High Resolution
Hirlam
Limited Area Model

Development of fine-scale NWP models

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Outline

- Needs for high-resolution modelling
- Mesoscale aspects, open issues and challenges:
  - Dynamics
  - Physical parametrizations
  - Boundaries
  - Data assimilation and use of observations
  - Initialization
  - Surface aspects
  - Validation and verification
- Status of mesoscale modelling within Europe and elsewhere

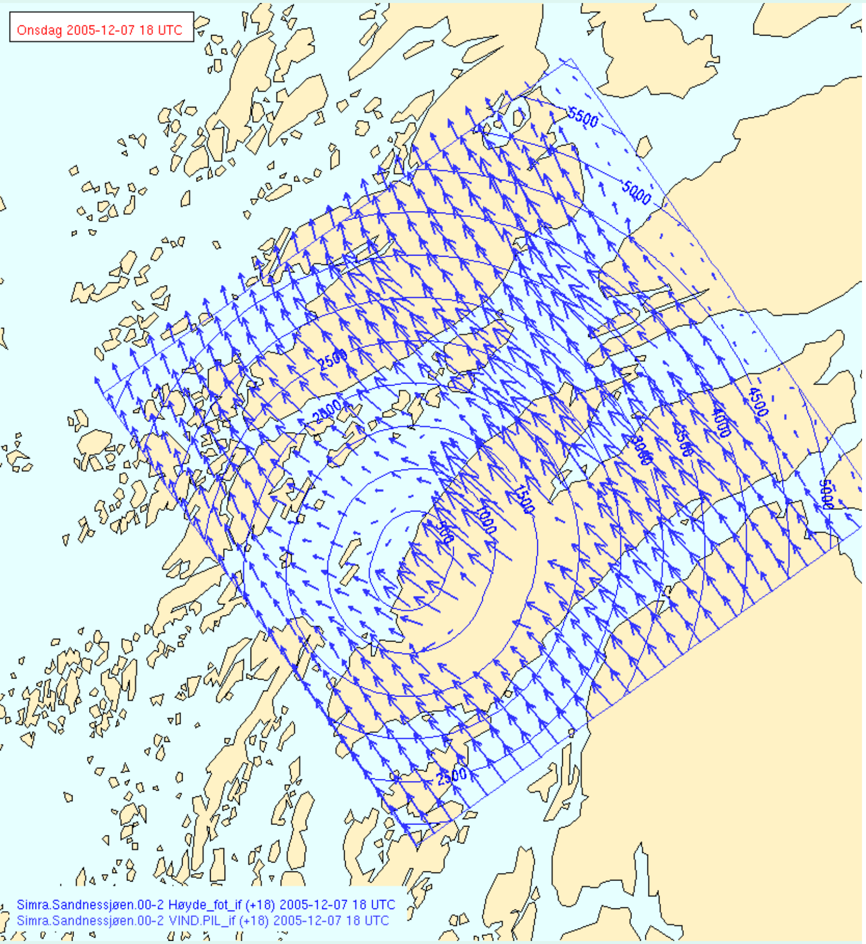
Needs for mesoscale modelling (1)

Accurate description of small scale weather systems:

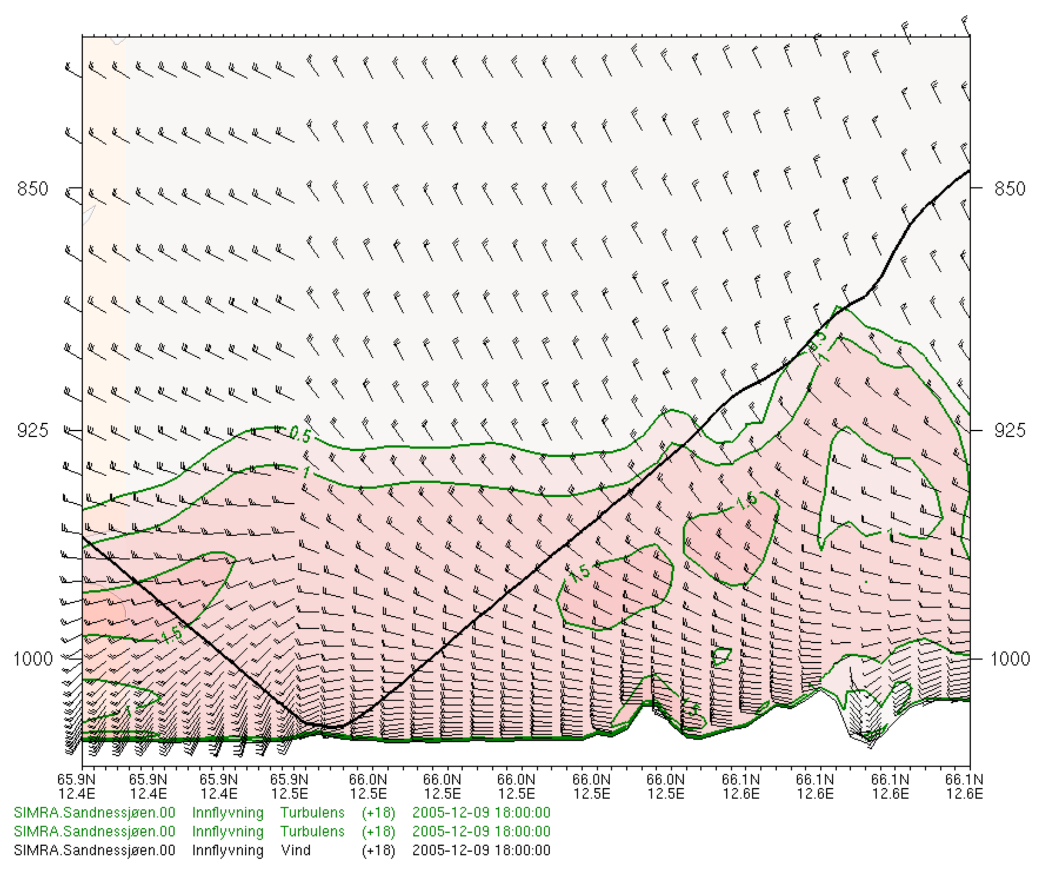
- Onset and development of severe convection, MCS
- Fog
- Severe precipitation, flash floods
- Wind, turbulence and precipitation in presence of steep topography

Needs for mesoscale modelling (2)

Weather which is strongly orographically driven:



Simra.Sandnessjøen.00-2 Høyde_fot_if (+18) 2005-12-07 18 UTC
Simra.Sandnessjøen.00-2 VIND.PIL_if (+18) 2005-12-07 18 UTC



SIMRA.Sandnessjøen.00 Innflyvning Turbulens (+18) 2005-12-09 18:00:00
SIMRA.Sandnessjøen.00 Innflyvning Turbulens (+18) 2005-12-09 18:00:00
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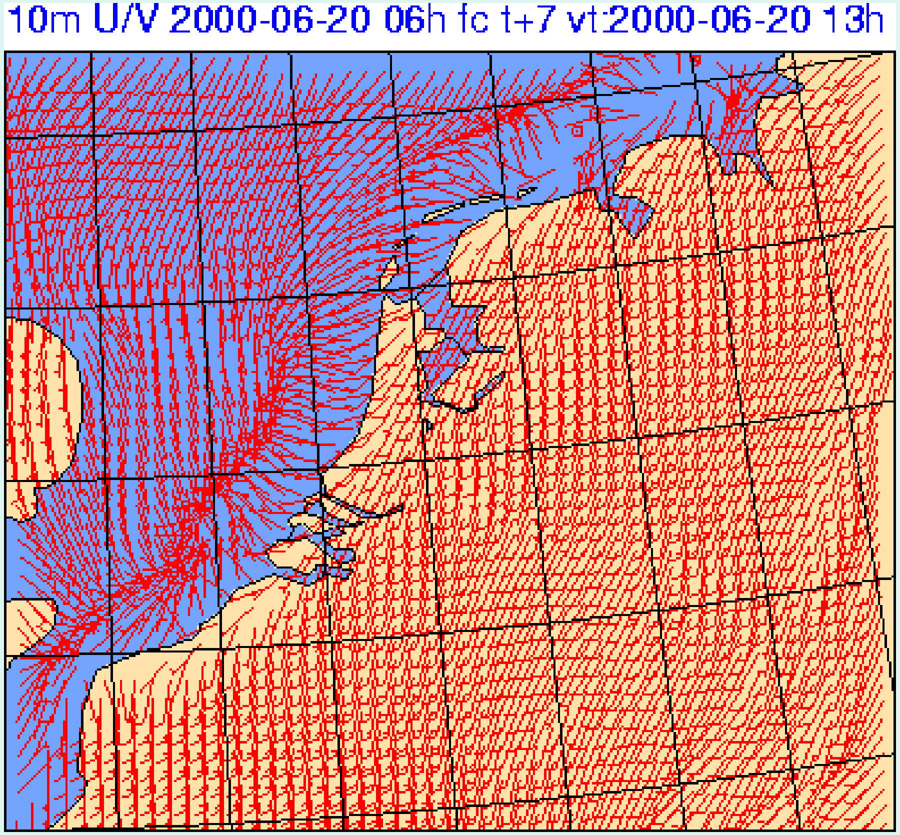
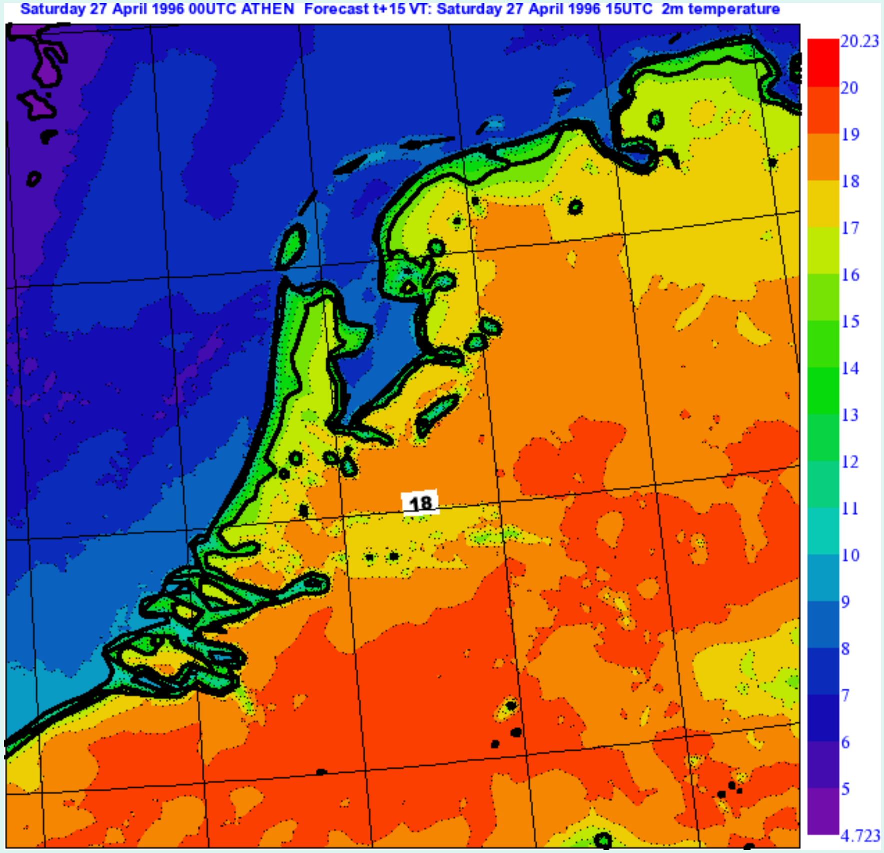
Needs for mesoscale modelling (2)

