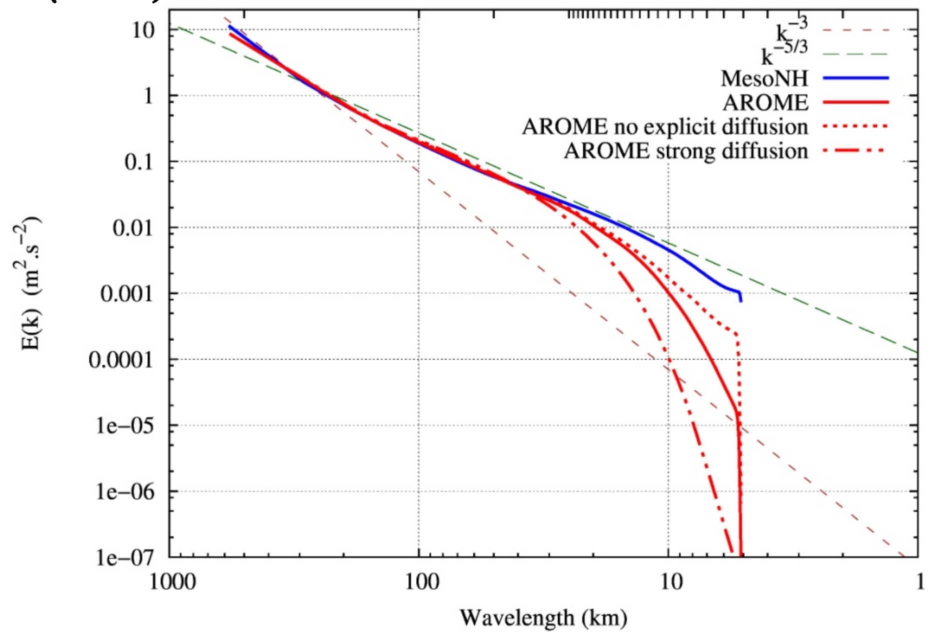


Impact of diffusion

- Example of comparison between AROME and Meso-NH spectra for convective cells over plain in the **free troposphere**, averaged over a 4-h period.

Courtesy of D. Ricard (CNRM)





- The **effective resolution** for Meso-NH is **finer** about 5-6 Δx (Δx=2.5 km). Moreover the slope of the spectral tail is **steeper** for **AROME** suggesting **more dissipating effects**.

- Removing explicit dissipation → significant damping remains due to **implicit diffusion of the SL scheme** **(red dotted line)**.

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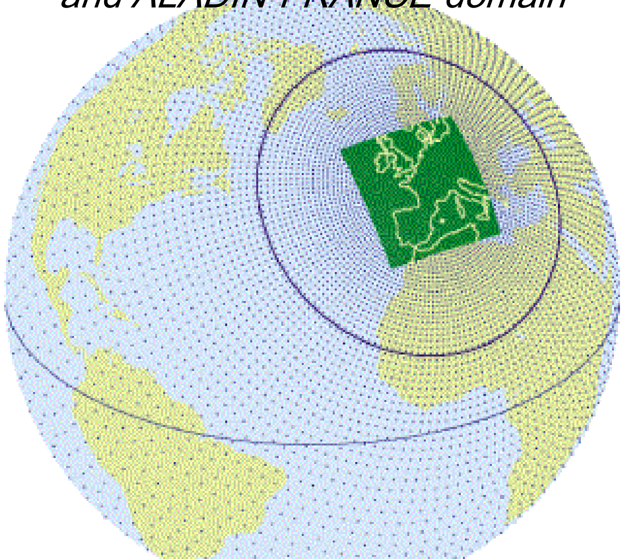
The AROME project (1)

AROME model has completed the French NWP system since the end of 2008 :

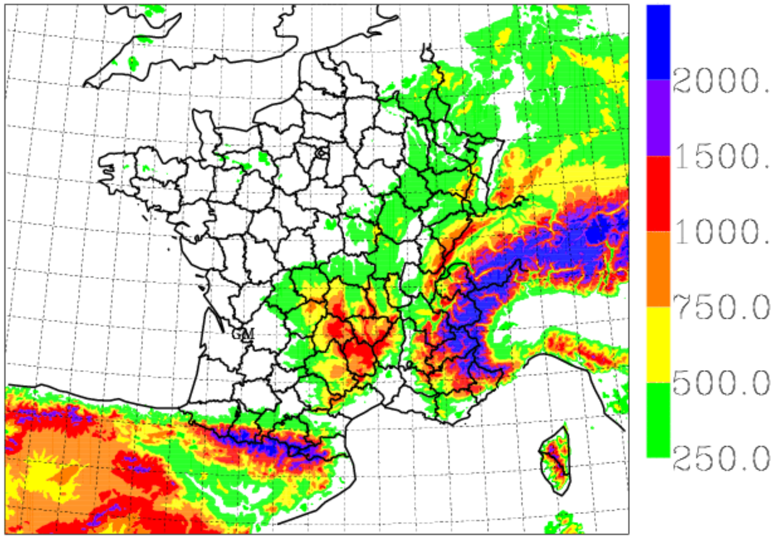
- ARPEGE : global model (10 km over Europe)
- ALADIN-France : regional model (10km)
- AROME : meso scale model (2.5km)

Aim : to improve local meteorological forecasts of potentially dangerous convective events (storms, unexpected floods, wind bursts...) and lower tropospheric phenomena (wind, temperature, turbulence, visibility...).

ARPEGE stretched grid and ALADIN-FRANCE domain



operational AROME France domain



The AROME project (2)

- Means : the AROME software merging research outcomes and operational progress (Seity *et al.*, 2010) :
  - physical package from the Meso-NH research model
  - Non-Hydrostatic version of ALADIN's dynamical core
  - Complete **data assimilation** system adapted from ALADIN's

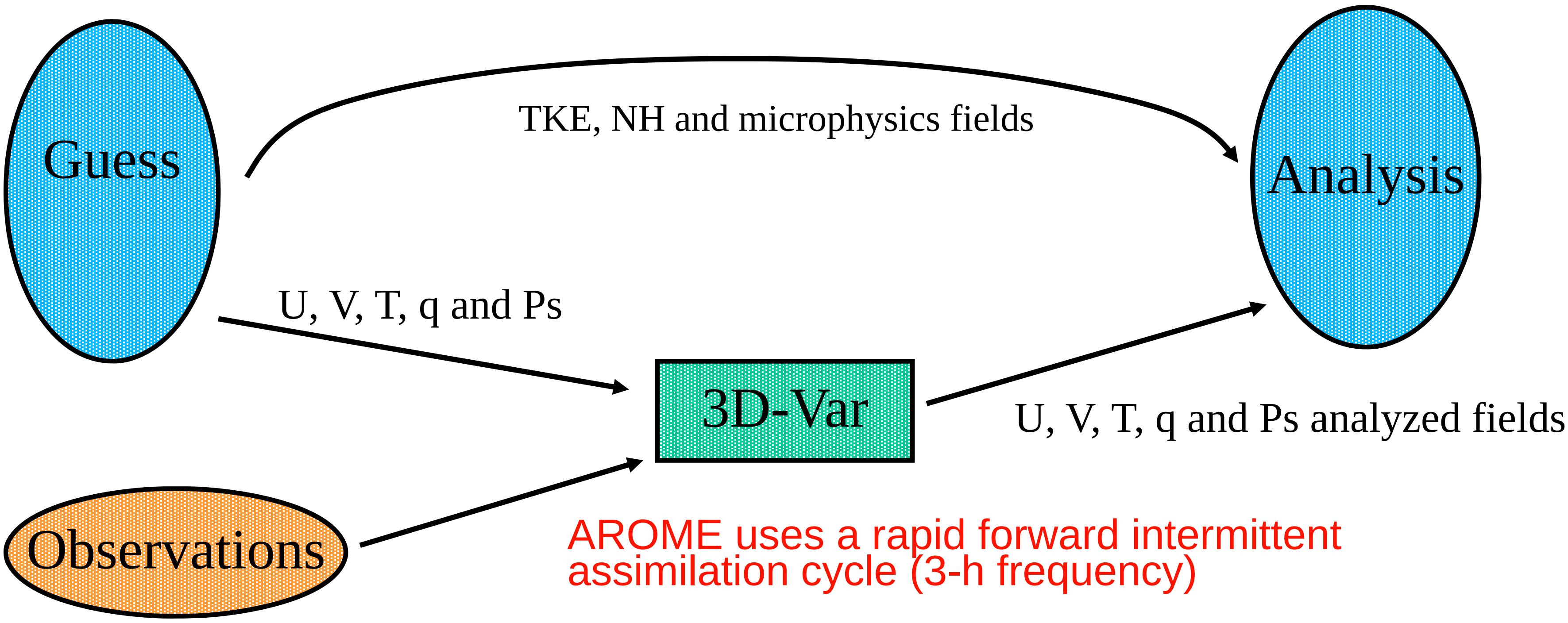
- Benefits of the model: high horizontal resolution (2.5km), realistic representation of clouds, turbulence, surface interactions (mountains, cities, coasts, ...)

- Benefit of the assimilation : use of satellites at higher resolution, **radars**, regional network...

The AROME 3D-Var assimilation scheme

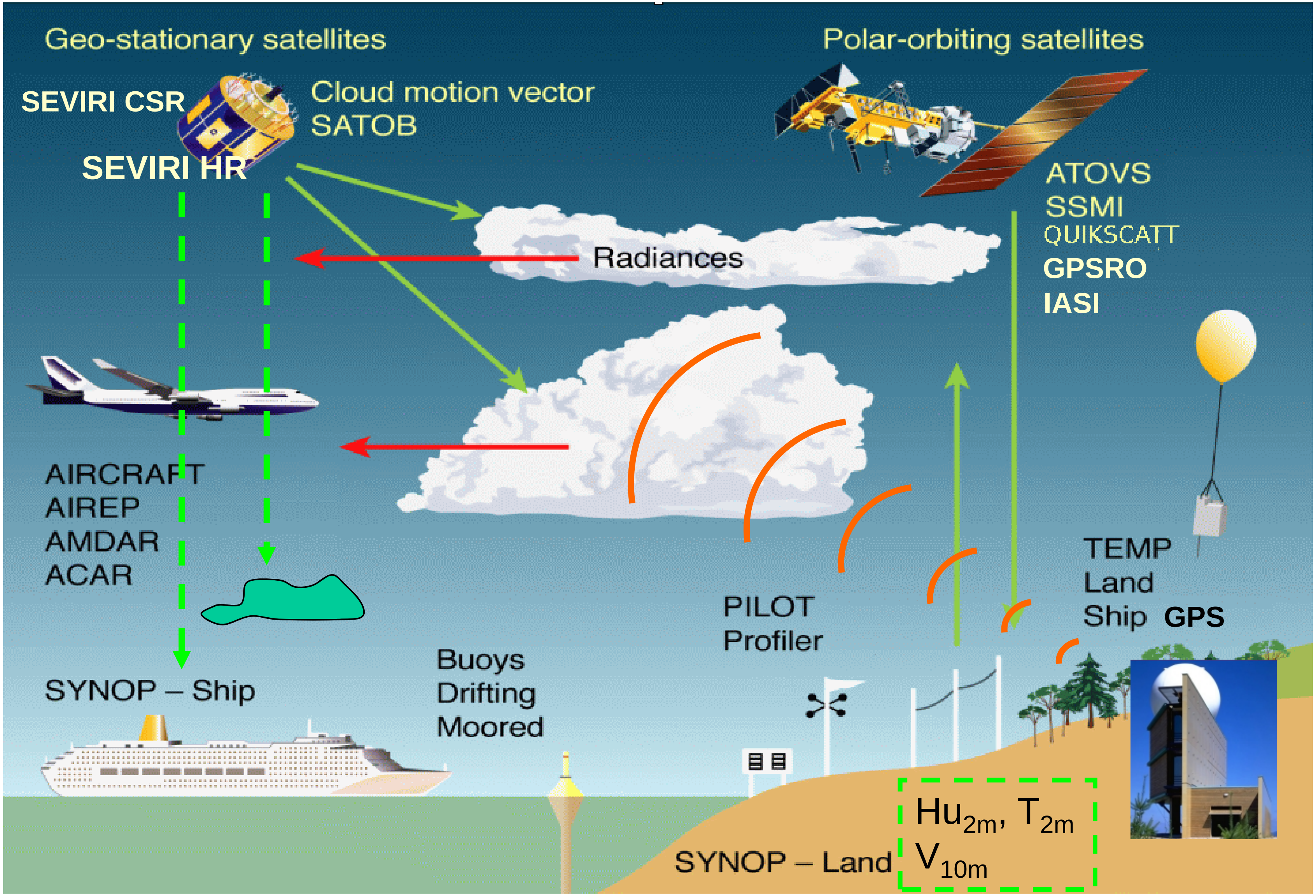
Control variable : vorticity, divergence, temperature, specific humidity and surface pressure :

