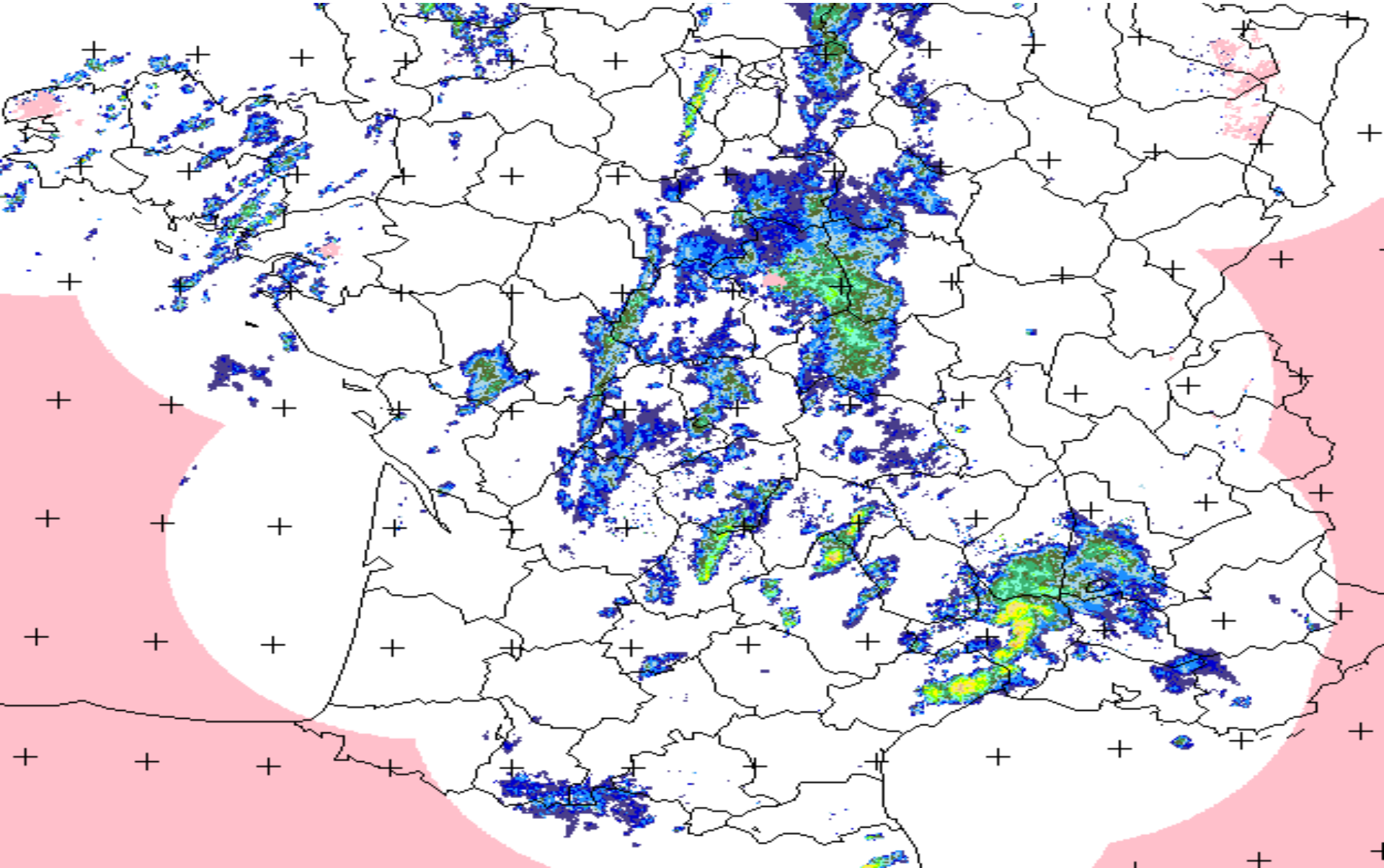
The birth of the Arome project

- Application of Research to Operations at MesoscalE
- AROME driven by user requirements : flash floods, squalls, actual weather, hydrology, pollution, fog... increase in business demand and lawsuits on underprediction of severe weather. Technological gap between imagery-based nowcasting and NWP scales & ranges.
- physical opportunity: meteorological improvements of using better microphysics, turbulence, radiation, land surface, NH dynamics.
- computational opportunity: 3-9km resolution range ok for simple orographic adaptation, but problematic for rain forecasting (according to experts worldwide). The problem can be bypassed by waiting for computers around 2010.
- software opportunity: IFS/Arpège/Aladin framework is ideal with nearly ready-to-wear Méso-NH physics.

The convective storm forecast challenge: 8/9 Sept 2002 floods



The birth of Arome (2)

- network opportunity: 2-km datasets available from radars and Meteosat Second Generation. Initialization of boundary layer, convective cell and mesolows will be possible using mesonet SYNOPs, profilers, aircraft, NPOESS/Metop satellites, GPS.

- institutional opportunity: AROME will be a synergy between NWP teams, mesoscale research labs,environment/hydrology/chemistry/ satellite communities. Will attract external experts and grants to the NWP world.

- competing projects in US (WRF), Germany (LM), UK, Hirlam, Canada, Australia. Strategic issue given the improvement of global resolution models (ECMWF = 10km in 2010 ?).

A Brief History of Arome (1)

- prompted by US experiments on storm-scale analysis and UKMO work on moisture initialization and nowcasting.
- 1998/1999 pilot studies in Méso-NH (CNRM/GMME, Toulouse) on thunder- and hail-storms showed superiority of 2.5km-Méso-NH model with crude humidity nudging using SYNOPs and satellite imagery.
- essential ingredients: NH 2.5-km model, prognostic cloud microphysics and turbulent mixing.
- Météo-France's public funding for 2000-2008 with a commitment to implement Arome by 2008 (consistent with funding of radar/mesonet networks, MSG and Metop/IASI plans).
- in-depth expert discussions in Météo-France lead to the Arome project in 2001 with specially appointed staff (9 people in 2003, and still growing), plus commitment of existing staff (6 so far) throughout Météo-France.
- dilemma: base Arome on Méso-NH (proven quality but no data assimilation software) or Aladin (not designed for kilometric resolution but better suited for NWP)

A Brief History of Arome (2)

- The December 2002 meeting of the Météo-France's Board of Directors (CIPN):
- key decision: choose Aladin-NH as Arome's dynamical core after its superiority was rigorously demonstrated by intercomparison with Méso-NH and Hirlam-NH.

- consequences: (1) use IFS/Arpège/Aladin as software basis, (2) use Aladin's 3DVar for analysis, (3) import Méso-NH suitable physics.

- worries about Arome's cost and potential conflicts of interest with Aladin lead to: (4) extend the Arome project to support 10-km NWP applications: the 'Arome-10km' subproject.

- Arome-10km will be an alternative to Arome-2.5km for computationally critical applications. It will be better, and a bit more expensive than Aladin-10km.

Arome general design

- Arome IS Aladin plus different physics and expanded ambitions on data assimilation and coupling (physics/dynamics, atmosphere/surface, large scale/small scale). Most (but not all) current Aladin plans are compatible with Arome plans.
- Arome will keep a close compatibility with ECMWF on data assimilation and technicalities. Like Arpege, except that Arome and Arpège physics are going to be different.
- During its prototyping phase (2003-2005) Arome will NOT be closely phased with the official Arpège/IFS/Aladin cycles.
- Arome-10km software will be very close to Arome-2.5km, probably with Kain-Fritsch-Bechtold convection and 1-D prognostic turbulence physics.
- Aladin-10km will cease to be supported by Météo-France around 2007. The likely phasing problems in the physics/dynamics interface must be considered between Météo-France and Aladin partners.
- Arome's openness to the research community means a reasonably reduced emphasis on technical optimization (computational speed, memory, I/O, coupling file size) compared to Aladin.

Arome general design: conclusion

- Arome is not about developing a new NWP system from scratch. It aims to integrate subcontracted software. Our job is to develop the missing parts and make the integration work well.

- Arome is not just about software. Interacting with scientists to make them useful for NWP is good science. So is making our NWP software useful for scientists (e.g. field studies and coupled models).

- The 'old' Arpège/Aladin physics are doomed unless heavy & painful maintenance is invested in it - and not by Météo-France.

- Arome is an unavoidable Darwinistic evolution of Aladin. It opens up a new world of mesoscale predictability that will make regional NWP even more useful than before.

Arome's components : dynamics & numerics

- Aladin-NH semi-Lagrangian dynamics are currently the best choice in the world. Proven against MésoNH, Hirlam-NH and UM.

