Overview of the AROME project

G. Hello and F. Bouttier, Météo-France

with contributions by Yann Seity, Pierre Brousseau, Sylvie Malardel, Christine Lac, Patrick Santurette, Pierre Bénard, Eric Wattrelot, Thibaut Montmerle, Claudia Faccani, Olivier Caumont, Ludovic Auger, Valéry Masson, Pierre Le Moigne, Eric Martin, Joël Stein, Francis Pouponneau, Eric Sevault, Ryad El Khatib, Damien Lambert, Jean-François Mahfouf, etc...

- **Highlights of recent history**
- **Solved & unsolved problems**
- **Current performance of Arome**
- **The future**

the AROME project objectives

- **An MF-born project driven by two objectives:**
  - To build a numerical weather prediction model with a horizontal mesh-size of **2/3 km** and a specific **mesoscale** data **assimilation**. The first operational implementation is foreseen for the year **2008.**
  - connect the atmospheric research and NWP communities

The little story of the AROME model

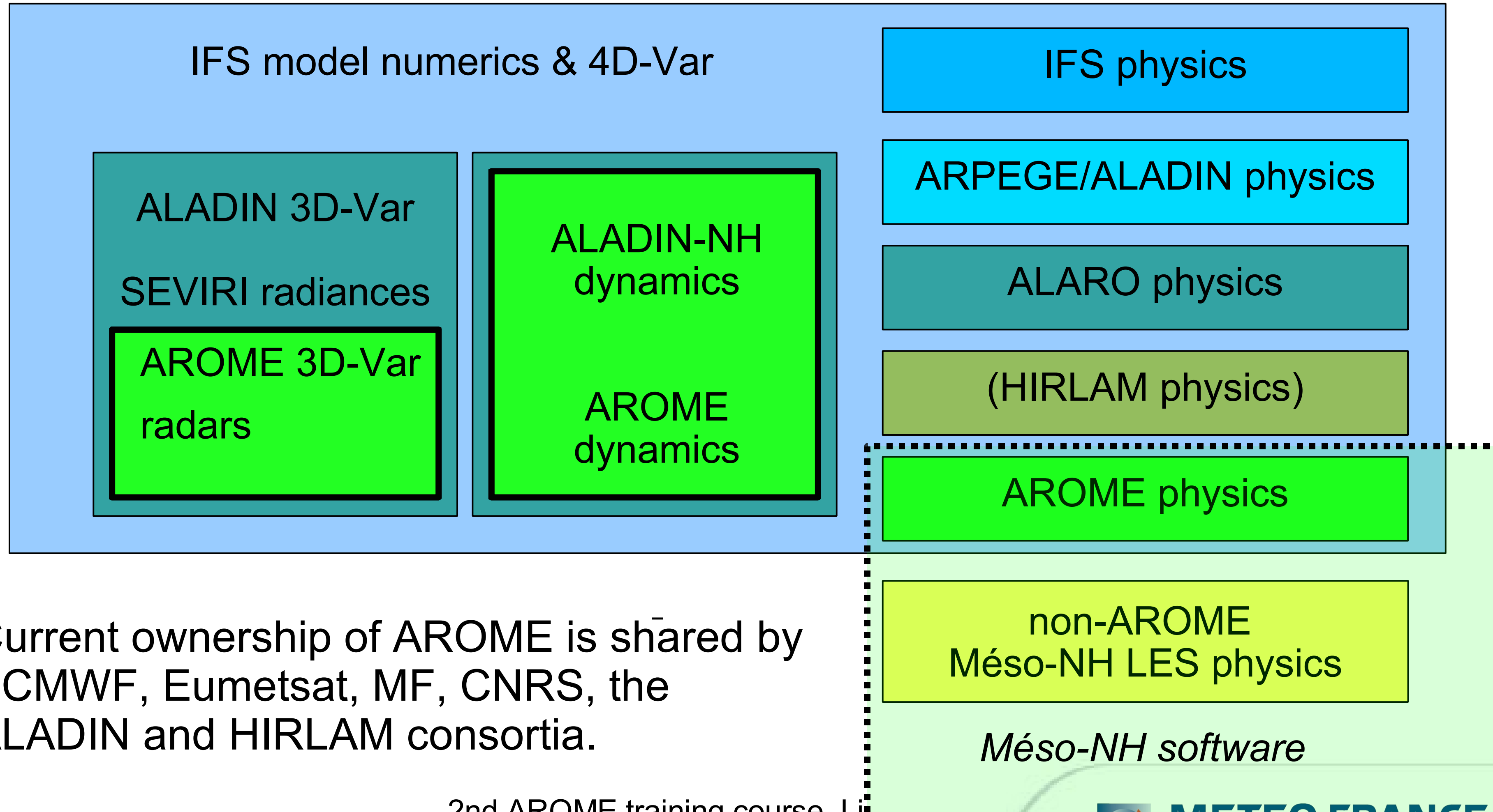
- From 2000 to 2001 the « meso project »
- From 2001 to 2002
  - meso ➔ Arome
  - Human ressources devoted to the project
  - Tests (dynamical intercomparison)
- 2002 : some decisions on the main characteristics of the model
  - ARP/IFS/ALD chosen as the software basis
  - ALADIN-NH chosen as the dynamical kernel
  - P art of the Méso-NH physics to be plugged
- 2002 → 2005 : building of the prototype AROME
  - First 3D run (june 2005)
  - Alaro framework starts to be developped
- 2005 → 2008 : towards operation
  - Sytematic runs (january 2006 over France)
  - Data assimilation (november 2007)

AROME presentation

- **Defined as a hybrid software (2002 choices) :**
  - Based on the existing ALADIN framework.
  - Sharing Physics up-to-date libraries with the Méso-NH model
- **The first results:**
  - initial working model prototype developed in 6 months, allowing safe, incremental model improvements over the years
  - the essential data assimilation components were developed in the common IFS/ARPEGE/ALADIN framework, even before the AROME model existed
- software basis allows development in **cooperation with ALADIN, HIRLAM**, ECMWF and the Méso-NH research community.

AROME software structure

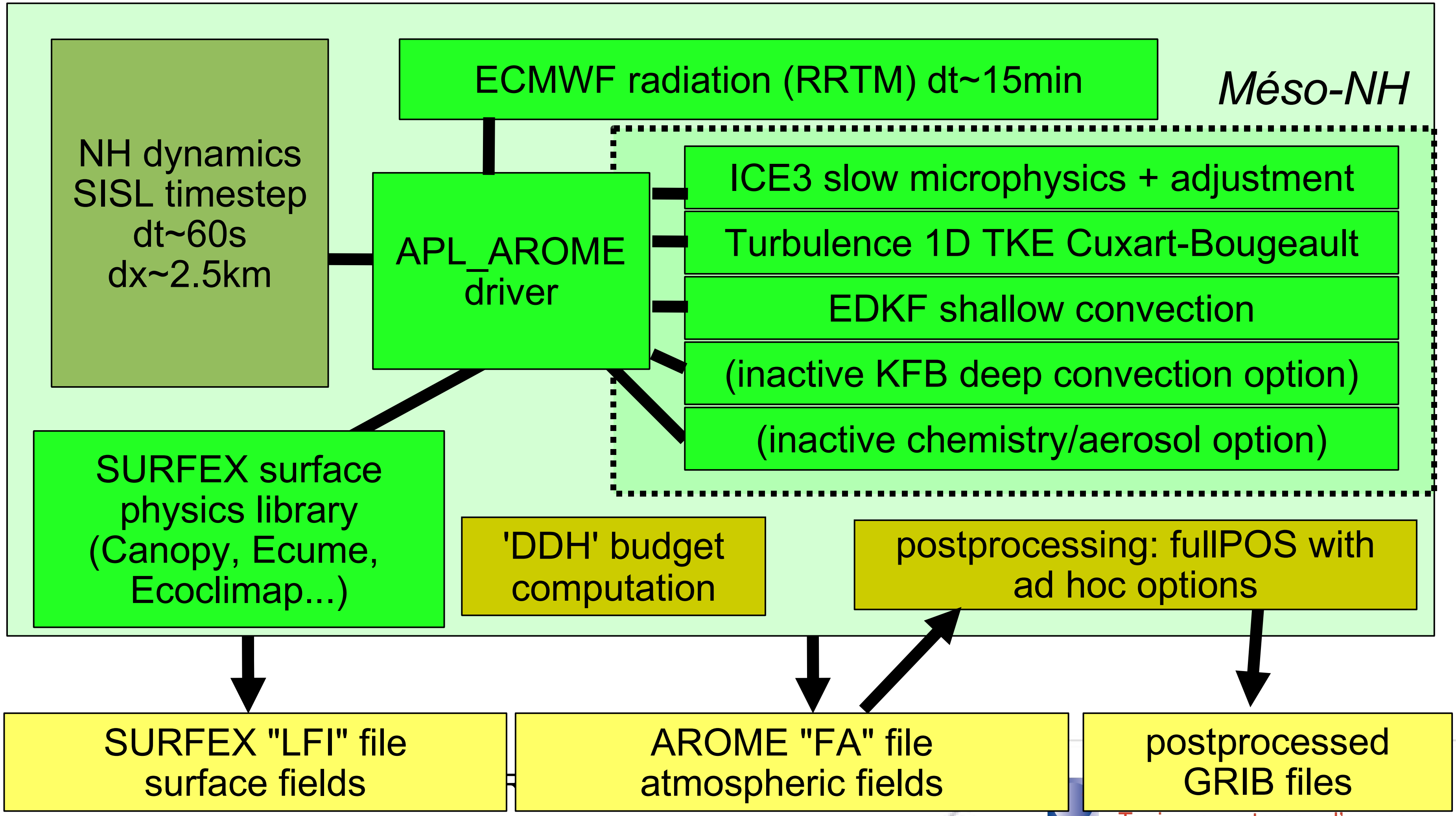
A multipurpose toolbox: AROME pieces are in **green**



Current ownership of AROME is shared by ECMWF, Eumetsat, MF, CNRS, the ALADIN and HIRLAM consortia.

AROME model design

Other physics options can be (have been) plugged in.



AROME recent chronology (1/2)

Spring 2005 - model: Arome-Hungary tests (L Kullman) and 'hirald' Aladin-NH tests at HIRLAM (U. Andrae). Tests on MAP experiment cases and T1 (Dec99) storm. Start of SLHD diffusion tests. Code release ***cy29T2.***

July 2005 - **start Arome daily runs** in MF on small domains. Arome-chemistry tests.

Summer 2005 - the **Aladin 3DVar assimilation** goes operational at MF (with SEVIRI radiances) and Hungary. First GPS-ZTD assimilation experiments.

Fall 2005 - start testing of KF subgrid convection. Options for cirrus, and cloud sedimentation. Arome tests in Hungary, Slovenia, Austria, Sweden, Denmark, Finland. Tests of a coastal ocean model coupled to Arome. Fix 'chimney' problem. Postprocessing development. Surfex 'NPROMA' technical optimisation. First evaluations by forecasters. **1st AROME training course, Romania**.