- U, v, T, q and P_S are analysed at the model resolution (2.5 km)
- Other model fields (TKE, Non-hydrostatic and microphysics fields) are cycled from the previous AROME guess



AROME uses a rapid forward intermittent assimilation cycle (3-h frequency)

Assimilated data



ARPEGE → **ALADIN** (SEVIRI HR instead of CSR, Hu_{2m},T_{2m},V_{10m}) → **AROME** (+ radars + more GPS)

Radar data in AROME

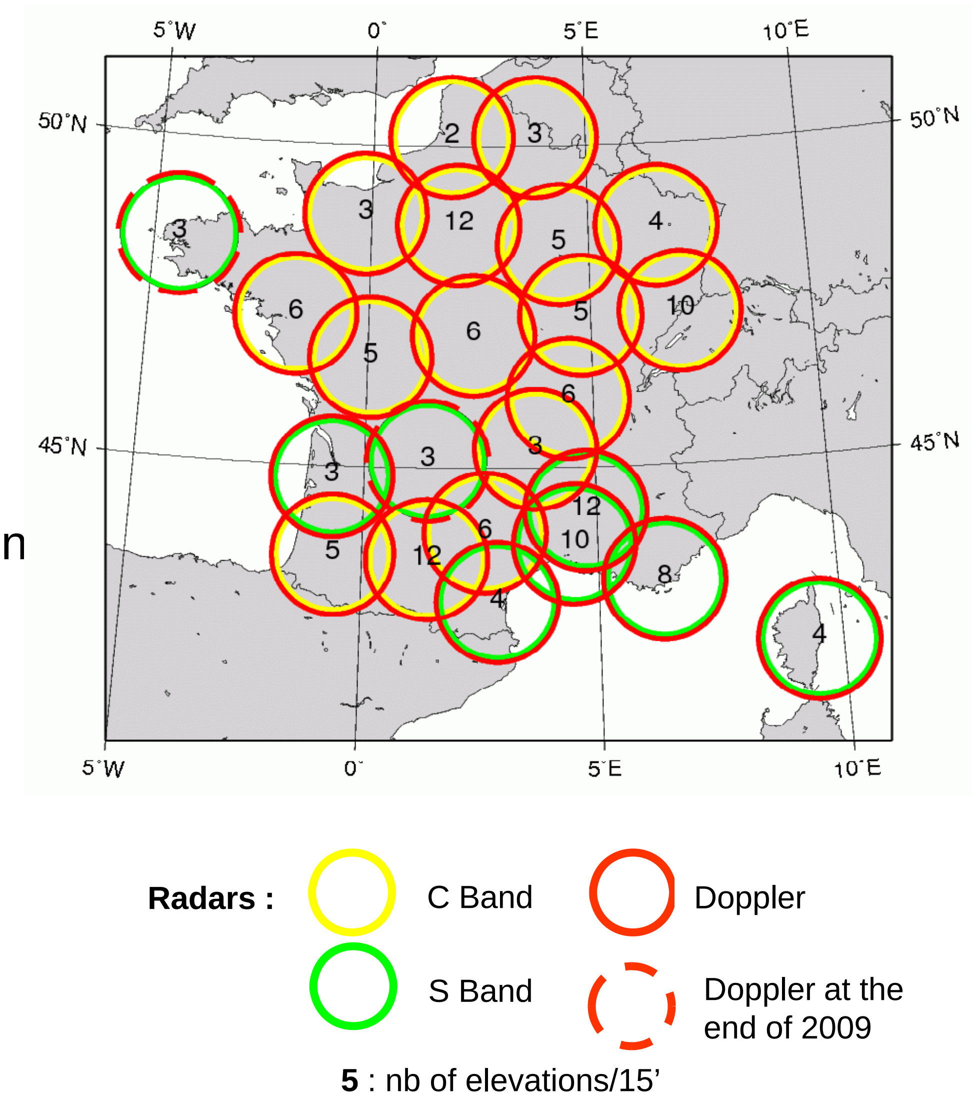
The ARAMIS radar network

• 24 radars (incl.22 Doppler), performing between 2 and 12 PPIs/15’

In AROME:

• **Radial velocities** of 15 Doppler radars currently assimilated operationally. The remaining 7 are often contaminated by non meteological targets, but should be included soon thanks to the use of new detection algorithm.

• **Reflectivity** of every radars assimilated operationally since April 2010.



Assimilation of radar data in AROME

- Assimilation of Doppler winds in AROME (***Montmerle and Faccani, 2009***) :
  - Radar data are preprocessed before assimilation : (i) velocity dealiasing, (ii) removal of noise and unrealistic echoes, and (iii) data setup.
  - An observation operator (*Salonen et al., 2003; Caumont et al., 2006*) has been developed to simulate radial wind measurements from AROME.
  - Radial velocities are assimilated in the AROME 3D-Var scheme.

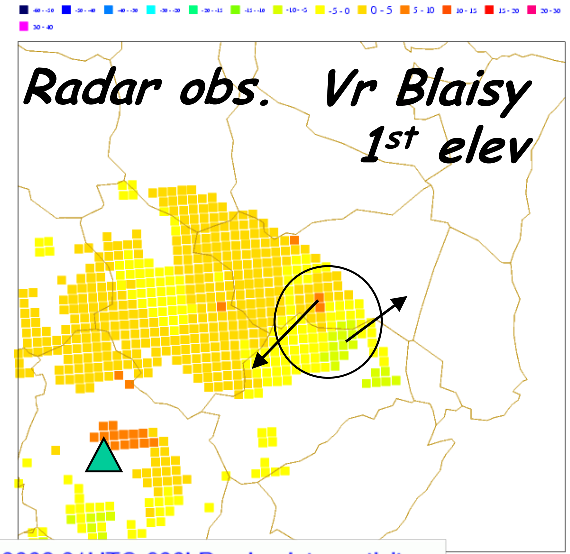
- Assimilation of reflectivities in AROME (***Caumont et al., 2010***)
  - Pseudo-observations are first retrieved from observed reflectivity vertical profiles through a unidimensional (1D) Bayesian retrieval.
  - An observation operator has been coded to simulate reflectivities from AROME.
  - Pseudo-observations of humidity are assimilated in the AROME 3D-Var scheme

Impact of Doppler winds (1)

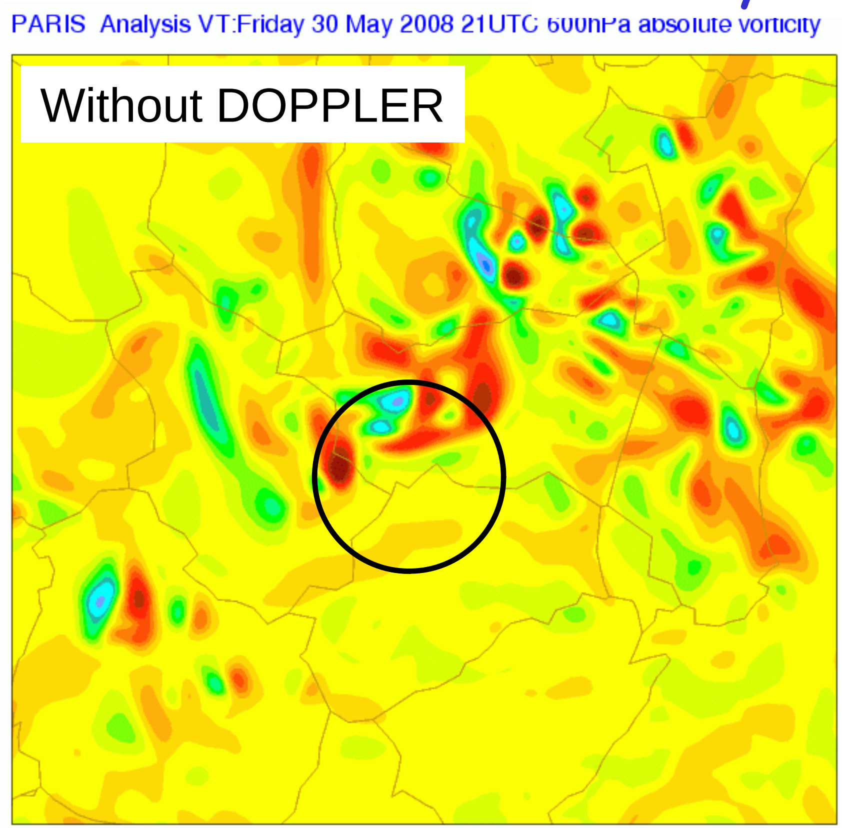
ex: 2008/05/30 case

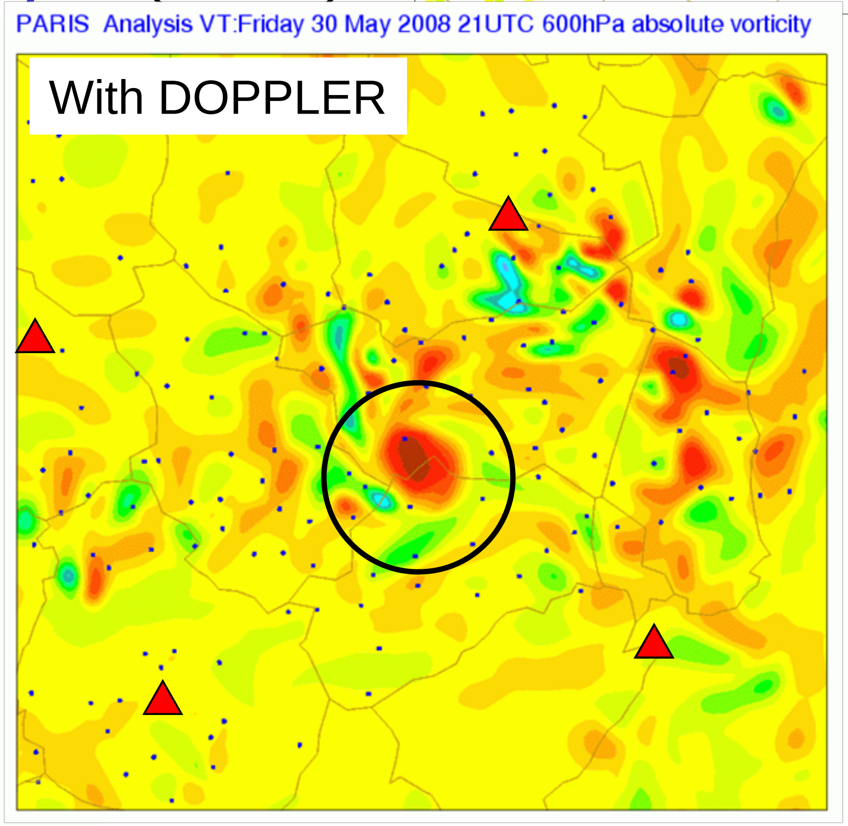
Meso-vortex

Courtesy of T. Montmerle (CNRM)



Vorticity Analysis (600 hPa)