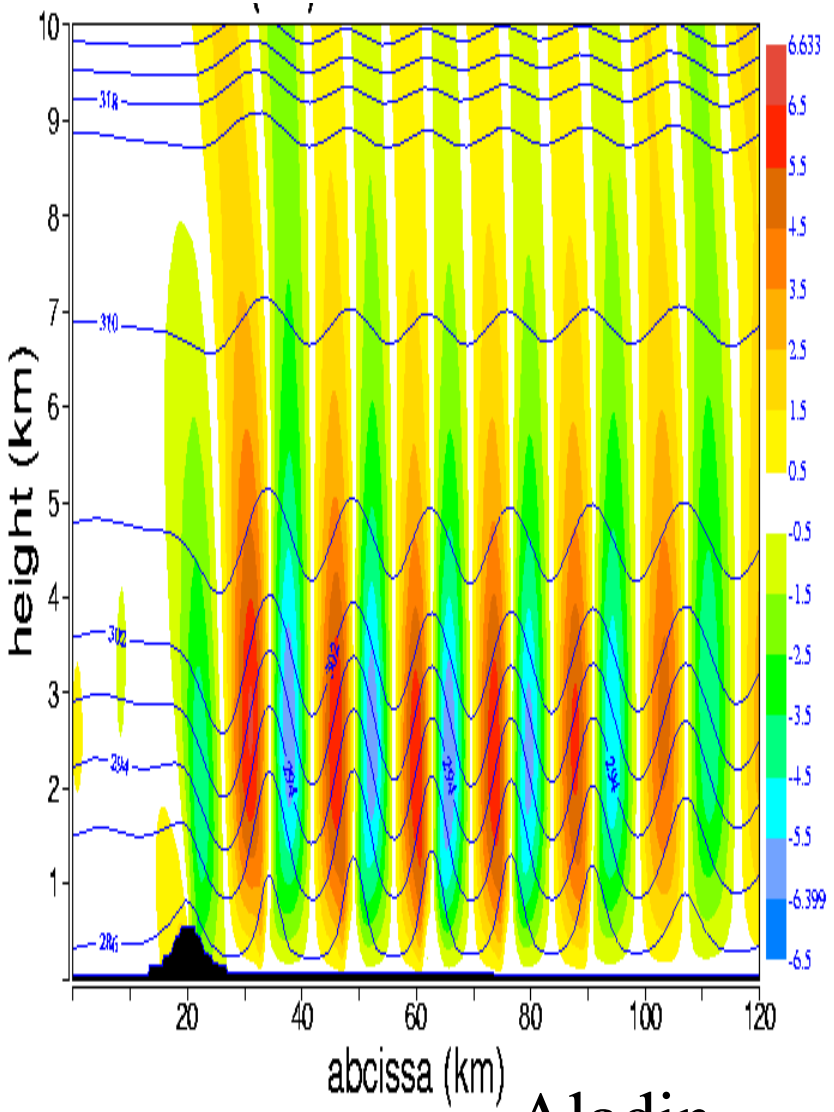
- Envisioned timestep is 1-2min at 2.5km, 4-8min at 10km (prototyping is needed)

- Go from elliptic quadratic to rectangular linear truncation (to eliminate spectral fit and biperiodization impacts)

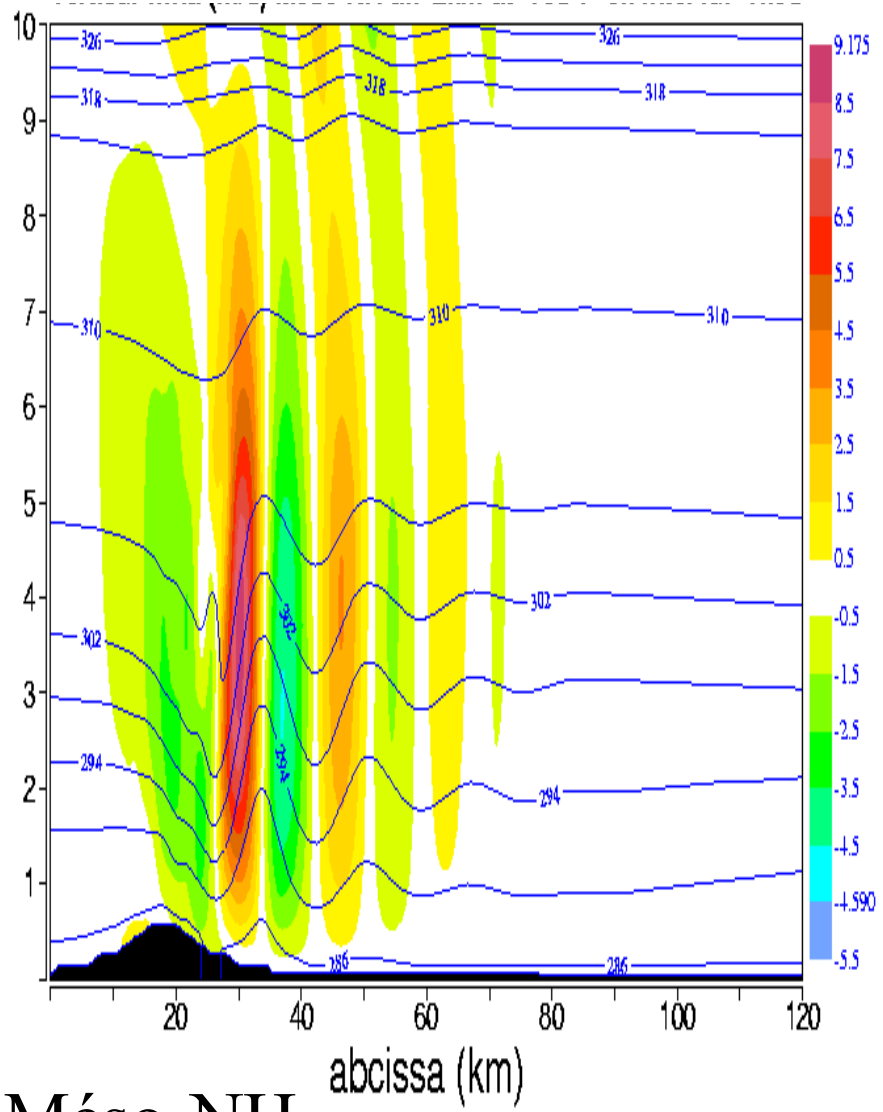
- Extension zone will remain useful in 3D-Var

- Large-scale coupling will evolve a lot (to be determined. Need high frequency and good mesoscale waves I/O. Méso-NH uses a buffer model with 2-way coupling).

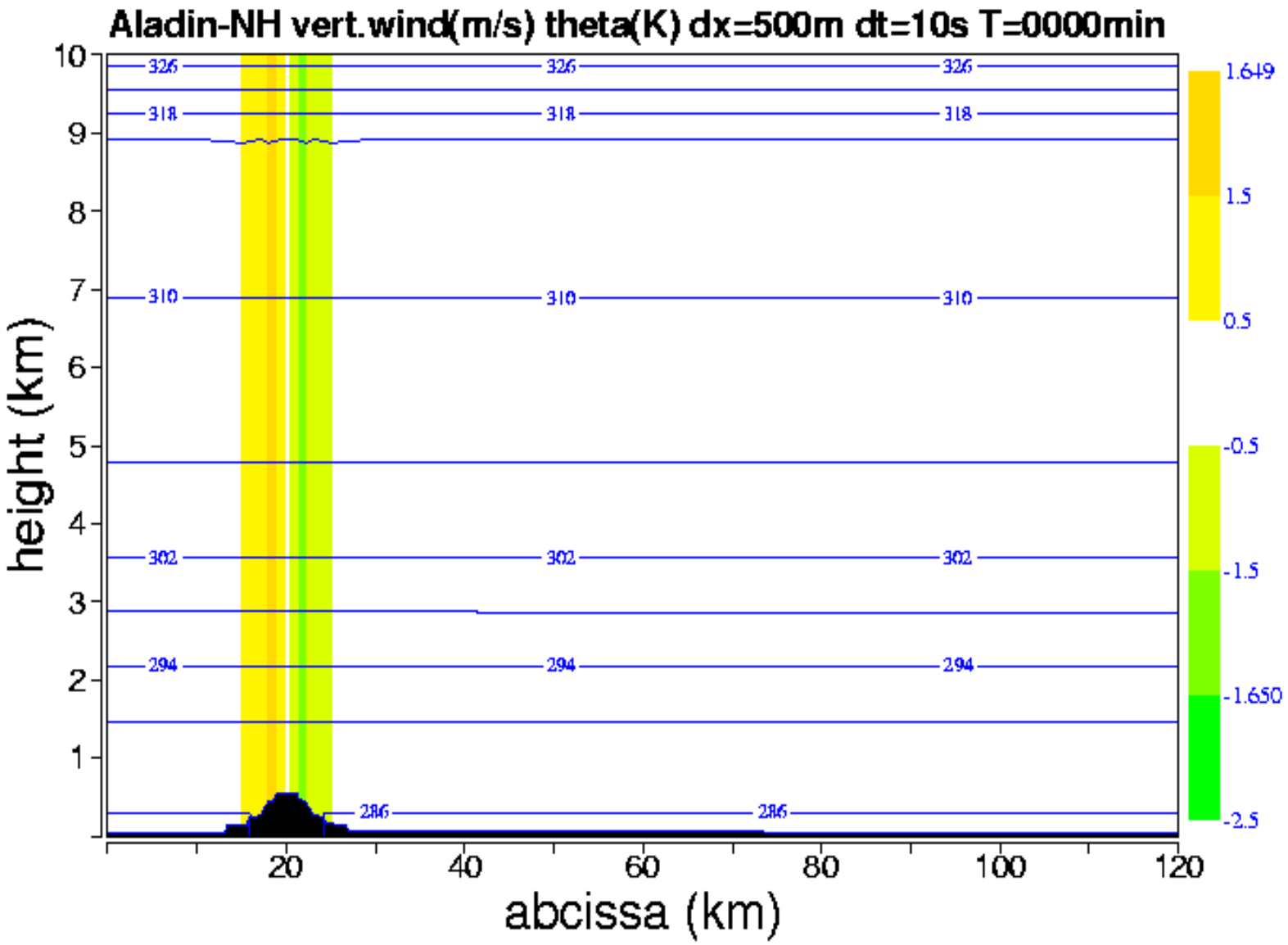
Aladin-NH vs Méso-NH 2D validation
vertical wind and theta at 500m resolution



