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Role of PBL parameterization in NWP – experiences from HIRLAM

relayed by Carl Fortelius

1.6.2007

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  - Origin of parameterization
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  - Wind, pressure, and surfaced stress
- **Summary**

Origin of parameterizations

Unapproximated model:

$$\dot{\tilde{X}} = \tilde{F}[\tilde{X}]$$

After discretization:

$$\dot{X} = F[X] + P[X]$$

Or, in practice, in a sub space associated with a grid box j:

$$\dot{X}_j = F_j[X] + P[X_j]$$

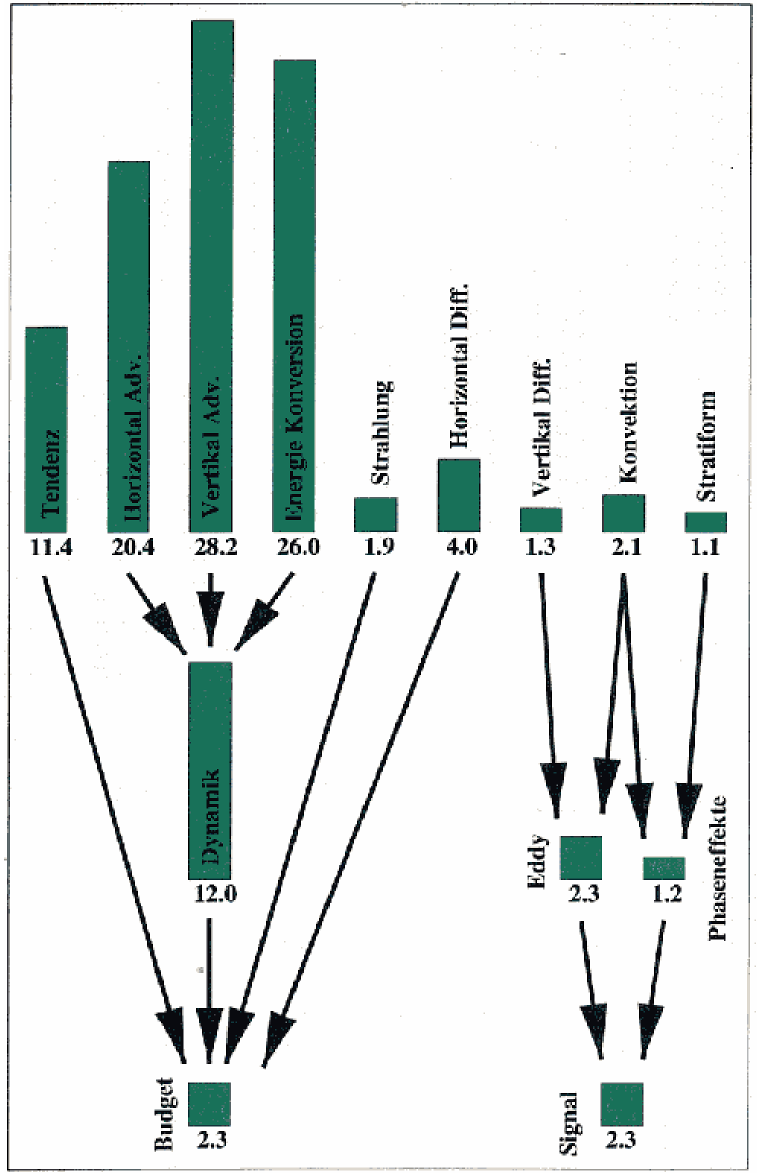
But how well can the sub-grid scale effects P really approximated in terms of the resolved state vector, X?

Role of parameterizations

- **Dynamicist’s view:**
  - Unavoidable nuisance, needed to remove instabilities
  - Unbiased net effect of sub-grid scale phenomena, expressed in terms of resolved variables and known physiographic characteristics; computationally affordable, please

- **Physicist’s view (user’s view):**
  - Accurate rendering of prevailing conditions and ongoing processes locally, subject to resolved dynamical forcing

An example:

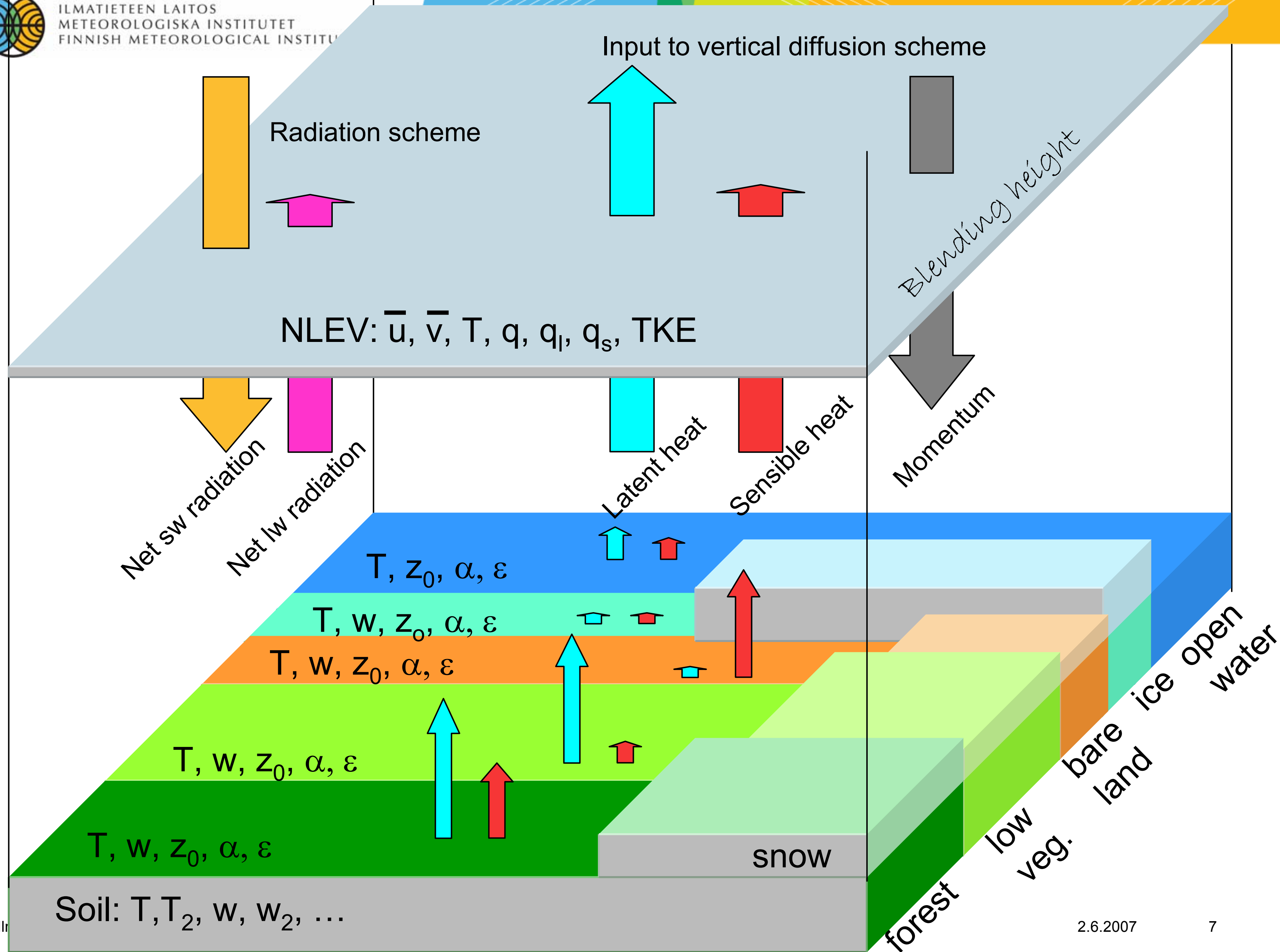


- Scales of the terms in the prognostic eq. for moist enthalpy. Shown are RMS-values of 6-hourly tendencies in K/day in the Europa-Modell at the 700 hPa level over northern Europe for the 9-day period 26. Aug.. 3. Sept. 1995. (From: Hamelbeck, 2000)

HIRLAM in a nutshell (model version 7.1)

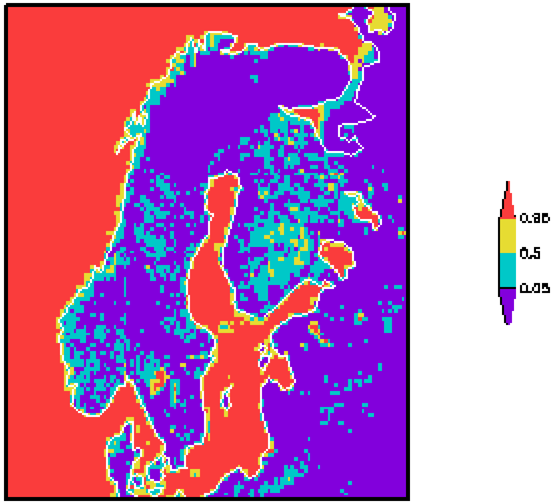
- **Basic equations: primitive equations in flux form (hydrostatic)**
- **Independent variables: lat, lon (rotated), terrain following pressure-coordinate, time**
- **Dependent variables: surfacfe pressure, horizontal wind, temperature specific humidity, liquid and solid cloud condensate, turbulent kinetic energy**
- **Grid: Arakawa C horizontal staggering, Lorenz vertical staggering**
- **Time-integration: 2 time level semi-Lagrangean semi-implicit**
- **Topography: HIRLAM physiographic data base, filtered orography**
- **Physical parameterizations:**
  - Savijärvi radiation scheme
  - STRACO- condensation/convection scheme
  - turbulence based on turbulent kinetic energy and a diagnostic mixing length
  - surface fluxes based on a stability-dependent drag formulation
  - surface and soil processes using a tiling scheme
  - Horizontal diffusion: implicit fourth order

