Snow Analysis
for Numerical Weather prediction
at ECMWF

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European Centre for Medium-Range Weather Forecasts

ECMWF

Land surface data assimilation

1999	2004	2010/2011

OI screen level analysis

Douville et al. (2000)

Mahfouf et al. (2000)

Soil moisture 1D OI analysis

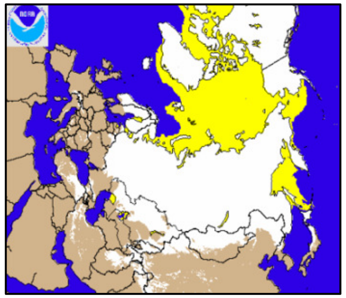
based on Temperature and relative humidity analysis

SYNOP Data

Revised snow analysis

Drusch et al. (2004)

Cressman snow depth analysis using SYNOP data improved by using NOAA / NSEDIS Snow cover extend data (24km)



NOAA/NESDIS IMS

Structure Surface Analysis

Optimum Interpolation (OI) snow analysis

Pre-processing NESDIS data

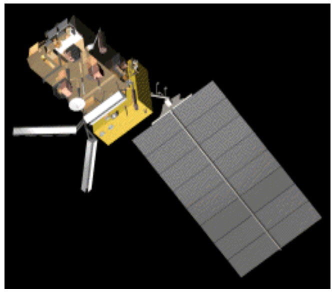
High resolution NESDIS data (4km)

SEKF Soil Moisture analysis

Simplified Extended Kalman Filter

Drusch et al. GRL (2009)

De Rosnay et al. ECMWF NewsLett. (2011)



METOP-ASCAT

SMOS

Snow Analysis

Snow Quantities:

- Snow depth SD (m)
- Snow water equivalent SWE (m) – ie mass per m^2
- Snow Density ρ_s, between 100 and 400 kg/m3

$$SWE = \frac{SD \times \rho_S}{1000} \quad [\mathrm{m}]$$

Background variable used in the snow analysis:

- Snow depth S^b

  computed from forecast SWE and density
  model parameterization revised in 2009
  (Dutra et al., J Hydromet. 2009)

Observation types:

- Conventional data: SYNOP snow depth (S^O)
- Satellite: Snow cover extent (NOAA/NESDIS)

NOAA/NESDIS Snow extent data

Interactive Multisensor Snow and Ice Mapping System

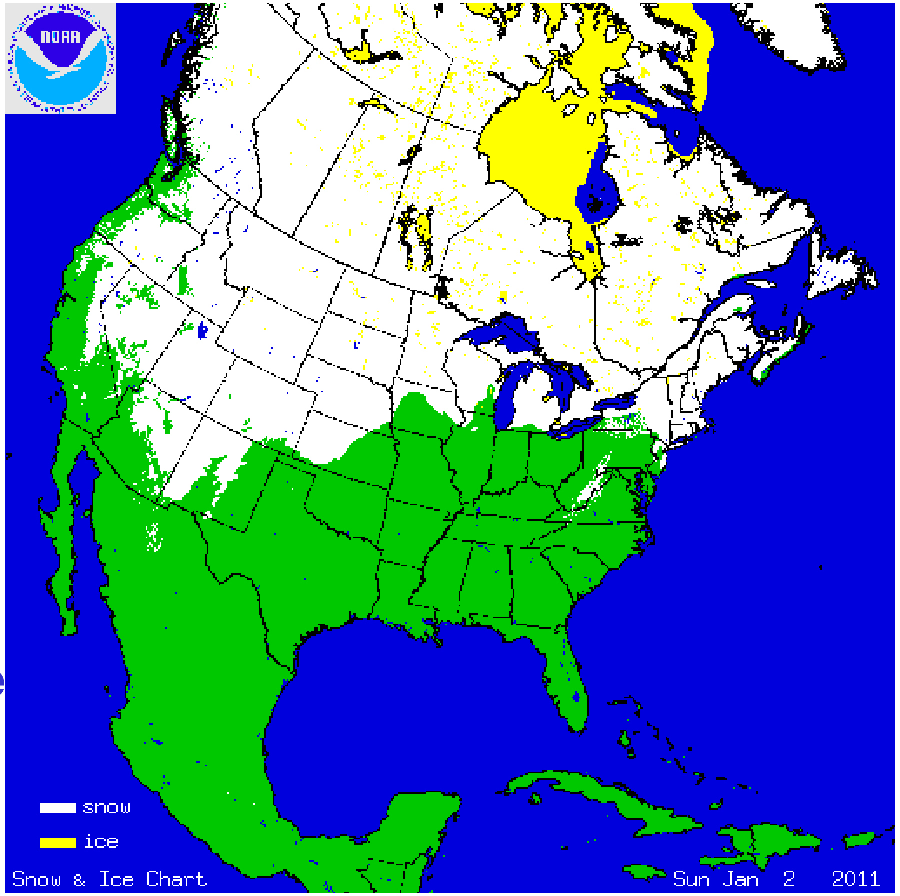
- Time sequenced imagery from geostationary satellites
- AVHRR,
- SSM/I
- Station data

Northern Hemisphere product

- Daily
- Polar stereographic projection

Resolution

- 24 km product (1024 × 1024)
- 4 km product (6044 x 6044)



Information content: Snow/Snow free

Format:

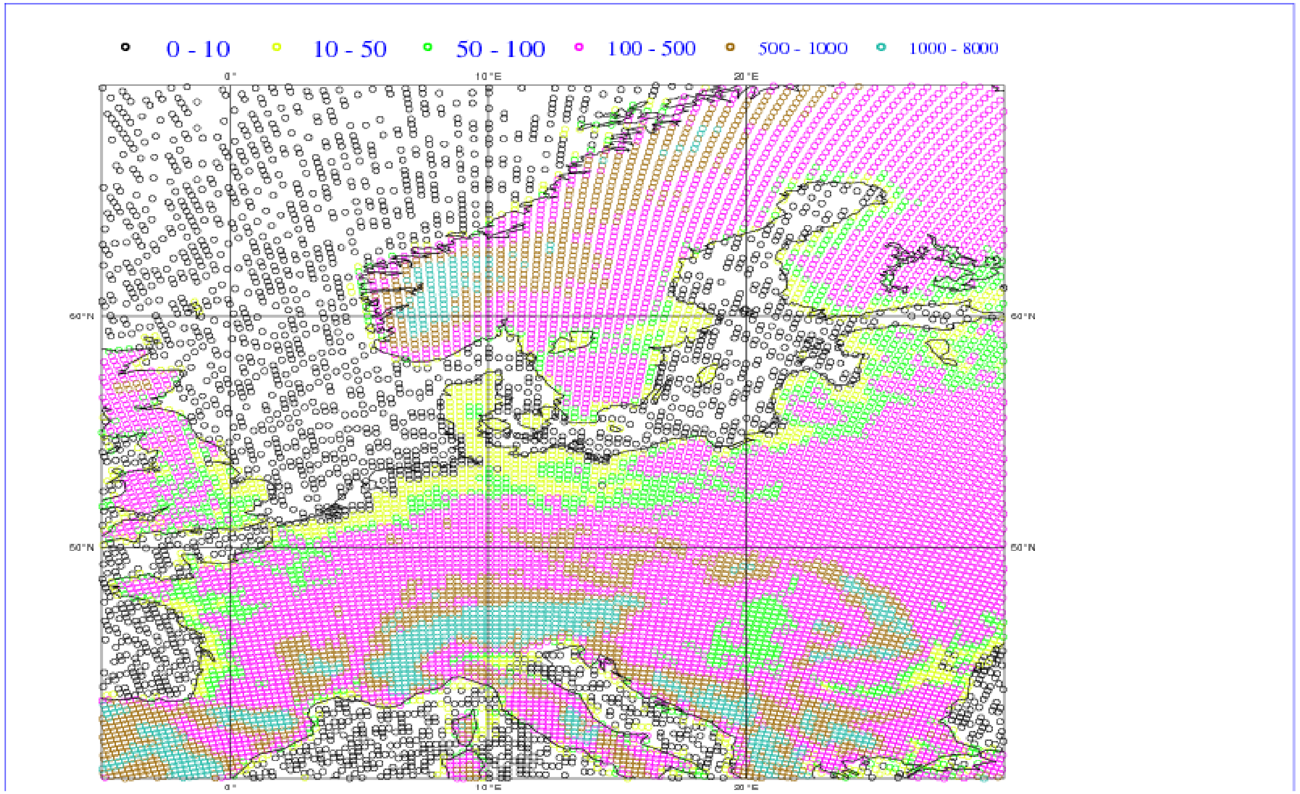
- 24km product in Grib
- 4 km product in Ascii

More information at: http://nsidc.org/data/g02156.html

ECMWF

NOAA/NESDIS Pre-Processing

- Pre-processing revised in 2010.
- NOAA/NESDIS data received daily at 23UTC.
- Pre-processing:
  - Conversion to BUFR
  - BUFR content: LSM, NESDIS snow extent (snow or snow free), and orography, interpolated from the model orograpghy on the NESDIS data points.



