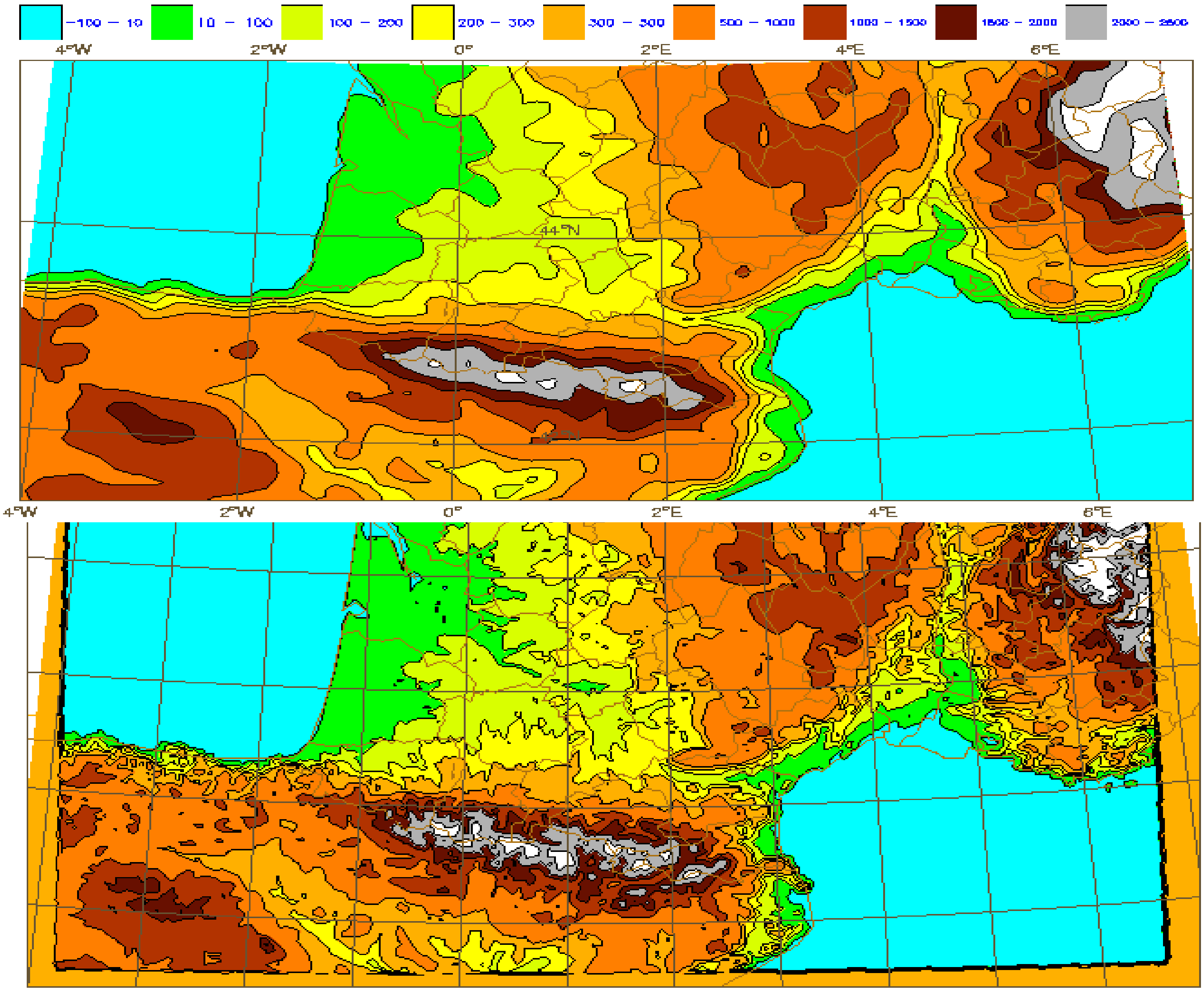
The Arome mesoscale project

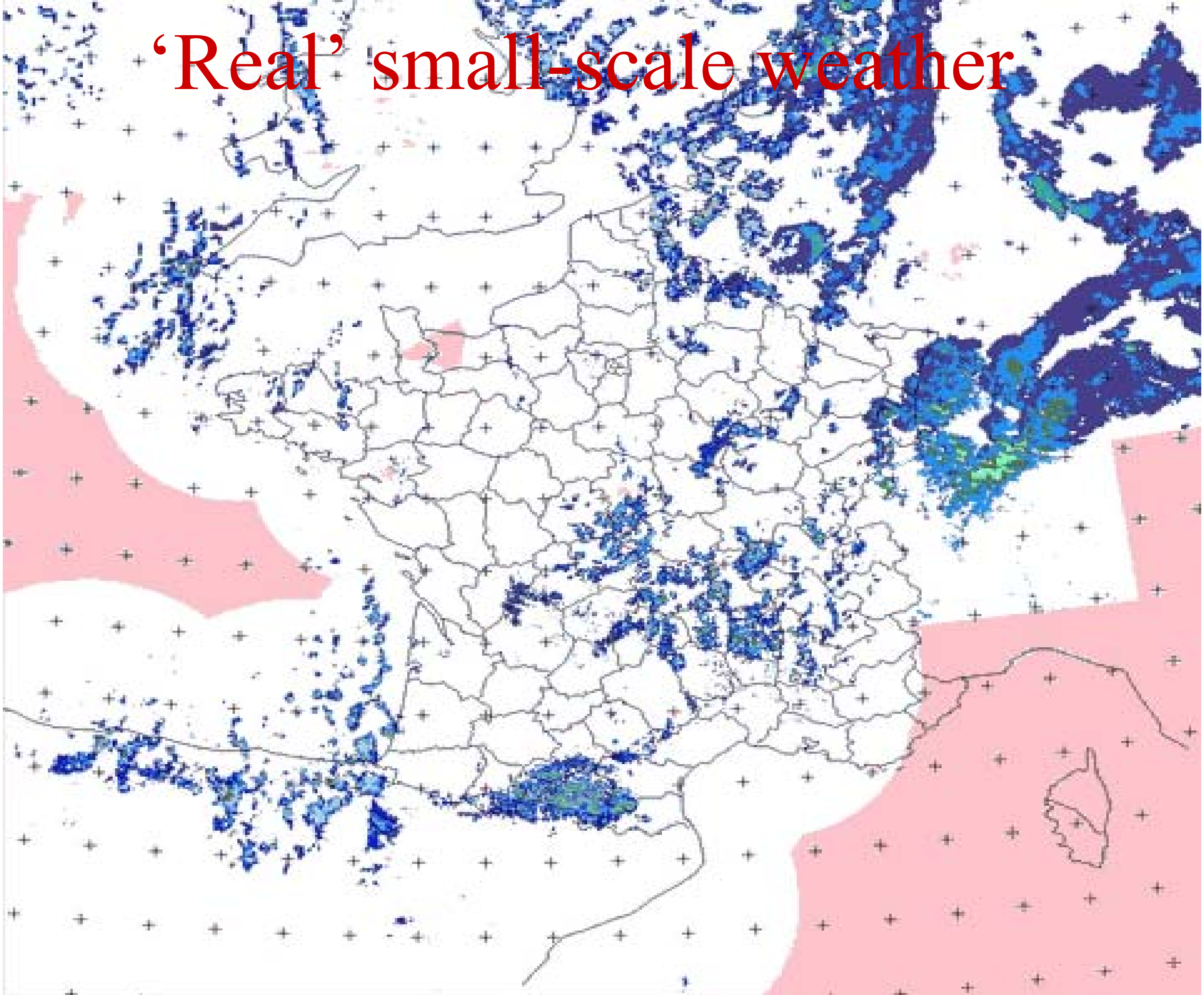
(F.Bouttier, Météo-France)

- context and motivation
- ingredients of convection-resolving NWP
- data assimilation issues
- large scale/mesoscale coupling
- towards integrated NWP facilities

The 10->2km resolution jump



‘Real’ small-scale weather



CONTEXT AND MOTIVATION OF MESOSCALE NWP

- What is Arome ? Applications of Research to Operations at MEsoscale
- Development of a convection-resolving (dx=2km) NWP model and data assimilation
- Raises new issues in forecast verification, data processing, use of global models, nowcasting, organisation
- Requires a large software project (like global NWP systems)
- Main originality: link between applied and upstream research

CONTEXT

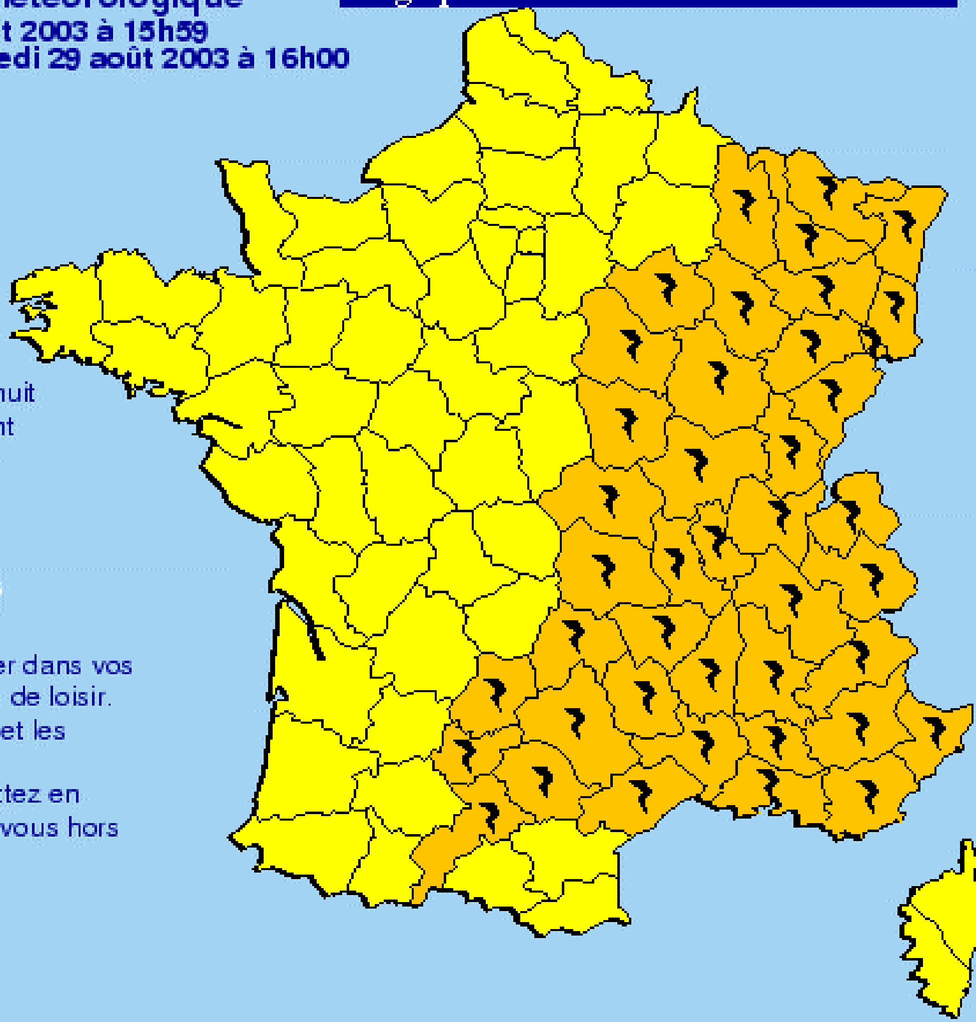
- Strong public demand for better weather forecasts at finer scales and short ranges
- Push for integration with hydrology, civil protection, environmental agencies, etc.
- Computers and obs networks now allow convergence between fine-scale NWP and mesoscale research communitities
- Need to jump the 'convection gap' between 10- and 2-km resolutions
- Divide between the nowcasting and NWP systems: 1-6 hours ranges
- Similar moves worlwide:
  - US WRF project
  - UM mesoscale studies
  - LM/COSMO group
  - Plans in Hirlam, Canada/MC2, JMA…

METEOROLOGICAL AWARENESS = RISK

METEO FRANCE

Carte de vigilance météorologique
Diffusée le jeudi 28 août 2003 à 15h59
Valable jusqu'au vendredi 29 août 2003 à 16h00

Cliquez sur un département orange ou rouge pour obtenir le bulletin de suivi



- Vent violent
- Fortes précipitations
- Orages
- Neige–Verglas

Commentaires Météo-France

En fin d'après–midi et cours de nuit prochaine une situation fortement orageuse se met en place sur la moitié est de la France.