Winter 2006 - ensemble calibration of Jb. Start tests of a variational (Jk) coupling. Development of a Lidar obs simulator. Tests of various shallow-convection schemes (KFB mods, Soares). Arome installation on ECMWF HPC.

Spring 2006 - Release ***cy31***. Tests on Czech Rep, Tunisia. Start tests with high vertical resolution. Surfex bugfix (soil ice). Radiation improvement (aerosols, cloud overlap). First radar obs simulations. Implementation of radar data in ODB. First Arome assimilations tests. **First objective scores** (precipitation over Austria). Arome interfaced with MF forecasters' workstations.

Summer 2006 - Release ***cy31t1***, downloadable from website. Real time runs over Africa (AMMA experiment). shallow convection : EDMF tests and MF/HIRLAM workshop. High-resolution fog experiments. Tests on Morocco.

AROME recent chronology (2/2)

Autumn 2006 - HIRLAM and Turkey daily test runs. Release of **Arome-1D 'MUSC' model**. Encouraging first assimilation experiments and Mediterranean flood cases. Assimilation of low-level obs. **First objective model scores**, reveal biases in French and in HIRLAM configs. **Bugfix on postprocessed wind direction.** Synthetic satellite images using RTTOV. Temperature biases identified in narrow valleys.

Winter 2007 - start France-domain runs, migrate to new NEC SX8. Release ***cy32t2***. Deactivation of SLHD diffusion. New, **cheaper PDF-based sedimentation algorithm**. Identification of winter vs summer Jb differences. First comprehensive assessment by MF forecasters, pointing out the "fireworks" problem. Objective verification of precipitation over several months.

Spring 2007 - **first radar assim exps**. NEC profiling of model and technical optimisations. Tests of LBC coupling modifications.

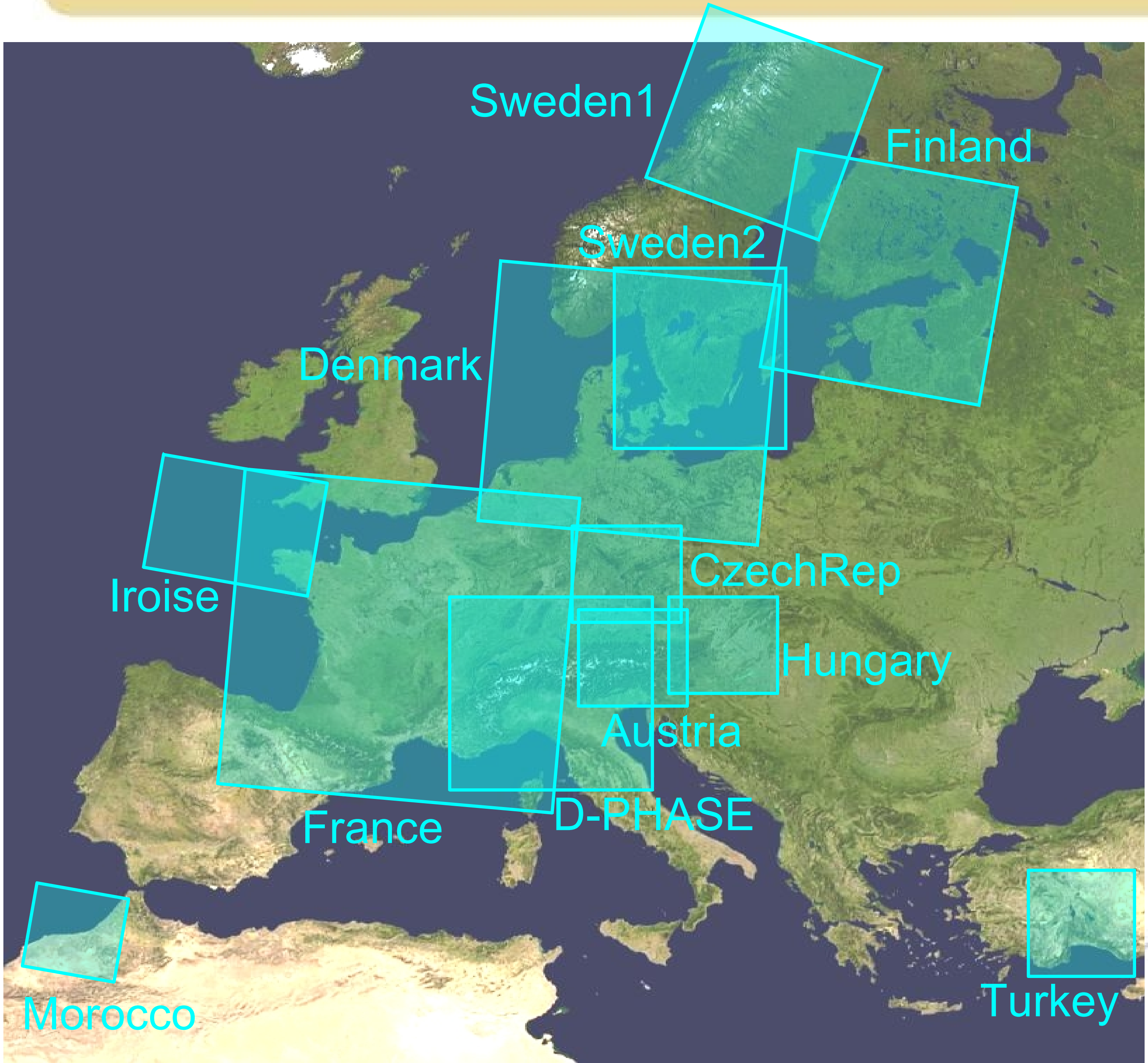
Summer 2007 - French forecasters point out more problems (herringbones, PBL biases). Arome tests at 1km resolution.

Autumn 2007 - Release ***cy32t3***. Switch off PC and hydrometeor coupling. **Start daily assimilation runs,** enlarge French domain. **Implement Canopy** (fixes most biases), Ecume sea fluxes, TKE bugfix, postprocess gusts, **horizontal diffusion tuning (fixes fireworks)**, **start EDKF experimentation (fixes herringbones)**, investigation of model crashes and unrealistic precip near model edges.

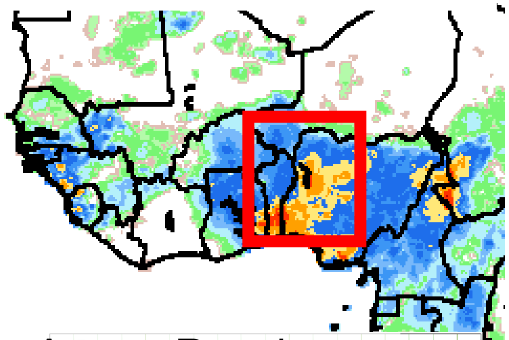
Winter 2008 - **Release cy33t0 for MF operations**. DDH diagnostics validated. Tests on a tropical cyclone case, with assimilation. Scores vs satellite radiances. Launch developement of OI surface data assimilation.

Mars 2008 - **2nd AROME training course, Portugal**.

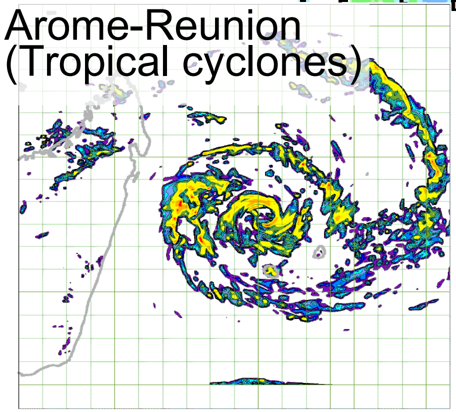
Some already tested AROME models



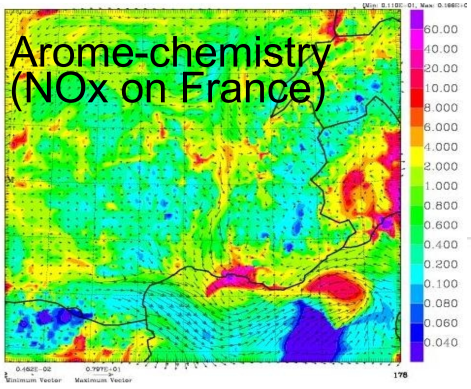
Arome-AMMA
(Western Africa)



Arome-Reunion
(Tropical cyclones)



Arome-chemistry
(NOx on France)



Summary of Arome tests

- **Various AROME test versions have run for over 2 years now, as daily runs and offline runs, in many HIRLAM and ALADIN countries.**
- **Tests quickly showed interesting new details in the simulations: orographic adaptation, fog & low clouds, urban heat islands, organized convective structures... plus a few excellent forecast cases**
- **But detailed evaluation (objective scores & forecaster evaluation) only recently available, and showed real performance problems - just like any other new model :**
  - **errors in the diagnostics themselves: cf. bugfixes & Canopy scheme**
  - **precipitation biases and the "fireworks" (explosive convection) model problem**
  - **'double penalty' in precip scores (classicaly for a mesoscale model)**
  - **I/O and scalability issues on some computer platforms**
  - **specific physical issues (valleys, subgrid convection, lateral boundary conditions...)**
  - **issues with coupling and data assimilation in many centres (e.g. soil moisture)**
  - **and bugs !**
- ***Most problems have now been solved, more fixes are under way.***

Highlights of AROME development (1/2)

- **Long-term research on subgrid shallow convection, with several improvements of the KFB scheme (now called EDKF); cooperation with KNMI (among others). Recently proved to cure unrealistic low-level wind organization ("herringbone pattern").** ***(see talk on shallow convection)***

- **Development of a new DDH-like diagnostic mechanism, to facilitate study & intercomparison of the physics. (*J.-M. Piriou, T. Kovacic and O. Rivière*)** ***(see talk on DDH)***

- **Much work on SURFEX and the fullPOS postprocessing, to improve performance and functionality (e.g. NPROMA parallelisation, LFI file I/O, diagnostic fields in FA files for NWP applications). Mostly on the SURFEX/AROME interface and the physiography preparation and LAM coupling (~'923' and '927' configs).** ***(G. Hello, Y. Seity, E. Martin, P. Le Moigne et al) (see talk on SURFEX)***

- ***Important testing & optimisation of the dynamics: deactivation of the predictor-corrector and SLHD options, retuning of the horizontal diffusion (see talks on NH dynamics)***

- ***Studies of the lateral boundary coupling showed (sometimes big) sensitivity to its formulation, main plan is to smooth the orography mismatch at the edges. (G.Hello, K.Essaouini) No easy big improvement to the LBC algorithm (Ph.D by F. Voitus)***

Highlights of AROME development (2/2)