Orography (m) included in the BUFR

→ used in the snow analysis

ECMWF

Snow Analysis

SYNOP Pre-Processing:

- SYNOP reports converted into BUFR files.
- BUFR data is put into the ODB (Observation Data Base)

Snow depth analysis in two steps:

1- NESDIS data (12UTC only):

- First Guess snow depth compared to NESDIS snow cover

NOAA snow & First Guess snow free → put 0.1m snow in First Guess

(First Guess snow free: < 0.01m of snow, ie SWE in [1; 4] mm;
Update: SD 0.1m, snow density=100kg/m3, SWE=0.01m)

- NESDIS snow free → used as a SYNOP snow free data

2- Snow depth analysis (00, 06, 12, 18 UTC):

- Cressman interpolation: 1987-2010
  Still used in ERA-Interim
- Optimum Interpolation: Used in Operations since November 2010

ECMWF

Cressman Interpolation

$$S^a = S^b + \frac{\sum_{n=1}^{N} w_n \left(S_n^O - S^{b'}\right)}{\sum_{n=1}^{N} w_n}$$

- (**Cressman 1959**)
- S^O snow depth from synop reports,
- S^b background field estimated from the short-range forecast of snow water equivalent,
- $S^{b'}$ background field at observation location, and
- w_n weight function, which is a function of horizontal r and vertical difference h (model – obs): w = H(r) v(h) with:

$$H(r) = \max\left(\frac{r_{max}^2 - r^2}{r_{max}^2 + r^2}, 0\right)$$

r_{max} = 250 km (influence radius)

$$v(h) = \begin{cases} 1 & \text{if } 0 < h \\ \dfrac{h_{max}^2 - h^2}{h_{max}^2 + h^2} & \text{if } -h_{max} < h < 0 \\ 0 & \text{if } h < -h_{max} \end{cases}$$

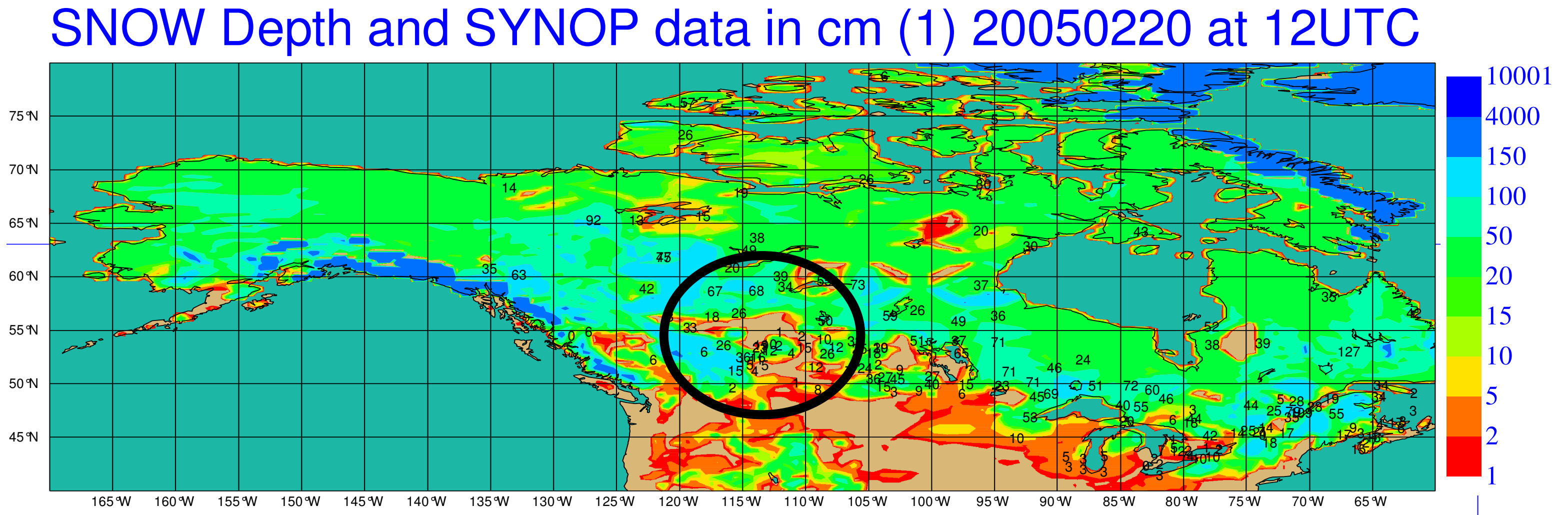
Model above observing station

h_{max} = 300 m (model no more than 300m below obs)

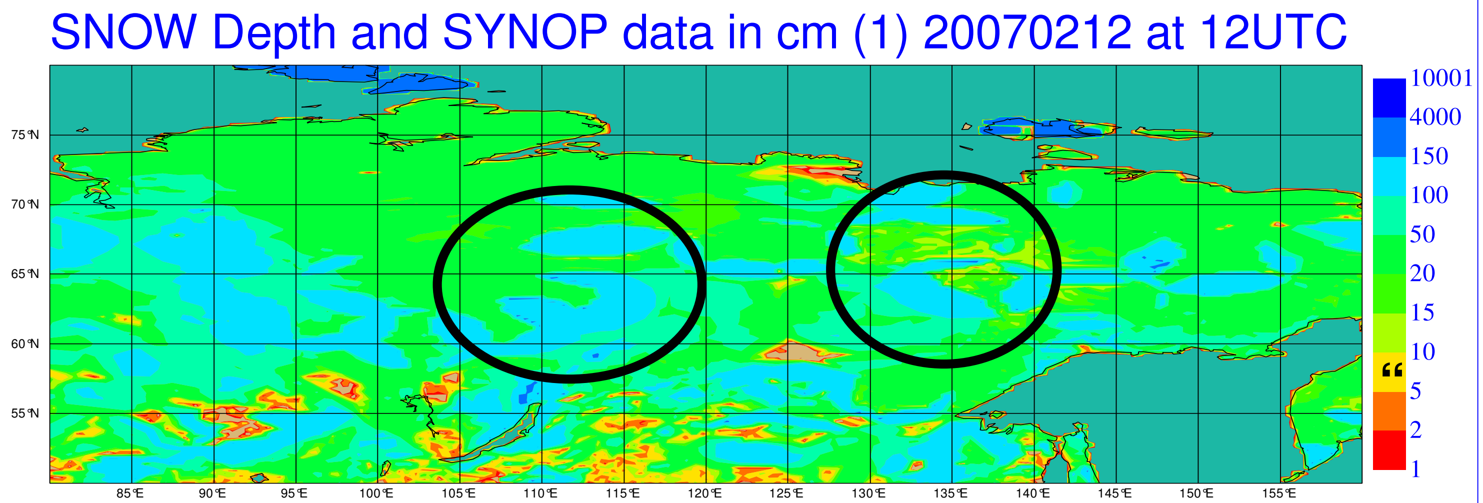
Obs point more than 300m higher than model

Some issues in the Cressman Snow analysis

“PacMan” Snow Patterns where observations are scarce



North America 2005

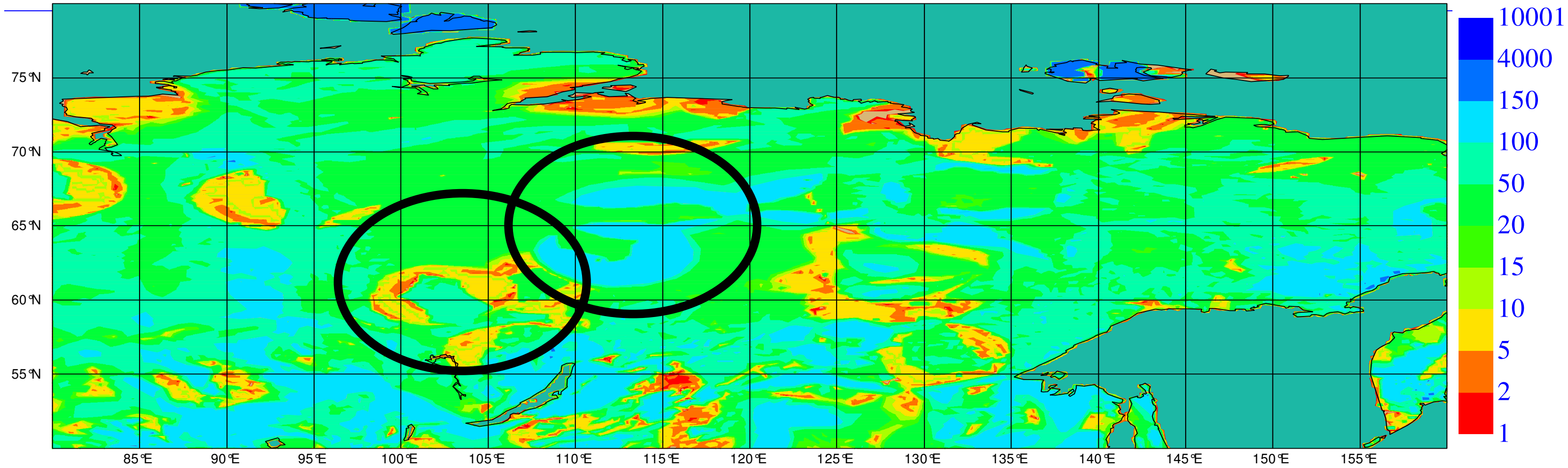


Siberia 2007

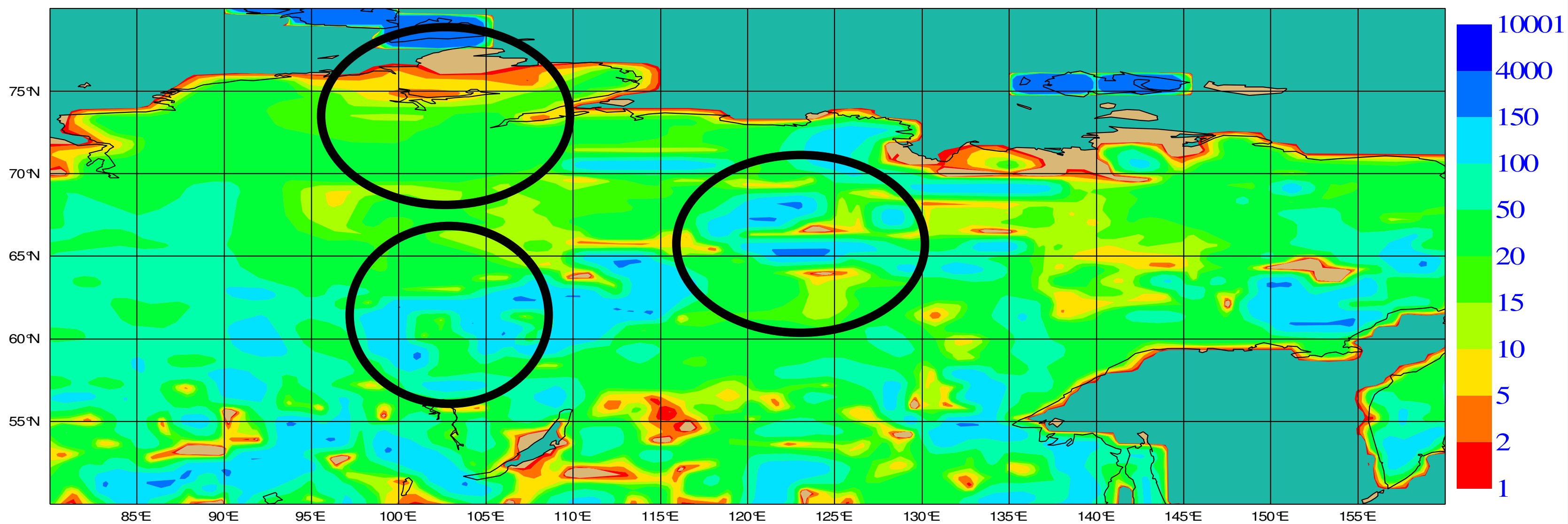
Snow Patterns, “PacMan” issues – example on 23 Feb 2010

