AROME status and plans

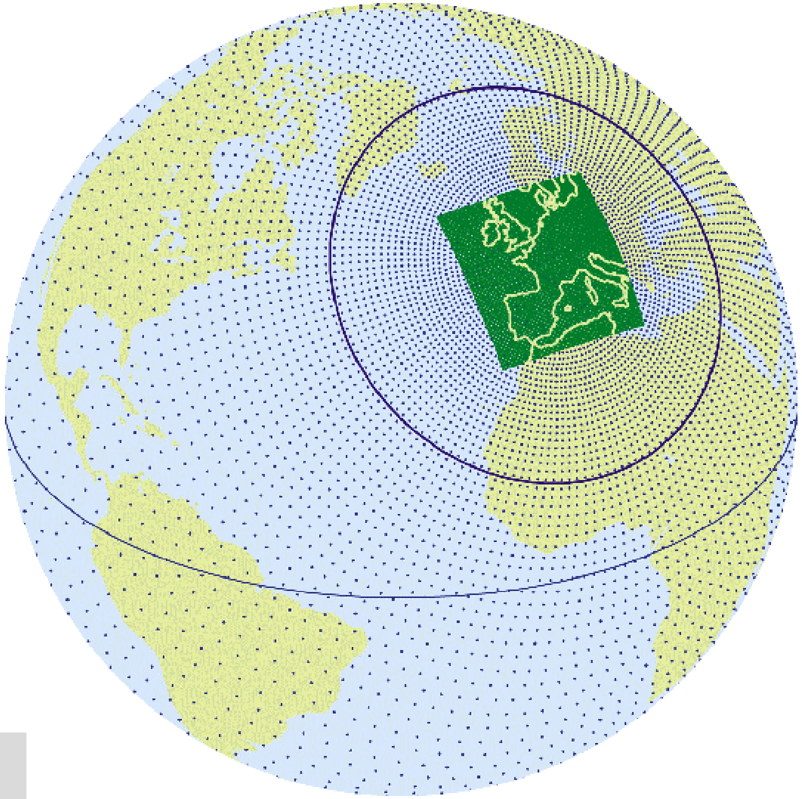
F.Bouttier, Y. Seity, S. Malardel, G. Hello (Météo-France)
presentation to COSMO meeting, Milano, Sept 2004

- The IFS/Arpège/Aladin/Arome/mesoNH software strategy
- Aims and schedule of Arome
- Arome model
- Arome data assimilation

NWP software cooperation

- Much software is shared with the **ECMWF IFS model and 4D-Var.** Most useful for satellite assimilation and computer optimization.
- **ARPEGE global system** has completely different physics, data processing, resolution (stretched grid) = **designed for short-range NWP.**
- **ALADIN cooperation** = adaptation of ARPEGE to LAM geometry, 10km resolution, 3DVar assimilation, **coordinated software development and scientific studies**
- **AROME** = adaptation of AROME to 2km resolution, completely **different physics shared with MesoNH model = mesoscale research community**, delegation of in-depth scientific work: 'Applications of Research to Operations at Mesoscale'

Global ARPEGE 4-day forecasts every 6 hours, dx=23km on Europe, 130km on South Pacific

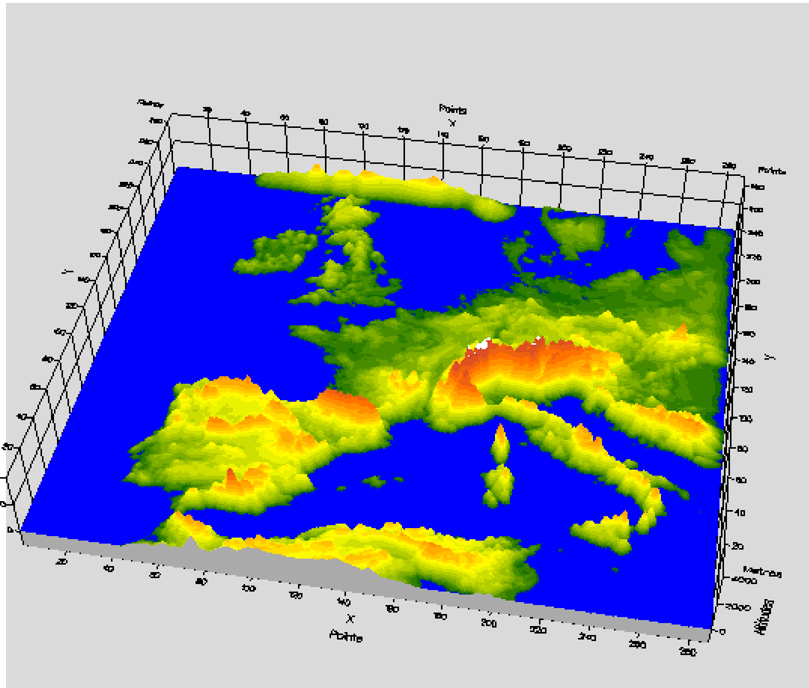


METEO FRANCE

Aladin France Orography

Altitudes (m)

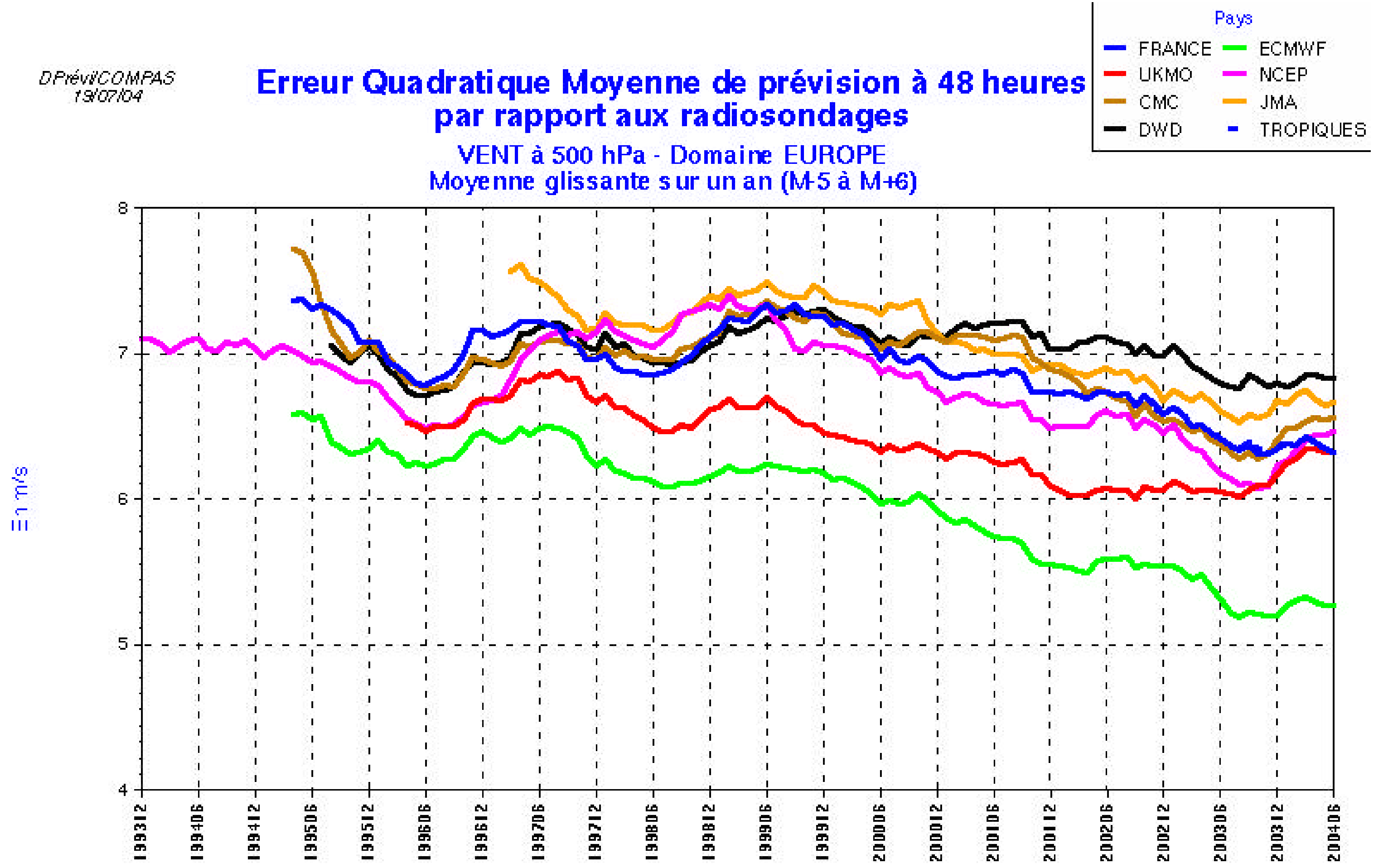
Above	3100
3000 -	3100
2600 -	3000
2300 -	2600
2000 -	2300
1700 -	2000
1400 -	1700
1200 -	1400
1050 -	1200
900 -	1050
750 -	900
550 -	750
400 -	550
300 -	400
200 -	300
150 -	200
100 -	150
50 -	100
25 -	50
15 -	25
Below	15



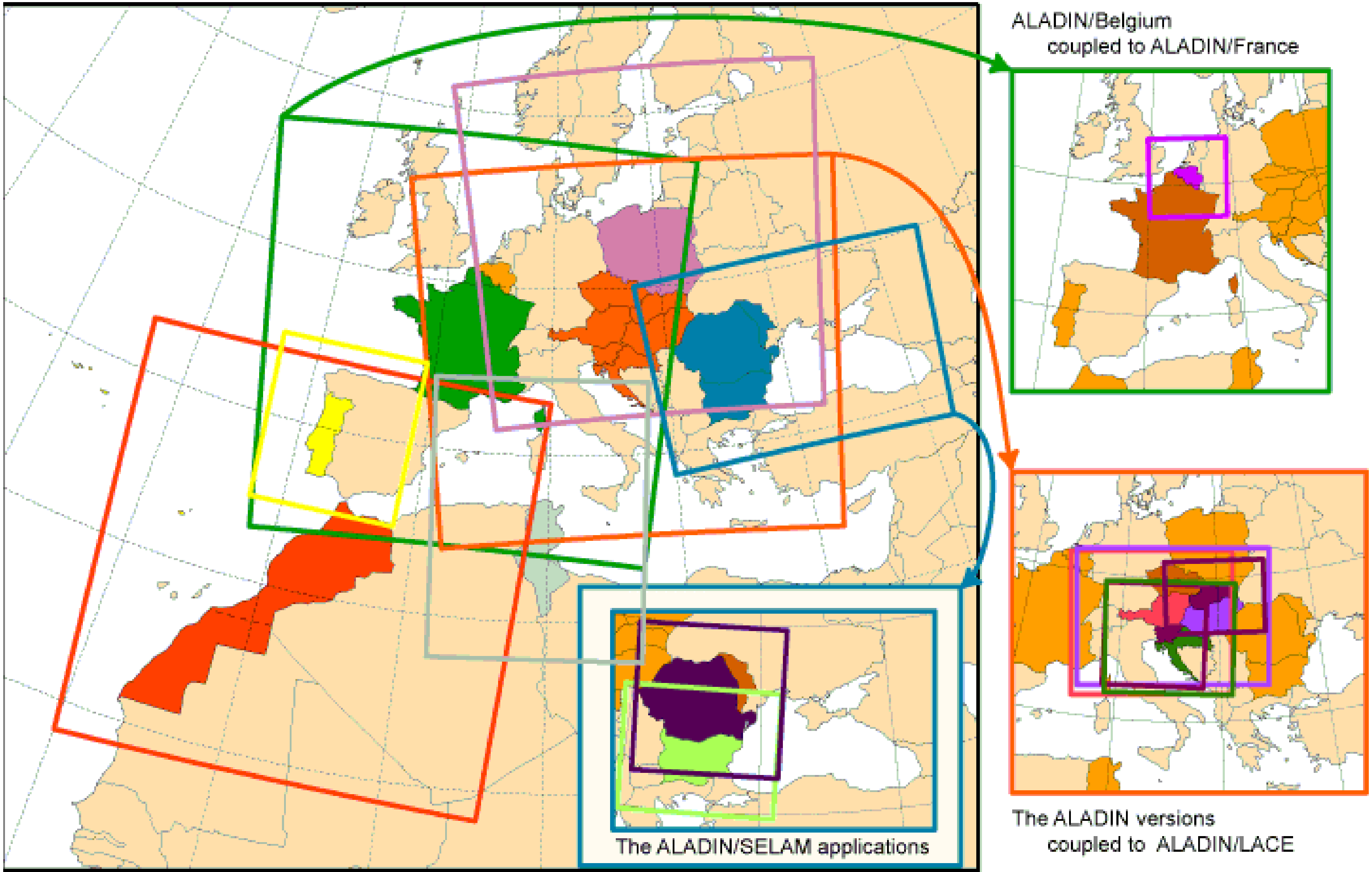
ALADIN regional adaptation higher-resolution model, dx=10km

ARPEGE model performance

500hPa wind 2-day forecast scores over Europe for past 10 years



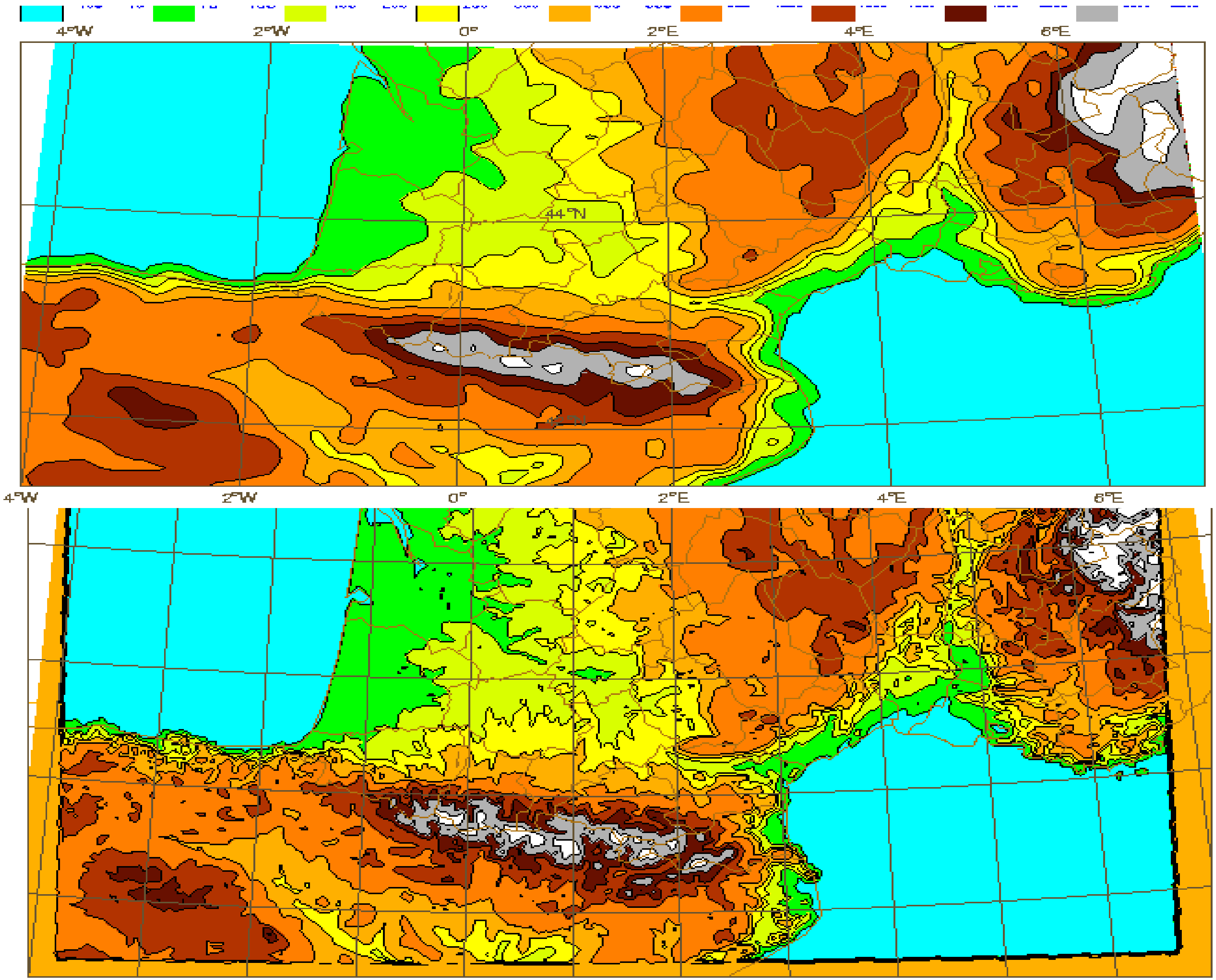
ALADIN international cooperation, 14 operational domains