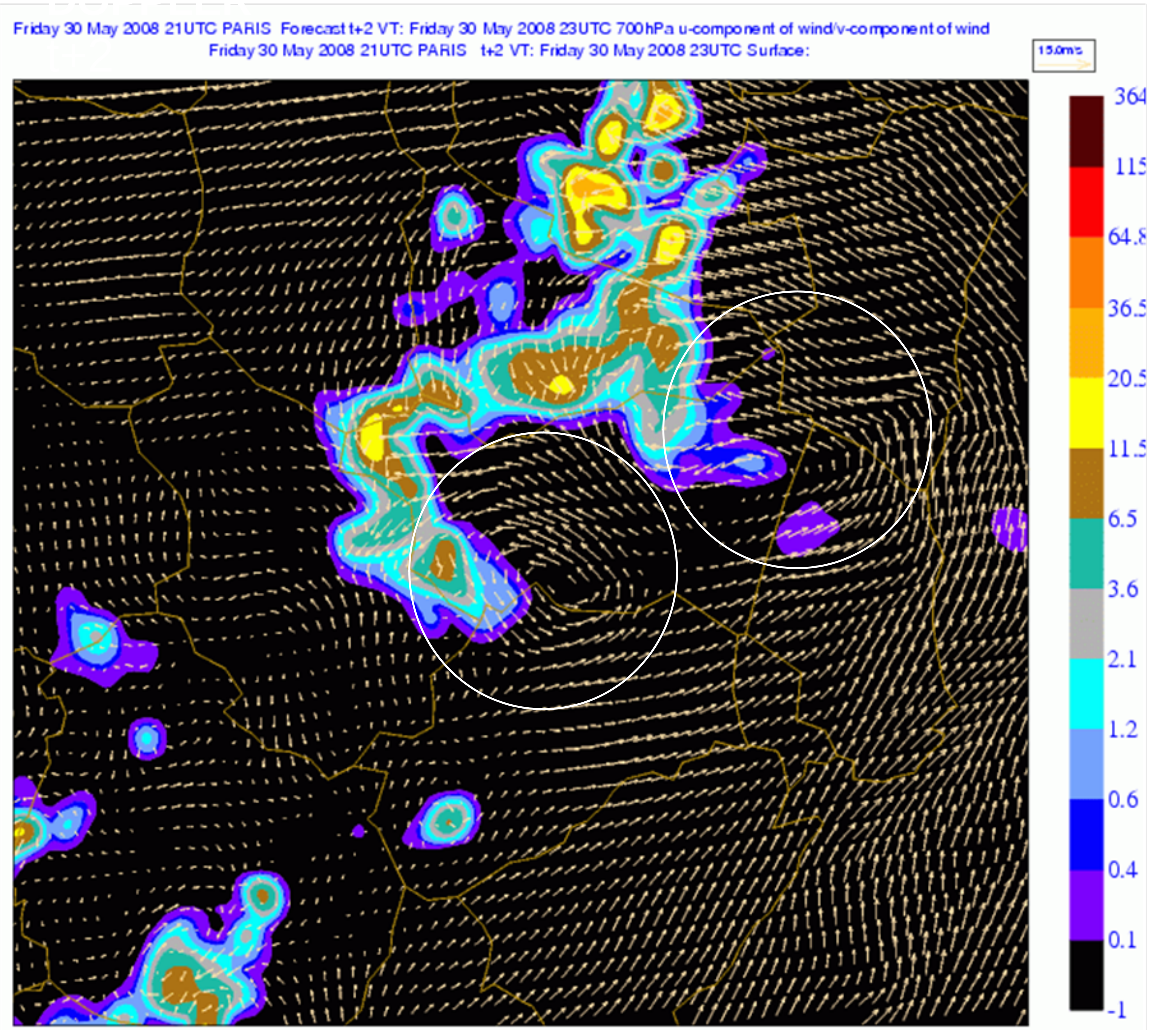


Impact of Doppler winds (2)

ex: 2008/05/30 case

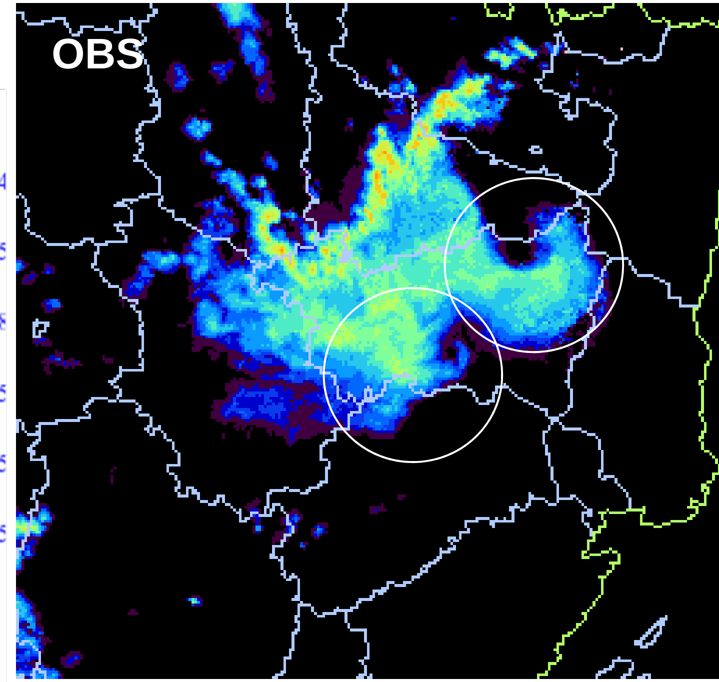
Meso-vortex

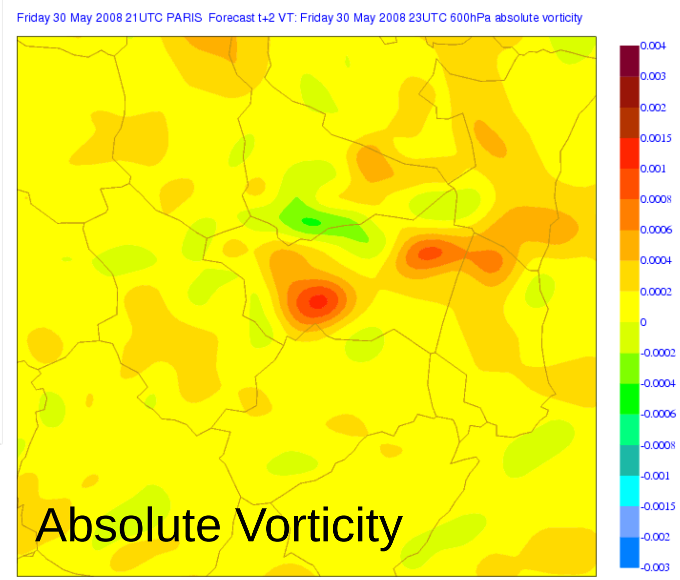
Courtesy of T. Montmerle (CNRM)



Wind at 700 hPa

+ simulated reflectivity at 850 hPa



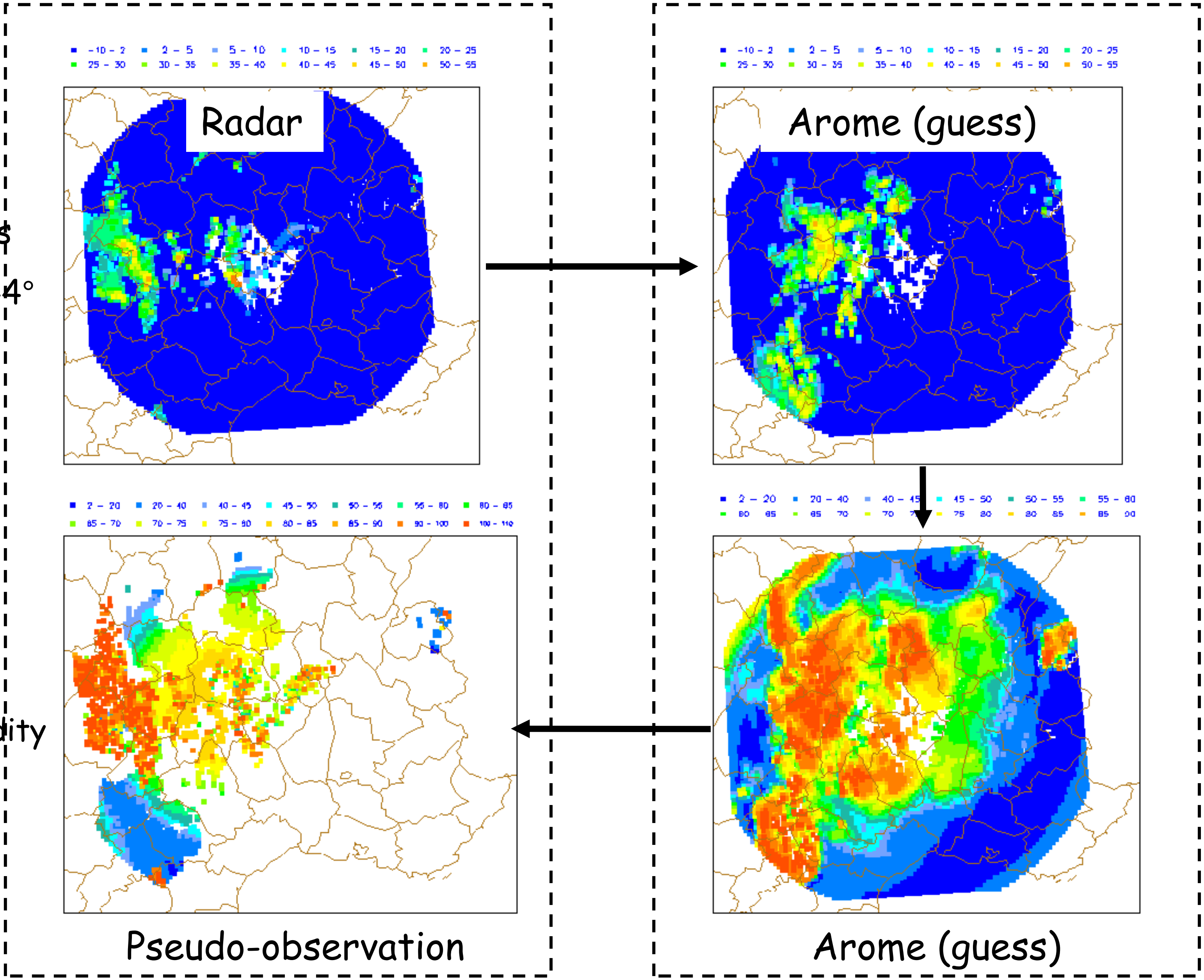


Radar reflectivity assimilation: example of retrieval

Reflectivities

Elevation 0.44°

Relative humidity



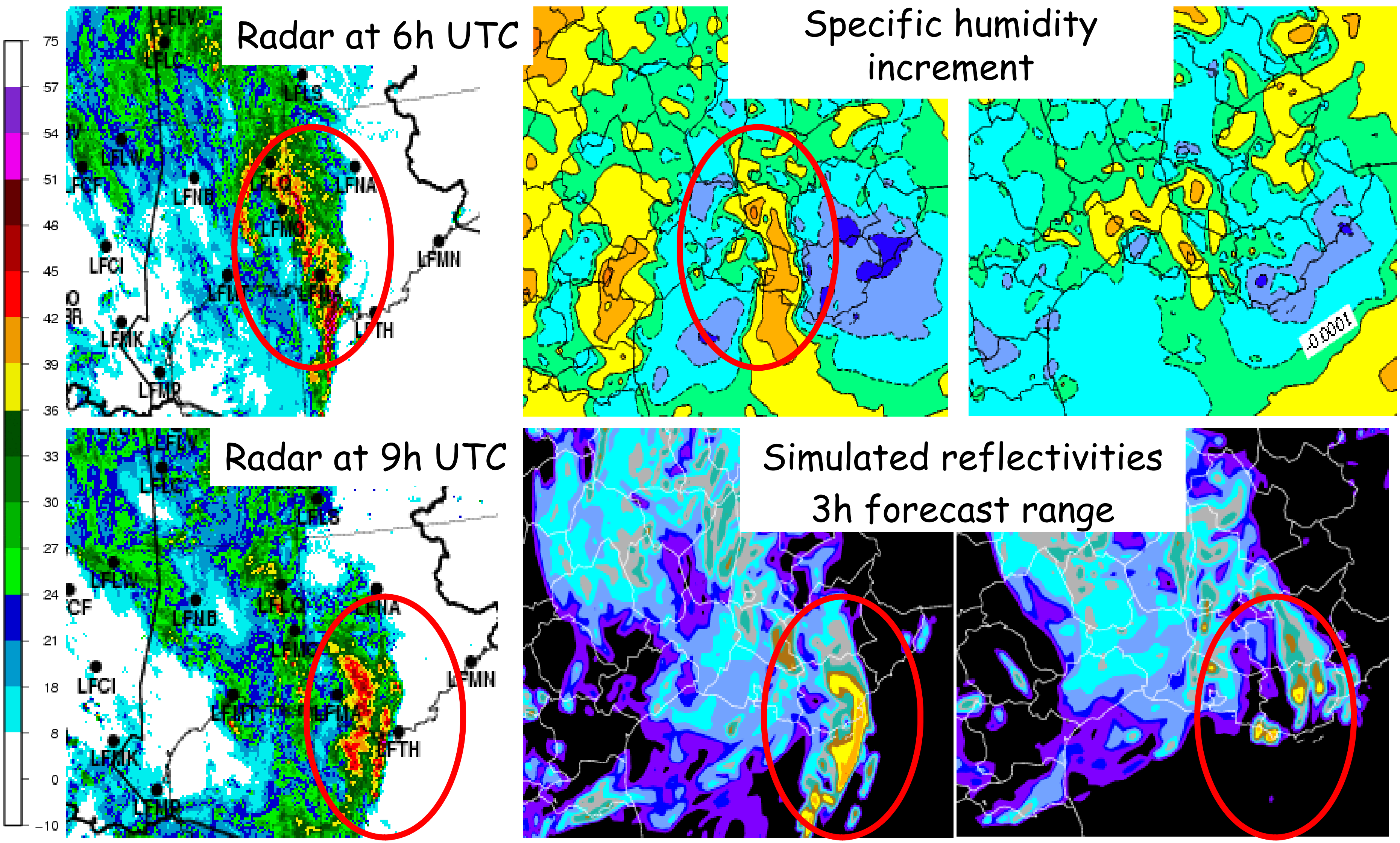
Impact of radar reflectivities

ex: 2008/10/08 case

Convective line over Southeastern France

Courtesy of E. Wattrelot (CNRM)