- **Data assimilation works since summer 2007, it showed small but interesting benefits (e.g. hydrometeors spinup), it is a first step for other big developments *(see talk by P Brousseau)***
- **Radar data assimilation required enormous technical work, the radar doppler winds are very useful to forecast convective cases: ok for MF operations. *(E. Wattrelot, T. Montmerle, C. Faccani, O. Caumont).* Radar reflectivity assimilation has been tested, but not yet reliable enough for operations. *(see talk by E Wattrelot)***
- ***Long-term work on Arome/sea coupling: research on the ocean/atm interaction, and improved flux parametrisation (Ecume scheme) (C. Lebeaupin, G.Hello, C. Renaudié, H. Giordani, V. Ducrocq, E. Martin...)***
- ***The model efficiency has improved thanks to the development of a PDF-based microphysics sedimentation scheme (Y. Seity, Y. Bouteloup), the deactivation of the predictor-corrector option (Y. Seity, G. Hello), tunings of the MPI parallelisation and I/O.***
- ***Did you know that Arome has options for interactive chemistry, aerosol & dust ?***

2 - Solved & unsolved problems

- **Known performance problems**
- **Technical issues**
- **Unsolved questions**
- **Example of problems that have been fixed**

Some known performance problems (1/2)

- **Lack of realism in narrow valleys (too much mixing with the upper-level atmosphere i.e. valley bottoms often too warm and windy)**
- **Wind too weak over peaks (limitation of the horizontal resolution, problem of obs representativeness ?)**
- **Low-level biases (e.g. too hot daytime T2m) due to unrealistic soil moisture initialisation (lack of a SURFEX-specific surface data assimilation)**
- **Lack of clouds in some situations, especially over sea (suspected sensitivity to humidity biases in the coupling model)**
- **Strong precipitations are too strong (under investigation)**
- **Precipitating events lag behing reality (under investigation)**
- **Unrealistic strong precipitation near model boundaries in mountains (lateral smoothing of orography to be implemented)**

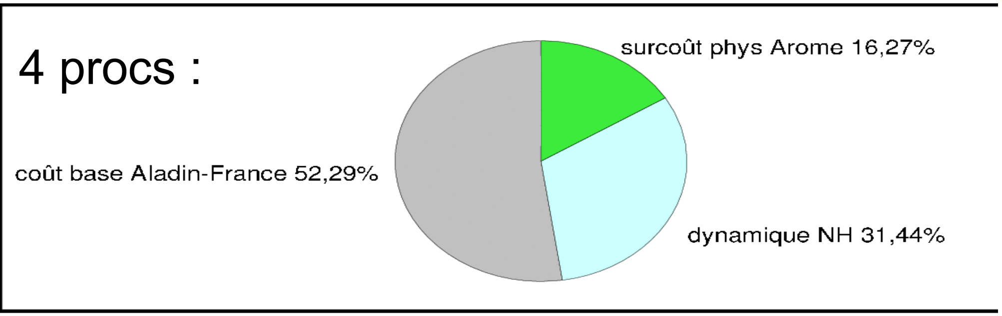
Some known performance problems (2/2)

- **The assimilation can harm the low cloud forecasts (in stable winter conditions) ;Poor 3DVar vertical low-level structure functions (inability to analyse inversions, detrimental impact of surface observations)**
- **Some upper-level scores are poor (cf. radiosondes) – not easy to use due to representativeness of verificaying observations.**
- **...**

Main technical issues

- **Lack of consistency between the APL_AROME physics caller, and the older APLPAR/CPTEND interface used in ARPEGE/ALADIN/ALARO**
- ***Complexity of using* SURFEX, e.g. when preparing new domains *(developments are ongoing to simplify this)***
- **Computer time spent in communications when running large domains *(but is it avoidable ?)***
- ***Ability to run AROME over a very wide area, due to the map factor representation (remains to be tested)***
- ***Surface fields initialisation, and interface to ECMWF (IFS and ERA) (cf. planned development of an AROME surface assimilation)***
- ***...***

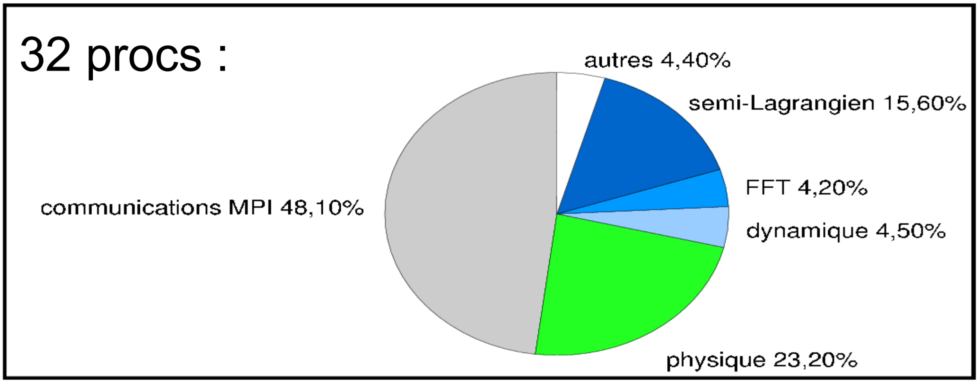
Technical issues: cost & scalability (on NEC)



per timestep overhead vs ALADIN

4 procs : 1.9 (x1.3 Phys x1.5 dyn)

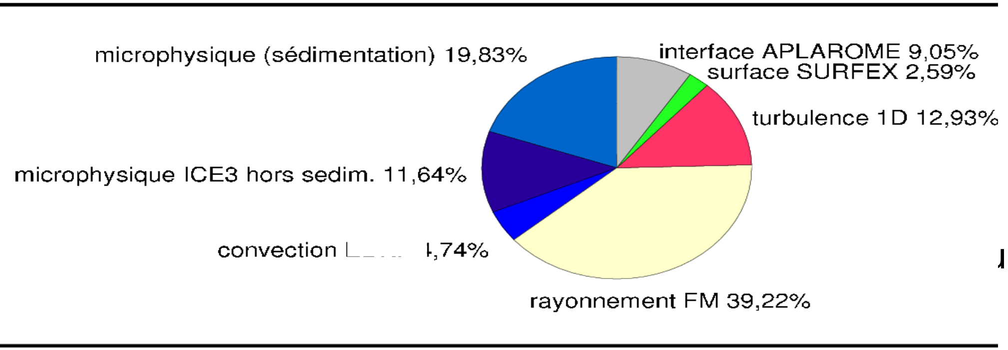
32 procs : 2.5 (x1.3 Phys x 1.9 dyn)



cost breakdown of AROME

4 procs : 40% Phys

32 procs : 23.2 % Phys



cost breakdown of physics:

mostly radiation & sedimentation

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Some unsolved questions

- The SLHD (semi Lagrangian horizontal diffusion) failed to improve the model, perhaps more work on it is needed.
- The (numerically expensive) predictor-corrector option of the dynamics (a.k.a. iterative scheme) does not improve the robustness of the model, contrary to what academic tests initially suggested.
- Lack of a clear plan to improve the LBC coupling algorithm (due to the spectral dynamics)
- How to initialize fog, low clouds and hydrometeor species in the 3DVar analysis
- What are the resolution limits of AROME:
  - above 3km ? (the deep KFB convection has not been much been tested)
  - below 1km ? (little knowledge of what 3D turbulence scheme we would need)

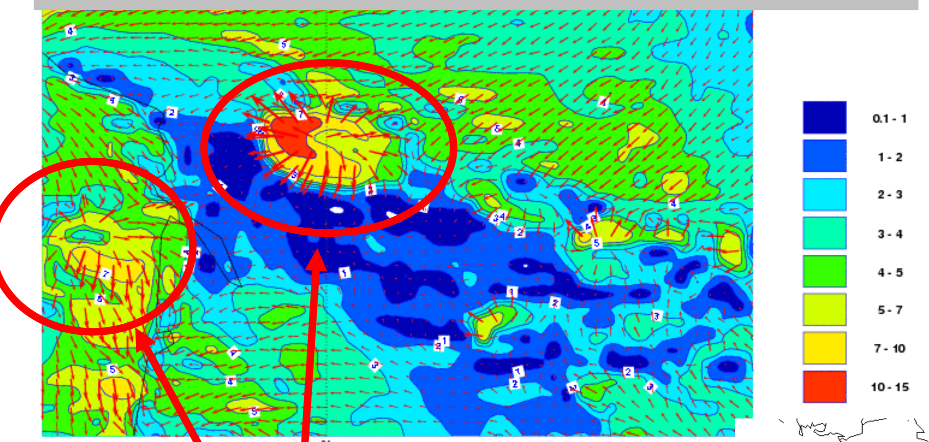
Examples of (nearly) solved problems

- **"fireworks": overactive thunderstorms with strong cooling and divergent wind**
- **"herringbones": excessive organisation of low-level winds and shallow cumulus in weakly convective boundary layers**
- **correction of strong low-level score biases by implementation of the "Canopy" scheme**

the "fireworks" problem & solution

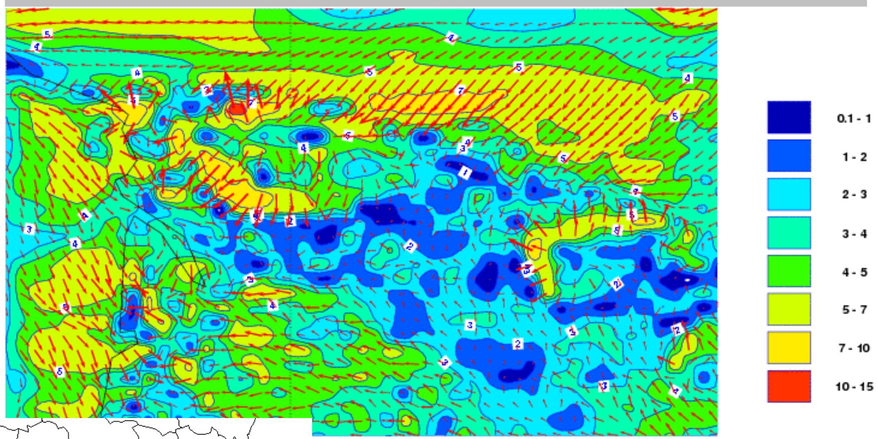
- **"fireworks": overactive thunderstorms with strong cooling and divergent wind underneath, sometimes organised as violent squall lines:**
  - **very detrimental to all AROME evaluations until end 2007**
  - **mostly solved by a recalibration (reduction) of horizontal diffusion (MF, Oct 07)**
  - **some tuning may still be needed on diffusion & microphysics**

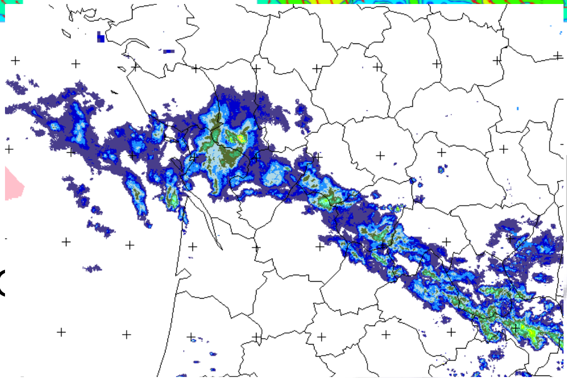
Arome low-level wind under a thunderstorm, using summer 2007 setup