The AROME project

- **Non-hydrostatic, convection-resolving** model, concept similar to MM5, WRF, LM
- Main mission: improve forecasts of short-range heavy convection, QPF and low-level weather forecasts, operational in 2007
- Claim of originality : **very efficient numerics** and **advanced data assimilation**
- **New 3D fields:** NH dynamics, 5 cloud water species, turbulent kinetic energy, chemicals/aerosols and **new physics**
- Coupled with **models of soil/town/biosphere and ocean**
- 30 times more expensive than ALADIN, but affordable (dt=1min with dx=2.5km, per-gridpoint computation is 3x more expensive than Aladin)
- Assimilation nearly as sophisticated than ECMWF's, with **customized 3D-Var algorithm** and **much more mesoscale data** (low-level, satellite, radar)

Higher horizontal resolution (from 10 to 2km)



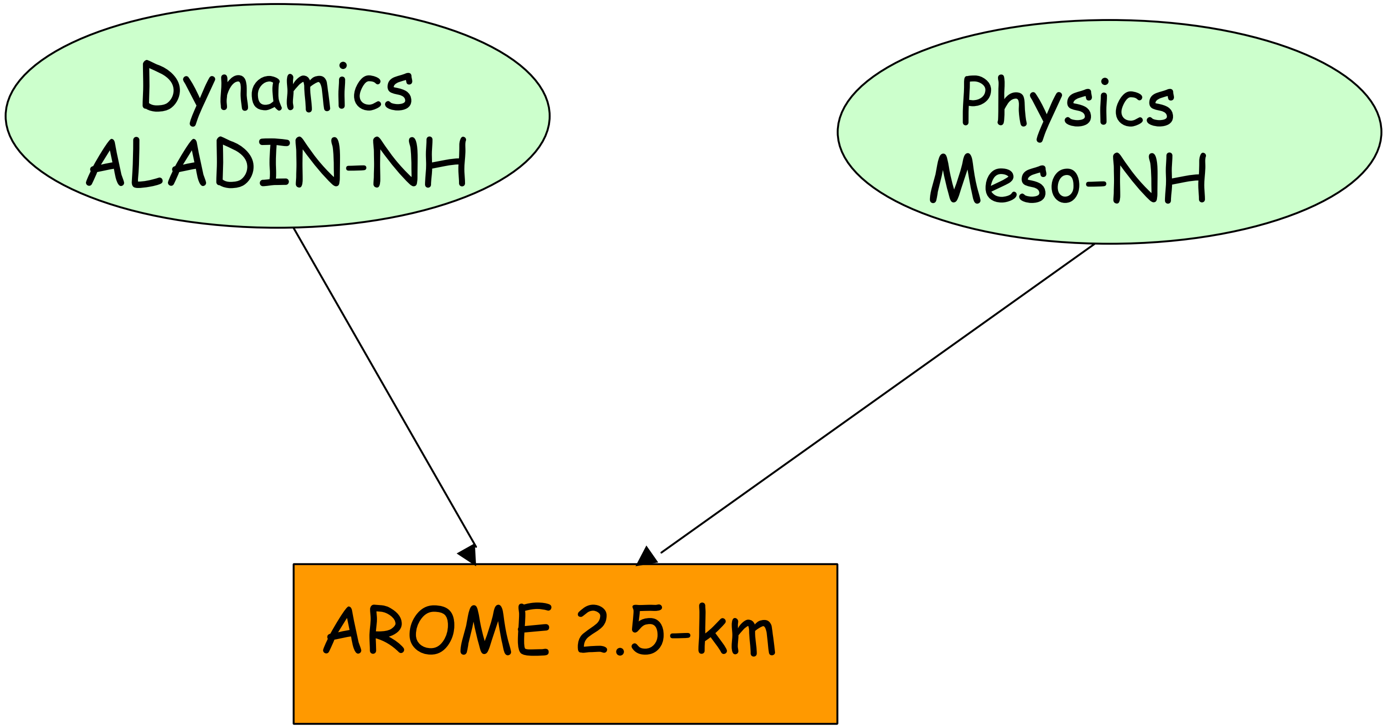
Arome deliverables

- **NWP with added value** over global models on **precipitation, actual weather, extreme weather**
- Justify funding of high-resolution **regional observations**
- Forecasts for **hydrology, urban air quality, nowcasting**
- **Better interaction with scientific community** by giving them data assimilation and NWP-oriented validation tools

Arome team

- **François Bouttier** and **Gwenaelle Hello** : management and PR
- **Sylvie Malardel:** Meso-NH physics
- **Yann Seity:** model, software management
- **Frédéric Duret:** experimentation, support to external users
- **Eric Wattrelot:** radar data assimilation
- **Ludovic Auger:** nowcasting-oriented data assimilation
- **Jean-François Geleyn**: management of Aladin? Arome international transition
- About 10 more direct contributors in Météo-France and Aladin NWP institutes
- About 100 people doing related work on IFS, Arpège, MesoNH, Hirlam

Arome model (1/9)



AROME numerics (2/9)

- Spectral LAM with linear collocation grid and rectangular truncation i.e. no spectral aliasing
- Semi-Lagrangian advection
- Dynamics derived from Laprise's system: terrain-following mass vertical coordinate, compressible non-hydrostatic equations
- (very !) careful discretisation, 2nd-order accurate, preserving energy and angular momentum
- NH dyn variables: vertical divergence, NH mass departure
- SI timestep, iteration of nonlinear terms, spectral solver
- A major research effort since 1994

AROME physics (3/9)

=

Microphysics (tendencies+adjustment)

+

Turbulent mixing

+

Radiation

+

Surface (coupled model)

Not yet implemented features

- Large-scale coupling of hydrometeors (=w=0), TKE (=constant)
- Orthogonal projection w.r.t slopes (surface, turbulence, radiation)
- Monotonous SL advection (but adjustment of negative microphysics values is implemented)
- Diffusion of microphysics and TKE fields

AROME physics (4/9)

Microphysics : ICE3 : 6 species of water = vapour, cloud liquid, rain, cloud ice, graupel, snow

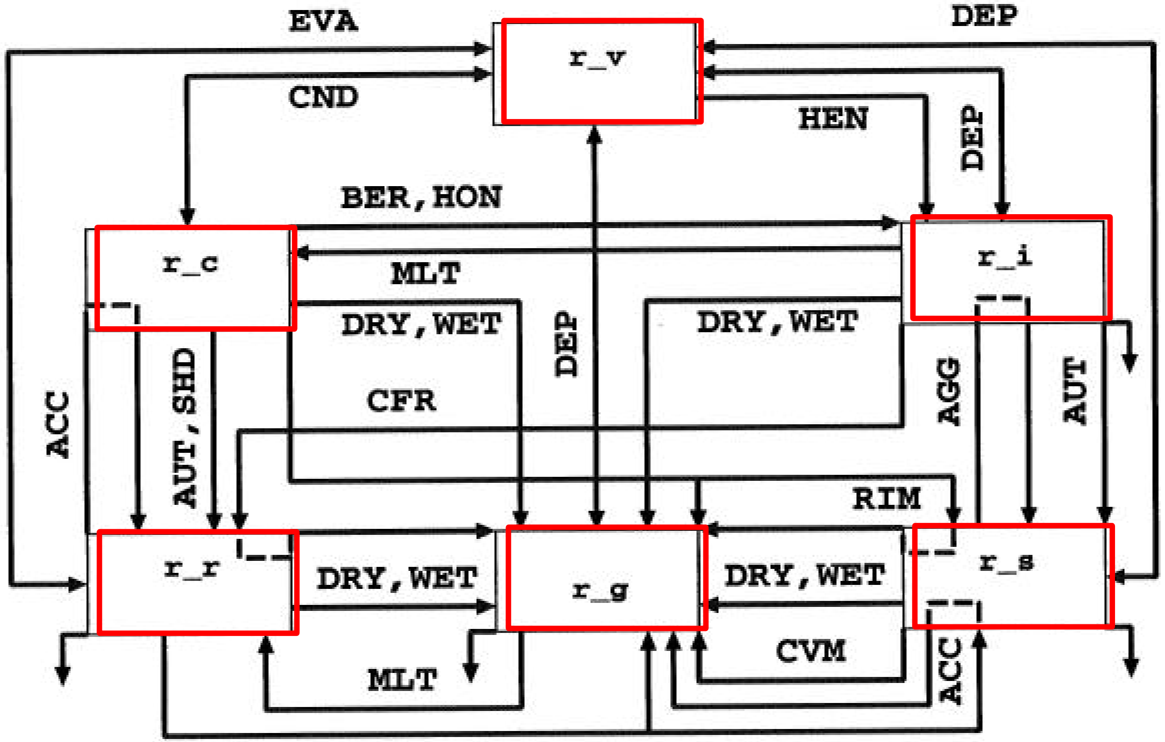


Diagram of the microphysical processes for mixed phase cloud in the present scheme

AROME physics (5/9)

Turbulence :

=1D version of the MesoNH scheme :

- ➢ Prognostic TKE
- ➢ Bougeault-Lacarrère mixing length closure
- ❖ Current work on improving:
  - 3rd order moments (counter gradient)
  - mixing length inside clouds
  - Lateral mixing on cloud sides

AROME physics (6/9)

Radiation : from ECMWF (SW = Fouquart-Morcrette, LW = RRTM)

6 visible spectral bands, over 140 IR bands, ozone and aerosols

Surface : external software (towns, vegetation, sea, lakes, snow) with pluggable slow- and fast-hydrology, prognostic marine mixed layer

AROME physics (7/9)

Surface : town :TEB (Masson, 2000)
vegetation : ISBA (Noilhan and Planton, 1989)
sea/lakes : Charnock closure and constant SST so far.

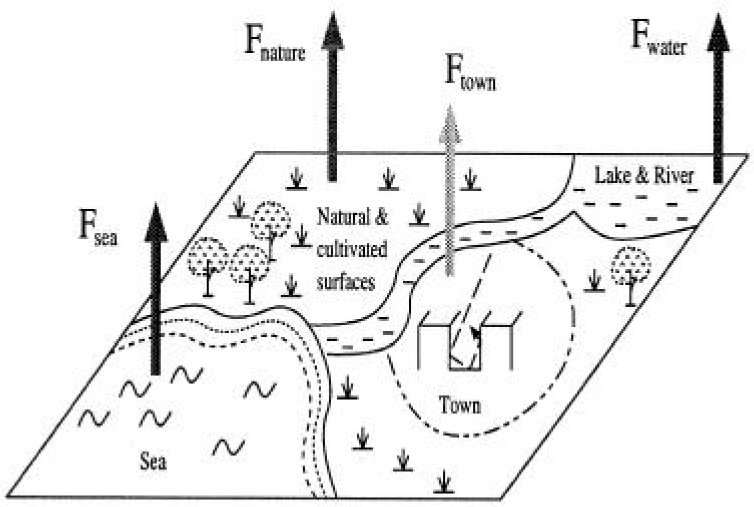
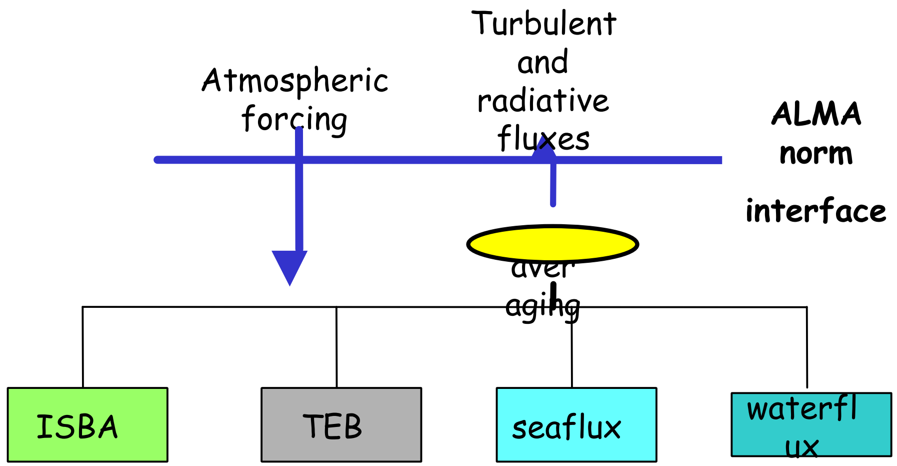
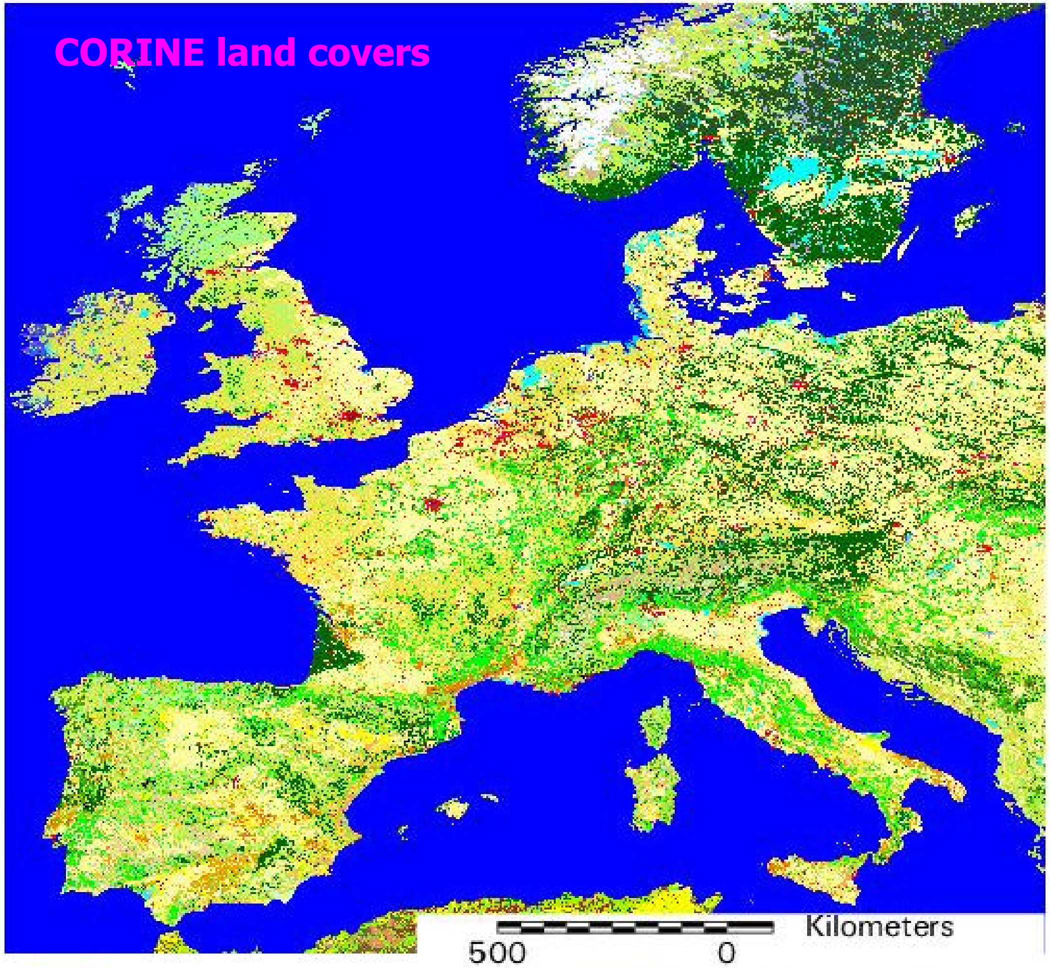


Figure 15.1: Partitioning of the MESO-NH grid box, and corresponding turbulent fluxes. F stands either for M (momentum flux), H (sensible heat flux), LE (latent heat flux), $S^{\uparrow}$ (the reflected solar radiation) or $L^{\uparrow}$ (the upward longwave radiation).