SNOW Depth (cm)

Deterministic Analysis, T1279 (16km)
Integrated Forecasting System IFS cycle 36r1



ERA-Interim re-analysis, T255 (80km), IFS cycle 31r1



Revised snow analysis

Winter 2009-2010 highlighted several shortcomings of the snow analysis related to the Cressman analysis scheme as well as to a lack of satellite data in coastal areas, as well as issues in the NESDIS product pre-processing at ECMWF, fixed in flight in operations on 24 Feb 2010.

<u>Revised snow analysis from Nov. 2010:</u>

(from Integrated Forecasting System, IFS cycle 36r4)

- **OI:** New Optimum Interpolation Snow analysis, using weighting functions of Brasnett, J. Appl. Meteo. (1999). The OI makes a better use of the model background than Cressman.
- **NESDIS:** NOAA/NESDIS 4km ASCII snow cover product (substituting the 24 km GRIB product) implemented with fixes in geometry calculation. The new NESDIS product is of better quality with better coverage in coastal areas.
- **QC:** Introduction of blacklist file and rejection statistics. Also allows easier identification of stations related to MS queries.

Snow depth Optimum Interpolation

1. Observed Increments from the interpolated background ΔS_i are estimated at each observation location i.

2. Analysis increments ΔS_j^a at each model grid point j are calculated from:

$$\Delta S_j^a = \sum_{i=1}^{N} w_i \times \Delta S_i$$

3. The optimum weights w_i are given for each grid point j by: (**B** + **O**) **w** = **b**

b : **background error vector** between model grid point j and observation i (dimension of N observations) b(i) = σ^2_b . X μ(i,,j)

B : **error covariance matrix of the background field** (N × N observations) $B(i_1,i_2) = \sigma^2_b \times \mu(i_1,i_2)$ with the horizontal correlation coefficients $\mu(i_1,i_2)$ and σ_b = 3cm the standard deviation of background errors.

$$\mu(i_1,i_2) = \left(1+\frac{r_{i_1 i_2}}{Lx}\right)\exp\left(-\left[\frac{r_{i_1 i_2}}{Lx}\right]^2\right).\exp\left(-\left[\frac{z_{i_1 i_2}}{Lz}\right]^2\right)$$

(Brasnett , 1999)

O : **covariance matrix of the observation error** (N × N observations):
O = σ^2_o × **I** with σ_o = 4cm the standard deviation of obs. Errors
Lz; vertical length scale: 800m, **Lx:** horizontal length scale: 55km
Quality Control: if $\Delta S_i > Tol\ (\sigma b^2 + \sigma o^2)^{1/2}$; Tol = 5

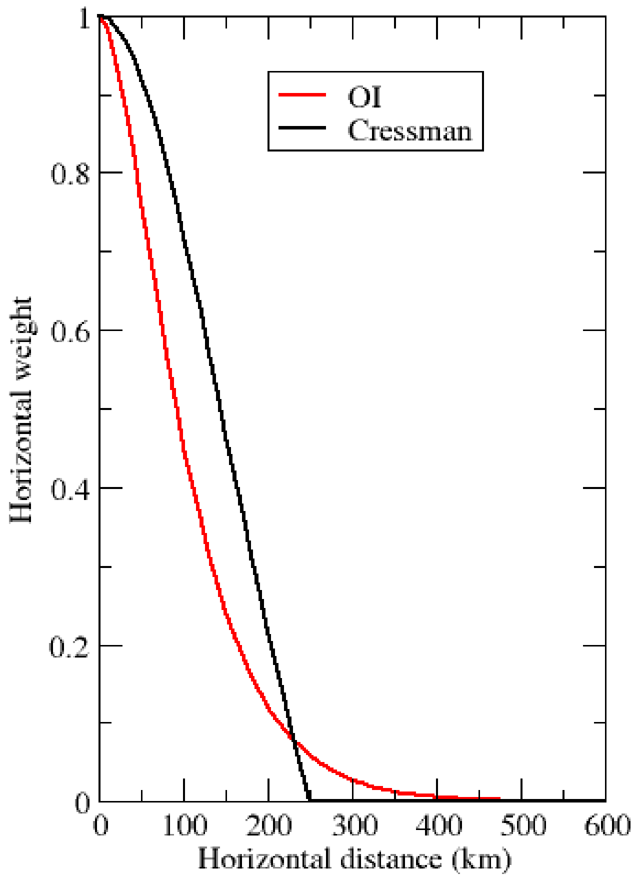
OI vs Cressman

In both cases: $\Delta S_j^a = \sum_{i=1}^{N} w_i \times \Delta S_i$

Cressman (1959): weights are function of horizontal and vertical distances.

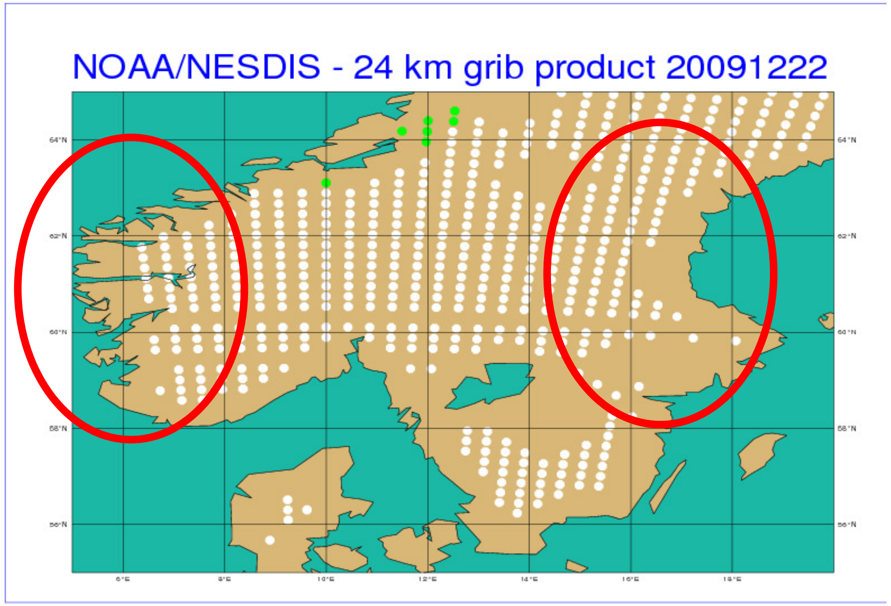
OI: The correlation coefficients of B and b follow a second-order autoregressive horizontal structure and a Gaussian for the vertical elevation differences.

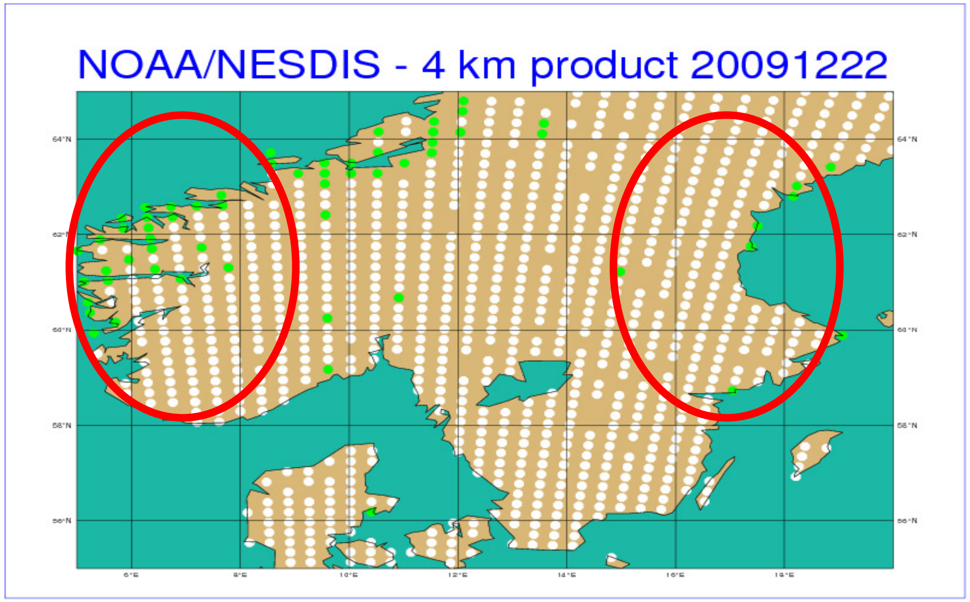
OI has longer tails than Cressman and considers more observations. Model/observation information optimally weighted by an error statistics.