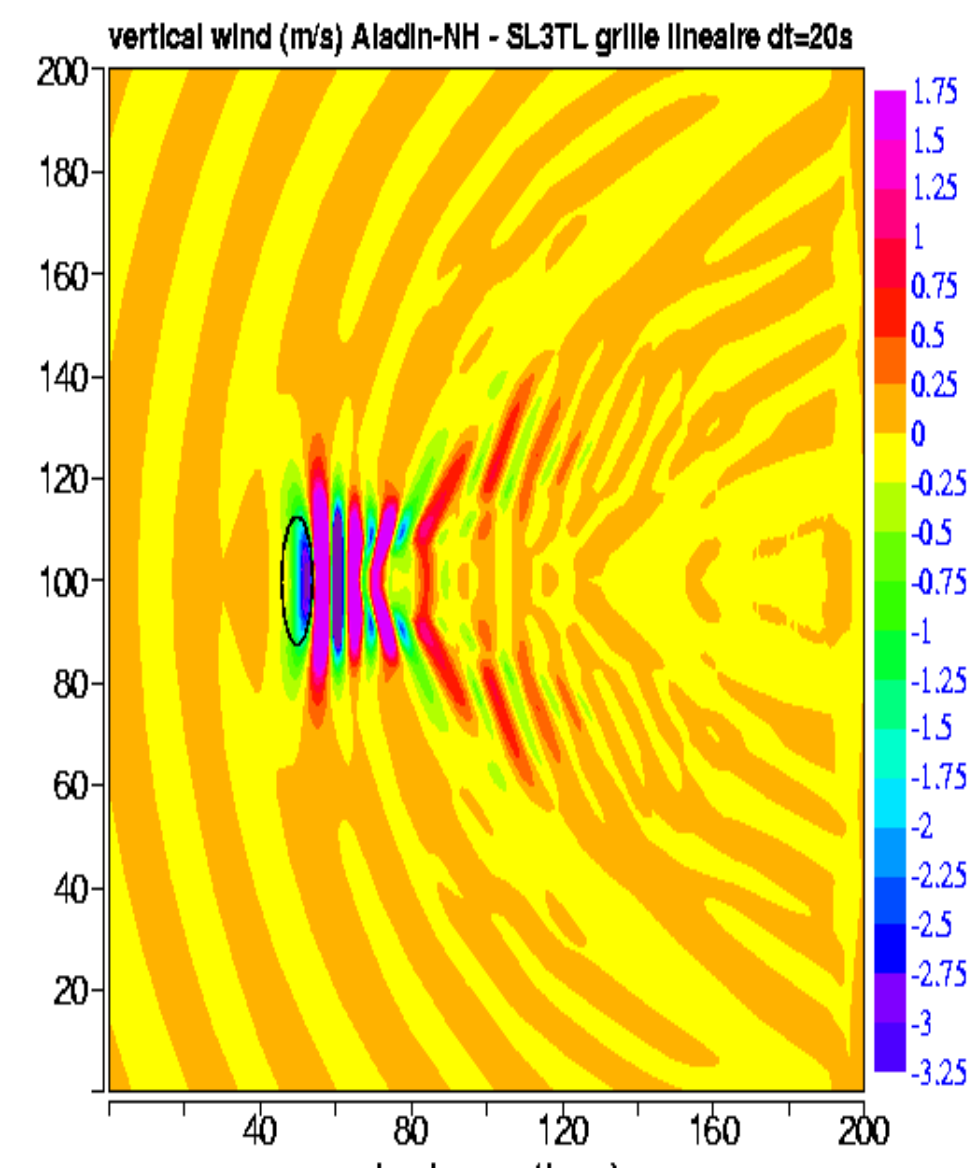
Aladin

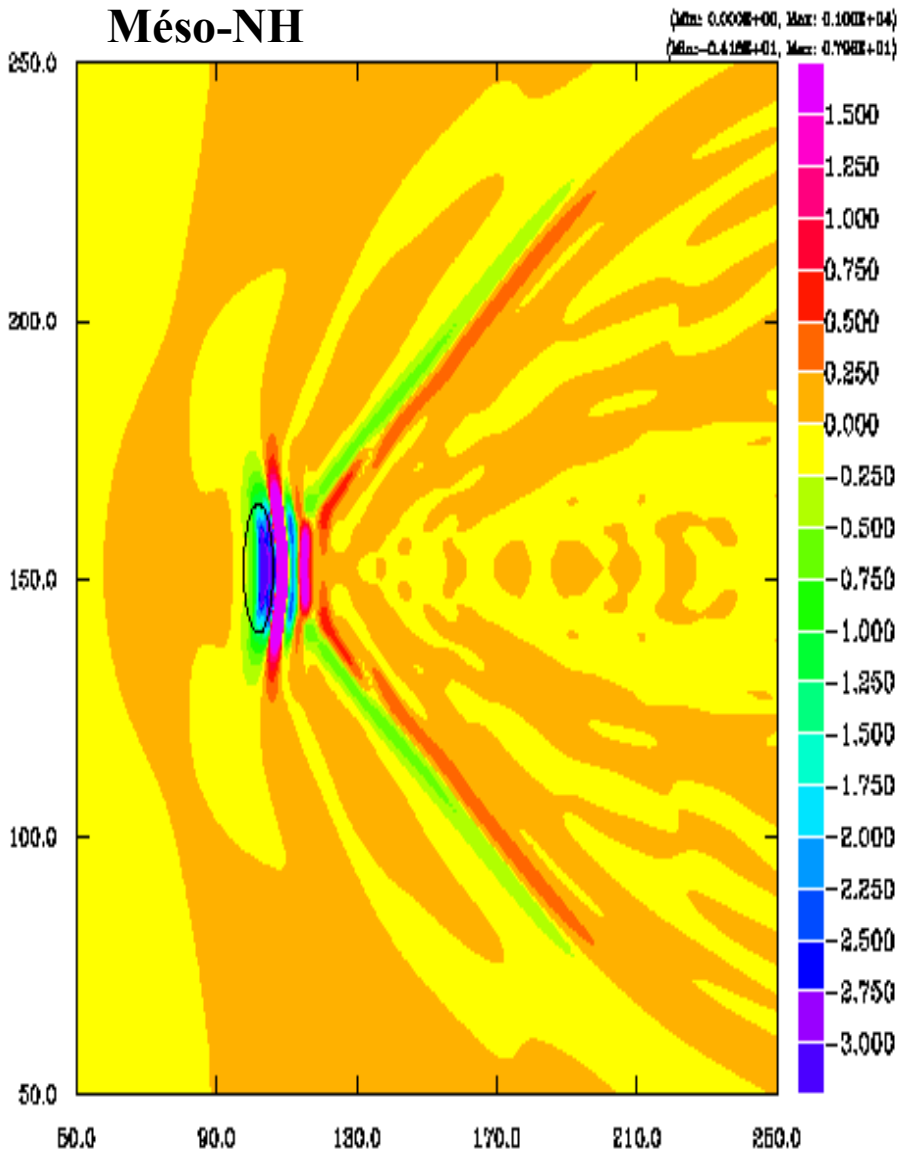


Méso-NH


Aladin-NH vert.wind(m/s) theta(K) dx=500m dt=10s T=0000min
height (km)
abcissa (km)
326
318
310
302
294
286
1.649
1.5
0.5
-0.5
-1.5
-1.650
-2.5

Aladin-NH vs Méso-NH 3D validation at 2.5km resolution
vertical wind





Arome's components : technicalities

- Model file format will evolve (many new descriptors, and surface physiography will be externalized)
- ECMWF computer business is a guarantee of portability despite their use of a scalar IBM.
- Phasing issues with coupled models and Méso-NH coordination on shared parametrizations.
- Demand for easy domain setup procedures for Arome assimilation & forecast anywhere on the Globe (including tropics).
- Execution under SMS/Olive in Toulouse. Installation of Aladin on ECMWF IBM and Linux in 2003 is likely.