AROME physics (8/9

Surface physiography (TEB, ISBA) from Ecoclimap classification (Mas:



242 cover types

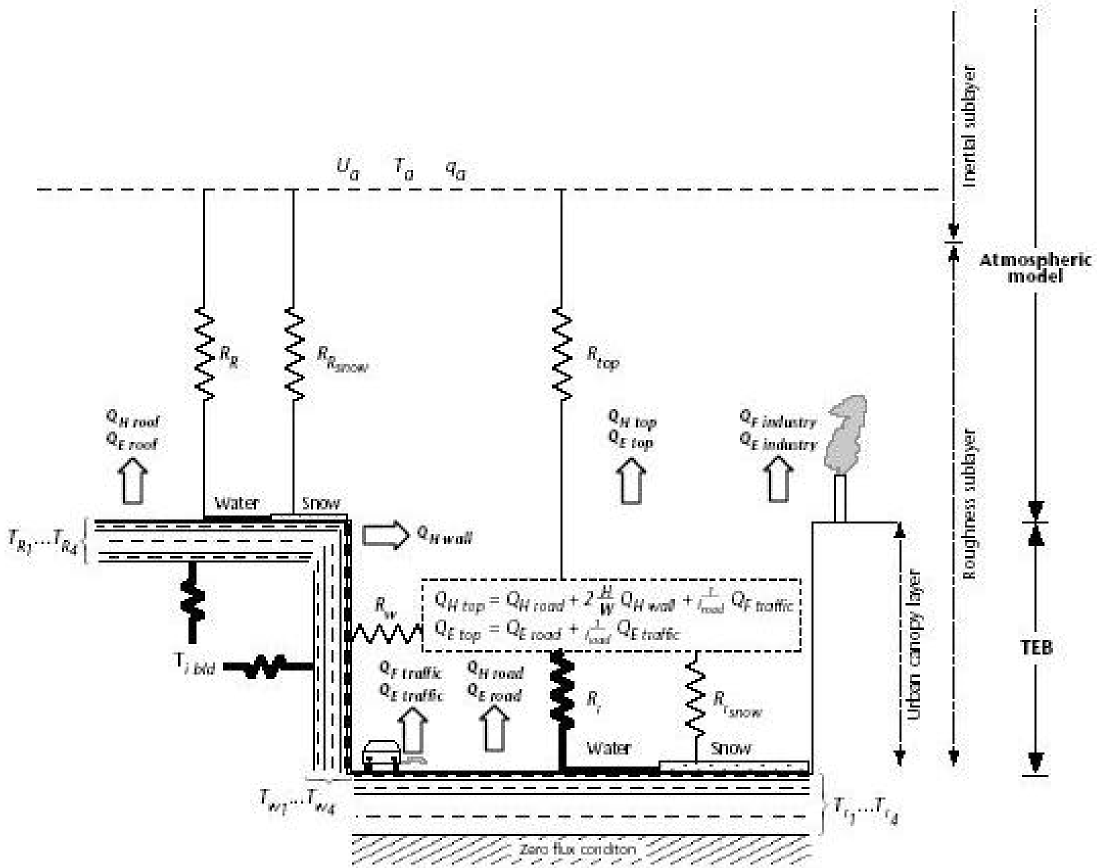
+

1km-resolution cover fractions

La physique AROME (9/9)

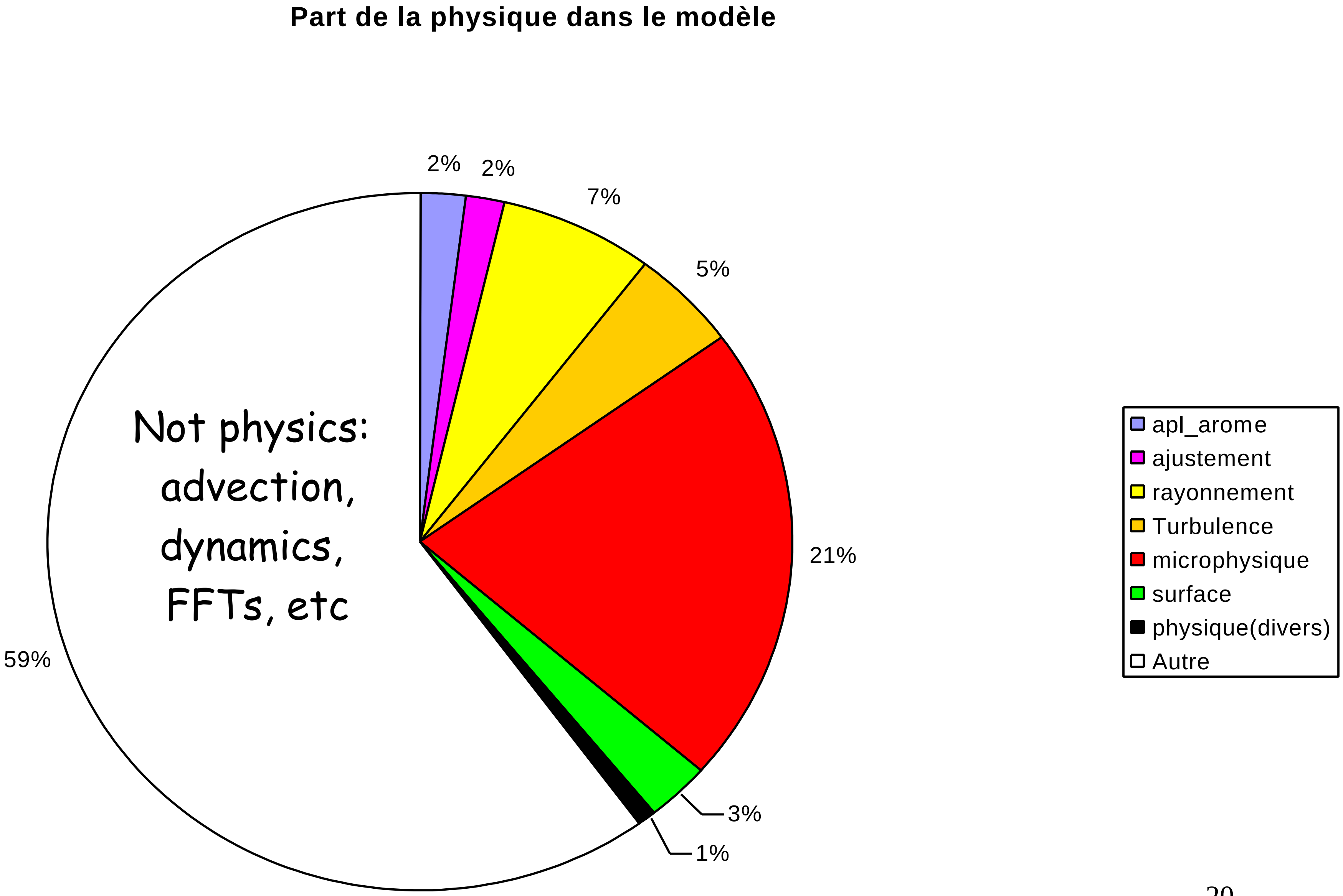
Town Energy Balance (TEB)

- Based on urban canyon concept
- Radiation trapping
- Heat storage in surfaces (walls, roads, roofs)
- Urban hydrology
- Antropogenic fluxes

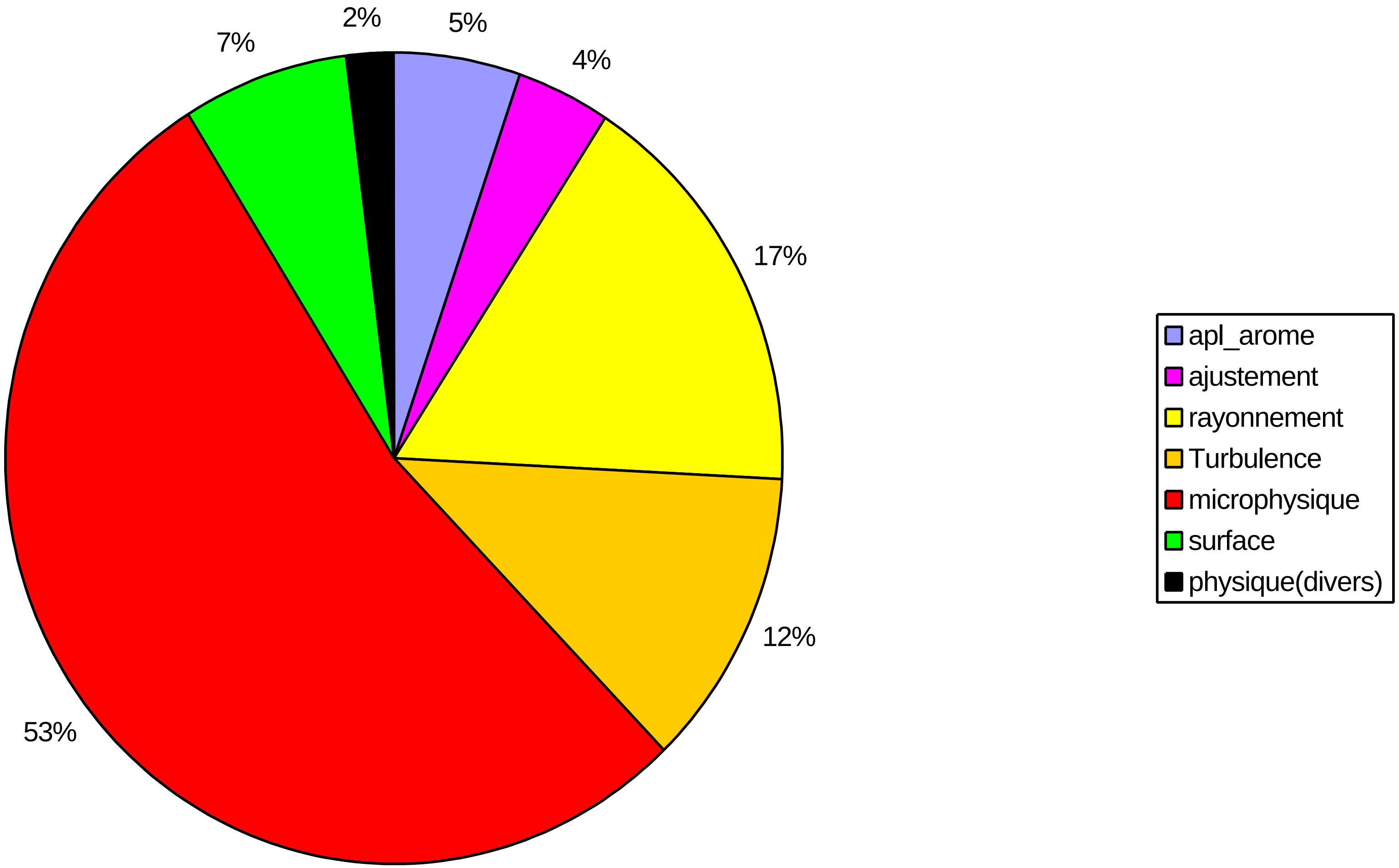


Documentation : http://www.aero.obs-mip.fr/~mesonh/

Breakdown of Arome model CPU cost



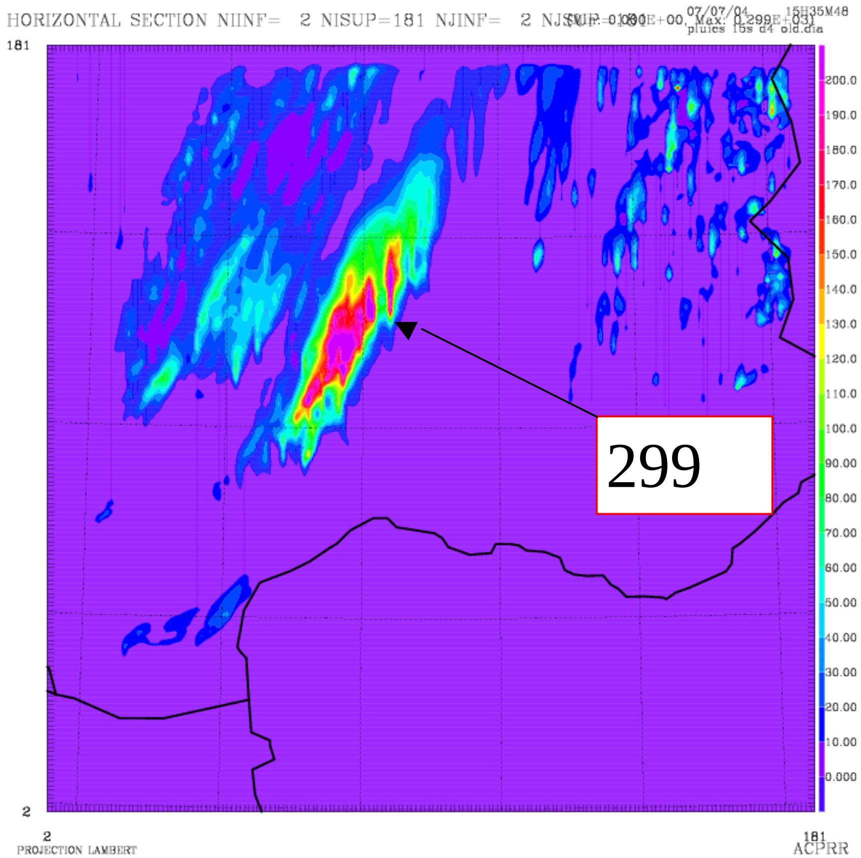
Breakdown of physics cost (dt=60s, radiation every 15min, heavy Mediterranean convection case)



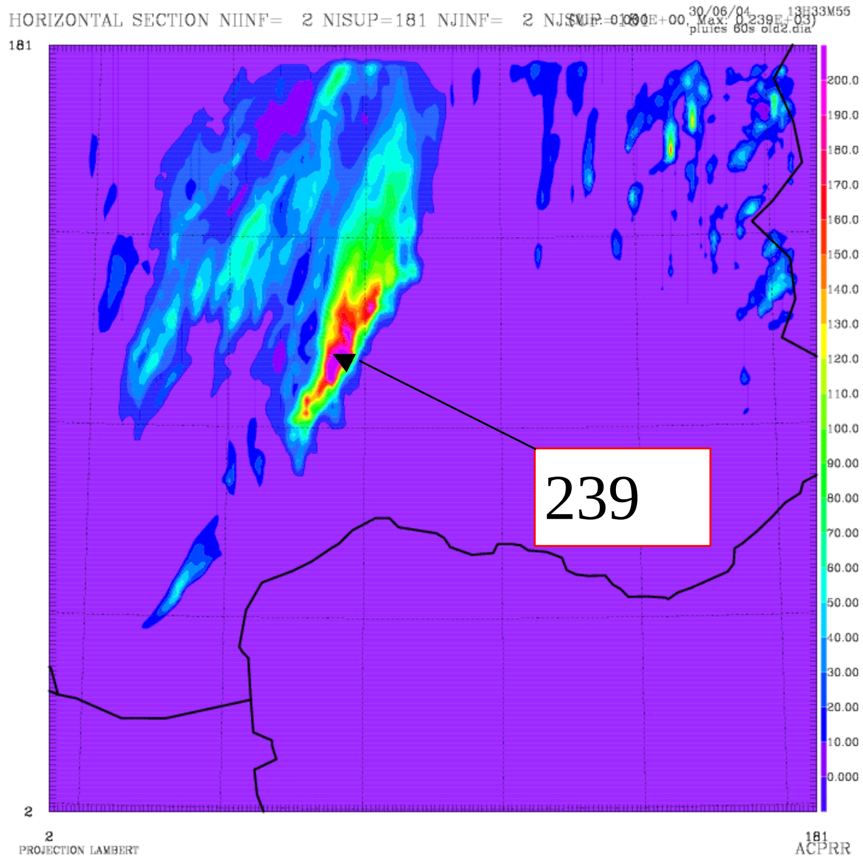
How long can the timestep be ?