NESDIS 4km product

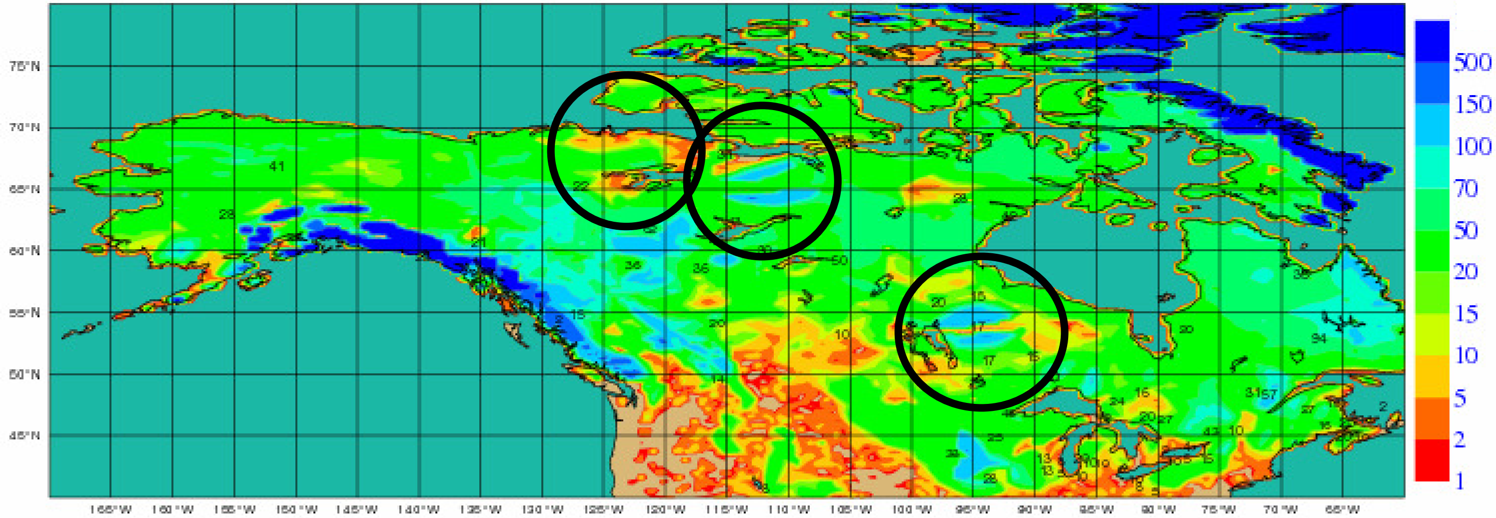
- Data thinning to 24 km -> same data quantity, improved quality
- Data Orography interpolated from high res (T3999, ie 5km) IFS



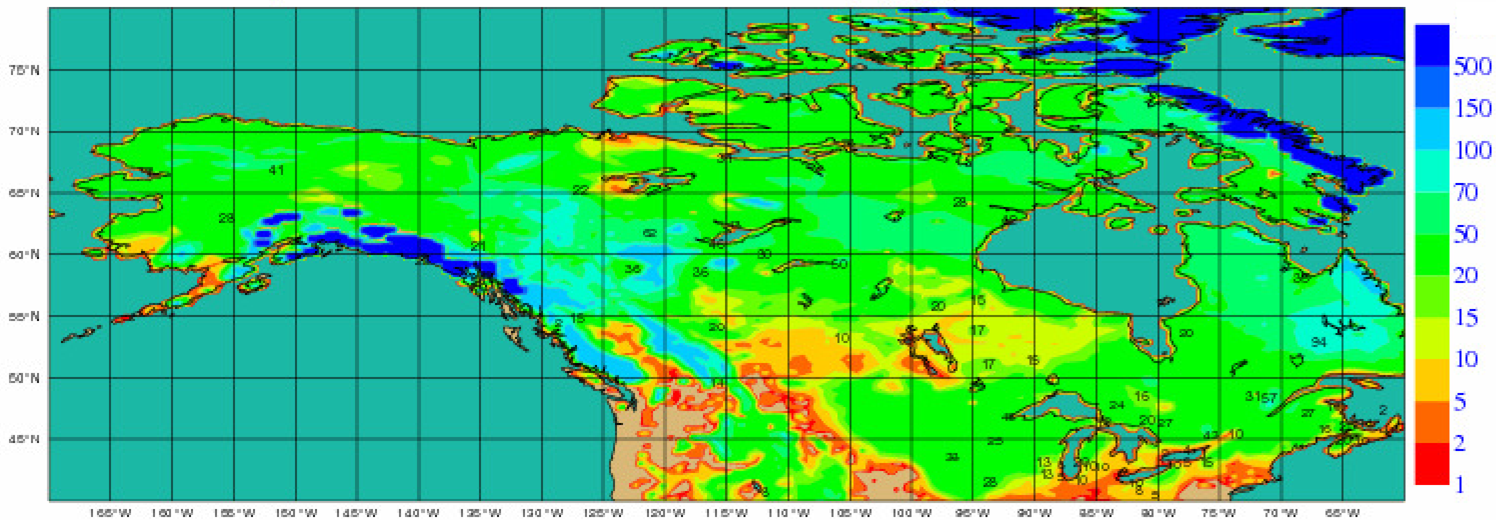


Snow Depth Analysis

SNOW Depth and SYNOP data in cm (figf) 20100115 at 18UTC



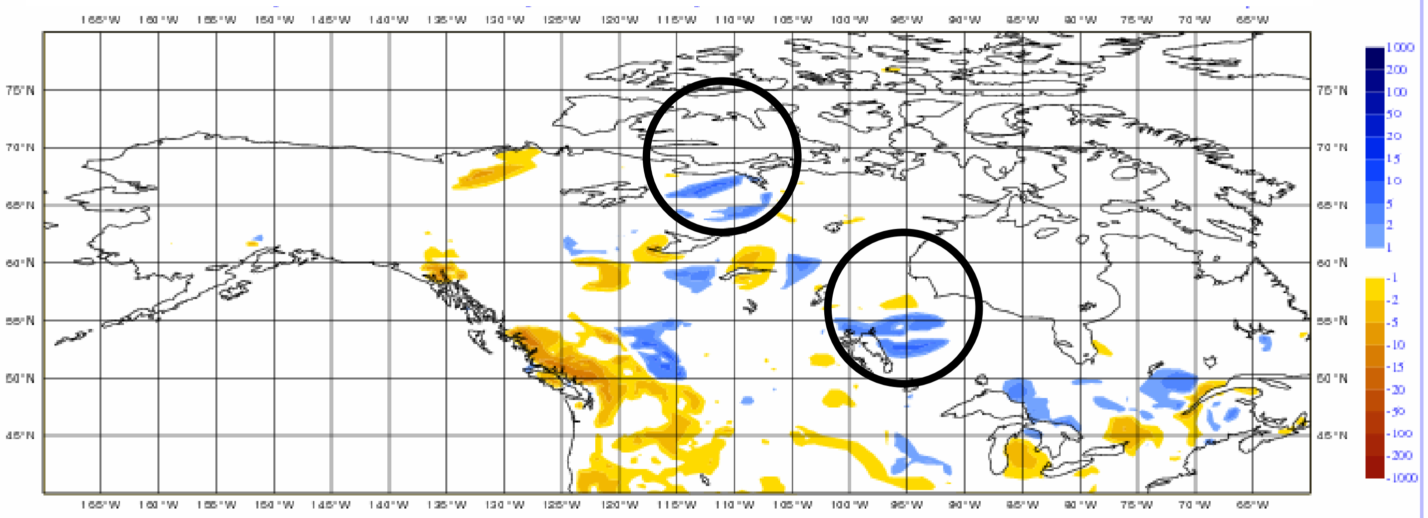
Old:
Cressman
NESDIS
24 km



New:
OI
NESDIS
4km

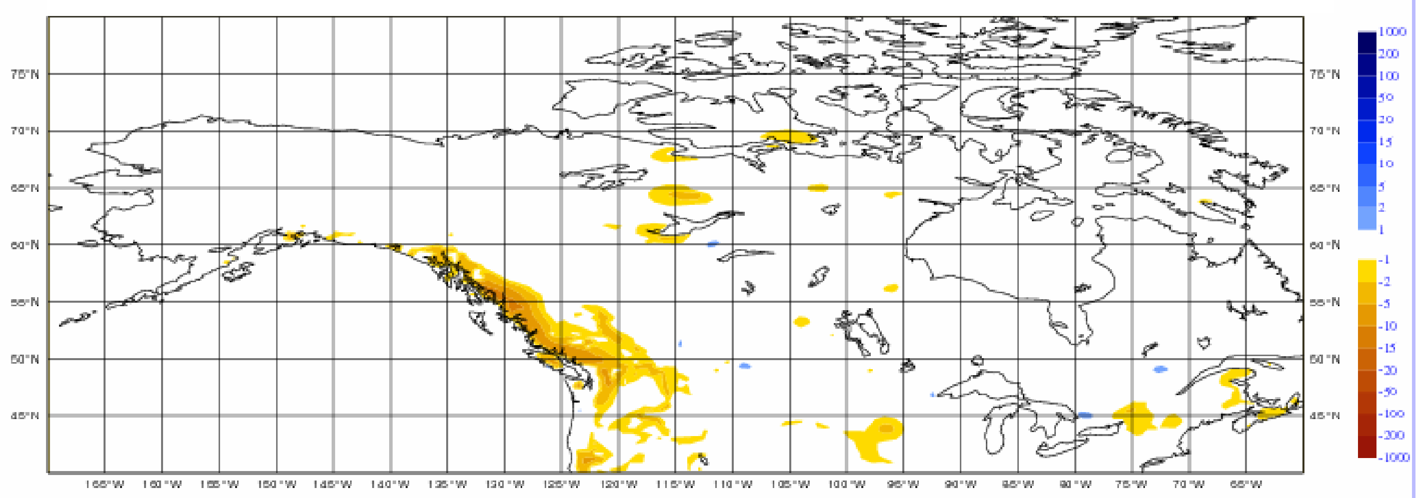
Snow Water Equivalent Analysis increments