Surface tiles

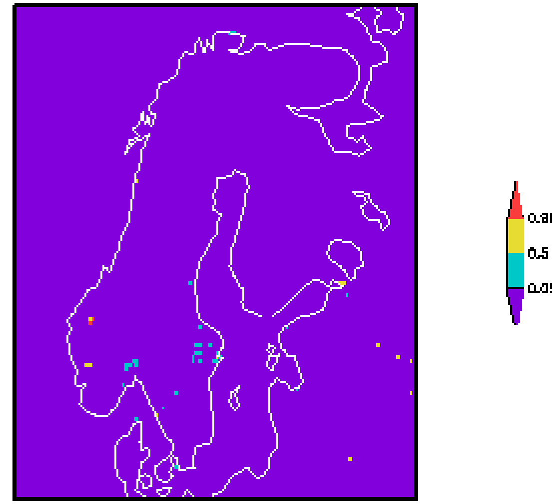


Surface types

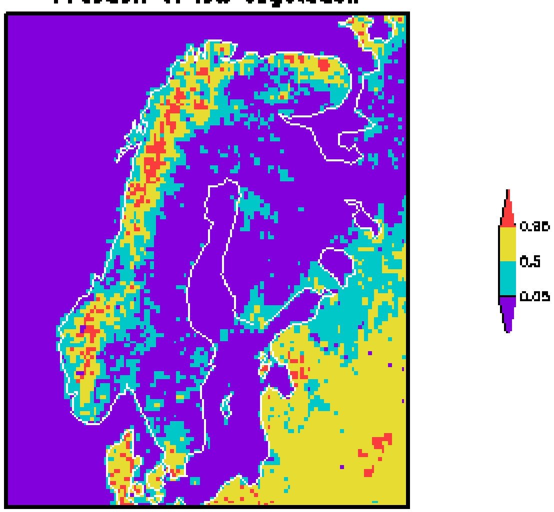
Fraction of open water



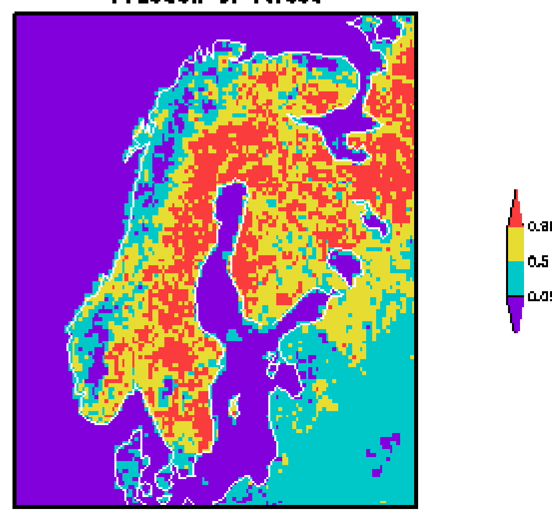
Fraction of bare land



Fraction of low vegetation



Fraction of forest



HIRLAM domains in use at FMI

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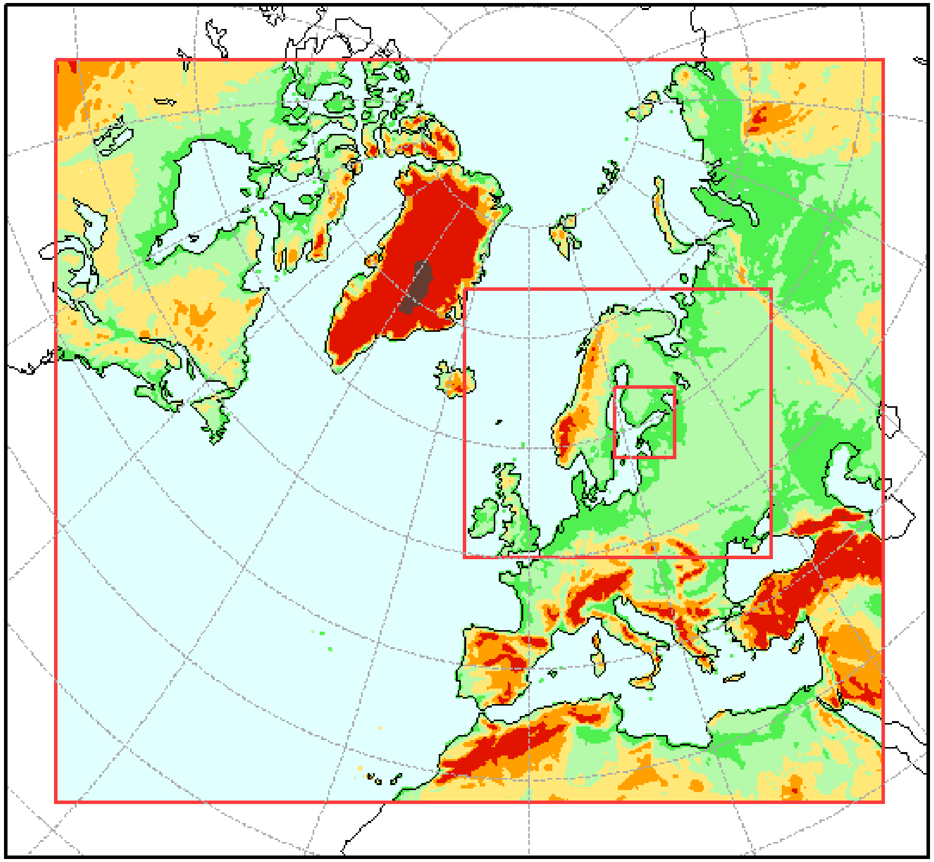
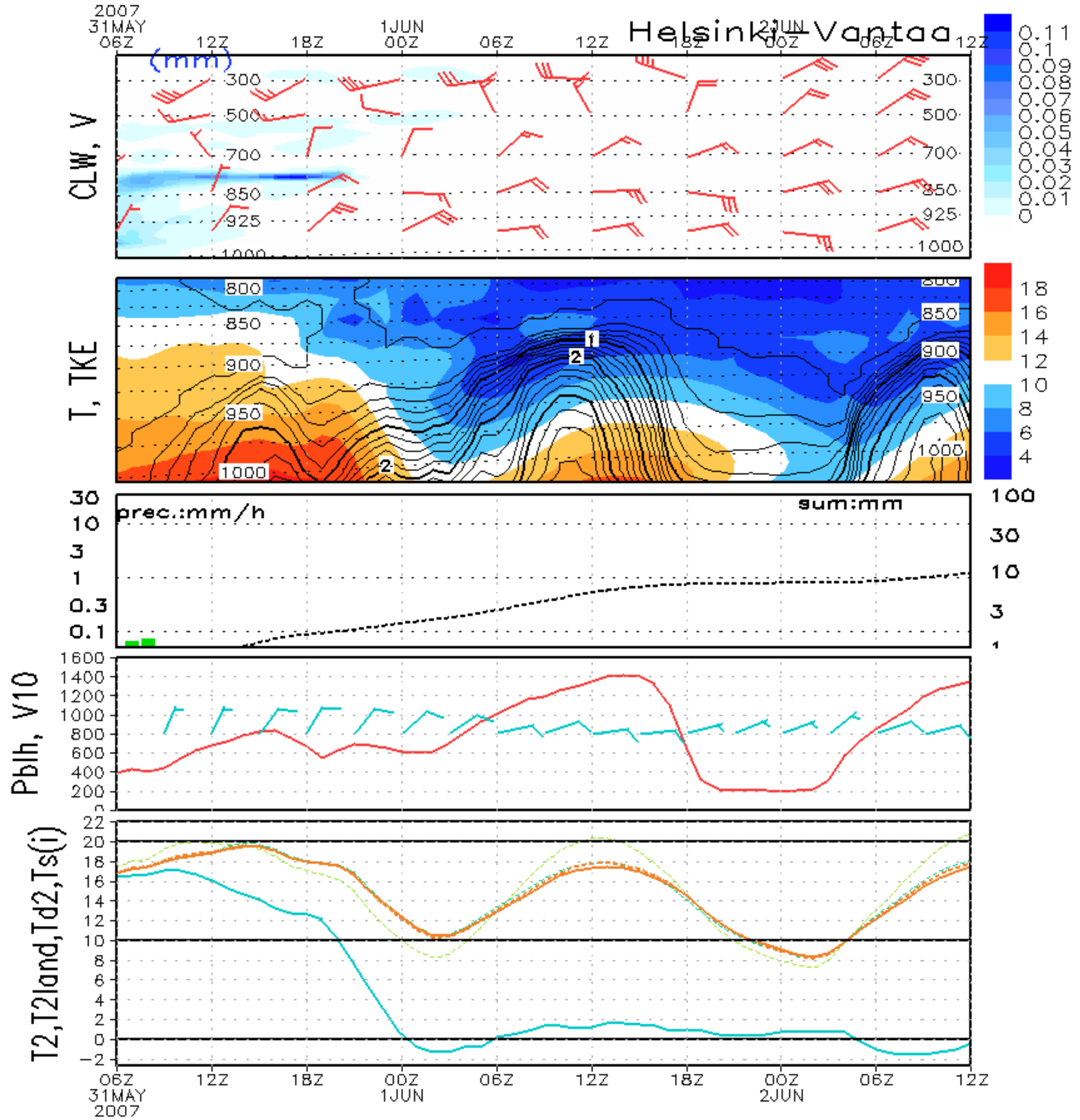
HIRLAM areas at FMI
RCR->MBE->AROME