'fireworks'

with new diffusion tuning

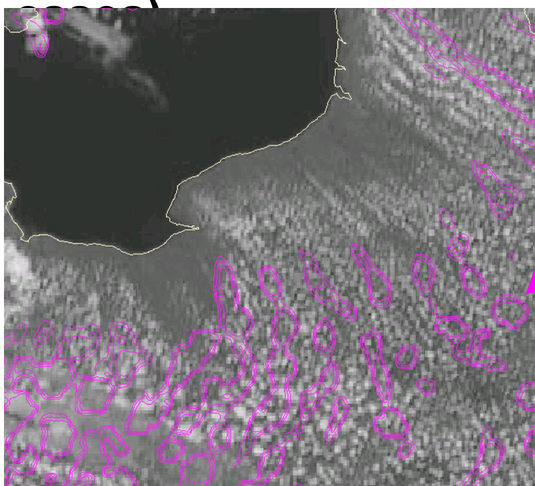




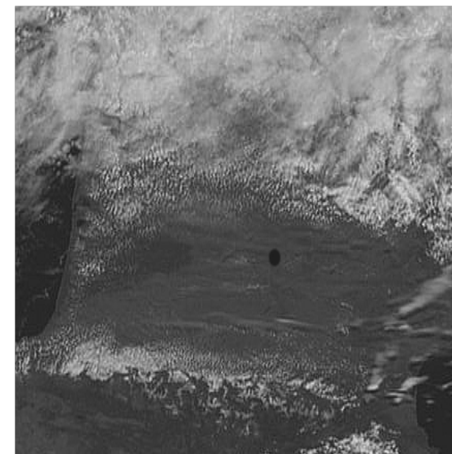
observed radar precip

the "herringbone" problem & solution

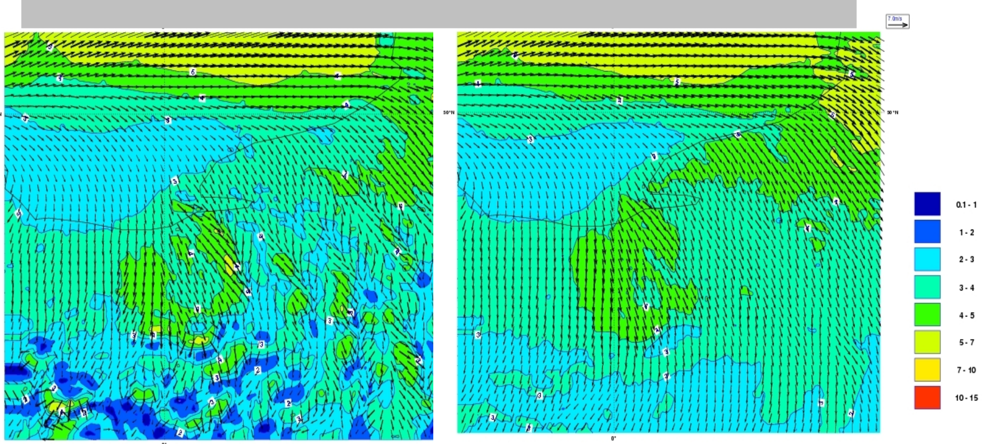
- **"herringbones": strong organisation of low-level winds and shallow cumulus in weakly convective boundary layers over land**
  - **a spurious organisation of PBL eddies as 'streets' on the model grid**
  - **solved by activation of the EDKF subgrid convection scheme (even in dry cases)**



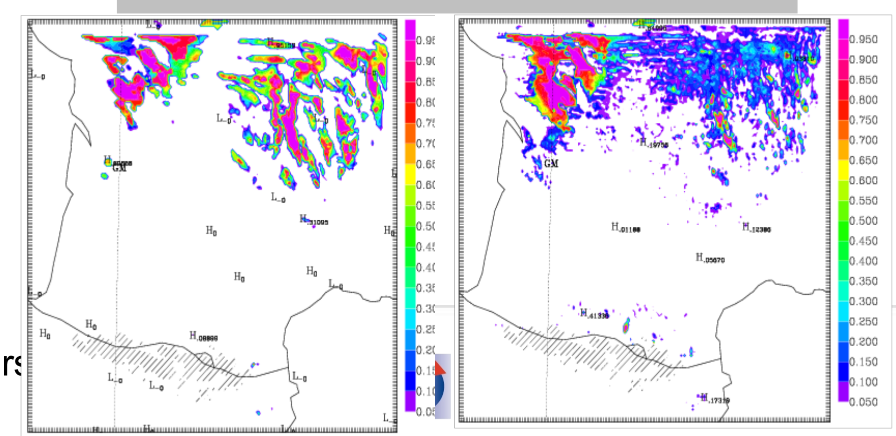
Model clouds without EDKF



Low-level winds without and with EDKF



Clouds without and with EDKF

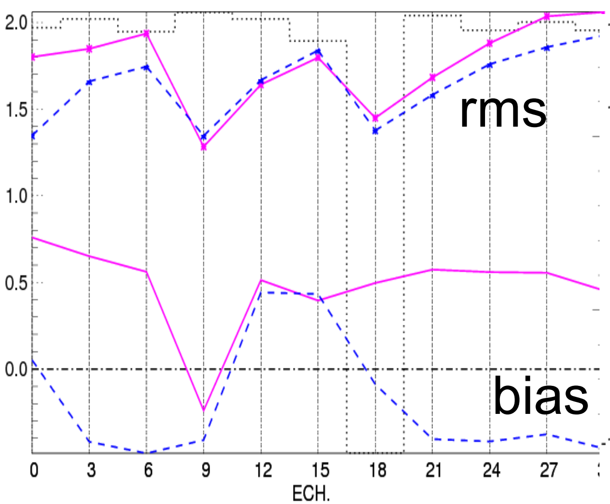


the low-level bias problem & the solution

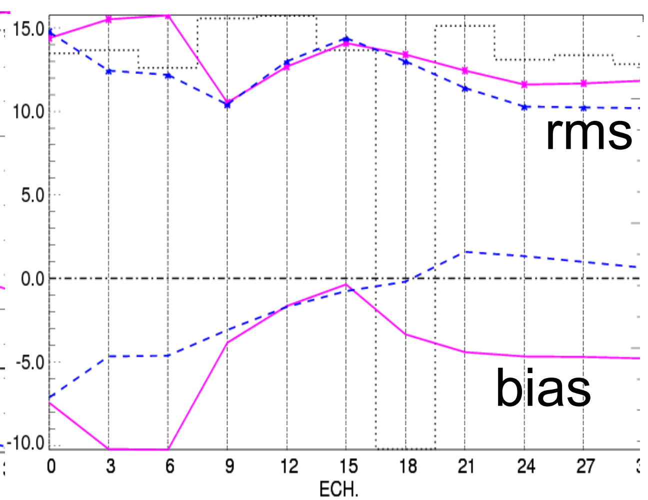
- **strong PBL obs biases: diurnal biases on 10m wind, T2m, HU2m**
  - **a problem of modelling the fluxes between the SURFEX surface and the model lowest level**
  - **solved by implementation of "Canopy", a 1D-subgrid model of the low PBL**
  - **fixes most obs biases and improves low-level fluxes**
  - **does not fix ocean surface fluxes or soil initialisation problems**

Forecast scores with Canopy (blue) and without (pink)

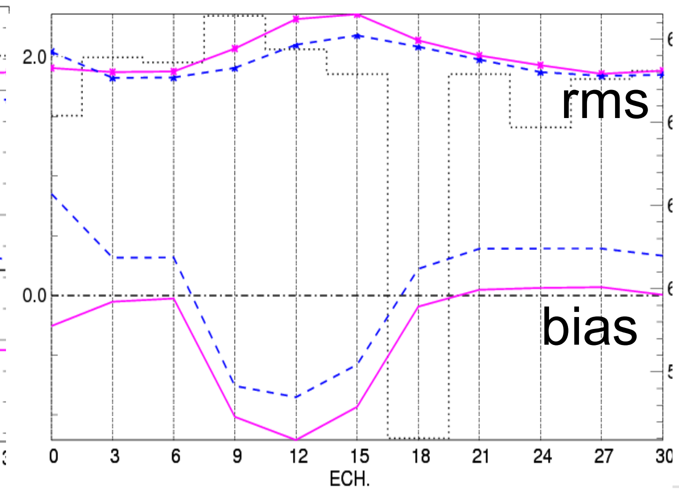
T2m



HU2m

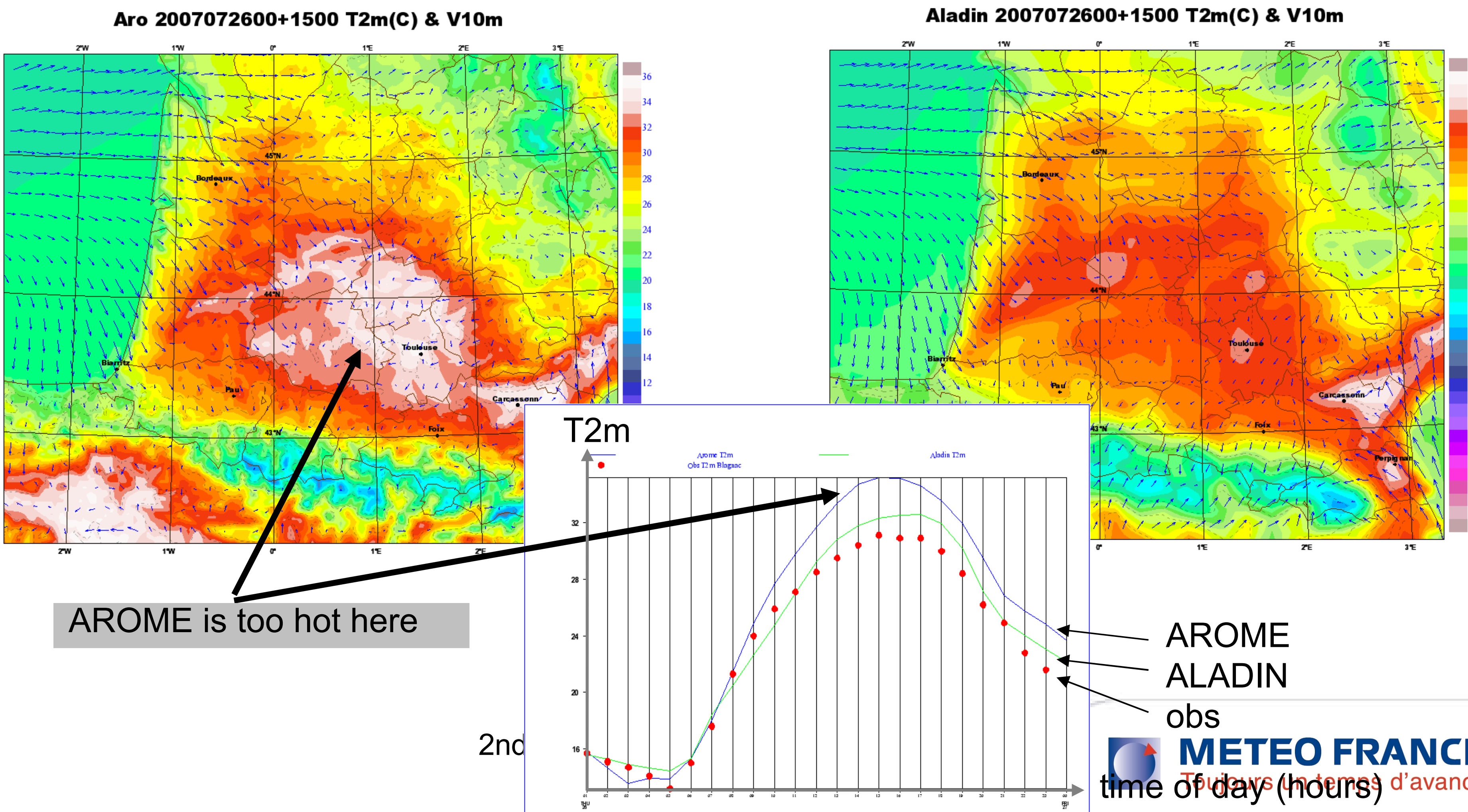


ff10m



The importance of surface data assimilation

- **Converting soil moisture from one surface scheme (ARPEGE/ALADIN) to another (AROME-SURFEX) creates errors because the surface physics are different. A native AROME surface analysis is needed.**