With reflectivities | Without reflectivities

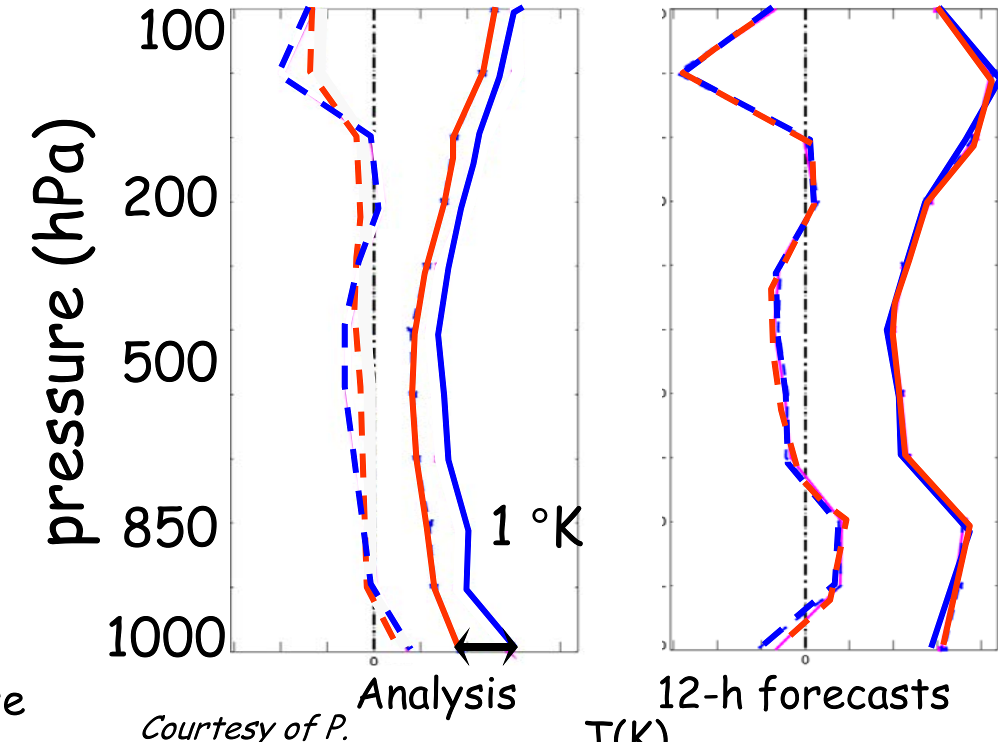


Objective scores: comparisons to radiosondes

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

- 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.

⇒ the general benefit of the AROME analysis appears during the first 12-h forecast ranges, then lateral conditions mostly take over the model solution



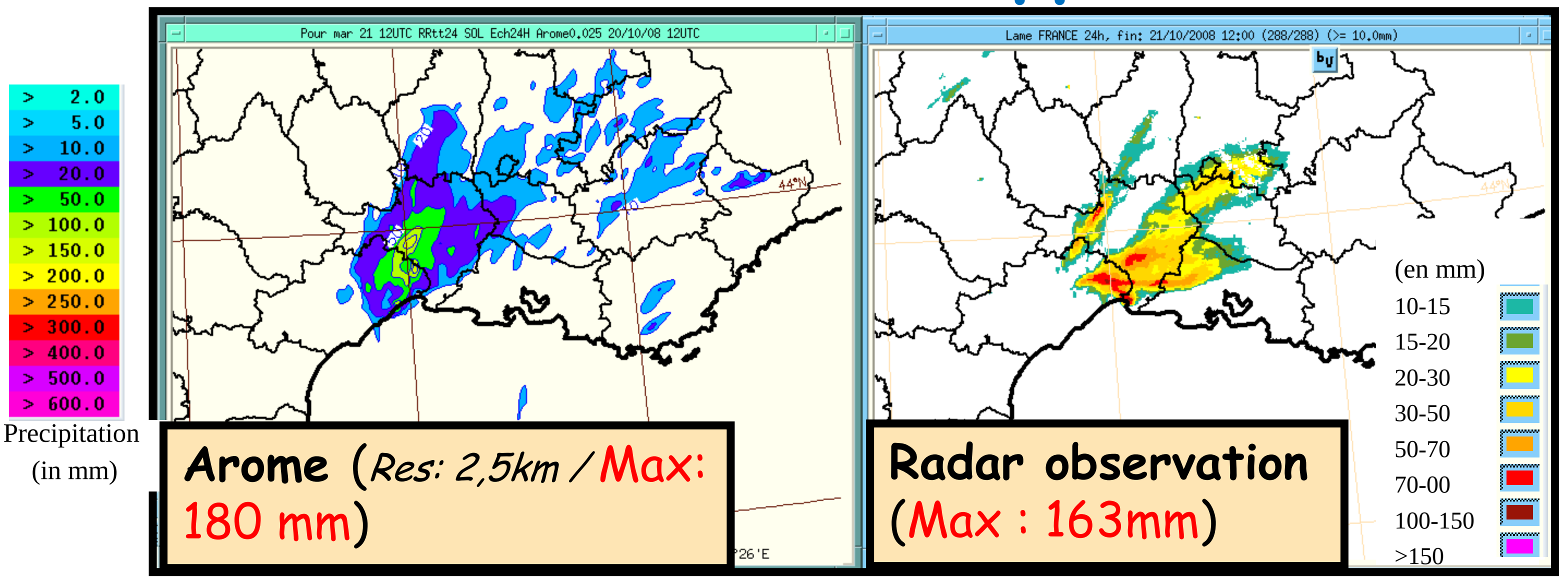
Vertical profiles of rmse and bias for temperature compared to radiosonde measurements

- - - Bias

——— rmse

Courtesy of P. Brousseau (CNRM)

Why we need a cloud-resolving ensemble approach ?



Courtesy of F. Saix (Météo-France DIRSE)

24-h observed and simulated rainfall, from 20 oct. 2008 at 12h to 21 oct. 2008 at 12h

- Cloud-resolving non-hydrostatic models are able to simulate very realistic features of heavy precipitation events (improvement of mesoscale initial conditions).
- However Quantitative Discharge Forecasts (QDFs) are very sensitive to QPFs, especially for small to medium catchments (~ 1000 km^2).
- Ensemble forecasts are one approach to quantify the uncertainty of hydrometeorological forecasts.

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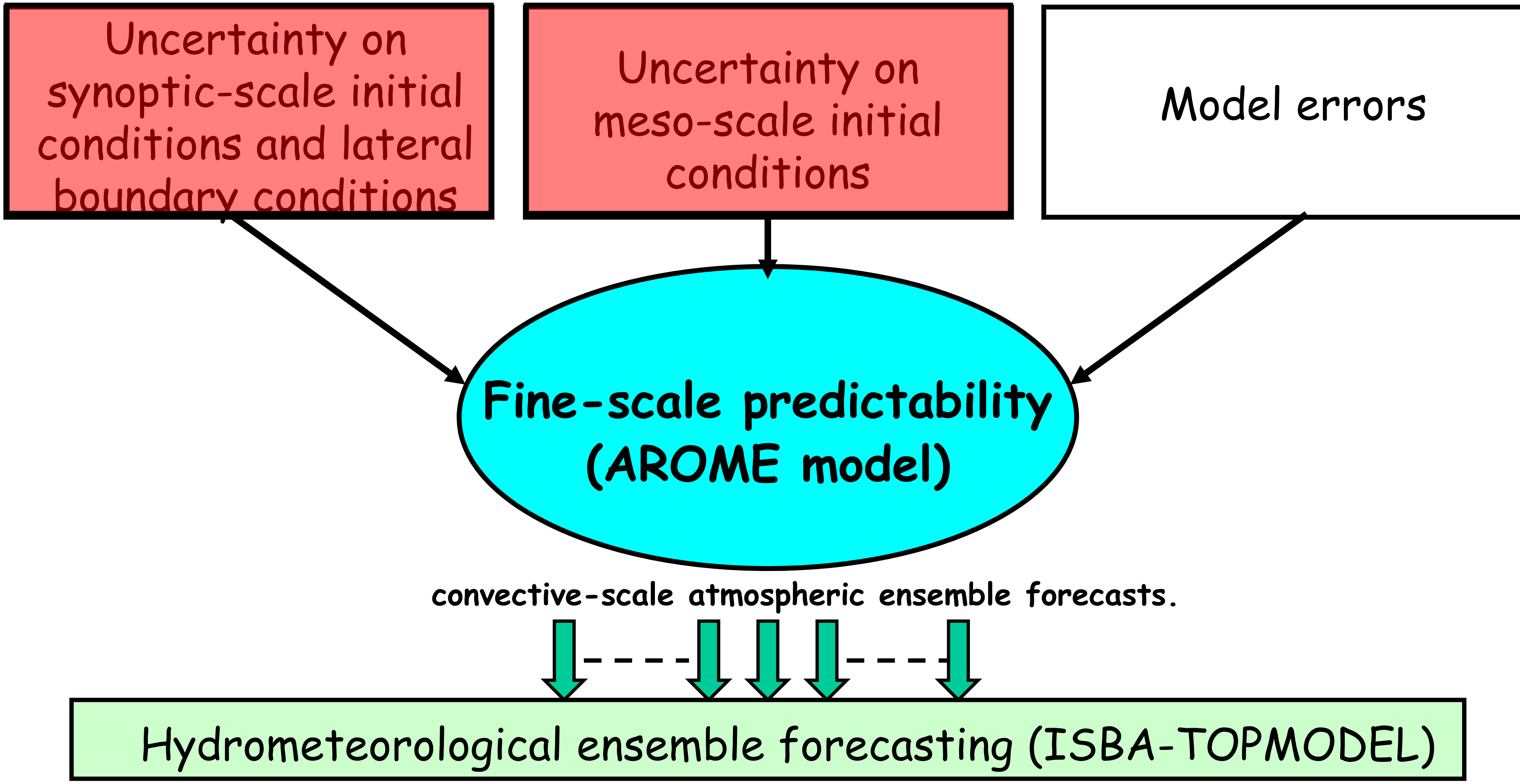
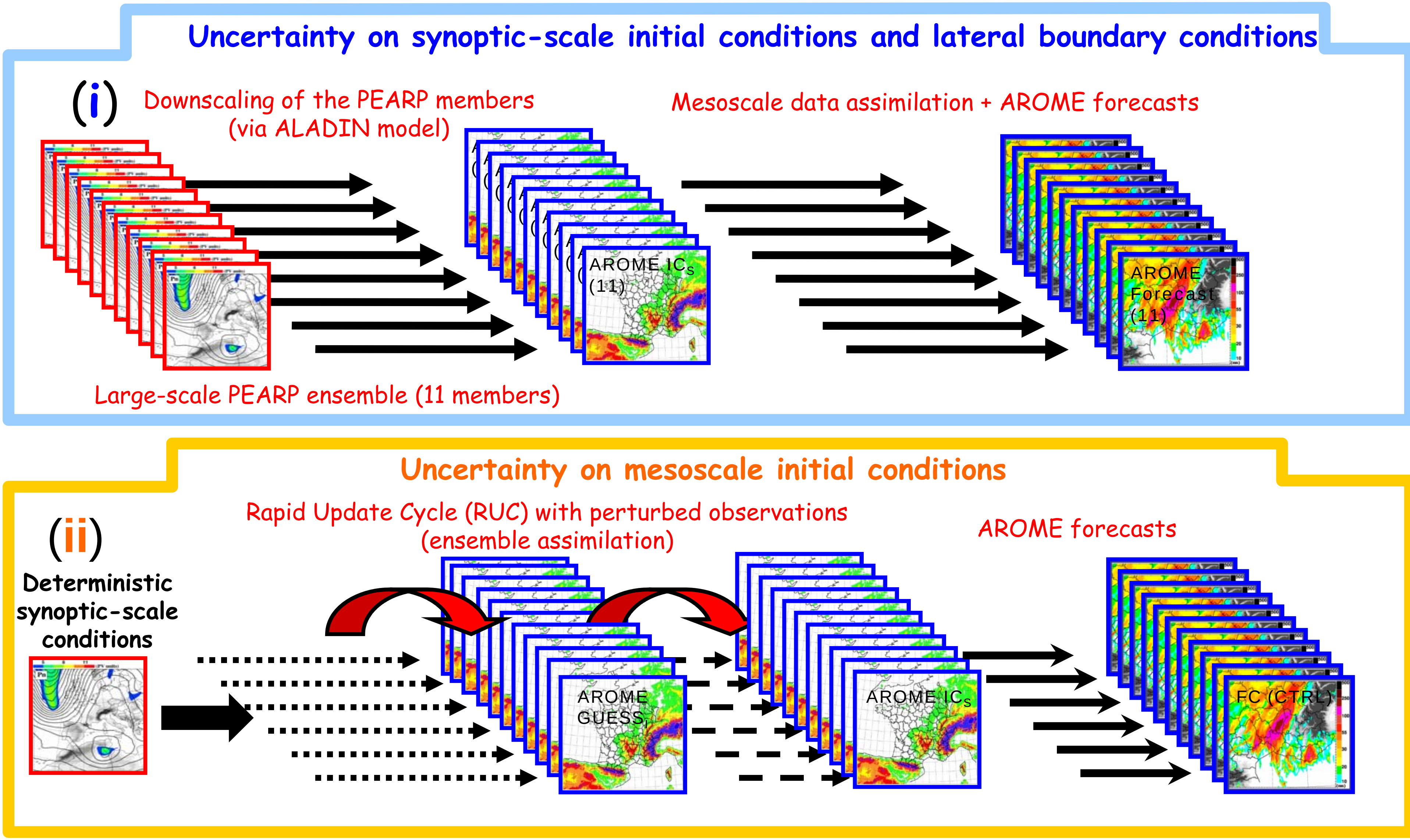
Convective-scale predictability of Mediterranean Heavy Precipitation Events: scientific issues