12-h cumulated rainfall, AROME model with dx=2.5km

dt=15s



dt=60s



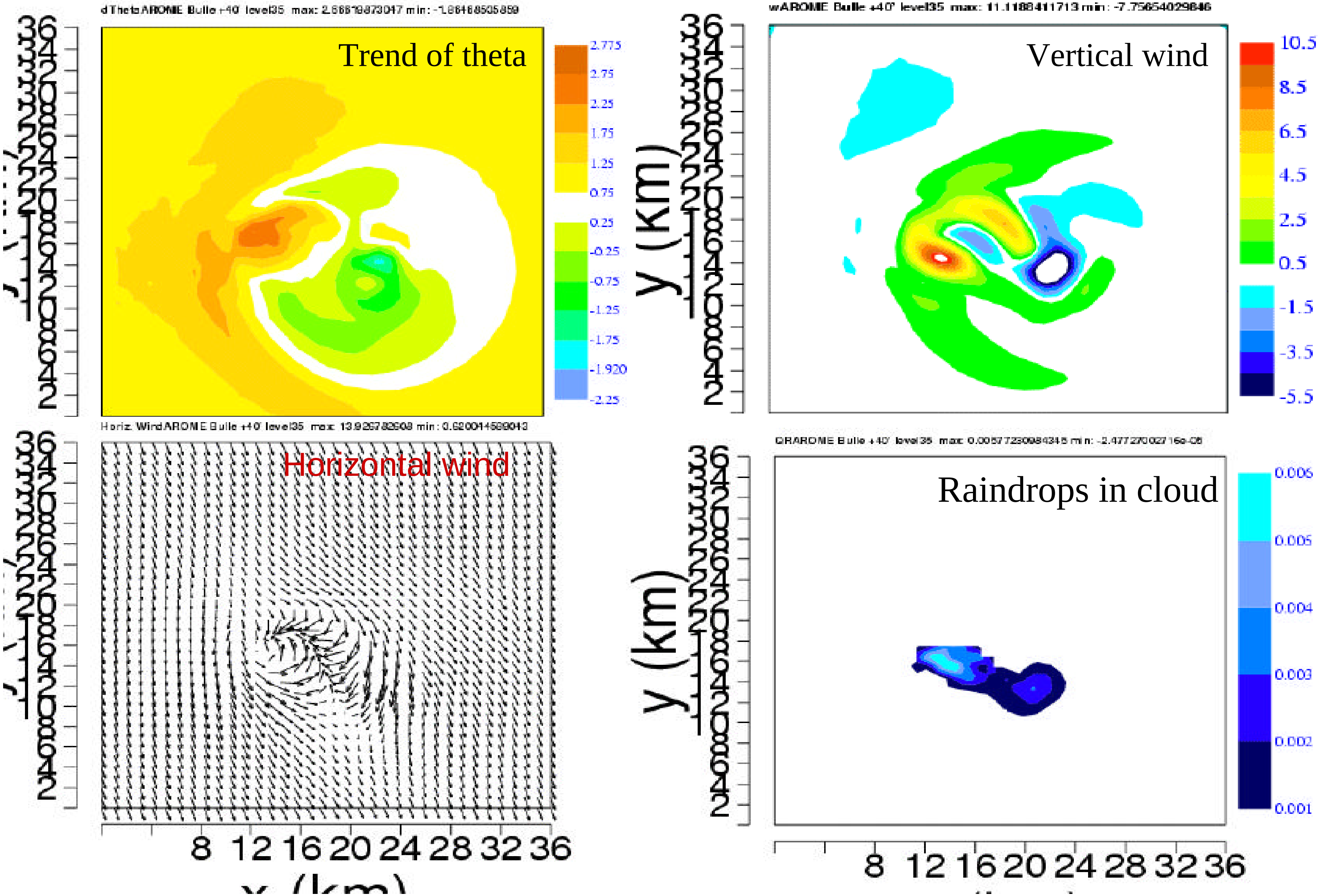
Arome status in Sept 2004

- model prototype is **rigorously validated in academic tests and 1D** column mode
- Full 3D code compares well with MesoNH ref simulations, with 10x cheaper model
- 10-km Arome model with subgrid convection does not beat Aladin
- Model code was released to Aladin NWP partners
- Assimilation has proved beneficial on Mediterranean flood cases and African AMMA tests
- 3DVar software is going operational in Dec 2004 with 10km-Aladin and MSG radiances
- Development of radar reflectivity assimilation has started, operational end 2005

short-term plans

- Optimized **multiplatform benchmark release** end 2004
- radar assimilation and cloud analysis, winter 2005
- Intercomparisons with UM and WRF, winter 2005
- Physics work in 2005/2006: 3D turbulence aspects, shallow clouds, chemistry, 3D coastal ocean model, cleaning of physics interface
- Official **demonstration version in mid 2005** (AMMA, MAP FDP, scientific cooperations)
- NWP-oriented validation and optimization in 2006/2007
- **Real-time preoperational runs to start at MF in mid-2007**

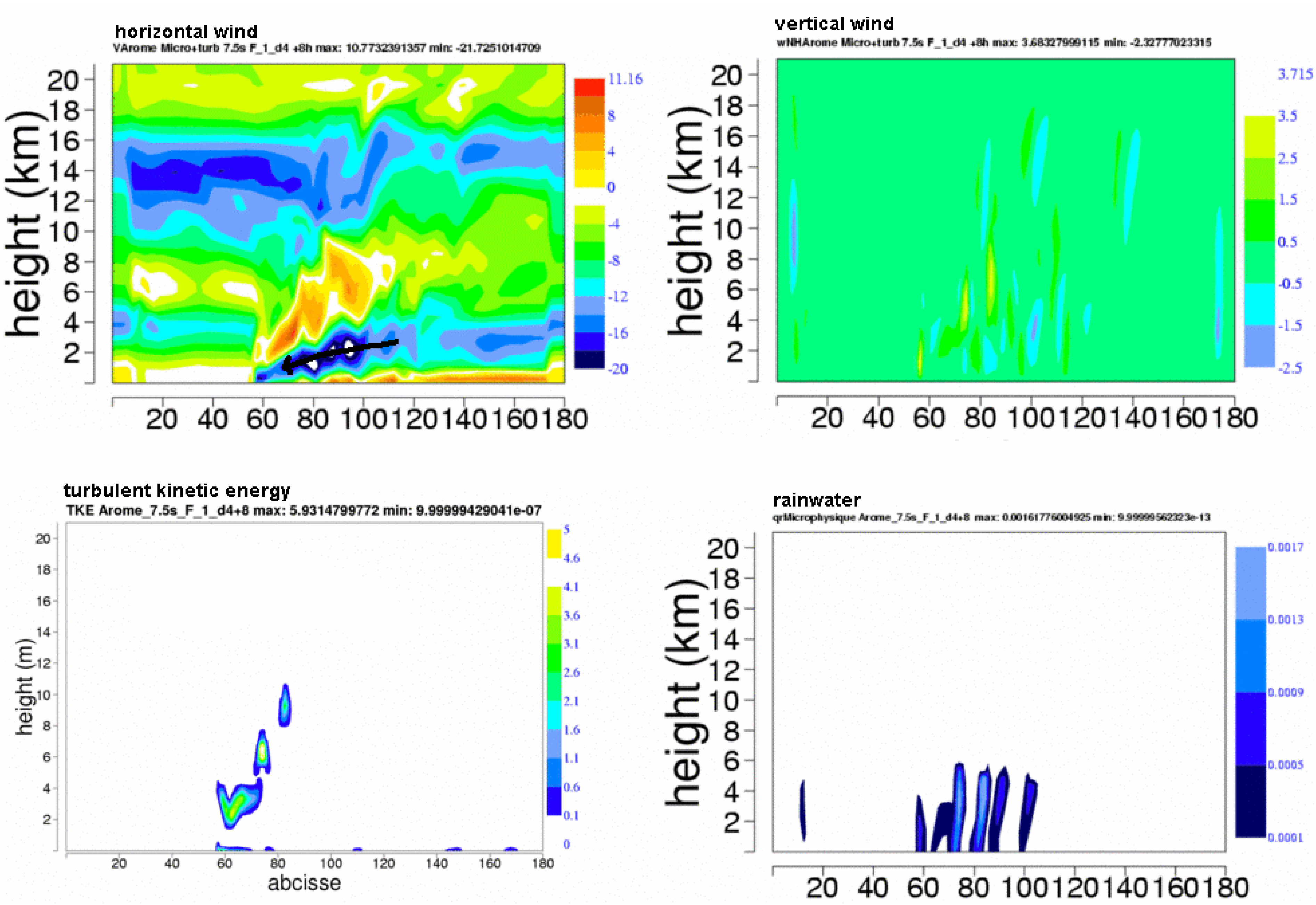
Test-run: fully 3D case with physics, academic convective cloud at 1-km resolution (compares well with MésoNH, with 4x longer timestep)



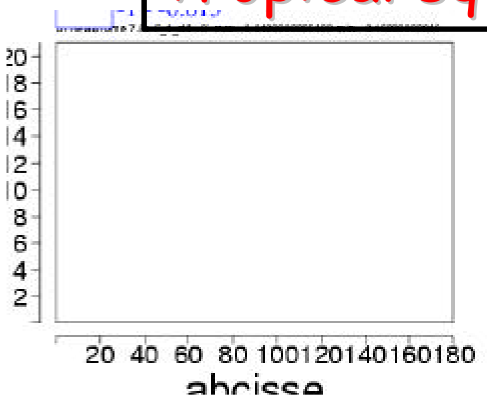
2D test

- Idealised squall line with generation of convective cells by density current.
- wind, T, Hum initialised from COPT81 real sounding
- Triggering by a 0.001 K.s-1 cooling imposed for 10min over part of the domain.
- 2.5km resolution, 8h run duration.
- Turbulence + microphysics

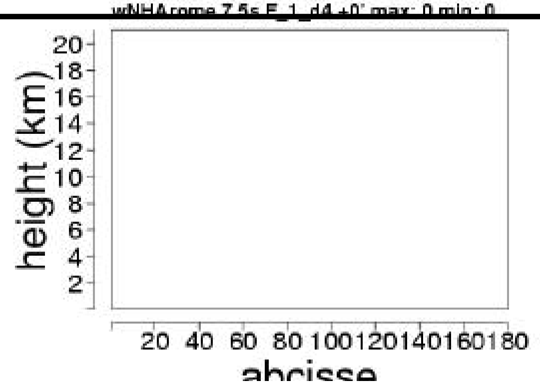
Tropical squall line simulated by AROME (vertical cross-section)