Arome's components: physics (a)

- (see Jean-Francois' presentation)
- select a subset of Méso-NH physics suitable for 2.5km and 10km runs. CNRM/GMME will keep improving their physics for Arome.
- Kain-Fritsch-Bechtold **convection** and Fouquart-Morcrette **radiation** are already coded in Arpège.
- **Turbulent mixing** shall be 3-D but CNRM/GMME will deliver an improved version of their 1-D turbulence in a first step. 3-D will require a special parallelization effort for lateral fluxes.
- Méso-NH 'ICE3' **microphysics** with prognostic: cloud water and ice, graupel, rain, snow, hail. Slow and fast adjustment schemes. Need to redefine Arpège's flux-based interface and fundamental conservation hypotheses (they are dodgy in Méso-NH too !).
- The surface schemes are becoming hugely complex: tiles, towns, chemistry... Arome offloads the burden to CNRM/GMME and related labs, by externalizing the **land surface scheme** and related **physiographies**. (common interface with Arpège-climate and the PRISM community)

Arome's physics (b)

- All Arome physics have time-explicit interface (they may be internally implicit). Radiation may not be called at each timestep.
- **Land surface assimilation** still to be defined (reconcile forced-fluxes and variational algorithms).
- Sea surface will have a simple 1-D **ocean prognostic mixing layer and sea state** representation.
- Specific developments for **chemistry/aerosol** coupled models: plug-in interface for chemical equation compilers and MPDATA conservative advection for hundreds (!) of species (long-term Arome only). Short-term = frequent outputs for MOCAGE transport model.
- Most of the Arome's CPU cost will be in the physics. Most of physics' cost will be in the 3-D turbulence and the microphysics.

Arome's physics (c)

- Development of a **working prototype** by end 2003 [S. Malardel and Y. Seity] using Méso-NH and Arpège-1D models. Work on the 3-D interface to be synchronized with IFS/Arpège's new fields data structure [M. Hamrud, ECMWF].

- Parametrizations that are not already coded in Arpège will be made common to Méso-NH and Arome - with different interfaces. This will allow validation studies with 2-way nested runs and Cloud-Resolving resolutions.

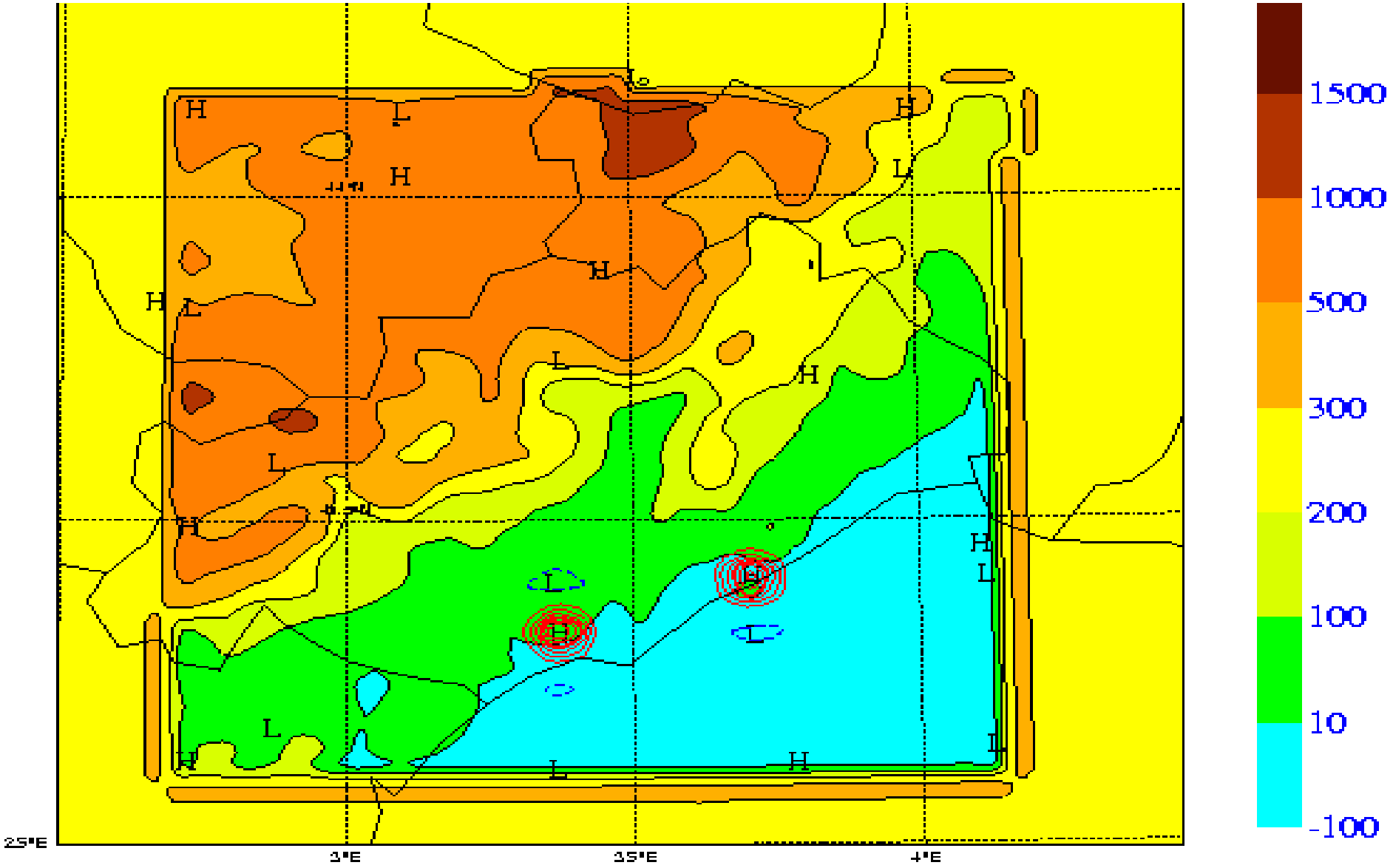
Arome's components: data assimilation (a)

- LAM Predictability studies (lagged-NMC and breeding cycles) prove that boundaries affect the entire LAM domain after a few hours...but internal small-scale errors survive for several days. So we need data assimilation.
- A perfect large-scale forecast will not make a perfect LAM forecast without mesoscale assimilation. But poor large scales will surely mess it up, so Arpège shall improve too.
- 4D-Var will be too costly at 2.5km: 3-36h forecast ranges require production within 1h. So 3D-Var is preferred until 2008.
- 3D-Var algorithmic issues: FGAT, accelerated minimization for nowcasting, elimination of boundary echoes (compactly supported Jb and wide extension zone), Jc initialization for orography and microphysics, new cost-function term to apply consistency with the large-scale model a la blending.