Conseils des pouvoirs publics

Orages/orange

- Soyez prudents, en particulier dans vos déplacements et vos activités de loisir.
- Evitez d'utiliser le téléphone et les appareils électriques.
- A l'approche d'un orage, mettez en sécurité vos biens et abritez–vous hors des zones boisées.

Niveau 4 : Une vigilance absolue s'impose; des phénomènes météorologiques dangereux d'intensité exceptionnelle sont prévus; tenez–vous régulièrement au courant de l'évolution météorologique et conformez vous aux conseils ou consignes émis par les pouvoirs publics.

Niveau 3 : Soyez très vigilant; des phénomènes météorologiques dangereux sont prévus; tenez–vous au courant de l'évolution météorologique et suivez les conseils émis par les pouvoirs publics.

Niveau 2 : Soyez attentif si vous pratiquez des activités sensibles au risque météorologique; des phénomènes habituels dans la région mais occasionnellement dangereux (ex mistral, orage d'été) sont en effet prévus; tenez–vous au courant de l'évolution météorologique.

Niveau 1 : Pas de vigilance particulière.

Les cartes de vigilance météo paraissent 2 fois par jour à 06h et à 16h.

En cas de vigilance orange (niveau 3) ou rouge (niveau 4), des bulletins de suivi sont disponibles.

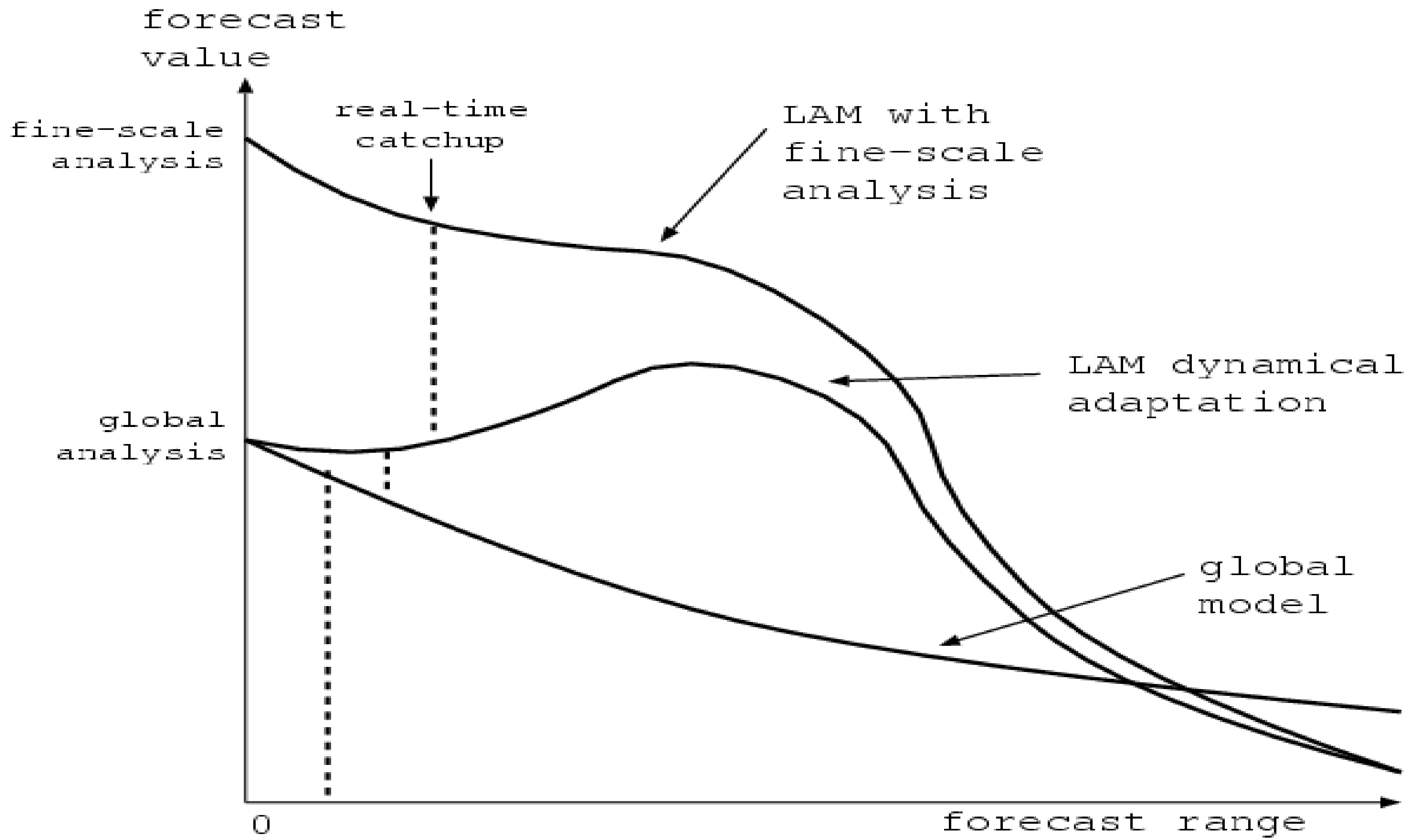
Carte n° 28082003_16_01

Choisissez > Actualiser la page

MOTIVATION

- Provide reliable input to meteorological awareness products
- Improve analysis and forecast of strong convection: floods, gusts, hail, location and timing
- Improve model output of actual weather parameters: visibility, turbulence, temperature, local effects.
- Maximize work efficiency by seeking synergies in software (IFS/Arpège/Aladin/MésoNH legacy) and institutions (NWP offices, research labs, European agencies)

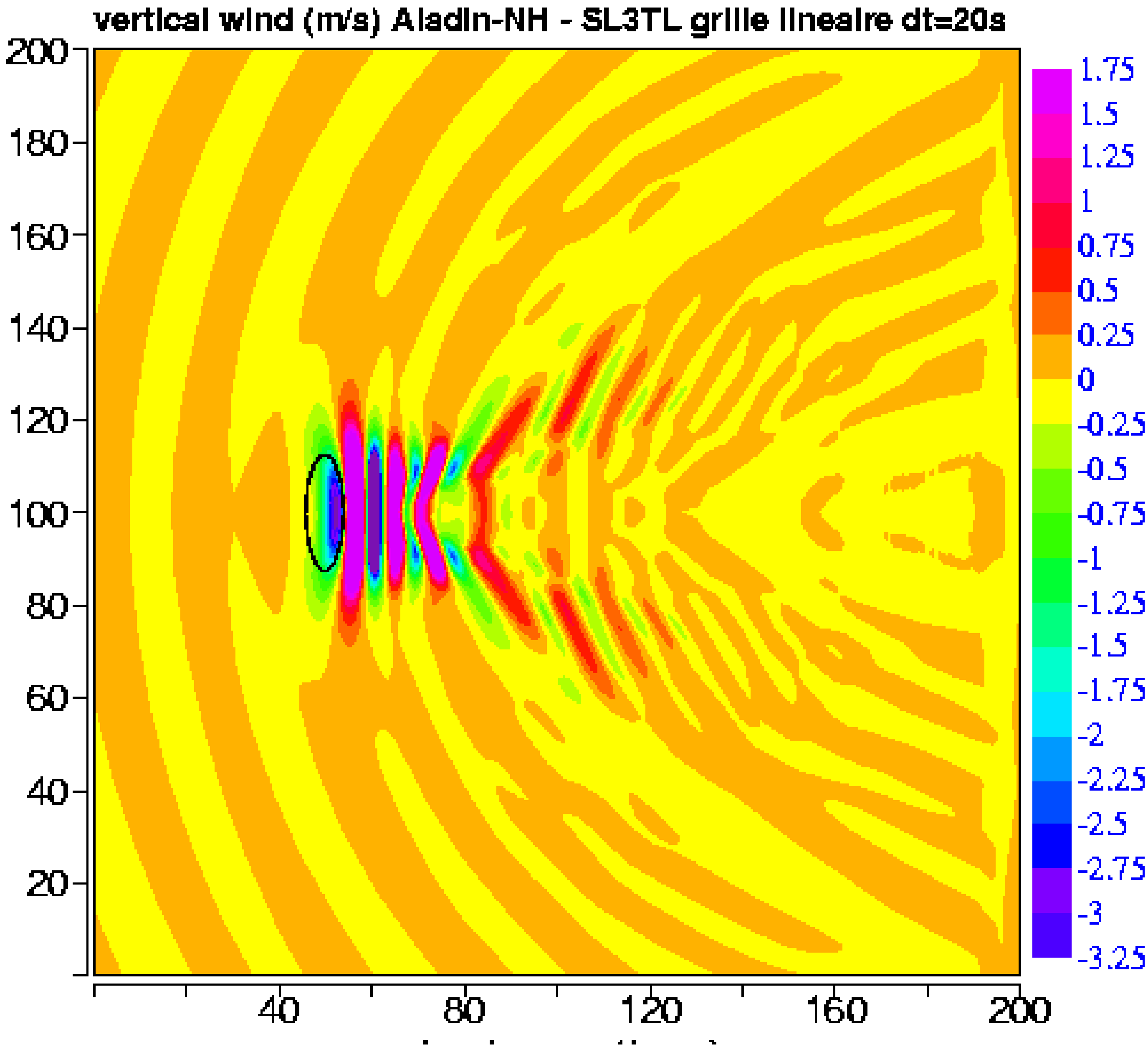
Real-time value from local adaptation and assimilation



INGREDIENTS OF CONVECTION-RESOLVING NWP

- dx better than 3km, dz better than 400m (100m for stratiform clouds), dt of the order of 1mn
- domain size of at least 1000km to keep some internal predictability over 24h i.e. 500x500x60
- explicit 3D wind (non-hydrostatic), T, mass, water vapour, cloud & precipitating species, TKE i.e. 12 + chemicals
- main obs repeat times are between 10mn and 1hour
- Variational analysis is required (radiances and reflectivities) with optimised structure functions (PBL structure, humidity, cloud/environment balance)
- Is 4DVar desirable ? Problematic for short cutoffs and non-linear effects.
- Information on predictability is essential: mesoscale EPS ?