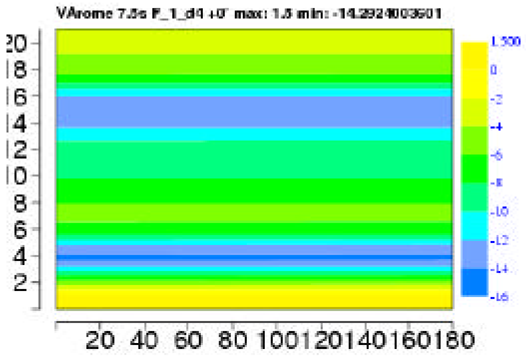
Tropical squall line



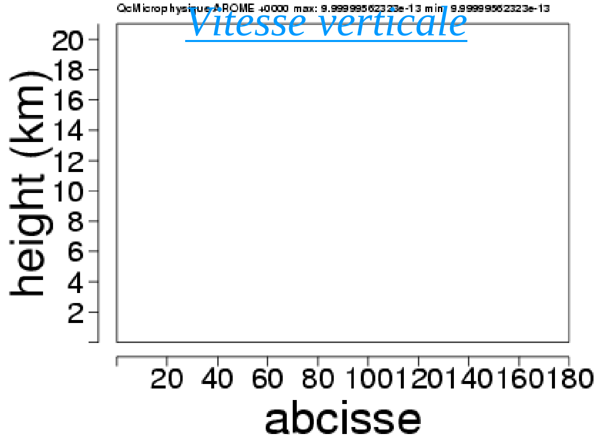
Theta-theta0



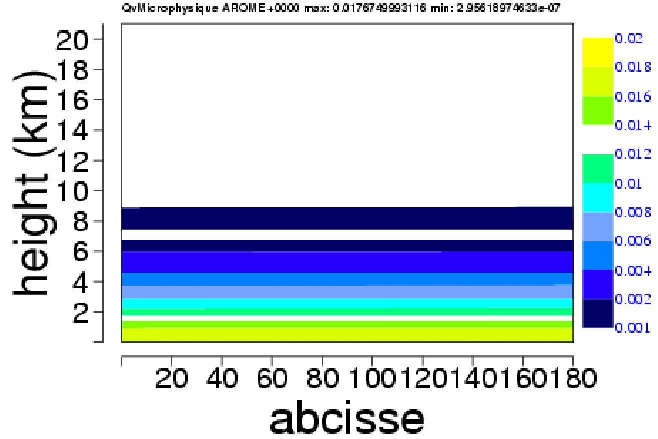
Vitesse verticale



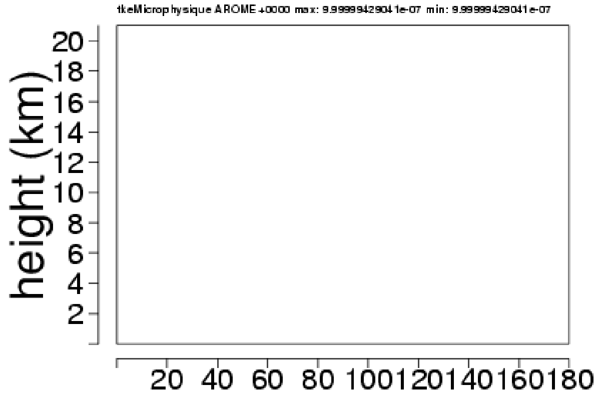
Relative wind



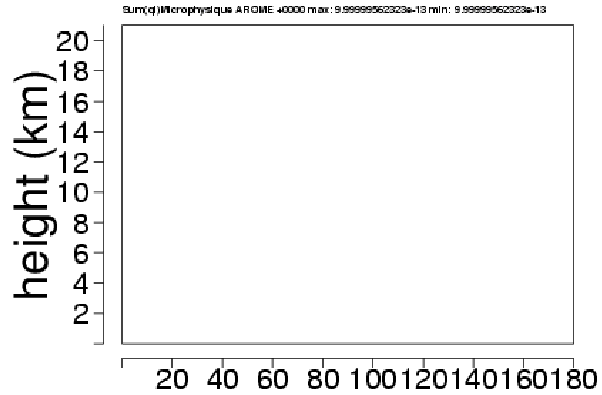
nuage



humidité



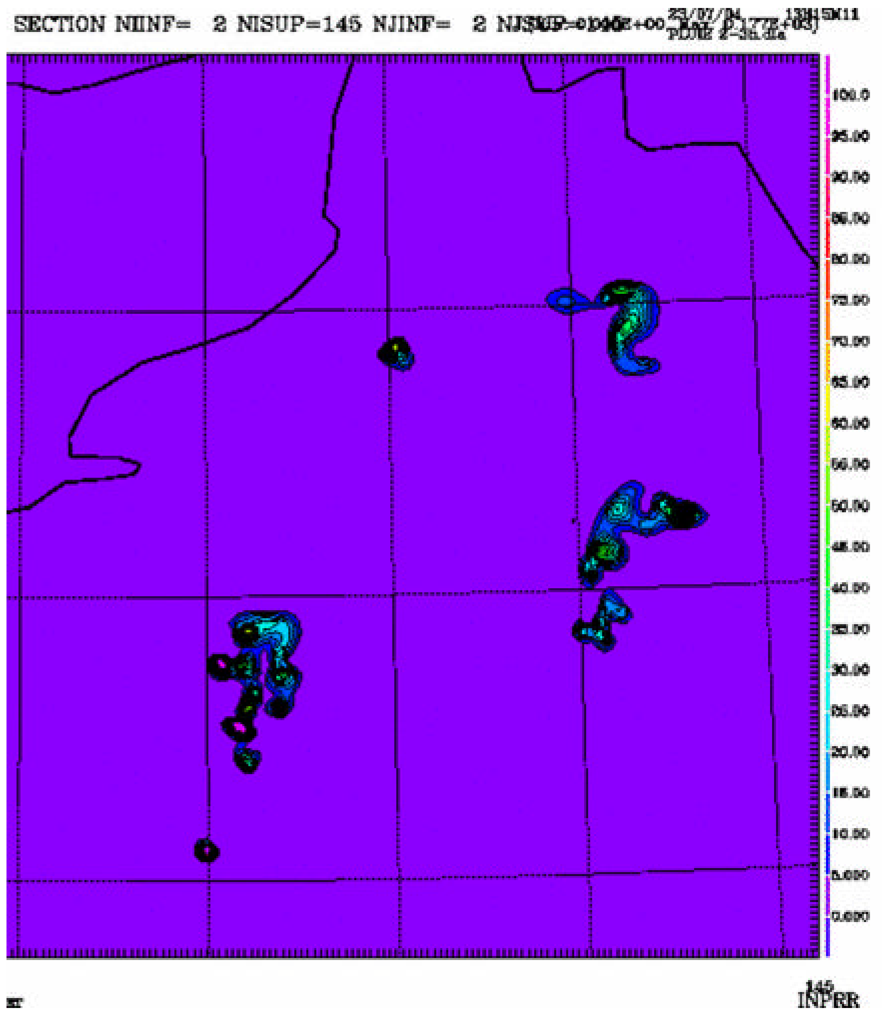
TKE



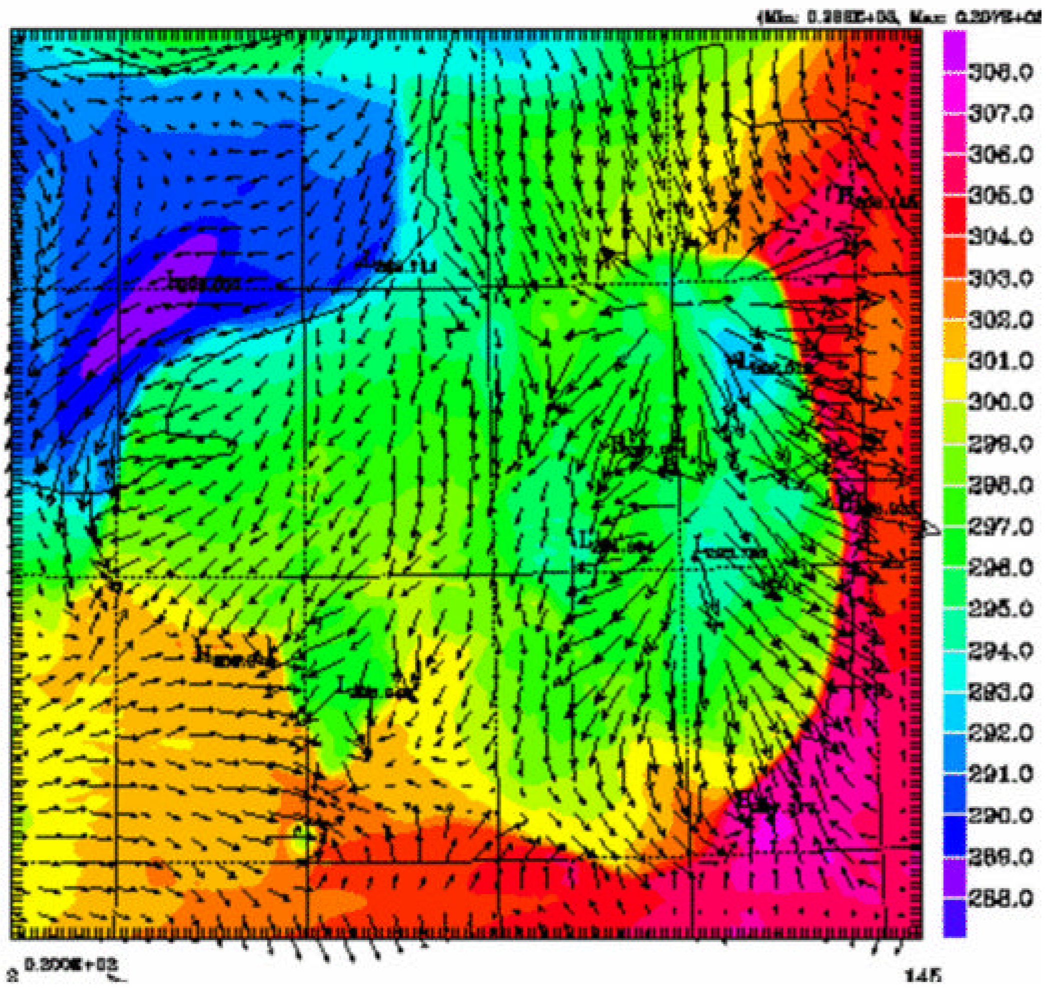
Total condensates

Thunderstorms simulated by Arome, 2.5km resolution started from mesoscale analysis

Rain rate



Low-level potential temperature and wind



Real case

Gard river floods 8-09-2002

Simulation characteristics :

192x192x41 point domain, dx=2.5km

Complete physics

Radiation call every 15'

Large-scale coupling with Aladin France every 3h

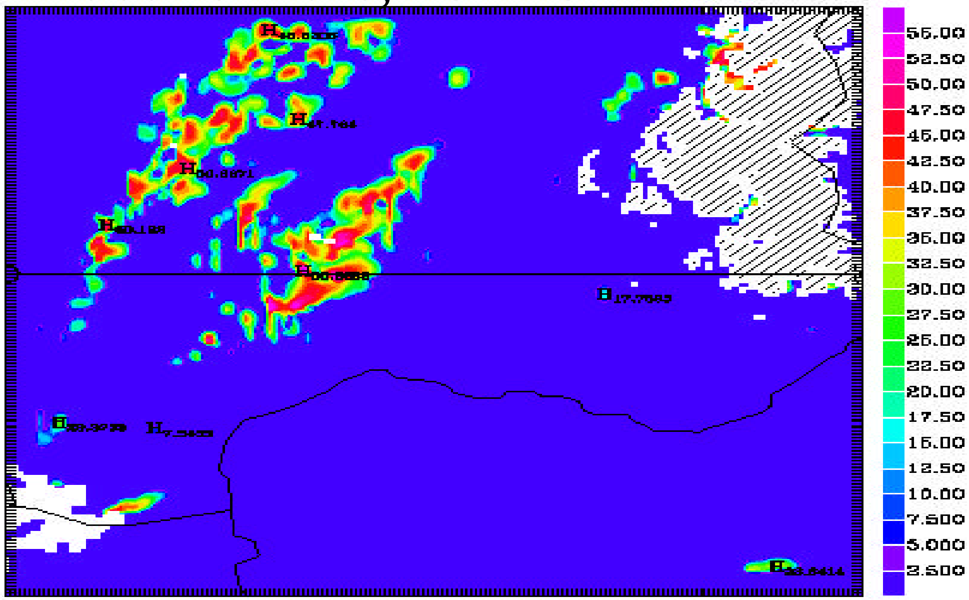
Starting time: 12UTC, 8 Sept 2002 from Arpege analysis

7.5s timestep for comparison with MesoNH

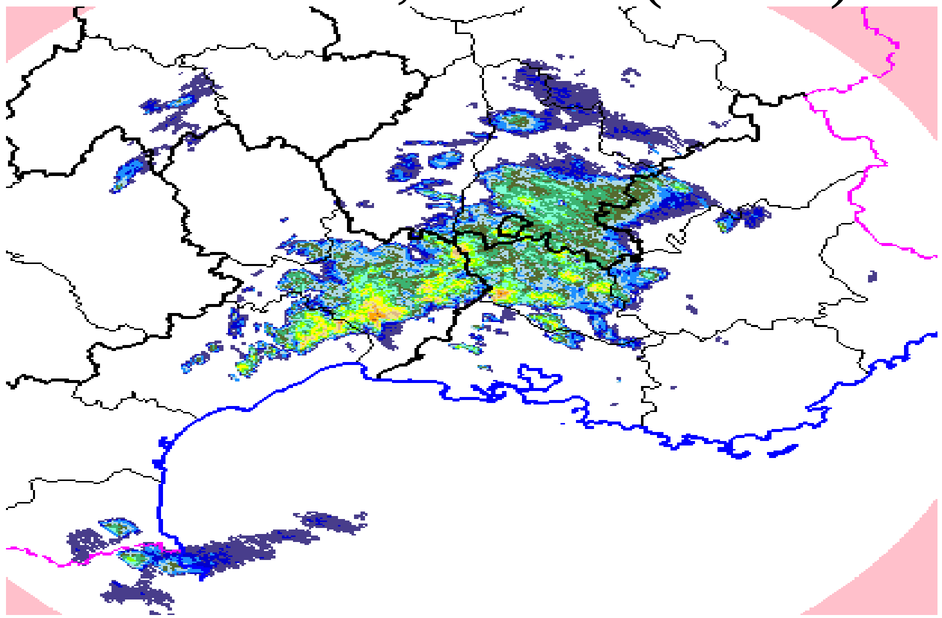
First Arome forecast, 2.5km resolution

Mediterranean floods, 8 Sept 2002

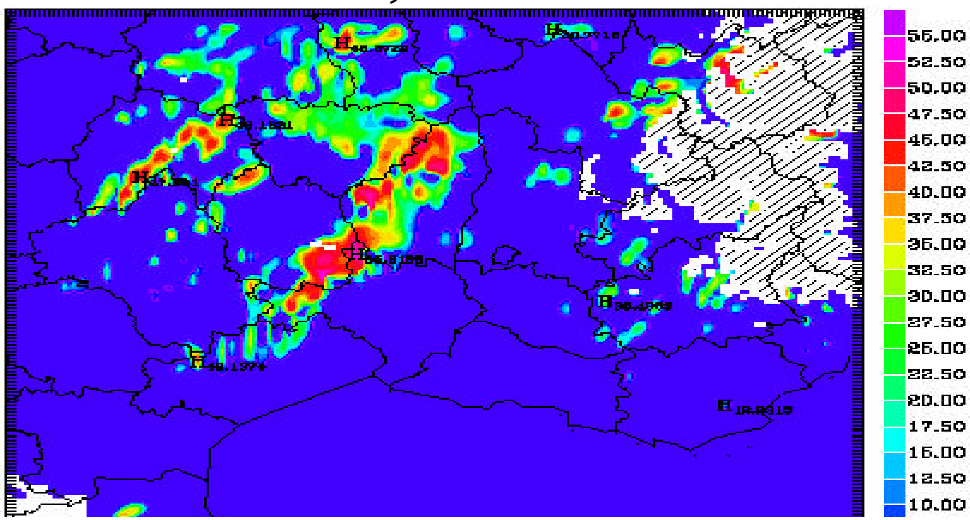
Radar simulé, 15hTU



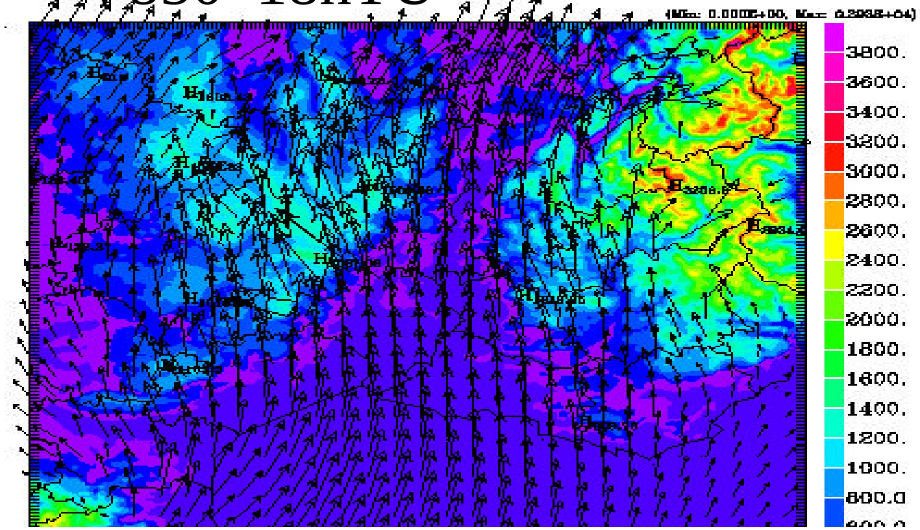
Radar observé, 15h TU (Nîmes)



Radar simulé, 18hTU

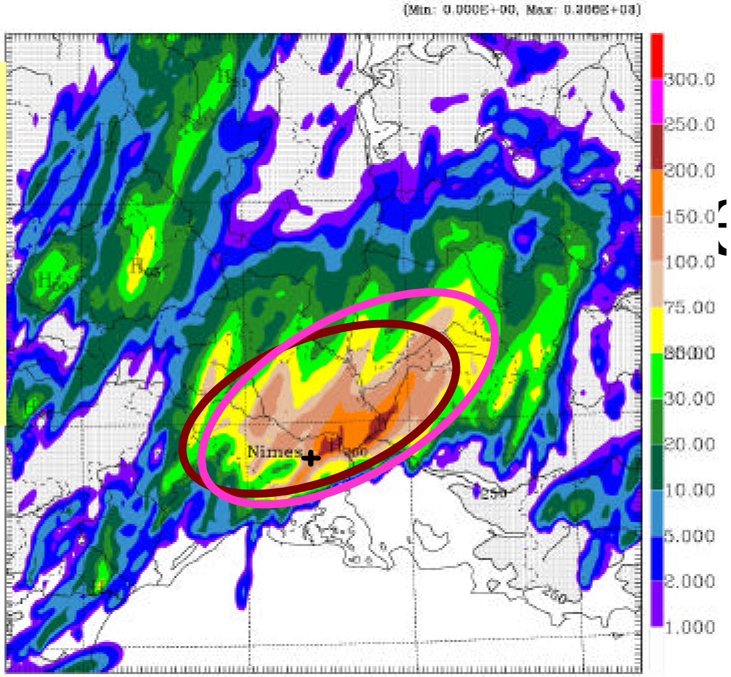


V850 18hTU

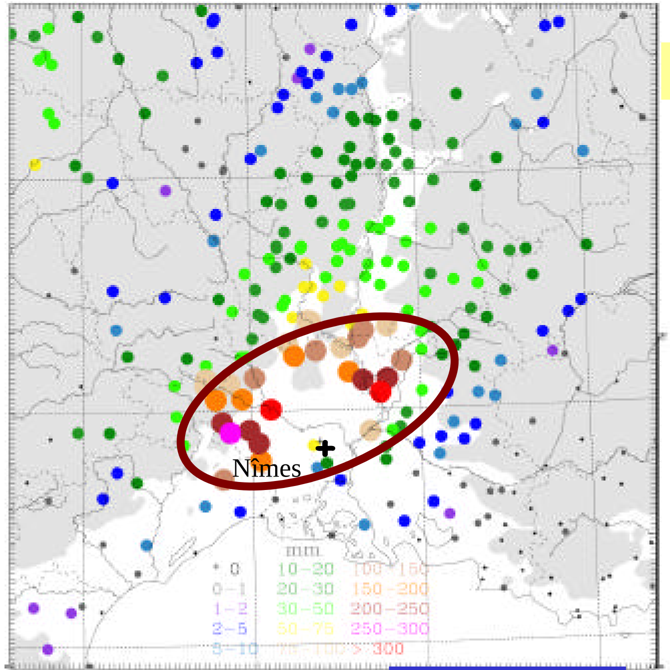


Accurate convection location requires mesoscale data assimilation

Prévision avec analyse à échelle fine (surface obs, radar, satellite) pour 12UTC, 8th Sept. 2002



PLuviomètres

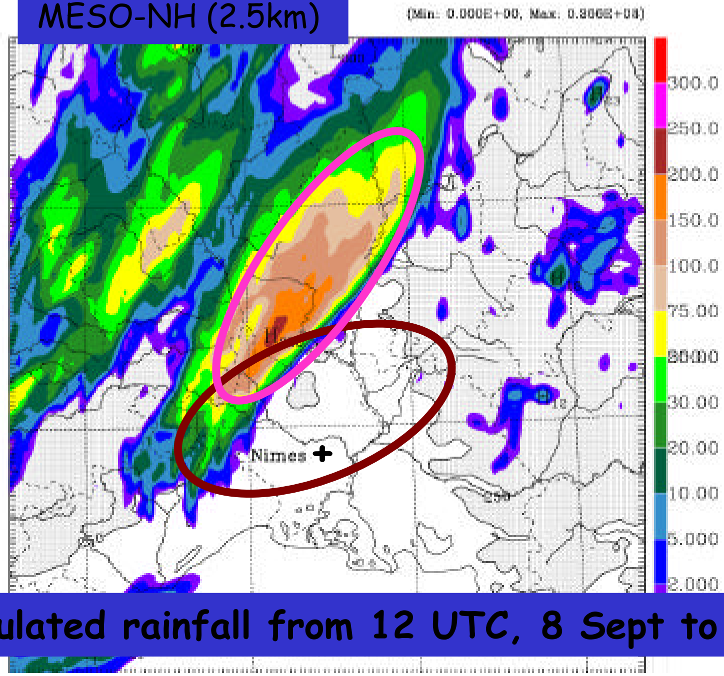


MESO-NH (2.5km)