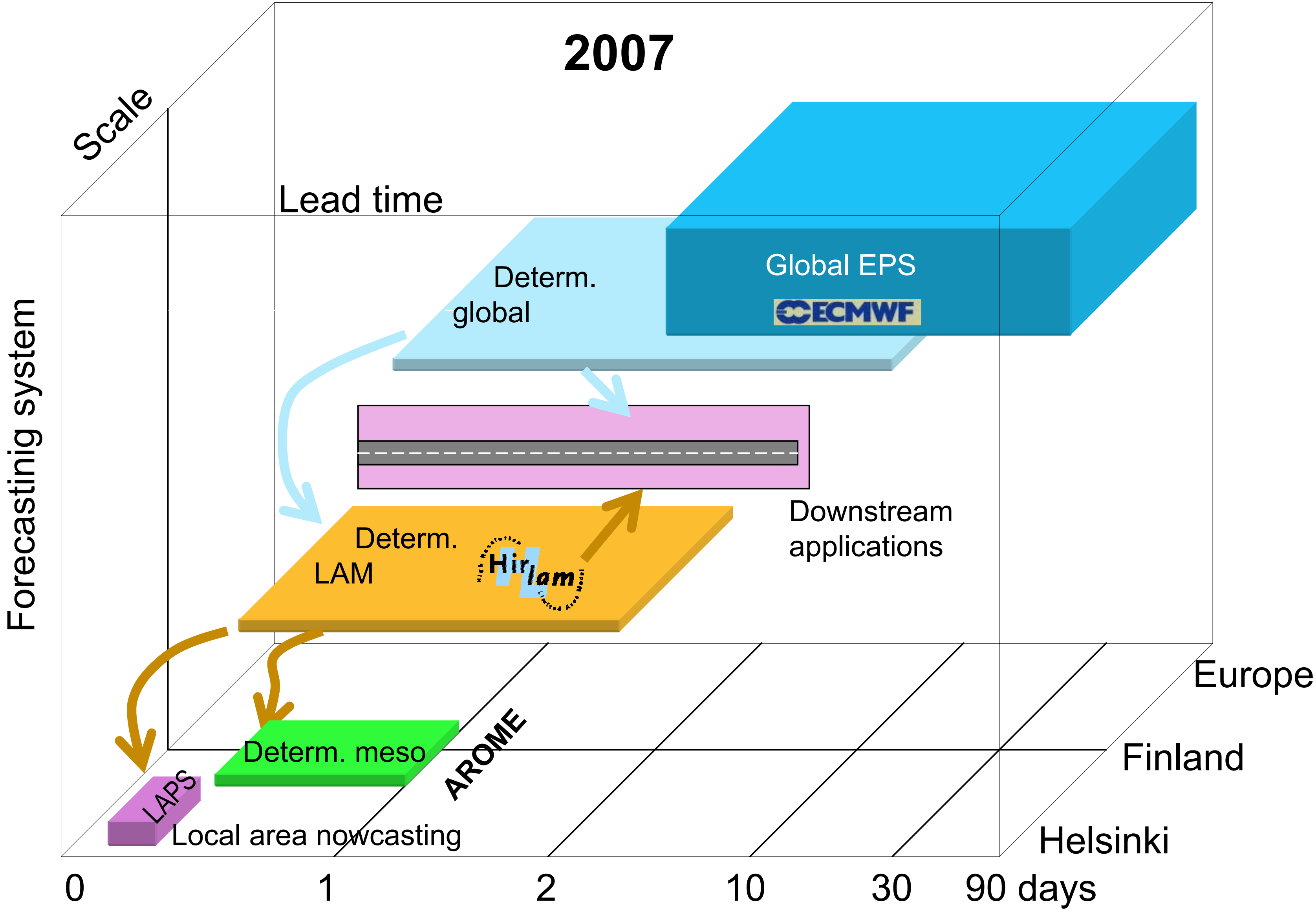


- **HIRLAM reference runs (RCR):**
- **582 x 448 grid points, grid spacing 0,15 ° (~16 km)**
- **60 levels, approximate altitudes of the lowest levels: 30, 90, 150, 216, 280, 350, 420, 490, 570, 650, 731, 820, 910, 1000 m**