non-hydrostatic dynamics: trapped lee waves



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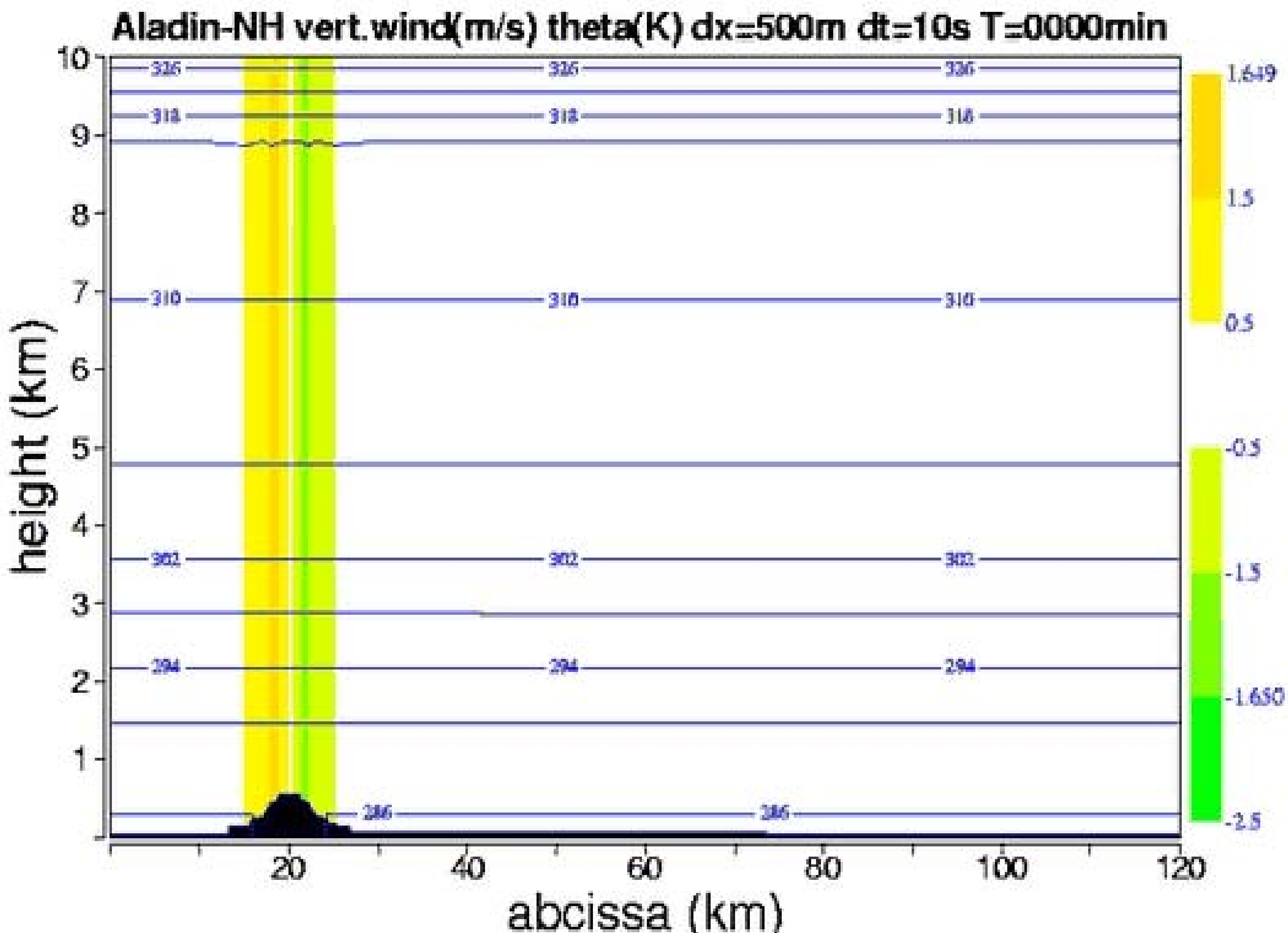


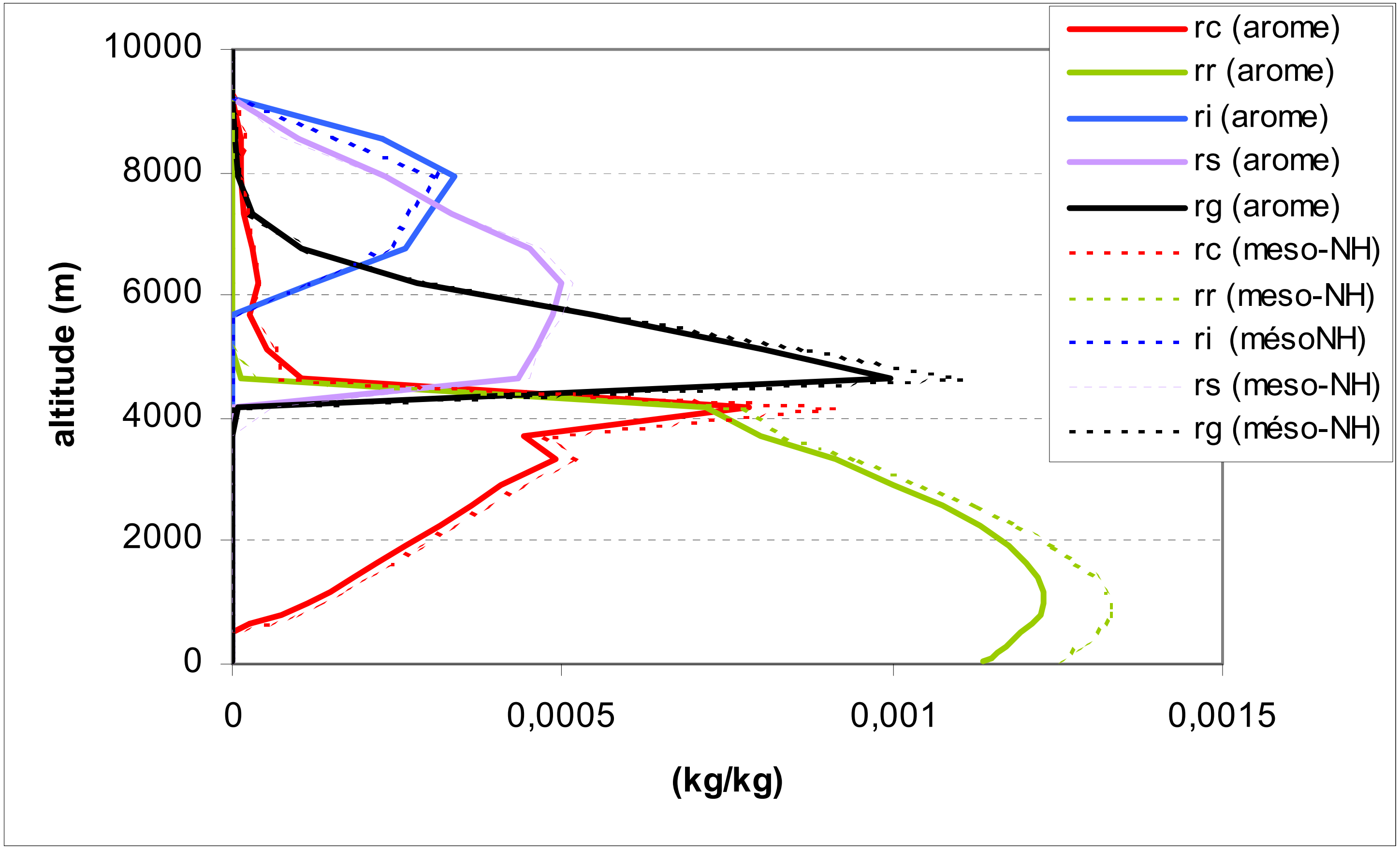
MODELLING ASPECTS: NUMERICS

- limited area with the lateral boundary condition problem. Is variable resolution feasible ?
- terrain-following vertical coordinate still widely used. Problematic in stratified weather.
- stratosphere less important than in global models (except for radiance assimilation)
- Lateral boundary condition: discontinuities in resolution, physics, orography. Consider ingoing and outgoing waves.
- non-hydrostatic dynamics are essential.
- Biperiodized spectral or gridpoint, semi-Lagrangian. Competing approaches for timestepping (implicit solver or time-splitting).
- 1mn timestep means most physical processes are slow w.r.t dynamics: explicit physics timestepping
- problem of moist air parcel definition (does air rain into the ground ?!?)

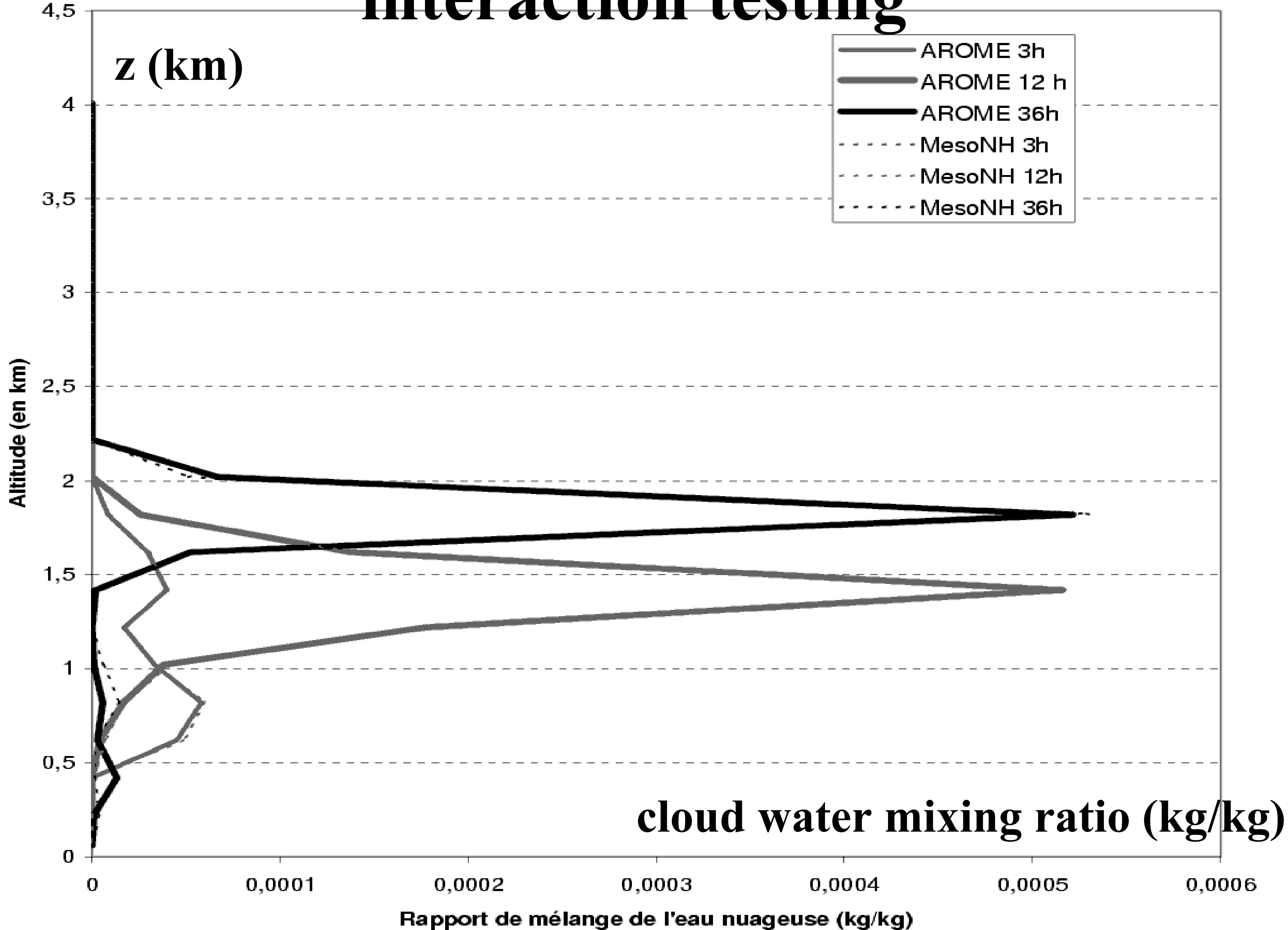
MODELLING ASPECTS: PHYSICS

- some large-scale issues disappear at kilometric scales: deep convection, gravity wave drag.
- remaining parametrized processes: turbulent mixing, microphysics, radiation, surface fluxes, shallow convection.
- 3D lateral aspects are significant (radiation, turbulence)
- microphysics combine slow (fall speed) and fast (condensation etc) processes
- turbulence and microphysics remain ill-posed subgrid problems
- definition of fluxes is non trivial at small space/timescales.
- relative cost of physics vs numerics is larger than in large-scale models.

