Numerical weather prediction at high latitudes

Nils Gustafsson

SMHI, Norrköping, Sweden

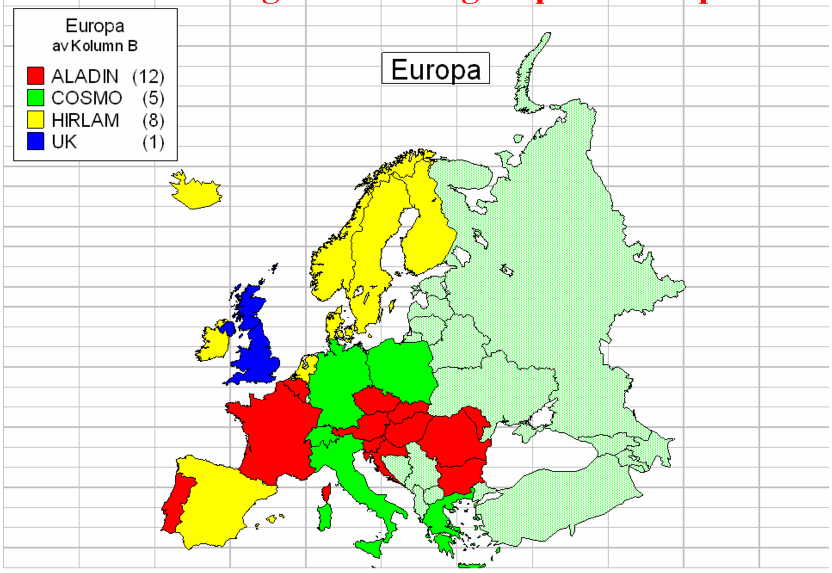
Material for this talk was contributed by:

**Tage Andersson, Per Dahlgren, Stefan Gollvik,
Xiang-Yu Hans Huang, Lars Meuller, Patrik Samuelsson,
Harald Schyberg, Sander Tijm, Vibeke W. Thyness,
Frank T. Tveter and Xiaohua Yang**

High latitude NWP - outline of talk

- **The HIRLAM-A program**
- **The reference HIRLAM forecasting system**
- **Verification scores**
- **The Nordic temperature problem – a new snow scheme**
- **(Turbulence in stable boundary layers)**
- **Snow band simulations (very old slides!)**
- **Data assimilation developments (4D-Var, AMSU-A and AMSU-B over sea ice)**

Regional NWP groups in Europe



Three recommendations by the international evaluation of HIRLAM - strategy for the HIRLAM-A program

- Continue develop synoptic scale forecasting systems based on a merge of the HIRLAM and ALADIN systems.
- Develop a meso-scale forecasting system in collaboration with ALADIN
- Develop EPS, first for synoptic scale forecasting

(shorter than the original text)

The HIRLAM synoptic scale forecasting system

- The semi-implicit, semi-Lagrangian grid-point model
- The 3-Dimensional Variational data assimilation; 3D-Var → 4D-Var
- The incremental Digital Filter initialization (to disappear with 4D-Var)

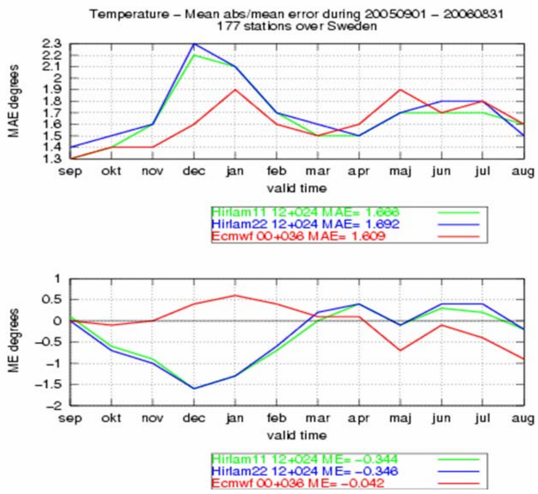
Physical parameterizations in the HIRLAM gridpoint forecast model

- CBR turbulence (Cuxart et al.)
- STRACO condensation, clouds and convection (Sass); Rasch-Kristjansson + Kain-Fritsch as an option (used by SMHI)
- Savijärvi-Sass-Rontu radiation
- ISBA surface and soil → new scheme including canopy temperature and snow

Use of observations in HIRLAM

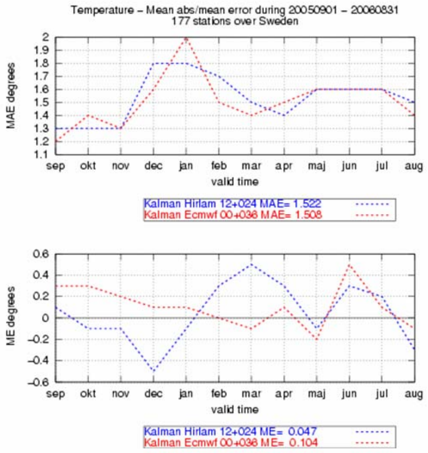
- **Operationally**: TEMP, PILOT, SYNOP, SHIP, AIREP, AMDAR, DRIBU, SATOB and AMSU-A radiances
- **Being implemented**: Scatterometer winds
- **Trials with**: AMSU-B radiances, AMSU-A/B over ice and land, groundbased GPS (zenith and slant delays), MODIS winds, radar radial winds

Verification of 2 m temp. forecasts against Swedish SYNOPs

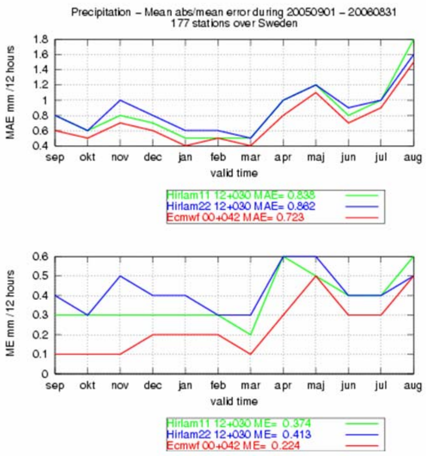


Verification of 2 m temp. forecasts against Swedish SYNOPs

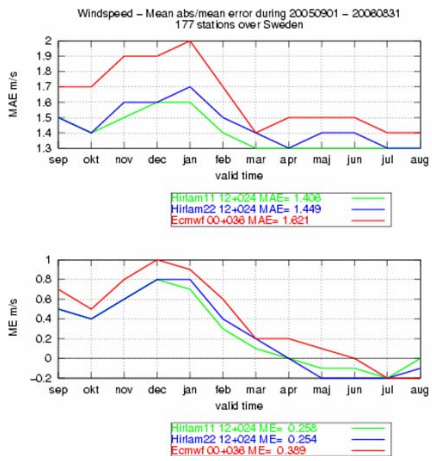
(after post-processing with Kalman filter)



Verification of precip. forecasts against Swedish SYNOPs



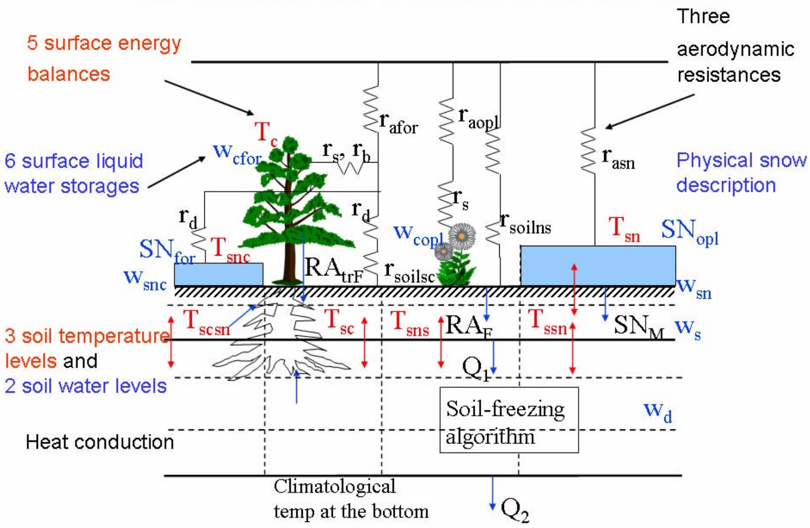
Verification of 10 meter wind forecasts against Swedish SYNOPs