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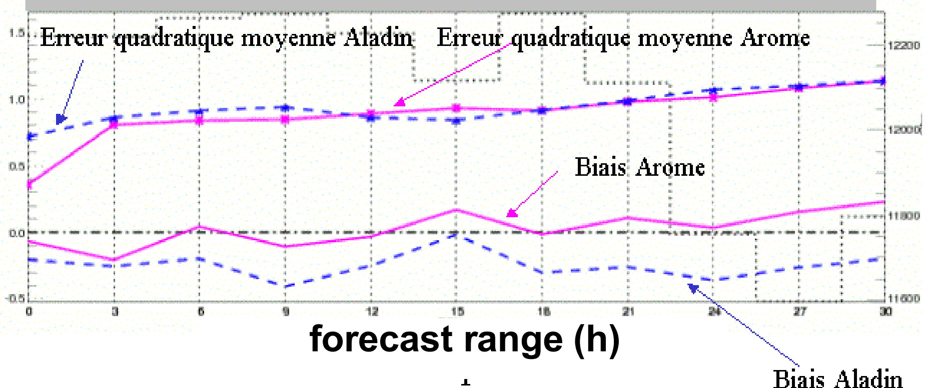
3 - AROME performance

- **Objective scores**
- **Subjective evaluation**

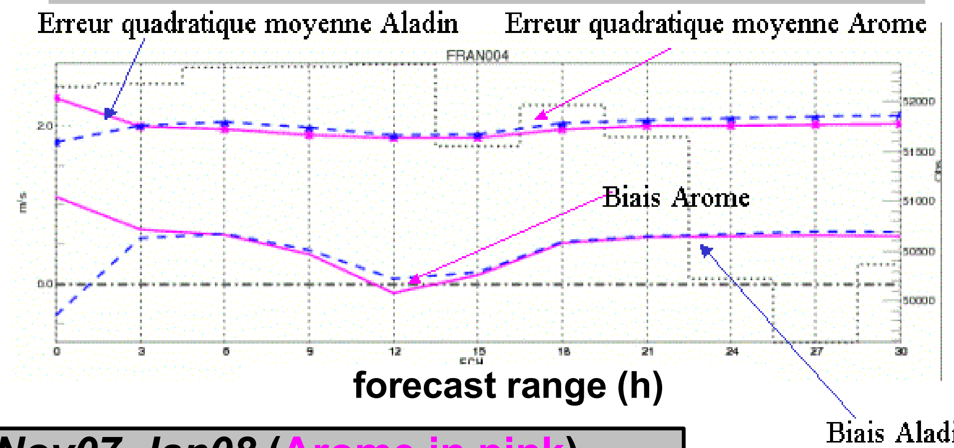
Model performance (1/5): low-level scores

- **objective scores of AROME-France using French automatic surface obs network (hourly data every ~30km)**
- **Beats ALADIN-France in most respects**

MSL pressure

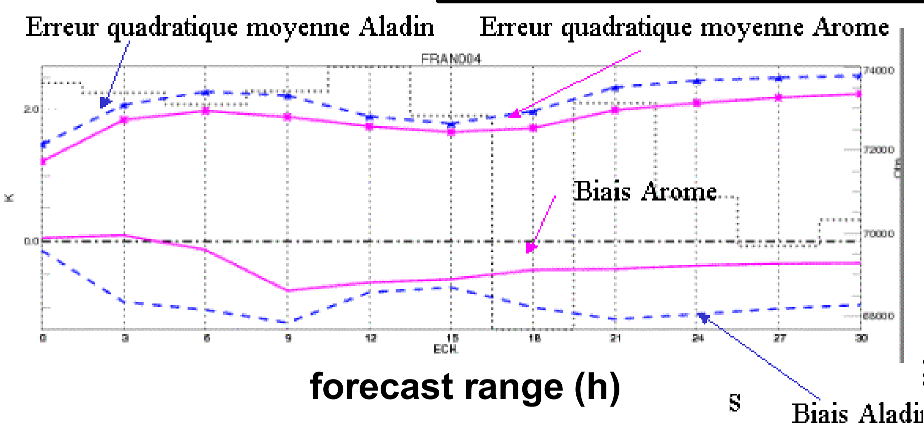


10m windspeed

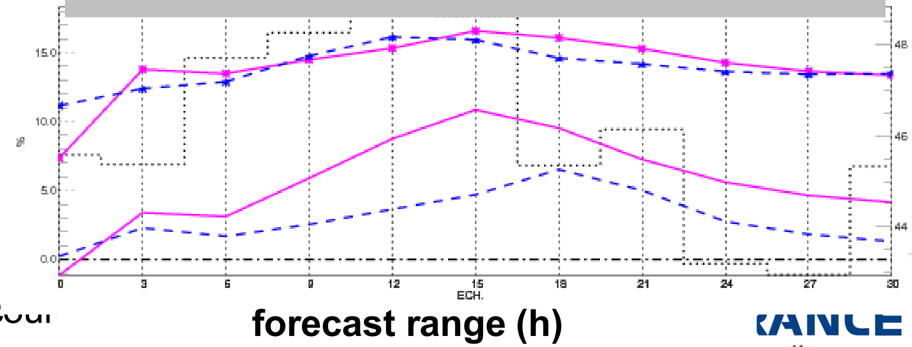


Scores over France for Nov07-Jan08 (Arome in pink)

2m Temperature



2m Humidity (buggy diag, being fixed)

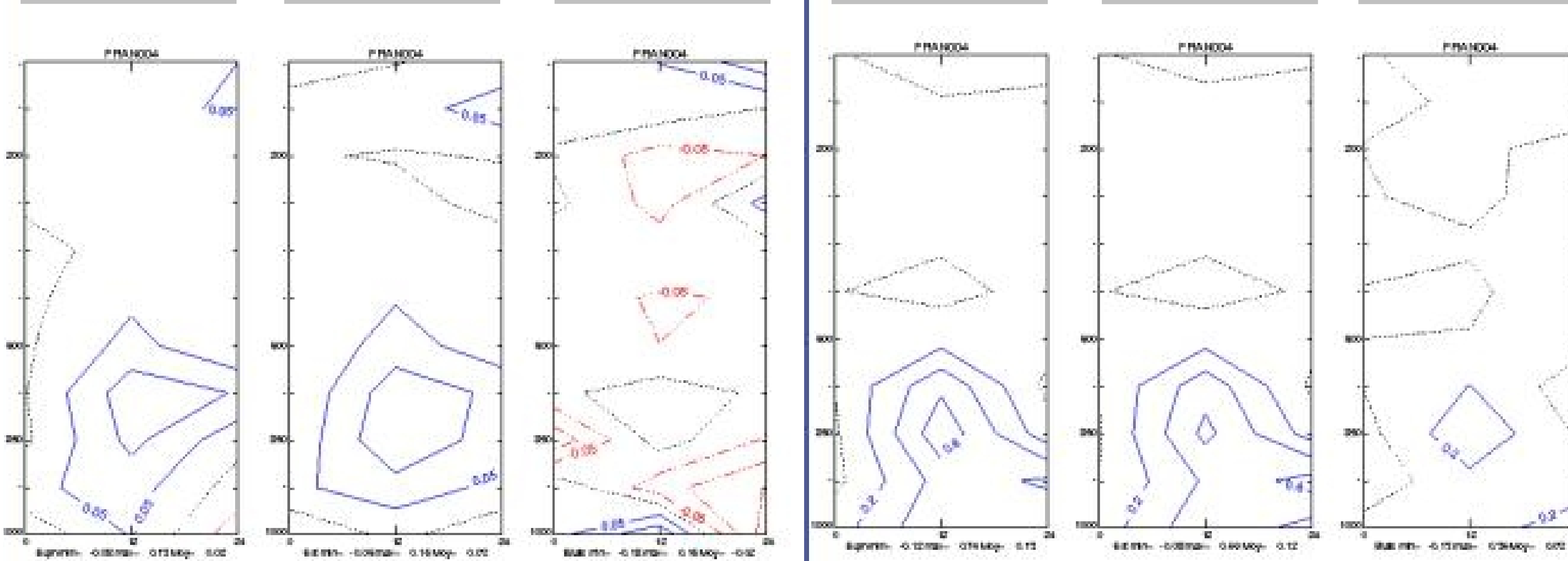


Model performance (2/5): upper-level scores

- **scores of AROME-France using radiosonde data (7 stations every 12 hours, i.e. not much representative)**
- **some partly understood performance problems (TKE scheme retuning to do)**