Convective-scale predictability of HPEs with AROME model



Experimental design – characteristics of the experiments

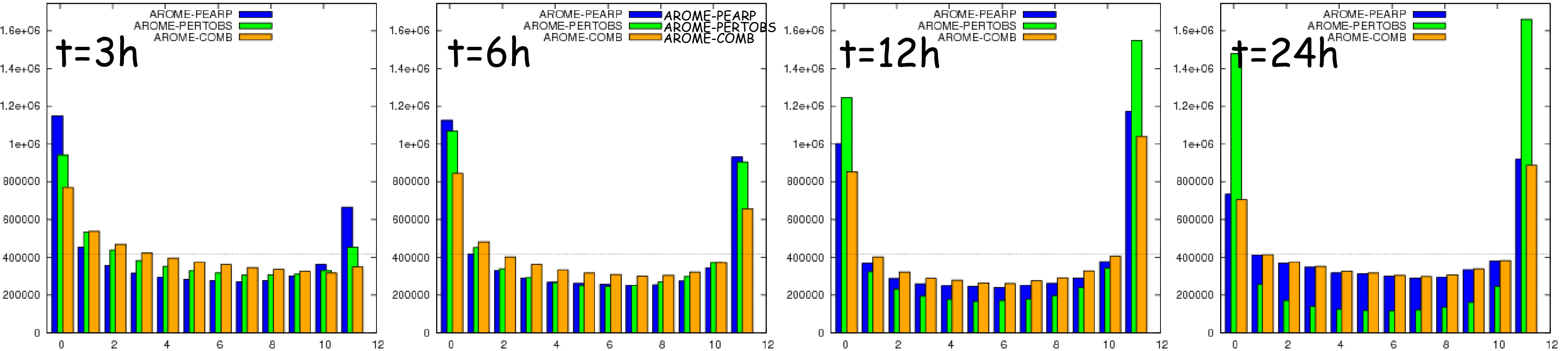
Experiments (nbr of members)	LBC conditions	ALADIN downscaling procedure	AROME data assimilation
AROME-PEARP (11)	PEARP EPS	Dynamical downscaling	Unperturbed obs.
AROME-PERTOBS (11)	ARPEGE deterministic forecast	Deterministic data assimilation cycle	CTRL → unpert. obs P1-P10 → pert. obs
AROME-COMB (11)	PEARP EPS	Dynamical downscaling	CTRL → unpert. obs P1-P10 → pert. obs

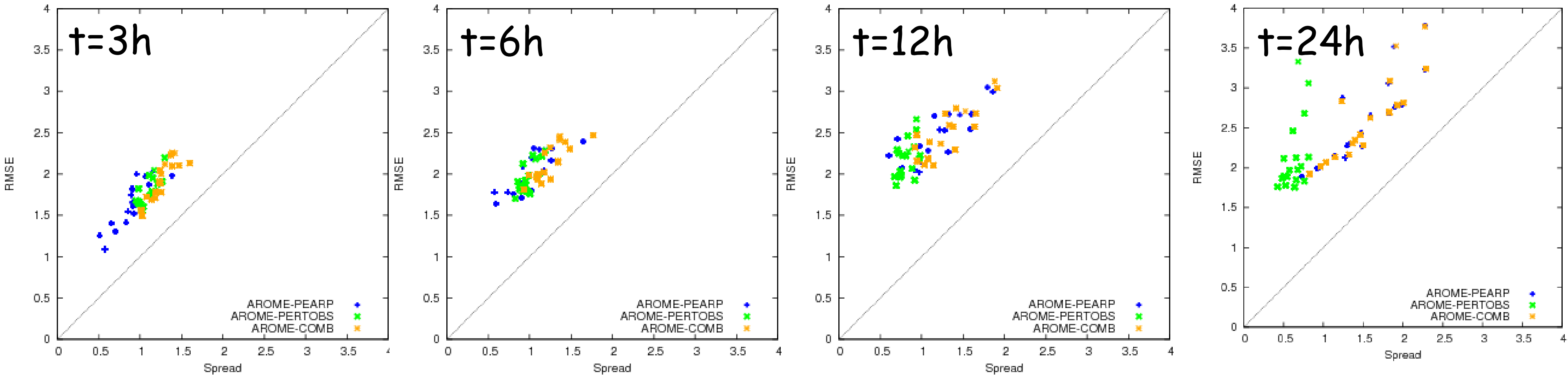
- The impact of uncertainty on **Lateral Boundary Conditions** (LBCs) is assessed coupling AROME with a **global EPS** (PEARP). Convective-scale assimilation is also performed for each member.

- Uncertainty on **convective-scale Initial Conditions** (Ics) is sampled through **ensemble data assimilation** technique (Berre *et al.*, 2006). Every observations are **randomly perturbed**, then assimilated in the AROME's 3D-Var assimilation scheme.

Probabilistic evaluation

- Evaluation period: 05/10/2008 → 05/11/2008
- Rank histograms are shown for 925 hPa wind





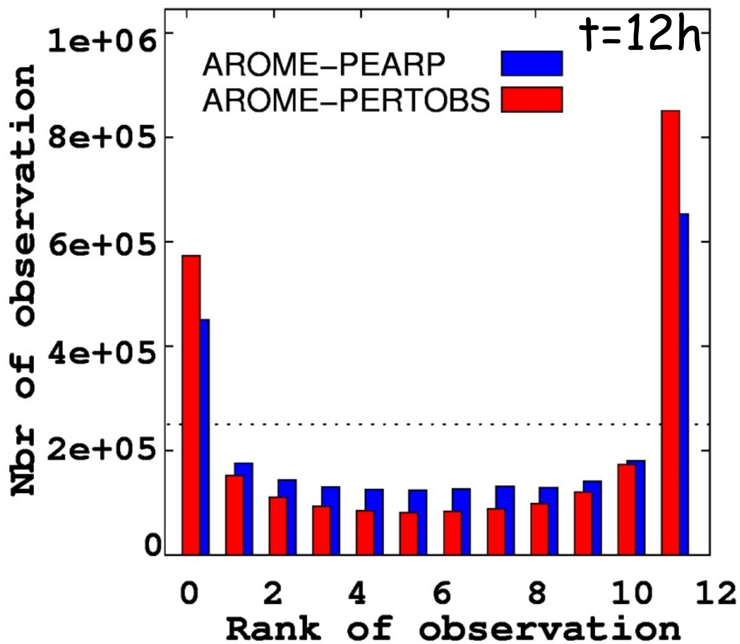
RMSE vs. Ensemble spread

Results of this study are summarised in Vié *et al.*, 2010 (submitted to Mon. Wea. Rev.)

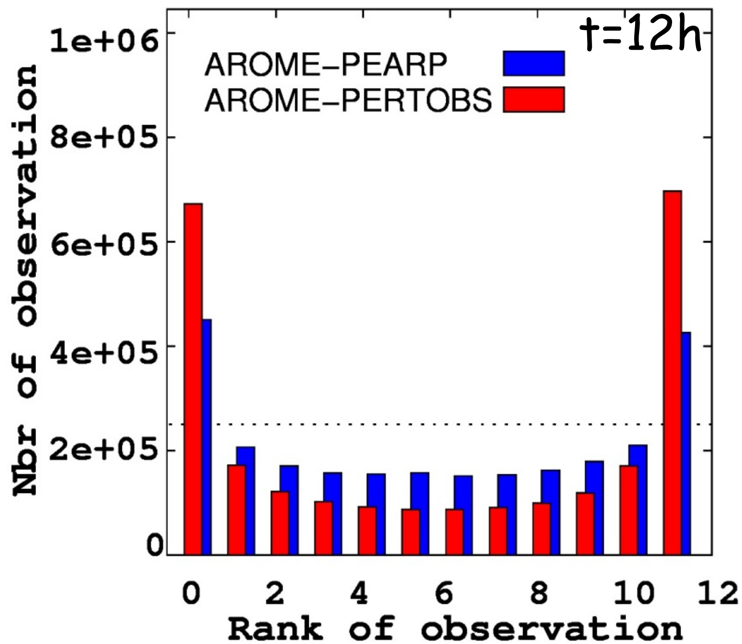
Sensitivity to synoptic-scale conditions

- Days have been partitioned into two categories on the basis of the **synoptic-scale pattern**
  - Several parameters (**Z**, **U**, **mean wind** @ 500 hPa) are considered to partition days

weak synoptic-scale forcing



strong synoptic-scale forcing

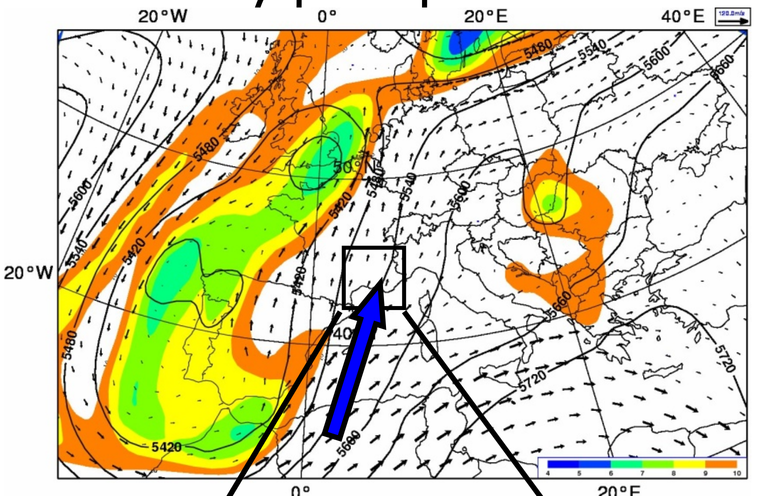


- The U-shape of rank histogram for AROME-PERTOBS ensemble slightly increases during strongly forced days.

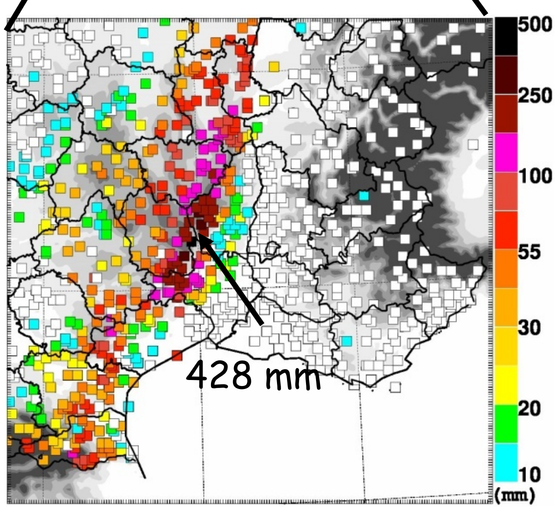
- The AROME-PEARP ensemble performs better than AROME-PERTOBS during strongly forced days.