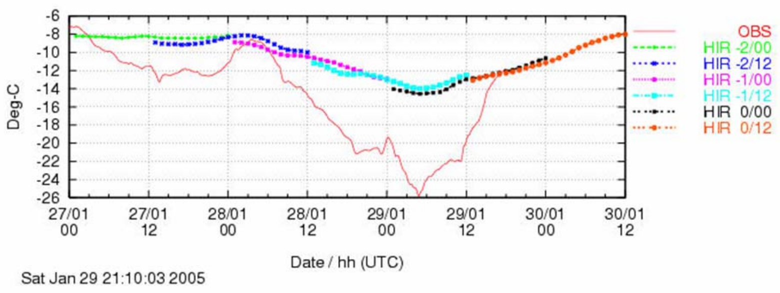
The Nordic temperature problem

- **A new surface and snow parameterization scheme by Stefan Gollvik and Patrik Samuelsson (similar for HIRLAM and the Rossby Center regional climate model)**
- **A HIRLAM 1D model study by Sander Tijm**

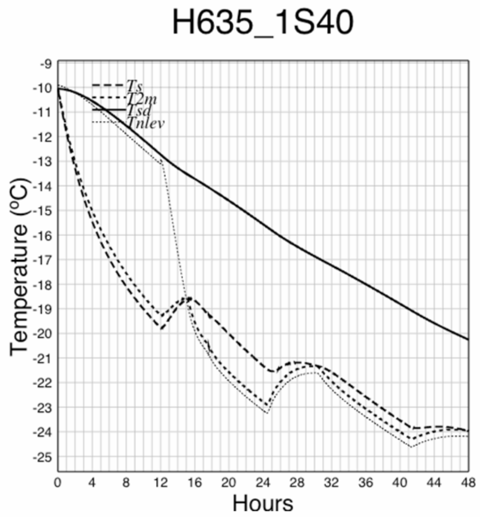
HIRLAM NEW SURFACE SCHEME



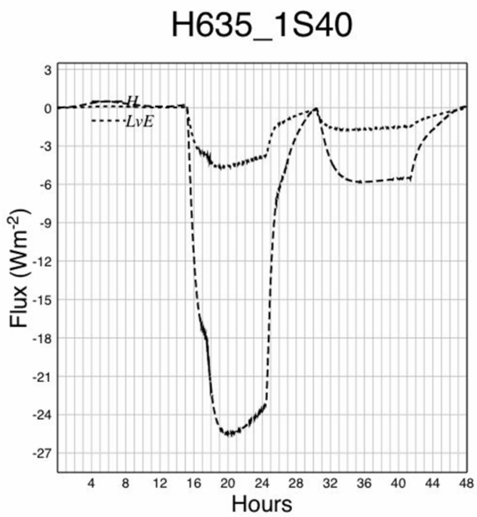
The Nordic cold winter temperature problem



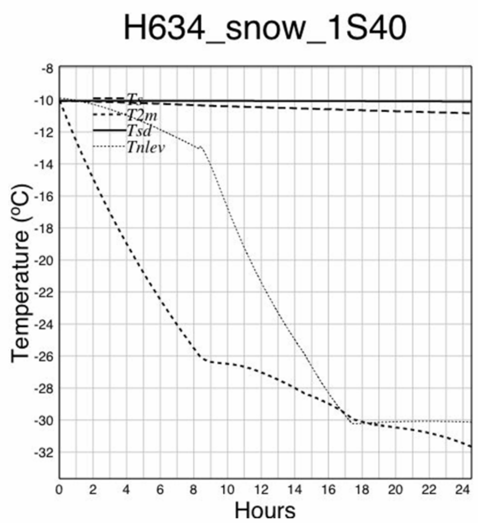
The Nordic cold winter temperature problem

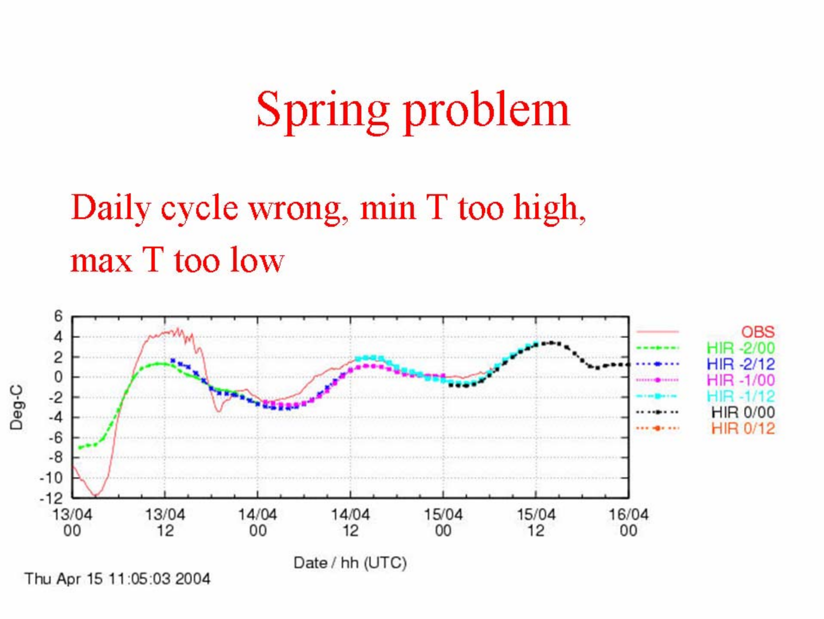


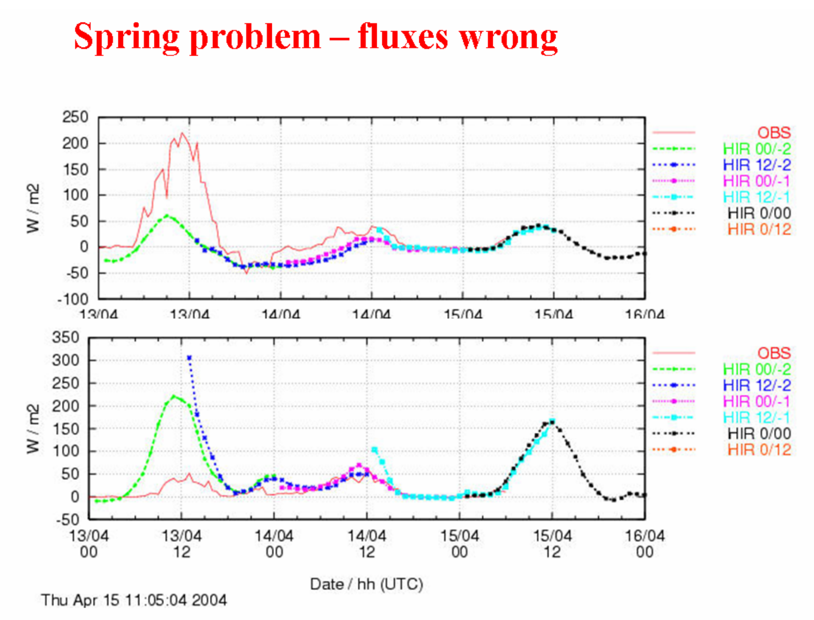
The Nordic cold winter temperature problem