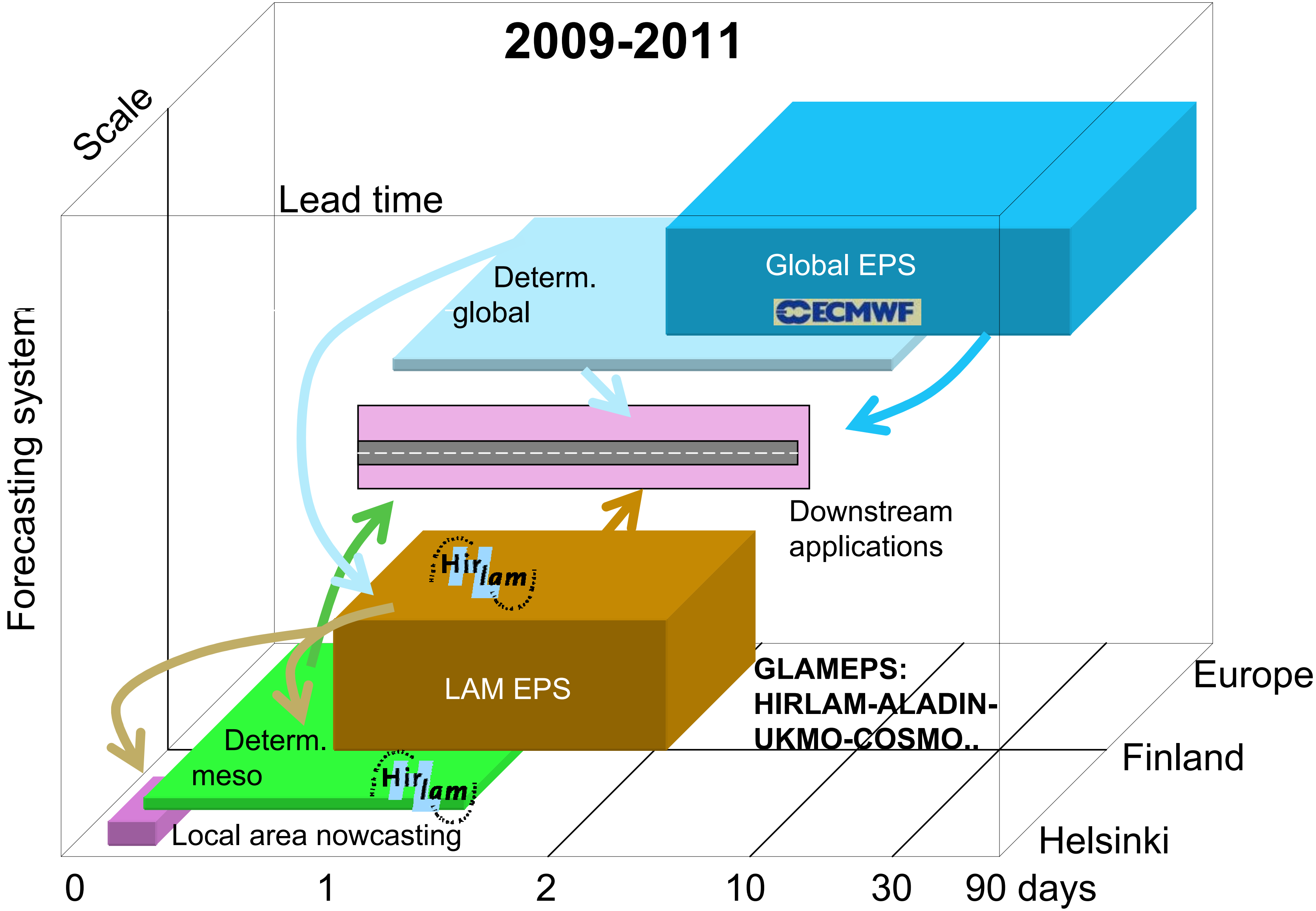
HIRLAM
in
HELSINKI



HIRLAM at FMI



HIRLAM at FMI



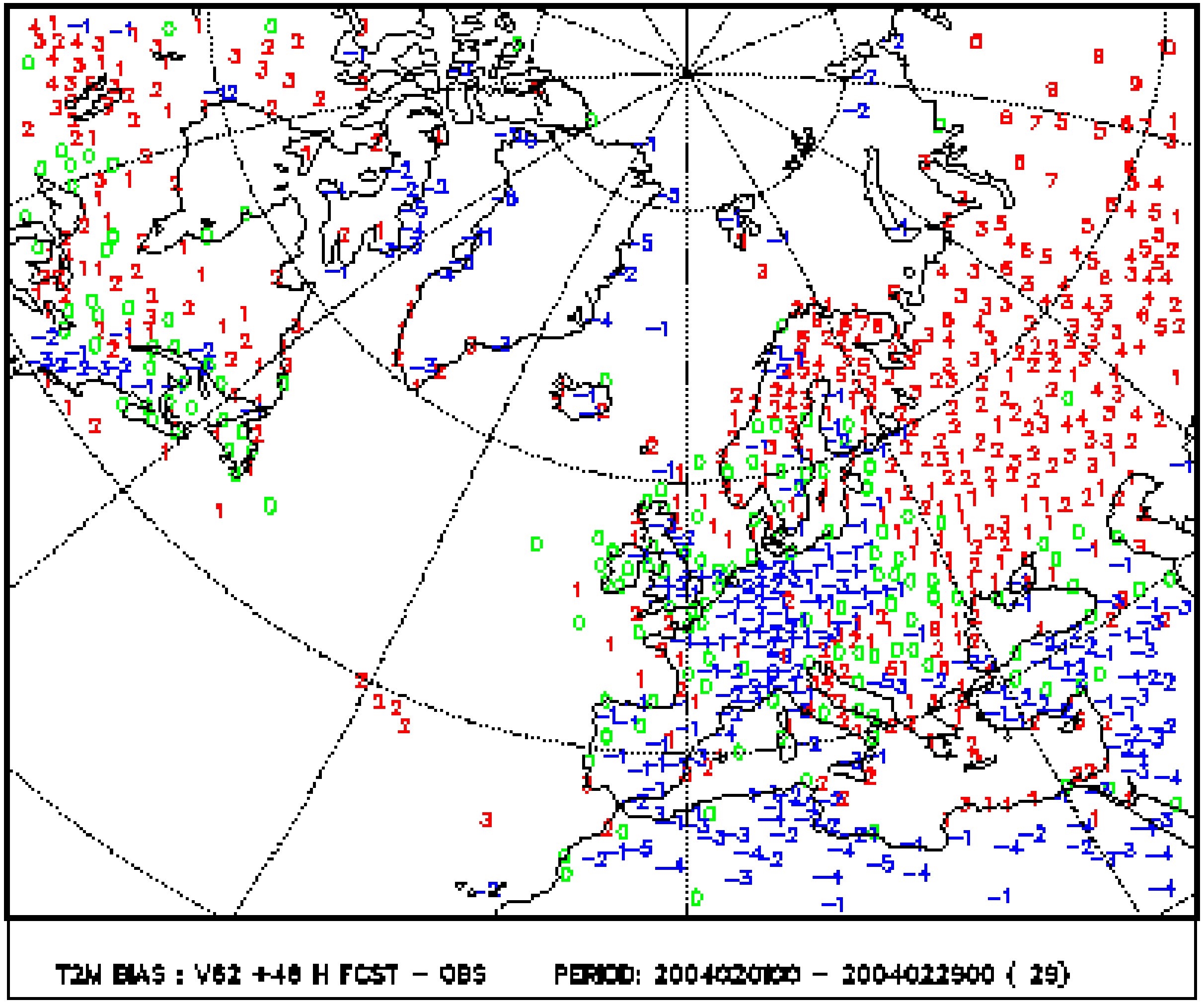
Experiences and examples

- **Temperature bias in winter**
- **Temperature bias in spring**
- **Pressure bias wind bias and surface stress**

”The winter problem”

- **Underprediction of surface inversions and associated low temperatures**
- **Forecast errors of 10-20 degrees**
- **Misleading mixing and mixing height!**
- **Spurious data rejection in the analysis step**

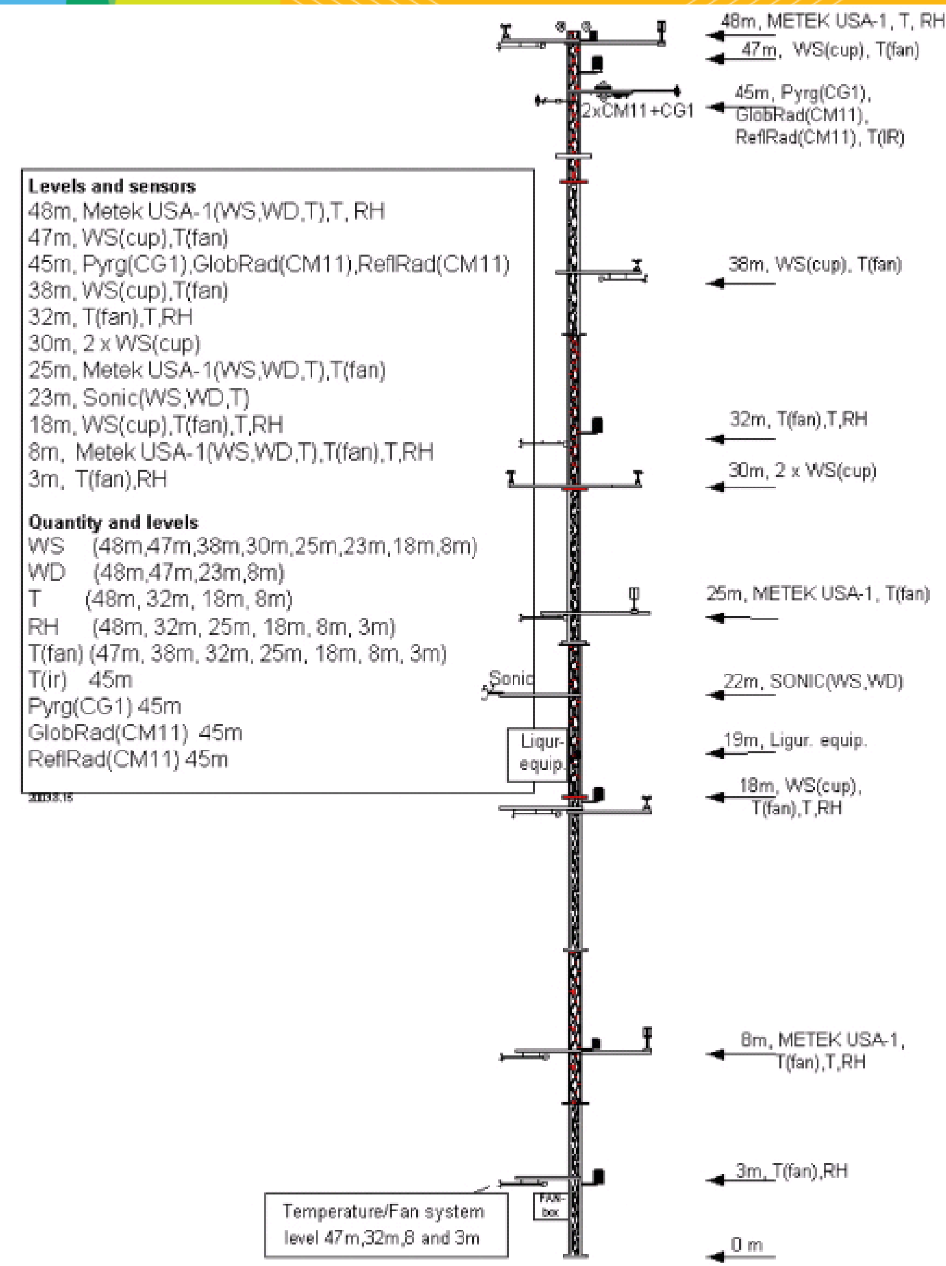
Temperature bias in winter

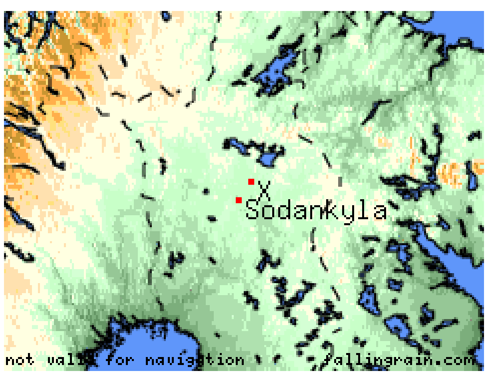


- **Bias in screen level temperature in February 2004**
- **HIRLAM RCR**
- **Valid at 00 UTC**
- **Step: 48 h**
- **From: Järvenoja, 2005**
- **Why?**
  - Clouds, radiation?
  - Wind, turbulence?
  - Surfce fluxes?
  - ???

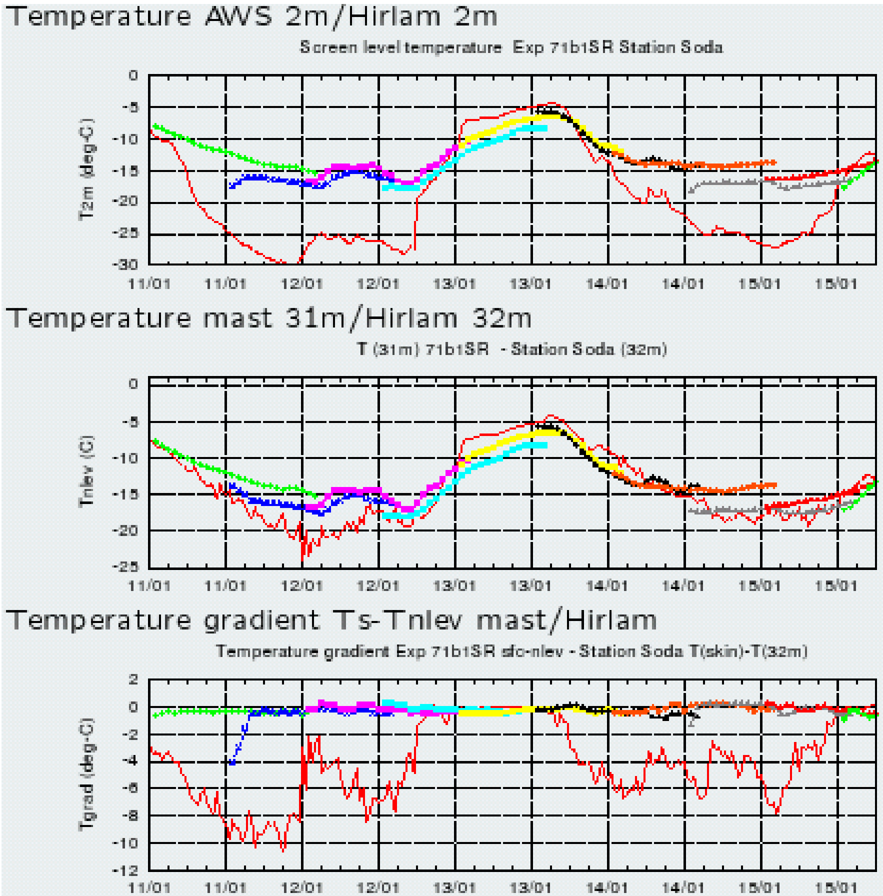
The Sodankylä mast

- **Arctic Research Centre of the Finnish Meteorological Institute (FMI-ARC)**
- **Details: Atlaskin and Kangas, 2006.**