A case study

The heavy precipitation event :

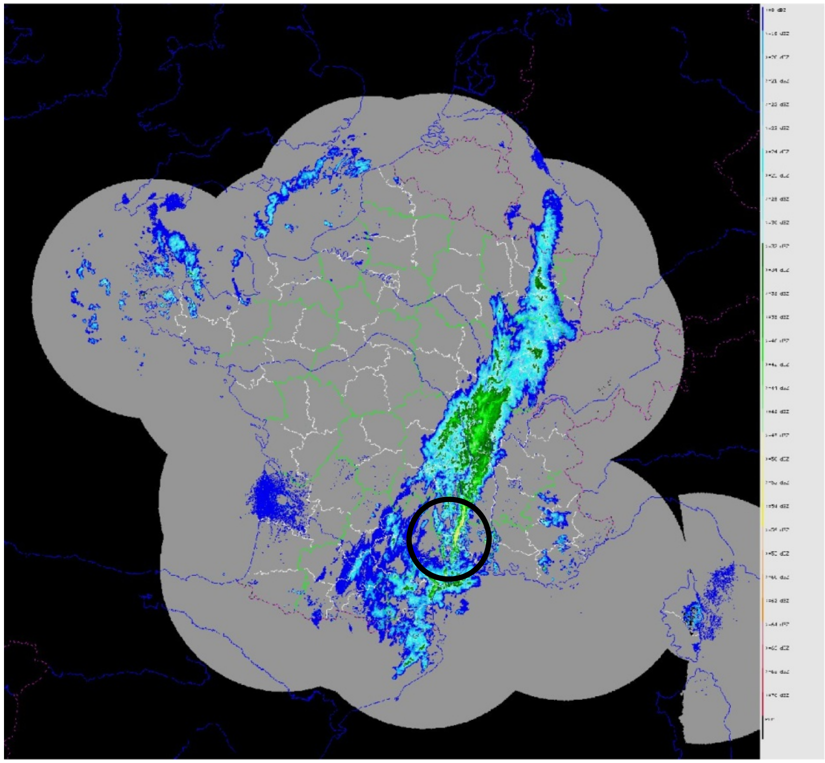


ARPEGE analysis for 1.5 PVU surface height (colour) and winds (arrows) ; 500-hPa height (black lines), 2 Nov. 2008 at 00 UTC



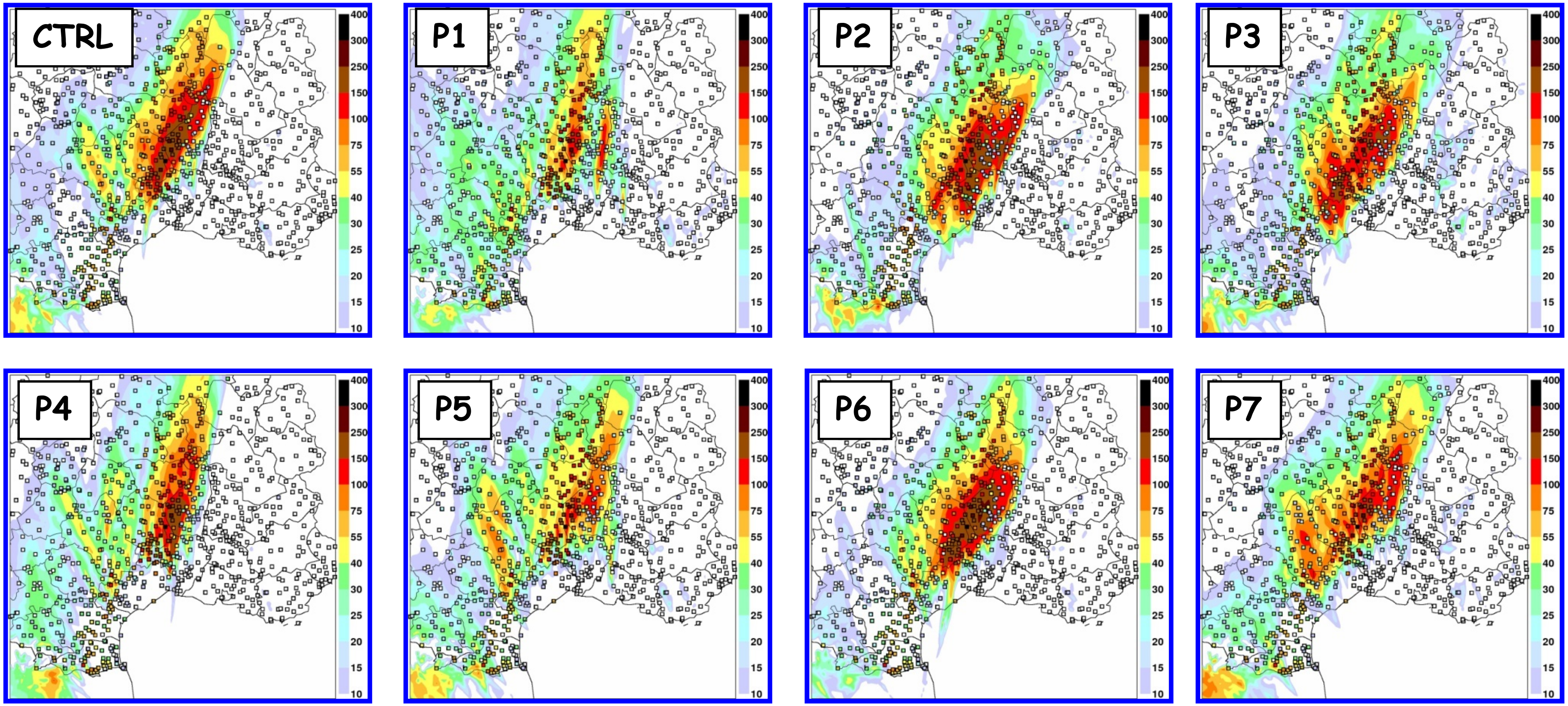
24h observed precipitation (raingauges)

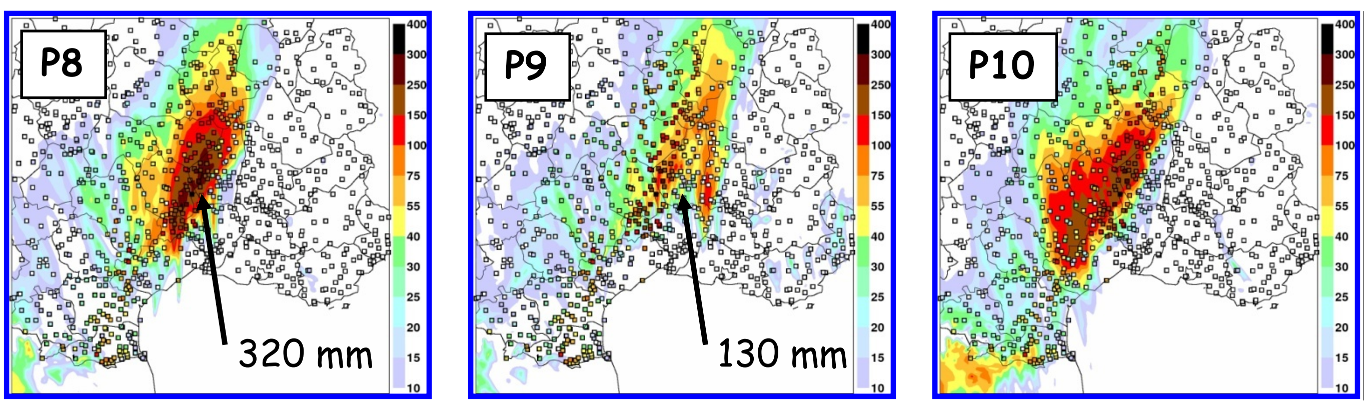
- From 1 Nov. 2008 00 UTC until 3 Nov. 2008 00 UTC
- MCS formed within the tail of a larger-scale quasi-stationary front
- Max rainfall : 428 mm (Villefort, Lozère)



Radar composite , 1 Nov. 2008 at 22 UTC

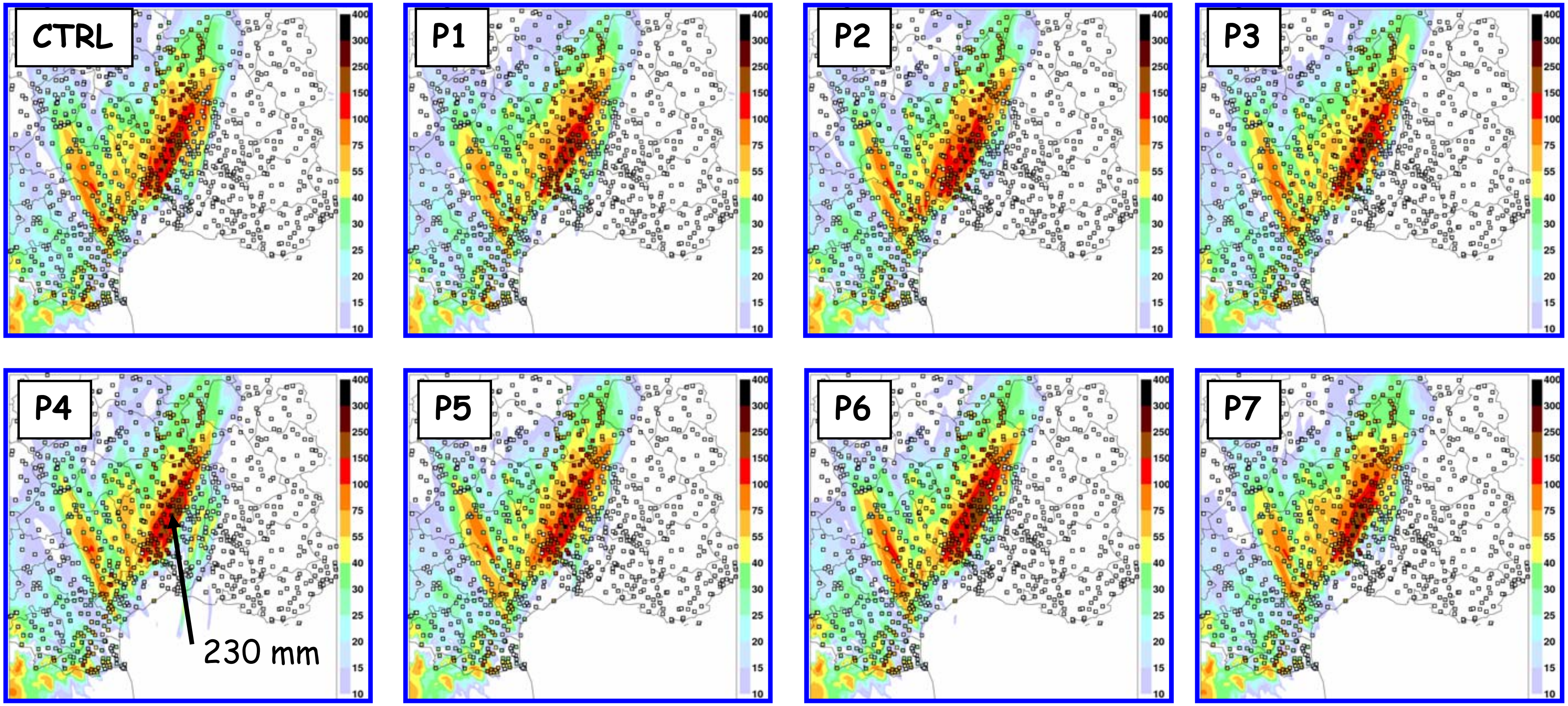
AROME-PEARP ensemble experiment

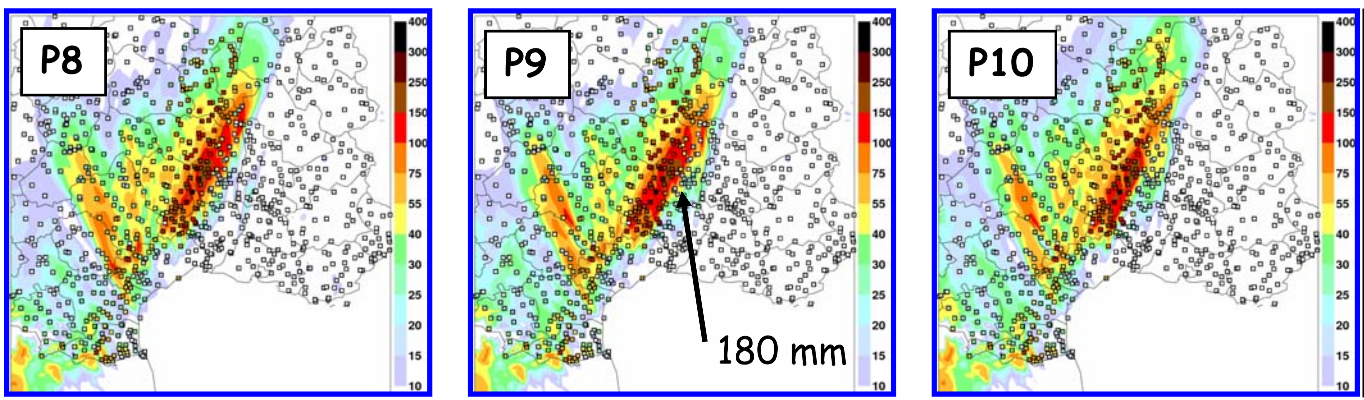




24h- simulated rainfall for *AROME-PEARP* ensemble. Initial and boundary conditions are provided by PEARP forecasts, 1 Nov. 2008 at 12 UTC