Weather which is strongly orographically driven:

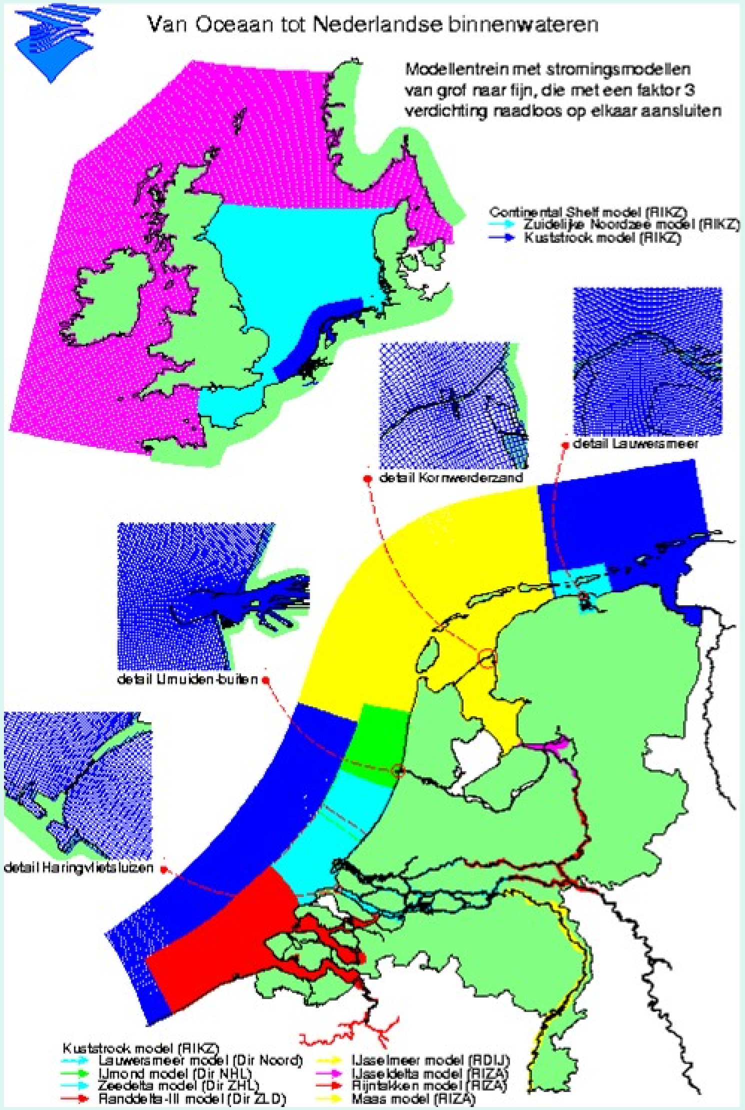




Needs for mesoscale modelling (3)

Users with need for high spatial and temporal detail:

- Aviation
- Hydrology, water management
- Wind energy
- Air quality forecasting
- …



A new type of forecast model

- At resolutions <= 10km, the hydrostatic assumption in NWP models breaks down
- At resolutions around 2 km still well above fully cloud-resolving (LES) scales
- How to deal with the “grey zone”?

➔go to fully compressible anelastic equations, or an approximation of them?

➔Still a mix of explicit physics (convection) and parametrizations; but what mix?

Dynamics formulations

Several flavours of non-hydrostatic model equations in use:

- fully compressible anelastic equations (most models) or an approximation (Tartu SISL scheme)
- deep or shallow atmosphere
- gridpoint (MetOffice, COSMO) or spectral (ALADIN/AROME)
- Vertical coordinate terrain-following (MetOffice), sigma (COSMO), Laprise (ALADIN)

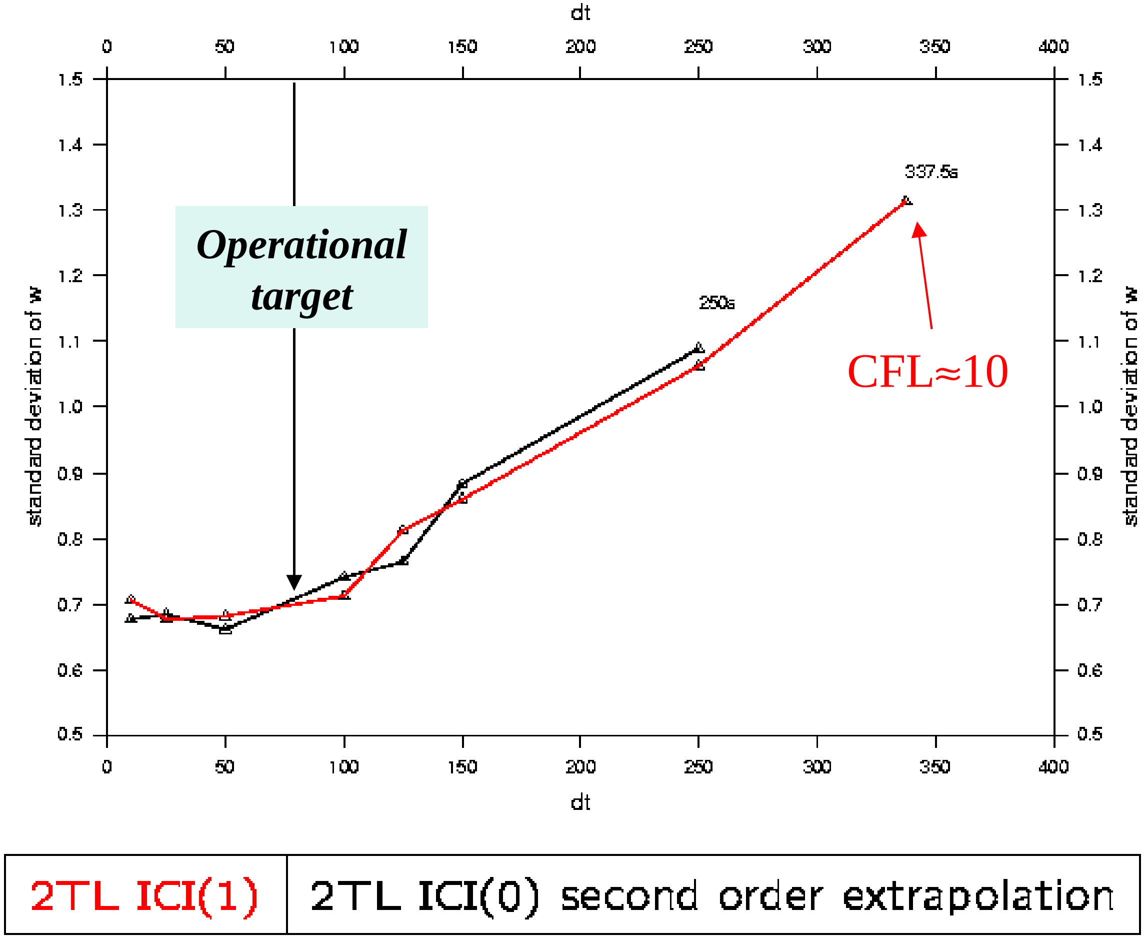
Need to be accurate and FAST!

➔ Most models semi-implicit semi-Lagrangian rather than Eulerian

ALADIN spectral SL dynamics: a ‘world record’!