Comparison of AROME and Meso-NH 1D microphysical response to a constant forcing (δt=5s)



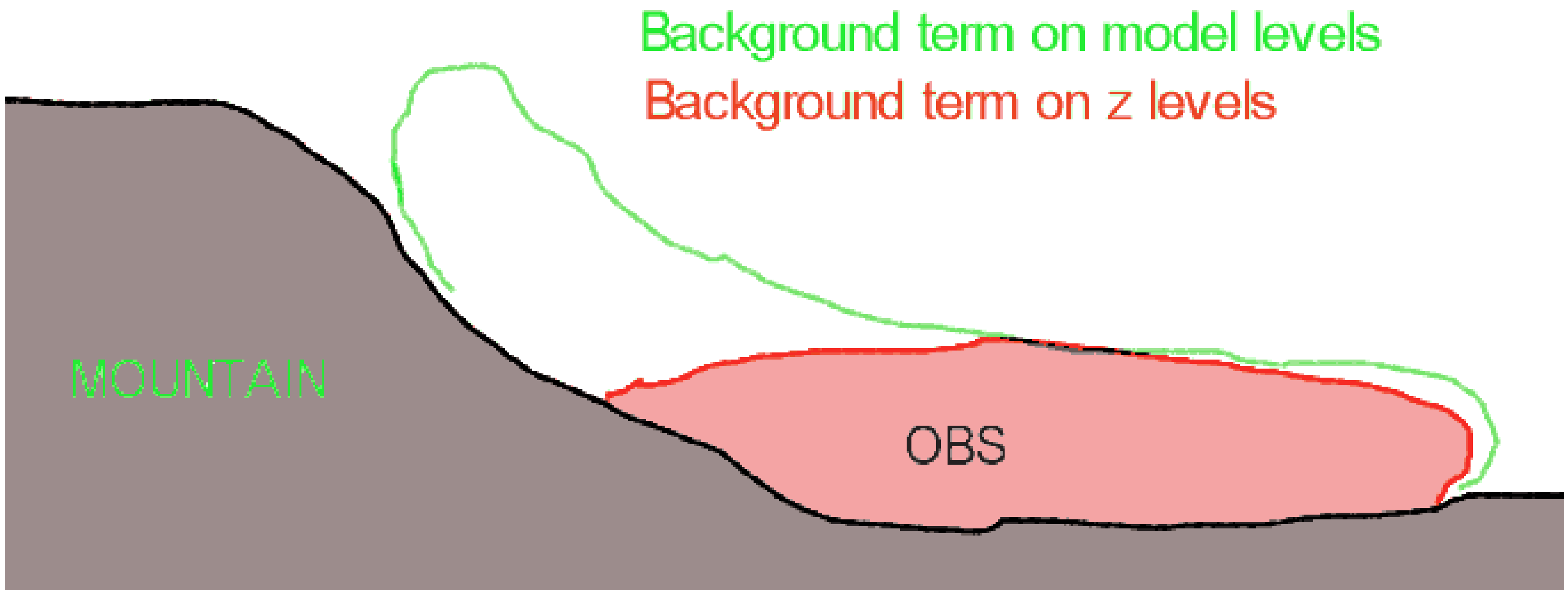
microphysics+turbulence+radiation+surface interaction testing



DATA ASSIMILATION ISSUES

- focus on features not already assimilated by global models
- precise initialization of clouds, humidity, PV anomalies
- take orography, lateral boundaries, global assimilation into account
- timeliness: 1-day forecast ready in 30-60 minutes at least every 6 hours
- i.e. observations in less than 30 min with 10mn to 1h frequency
- consistency with satellite and radar images
- optimize system for extreme weather

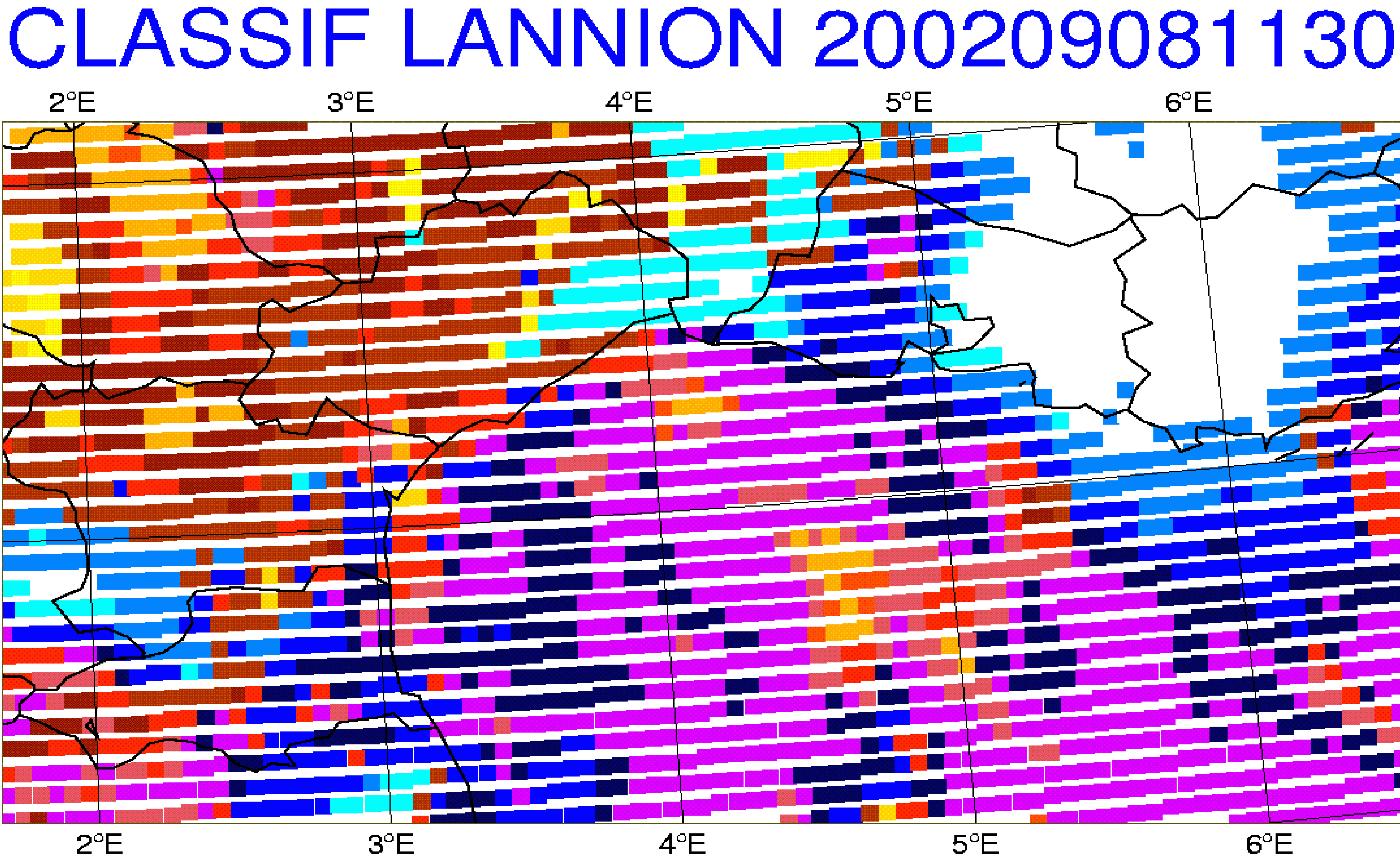
Orography treatment issues



DATA ASSIMILATION: SATELLITE OBSERVATIONS

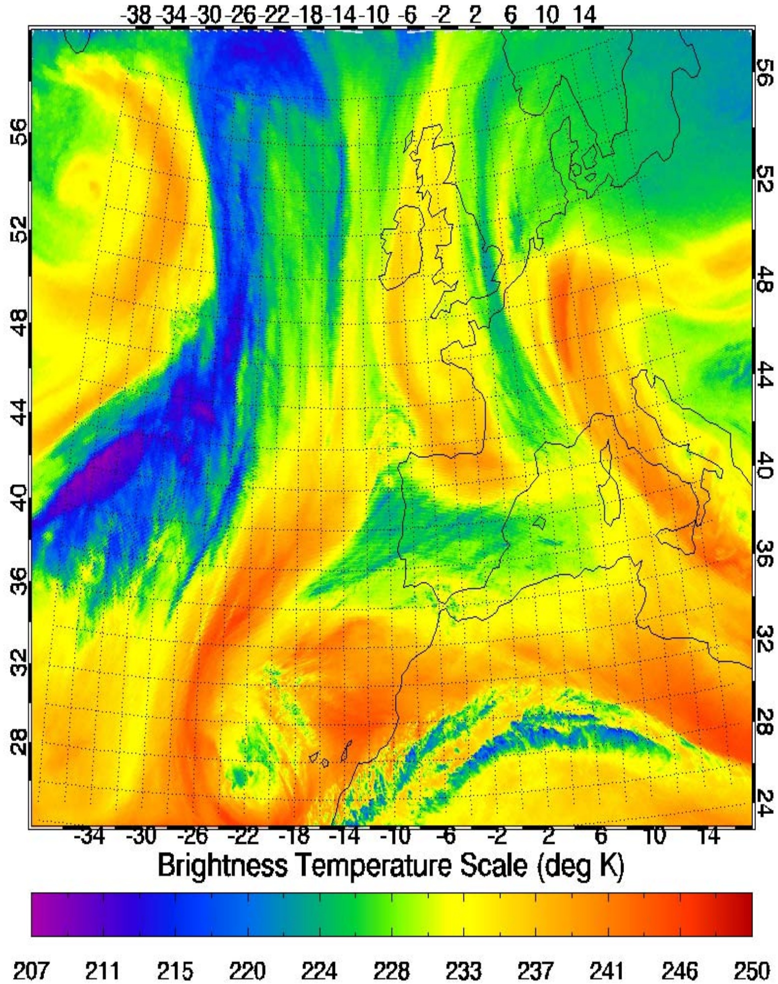
- polar-orbiting data about every 4 hours (EPS, NPOESS, EOS...)
- geostationary radiances every 30 min (MSG, GOES...)
- local reception systems necessary for timeliness (EARS, AAPP...)
- satellites without local reception useless for mesoscale NWP ?
- need nested assimilations to combine long- and short-cutoff analyses
- information: high-resolution IR, cloud tops, cloudy microwaves, sea surface winds, Doppler wind lidar, GPS
- major problem: IR cloud opacity
- large potential of microwave radiances and DWL over land.