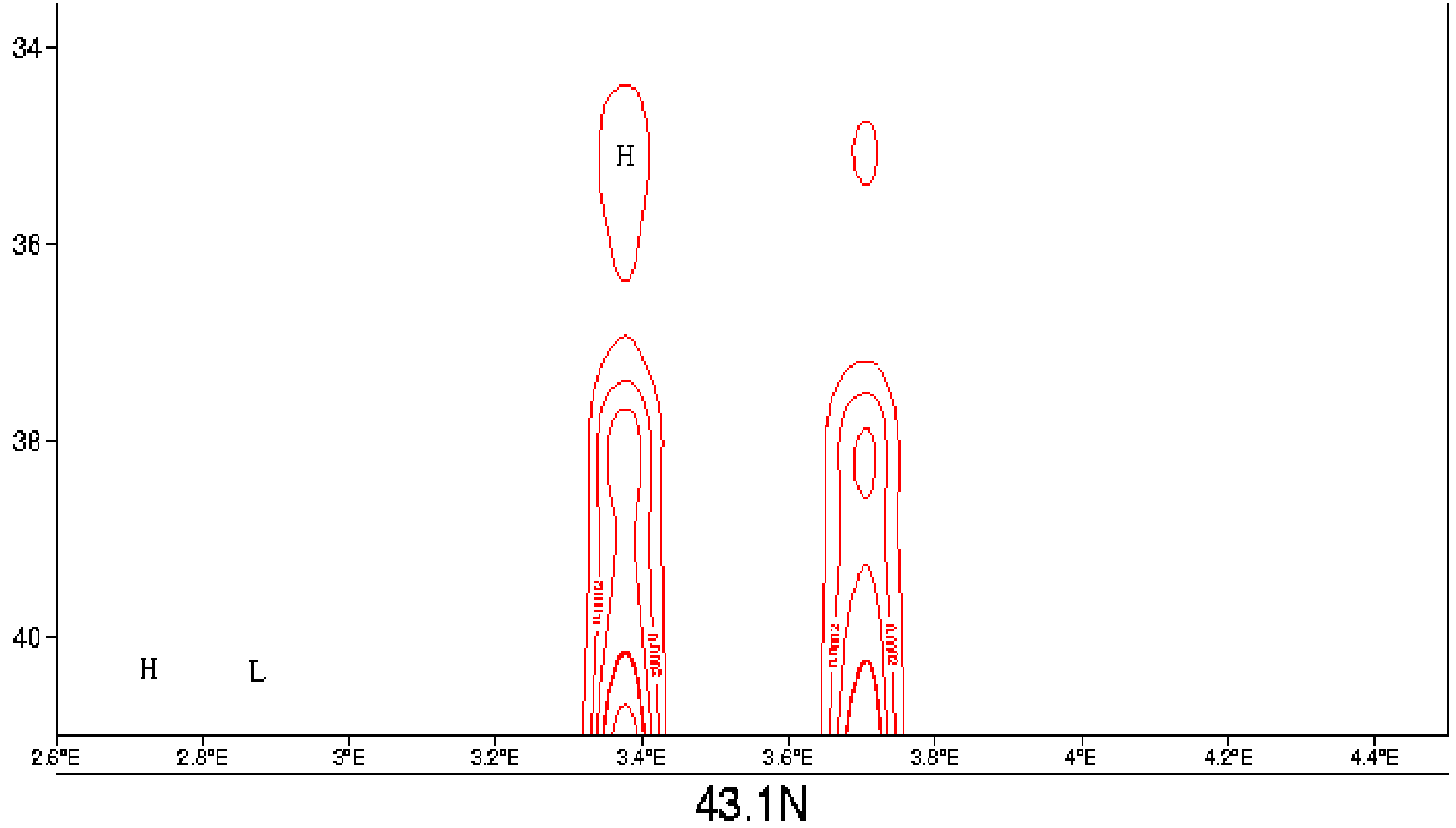
Arome's data assimilation (b)

- Assimilation cycle length will probably be 1h with 10min short cutoff, 50min long cutoff synchronized with polar satellite local acquisition, extra-long cutoff once/twice a day to provide polar satellites extra orbits and full synchronization with the global model.
- 3D-Var will run at full 2.5km resolution with enhanced Jb structure functions (30km horiz length-scale, 1500m vertical range, situation-dependent vertical humidity structure functions). A Jb geometry-changing program has been developed to bypass NMC recalibration [F. Bouttier].
- Aladin-3DVar is ready for experimental use, as is Méso-NH: the 2003/2004 reference data assimilation system will be an HYBRID system with Méso-NH forecast runs and a collocated Aladin 3D-Var to compute increments. First experiments are already running [P. Riber].

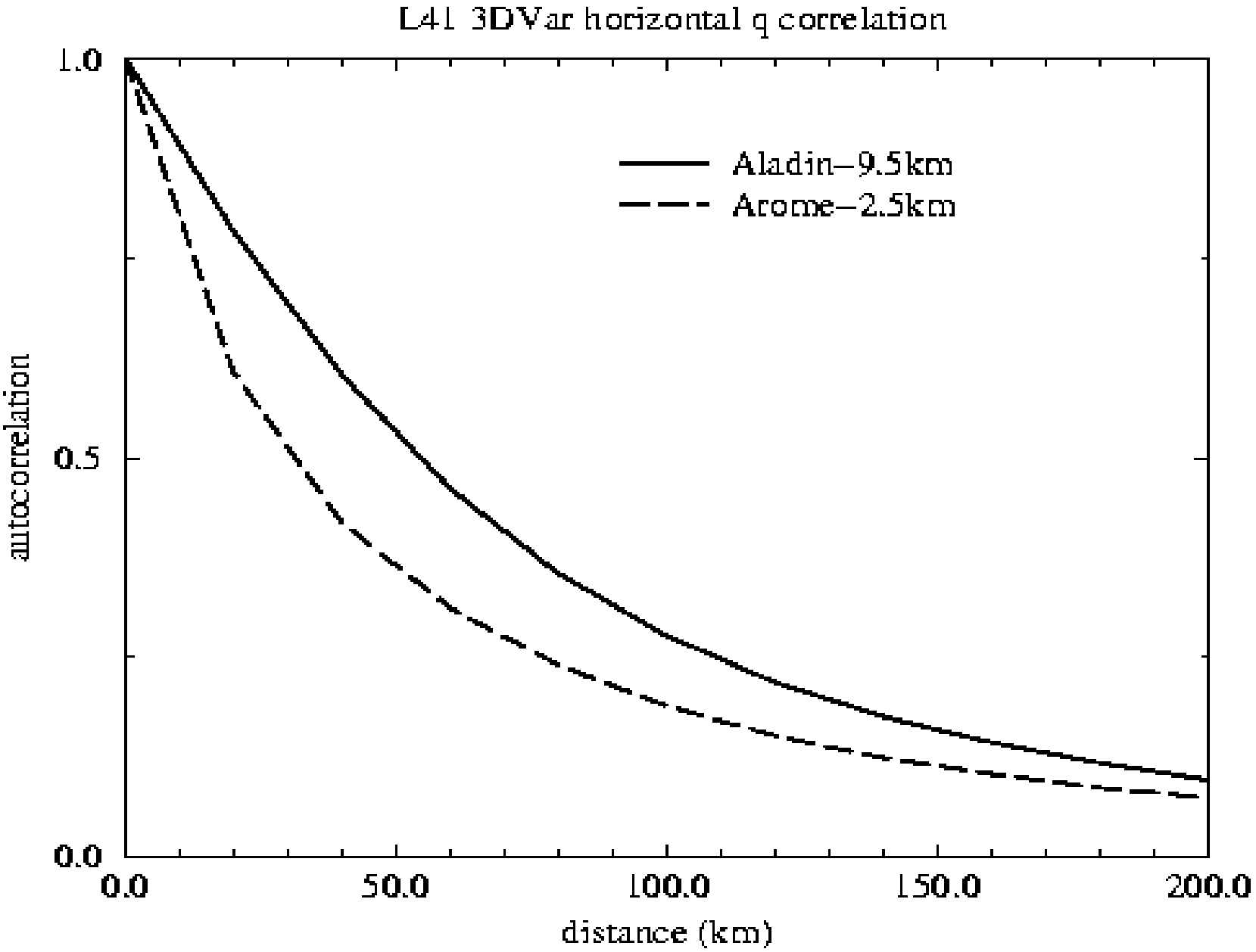
2.5km 3DVar prototype
low-level humidity increments



2.5km-3DVar extra-sharp structure functions test (vertical cross-section, 8-km length scale)