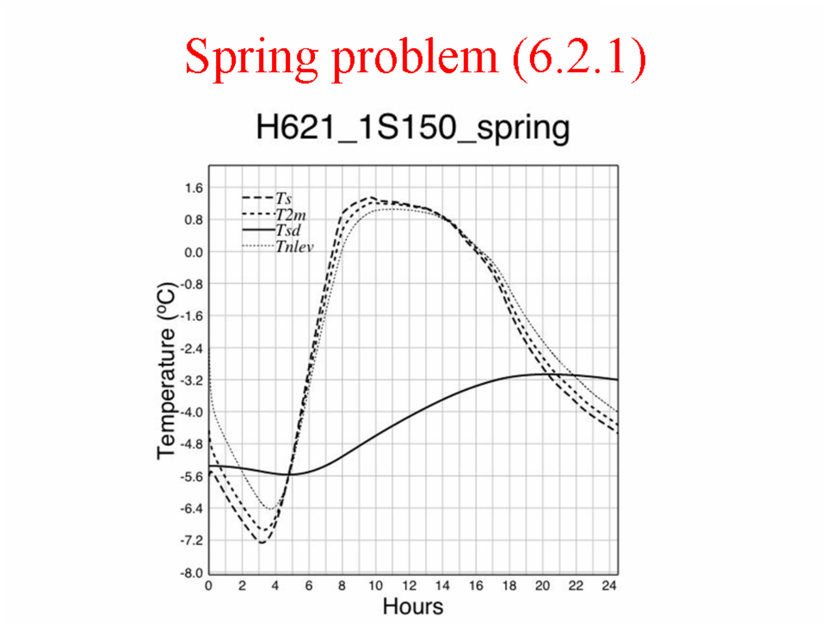


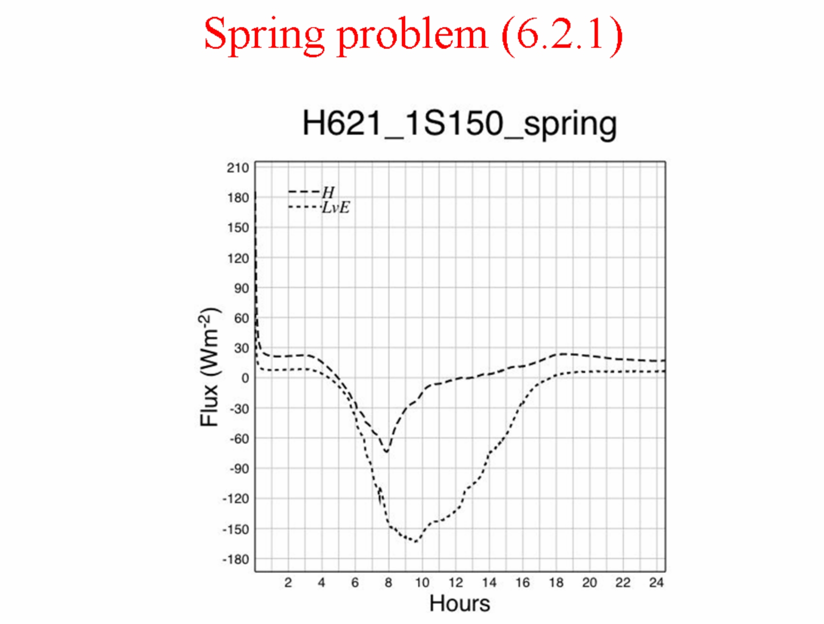
The Nordic winter cold temp. is less of a problem with new snow scheme

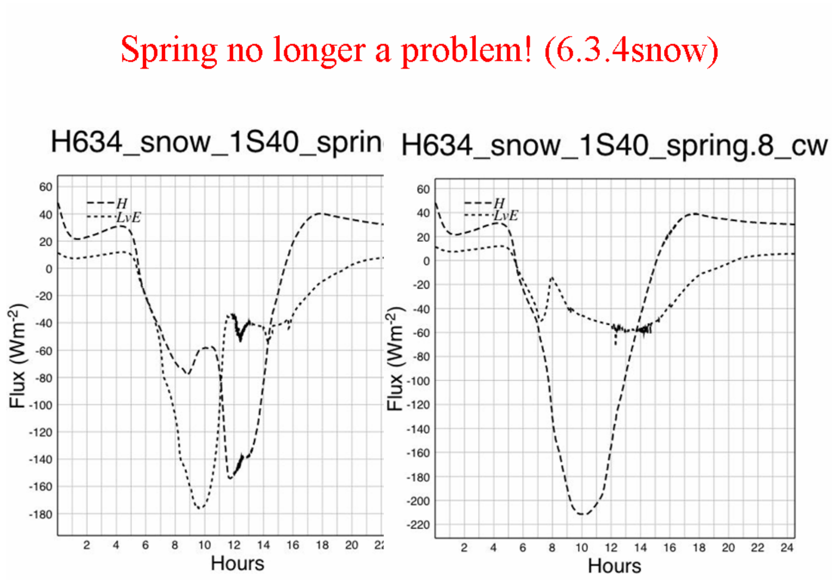


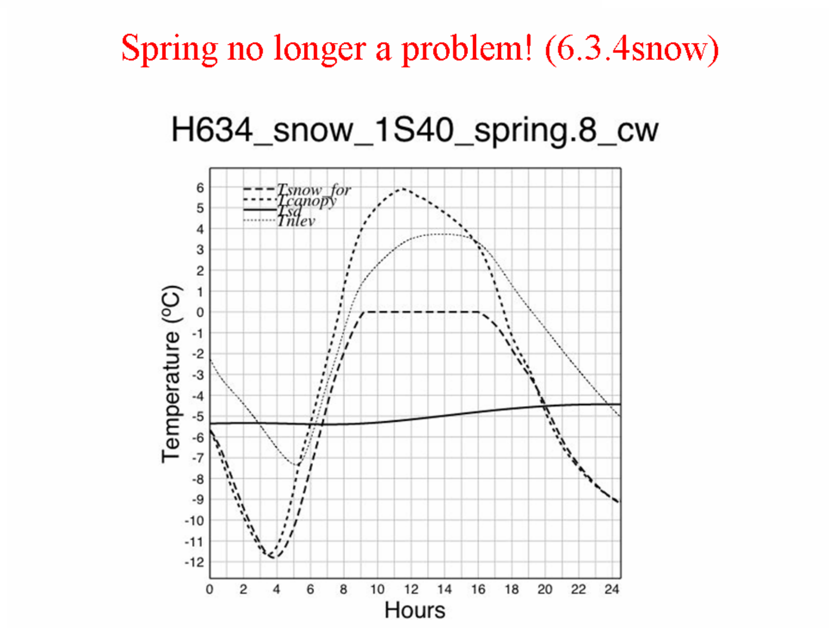

Spring problem
Daily cycle wrong, min T too high,
max T too low
Deg-C
Date / hh (UTC)
OBS
HIR -2/00
HIR -2/12
HIR -1/00
HIR -1/12
HIR 0/00
HIR 0/12
Thu Apr 15 11:05:03 2004


Spring problem – fluxes wrong
W / m2
Date / hh (UTC)
OBS
HIR 00/-2
HIR 12/-2
HIR 00/-1
HIR 12/-1
HIR 0/00
HIR 0/12
Thu Apr 15 11:05:04 2004