ICI scheme robustness - ALPIA 3D idealized case

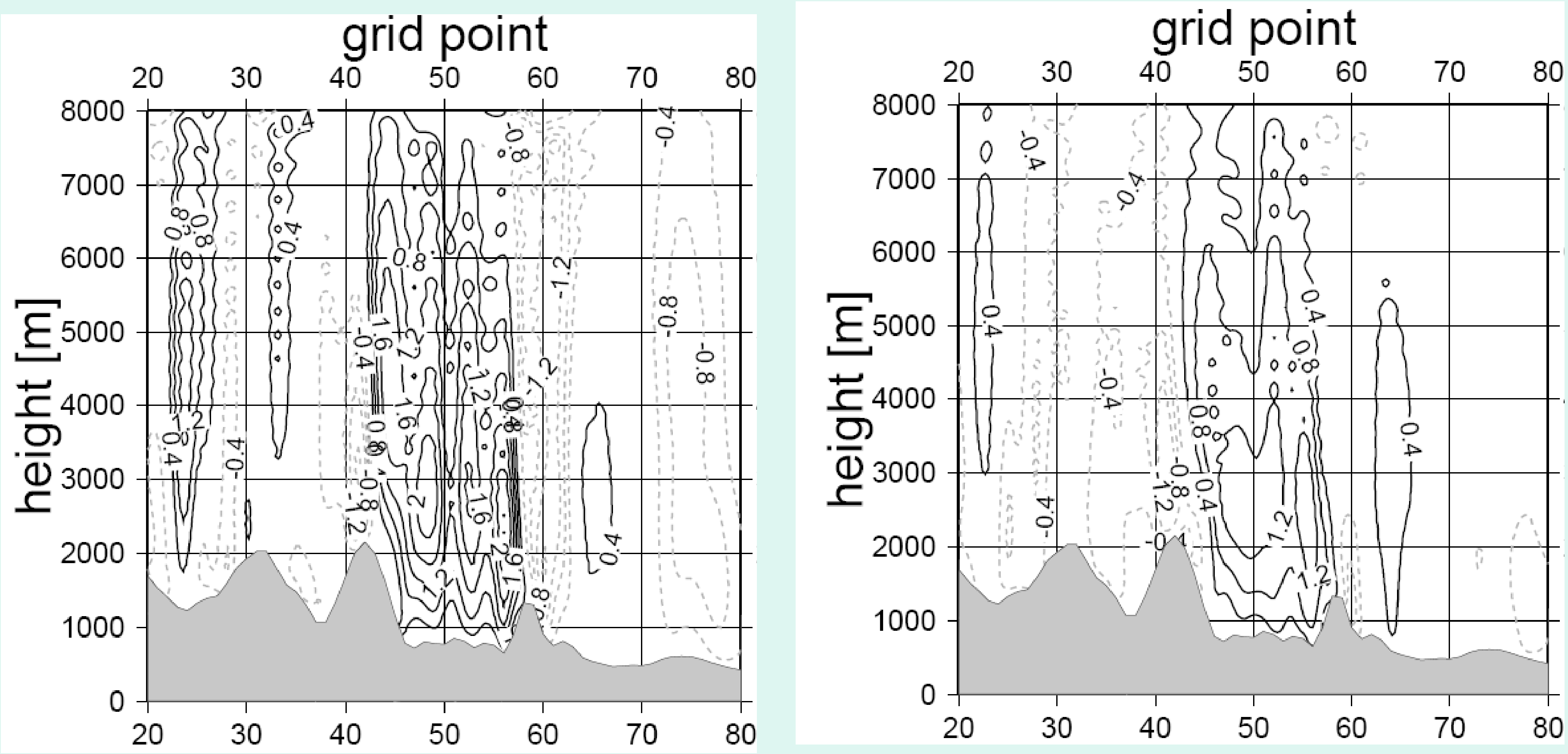
Stdev of w comparing to REF Eulerian experiment with $\Delta t = 10s$.



Operational target

CFL≈10

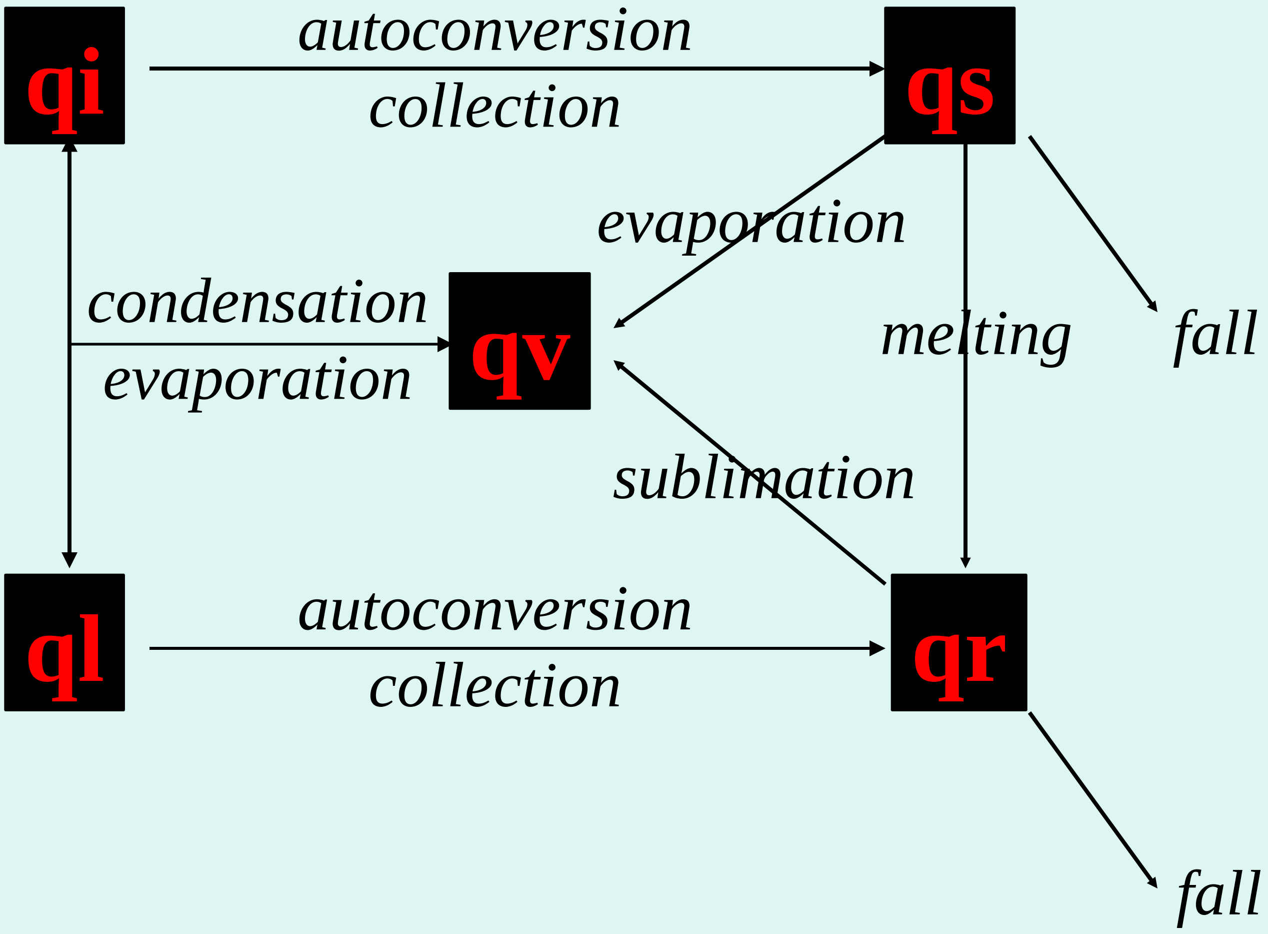
Accuracy testing for mountain lee wave situations: Example of a strong baroclinic zone case



North-South vertical cross-section; **Alpian region, x=2.5km**;
vertical velocity ***w***. Left: hydrostatic simulation, right: non-hydrostatic one.

Physics

- Convection and clouds:
  - Partly parametrize convection, or treat deep convection explicitly? Where does the “grey zone” end? More realistic cloud model / microphysics needed (with more prognostic components).
- Turbulence:
  - 1D or 3D?
  - (Moist) TKE
- Gravity wave drag, influence of orography on e.g. radiation
- How sophisticated do radiation and microphysics schemes need to be? Tradeoff between accuracy and computational requirements.
- Surface description more and more important



qi

autoconversion

collection

qs

evaporation

condensation

qv

melting

fall

evaporation

sublimation

ql

autoconversion

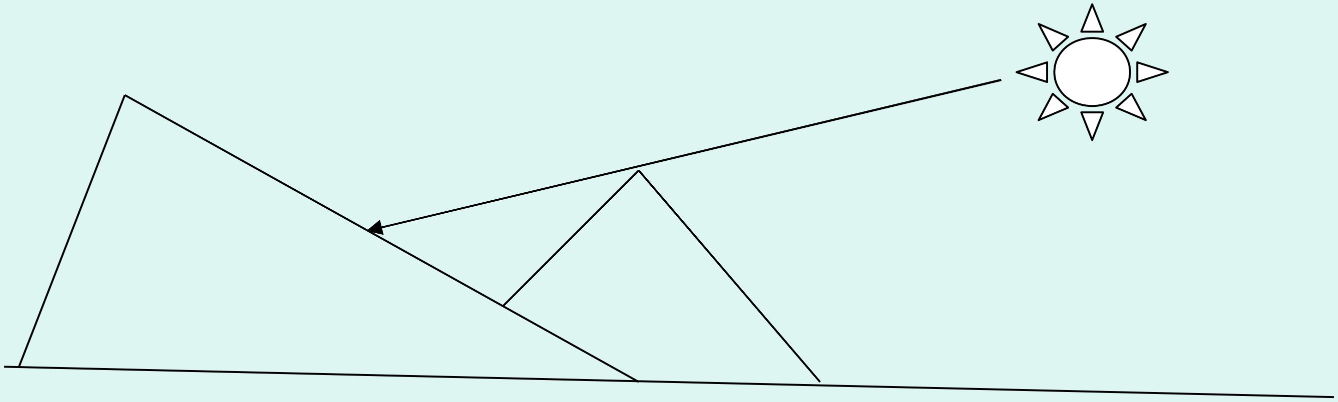
collection

qr

fall

Effects of orography on radiation:

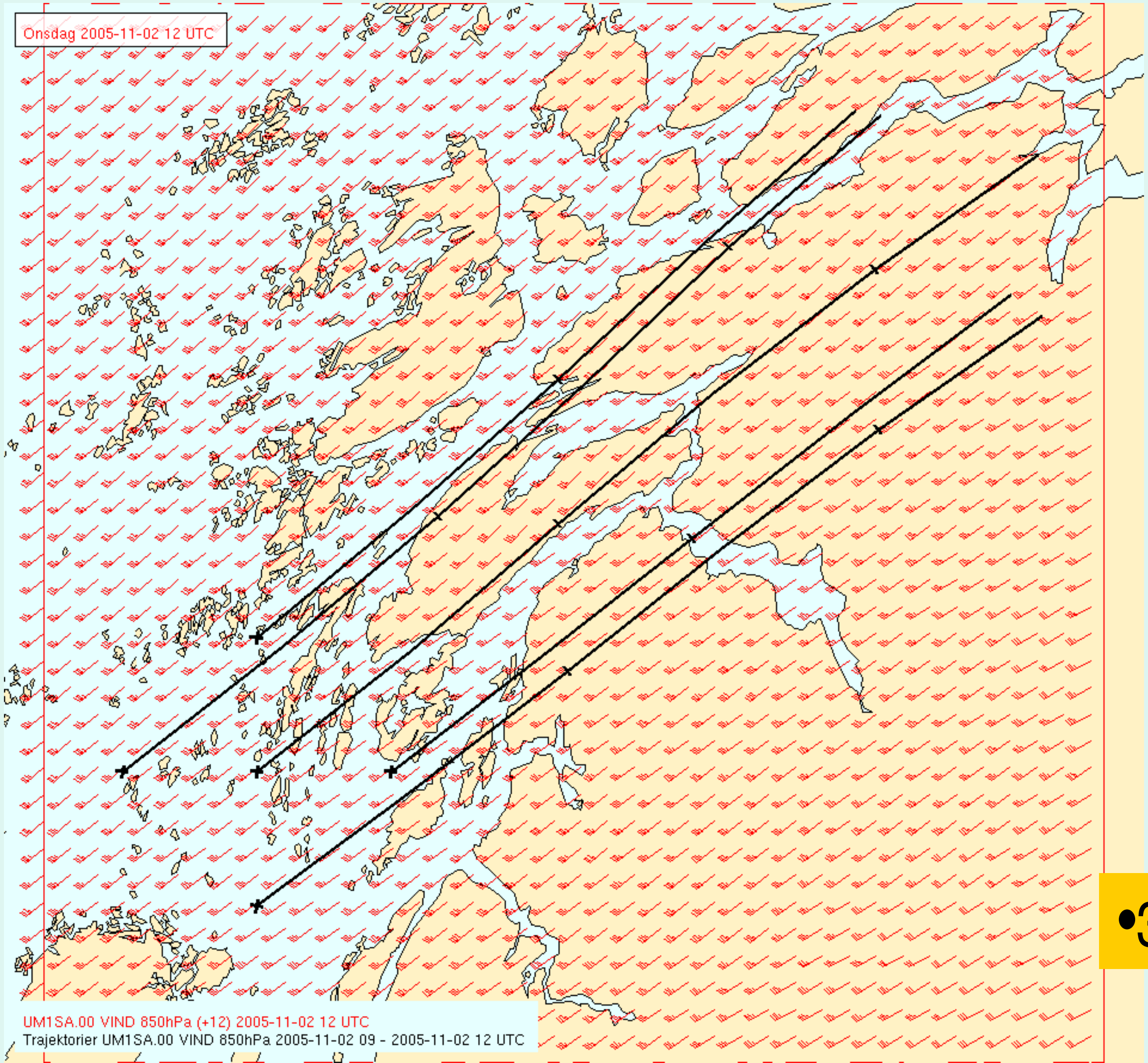
- Slope orientation: Incidence of direct radiation on slope
- Shadowing of areas by adjacent terrain
- Restricted visibility of sky (indirect radiation) due to surrounding terrain



Lateral boundaries

- Optimization of domain size: big or small?
- How to treat boundaries? Size of relaxation zone? LBC formulation transparent (i.e. not reflecting, or changing amplitude or phase of, incoming of outgoing sound/gravity waves) or not?
- If transparent LBC are needed, then
  - For grid point formulations: method of McDonald (2005,2006)
  - how to do this in a spectral model?
- How important is it to let outer model be the same as, or close to, the inner model?

The ”lifetime” of LBCs in a small grid



- 30min intervals

Mesoscale data assimilation

- Useful or not?
  - Forecast range between limitations on domain size and spinup problems
  - Are sufficient high-resolution observations available to initialize the model with?
  - What types of information does a mesoscale model need? Do we have that type of observations available?
  - How to optimize the use that a model analysis can make of the observations with which it is fed? Consequences for e.g. analysis of moisture? For structure functions? For surface analysis?
  - How to optimize a mesoscale observation system for Europe? A EUCOS design study on the mesoscale?

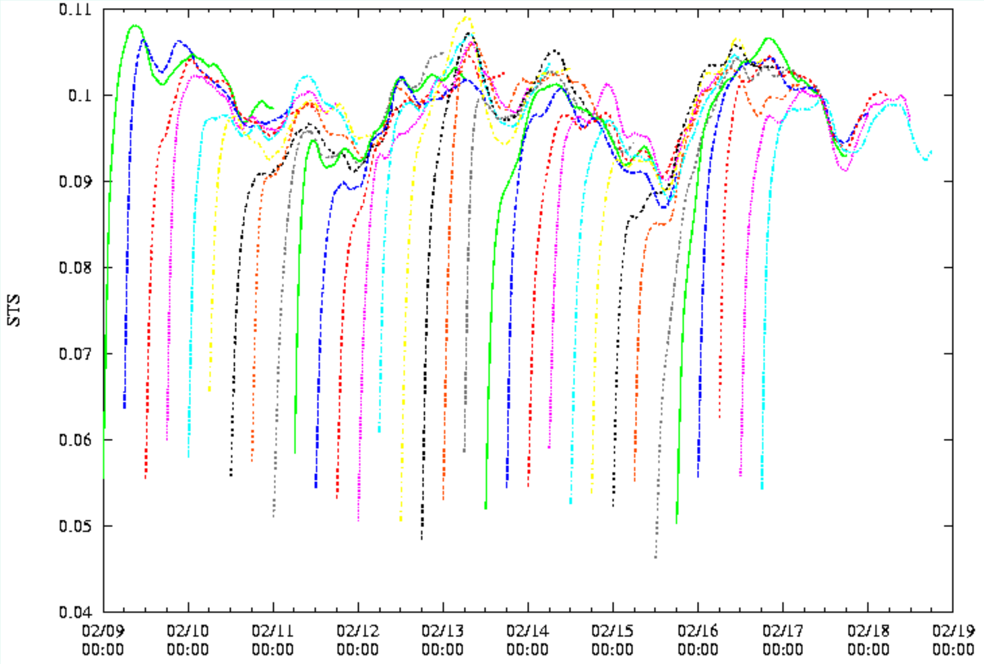
Data assimilation

- Choices of method: nudging, 3D-VAR /FGAT, 4D-VAR, (ensemble) KF, …?
- Assimilate radar precip/winds, GPS ZTD, high res satellite images and profiles, surface??? Reflectivities/radiances or retrievals?
- Nowcasting: a choice between rapid update cycling versus accurate assimilation?
- Structure functions and scales representative for mesoscale?
- Blending of scales? Assimilate twice?

Initialization

- Needed to remove high-resolution noise introduced by assimilation
- Presently used method: Digital Filtering Initialization
- Some residual imbalance: spin-up
- Points of attention for mesoscale:
  - how to distinguish signal from noise?
  - Possible to reduce spin-up times further to improve performance for nowcasting?

Spinup effects



Effect of DFI mechanism of backward – forward adiabatic – diabatic integration: systematic errors in first few hours, particularly severe on moisture.

Can be alleviated by some changes in DFI.

Surface model and analysis

- Model:
  - Usually 2-4 layer models, force-restore or diffusion, tiling approach
  - Complexity increasing: Land-sea and orography, vegetation characteristics, snow, lakes, urban characteristics, … More accurate but also much more vulnerable, sensitive to tuning
  - How to make optimum use of tiling information? How to validate it?

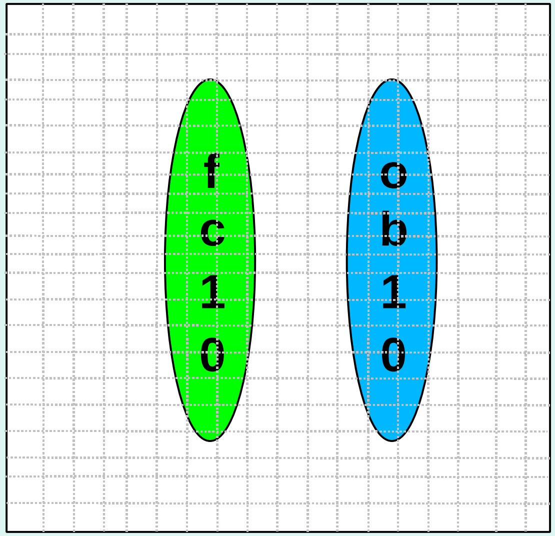
- Analysis:
  - Usually simple method: OI. Replace by more sophisticated 2D-VAR (ELDAS schemes)?
  - Sea surface essential to get correct, also snow.
  - Land surface analysis often used/tuned to optimize T2m, RH2m rather than soil properties. Need to analyze “true” soil characteristics? If so, then what types of observations to assimilate? Use e.g. LAI directly?