(18UTC) Accumulated for January 2010, in mm of water



Accumulated
January 2010
In mm of water

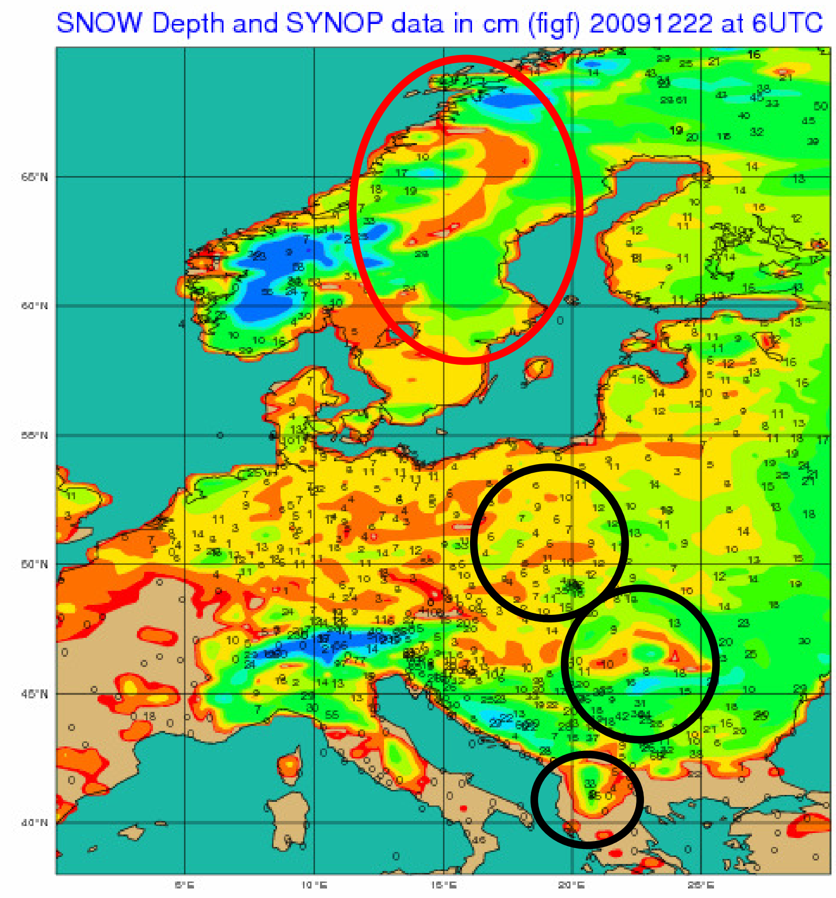
Old:
Cressman
NESDIS
24 km



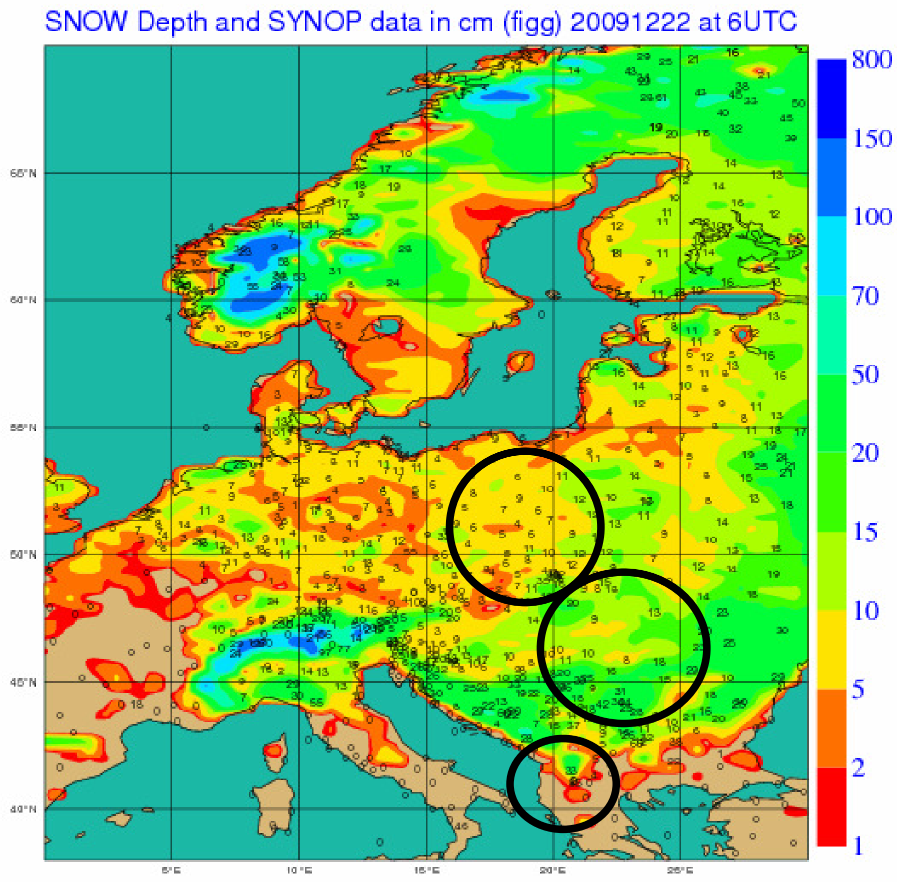
New:
OI
NESDIS
4km

Snow Depth Analysis

Cressman, NESDIS 24 km



OI, NESDIS 4km

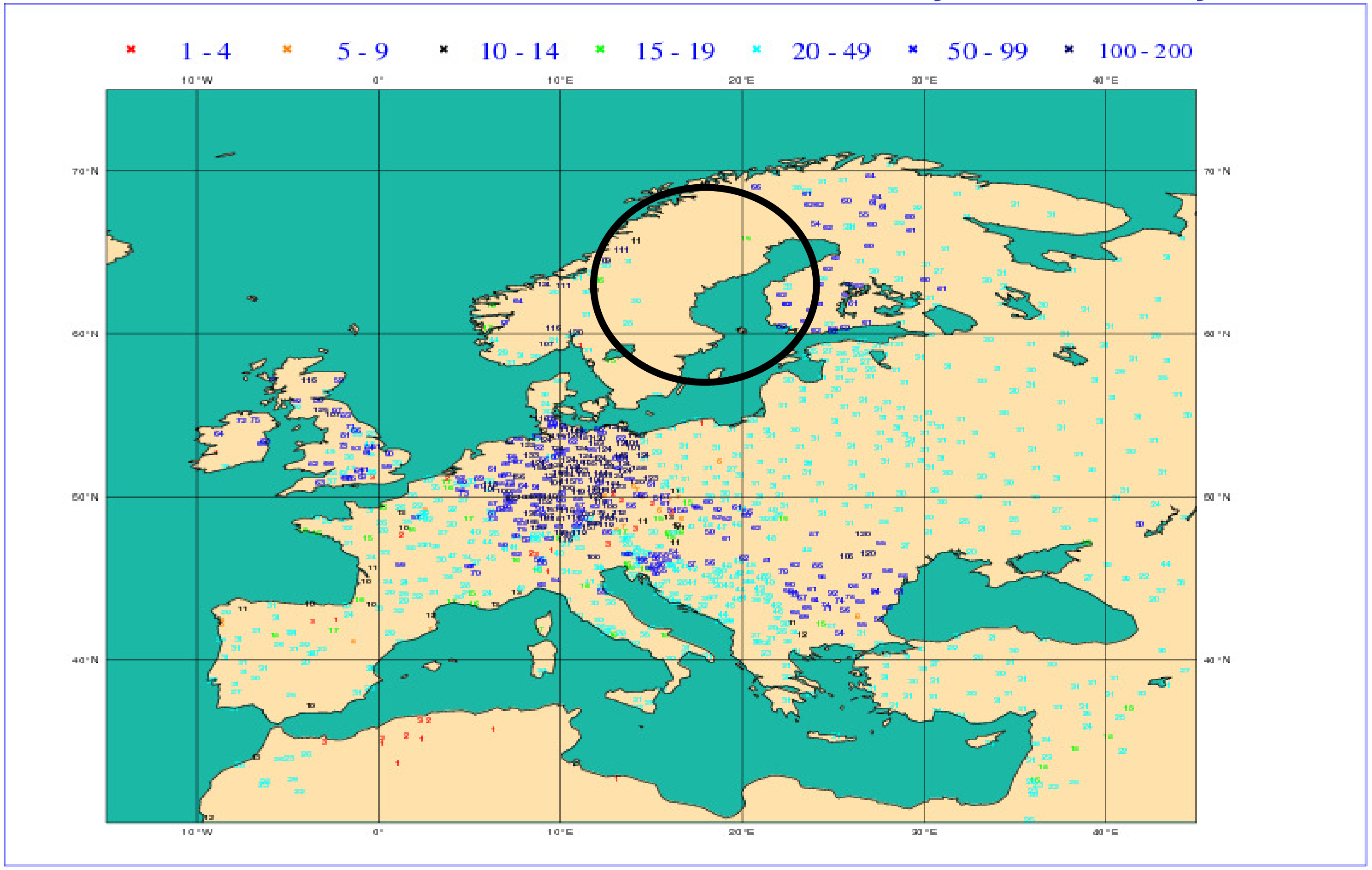


Case study: 22 december 2009 – major snow fall in Europe
- Removes snow free patches and overestimated snow patches
- Better agreement with SYNOP data and NESDIS data

New snow analysis

- Snow Optimum Interpolation using Brasnett 1999 structure functions
- A new IMS 4km snow cover product to replace the 24km product
- **Improved QC and monitoring possibilities**