Spring problem (6.2.1)
H621_1S150_spring
Ts
T2m
Tsd
Tnlev
Temperature (ºC)
Hours


Spring problem (6.2.1)
H621_1S150_spring
H
LvE
Flux (Wm-2)
Hours


Spring no longer a problem! (6.3.4snow)
H634_snow_1S40_sprin
H634_snow_1S40_spring.8_cw
H
LvE
Flux (Wm-2)
Hours


Spring no longer a problem! (6.3.4snow)
H634_snow_1S40_spring.8_cw
Tsnow_for
Tcanopy
Tsd
Tnlev
Temperature (°C)
Hours

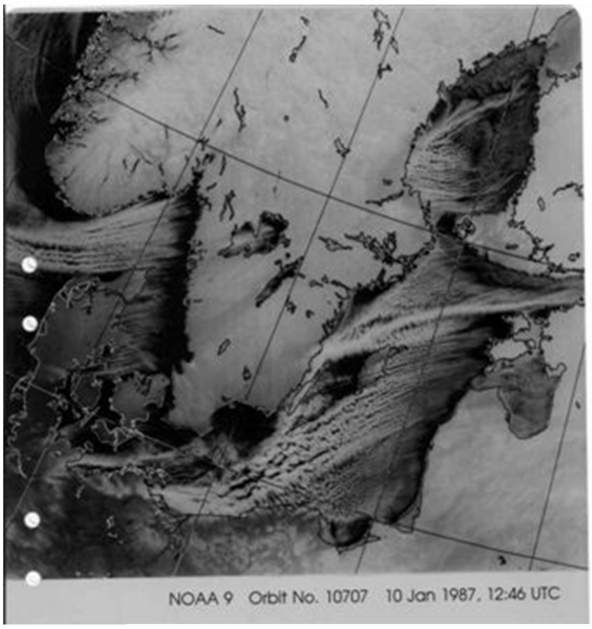
Simulation of snow-bands in the Baltic Sea

From

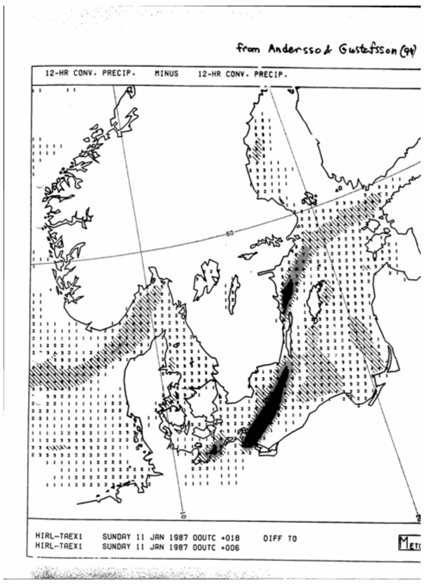
Andersson and Gustafsson, 1994:

Coast of Departure and Coast of Arrival: Two important concepts for formation of convective snowbands over seas and lakes. MWR

- **Snowbands in January 1987; Why does it snow so much in Oskarshamn?**
- **Simulations with HIRLAM 22 km, 16 levels**
- **Sensitivity to changes in coastlines, ice borders, orography heights and surface roughness**



Reference experiment: No changes to coastlines etc.



Experiment 1:

Removal of the Bay of Finland

(Coast of departure)

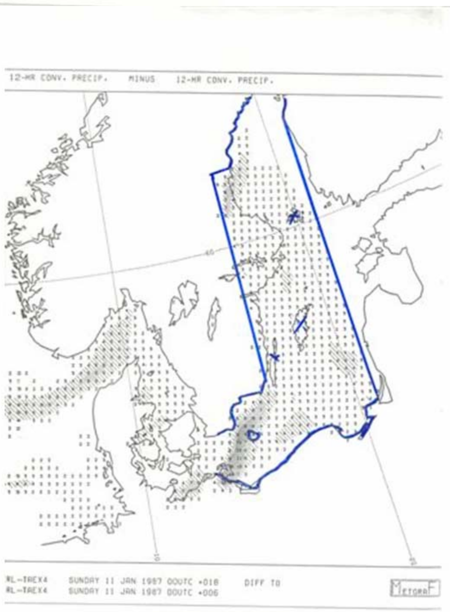
Experiment 2:

Removal of the Stockholm peninsula

(Coast of arrival)

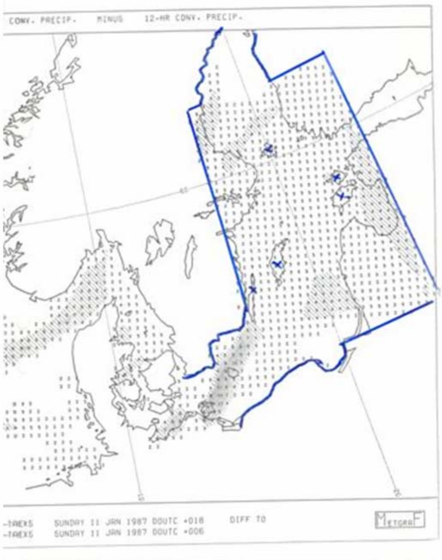
Experiment 3:

Removal of the Bay of Finland and the Stockholm Peninsula



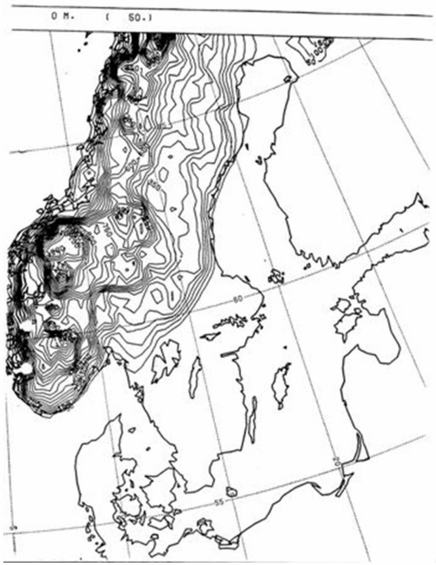
Experiment 4:

Widening of the "Baltic Sea"



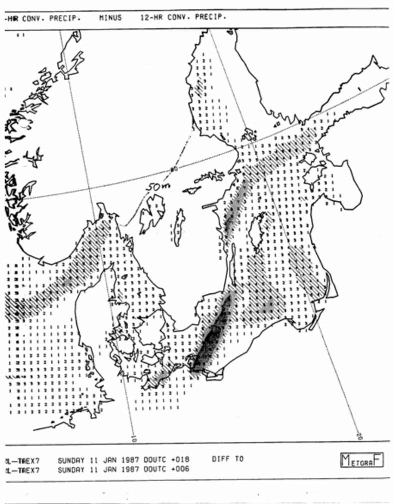
Experiment 5:

Flat orography in Southern Scandinavia



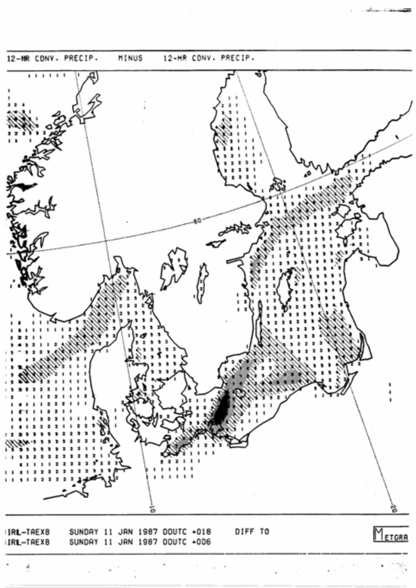
Experiment 5:

Flat orography in Southern Scandinavia

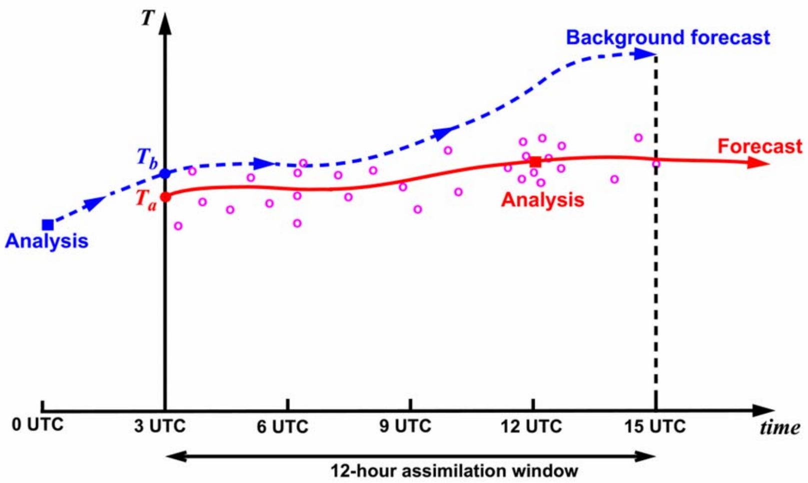


Experiment 6:

Flat orography + constant surface roughness length in Southern Scandinavia



4-dimensional variational data assimilation



Development of HIRLAM 4D-Var.

1995-1999: Tangent linear and adjoint of the Eulerian spectral adiabatic HIRLAM. Sensitivity experiments.Tangent linear and adjoints of the full HIRLAM physics.

2000: First experiments with ”non-incremental” 4D-Var.

2001-2002: Incremental 4D-Var. Simplified physics packages (Buizza vertical diffusion and Meteo France package).

2003-2004: Semi-Lagrangian scheme (SETTLS), outer loops (spectral or gridpoint HIRLAM) and multi-incremental minimization.

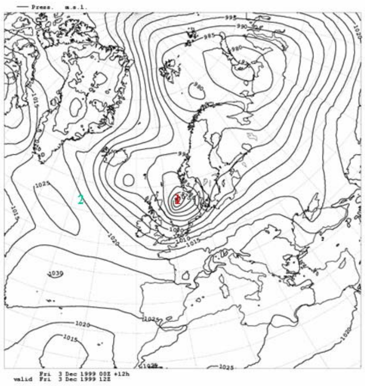
2005-2006: Extensive tests of 4D-Var. Poor results → **BUG correction → Good results**! Continued extensive tests. Weak digital filter constraint. Control of lateral boundary conditions.

Single observation experiment with HIRLAM 4D-Var;

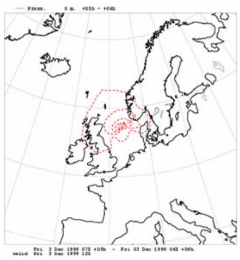
What is the effect of a single surface pressure observation increment of -5 hPa at + 5 hours in the assimilation window?

1: In the center of a developing low

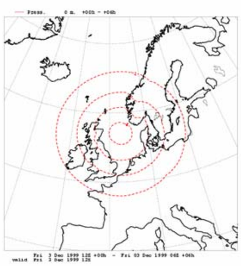
2. In a less dynamically active area



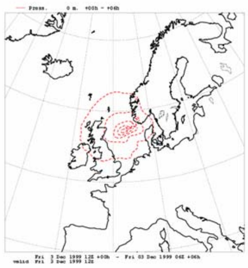
Surface pressure increments for the Danish storm



4D-Var, spectral TL prop. of incr



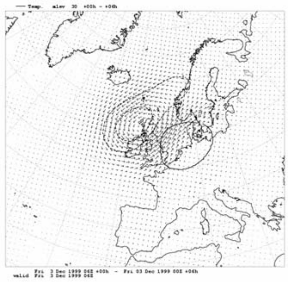
3D-Var



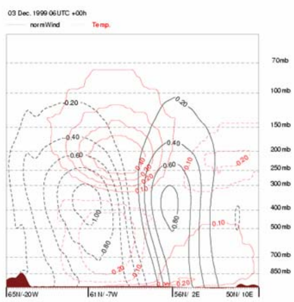
4D-Var; gp model prop. of incr.

Effects of a -5 hPa surface pressure observation increment at +5 h on the initial wind and temperature increments

Winds at model level 20 (500 hPa) and temperatures at level 30 (below)



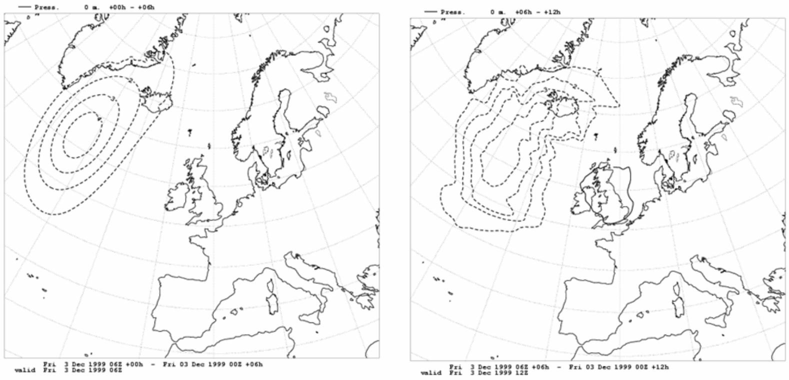
NW-SE cross section with temperatures and normal winds



Effects of a -5 hPa surface pressure observation increment at +5 h in a less dynamically active area

Surface pressure assimilation increment at +0 h

Difference between non-linear forecasts at +6 h with and without the 4D-Var assimilation increment

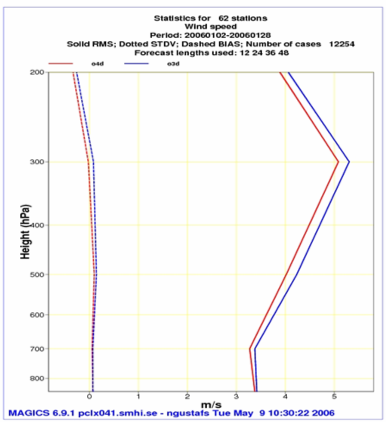


Recent HIRLAM 4D-Var tests

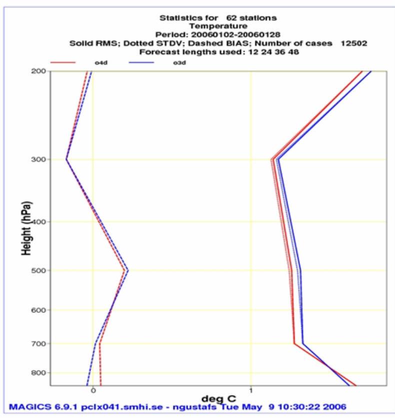
- The SMHI 22 km area (306x306x40 gridpoints)
- SMHI operational observations (including AMSU-A and ”extra” AMDAR observations)
- 6 h assimilation cycle; 3D-Var with FGAT; 6 h assimilation window in 4D-Var; 1 h observation windows
- 66 km assimilation increments in 4D-Var (linear grid); 44 km assimilation increments in 3D-Var (quadratic grid)
- Non-linear propagation of assimilation increments
- 3 months of data (January 2005, June 2005, January 2006)