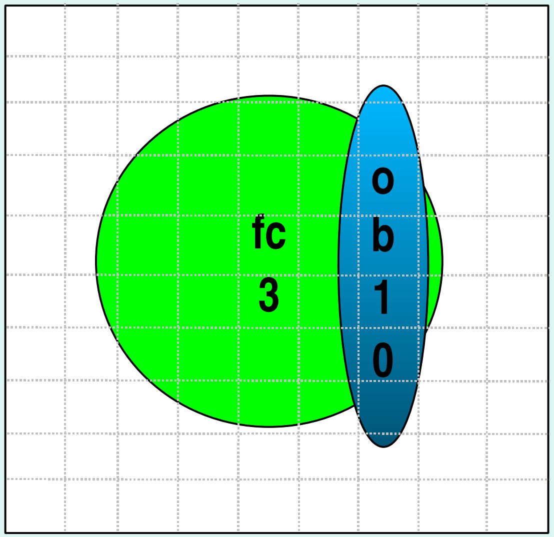
Validation and verification

- It looks realistic, but is it real?
  - The double penalty problem
  - For inherently stochastic processes: deterministic model is but a single “draw” from a probability distribution.
- Verify patterns, phase errors, peak intensities? Or verify probabilities?
- Against which high-resolution, representative observations?
- Some quantities less easily directly verifiable than others (e.g. cloud properties)

Double penalty: event predicted where it did not occur

no event predicted where it did occur





High resolution forecast

RMS ~ 4.58

POD = 0, FAR = 1, TS = 0

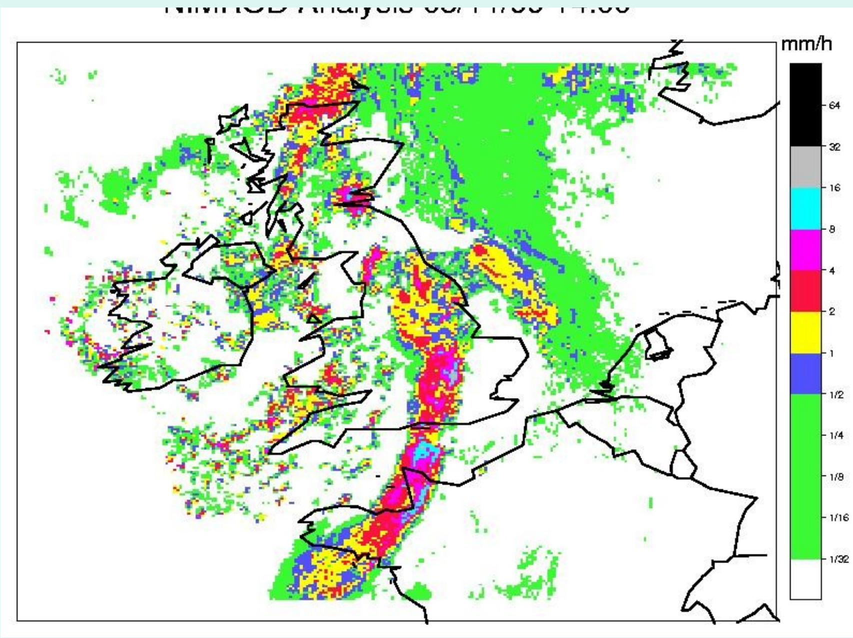
Low resolution forecast

RMS ~ 2.5

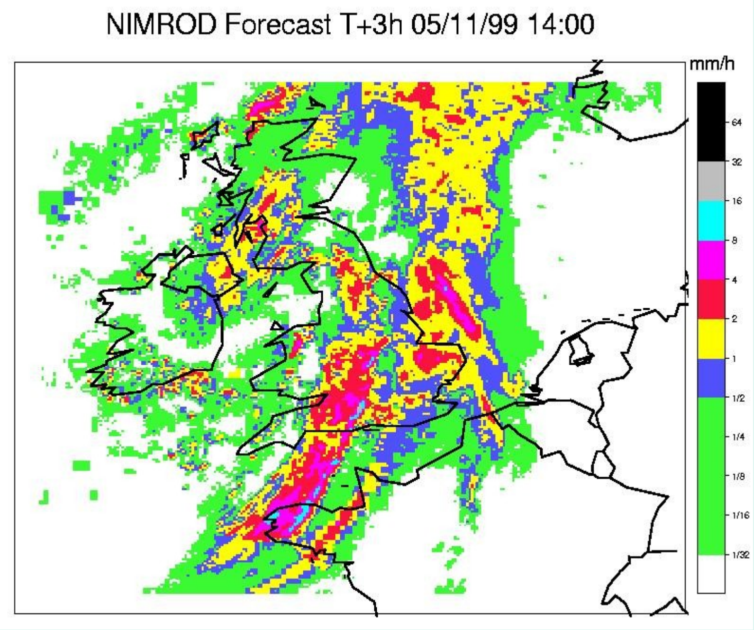
POD ~0,8, FAR ~0.7, TS ~0.27

It looks realistic, but is it real?

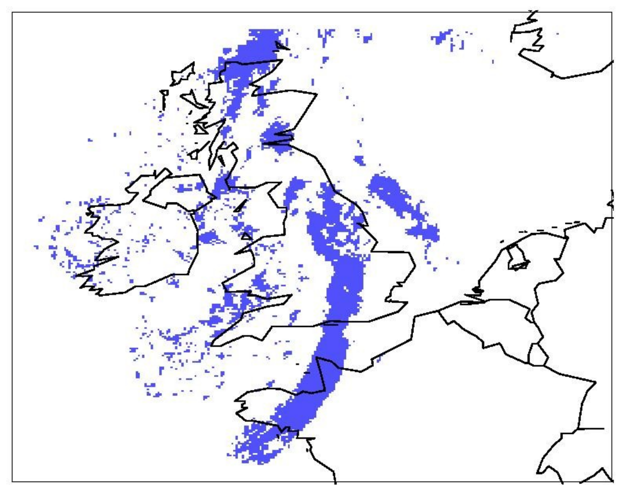
Radar



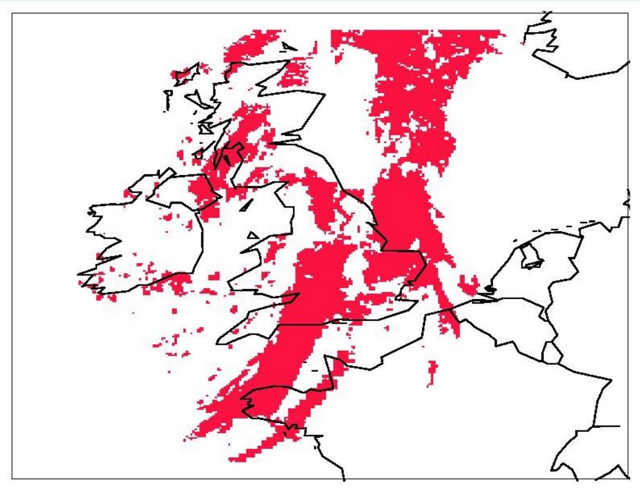
Model forecast



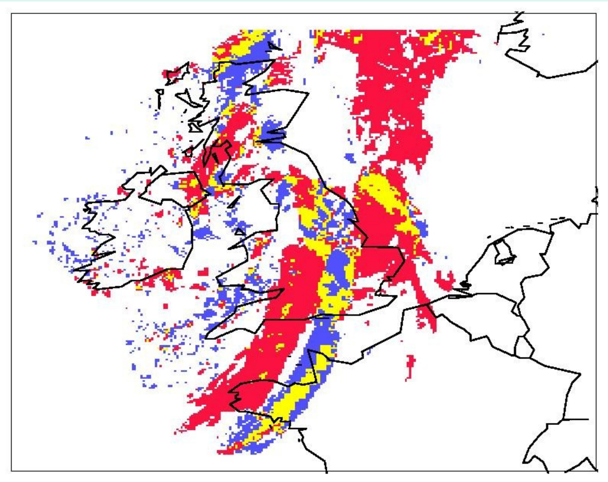
Radar > 1 mm



Forecast > 1 mm



Binary error image



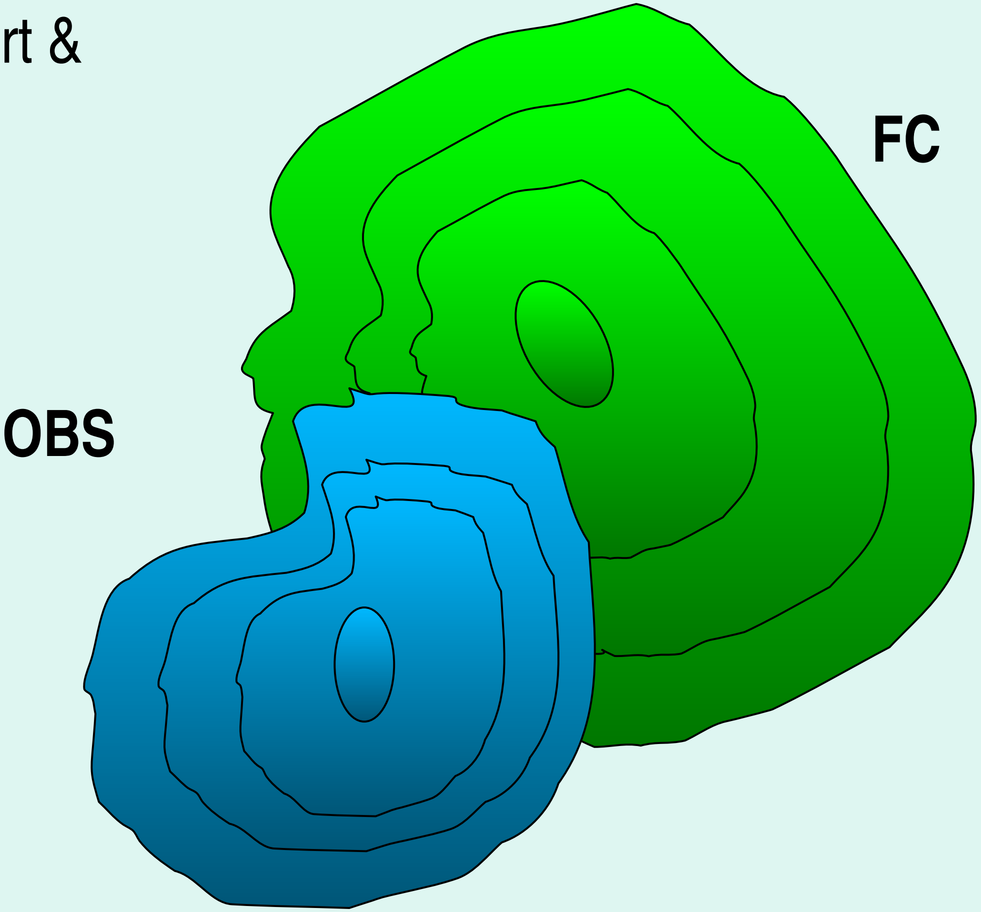
from Casati (2004)

General findings:

- Mesoscale models contain much more detail than their coarser counterparts (even when averaged to coarser grids)
- Spatial analyses show that this detail (although it looks realistic) does not necessarily imply accuracy: raw model output needs to be averaged (upscaling)
- To make such deterministic forecasts useful, apply either pattern recognition techniques (e.g. Ebert & McBride) and upscaling, or use postprocessing to make probabilistic forecasts.
- For verification of mesoscale models, the use of both deterministic and probabilistic techniques is strongly recommended (SRNWP Verification workshop, May 2006)

Error decomposition for features (Ebert & McBride):

- -Displacement
- -Intensity
- -Size/volume



$$MSE_{tot} = \frac{1}{N}\sum_{i=1}^{N}(f_i - o_i)^2$$

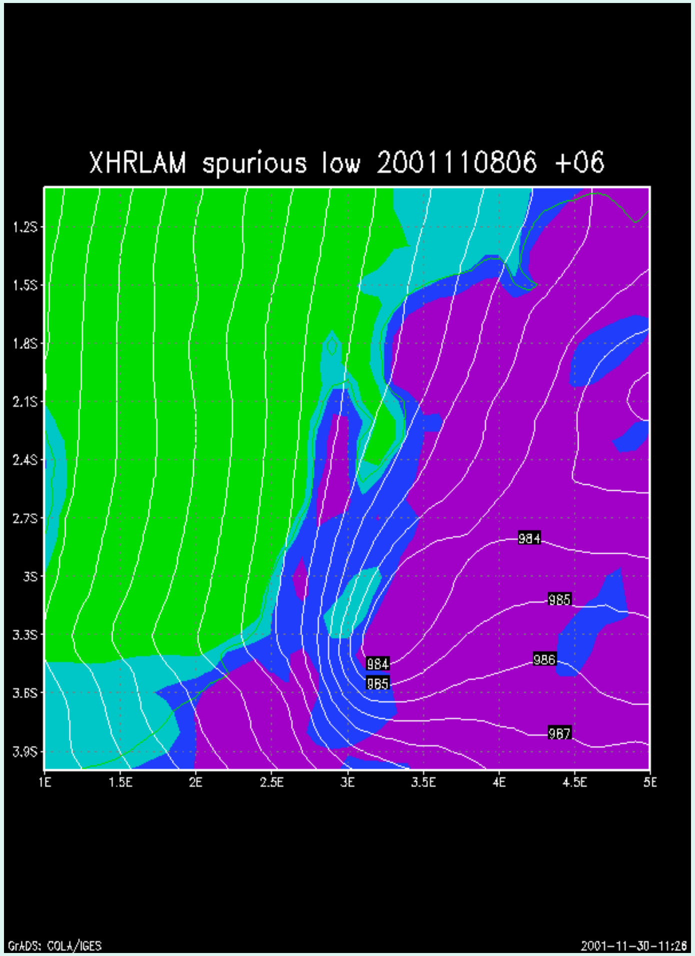
$$MSE_{tot} = MSE_{displ} + MSE_{vol} + MSE_{pat}$$

position wrong

volume / intensity

Probabilistic interpretation:

A mesoscale NWP forecast is a single realization of multiple possibilities. It is important to realize which mesoscale phenoma are predictable in a deterministic sense.



Predictability

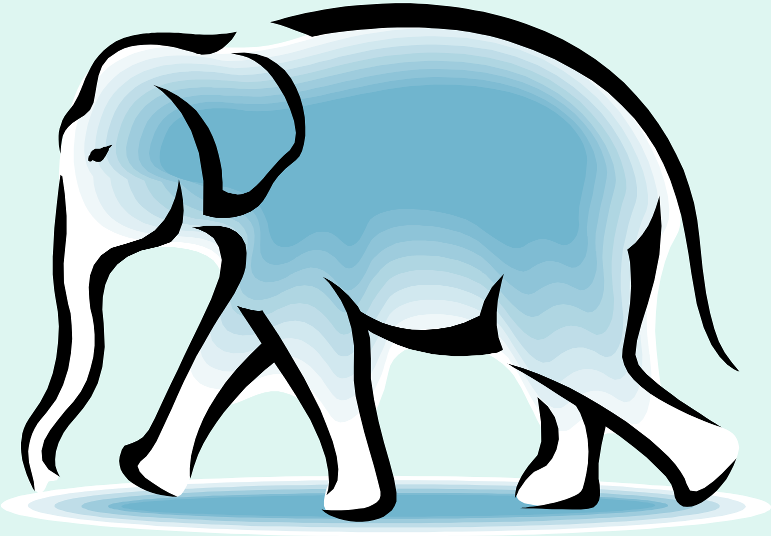
Small scale processes such as turbulence, triggering of convection are inherently stochastic

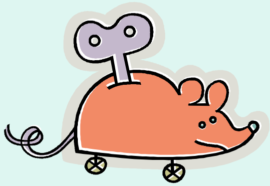
→complement deterministic model with probabilistic approach for

- Analysis: combine DA and EPS techniques?
- Forecast model: variations in physics?
- Validation and verification: preferably non-deterministic, in terms of probabilities?

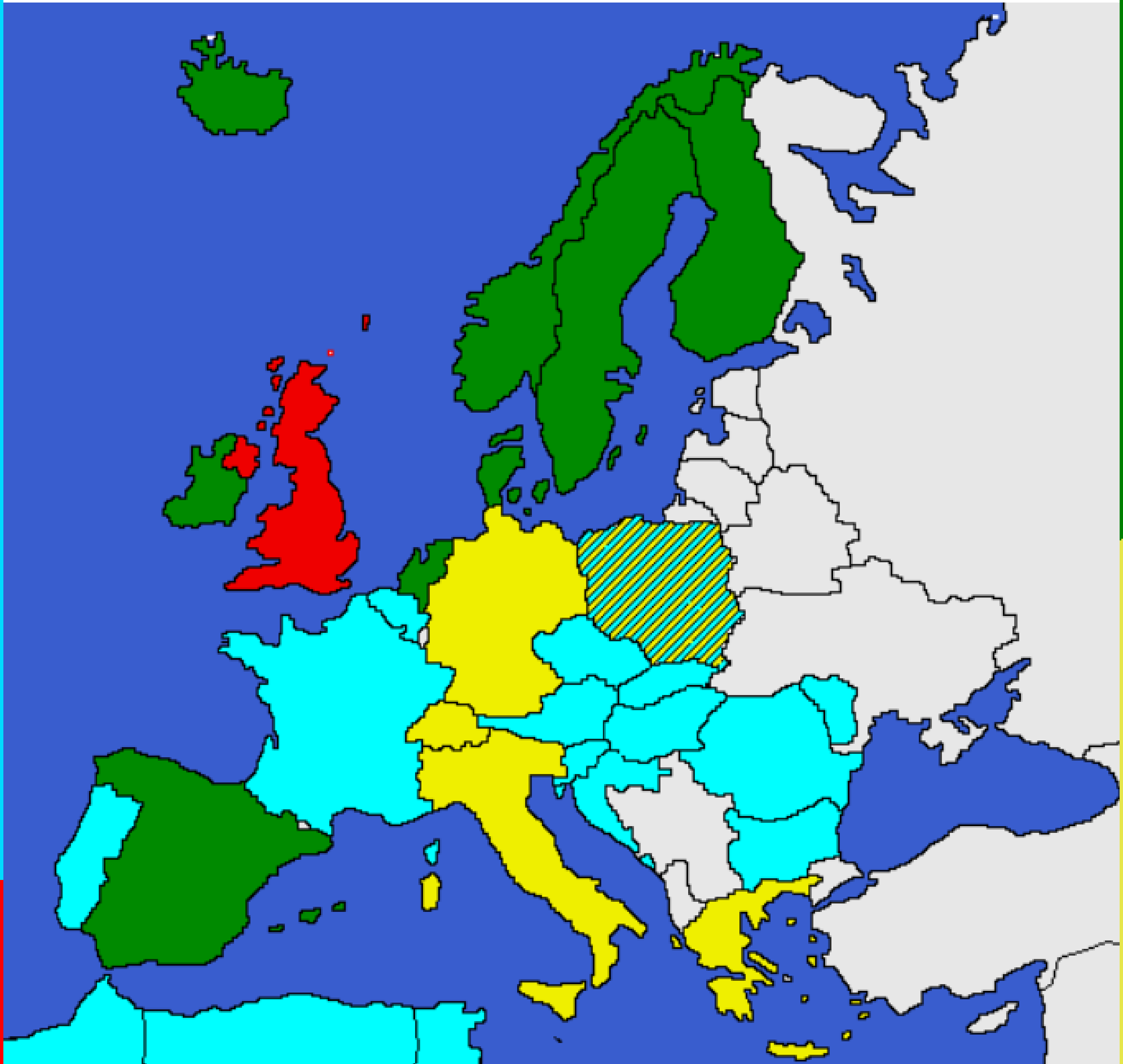
?