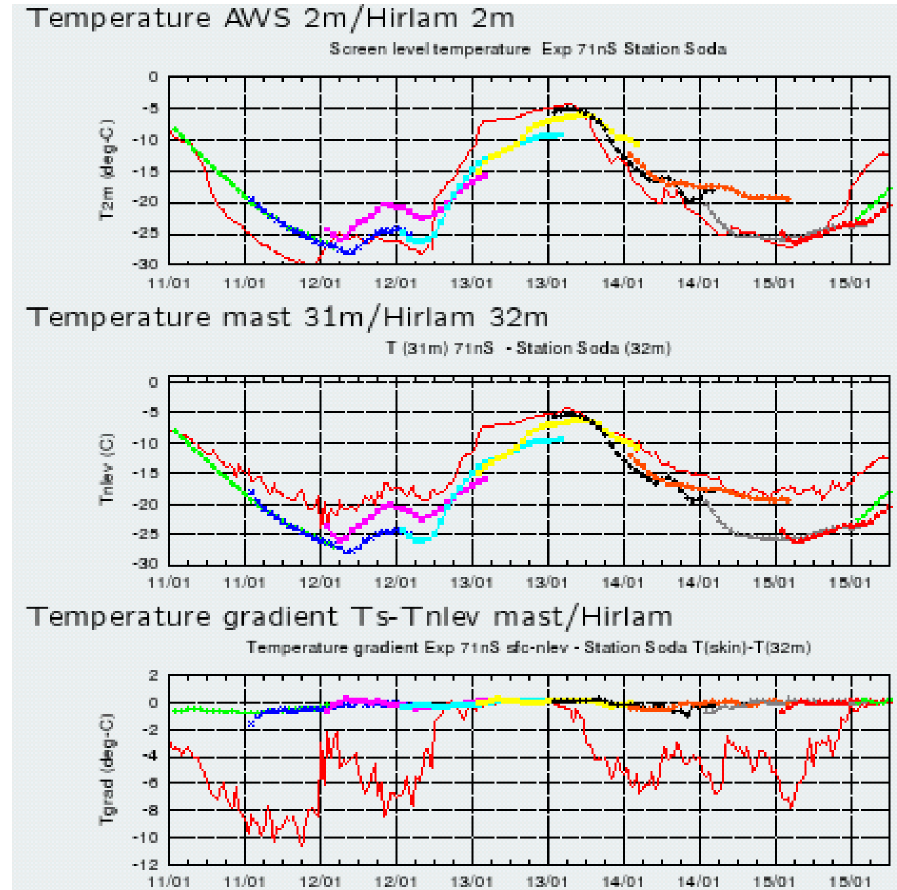




Sodankylä, January 2007



HIRLAM reference



HIRLAM, revised surface scheme

From: Rontu 2007

1 Features of the new surface scheme

The main changes from the earlier 5-tile Hirlam-ISBA, is that the force-restore formulation for temperature is replaced by heat conduction, and also that the snow and canopy have prognostic temperatures. The force-restore formulation is kept for soil moisture:

- Totally 7 tiles, sea, ice, snowfree open land, snowfree low vegetation, snowfree forest, open land snow and forest snow. With "open land snow" we mean the snow that is covering both the open land and low vegetation tiles.
- For all land tiles: three prognostic soil temperatures with depths 1 cm, 7.2 cm and 43.2 cm. A climatological deep temperature is used and the heat conduction is calculated.
- The forest tile has a common canopy temperature, for the snowfree and snow part, and is technically treated at the same time. Radiation is calculated both for canopy and forest floor.
- The two snow covers (open land and forest snow) are treated separately. They have, apart from the temperatures, also varying albedo, density and liquid water content (to allow for refreezing).

Gollvik, 2005

The ”spring problem”

- **Underprediction of the diurnal temperature-cycle during periods of nice spring weather**
- **Underpredicted daytime maximum temperature**
- **Causes problems to downstream applications, in particular hydrological models (snow melt, evaporation) and biosphere models (tree flowering)**

Temperature bias in spring

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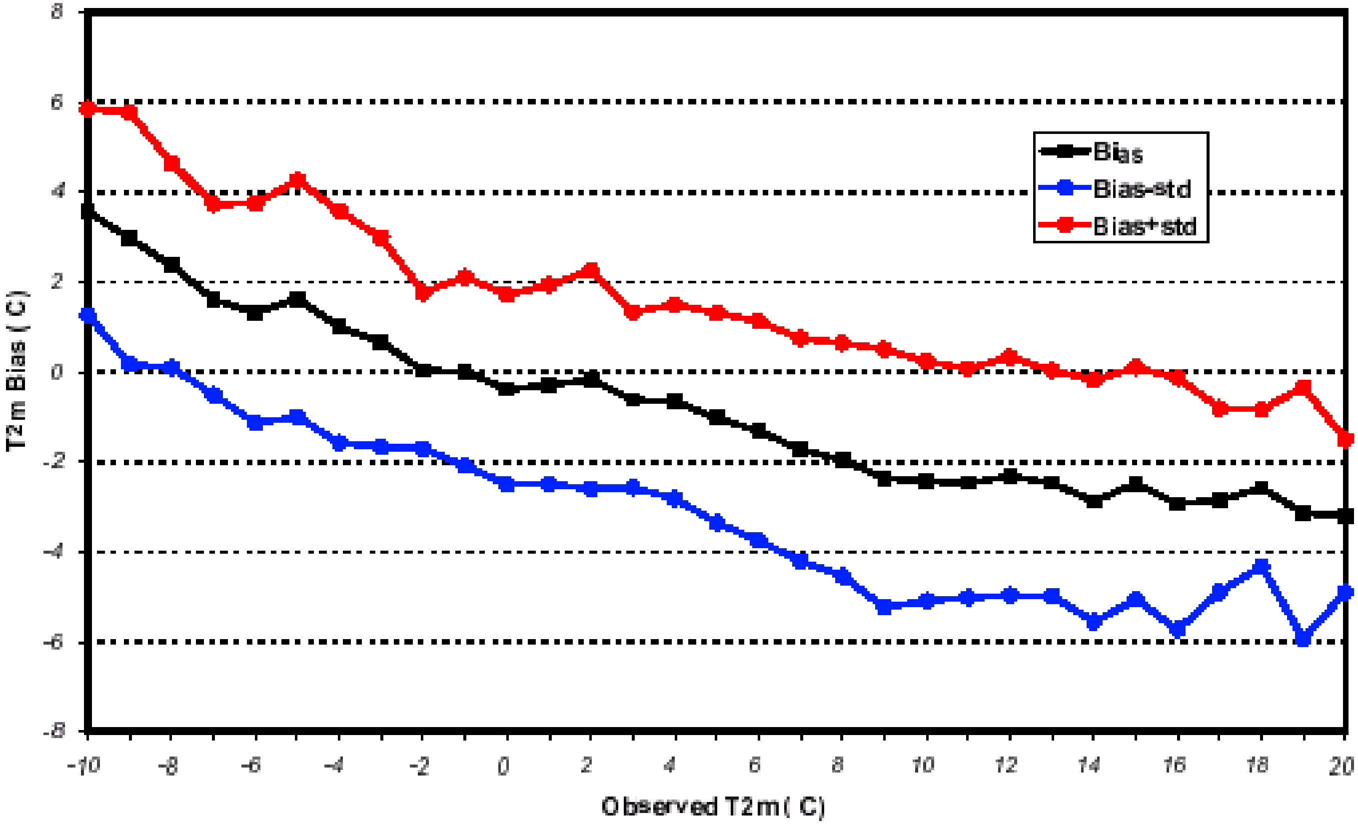
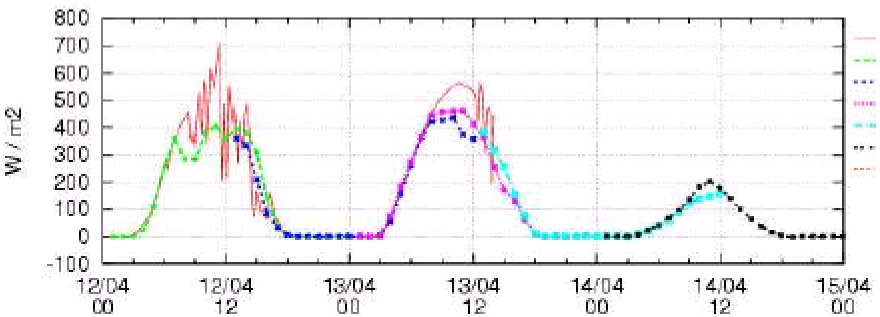


Temperature bias of 36 h forecasts valid at 12 UTC, as a function of observed temperature, Scandinavia and Northern Russia, April 2004. HIRLAM RCR.

