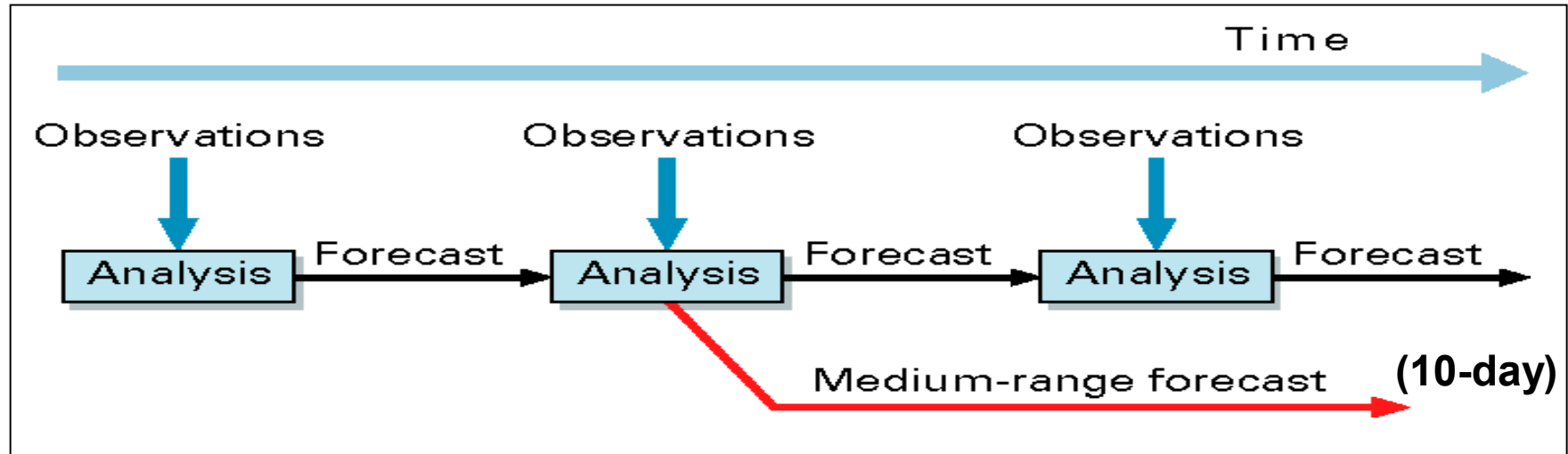


ECMWF snow observations data assimilation

ECMWF Integrated Forecasting System (IFS) for Numerical Weather Prediction (NWP)



- **Forecast Model:** GCM including the H-TESEL land surface model
- **Data Assimilation** → initial conditions of the forecast model prognostic variables
 - 4D-Var for atmosphere
 - Land Data Assimilation System

Snow in the IFS

Snow Model: Component of H-TESSSEL

Single layer snowpack Balsamo et al., JHM, 2009 and Dutra et al., JHM 2010

- Snow water equivalent SWE (m), ie snow mass
 - Snow Density ρ_s , between 100 and 400 kg/m³
- } **Prognostic variables**

Observations:

- Conventional snow depth data: SYNOP and National networks
- Snow cover extent: NOAA NESDIS/IMS daily product (24km & 4km)

Drusch et al., JAM, 2004 ; de Rosnay et al., SG 2014

de Rosnay et al., ECMWF Res. Mem. R48.3/PdR/1028 2010,
and ECMWF Res. Mem. R48.3/PdR/1139 2011

Data Assimilation:

- Optimal Interpolation (OI) in oper IFS
- Analysed variable: SWE, ρ_s

de Rosnay et al., Survey of Geophysics 2014



Snow Observations

Interactive Multisensor Snow and Ice Mapping System (IMS)