Number of SYNOP data used in the Analysis in January 2010

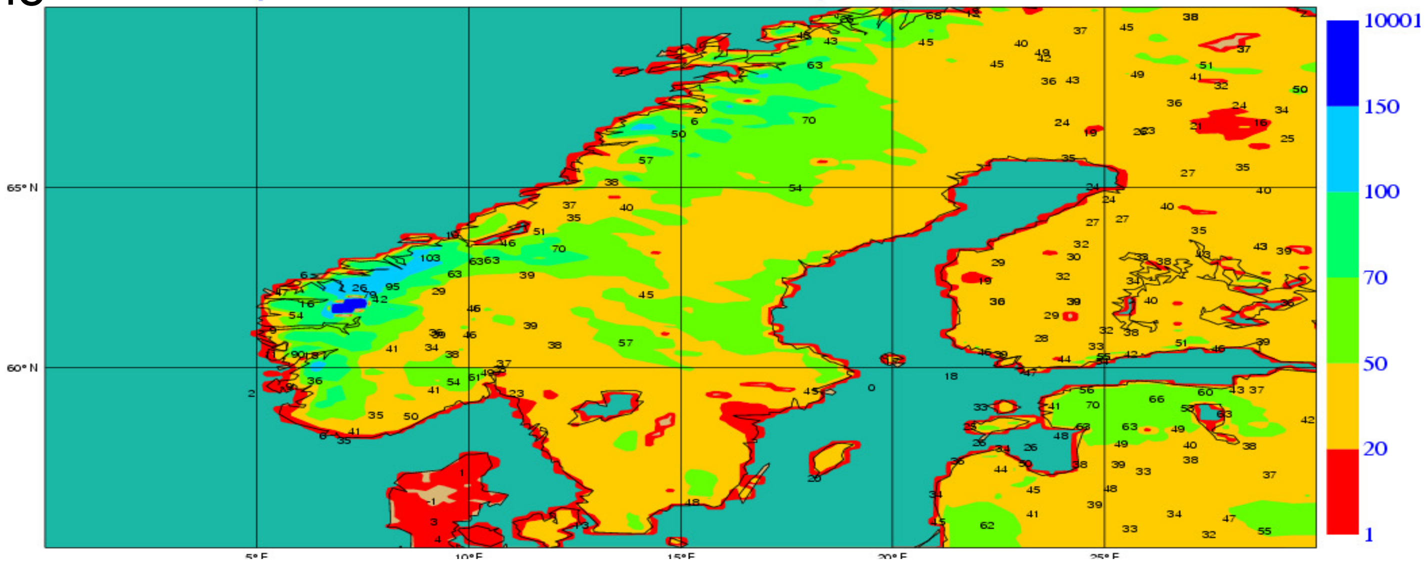


→ Identified a lack of SYNOP Snow depth data in Sweden

Use of Additional Snow depth data

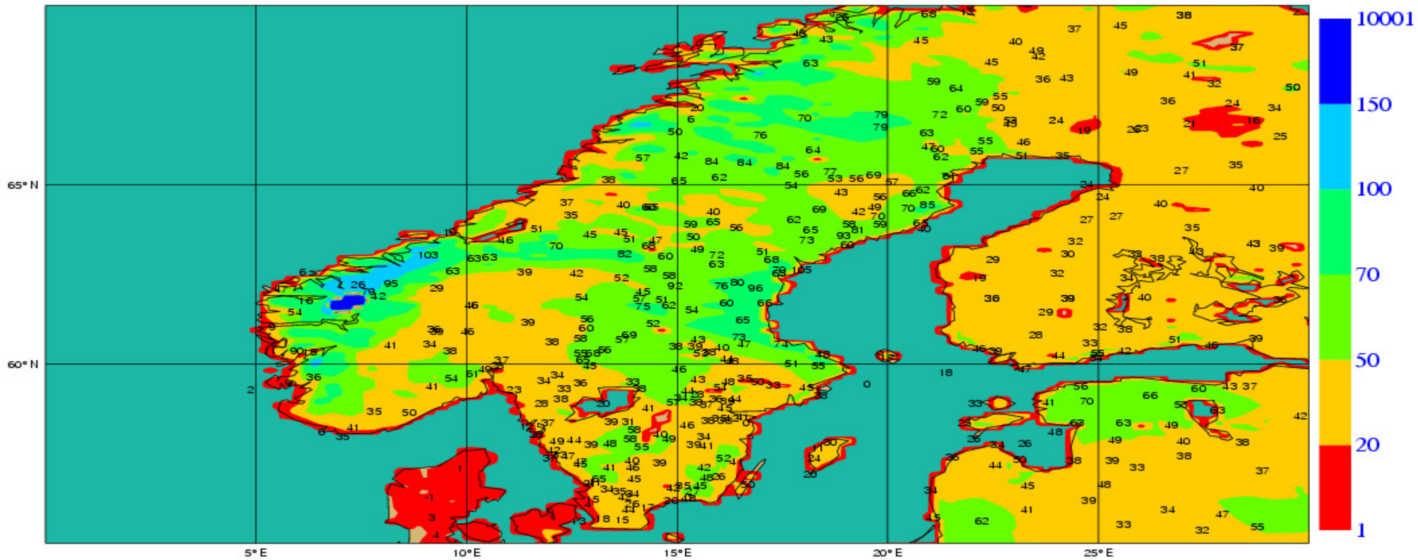
→Since December 2010, Sweden has been providing additional snow depth Data, Near Real Time (06 UTC) through the GTS

SNOW Depth and SYNOP data in cm (fi28) 20110107 at 6UTC



Snow depth analysis using SYNOP data

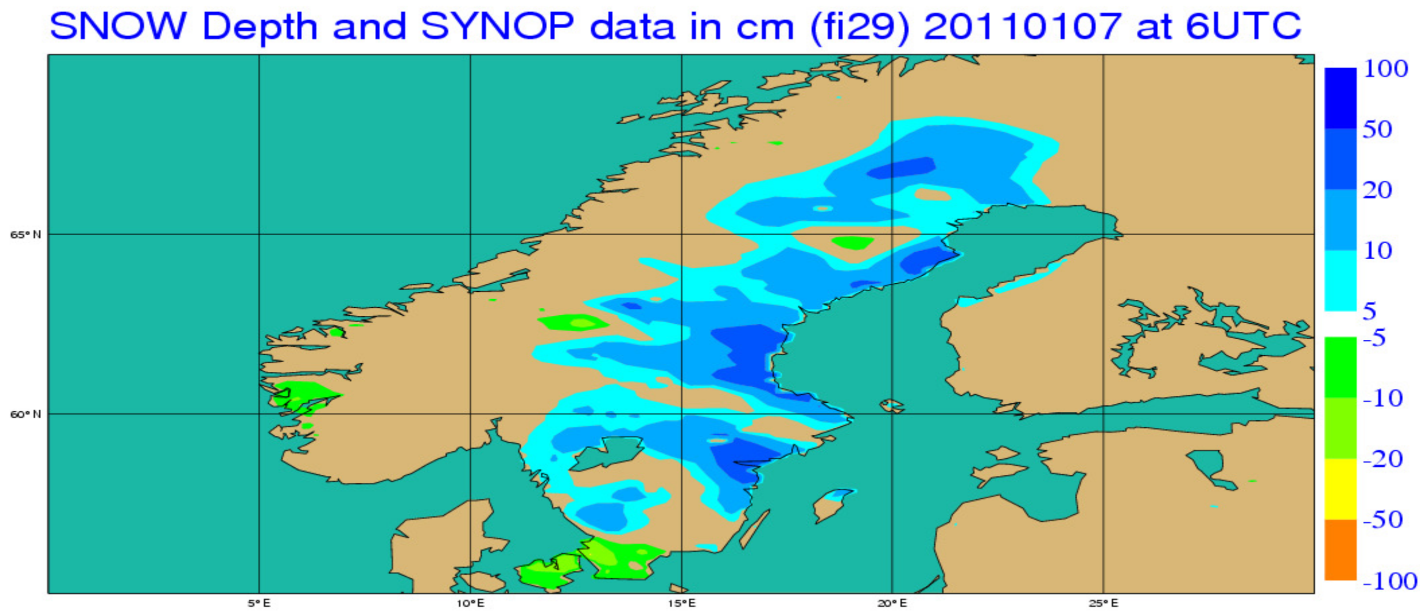
SNOW Depth and SYNOP data in cm (fi29) 20110107 at 6UTC