AROME-PERTOBS ensemble experiment

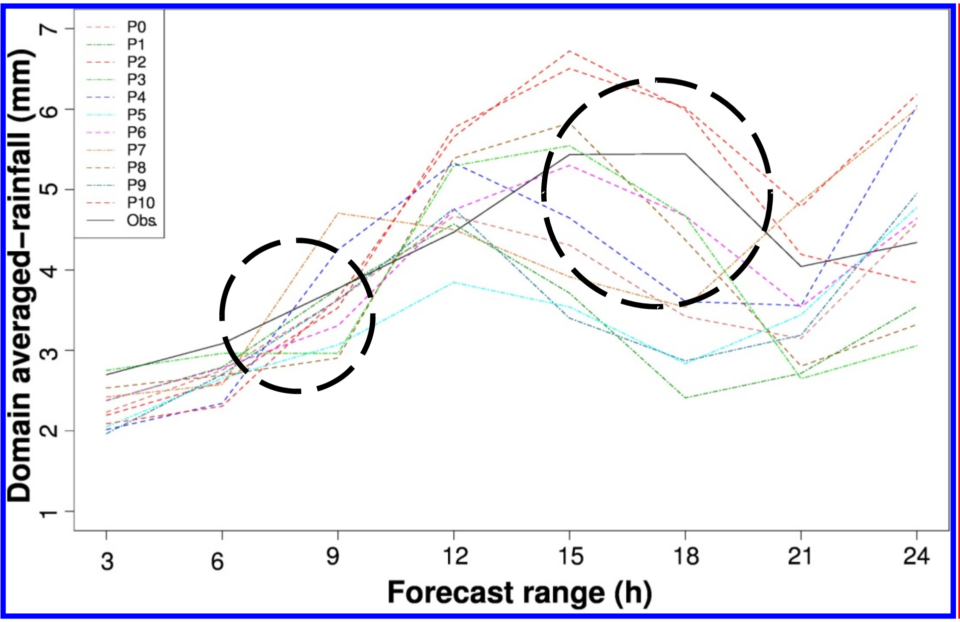




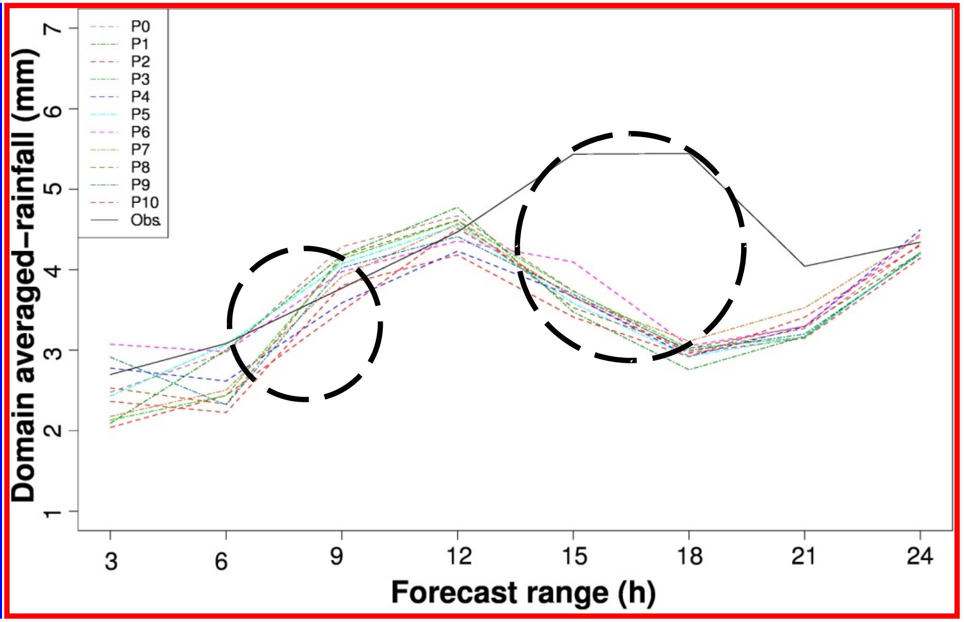
24h- simulated rainfall for *AROME-PERTOBS* ensemble. Mesoscale initial conditions are obtained by ensemble assimilation method, 1 Nov. 2008 at 12 UTC

Ensemble experiment evaluation

AROME-PEARP **ensemble experiment**



AROME-PERTOBS **ensemble experiment**



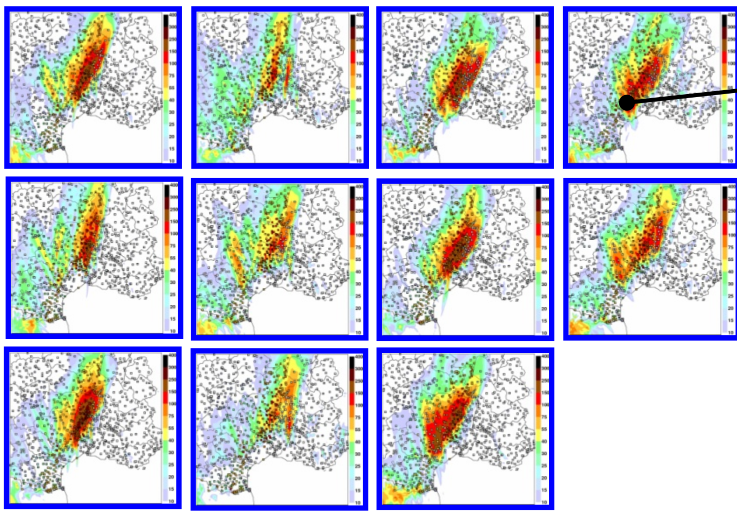
The maximum rainfall peak is better captured in ***AROME-PEARP*** ensemble over the second half of forecast period

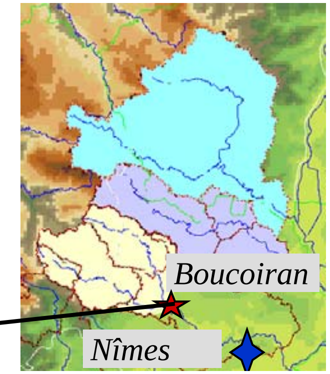
During the 12-h, the uncertainty is fairly reduced and better distributed around observations in ***AROME-PERTOBS*** ensemble but it fails to reproduce the precipitation peak

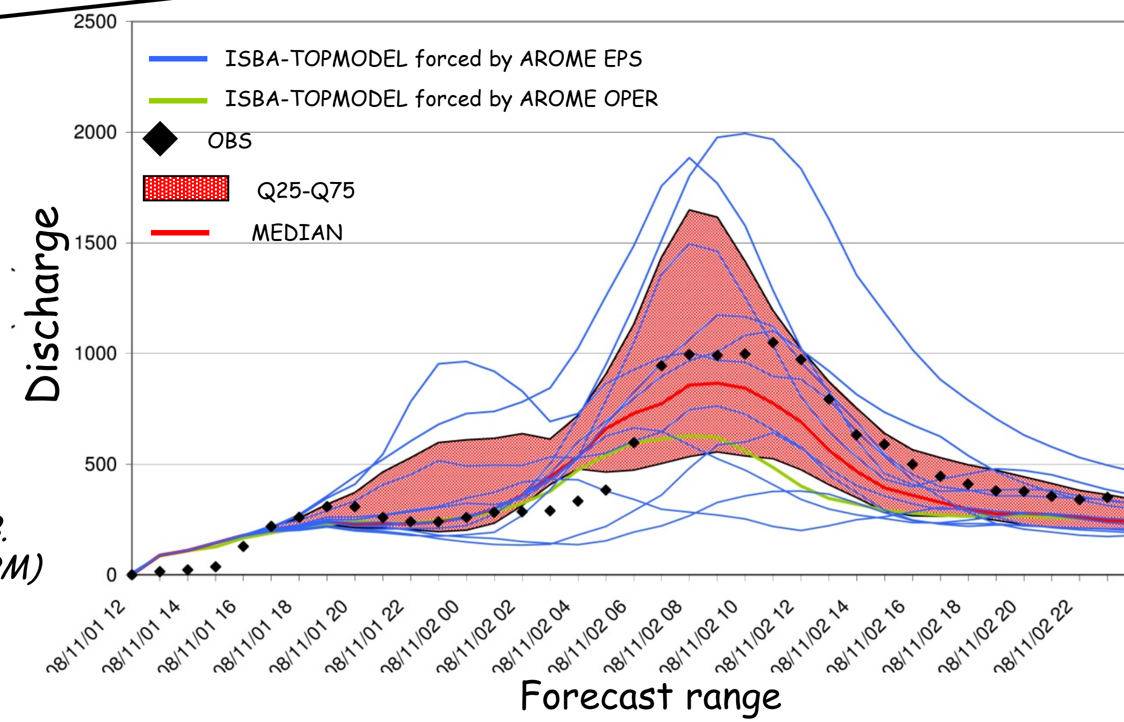
Ensemble simulations of QDF

- Ensemble simulations of Quantitative Discharge Forecast (QDF) performed coupling ISBA-TOPMODEL with AROME-PEARP ensemble experiment.

24-h accumulated rainfall from AROME-PEARP ensemble







Courtesy of B. Vincendon (CNRM)

This ensemble approach points out a possible flood of the Gardon river at Boucoiran, in contrast to the simulation using the deterministic AROME forecast

Link with the HyMeX program

HyMeX (HYdrological cycle in the Mediterranean Experiment) is organised around two main objectives (http://www.hymex.org/):

- **to improve our understanding of the *water cycle*, with emphases on the *predictability and evolution* of *intense events***

  → by monitoring and modelling:

  the Mediterranean *coupled system* (atmosphere-land-ocean),

  its *variability* (from the event scale, to the seasonal and interannual scales)

  and characteristics over *one* **decade in the context of global change**

- **to evaluate the *societal and economical vulnerability* to extreme events and the *adaptation capacity*.**

In order to make progress in:

→ The observational and modelling systems, especially of coupled systems. This requires new processes modelling, parameterization development, data assimilation of new observation types for the different Earth compartments, reduction of uncertainty in climate modelling.

→ The prediction capabilities of high-impact weather events,

→ The accurate simulation of the long-term water cycle,

→ The definition of adaptation measures, especially in the context of global change.

Major disciplines: Meteorology, Oceanography, Hydrology, Climatology, Societal sciences

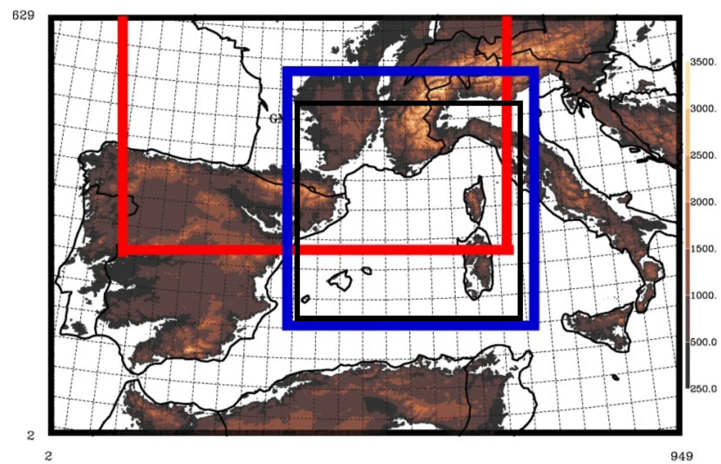
Modelling strategy

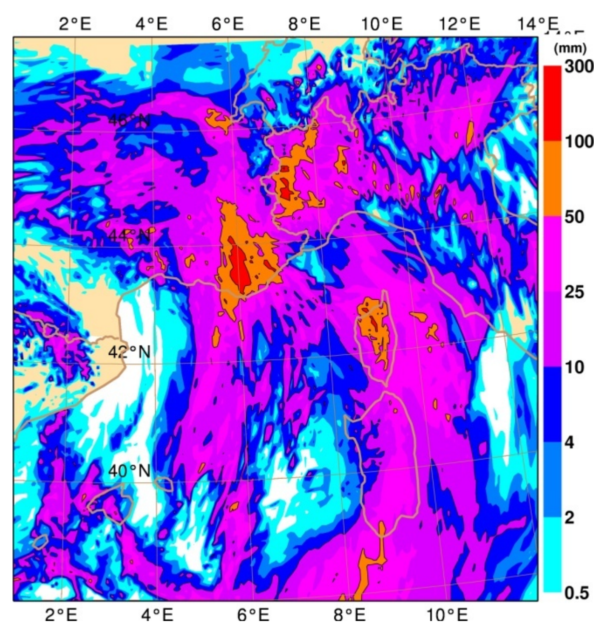
The HyMeX modelling strategy includes :

- **The improvement of convective-scale (deterministic and ensemble) forecast systems to improve the prediction capabilities of Mediterranean high-impact weather events.** HyMeX field campaigns should provide an unique high-resolution database to validate these new NWP systems: microphysical properties (polarimetric radars, aircraft measurements), marine boundary layer characteristics and air-sea fluxes measurements (buoys, research vessels), novel high-resolution moisture measurements (GPS delays on board ships, radar refractivity, water vapor from lidar, etc).