Time sequenced imagery from geostationary satellites

NOAA/NESDIS

IMS Snow extent data

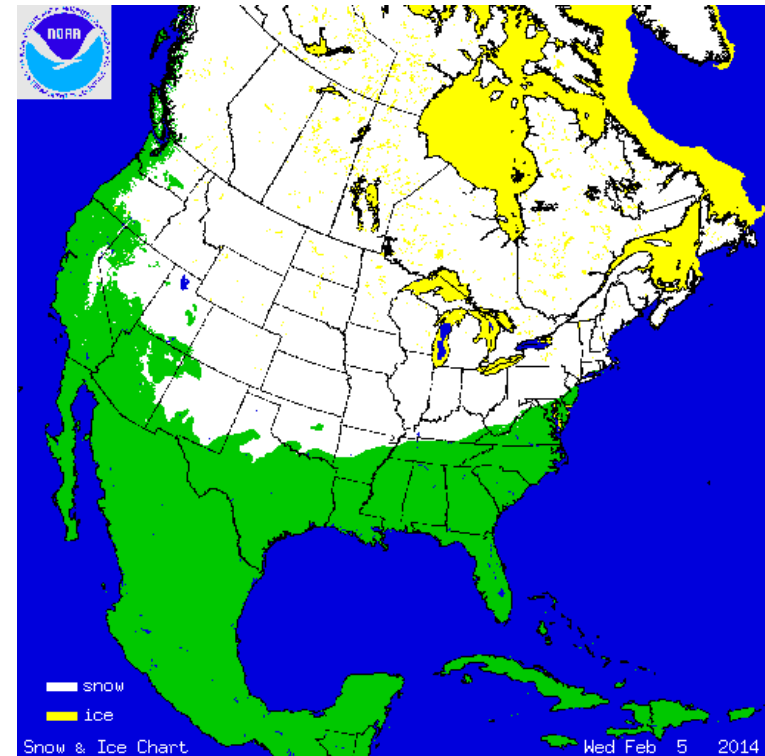
Northern Hemisphere product

- Daily, no time stamp
- Polar stereographic projection

Information content: Snow/Snow free

Data used at ECMWF:

- **24km product in Grib**
Used in ERA-Interim (2004-present)
and in operations (2004-2010)
- **4 km product in Ascii**
Revised pre processing
Used in operations (Nov 2010-present)