Average upper air forecast verification scores – January 2006

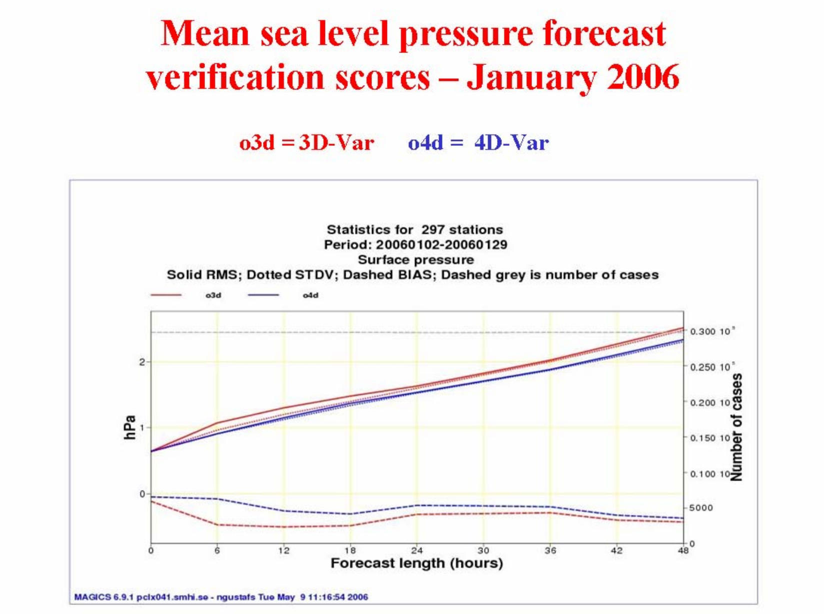
o3d = 3D-Var o4d = 4D-Var

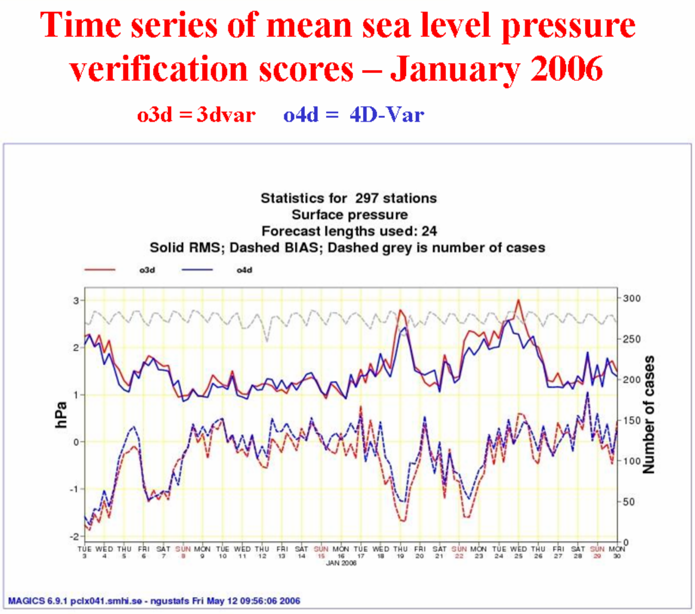


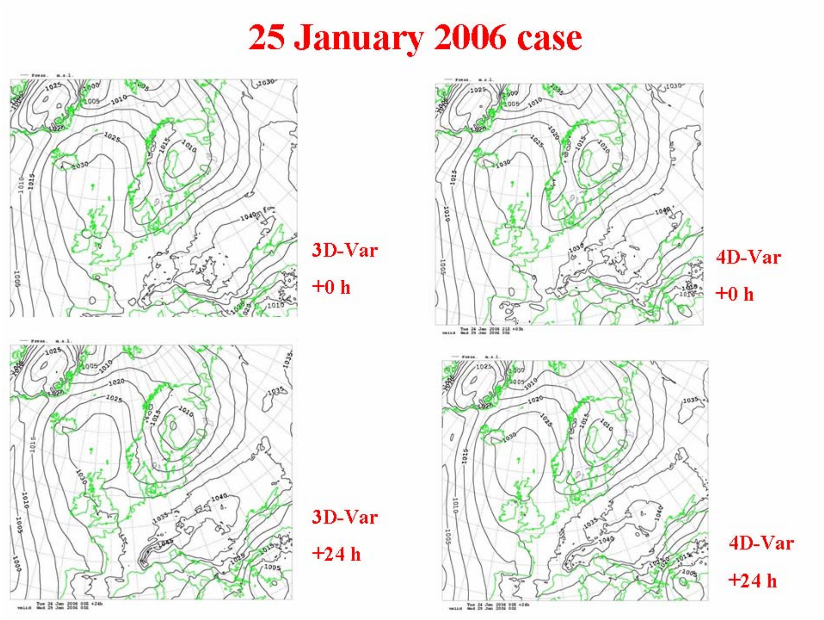
Wind speed



Temperature


Mean sea level pressure forecast verification scores – January 2006
o3d = 3D-Var
o4d = 4D-Var
Statistics for 297 stations
Period: 20060102-20060129
Surface pressure
Solid RMS; Dotted STDV; Dashed BIAS; Dashed grey is number of cases
o3d
o4d
hPa
Number of cases
Forecast length (hours)
MAGICS 6.9.1 pclx041.smhi.se - ngustafs Tue May 9 11:16:54 2006


Time series of mean sea level pressure verification scores – January 2006
o3d = 3dvar
o4d = 4D-Var
Statistics for 297 stations
Surface pressure
Forecast lengths used: 24
Solid RMS; Dashed BIAS; Dashed grey is number of cases
o3d
o4d
hPa
Number of cases
JAN 2006
MAGICS 6.9.1 pclx041.smhi.se - ngustafs Fri May 12 09:56:06 2006

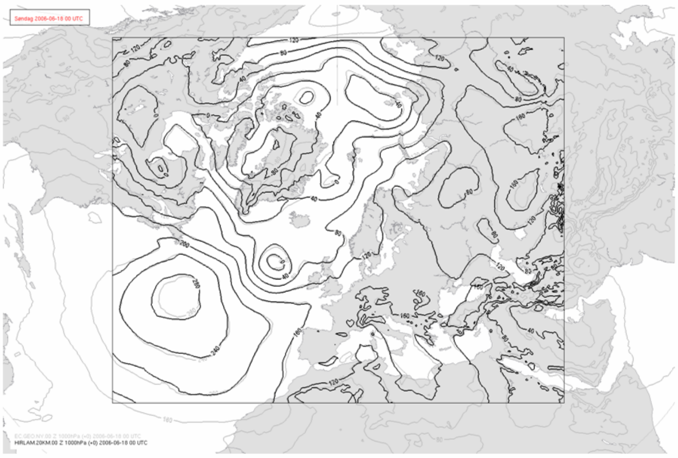

25 January 2006 case
3D-Var
+0 h
4D-Var
+0 h
3D-Var
+24 h
4D-Var
+24 h

Assimilating AMSU-A over sea ice in HIRLAM 3D-Var

From Harald Schyberg, Vibeke W. Thyness and Frank T. Tveter

Norwegian Meteorological Institute
met.no

Norwegian HIRLAM 20km model domain



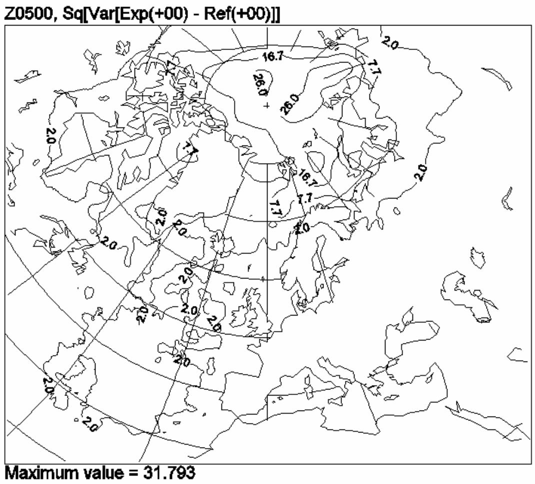
Impact of added AMSU-A over sea ice experiment setup