Cloud analysis using MSG classification (here: prototype from AVHRR) ➔bogus humidity profiles in 3DVar

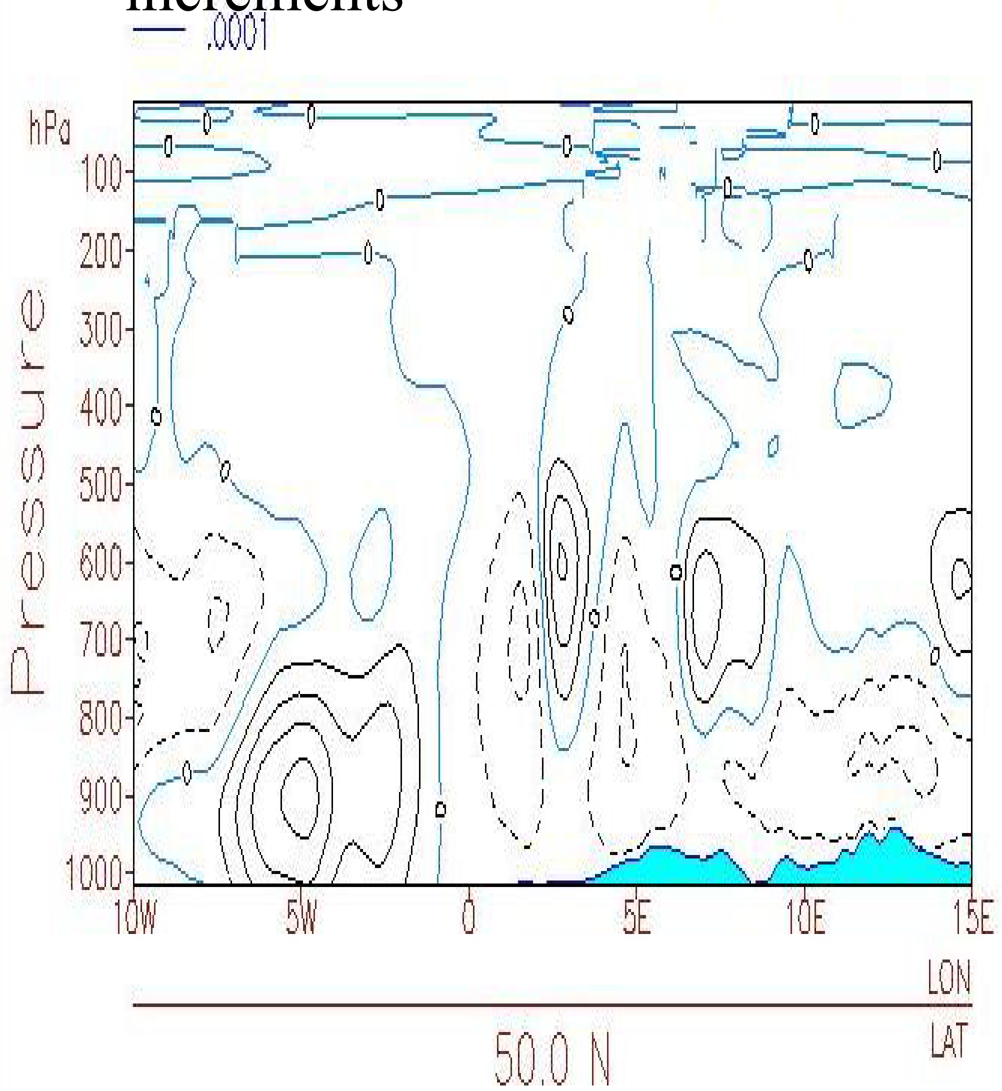


Humidity analysis from MSG water vapour clear radiances (10-km resolution)

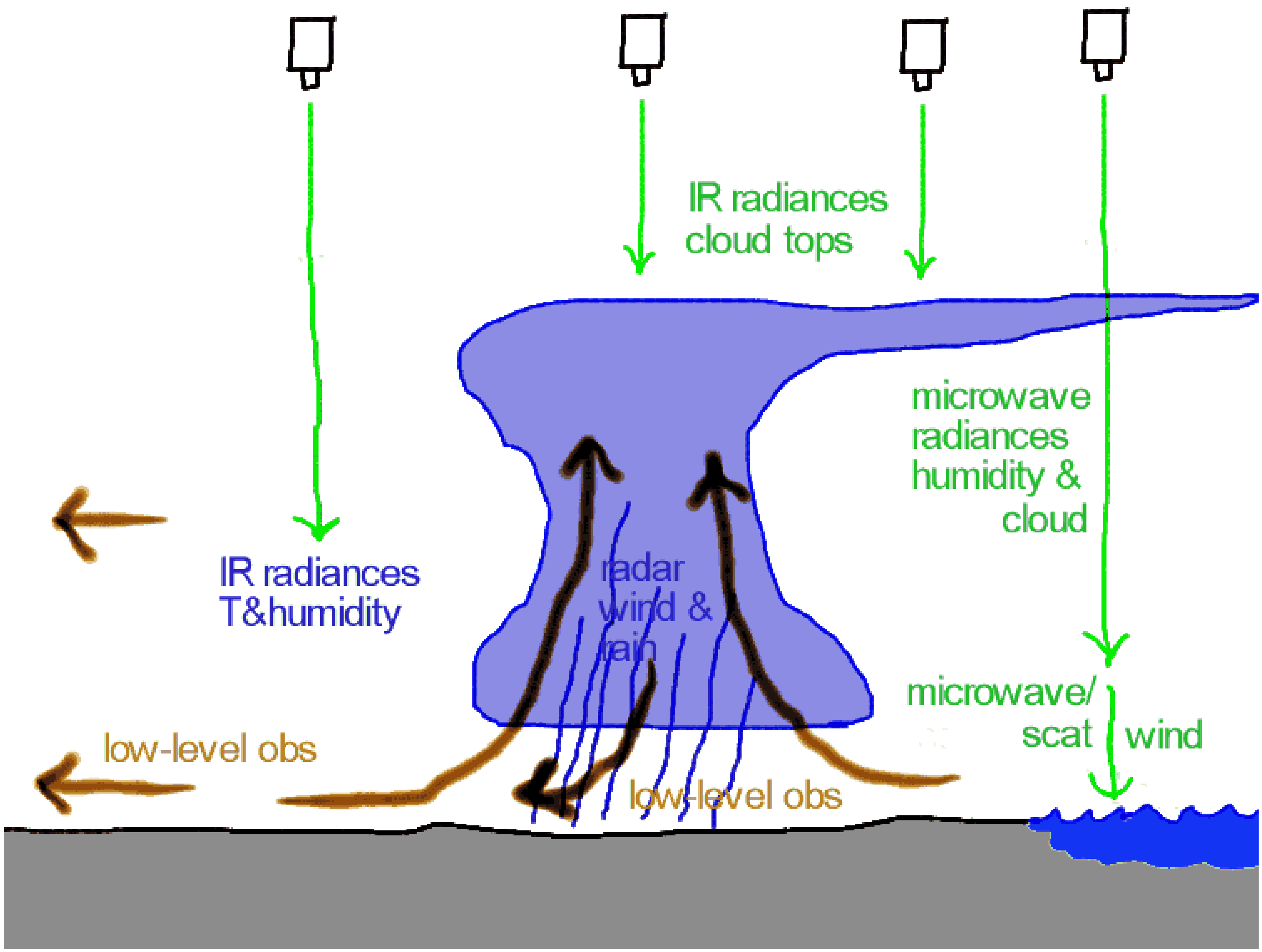
MSG/Seviri *WV 6,2 μ* Tb on 12 Feb 2003, 1330



3DVar specific humidity increments



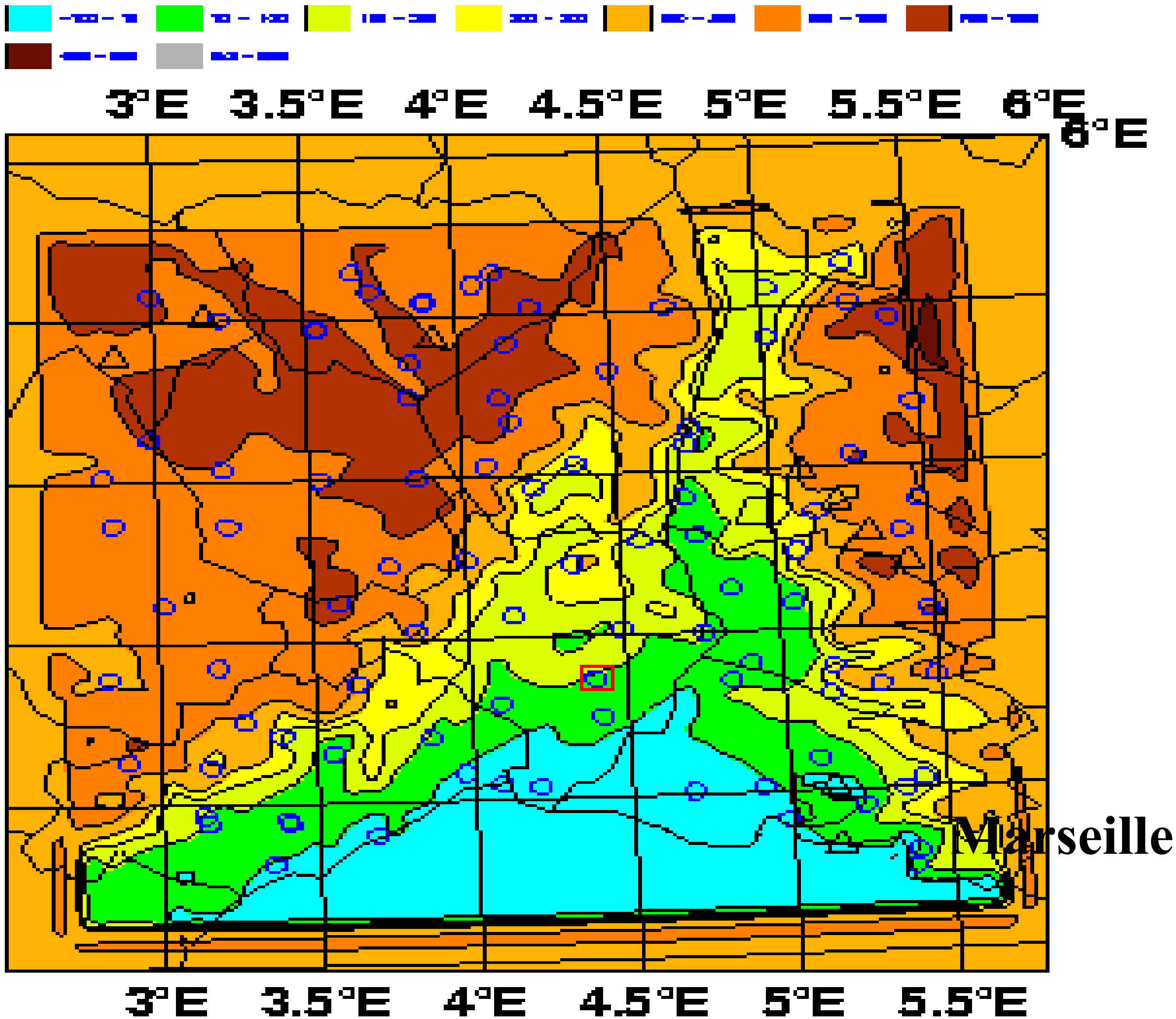
observations for mesoscale convection



DATA ASSIMILATION: NON-SATELLITE OBSERVATIONS

- radiosondes, profilers, aircraft, synoptic SYNOPs too sparse for mesoscale needs
- except near major airports and cities
- automated synop/dribu (every 30km) and radars will provide most of the data
- synop: pressure, wind, T, hum, rain rate, cloud type and base, visibility
- operational radars: Doppler wind, reflectivity, polarization, volumic scan
- availability problem outside well-equipped regions.
- dilemma: a few high-quality instruments or a low-tech network with good coverage ?