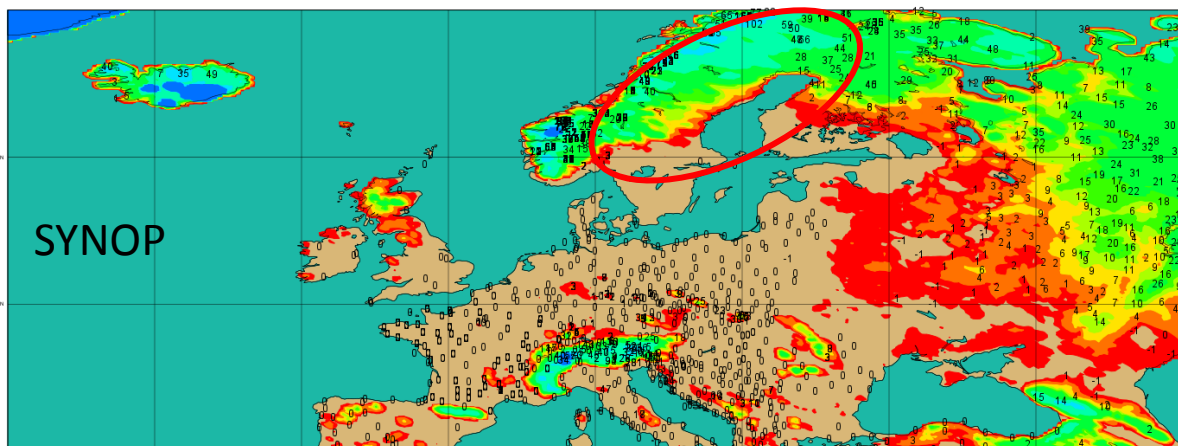
IMS Snow Cover 5 Feb. 2014

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

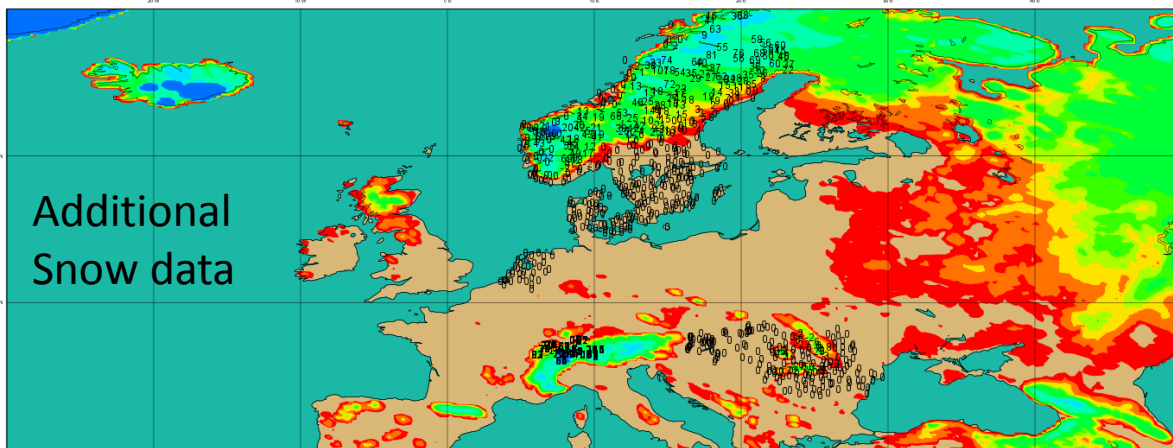
Snow Observations

2014 01 01 at 06UTC

Snow SYNOP and National Network data



Data available on the GTS (Global Telecommunication System)



Additional data from national networks (7 countries):

Sweden (>300), Romania(78), The Netherlands (33), Denmark (43), Hungary (61), Norway (183), Switzerland (332).

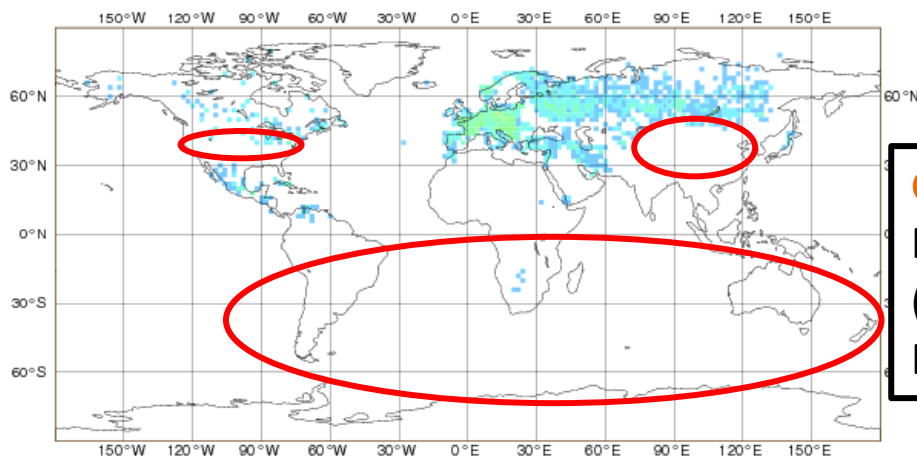
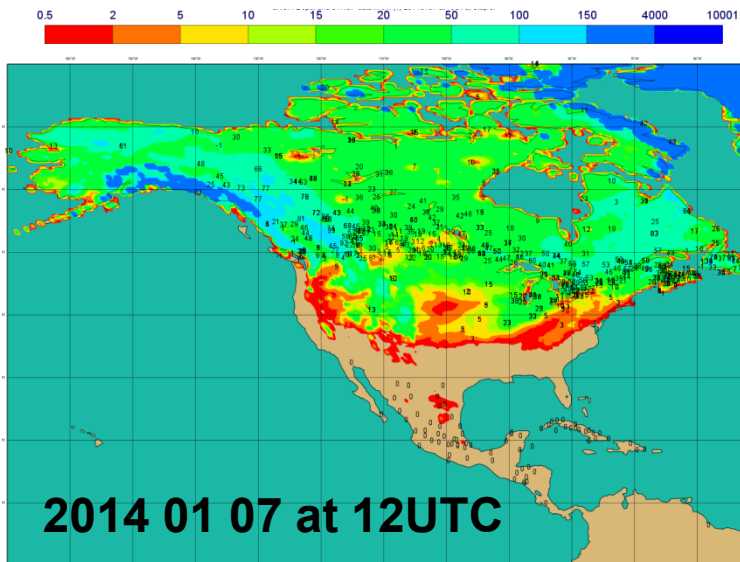
→ Dedicated BUFR (2011)