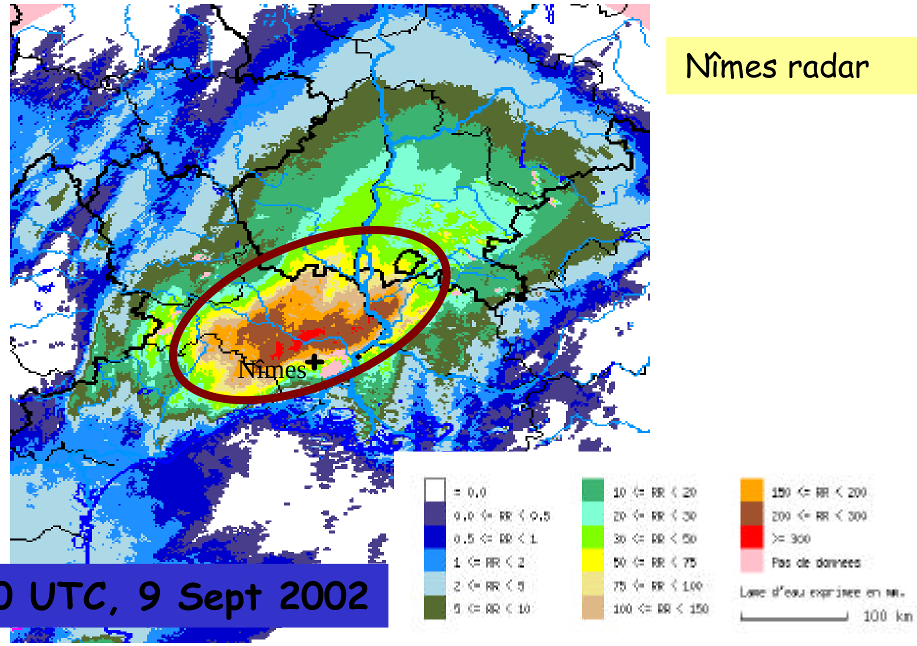
Observations

Ducrocq et al, 2003

Prévision sans analyse spécifique

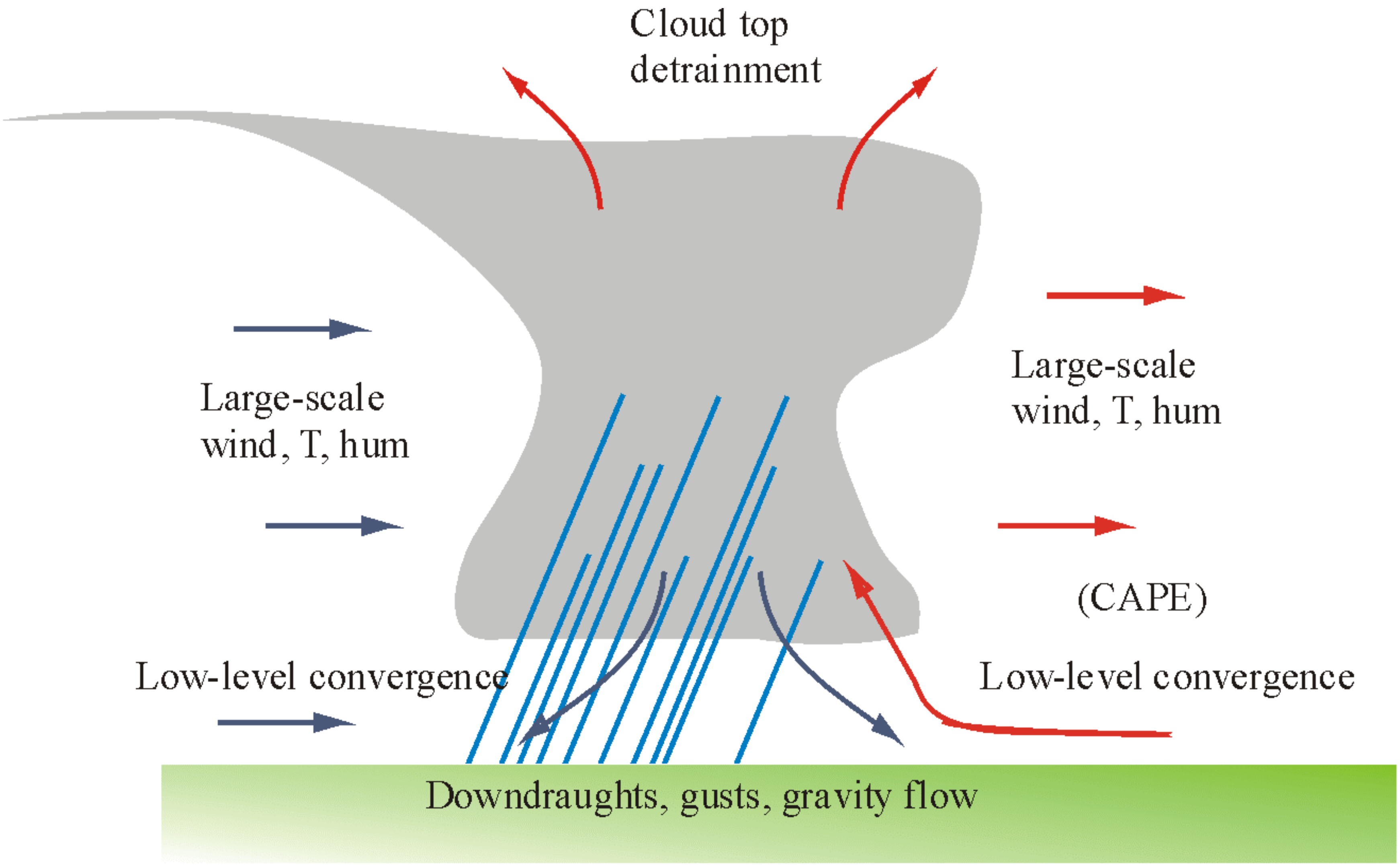


Nîmes radar

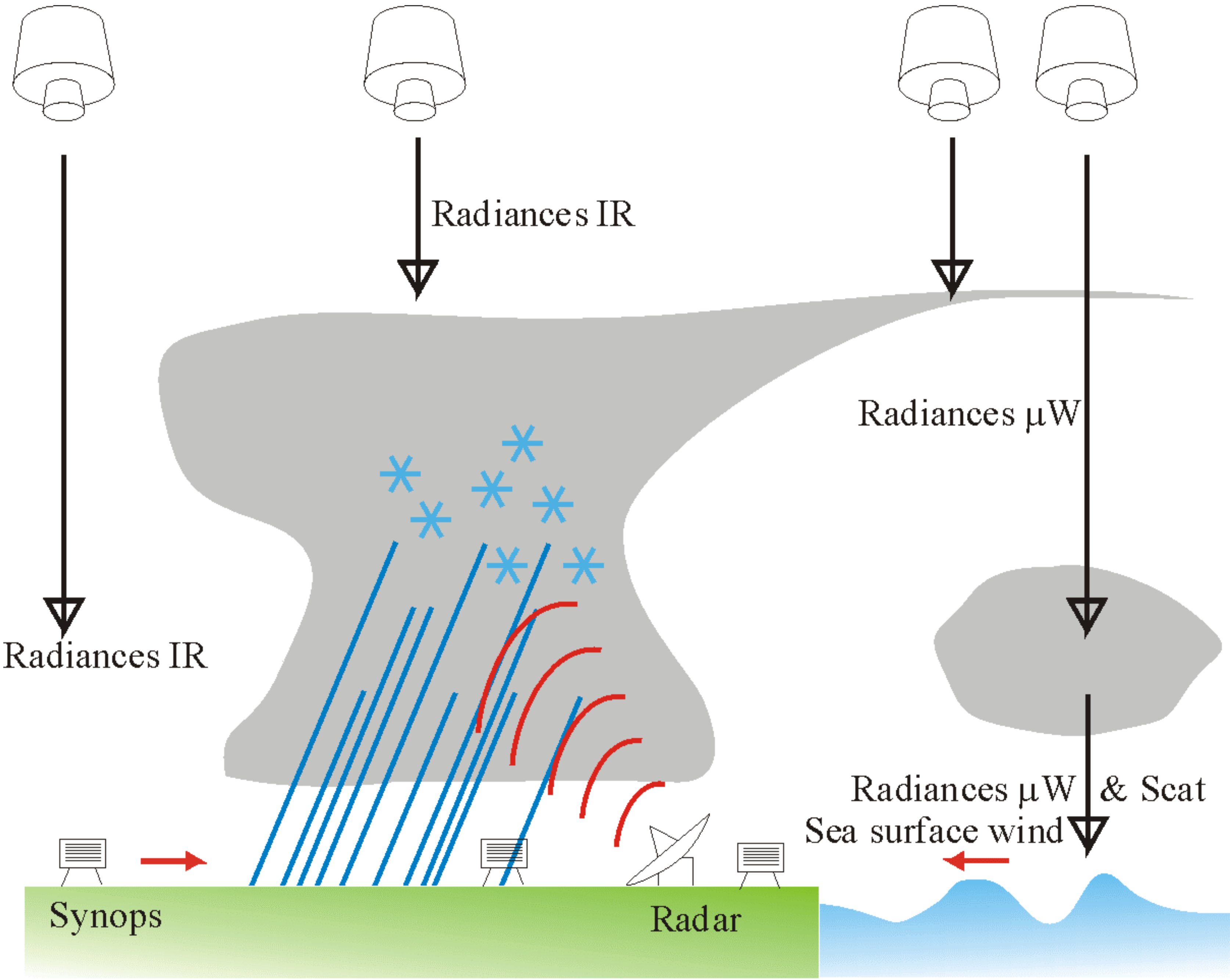


12-h accumulated rainfall from 12 UTC, 8 Sept to 0 UTC, 9 Sept 2002

Concept of convective-scale assimilation



Required observations at convective scale

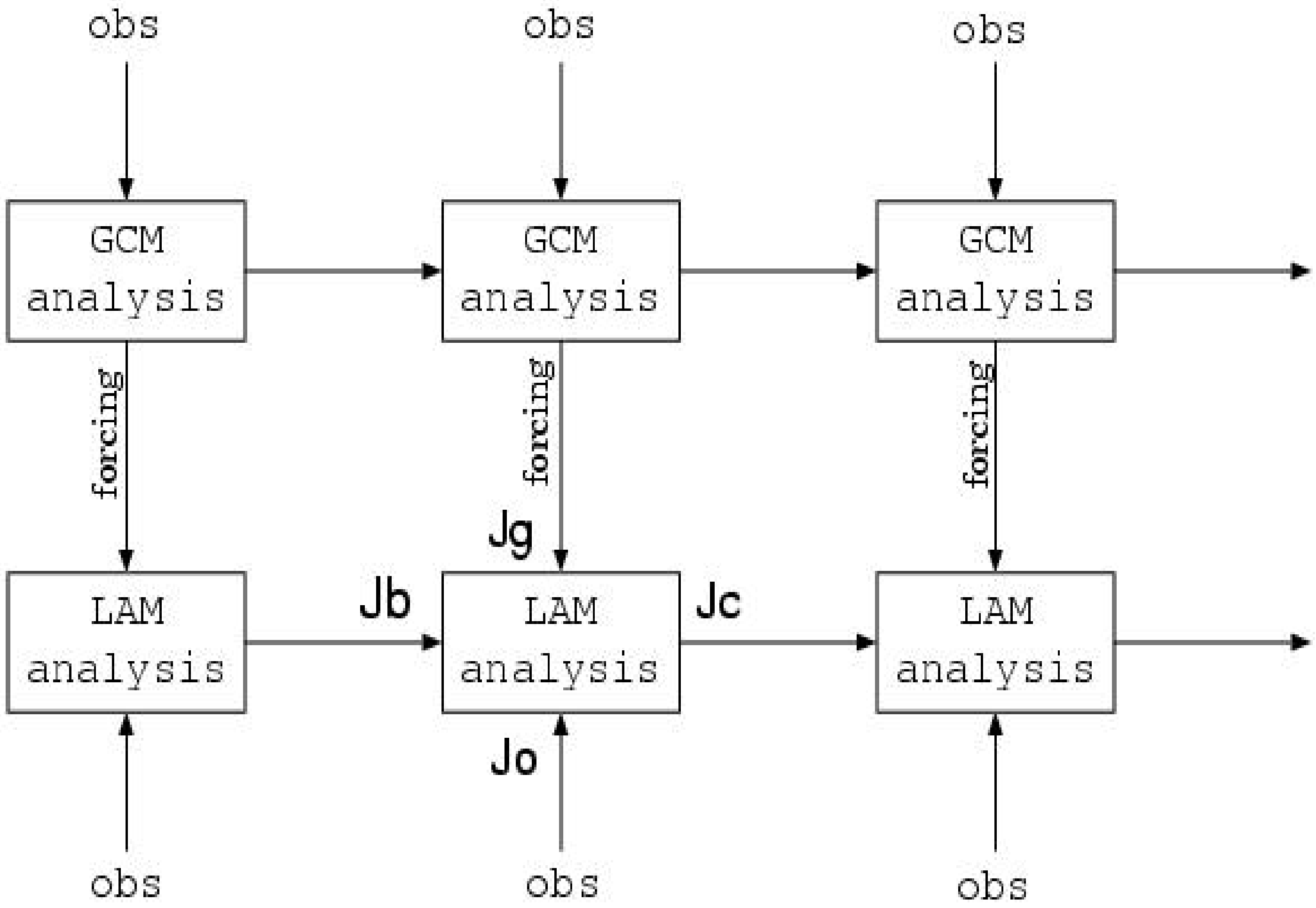


ALADIN/AROME 3D-Var: main differences with ARPEGE 4D-Var

- Non-incremental analysis at **full model resolution**
- Variational **digital filter initialization** at higher frequency
- J_b structures are smaller-scale (from **mesoscale ensemble**)
- J_b depends on latitude (very different in **tropics**)
- **humidity multivariate balance** in J_b (as an option)
- **Observations used at higher resolution** (less thinning)
- Extra observations : regional **hourly synops** of T_{2m}, HU_{2m}, V_{10m} ; **geostationary clear-sky radiances** at full resolution ; **cloud bogussing**

→ Expected **better humidity analysis** for rain, clouds, fog

ARPEGE/ALADIN assimilation coupling every 6 hours

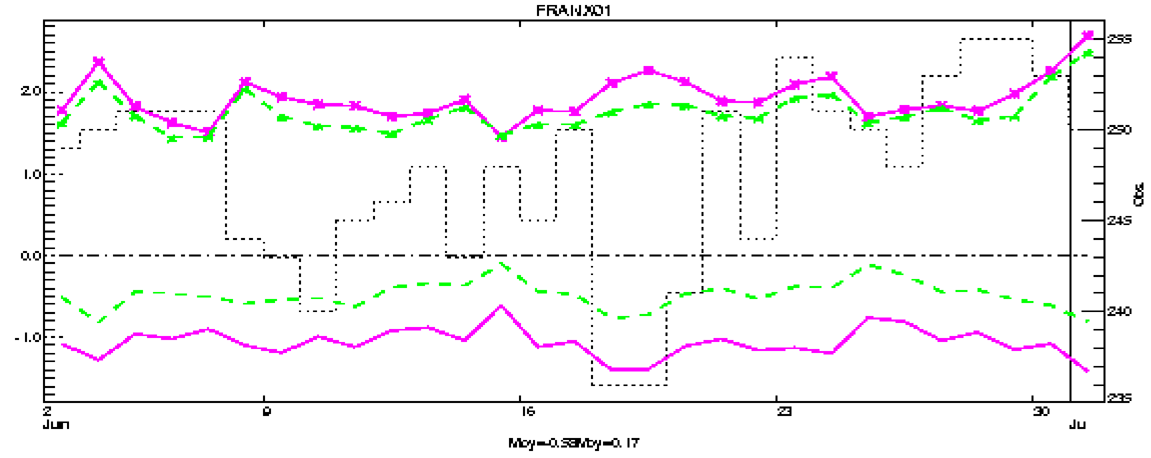


Usefulness of a regional analysis

Low-level wind model-observation error statistics over a few days:

Pink : large-scale ARPEGE 4DVar analysis

Green : ALADIN 3D-Var analysis with same observations

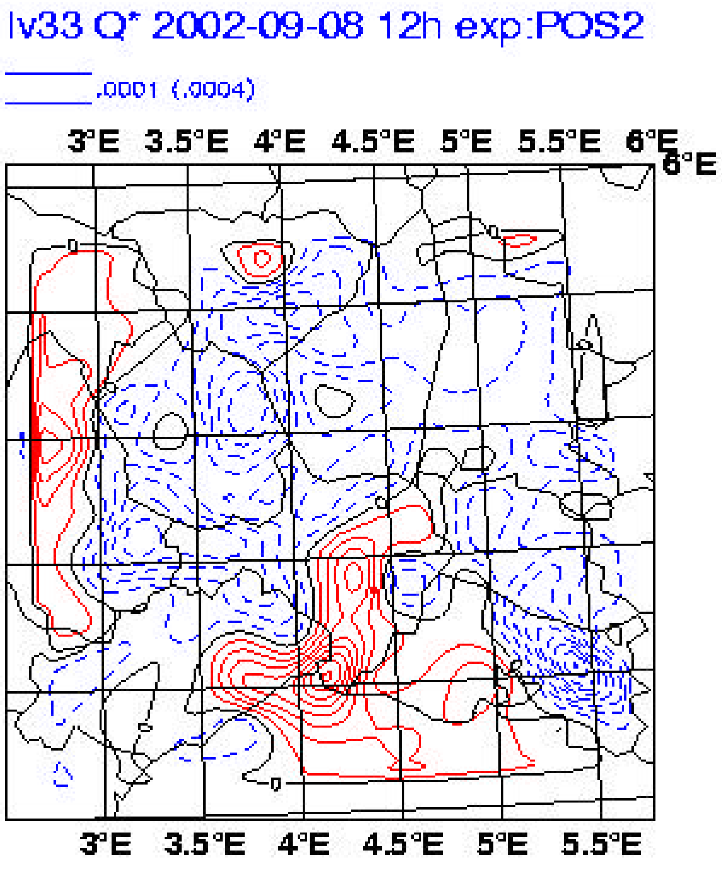


AROME analysis developments beyond ALADIN

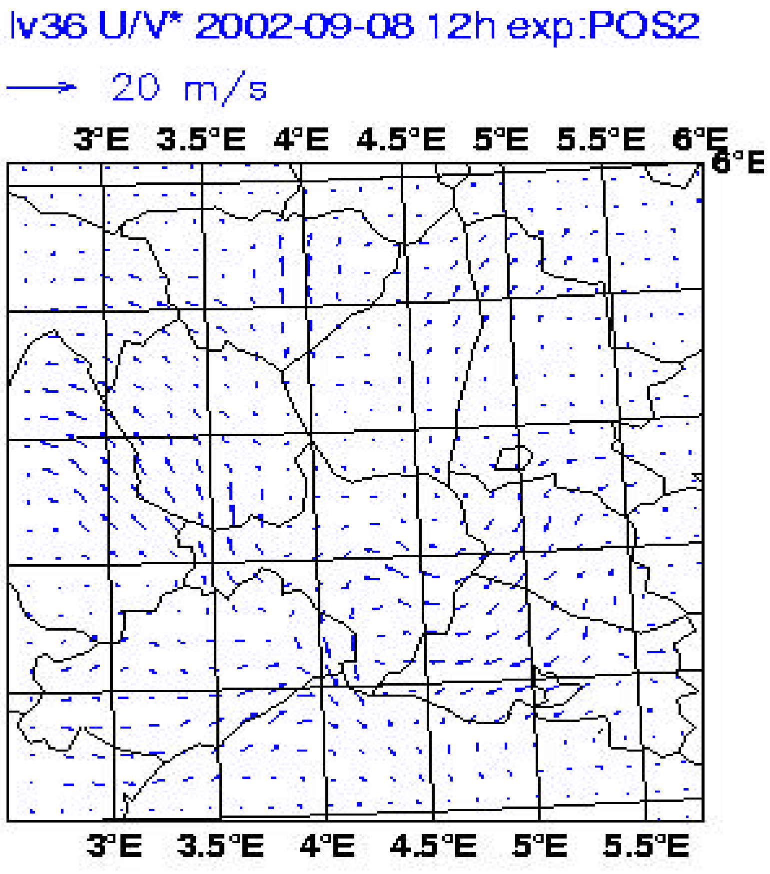
- High frequency observations with 3DVar-FGAT
- Radar (reflectivity & Doppler wind) & satellites with 1D-Var retrievals of cloud variables
- Surface fields in control variable for low-level obs
- High-resolution surface assimilation (SST, snow, soil moisture)
- Large-scale variational coupling term
- **J_b structure functions** : transformed humidity variable in, flow-dependent covariances, ensemble Kalman Filter
- **Slanted observation operators**
- Ensembles of analyses for **ensemble prediction**
- **4D-Var** using ALADIN 'cheap' incremental adjoint model (already coded) (2006)

3D-Var corrections of wind and humidity from 110 SYNOP reports in a 150x150km domain