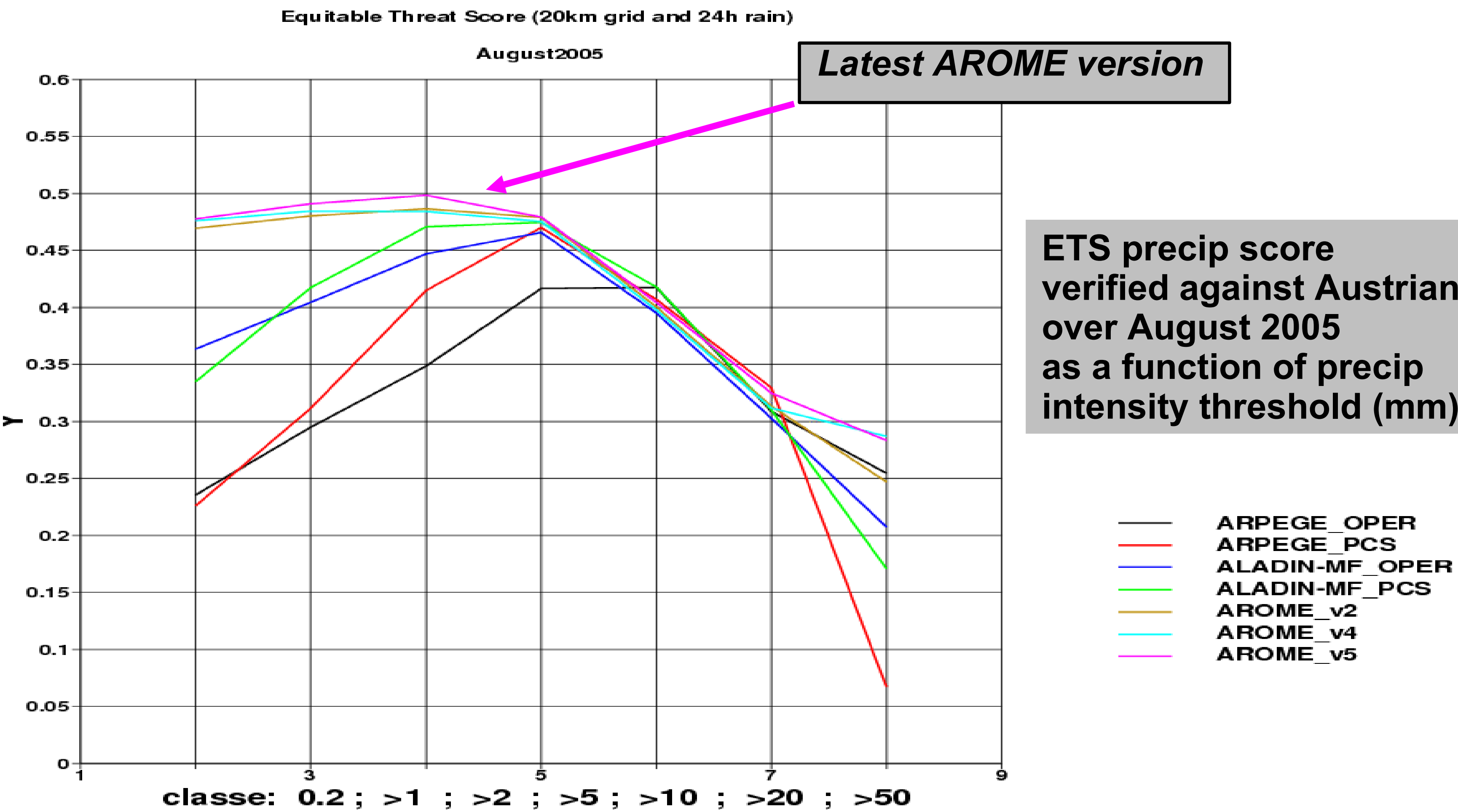
score difference vs Aladin (blue=Aladin is better) over 10 days (Nov07)

Temperature			Wind		
rms	std.dev	bias	rms	std.dev	bias



Model performance (3/5): precip scores

- **scores of AROME-France 24-h total precip, using dense raingauges and probabilistic QPF scoring techniques**
- **narrowly beats ALADIN-France, with some problems**

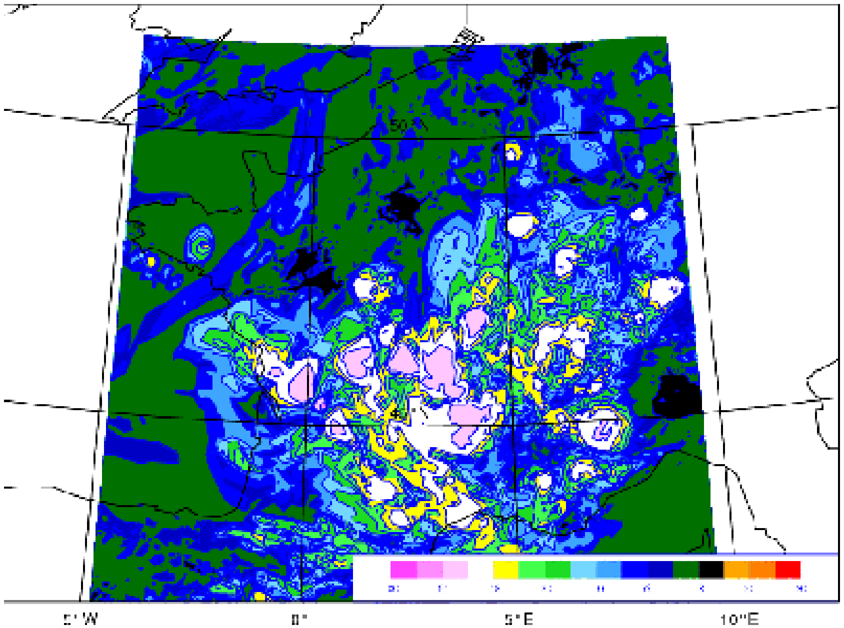


ETS precip score verified against Austrian obs over August 2005 as a function of precip intensity threshold (mm)

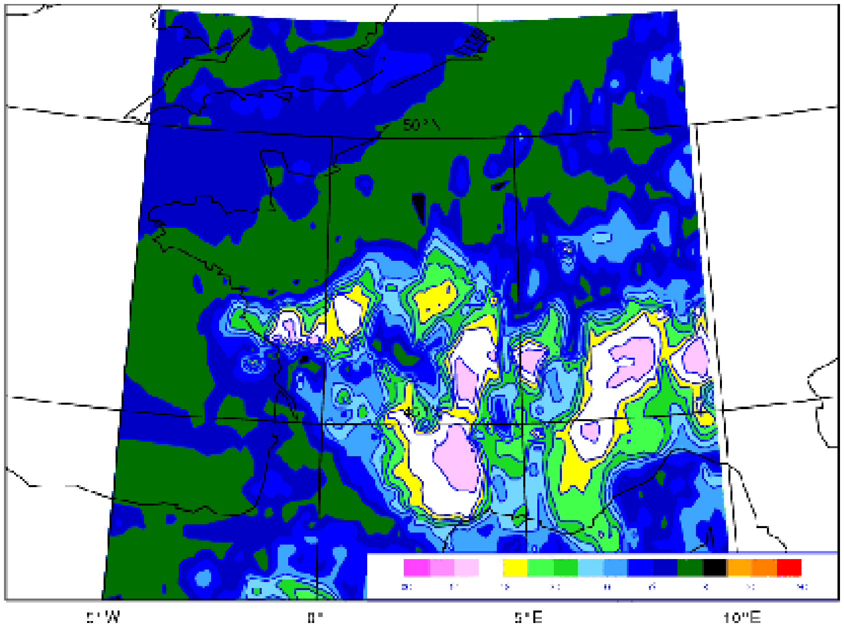
Model performance (4/5): radiance scores

- **scores of AROME-France radiances simulated by RTTOV, compared to Meteosat SEVIRI channels (sensitive to temperature & high clouds only)**
- **not bad, but some radiance and/or physics tuning seems necessary.**
- **no score yet for low clouds**

Arome IR10.8 forecast



MSG IR10.8 image



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Model performance (5/5): subjective validation

- **Bench forecasters have studied the subjective usefulness of AROME experimental products on their workstation in quasi real-time**
- **Three evaluations period were realised.**
- **early reports highlighted model problems that were fixed in recent evaluations**
- **conclusions vary between seasons and regions (i.e. different meteorological phenomena)**
- **as of early 2008, the overall perception of AROME is cautious but positive**
- **some contrasted forecasters' opinions, e.g.:**
  - **good low cloud & fog forecasts (unexpected)**
  - **some very good and some bad precip forecasts**
  - **disappointing performance of wind over mountains**
  - **'too many details' in some "synoptic fields" e.g. theta'w**
  - **a generally good opinion of the added detail**
- **a very important exercise to introduce this new tool to forecasters**