- Experiment period 26 February to 30 April 2005
- HIRLAM 20 km resolution, 3D-Var assimilation,
- Conventional observations and direct use of AMSU with forward model RTTOV

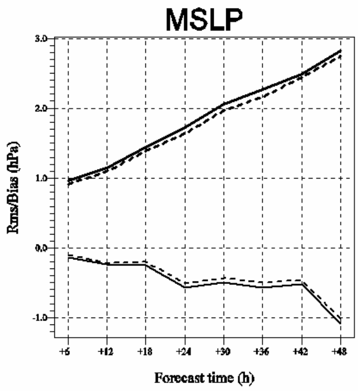
Parallel suites with 6 hr cycling, forecasts up to 48 hrs, to highlight effect of observations over sea ice:

- Reference: No AMSU
- Experiment 1: Upper AMSU-A channels over sea ice only (Ch 1 to 5 only in “passive mode”)
- Experiment 2: Both upper channels and surface sensitive channels over sea ice, using simple emissivity estimate (not completed)

Ref-Exp1 increments, analysis (RMS diff, Z 500 hPa)



MSLP verification results against EWGLAM list

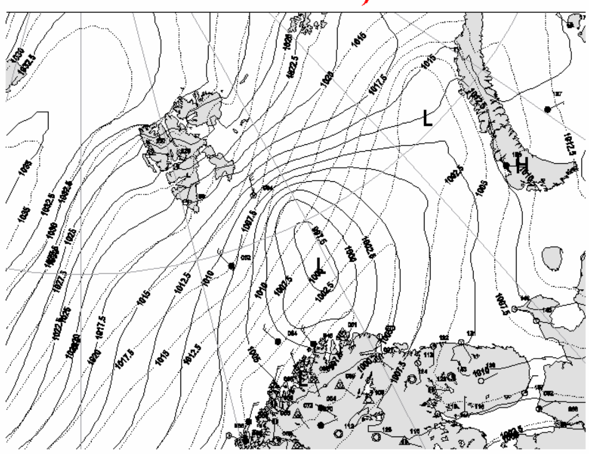


Verification statistics against observations on EWGLAM list (List of SYNOPs considered reliable over Europe)

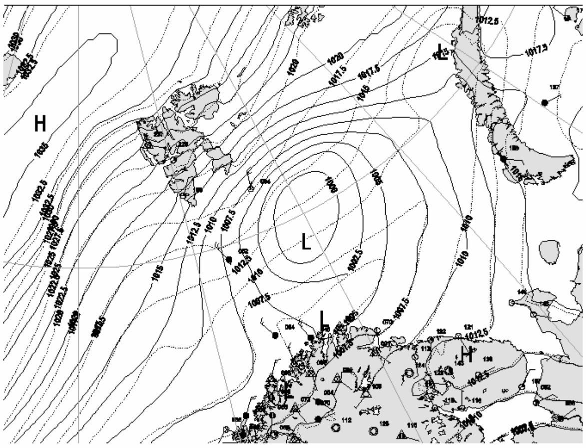
•Problem: Scarcity of Arctic conventional observations for verification

•Overall statistics: Positive impact of adding AMSU-A on EWGLAM verification, but impact highly situation dependent

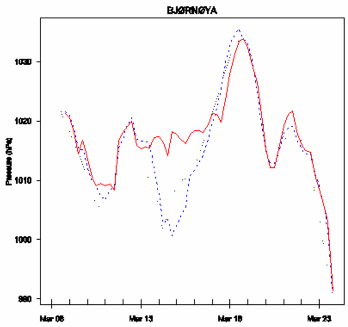
14 March 2005 00Z (+24 hrs exp solid and ref dashed)



14 March 2005 00Z (analysis exp solid and ref dashed)



Timeseries of pressure obs (blue dots) and ref (red) /exp (blue) forecasts (18-36hrs) at Bjørnøya



Conclusions from these impact and case studies

- Generally difficult to measure the impact over the sea ice regions
- Impact can be kept in model for long periods in data-sparse regions.
- Single observations sometimes not sufficient for bringing the model "back on track" – rejection by quality control checks
- Verifying with the conventional observation network over Europe, we find that the impact varies with circulation pattern. With general upper flow from the sea ice towards the North Atlantic: cases of significant impact identified.
- Inclusion in operational model runs with HIRLAM being implemented

Use of lower tropospheric channels

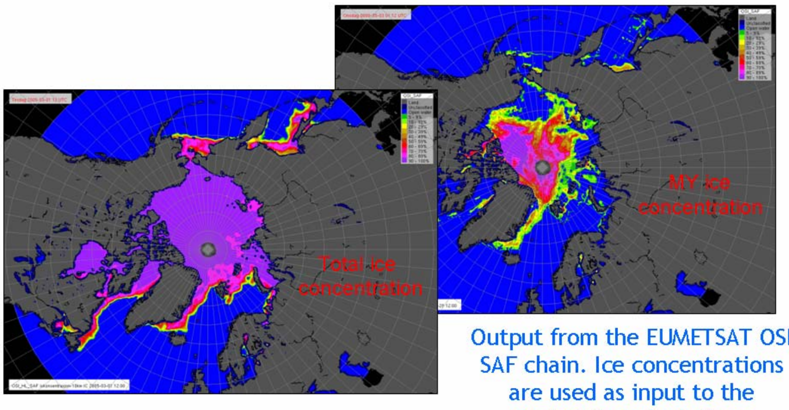
Large part of the Arctic ice cap comprised of closed, near 100% concentration, sea ice

Sea ice emissivity is usually more stable in time than typical weather systems

Can we take advantage of daily maps of sea ice properties (from SSMI) and use first-year (FY) and multi-year (MY) concentrations as predictors for AMSU channel surface emissivity over the inner Arctic?

Method implemented in IOMASA (starting point for further work in EU project DAMOCLES and possibly EUMETSAT OSI SAF)

Emissivities: A first simple approach



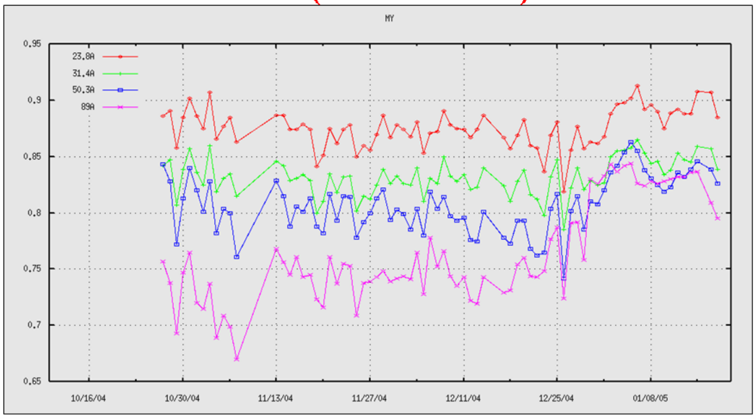
Output from the EUMETSAT OSI SAF chain. Ice concentrations are used as input to the emissivity calculations

Estimation of typical FY and MY sea ice emissivities (Toudal, 2005)

Simplified theory for microwave radiative transfer, where the main assumptions are that

- The atmospheric attenuation can be reasonably approximated by an absorption coefficient and an effective atmospheric temperature Ta
- The water vapour load is minimal so the main contribution to the absorption is from oxygen
- Then the surface emissivity can be estimated from the measured brightness temperature T_b