humidity

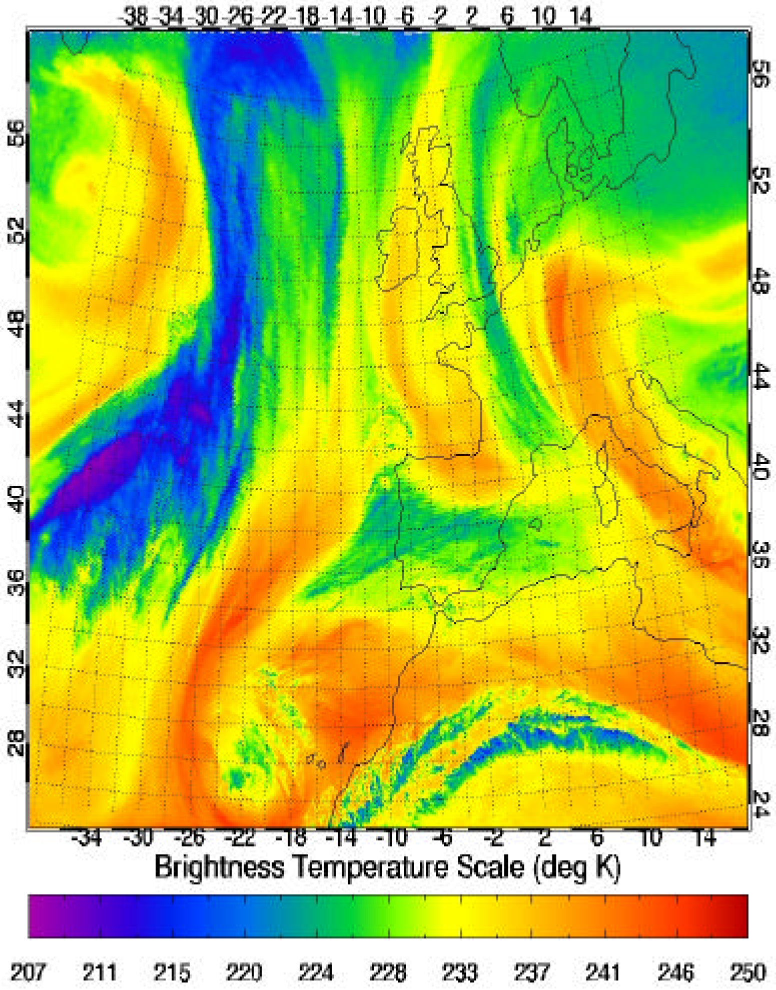


wind

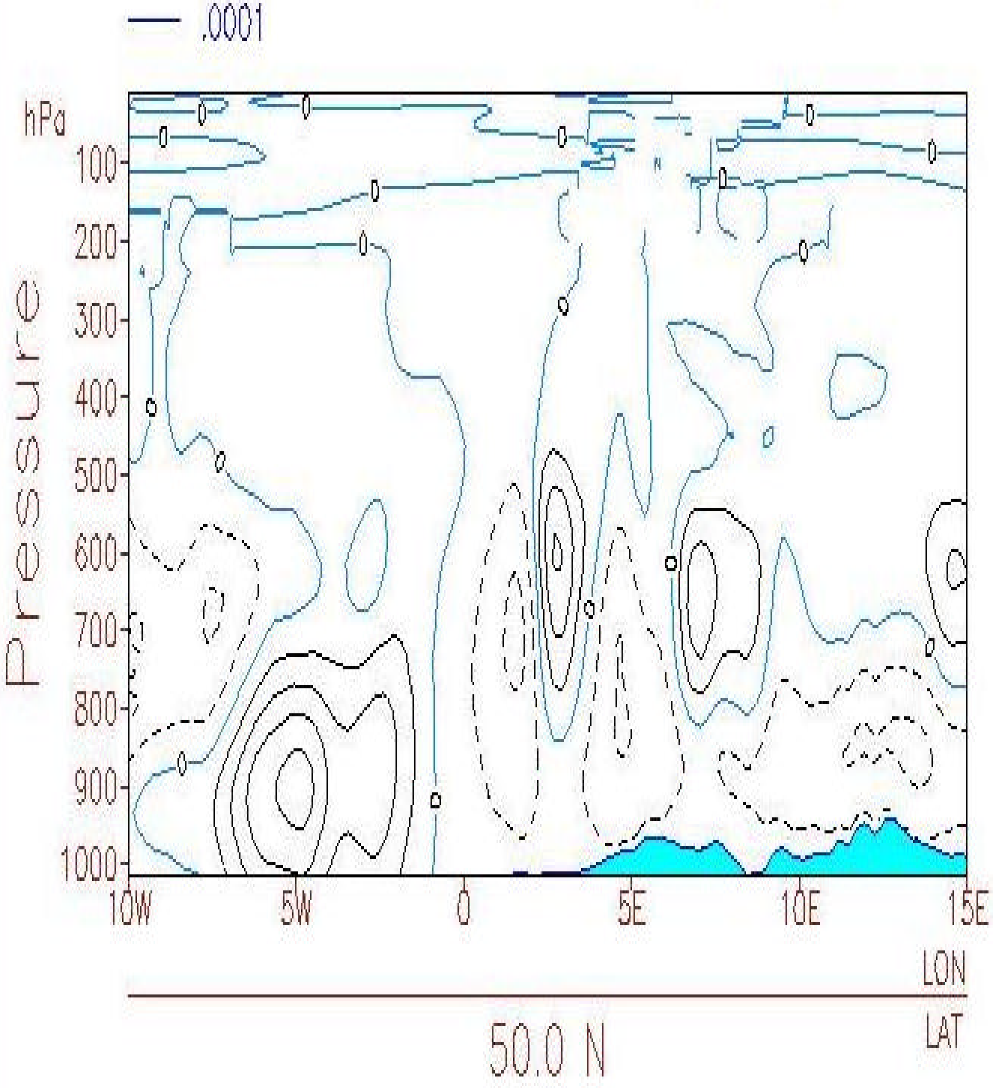


Mesoscale 3D-Var humidity analysis from geostationary radiances

MSG/Seviri *WV 6,2 m* Tb
on 12 Feb 2003, 1330

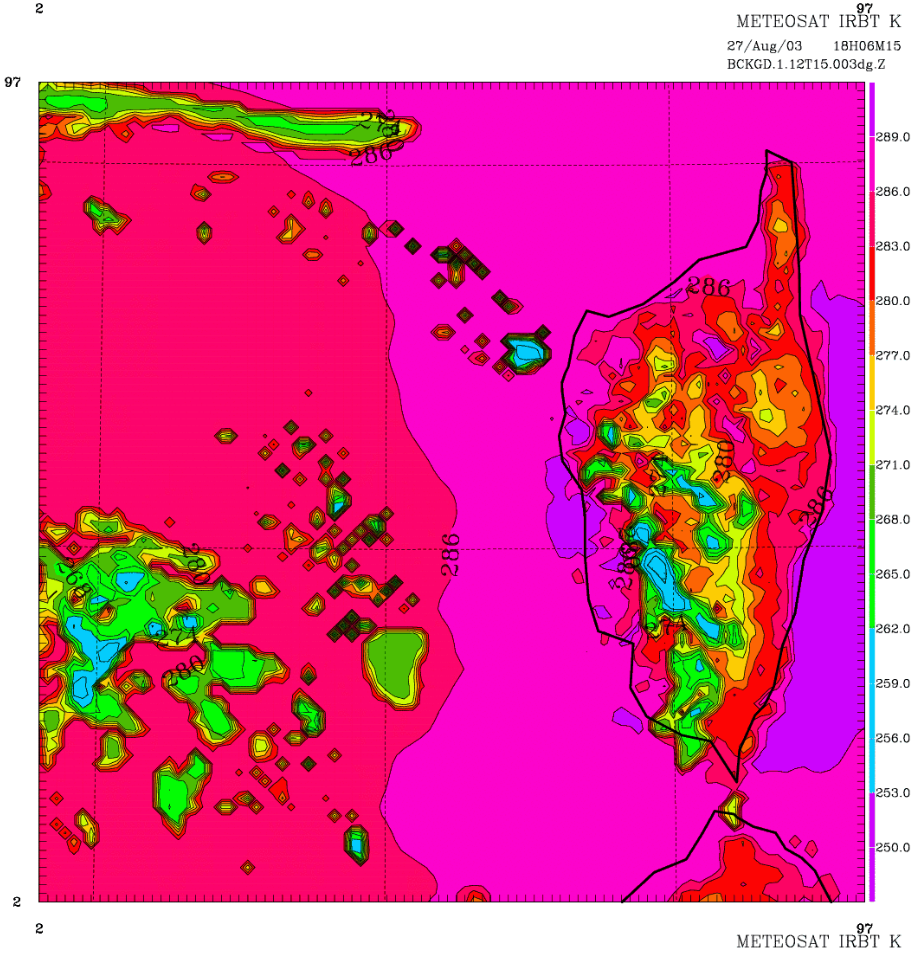


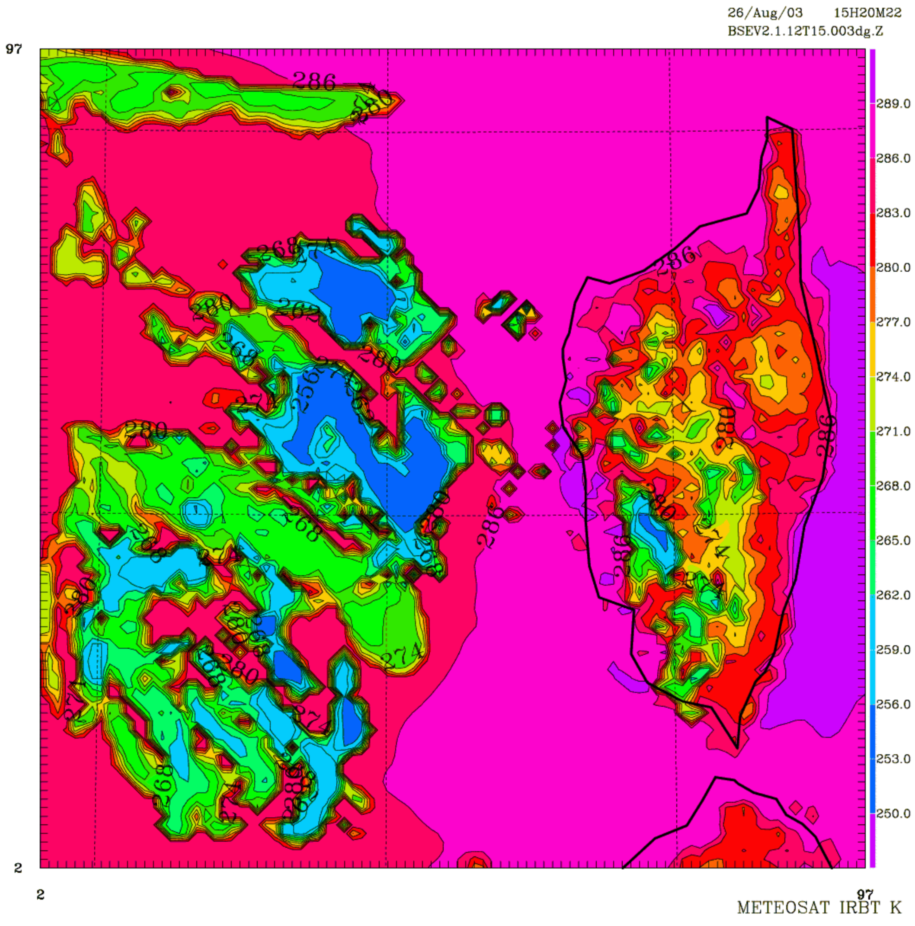
3DVar specific humidity
increments



Impact of MSG radiance assimilation on 2.5km convection forecasts

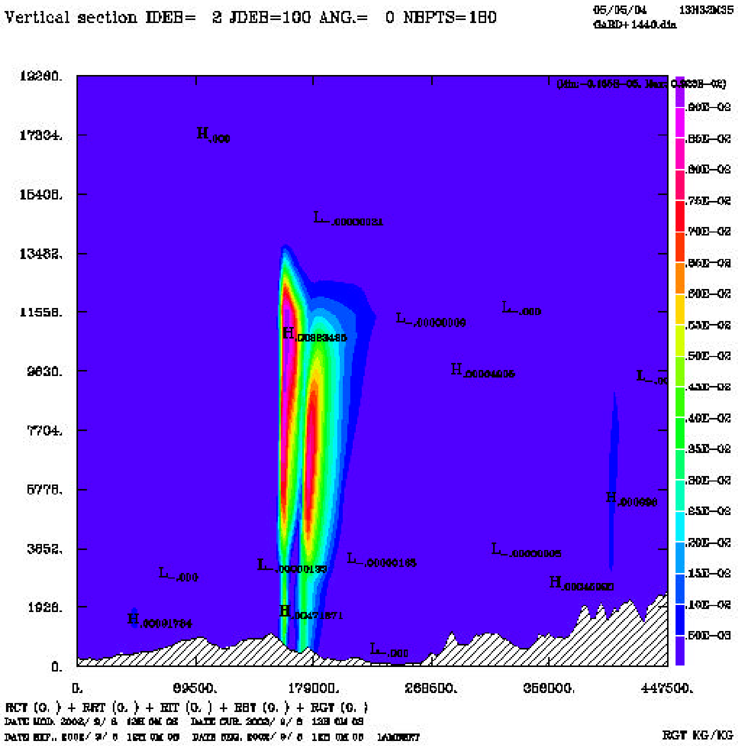
Forecast IR image, no analyis **with analysis**



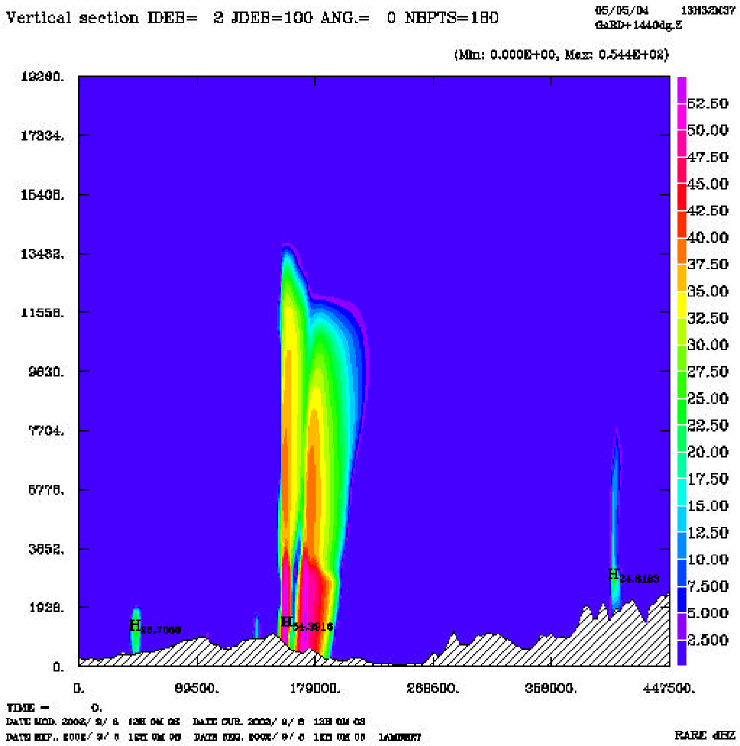


Radar simulation operator

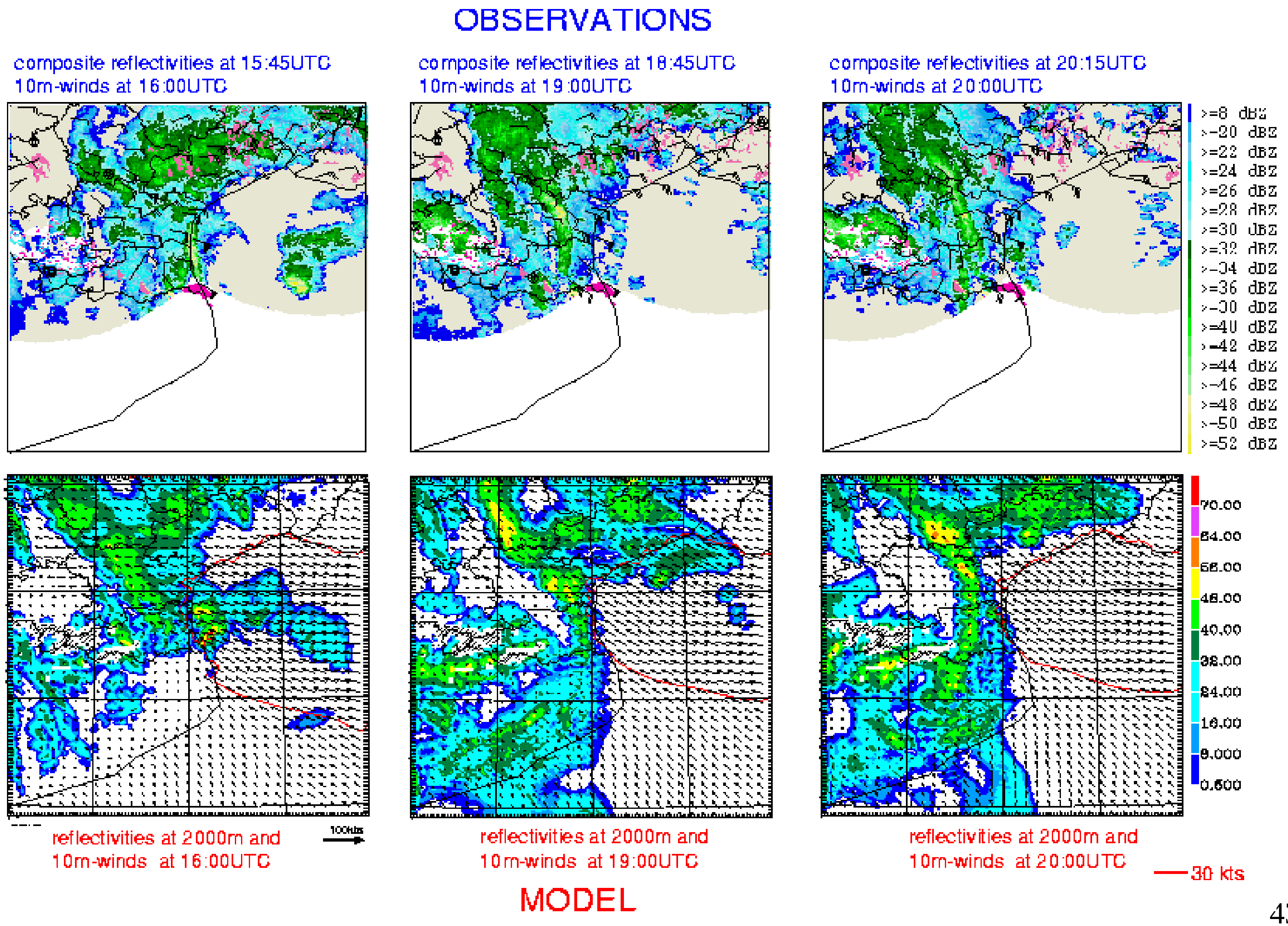
Hydrometeors



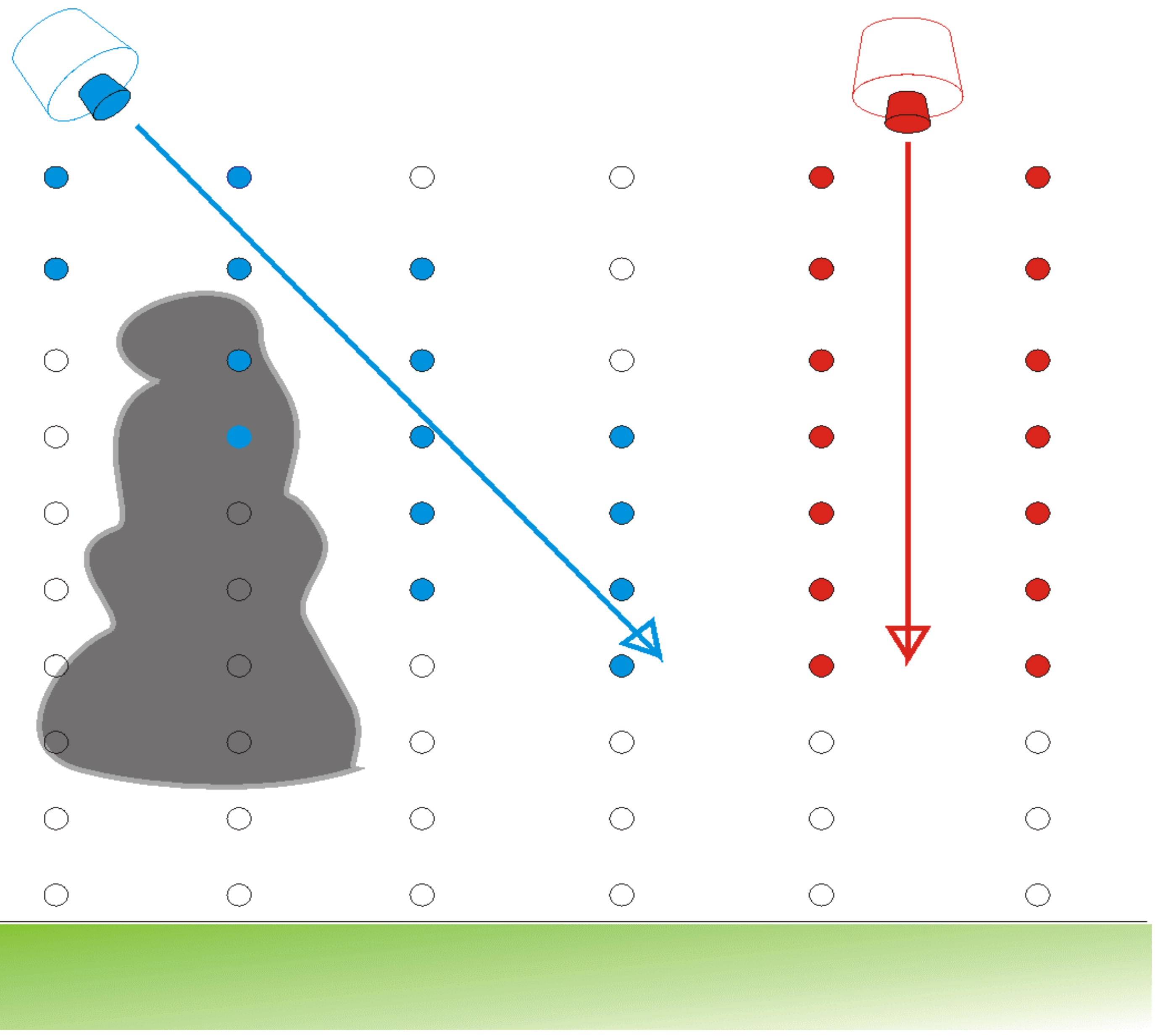
Radar reflectivity



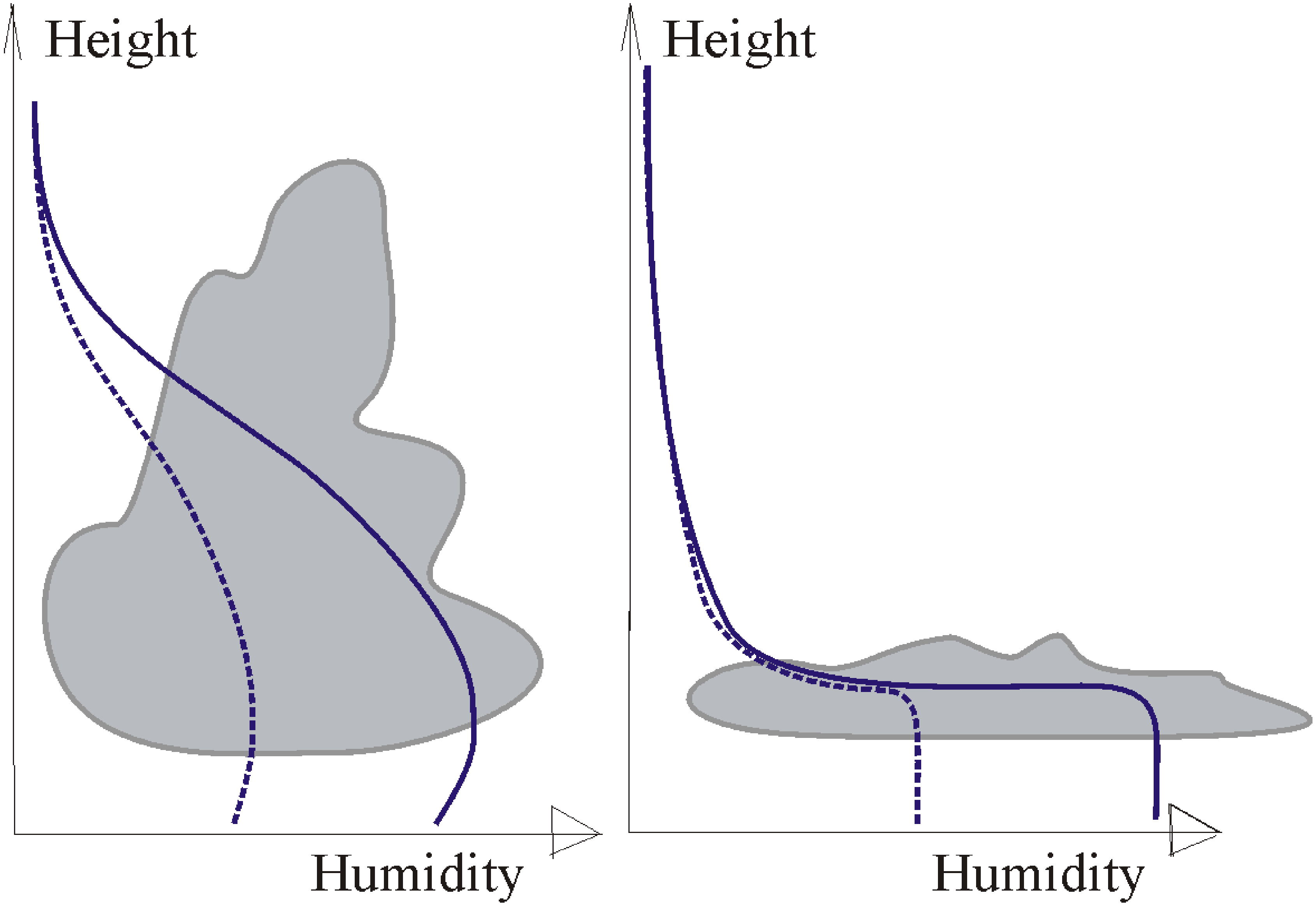
Radar assimilation : observed and model-generated reflectivities



Slanting observation operator for radar & satellites



Flow-dependent vertical structure functions for cloud analysis



CONCLUSION

Main research topics:

- **Shallow convection/stratiform clouds/fog**
- Flow-dependent **Jb structure functions** and **Ensemble forecasting**
- **Physical initialization** of clouds and boundary layer
- **non-linearities in 4D-Var**
- **NWP/nowcasting interaction**