- **Some versions (deterministic and ensemble approaches) of these systems will be run in real-time or in a "test-bed" framework during the SOPs to serve as guide for the dedicated instrumentation.** Other on-going studies based on NWP and modelling systems are carried out to prepare the deployment of observation platforms (aircraft, vessels, sounding, lidars, etc)

The AROME-WMED model is a research version of the Météo-France AROME NWP system running its own 3-hourly rapid update assimilation cycle at 2.5 km.





AROME oper.

AROME_WMED

AROME_NWMED EPS

zoom

Task Team Modeling TTM1a: High-resolution ensemble hydrometeorological modelling for quantification of uncertainties

Outlines

- Motivations and scientific issues
- Impacts of model parameterizations
  - Sensitivity to physical processes and dynamics
  - Case studies with AROME and Meso-NH models
- Impacts of meso-scale initial conditions
  - Assimilation of radar data (Doppler velocities and reflectivities)
  - Case studies with AROME model
- EPS approach for hydrometeorological forecasts
  - Probabilistic evaluation
  - Case studies with AROME and ISBA-TOPMODEL
  - Link with the HyMeX program
- Synthesis and future plans

Synthesis

- Benefit of using non-hydrostatic mesoscale numerical models for intense events:
  - AROME was able to reproduce the strong winds associated to Xynthia (strong positive impact of the non-hydrostatism).
  - For heavy precipitation, high-resolution and sometimes explicit parameterization of microphysical processes are crucial for better forecasts.
  - Moreover, other parameterizations (diffusion) can have also strong impact.

- Benefit of convective-scale assimilation of non-conventional data (radar data for instance):
  - Assimilation of **Doppler velocities** and **reflectivities** strongly improves mesoscale initial conditions for heavy precipitation events.
  - the **general benefit** of the analysis appears during the first 12-h forecast ranges, then lateral conditions mostly take over the model solution.
  - However, convective-scale ensemble forecasts are needed to assess predictability

- An ensemble simulation approach is used to assess the impact of uncertainty on convective-scale ICs and uncertainty on LBCs:
  - Convective-scale ensemble experiments have been performed, either coupling AROME with global PEARP ensemble, or doing convective-scale assimilation cycles of perturbed observations in AROME 3D-Var.
  - the uncertainty on convective-scale ICs is shown to have an impact at short-range (<12 h)

Future plans

- A few works currently in progress or planned on :
  - dynamics : conservation in the semi-lagrangian scheme (Malardel et al.).
  - physics : improvement of boundary layer clouds in cloud statistical schemes.

- A few works currently in progress or planned on :
  - the use of observations at a higher spatial resolution (IR radiances,…).
  - A surface assimilation coherent with the model's surface scheme and resolution
  - An AROME domain twice larger operational version is currently investigated

- Perturbations on LBCs will be improved, coupling AROME with more global ensemble members
  - selection of a few relevant forecasts from global EPS.

- The development of convective-scale stochastic physics is planned for AROME
  - A random generator of model tendency perturbations is being developed, using (at this stage) couples of AROME forecasts for its statistical calibration
  - Evaluate error model against uncertainty on Ics and LBCs

- Other perturbation generation techniques will be developped and assessed in AROME
  - EnKF, ETKF,…

Bibliography

– Berre L., Stefanescu S.E., Belo Pereira M. 2006: The representation of the analysis in three error simulation techniques. Tellus, **58A**:196-209.

–Caniaux G., Redelsperger J.-L., Lafore J.-Ph., 1994: A numerical study of the stratiform region of a fast-moving squall line. Part I: General description and water and heat budgets. J. Atmos. Sci., **51**: 2046-2074.

– Caumont O., Ducrocq V., Wattrelot E., Jaubert G., Pradier-Vabre S., 2010: 1D+3Dvar assimilation of radar reflectivity data: A proof of concept. Tellus, **62A**: 173-187.

– Cuxart J., Bougeault P., Redelsperger J.-L., 2000: A turbulence scheme allowing for mesoscale and large-eddy simulations. *Q. J. R. Meteorol. Soc.*, **126**: 1-30.

–Ducrocq V., Nuissier O., Ricard D., Lebeaupin C., Thouvenin T., 2008 : A numerical study of three catastrophic precipitating events over southern France. II: Mesoscale triggering and stationarity factors. *Q. J. R. Meteorol. Soc.*, **134**: 131-145.

– Gilet J.-B., Plu M., Rivière G., 2009 : Nonlinear baroclinic dynamics of surface cyclones crossing a zonal jet. J. Atmos. Sci., **66**: 3021-3041.

– Hohenegger C. and Schär C., 2007 : Predictability and error growth dynamics in cloud-resolving models. J. Atmos. Sci., **64**: 4467-4478.

– Lorenz E.N., 1963: Deterministic nonperiodic flow. *J. Atmos. Sci.*, **20** : 130-141.

– Montmerle T. and Faccani C., 2009: Mesoscale assimilation of radial velocities from Doppler radars in a preoperational framework. Mon. Wea. Rev., **137**: 1939-1953.

– Nuissier O., Ducrocq V., Ricard D., Lebeaupin C., Anquetin S., 2008. A numerical study of three catastrophic precipitating events over southern France. I: Numerical framework and synoptic ingredients. *Q. J. R. Meteorol. Soc.*, **134**: 111-130.

– Pinty J.-P. and Jabouille P., 1998: A mixed-phased cloud parameterization for use in a mesoscale non-hydrostatic model: Simulations of a squall line and orographic precipitation. Pp 217-220 in Preprints, Conference on cloud physics, Everett, WA. Amer. Meteorol. Soc: Boston.

– Rivière, G., Arbogast P., Maynard K., Joly A., 2010 : The essential ingredients leading to the explosive growth stage of the European wind storm « Lothar » of Christmas 1999. *Q. J. R. Meteorol. Soc.*, **136**: 638-652.

– Seity Y., Brousseau P., Malardel S., Hello G., Bénard P., Bouttier F., Lac C., Masson V., 2010: The AROME-France convective-scale operational model. Submitted to Mon. Wea. Rev. (accepted).

– Skamarock W.C., 2004: Evaluating mesoscale NWP models using kinetic energy spectra. Mon. Wea. Rev., **132**: 3019-3032.

– Vié B., Nuissier O., Ducrocq V., 2010: Cloud-resolving ensemble simulations of mediterranean heavy precipitating events: Uncertainty on initial conditions and lateral boundary conditions. Submitted to Mon. Wea. Rev.

– Zhang F., Snyder C., Rotunno R., 2003: Effects of moist convection on mesoscale predictability. J. Atmos. Sci., **60**: 1173-1185.

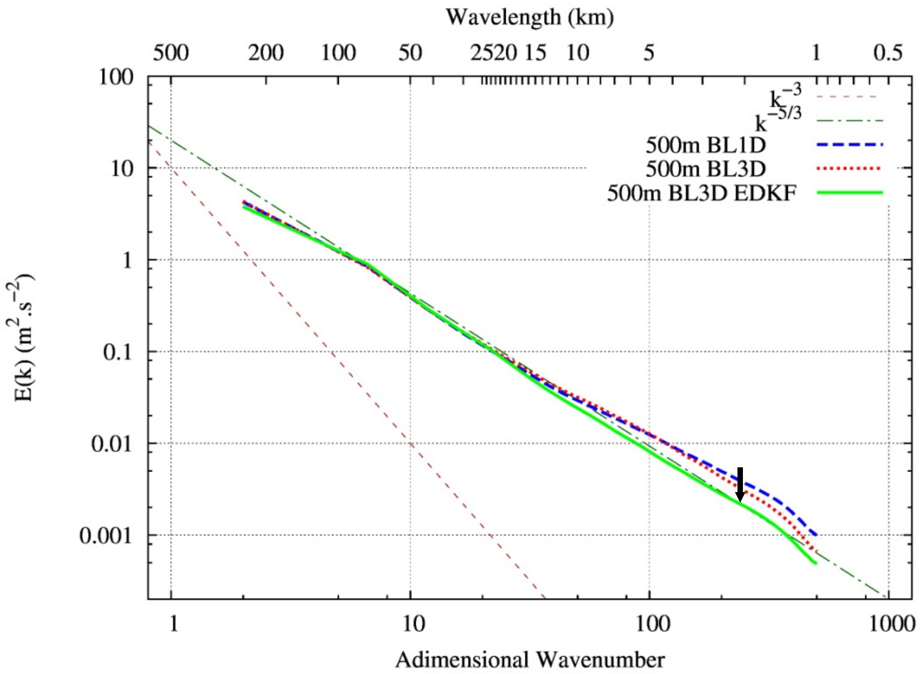
– Wernli H., Dirren S., Liniger M.A., Zillig M., 2002: Dynamical aspects of the life cycle of the winter storm Lothar (24–26 December 1999). *Q. J. R. Meteorol. Soc.*, **128**: 405-429.

THANKS TO MY OTHER COLLEAGUES FROM METEO-FRANCE !

THANK YOU FOR YOUR ATTENTION

Impact of physical parameterizations

- Example of comparison Meso-NH spectra (500 m) for convective cells over plain in the **boundary layer (BL)**, averaged over a 4-h period.
  - **500 m** res. simulations + mixing length **BL1D** (Bougeault and Lacarrère 1989)
  - **500 m** res. simulations + mixing length **BL3D**
  - **500 m** res. Simulations + mixing length **BL3D** + Eddy-Diffusivity / Kain-Fritsch (**EDKF**)

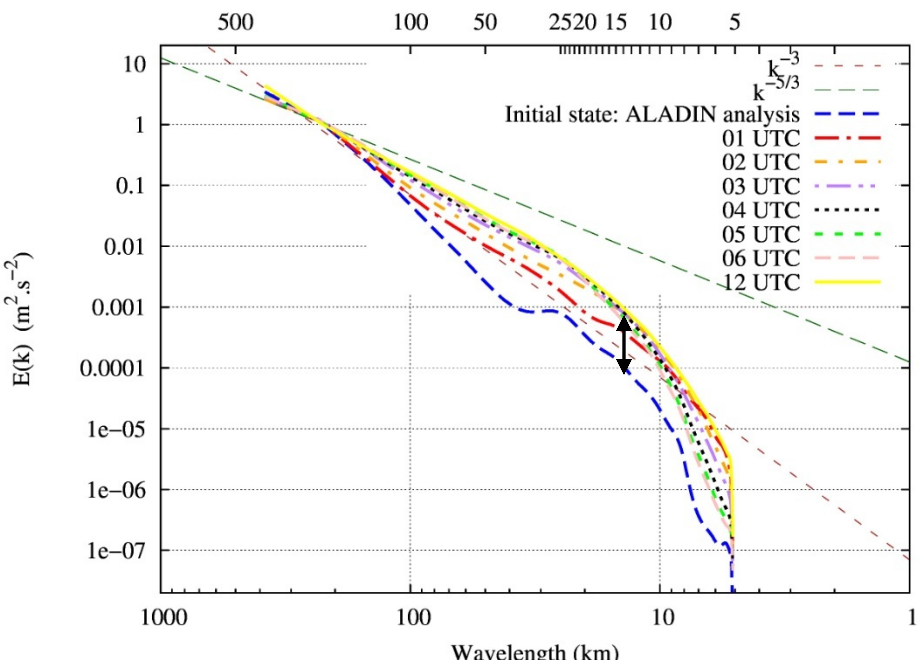


Courtesy of D. Ricard (CNRM)

- Kinetic energy in spectra is **stronger** at smaller scales due to increase of horizontal resolution (**2.5 km** → **500m**)
- **Mixing within the BL**, resulting from activation of parameterizations (turbulence 1D, 3D, and shallow convection), help to **dissipate** somewhat **energy**.

A tool to evaluate the spinup period

- Kinetic energy spectra are performed from AROME forecasts, with initial conditions provided by an ALADIN analysis (no assimilation is done with AROME)



Spectra from the 2.5-km AROME forecasts starting from an ALADIN analysis (~ 10 km)

Courtesy of D. Ricard (CNRM)

- The AROME initial conditions possess little energy in mesoscale (smoother ALADIN analysis).
- The development of the mesoscale portion of the spectrum takes about 3-4 h

⇒ development of finescale structures in the forecasts.