Nébulosité basse *(1)*

Image visible

2 Novembre 09 UTC

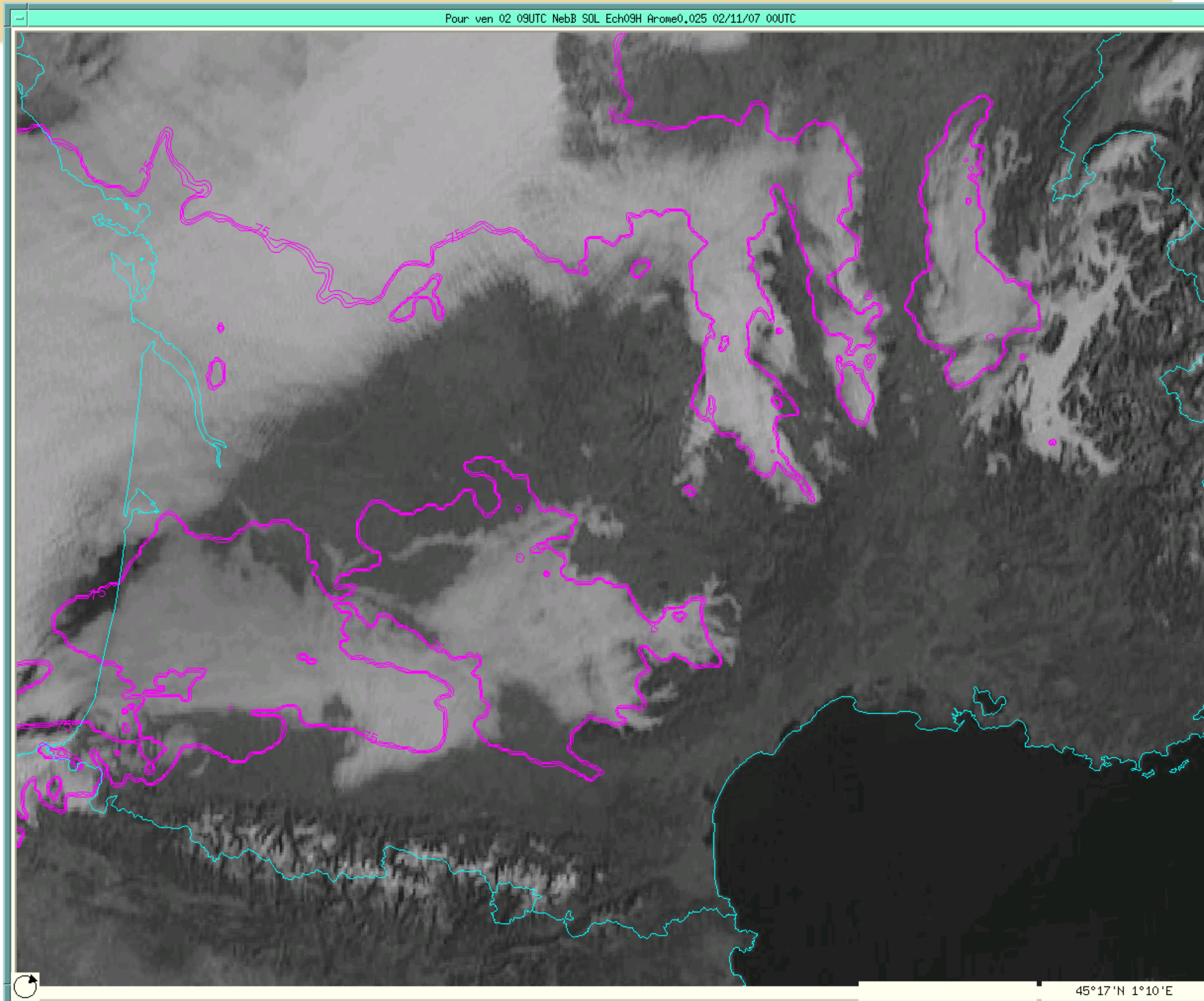
Avec

superposition

Neb basse

AROME

Prévi 9 h



9 hours forecast. Low level cloudiness in pink

Nébulosité basse *(3)*

Image visible

2 Novembre 09 UTC

Avec

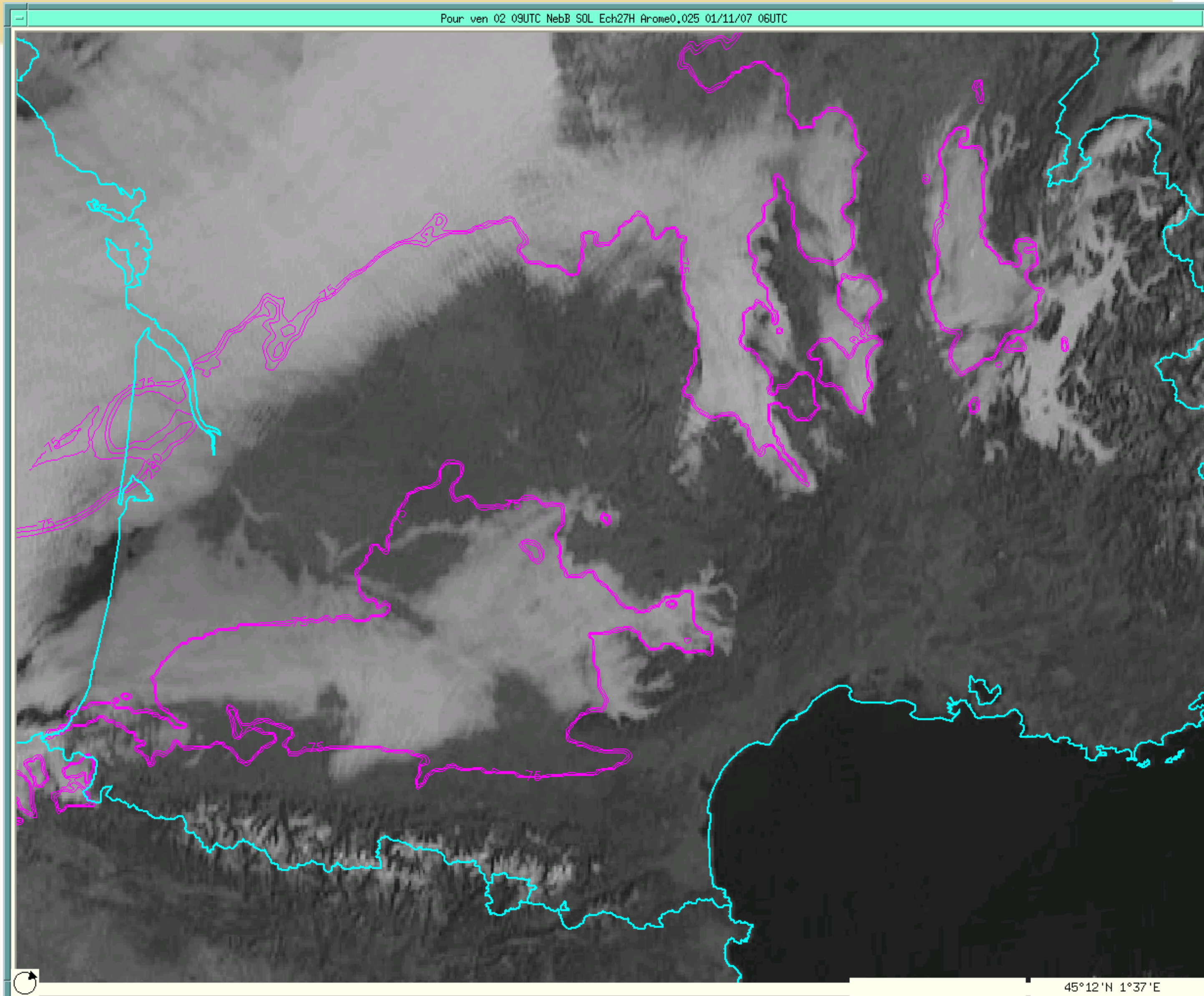
superposition

Neb basse

AROME

Prévi 27 h

27 hours forecast,
Low level cloudiness
in pink



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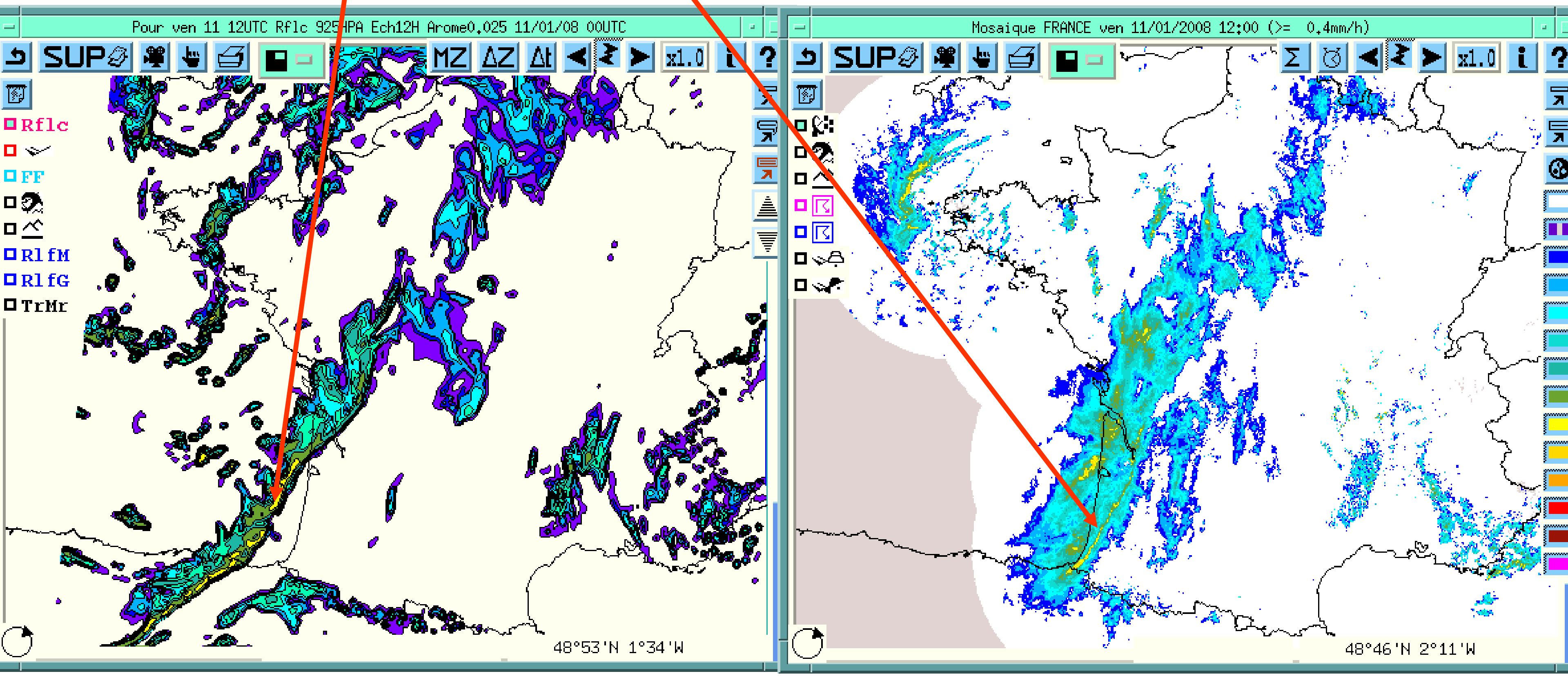
Bandes de précipitations frontales (1)

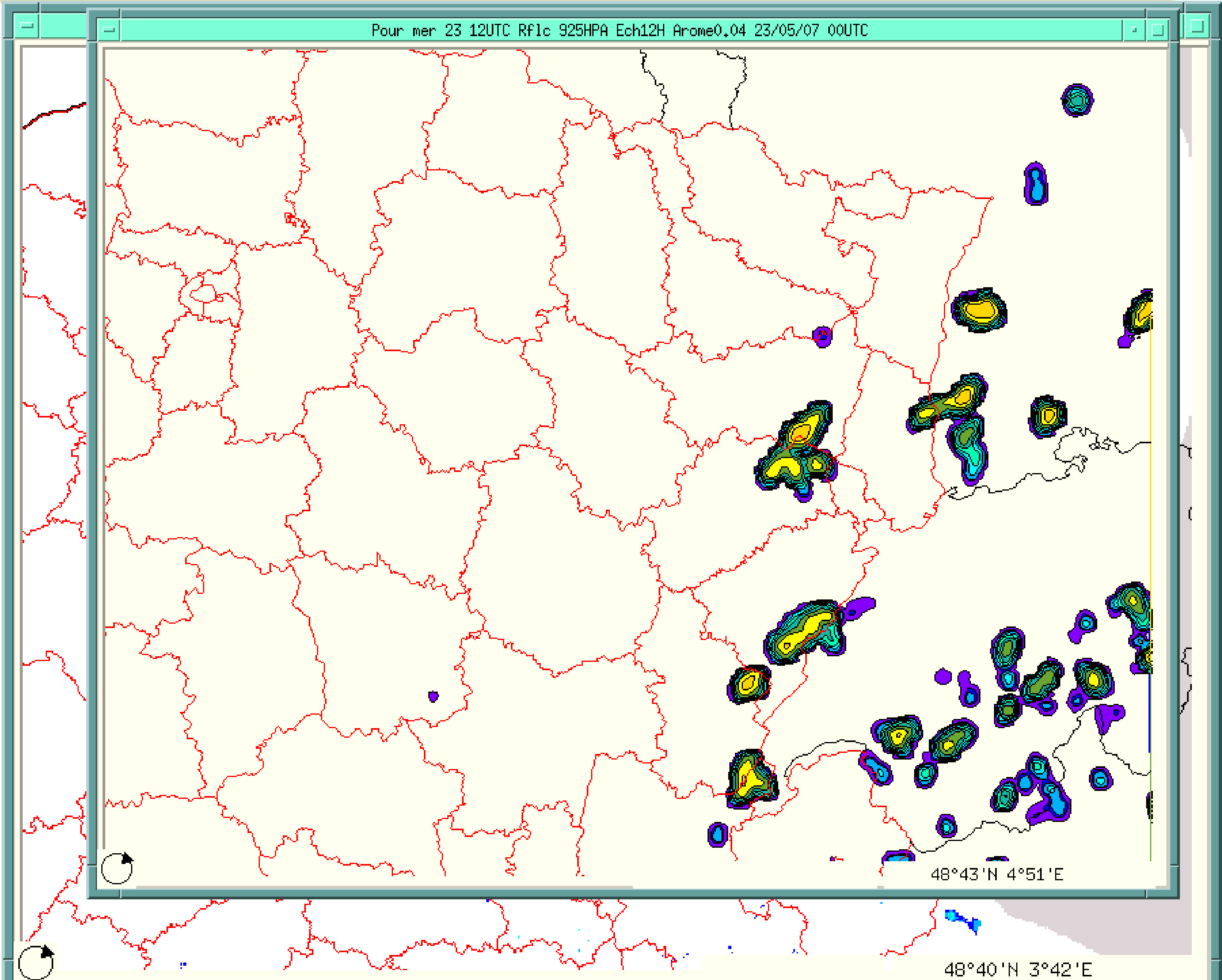
Réalisme bande étroite de front froid, bandes larges et secteur chaud