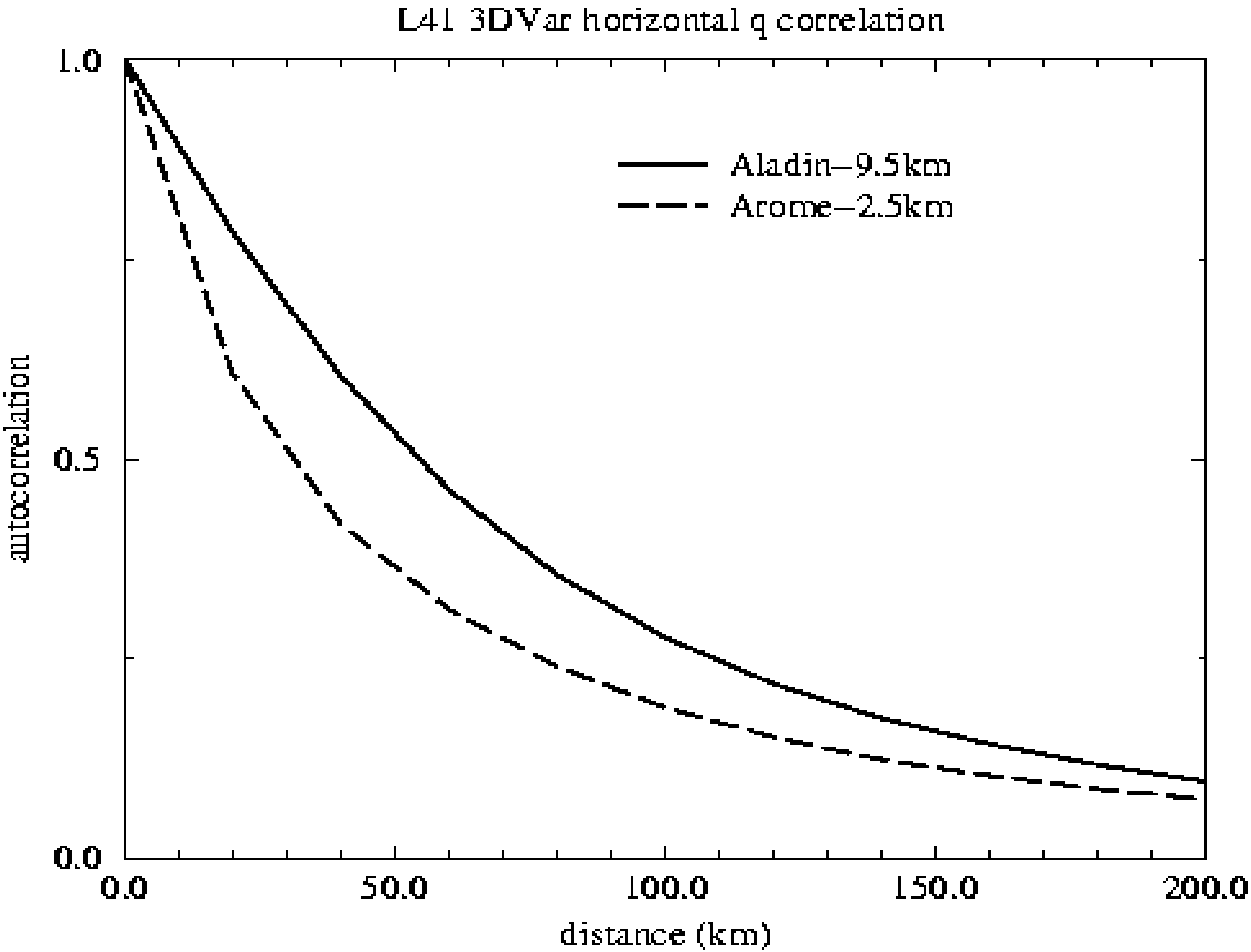
Data assimilation prototype
(domain size=150km, resolution=2.5km)



DATA ASSIMILATION ALGORITHMS (1)

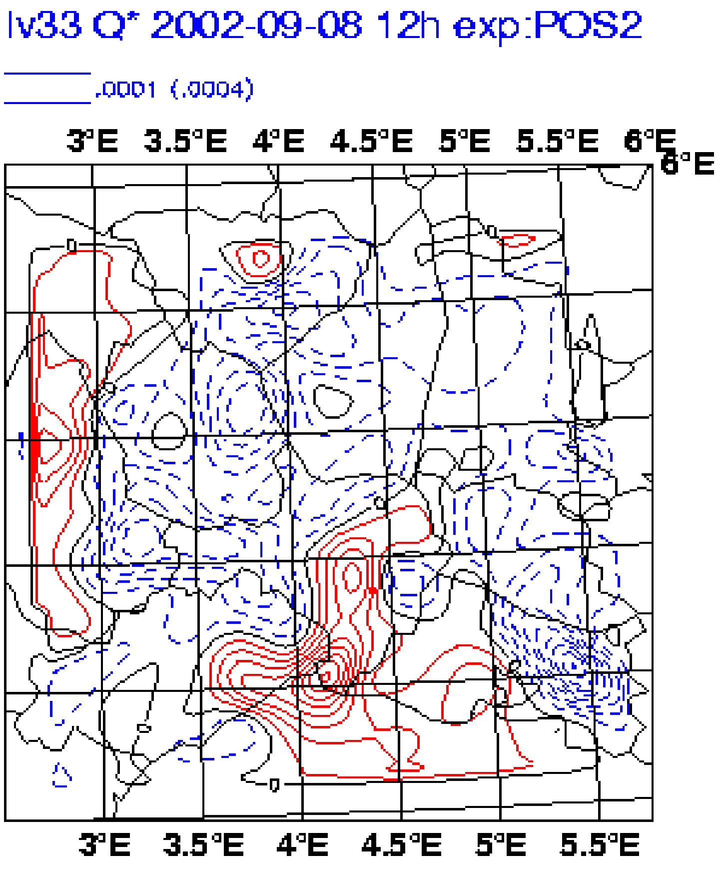
- 4D-Var not suitable for short cutoffs and threshold processes in clouds/precipitation
- 3D-Var-FGAT with enhanced structure functions (PBL and humidity)
- (simple Kalman filtering later)
- structure functions adapted for severe weather (convection), PBL structure
- problem: horizontal correlations vs lateral boundary conditions
- problem: quick setup of background error model without expensive NMC or ensemble calibration of statistics (multivariate spectral extrapolation)

Ajustable spectral multivariate 3D-Var structure functions

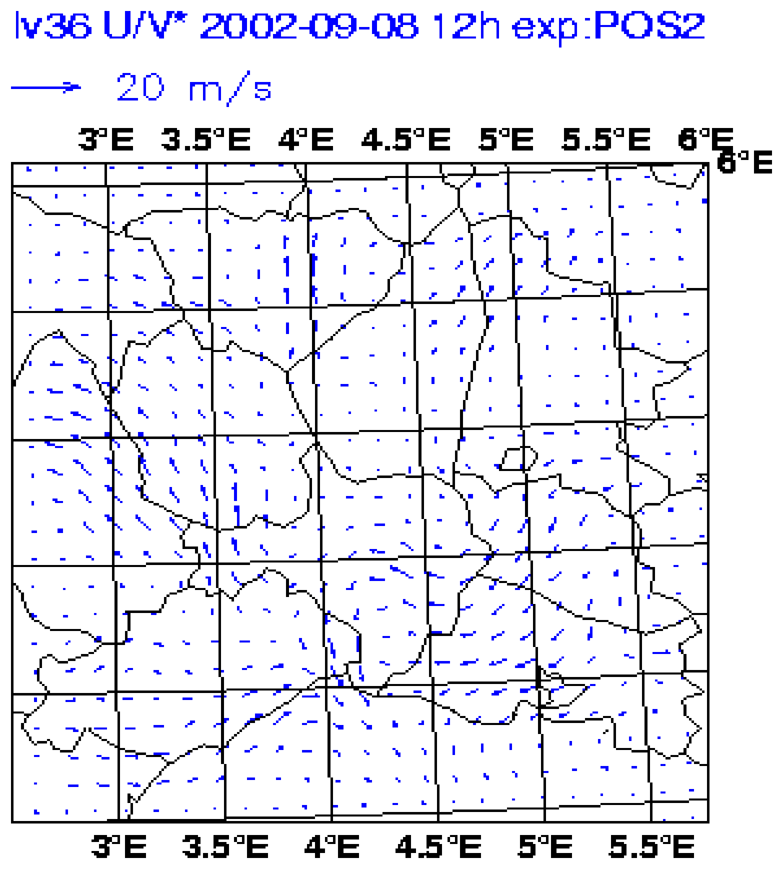


sample analysis increments using surface stations (ps,wind,humidity)