Example timeseries of AMSU-A emissivities for a limited area of Multi Year ice north of Greenland (from Toudal)



Emissivities

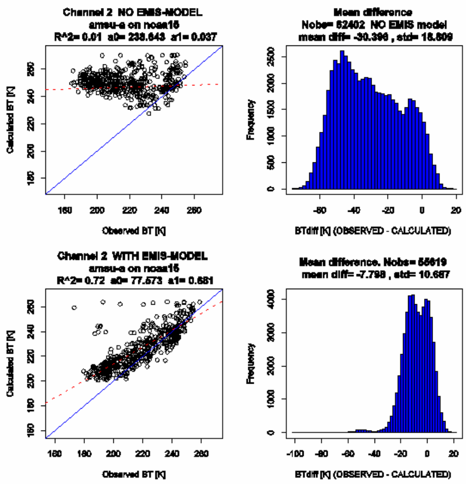
Use OSI SAF FY and MY ice concentrations with typical values (Toudal) of AMSU emissivities for these surfaces:

$$\varepsilon = c_W \varepsilon_W + c_F \varepsilon_F + c_M \varepsilon_M,$$

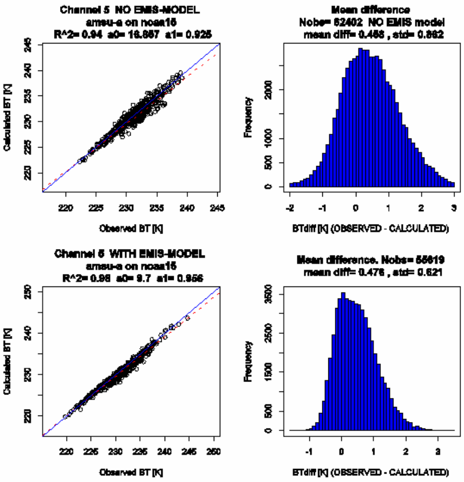
$$c_W + c_F + c_M = 1.$$

AMSU-A channel	First year ice	Multi year ice
1	0.971	0.874
2	0.970	0.829
3	0.928	0.796
4	0.928	0.796
5	0.928	0.796
6	0.928	0.796
7	0.928	0.796
8	0.928	0.796
9	0.928	0.796
10	0.928	0.796
11	0.928	0.796
12	0.928	0.796
13	0.928	0.796
14	0.928	0.796
15	0.913	0.744

Comparison with constant emissivity, channel 2



Comparison with constant emissivity, channel 5



Possbile further developments on emissivities

Could probably improve present method with

- Further tuning and adjustment of emissivities using background departure statistics
- Add regional/seasonal and incidence angle dependence to pure FY and MY AMSU emissivities

But the long-term strategy should probably be a combination of a statistical approach and a surface microphysical emissivity model

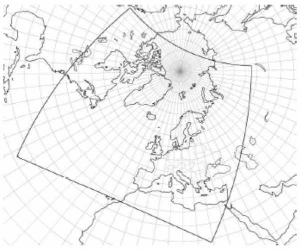
- Better predictors for emissivity than SSMI-based FY and MY concentration retrievals
- Correlations of emissivities between channels exploited more directly
- Emissivity in control variable (implemented at SMHI) with a first guess estimate
- Feedback of obs departures to emissivity predictors
- Include meteorological history in a microphysical model of the sea ice surface (snow, freeze, melt, …)

Assimilation of AMSU-B moisture retrievals or AMSU-B radiances over sea ice surfaces?

Work done by

Per Dahlgren, SMHI within

EU-IOMASA.



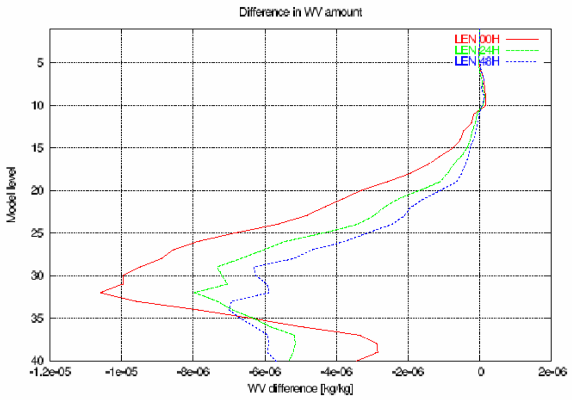
•Only AMSU-B moisture retrievals have been assimilated so far

•Illustrates the verification problem

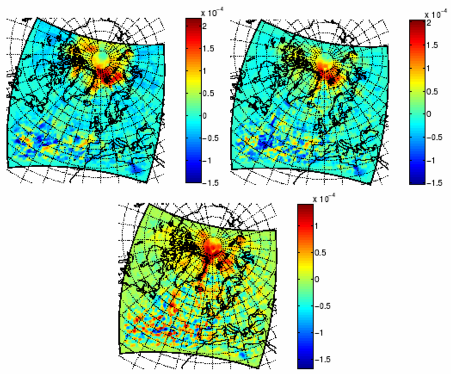
•REF:reference experiment, EXP:with assimilation of moisture retrievals

Impact of the AMSU-B moisture retrieval at different forecast lengths (REF-EXP):

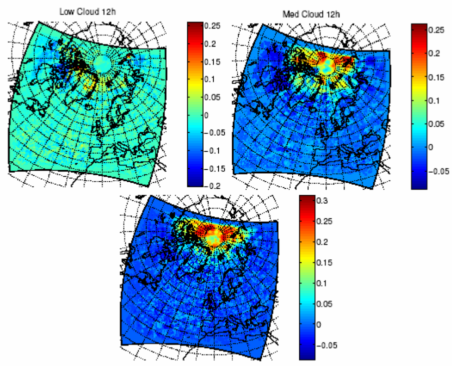
+00h, +24h and +48h



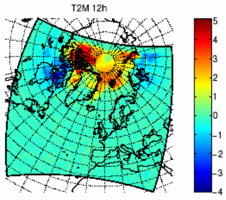
Differences (EXP-REF) between monthly means of water vapor at model 30: +00h, +24h and +48h



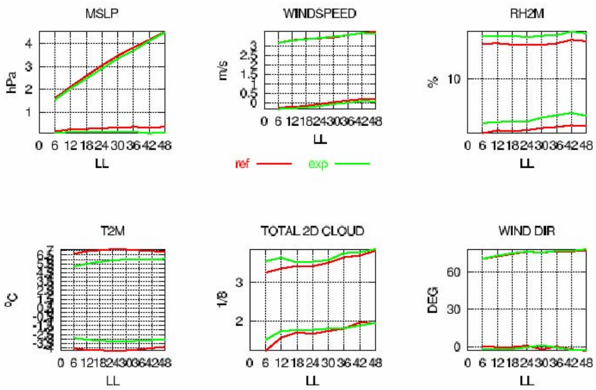
Differences (EXP-REF) between monthly means of cloudiness at +12h: Low clouds, middle clouds and high clouds



Differences (EXP-REF) between monthly means of 2 meter temp. forecasts (12h)



Verification of forecasts against Arctic SYNOPs



Concluding remarks

- The new HIRLAM surface/soil/snow scheme seems to “solve” important Nordic temperature forecasting problems (without degrading other features?)
- Convective snow band in the Baltic Sea in January 1987 were sensitive to distribution of land, sea and sea ice.
- HIRLAM 4D-Var seems to provide flow-dependent influence of observations and consistently improved forecast scores.
- More upper air data are needed in the Arctic (for example satellite radiances over sea ice). We need to improve the lower boundary conditions for the assimilation.
- Data impact studies may sometimes be confused by model (and observation) biases.