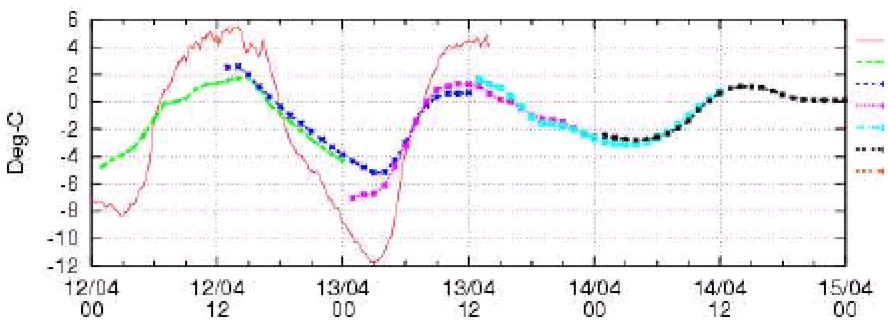
From: Järvenoja, 2005

Sodankylä, April 2004

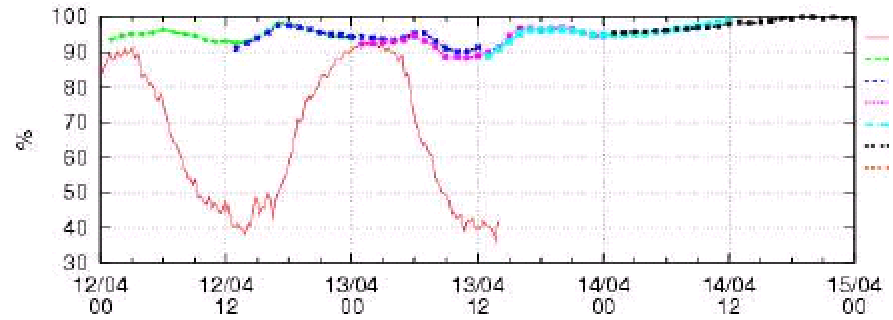
Global radiation



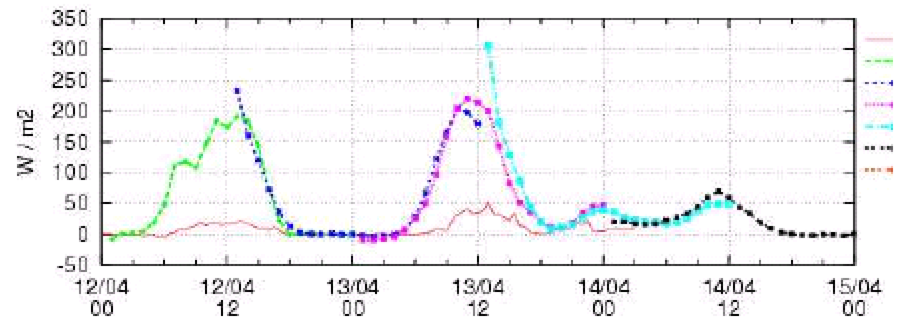
2 m temperature



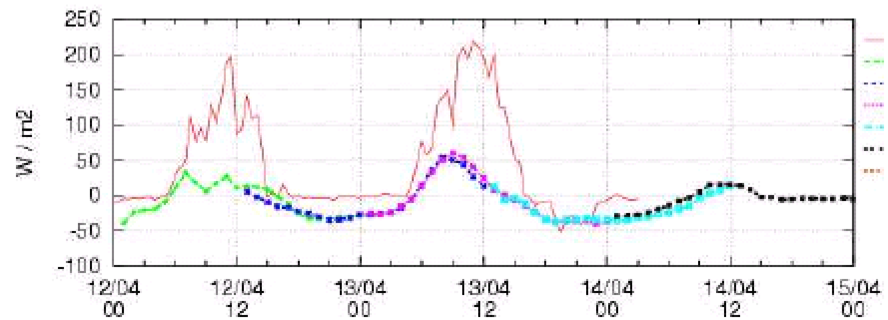
2m relative humidity



Latent heat flux



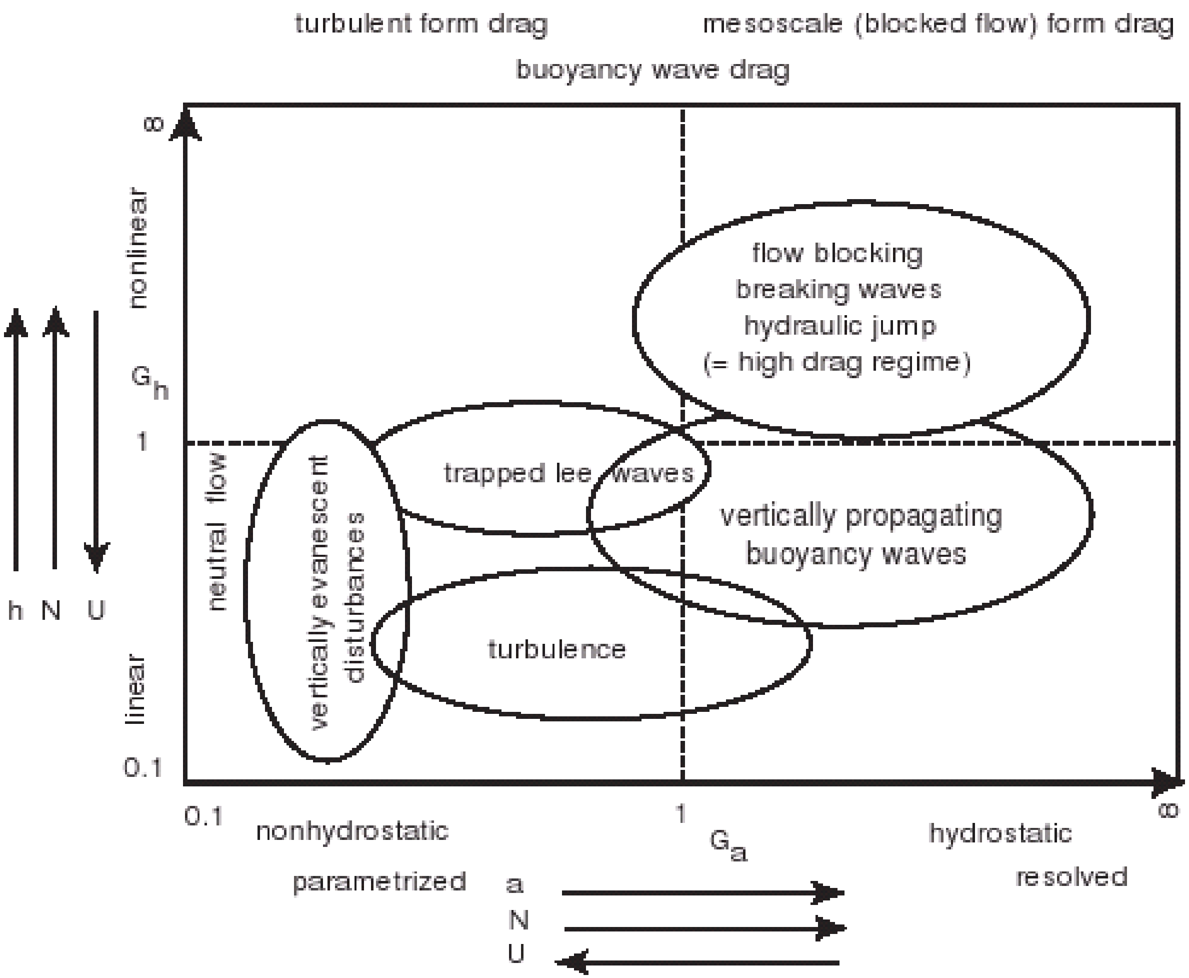
Sensible heat flux



From: Järvenoja, 2005

Pressure, wind, and surface stress

Interactions between flow and orography



Orographic flow characterized by non-dimensional height (Gh) and width (Ga) of the obstacle. From Rontu, 2007 (pers. comm.)

Parameterization:

- **Flow over a rough or incredibly rough flat surface:**
  - Local rougness: $z_{0,veg}$ (Charnock formula over sea)
    - Centimetres to decimetres (millimetres)
  - Orographic stress: $z_{0,oro}$ depending on sub-sgrid scale orographic variance, added to z_{veg}
    - Several metres
  - Drag-coefficient dependent on stability and shear
  - Vertical diffusion scheme: TKE-ε

A persistent weakness of several versions

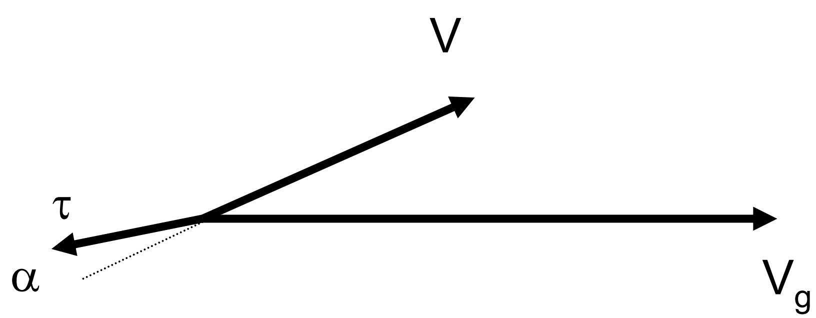
- **Too active cyclones**
  - Too fast development, too slow filling
- **Biased 10m winds over land**
  - Systematically ~1..1.5 m/s too fast, worst at night
  - Biased direction: Too little cross isobaric turning

<=

- **Underestimated surface drag? Errors in the vertical diffusion?**
- **Modifications to roughness parameters and/or vertical diffusion has not solved both problems simultaneosly**

The current solution (Sass and Nielsen, 2004)