humidity

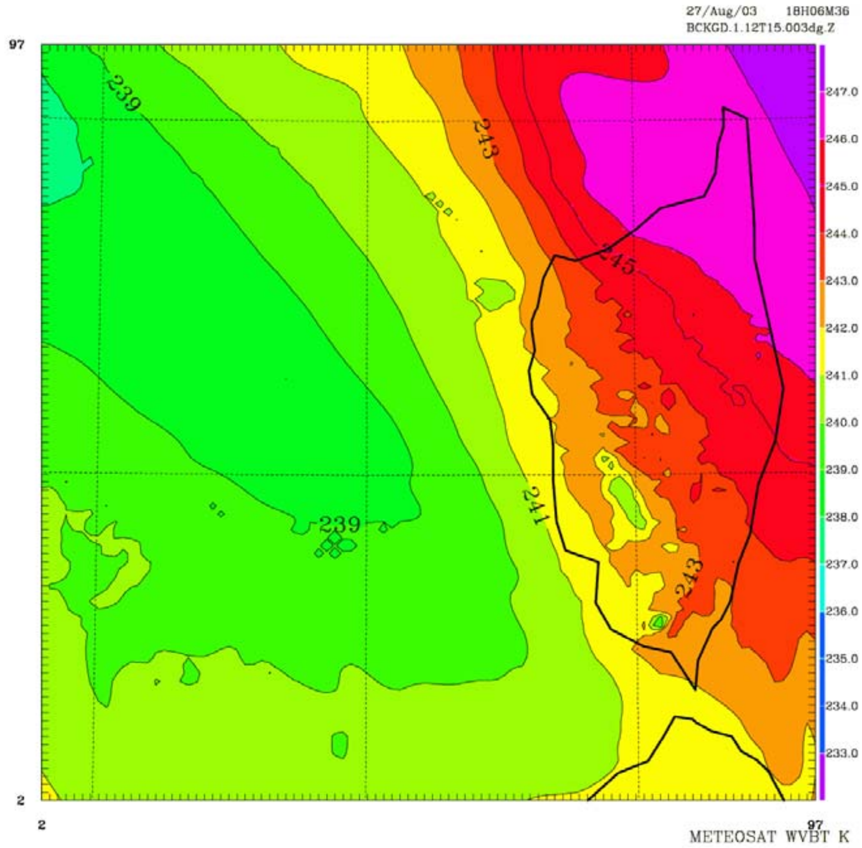


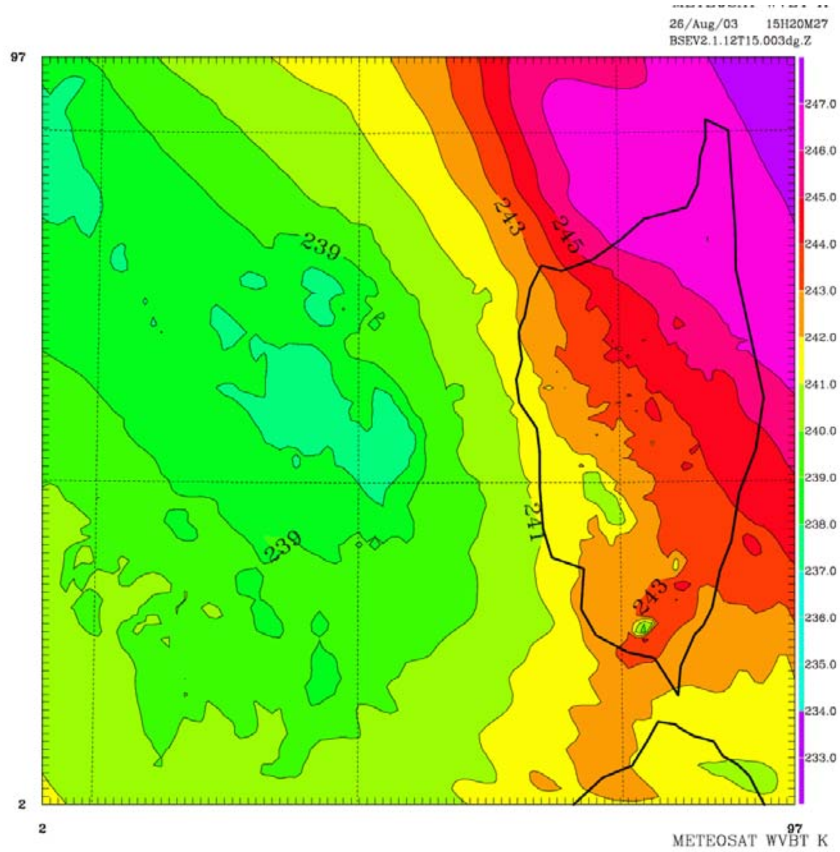
wind



sample 2.5km analysis impact on 6h forecast using full resolution MSG WV radiances

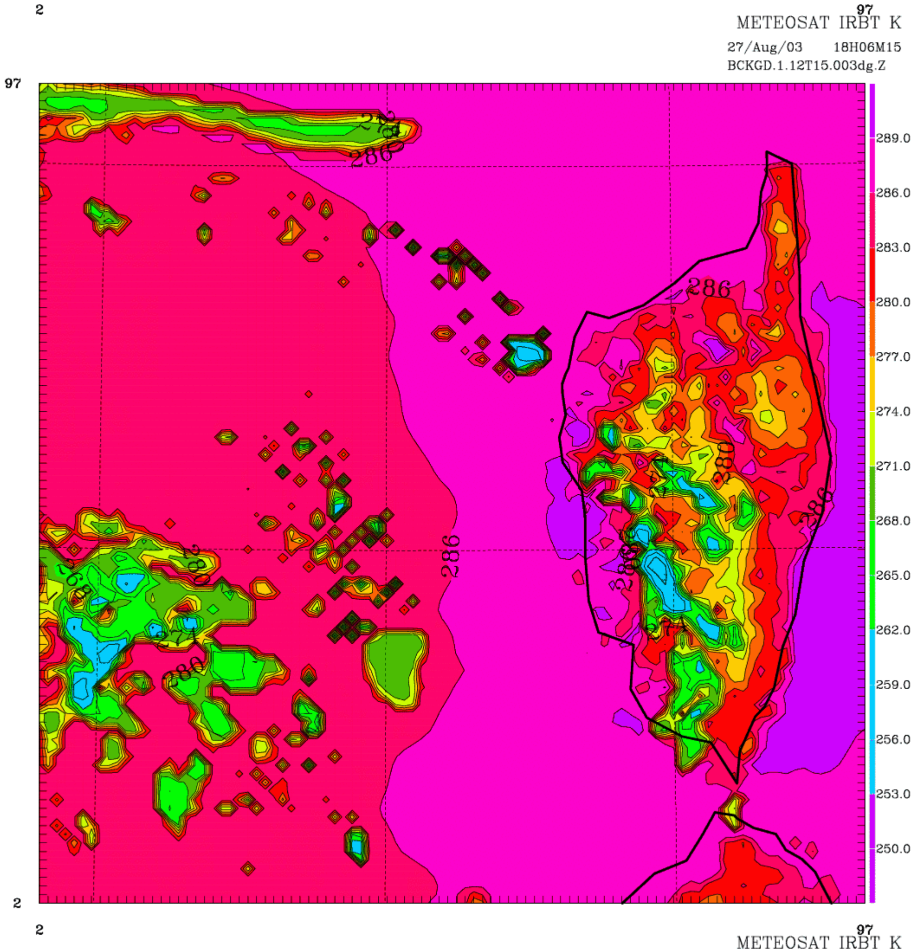
reference WV forecast **with analysis**



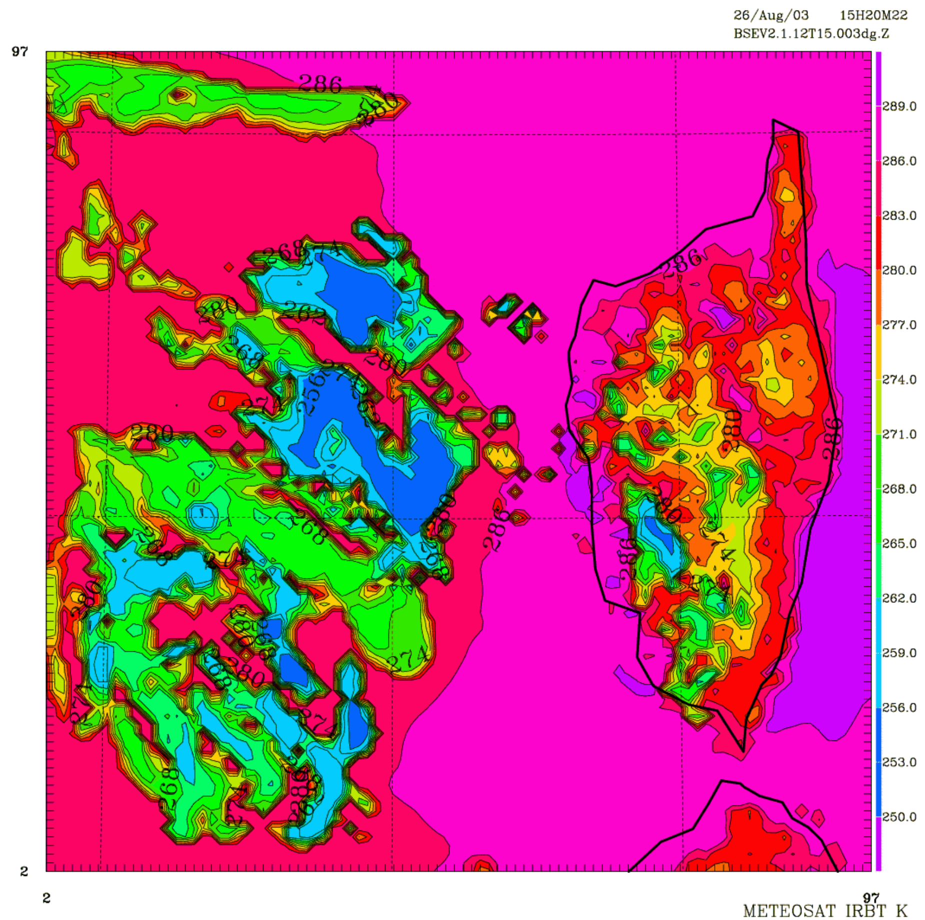


sample 2.5km analysis impact on 6h forecast using full resolution MSG WV radiances

reference IR forecast



with analysis



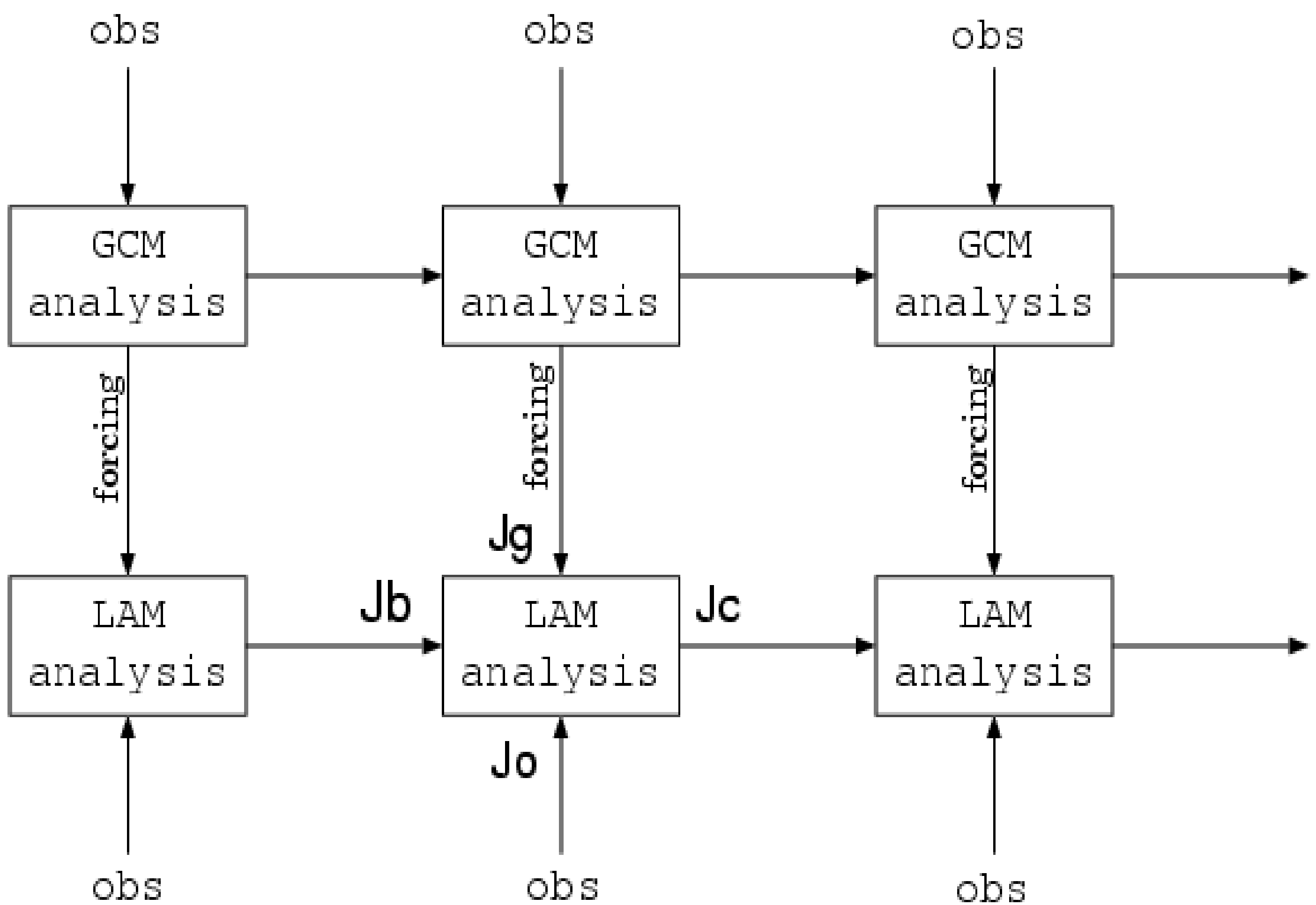
DATA ASSIMILATION ALGORITHMS (2)

- weak geostrophic balance: need to analyse all variables (wind, T, hum)
- new flow-dependent balance to invent: convective cells and stratified layers
- microphysical variables need not be analysed (timescale is about 30 min)...
- 'synchronisation' of LAM assimilation with global system using extra variational term
- ...but initializing them may help.