NWP in Europe:





SRNWP Consortia in Europe



ALADIN

Algeria
Austria
Belgium
Bulgaria
Croatia
zech Rep.
France
Hungary
Moldova
Morocco
Poland
Portugal
Romania
Slovakia
Slovenia
Tunisia

UKMO

United
Kingdom

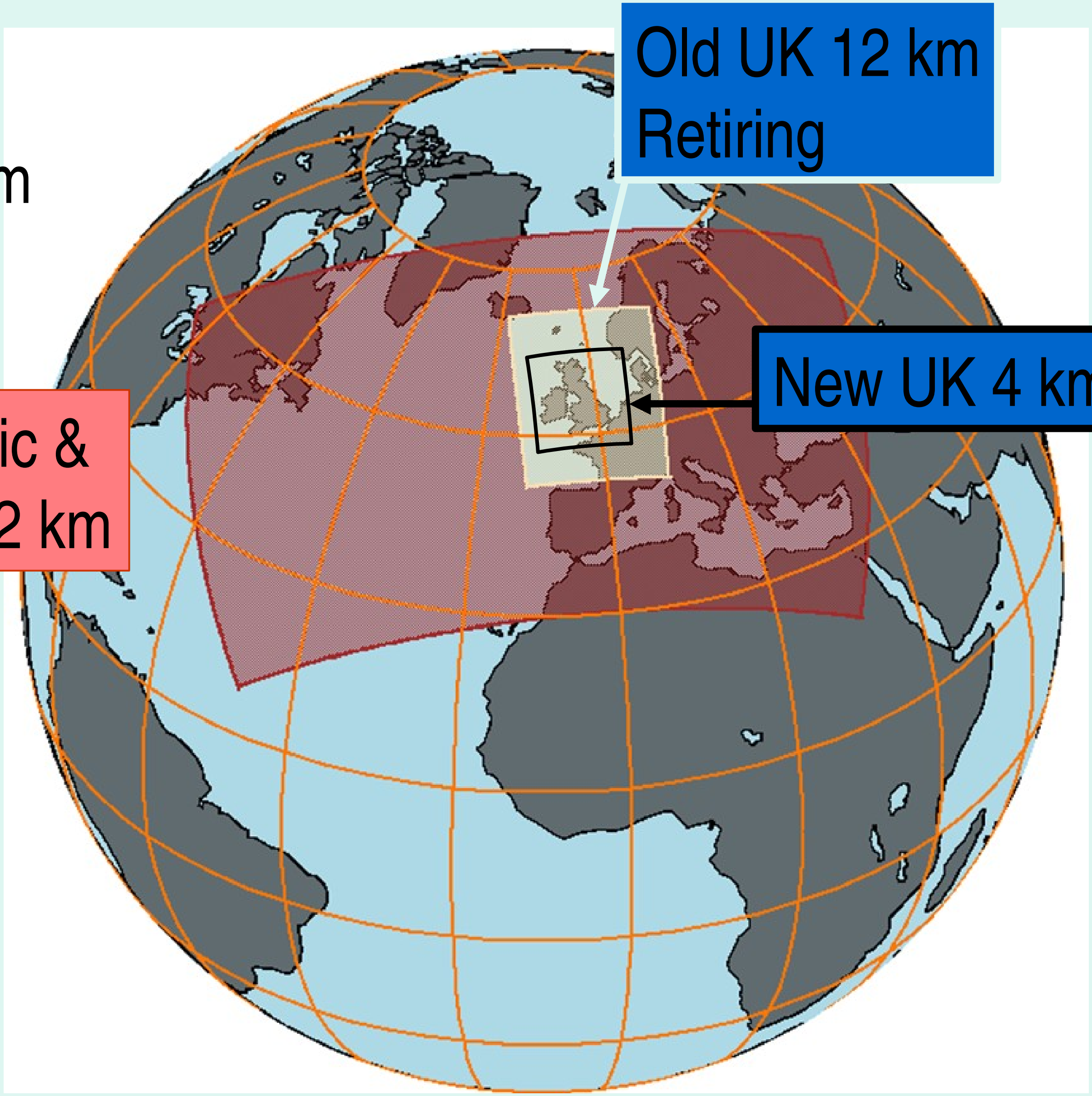
HIRLAN

Denmar
Finland
Iceland
Ireland
Netherlan
Norway
Spain
Sweden

COSMO

Germany
Greece
Italy
Poland
Switzerla

UM Configurations



Global 40 km

Old UK 12 km
Retiring

North Atlantic &
European 12 km

New UK 4 km

Unified Model at 4 km and 1 km resolution

- Non-hydrostatic, compressible, semi-Lagrangian, semi-implicit dynamics. Arakawa C horizontal rotated lat/long, Charney Philips vertical flexible terrain following height based.

- Main physics developments are microphysics and (3D) turbulence. Pragmatic fudges to convection for 4km, no convection parametrization at 1km

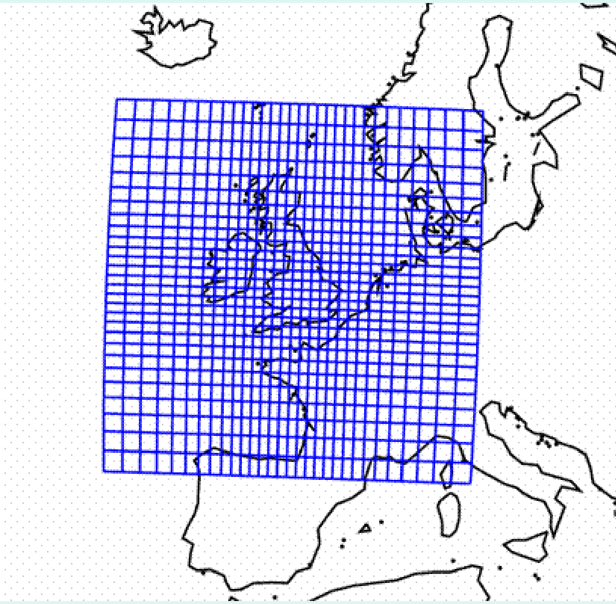
- Additional surface developments:
  - Enhanced urban scheme
  - Surface slope effects in radiation

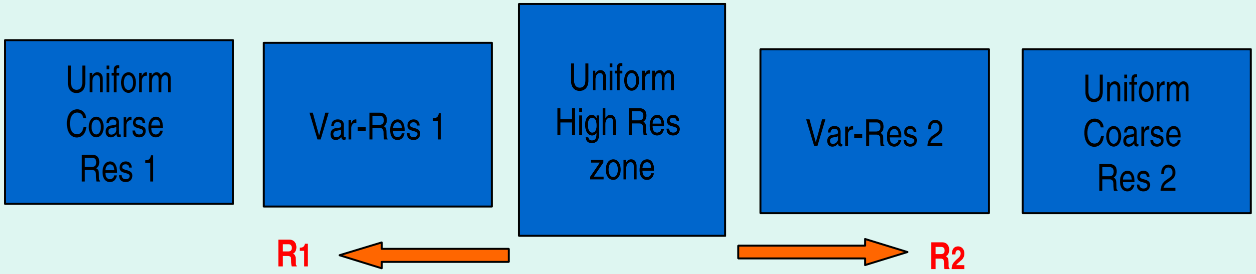
Model Physics

	12 km/L38	**4 km/L38**	**1 km/L76**
Convection Scheme	Full Gregory-Rowntree	Gregory-Rowntree with restricted mass flux	None
Microphysics	Prognostic ice	Prognostic ice and rain	Prognostic ice, rain. ice+graupel under test.
Surface	9 Tile MOSES	9 Tile MOSES	9 Tile MOSES
Diffusion	Del 4 theta + Targeted moisture	Del 4 theta +Targeted moisture	Del 4 To be replaced by 3D turbulence.
Boundary Layer / Turbulence	Standard 1D (Smagorinsky-Lilly eddy diffusivity)	Standard 1D	Standard 1D (3D Local likely)

Variable Resolution

- An alternative approach to 1-way nesting.
- Grid varies from coarse resolution at the outer boundaries smoothly to a uniform fine resolution in the interior of the domain
- Benefits close to hires domain boundary, e.g. reduces spin-up of convection at inflow boundaries





Typically, there are 3 regions, and ***inflation ratio R1 = R2 = 5~10%***

COSMO: DWD mesoscale model LMK

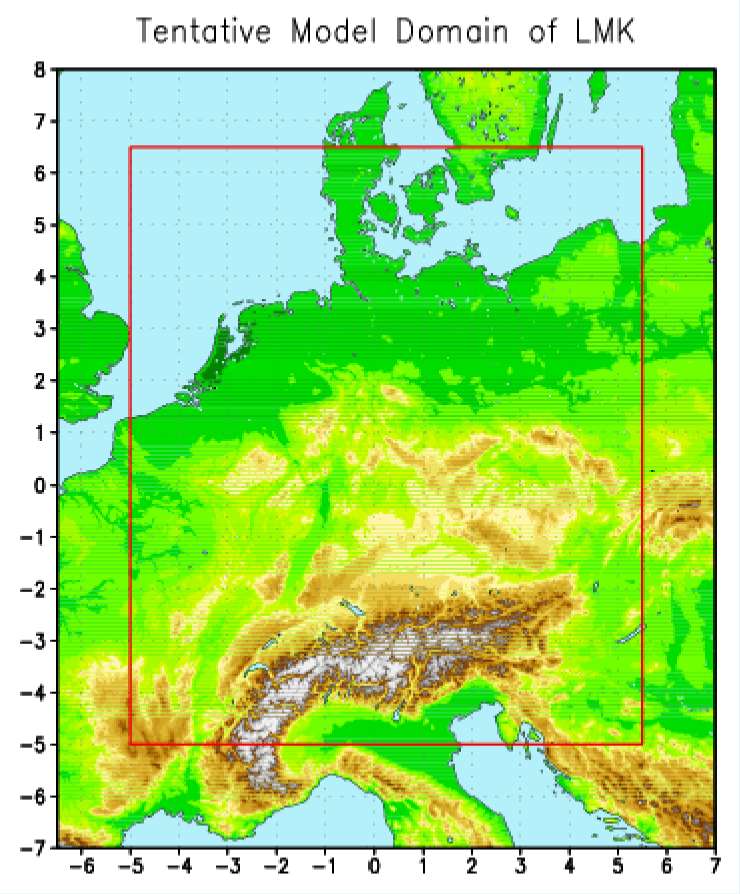
- center of model area 10° E, 50° N

- 421 x 461 grid points horizontally

- grid length: 2.8 km

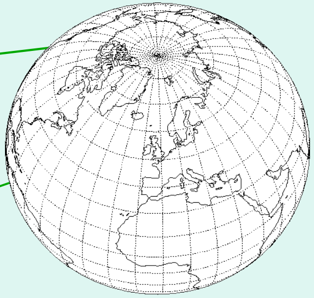
- 50 vertical layers,
  height of lowest layer: 40 m,
  height of lowest half level:
  22 m above ground