Réflectivité simulée (prévi 11 et 12 h) vs image radar, 11 Janvier 2008

Démarrage convection diurne et relief *(3)*

Obs radar

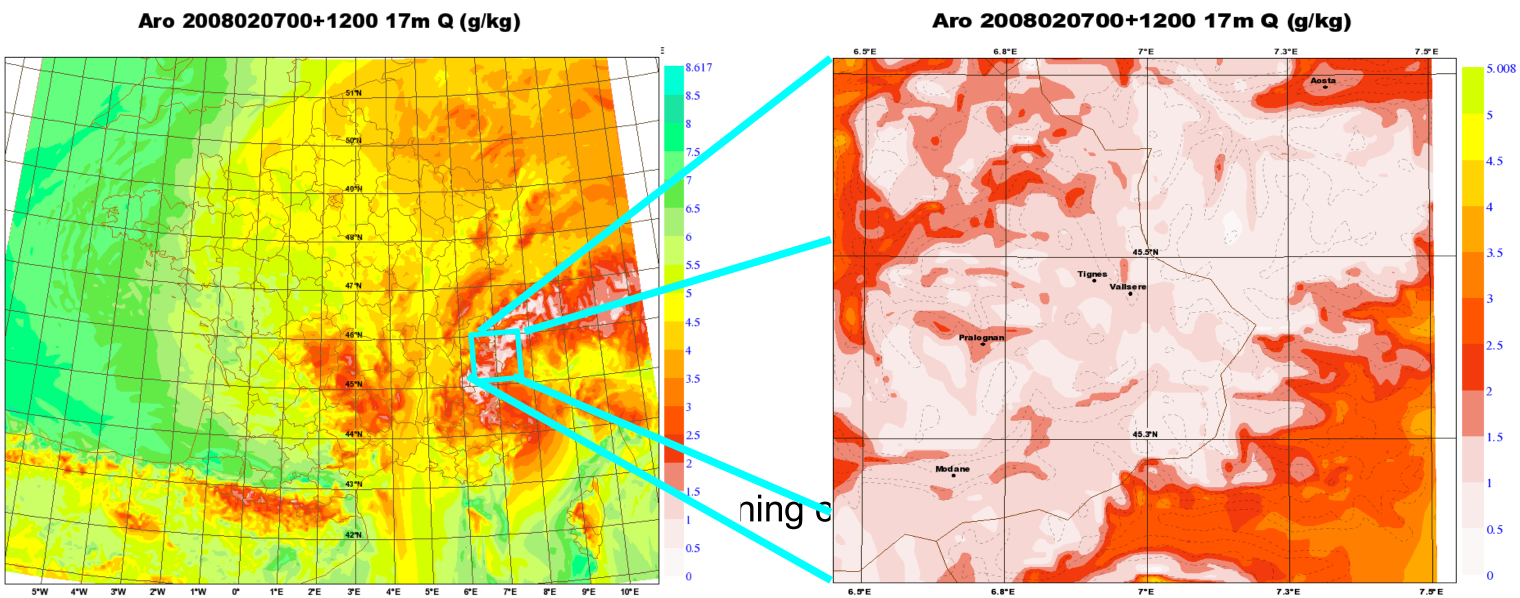


4 - Operational plans at MF: 2008

- **In 2008: 'V1 configuration'**
  - **2.5km 'AROME-France' model domain, 41 levels**
  - **30-h forecasts, 4 times a day**
  - **3DVar assimilation with 3-hourly cycles**
  - **assimilate Doppler radar data (on top of all ARPEGE/ALADIN datasets)**
  - **surface interpolated from ARPEGE**
  - **uses about as much supercomputer as the ARPEGE global 4DVar**

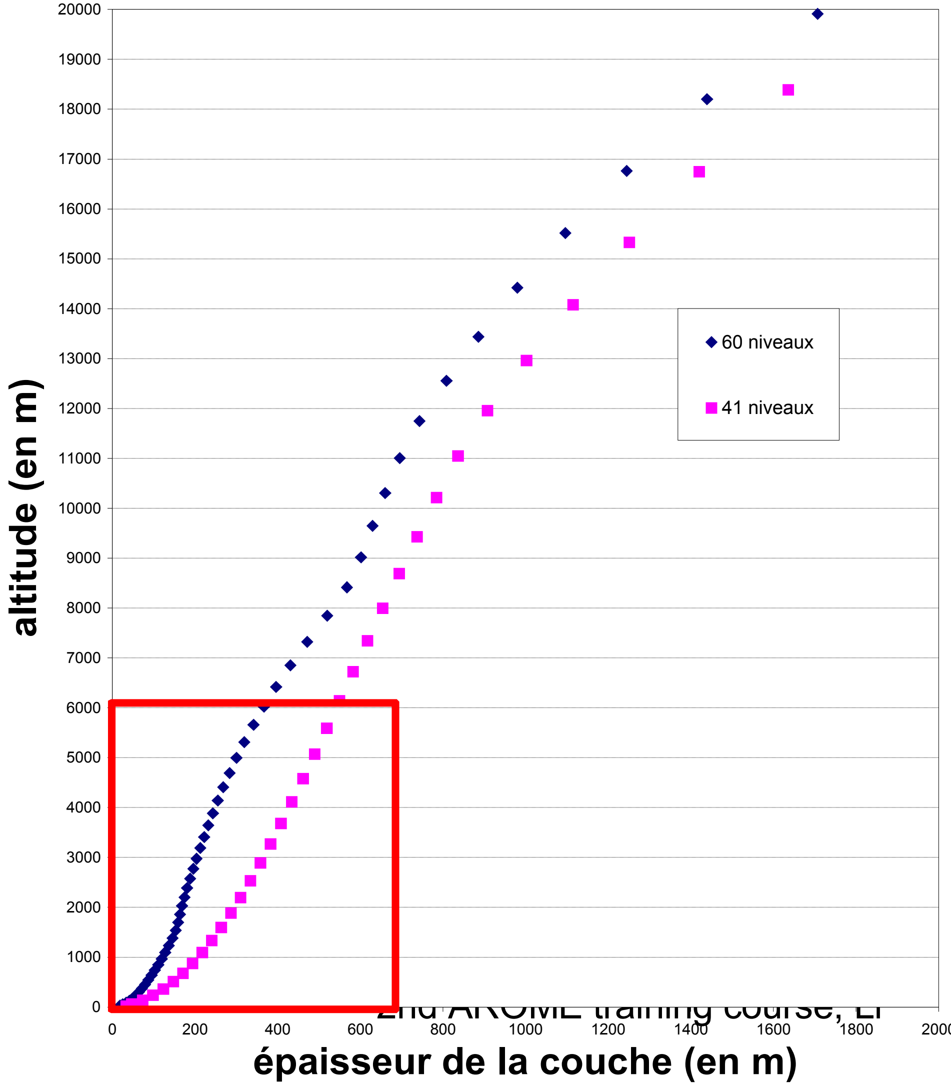
4 - Operational plans at MF: 2009

- **In 2009: 'V2'**
  - increase vertical resolution
  - better assimilation using 3DVar FGAT, Jk coupling and more data
  - assimilate radar reflectivities (as Bayesian humidity retrivals) (and all new ARPEGE/ALADIN datasets: IASI, new GPS ZTD...)
  - Arome surface assimilation (Canari plugged into surfex)
  - and several model improvements
  - (perhaps) short hourly forecasts for nowcasting applications
  - 1-km dynamical adaptation model over the Alps



4 - Operational plan on vertical resolution

- **for 2009, double the vertical resolution in the lower troposphere :**



<u>Moving from L41 to L60:</u>

•costs 37% extra CPU

•1st level at 8m (vs 17m)

•21 levels below 2000m (vs 12)

Supposed to improve forecasts of fog and low clouds

4 - Operational plans at MF: 2010-2011

- **Medium term plans:**
  - **direct coupling of AROME-France to the global ARPEGE**
  - **better surface assimilation (Kalman Filter algorithm)**
  - **bogussing of convective cells and low clouds, based on image processing**
  - **optional deployment on other areas (e.g. French islands), possibly coupled to the IFS**
  - **evolution of Jb in connection with the ARPEGE assimilation ensemble**
  - ***work on the model quality !* (microphysics, turbulence, 3D effects, coupled ocean model...)**

Conclusion: future strategy for AROME

- **In the short term:**
  - ***solve known problems to improve forecast performance - this is the top priority.***
  - **improve user-friendliness towards partners**
  - **work on the compatibility with other models ('convergence')**
- **AROME will be the basis of the numerical tools for short range forecasts of MF operations until at least 2012:**
  - **keep cooperation with Méso-NH group, ECMWF, ALADIN and HIRLAM**
- **But a more general concept of mesoscale model may emerge:**
  - **what connexion do we want with the research community ? (they need specific model features: gridnesting, LES capability...)**
  - **4DVar assimilation and ensemble prediction will be 'a must'**
  - **a mixing between AROME and other model physics might happen, depending on very practical questions:**
    - **what model improvements will it bring ?**
    - **what workforce will it cost/add ?**
    - **what are the long-term benefits ?**
    - ***... who knows ?...***

METEO FRANCE
Toujours un temps d'avance

Program of the training course

- **Tuesday**
  - **Morning Dynamical aspects :**
    - NH equations, academic tests (Pierre Bénard)
  - **Afternoon (1) Dynamical aspects to continue :**
    - how to run the NH kernel (Jozef Vivoda)
    - open questions on dynamics (discussion lead by Pierre Bénard)
  - **Afternoon (2) surface modelling (Patrick Le Moigne)**
- **Wednesday**
  - **Morning Physical aspects :**
    - Turb, shallow & link with cloud scheme (Sylvie Malardel)
    - Microphysics (Christine Lac)
    - Open discussion (discussion lead by Sylvie Malardel & Christine Lac)
  - **Afternoon (1) Data assimilation aspects :**
    - Arome data assimilation (Pierre Brousseau)
    - Radar observations aspects (eric Wattrelot)
    - Surface assimilation (Rafiq Hamdi)
  - **Afternoon (2)**
    - Arome runs in Hirlam (Samin Niemela)
    - DDH for Arome (Tomislav Kovacic)
- **Thursday & Friday**
  - **Practical exercice**
  - **Final discussion (lead by Maria Montero)**