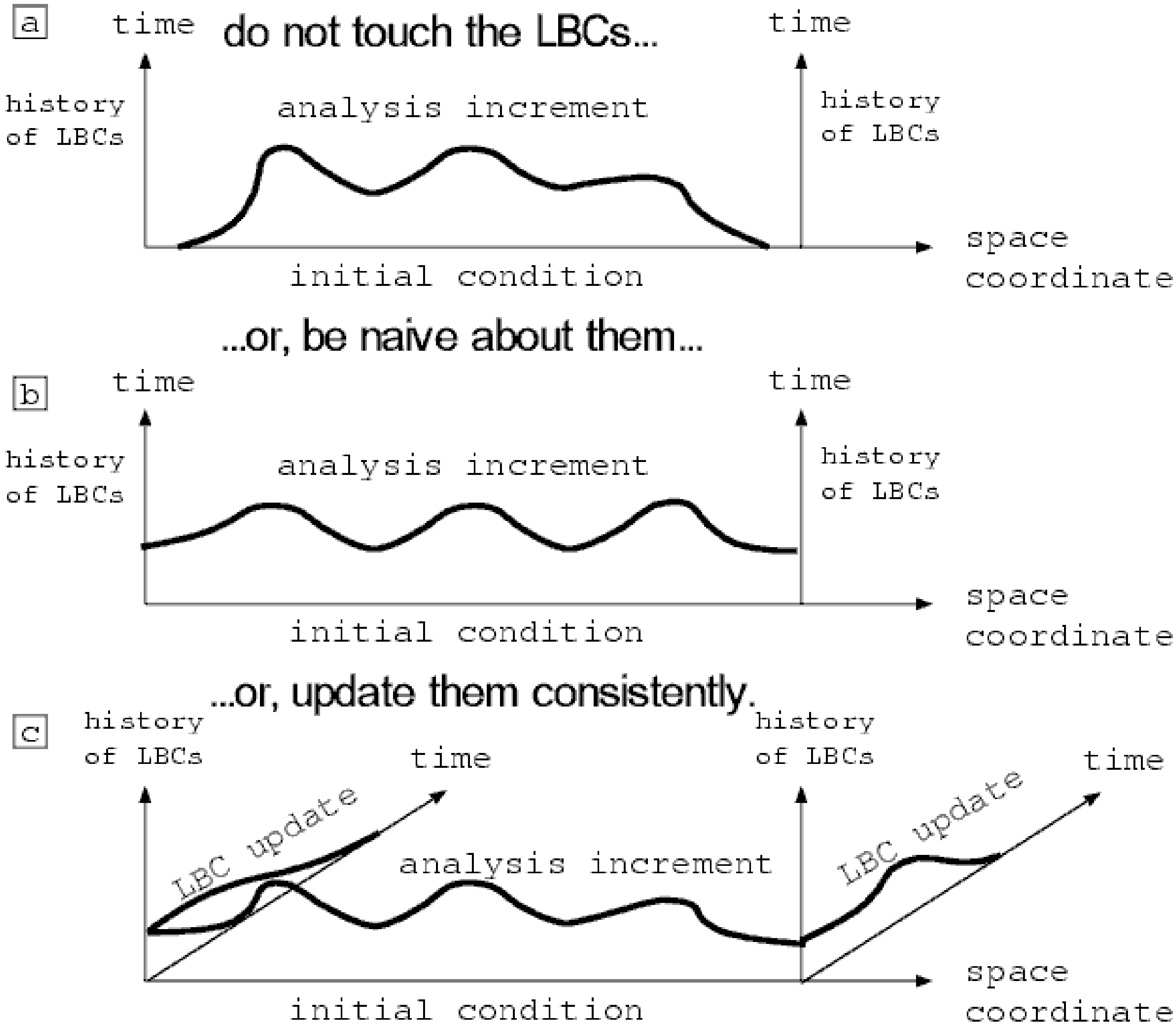
LARGE SCALE/MESOSCALE COUPLING: MODEL

- A LAM forecast is a mix of large-scale forcing and influence of initial state
- large-scale waves quickly cross any LAM domain
- internal LAM perturbations last for several days in a 3000km domain
- consequence 1: poor large-scale forcing will corrupt most LAM forecasts
- consequence 2: good large scales can be improved by a good LAM model and analysis.
- numerics of boundary coupling are still an unsolved problem
- need to force incoming waves and absorb outgoing waves
- update frequency consistent with the weather (hourly ?)
- scale-dependency in physics and orography = require relaxation zones

Global/local assimilation coupling



Three ways of handling lateral boundary analysis



COUPLING: DATA ASSIMILATION

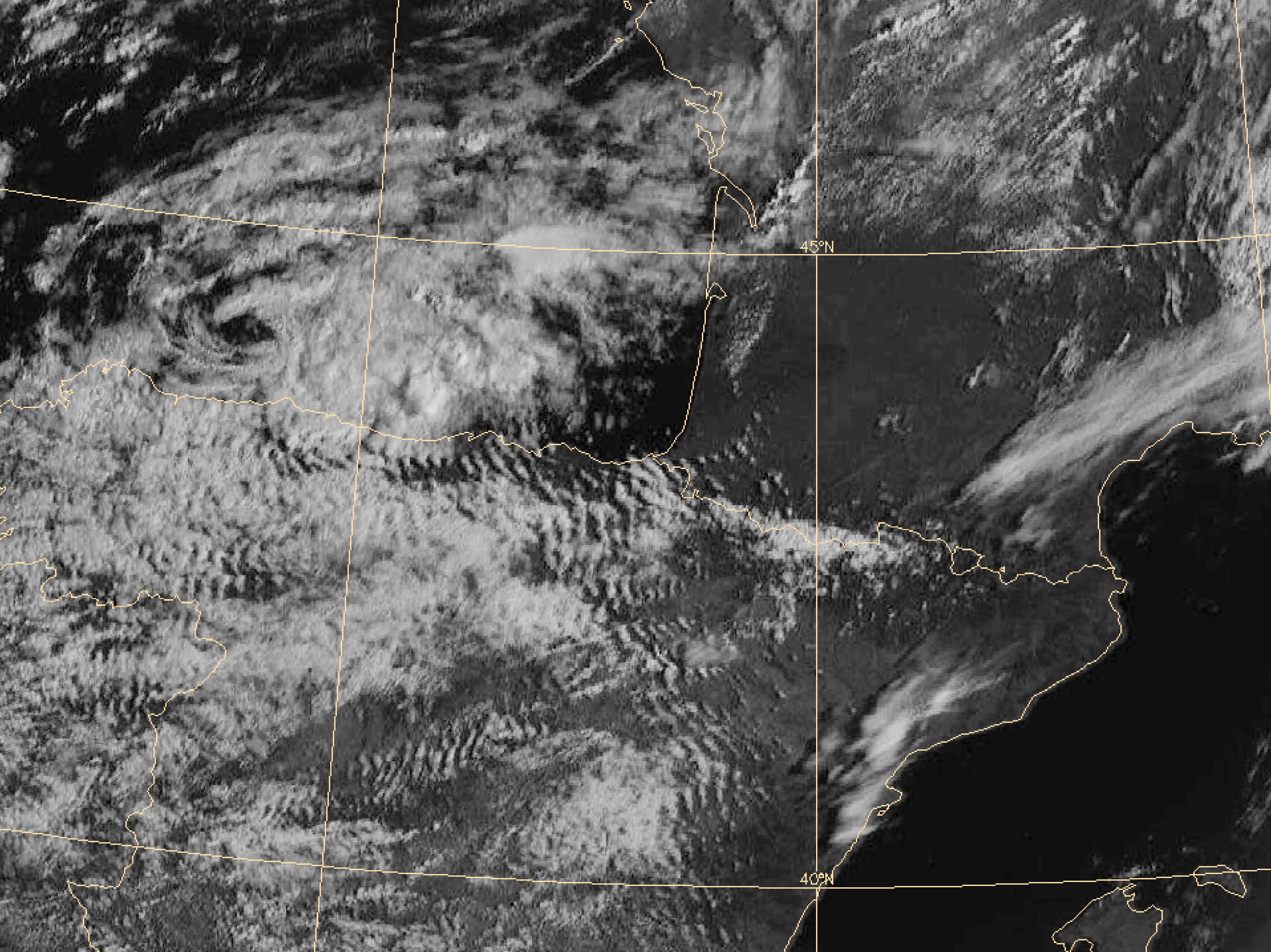
- 3 intertwined problems: model LBCs, analysis cutoff, analysis consistency.
- basic idea: medium scales should be driven by the global model
- mesoscale analysis only works on smaller scales
- problem: if the two systems have different observations/quality
- problem: scale separation is not always meaningful (fronts, rain bands, convective clusters).
- theoretical DA formulation requires working with distinct observations or scales.
- suggested approach: formulate coupling as variational term with scale selection and variable weight
- do not try to analyse the LAM boundaries (incompatible with smoothness constraint ?)
- multiple-catchup strategy in order to use valuable long-cutoff data

CONCLUSION 1: FUTURE TRENDS IN FINE-SCALE FORECASTING

- ever-increasing model resolution (a few metres on specific domains)
- 3D-effects (vertical slopes !)
- progress needed in microphysics, turbulence, radiation
- push for obs development: radars, lidars, automated stations, all-weather satellite data, lightning detection, obs targeting.
- use more image processing techniques (e.g. from nowcasting)
- quantitative precipitation forecasting and verification (extreme precip, total amounts, hydrometeor type)
- emphasis on precise event location and timing (fronts, showers, thunderstorms, fog)
- predictability issues as in synoptic meteorology, but on shorter ranges

CONCLUSION 2: TOWARDS INTEGRATED NWP FACILITIES

- User demand for real-time fine-scale environmental information:
- meteorology, pollution, flooding, fire, avalanches...
- Requires a modular approach with specialist coupled models a la GMES:
- land/city/snow, fast/slow hydrology, superficial ocean/cryosphere,
- chemicals/aerosols, fire, visibility...
- Problems: software maintenance, system validation, multiplication of data sources and agencies.
- Key tools: data fusion, model intercomparison and probabilistic validation.
- Quality approach: need to quantify all relevant aspects of the model performance.


45°N
40°N