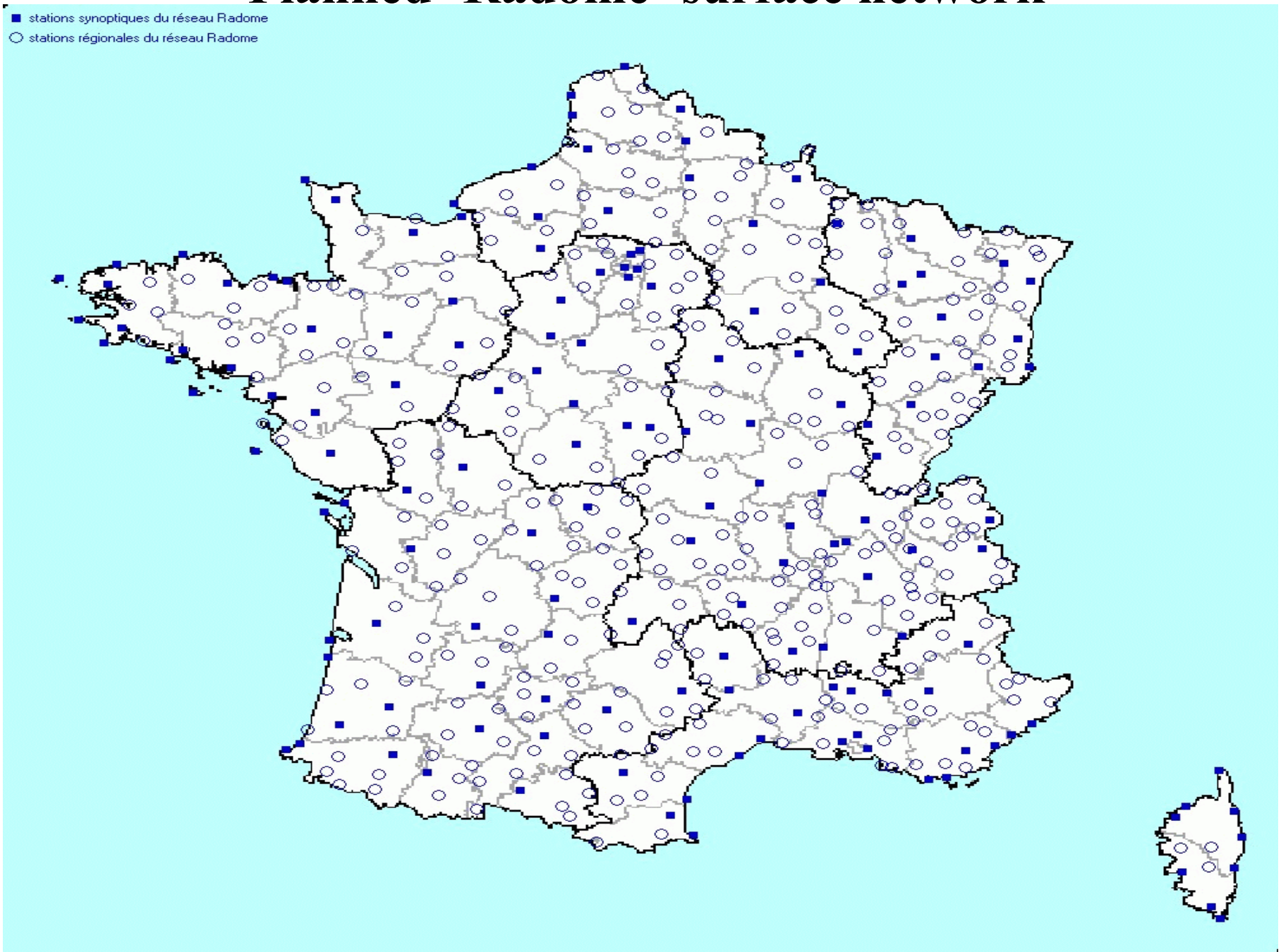
Ajustable spectral multivariate 3D-Var structure functions



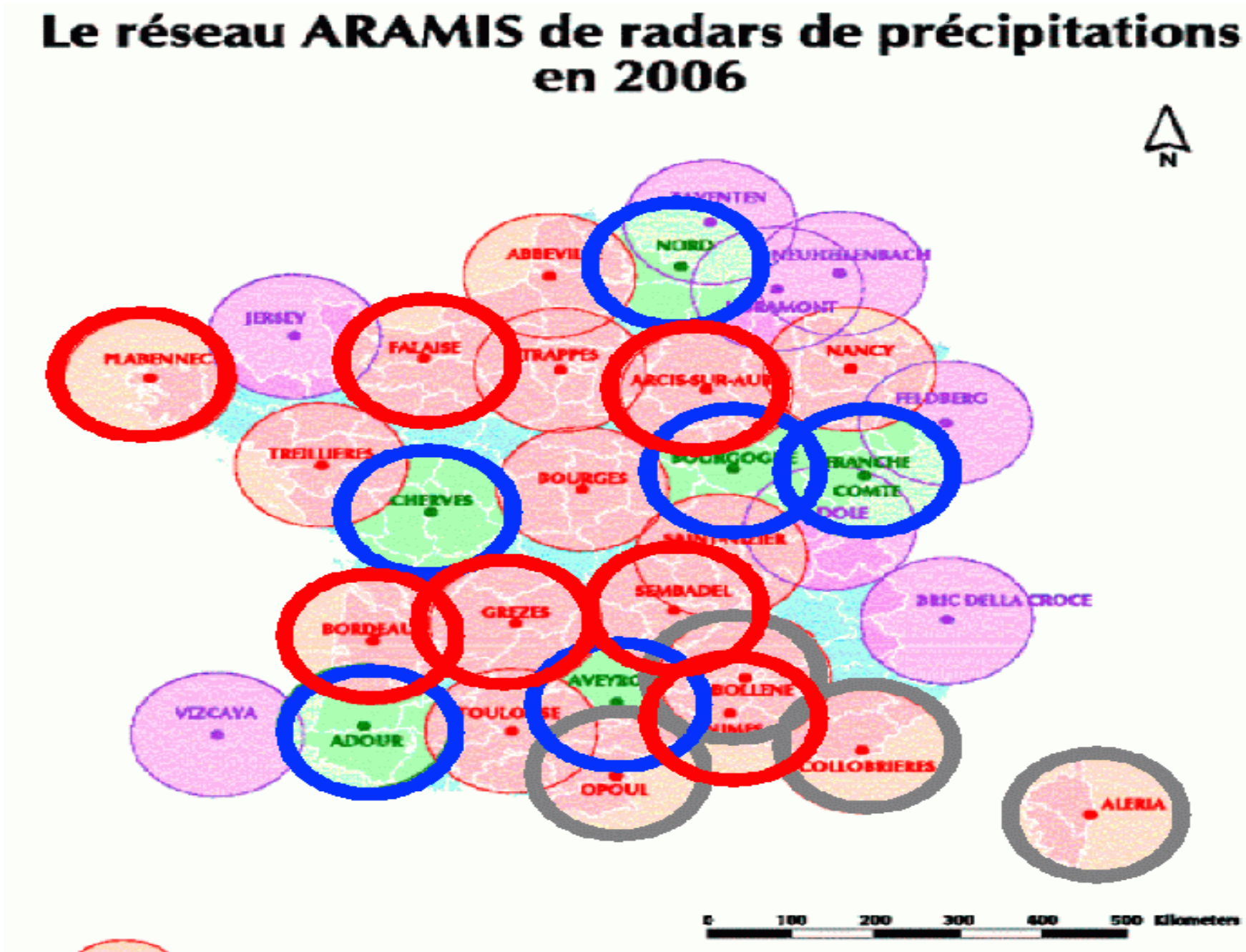
Arome's components: observations (a)

- Activation of all Arpège/Aladin observations, plus **SYNOP-land** 10m wind and 2m humidity to initialize convection.
- Use of **MSG radiances** has been implemented in Aladin-3DVar [T. Montmerle].Good impact on humidity analysis. Tested on a convective storm case.
- Bogus **cloud/humidity initialization** from MSG/radar products is being developed [M. Nuret, CNRM/GMME] (already validated by Méso-NH nudging)
- Radar developments need structuring. Research starts soon in CNRM/GMME [V. Ducrocq's nowcasting team]. Priority is on developing the **reflectivity** observation operators in 3D-Var. **Doppler winds** will be available later.
- Other data developments will come from Arpège ([F. Rabier's team]): **Radome mesonet** obs, **AIRS**, **CRIS**, **IASI**, **Quikscat**, **GPS**...
- Pilot studies on **lightning** and **nowcasting** data assimilation