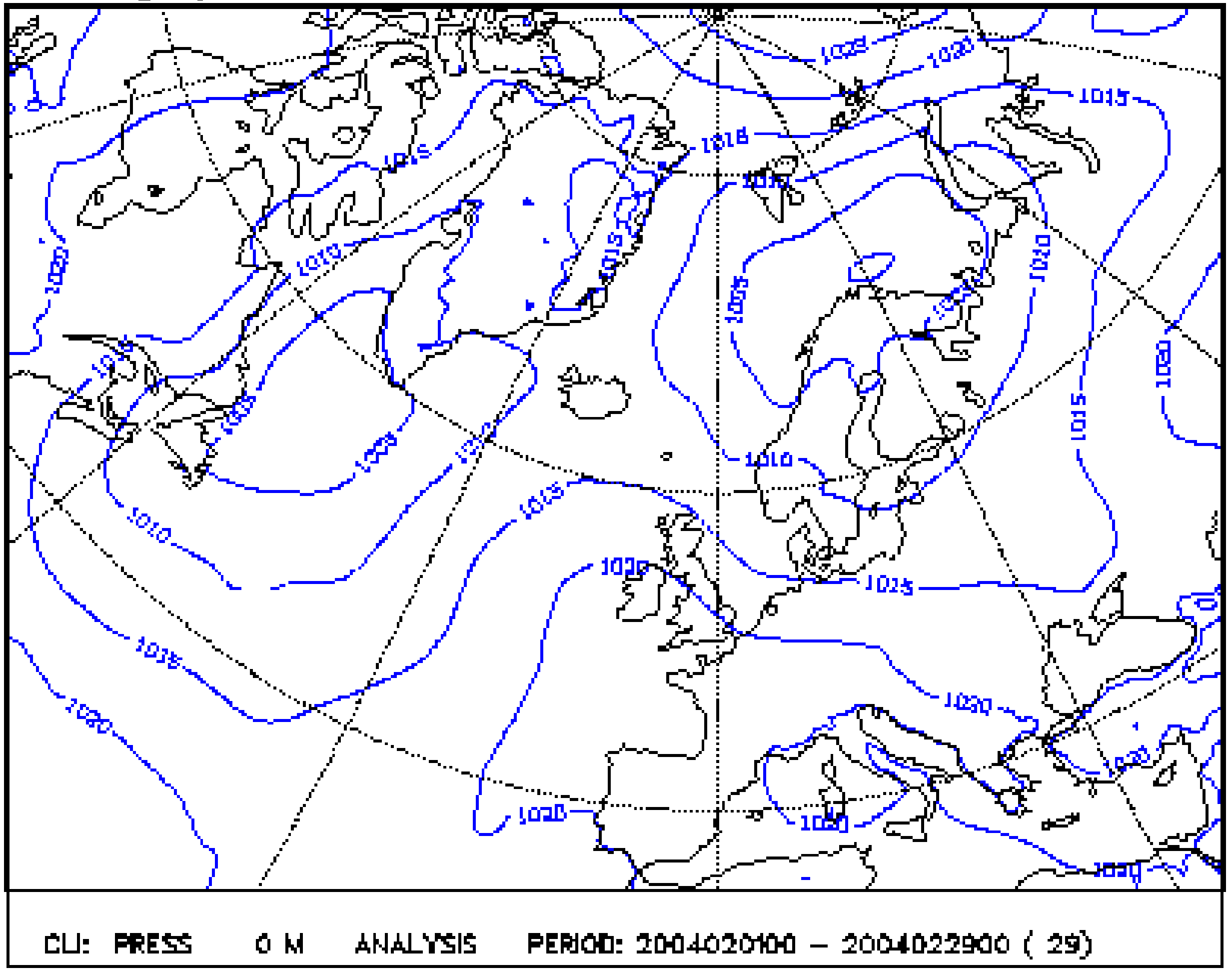
Turning the surface stress relative to the lowest model level wind:



The turning anlge α depends on the bulk Richardson number, and varies between 0 for unstable or neutral stratification and $\pi/4$ for very stable stratification

Effetcs of stress turning, Feb 2004

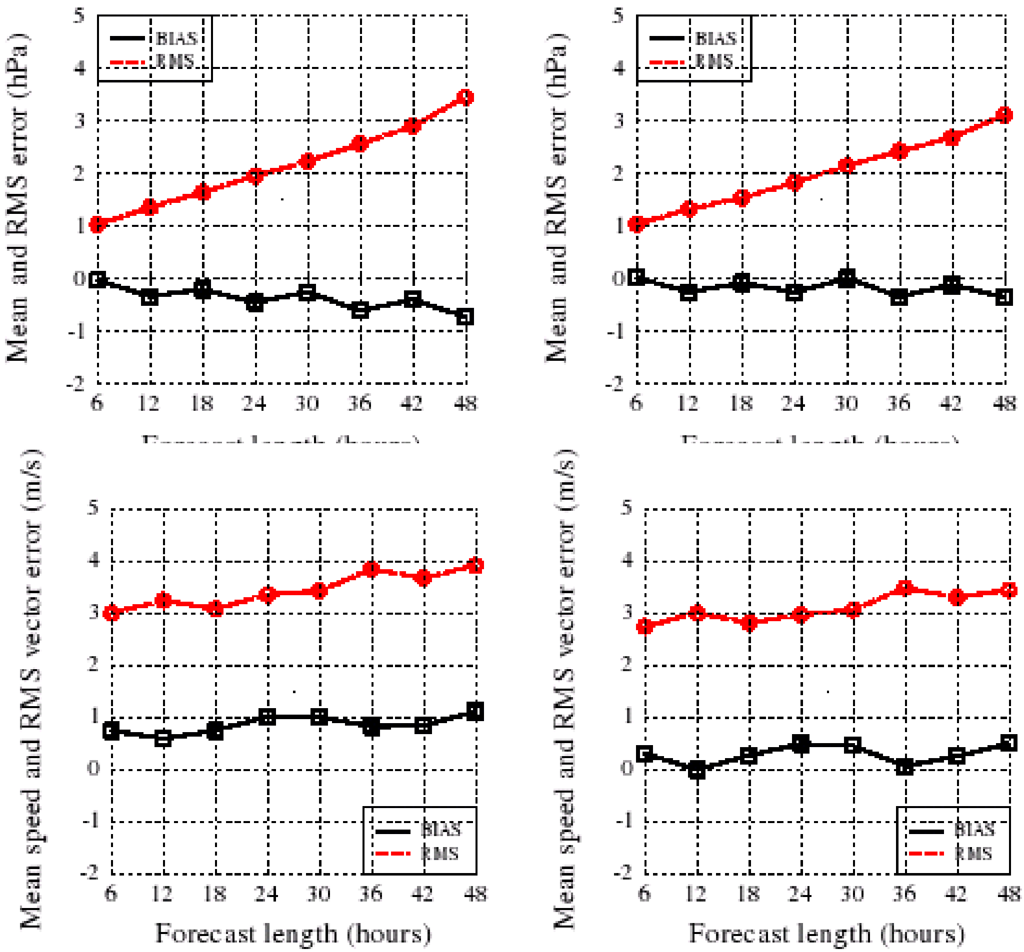
Järvenoja, 2004:



Average mean sea level pressure, Feb 2004

Statistics for EWGLAM stations:

Reference | Stress-turning

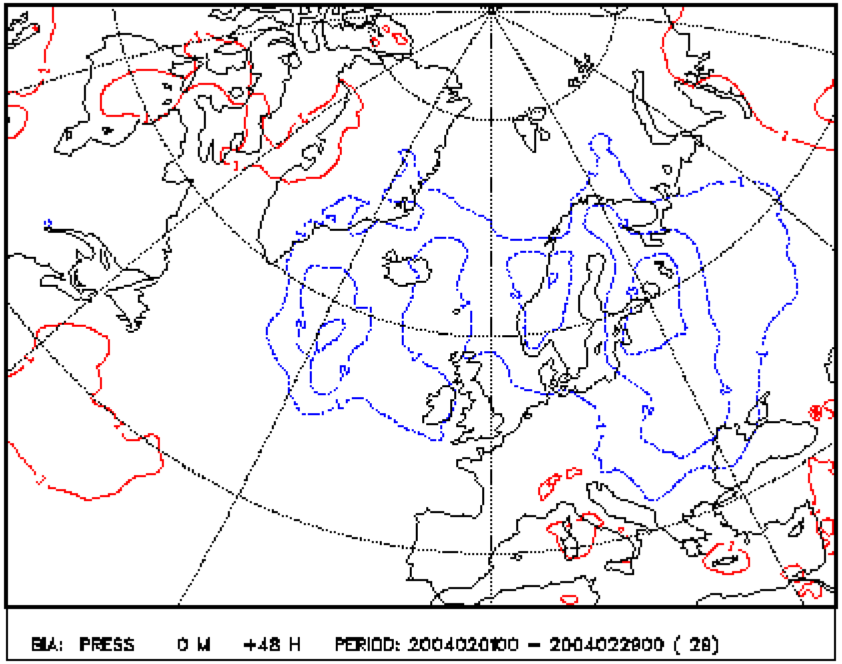


Pressure

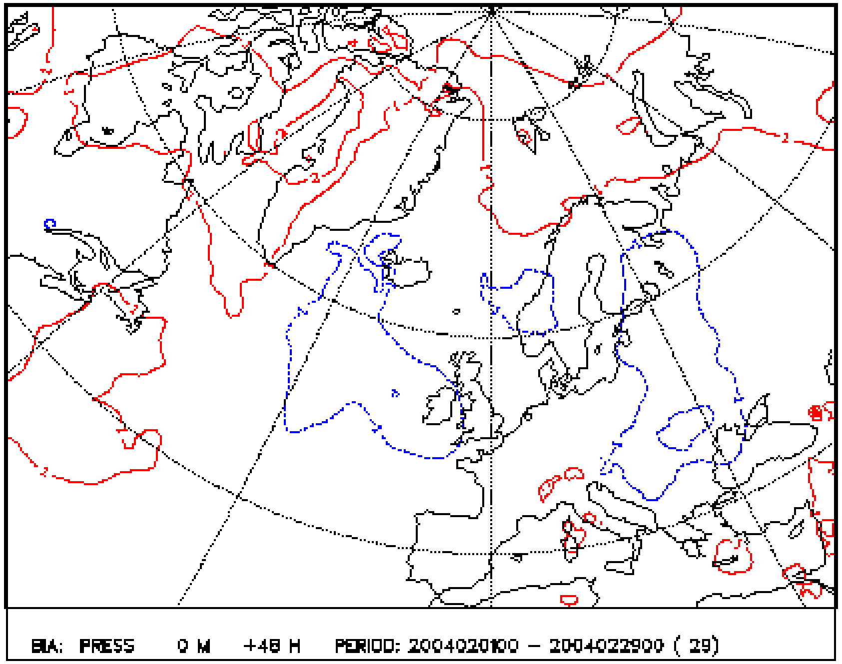
Wind speed

Pressure bias in February 2004

Reference



Stress-turning applied

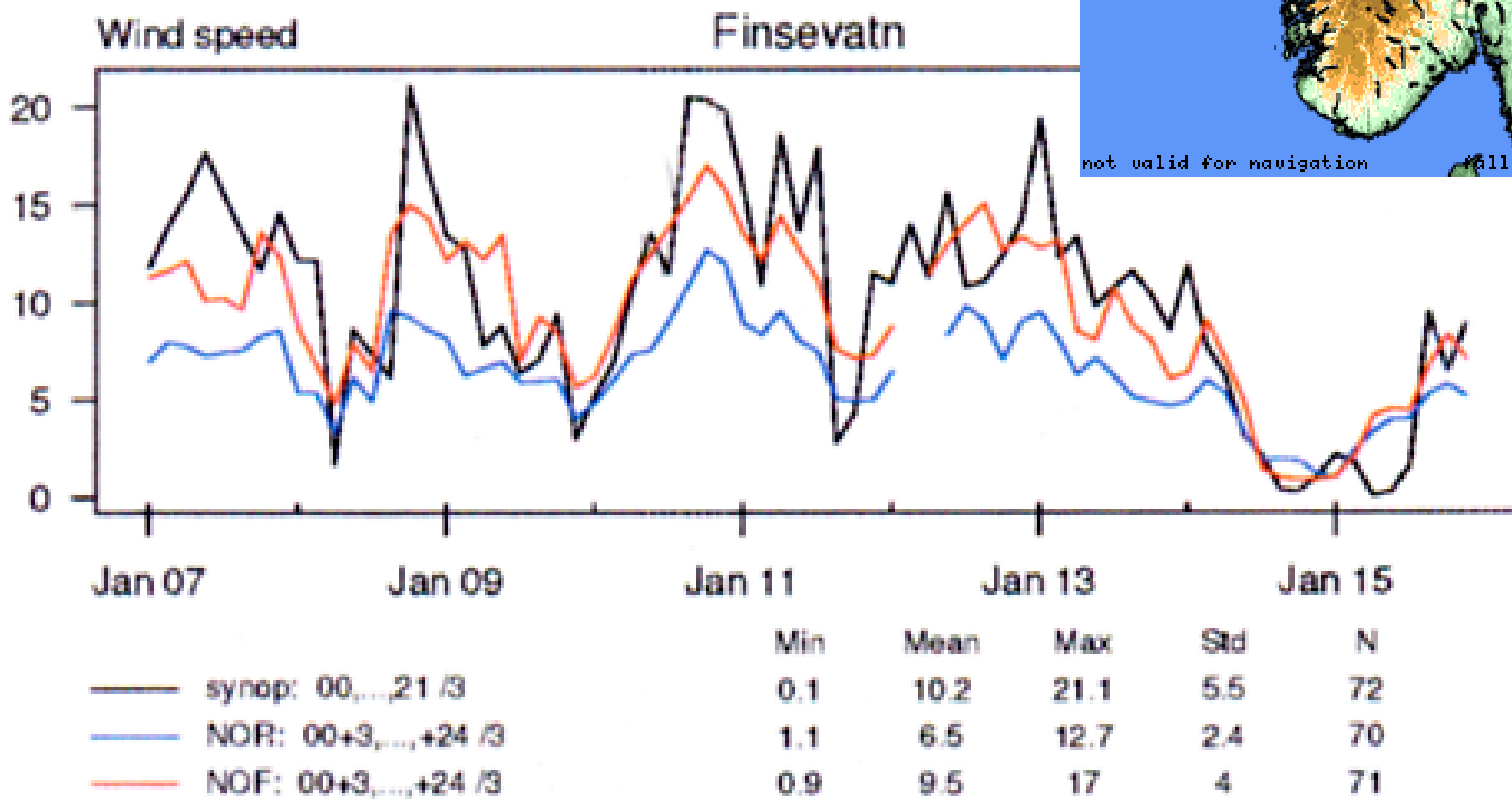


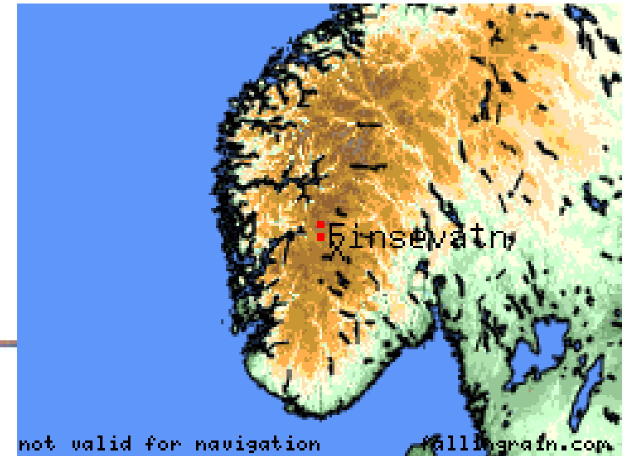
But

- **”Stress trurning” is difficult to derive from first principles**
- **”Orographic roughness” is still unsatifactory**
- **New parameterization of orographic effects (Rontu, 2006) includes:**
  - Turbulent surface drag due to surface roughness
  - Internal drag due to unresoved orography
  - Internal blocked flow drag due to meso scale orography
  - Internal drag due to breaking buoyancy waves
  - Turbulence TKE-ε

An example from Norway

2005

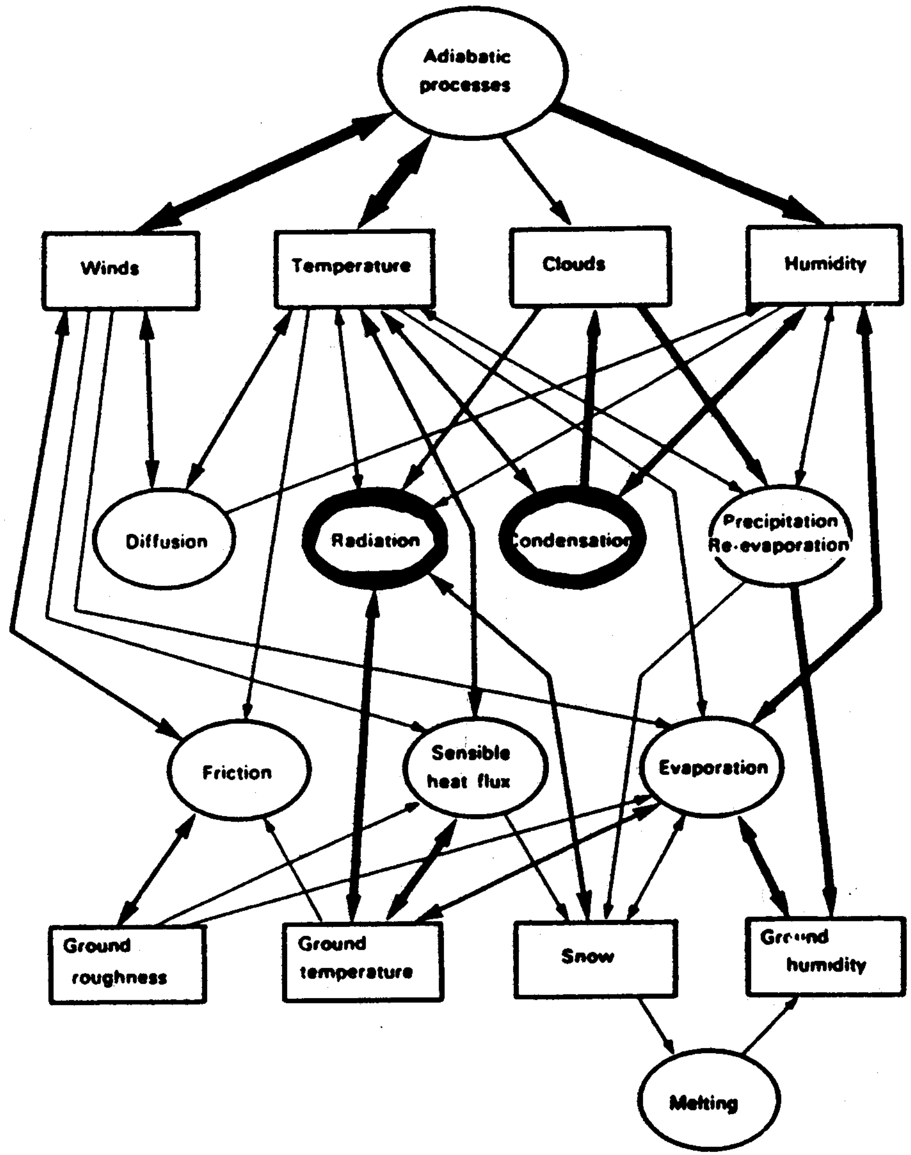




Courtecy: Laura Rontu

Summary

- **The role of parameterizations depends on the context**
- **In a model of the climate system, the interaction between processes may be as important as the processes themselves.**
- **Beware of compensating errors**



Thank you!

References

- **Atlaskin, E. and M. Kangas, 2006: Sodankylä data utilization for HIRLAM verification and 1D model studies. HIRLAM Newlsetter 51. pp 103-108.**
- **Gollvik, Stefan, 2005, A new surface scheme for HIRLAM. SRNWP/HIRLAM Workshop on Surface Processes, Surface Assimilation and Turbulence, Norrköping 15-17 September 2004.**
- **Hamelbeck, Felix, 2000: Evaluirung der Konvektion für Regionale Modelle über der Ostsee, Dissertation zur Erlangung des Akademisches Grades des Doktors der Naturwissenschaften, Universität Wien, im Mai 2000.**
- **Järvenoja, Simo, 2004: Experimentation with a modified surface stress. HIRLAM Newsletter 45, pp.113-117.**
- **Järvenoja, Simo, 2005: Problems in predicted HIRLAM T2m in winter, spring and summer. SRNWP/HIRLAM Workshop on Surface Processes, Surface Assimilation and Turbulence, Norrköping 15-17 September 2004**
- **Rontu, Laura, 2006: A studyon parametrization of orography-related momentum fluxes in a synoptic-scale NWP model.Tellus, 58A, 69-81.**
- **Rontu, Laura, 2007: HIRLAM in Sodankylä and at Vattnajökull. 2007 HIRLAM All-Staff Meeting/ALADIN Workshop. Oslo, 23 - 26 April, 2007.**
- **Sass, B. H., and N. W. Nielsen, 2004: Modelling of the HIRLAM surface stress direction. HIRLAM Newsletter 45, 105-112.**