- values for initialisation and boundaries
  from operational LM (7km) run



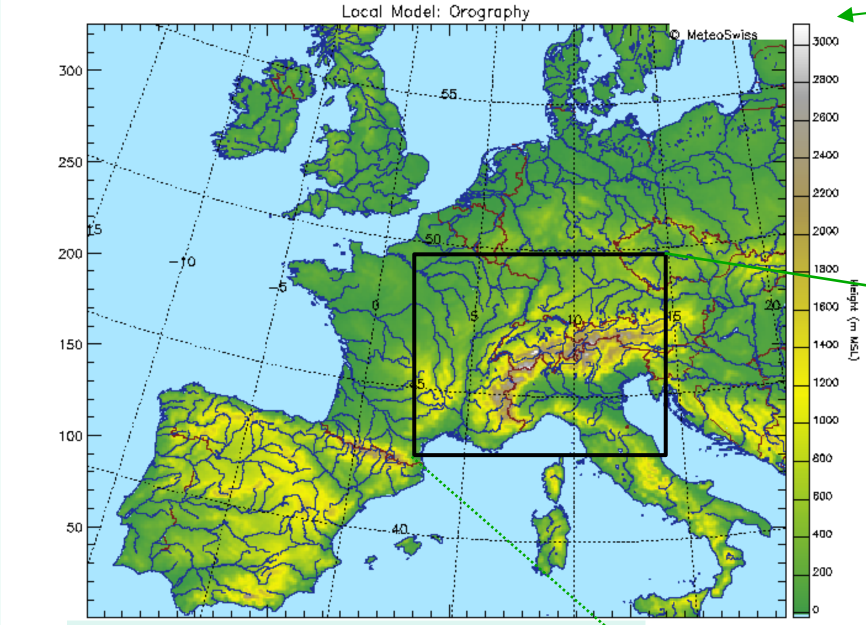
Configuration of aLMo at 2 km configuration pre-operational in 2007

IFS/ECMWF, 20km, synoptic scale



4 daily updates

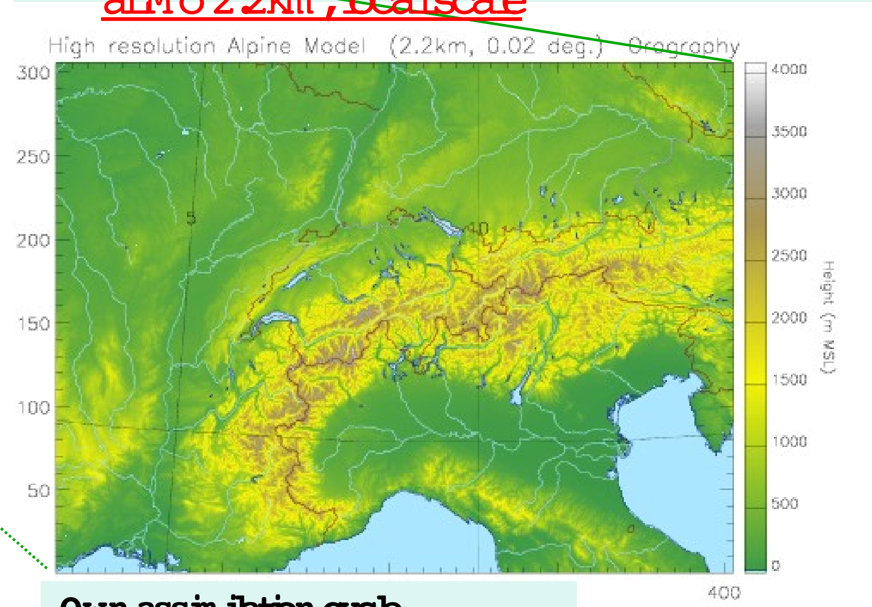
aLMo 7km, regional scale



Own assimilation cycle

2 daily 72h forecast

aLMo 2.2km, local scale



Own assimilation cycle

8 daily 18h forecast

LM(K) characteristics

Dynamics

- Model equations: non-hydrostatic, fully compressible, advection form
- Solver: Klemp-Wilhelmsson time-splitting scheme combined with Euler forward, leapfrog, Runge-Kutta 2d, 3d order
- Coordinate systems: rotated geographical coordinates
  generalized terrain-following height coordinate
  user-defined vertical stretching

Physics Tiedtke mass flux (LM)
explicit deep convection, Tiedtke mass flux for shallow convection (LMK)
3D-turbulence (Herzog et al. 2002, Baldauf 2005)
Müller and Scherer (2005) radiation, incl orography effects
microphysics: water vapour, liquid cloud water, ice, rain, snow

Surface 7-tile, 4 layers

Data assimilation Latent heat nudging (LM only)

HIRLAM-ALADIN-AROME

- MeteoFrance: cooperation with academia involved in meso-NH ➔ decision to build AROME (fully operational: 2008)
- ALADIN: bridge gap between ALADIN and AROME with ALARO
- HIRLAM – ALADIN: Complementary areas of expertise
- Full–code cooperation HIRLAM-ALADIN, within IFS-AAA framework

AROME model characteristics

Dynamics:

- ALADIN NH: Semi-implicit semi-Lagrangian spectral, Laprise vertical coord.

Physics:

- Combined eddy-diffusivity mass-flux scheme, with 1D moist TKE, statistical cloud scheme; 3D turbulence scheme under study
- Prognostic ice/rain in microphysics
- ACRANEB and Saavijarvi radiation schemes, incl orography effects
- Catry et al mountain wave drag

Surface:

- (Externalized) ISBA, 2-4 layer force-restore, incl sea, snow, vegetation, and urban surface. Up to 12 tiles. Lake model under development.

- 3D-VAR/FGAT
- Daily quasi-operational runs in several countries at resolutions of ~2km

‘Back-upscaling’ concept of ALARO

8 to 15 km

4 to 7 km

2 to 3 km

(ARPEGE)/ALADIN

ALARO

AROME

The biggest competition

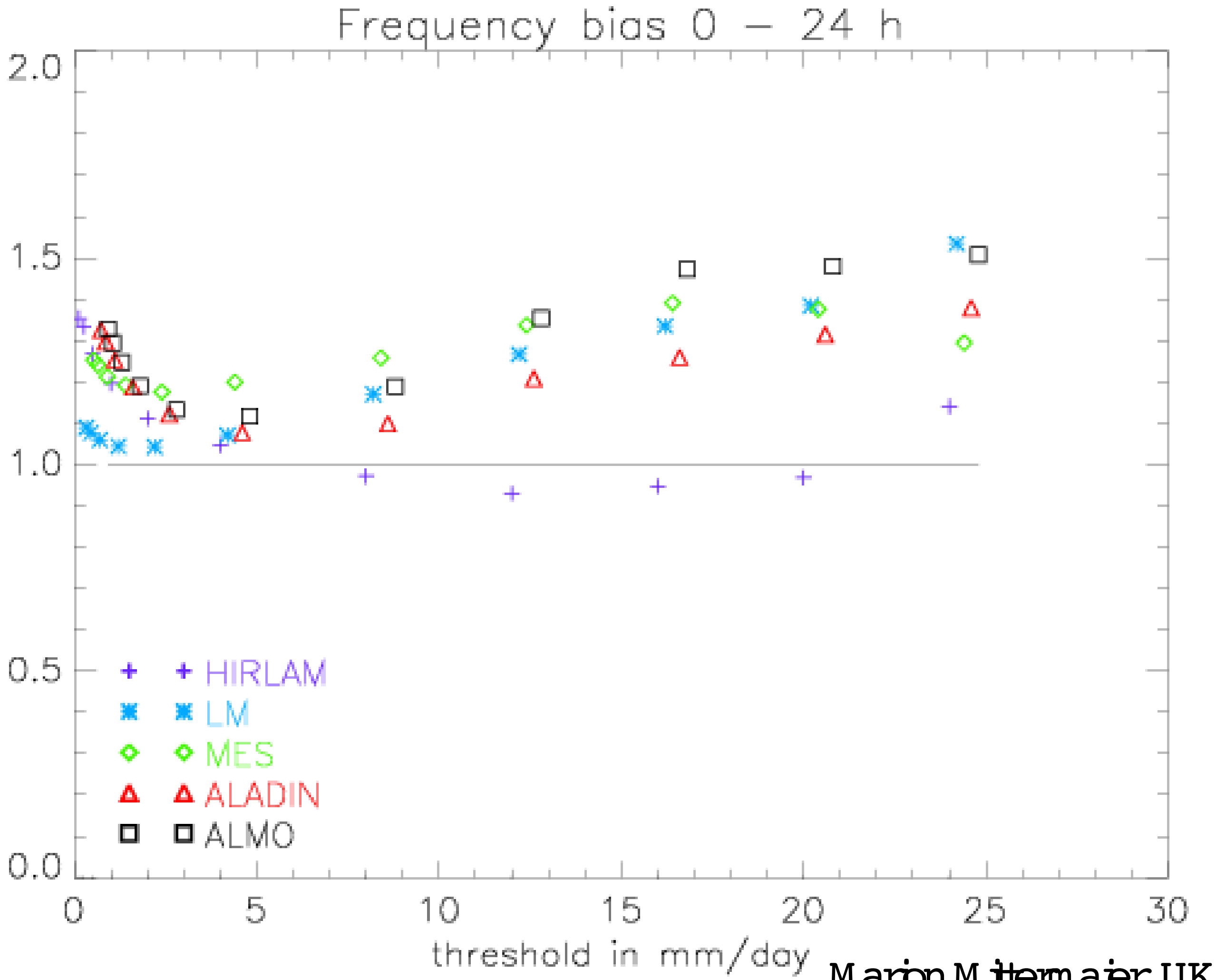
- MM5
  - Developed by large academic community
  - Hydrostatic and non-hydrostatic
  - Physics relatively simple for mesoscale; no data assimilation
  - Cheap, easy to set up, well-documented, couple with free data from NCEP ➔ Attractive for commercial service providers
- Its successor WRF
  - More advanced physics than MM5 (choice of several physics packages, modular setup, similar to meso-NH)
  - Development of mesoscale data assimilation
  - Developed for research <u>and</u> operational use
  - Number of (operational) users growing in US but especially Asia

Most models share the same problems

- Quantitatively accurate precipitation predictions
- Description of low clouds
- Transition regimes in convection
- Stable boundary layer behaviour
- Moisture initialization and sensitivity to moisture changes
- Precipitation shadow behind mountains
- …

➔ Obviously we have still got plenty of work to do!

QPF of various models against UK radar composite



Marion Mittermaier, UK Met Office