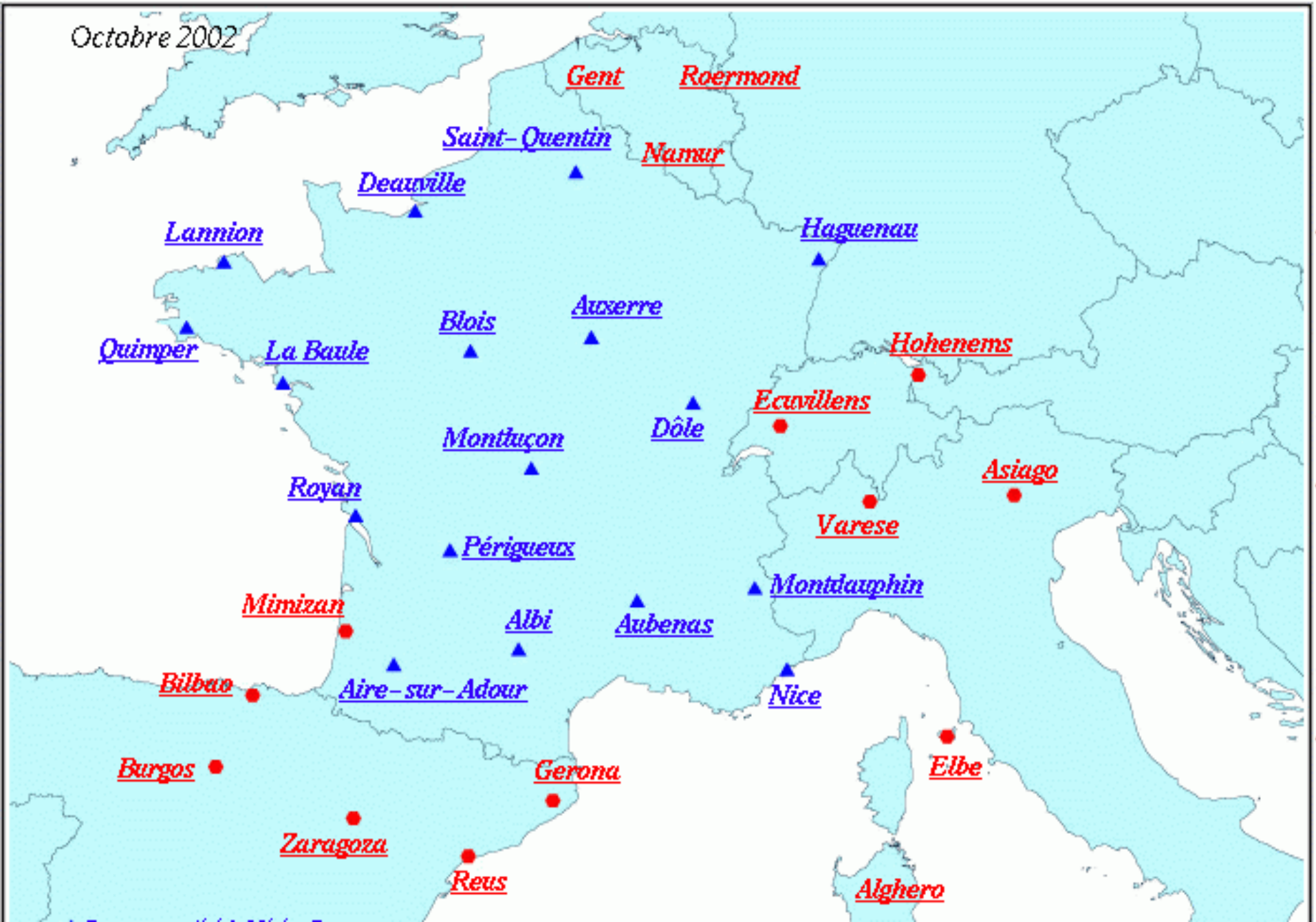
Planned ‘Radome’ surface network



Planned radar network

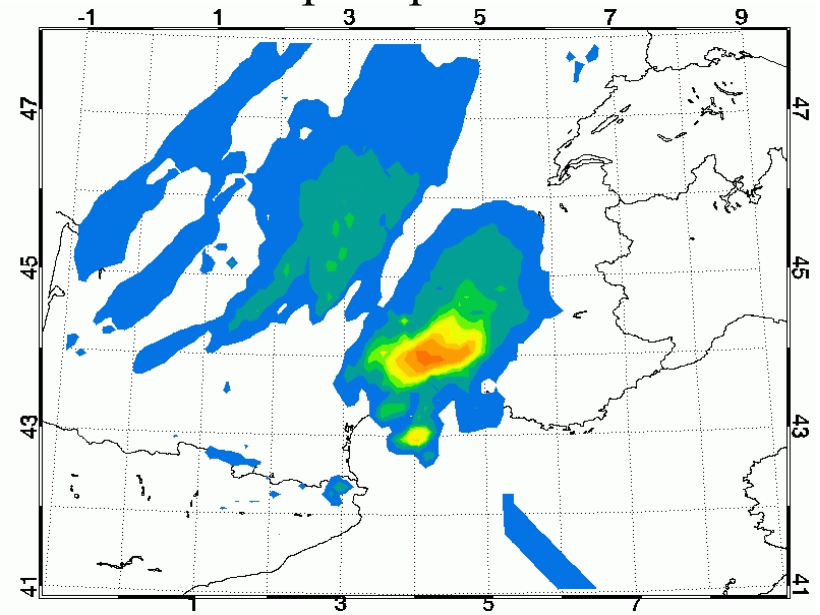


Lightning detection network

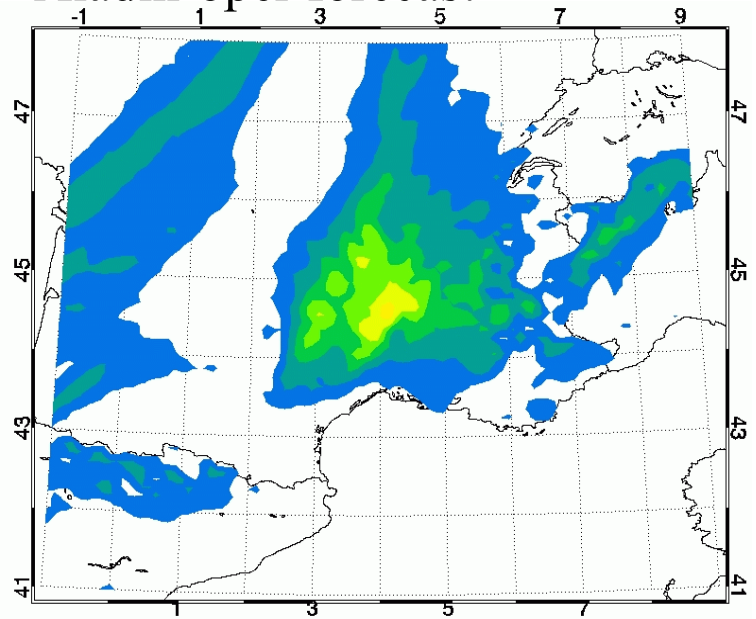


Impact of Meteosat vapour radiances in 10km-3DVar

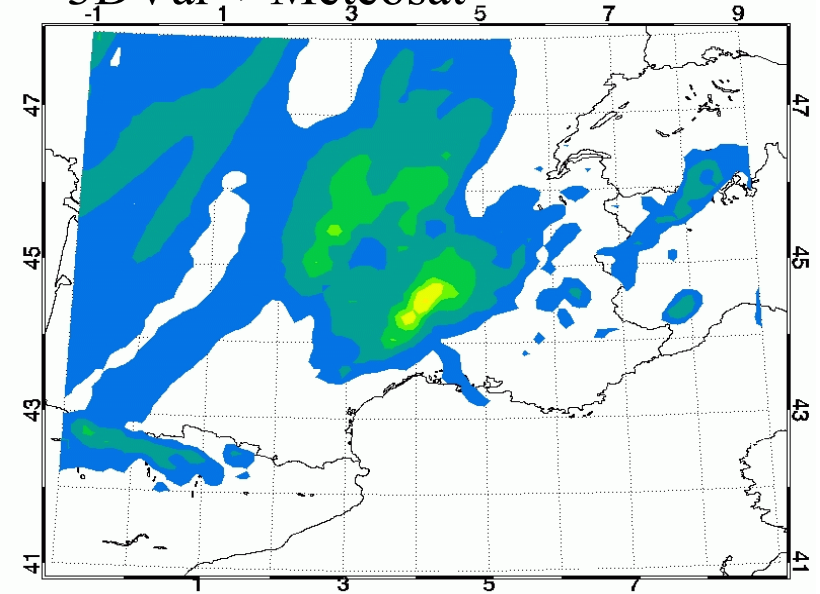
radar 36-h precip distribution



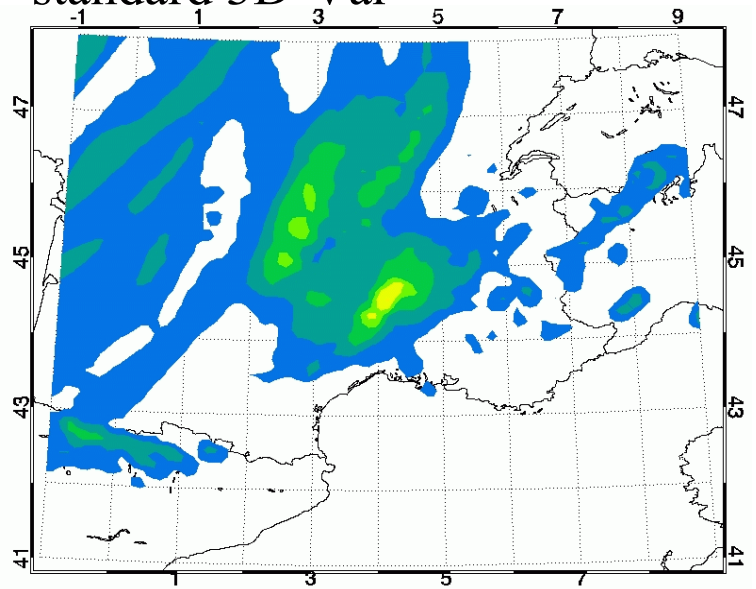
Aladin-oper forecast

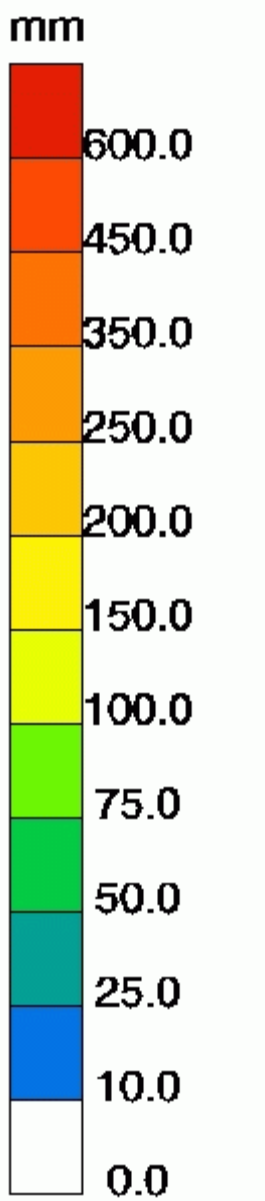


3DVar + Meteosat



standard 3D-Var



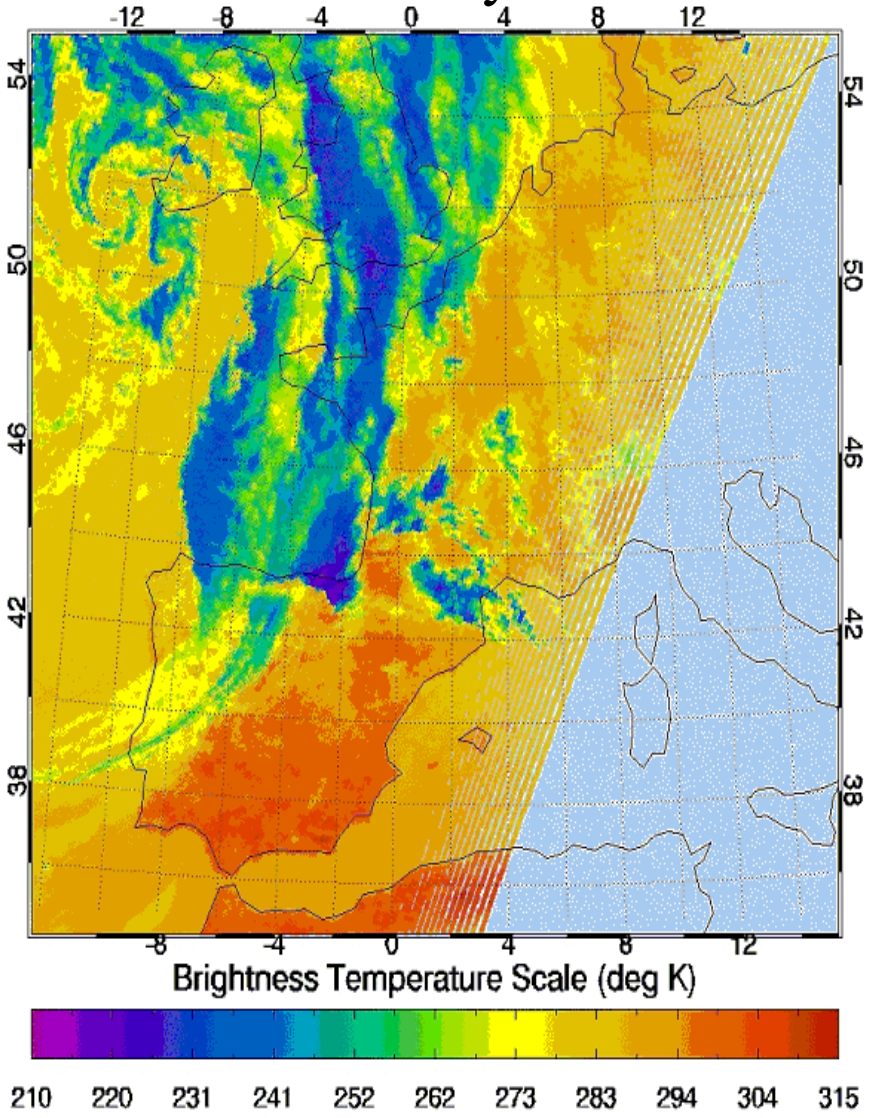


Arome's assimilation (c)

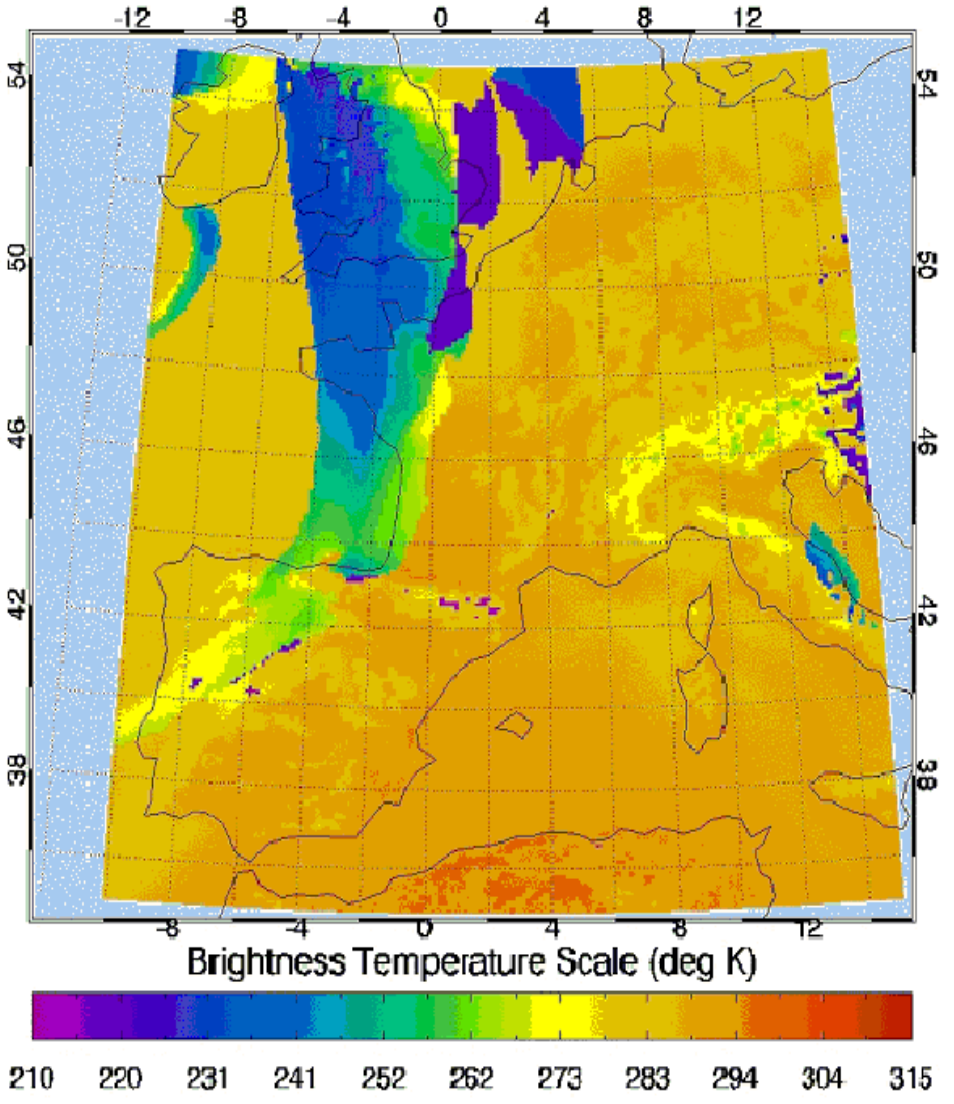
- Model comparison with radar/satellite images will be an important validation tool. Feature comparison algorithms (to replace rms) are being developed [A. Letouze].
- ODB needs installation on Linux.
- Current 3D-Var work in Aladin community is VERY important to Arome.
- **Spin-up** is a major concern for short-range forecasting. A full-time engineer [F. Duret] is investigating convection spin-up using Méso-NH.

Validation of model by MSG/Seviri satellite data

observed by Modis



simulated by Aladin-9.5km



The Vision...

- By end 2003, there will be a working Arome-2,5km model prototype and an hybrid 3D-Var/Méso-NH experimentation facility.
- 2004 = preparation of a 'public' Arome-10km phased version with new physics. Developments on radar, SYNOPs, initialization, coupling. New p/c NH physics/dynamics coupling. Validation in MAP reanalyses and use of MSG data. Plugging-in of the Méso-NH externalized surface scheme.
- 2005 = problem-solving and computational optimization phase. End of old-style Aladin developments.
- 2006 = start of heavy NWP-style assimilation/forecast experiments in Météo-France. First non-NWP operational applications: local studies and alert forecasts.

...The Vision

- 2007 = finalization of the large-coupling strategy. Start experimenting with LAM ensemble forecasting using Arome-10km. Initialization of upper-tropospheric PV anomalies from satellite imagery.
- 2008 = start of 2.5km operational production over mainland France. Activation of IASI and CRIS radiances at full resolution.
- 2010-2015 = extension of the domain around France. Ensemble forecasting.Tropical cyclone forecasting. 4D-Var experimentation.