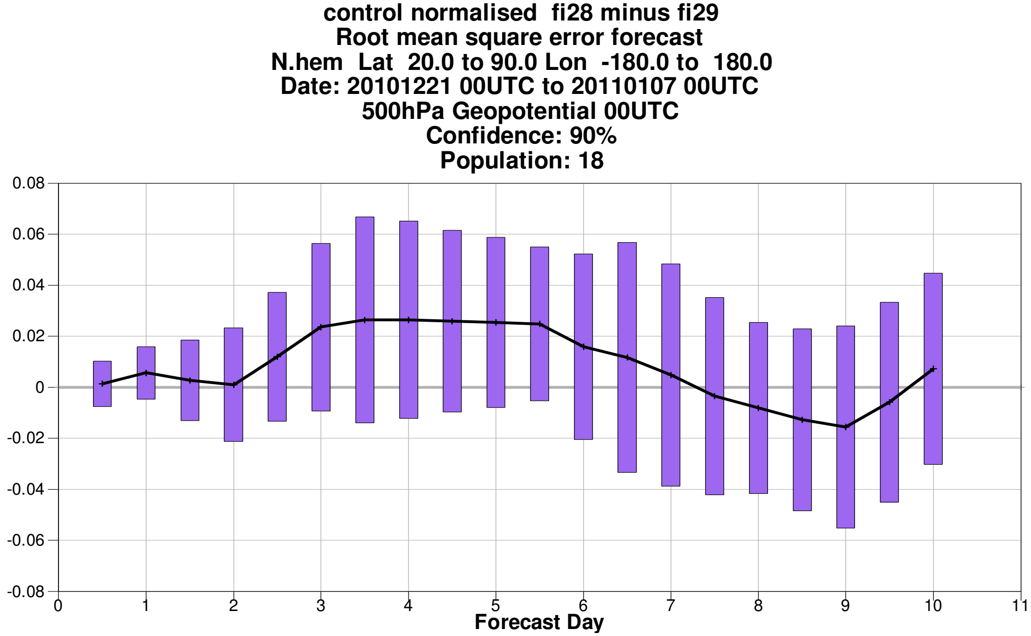


Snow depth analysis using SYNOP data + additional snow data

Implemented as a new report type, in flight from 29 March 2011

Use of Additional Snow depth data

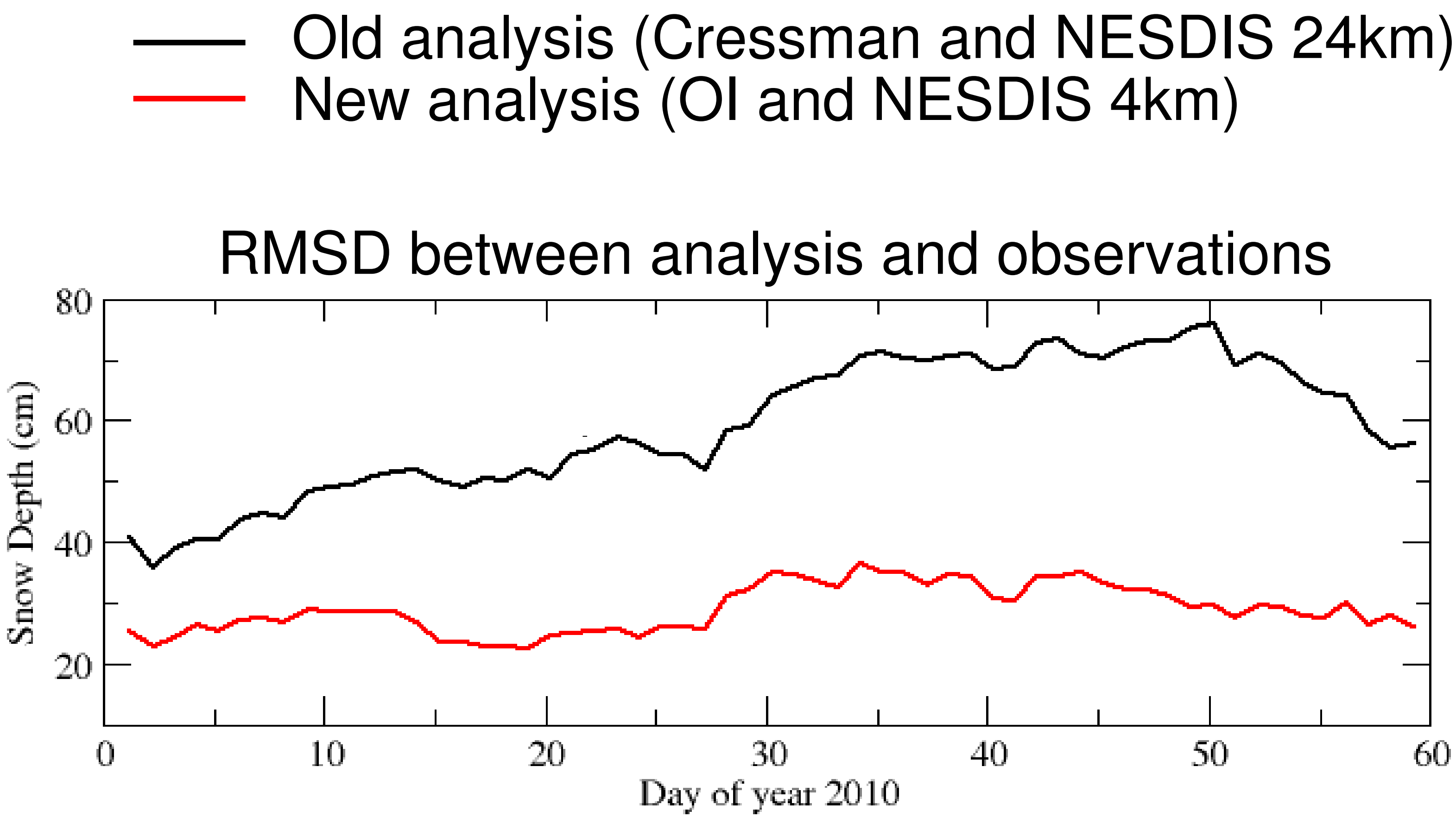




Snow Depth difference (cm)
Due to using additional non-SYNOP data in Sweden

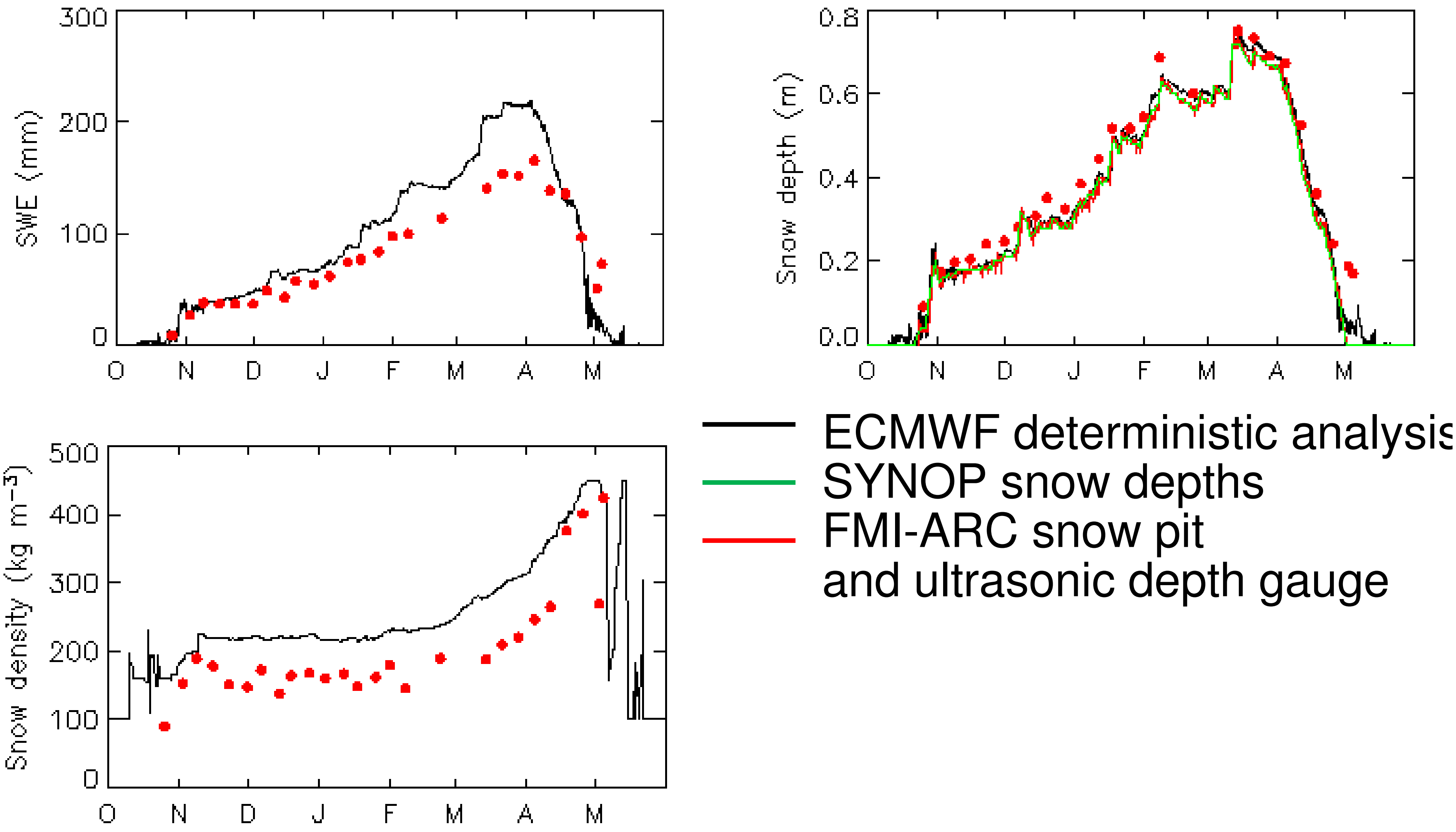
← Impact on 500hPa Geopotential

Comparison against SYNOP data



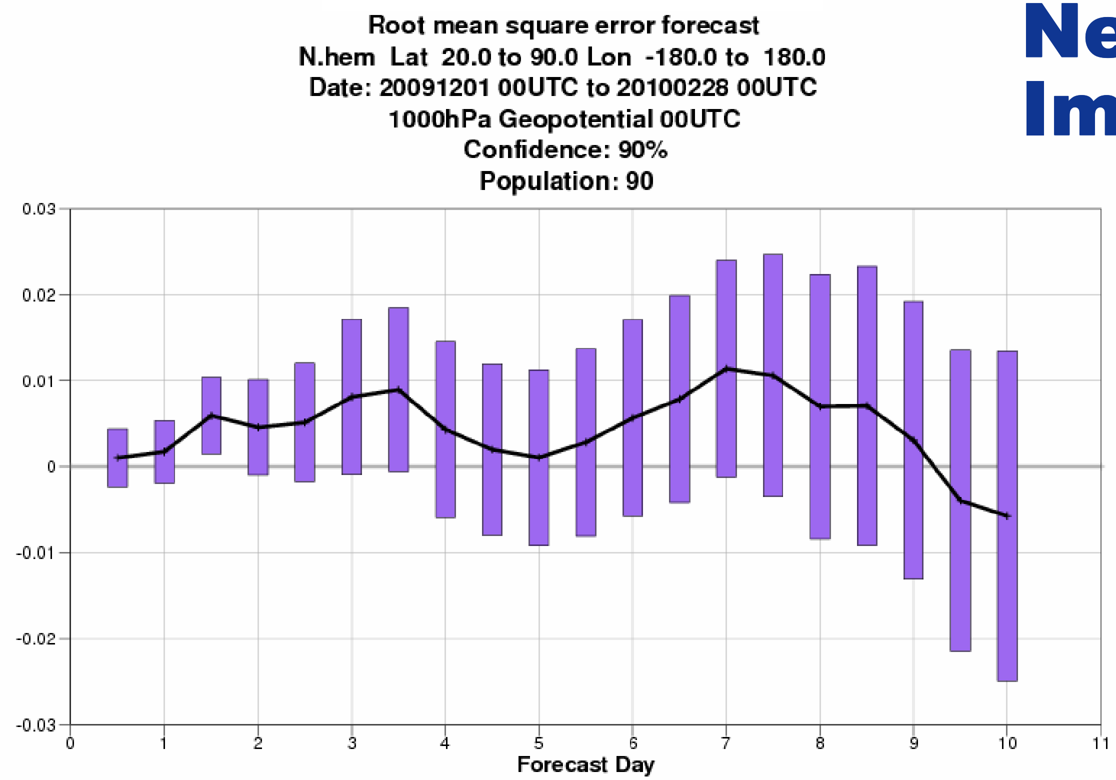
Independent validation

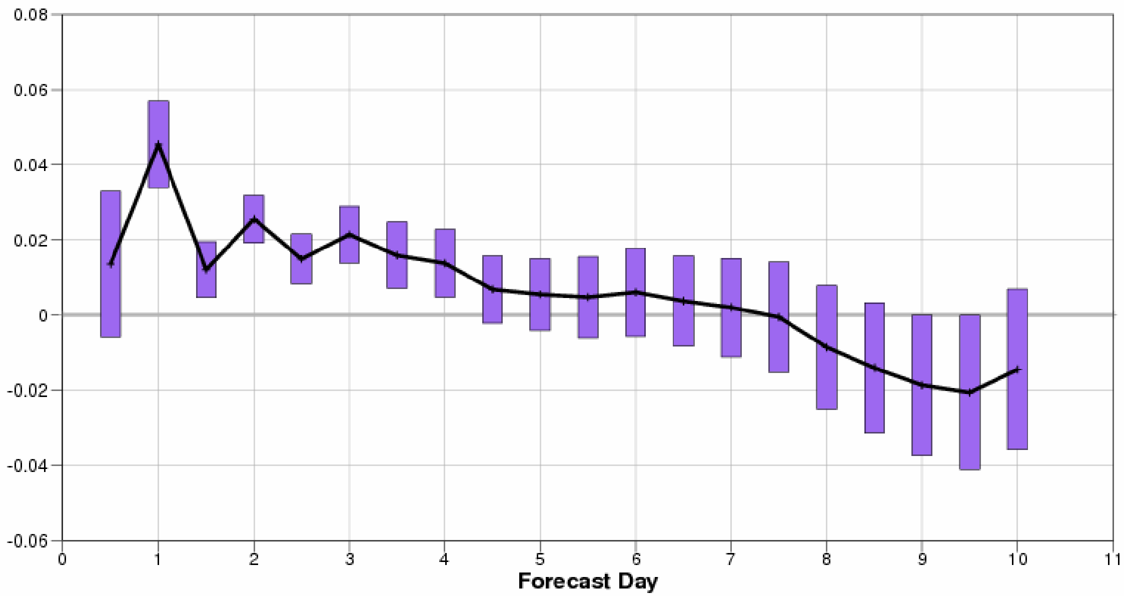
Sodankyla, Finland (67.368N, 26.633E) **Winter 2010-2011**



Figures produced by R. Essery, Univ Edinburgh)

New snow analysis Impact





RMSE Forecast 1000hPa Geopotentail in Europe

Improved when above 0

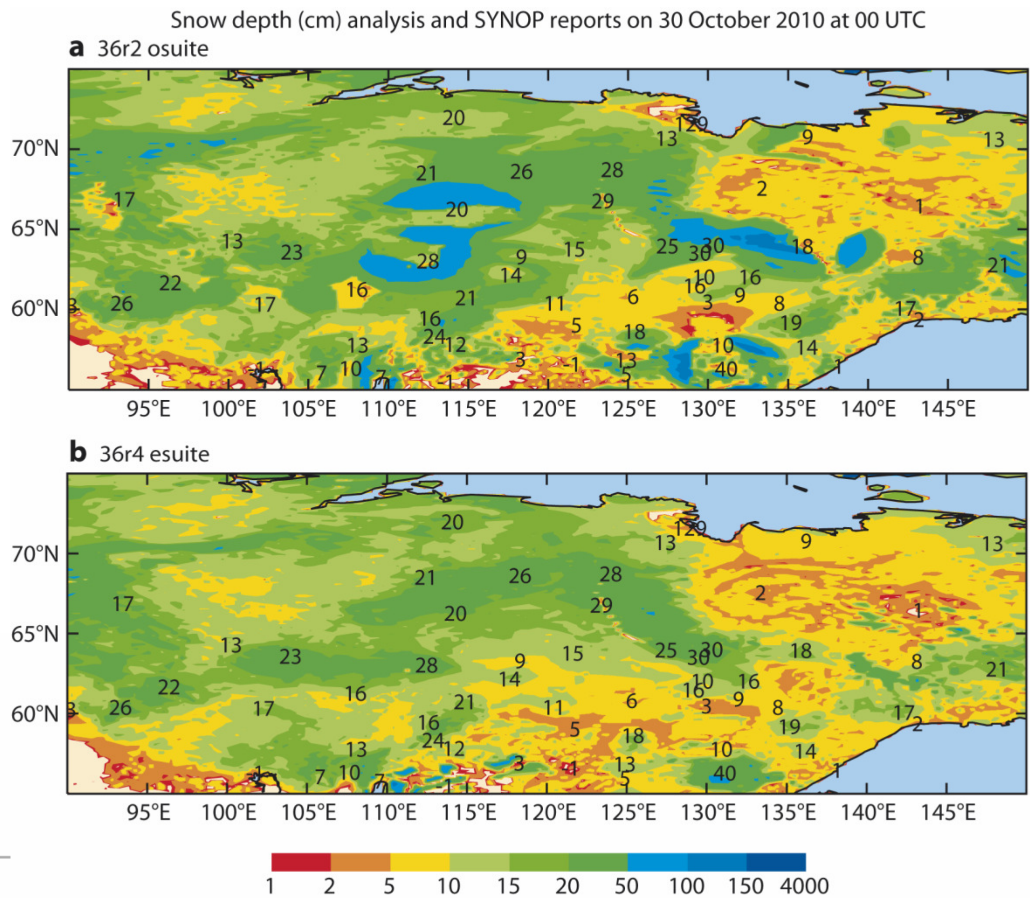
Impact of OI vs Cressman (both use NESDIS 24km)

Overall Impact of
OI NESDIS 4km vs
Cressman NESDIS 24 km

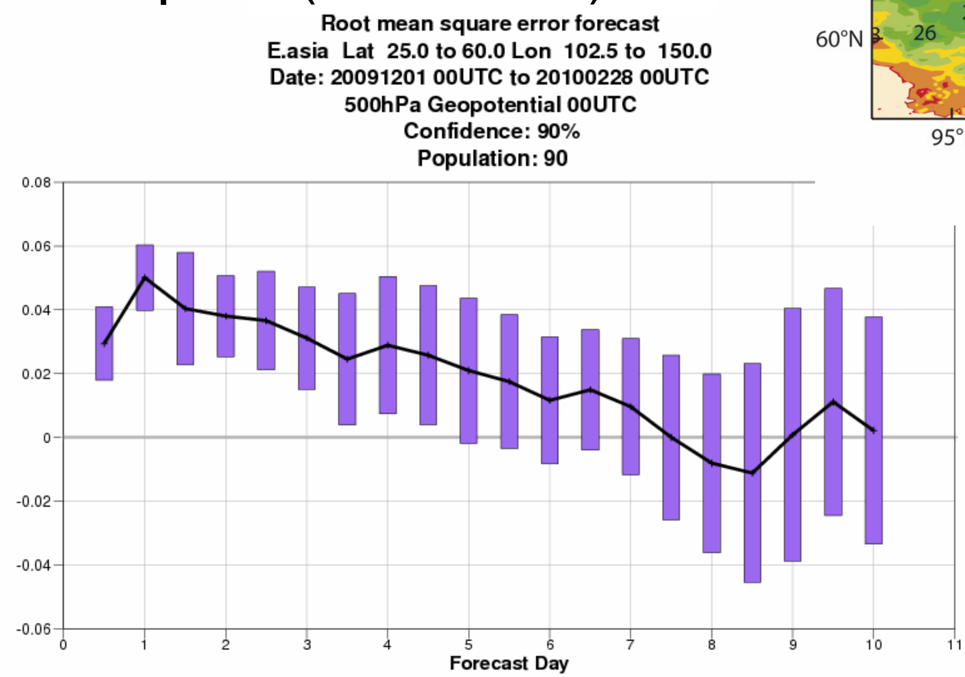
New snow Analysis in Operations

Old: Cressman
NESDIS 24km

New: OI
NESDIS 4km



FC impact (East Asia):



- OI has longer tails than Cressman and considers more observations.

- Model/observation information optimally weighted by an error statistics.

Summary and Future Plans

- New snow analysis implemented at ECMWF
  - Based on a 2D Optimum Interpolation
  - Uses Brasnett 1999 structure functions
  - Uses SYNOP and high resolution snow cover data from NOAA/NESDIS,
  - Flexible to use non-SYNOP reports (new report codetype)
  - Improved QC (blacklisting and monitoring possibilities).
- OI has longer tails than Cressman and considers more observations.
- Model/observation information optimally weighted with error statistics.
- Positive impact on NWP. However extensive validation using independent data needs to be done
- In the future, use of combined EKF/OI system for NESDIS/conventional information data assimilation.