(de Rosnay et al. ECMWF Res. Memo, R48.3/PdR/1139, 2011)

Snow Observations

GTS: SYNOP Snow depth availability Status in January 2014

Operational snow observations monitoring:
<http://old.ecmwf.int/products/forecasts/d/charts/monitoring/conventional/snow/>



Gap in USA, China and southern hemisphere
But NRT data exist and is available,
(e.g. >20000 station in USA)
But it is not on the GTS for NWP applications.

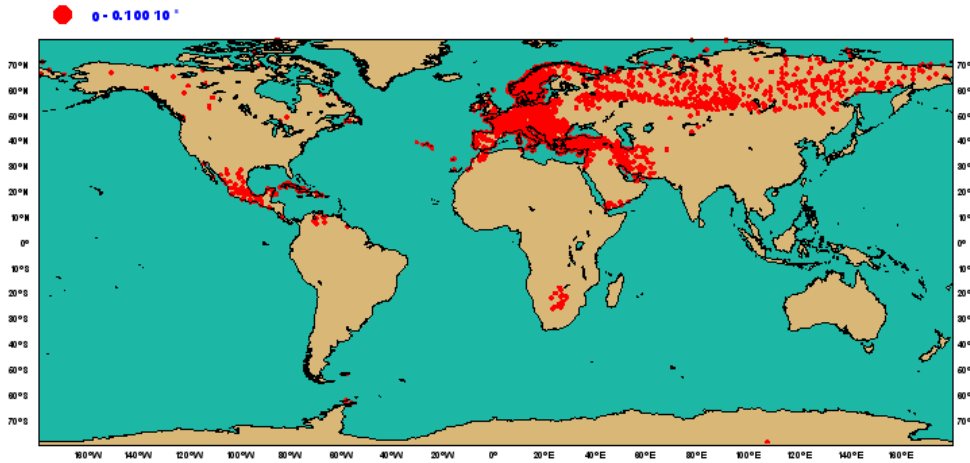
- WMO GCW Snow Watch initiative to improve in situ snow depth data access (NRT and rescue), Brun et al 2013
- Dedicated BUFR template (WMO approved 2014) or SYNOP report
- ➔ WMO Members States encouraged to put on the GTS their snow depth data

Snow Observations

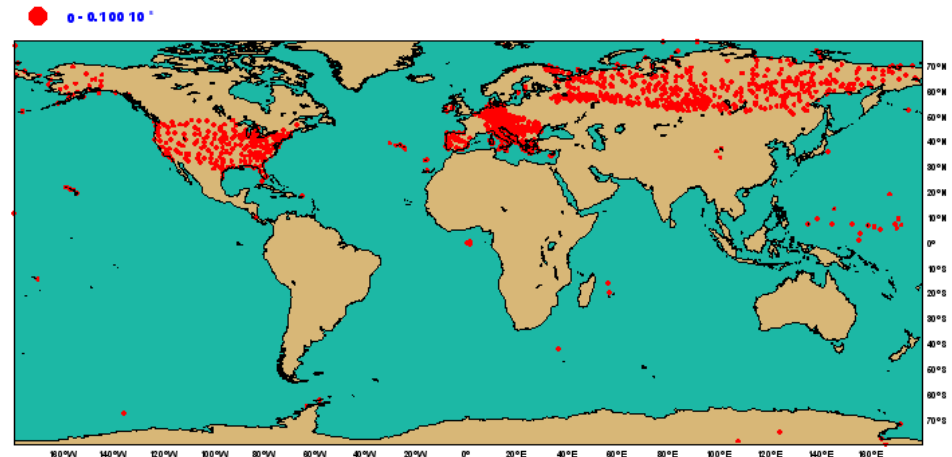
GTS Snow depth availability

Status on 18 October 2014

TAC SYNOP Snow Obs 6544



BUFR SYNOP Snow Obs 6455



Transition TAC to BUFR SYNOP
- Observations available in USA
- Ongoing developments to use BUFR SYNOP snow data in oper

Snow Data assimilation

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

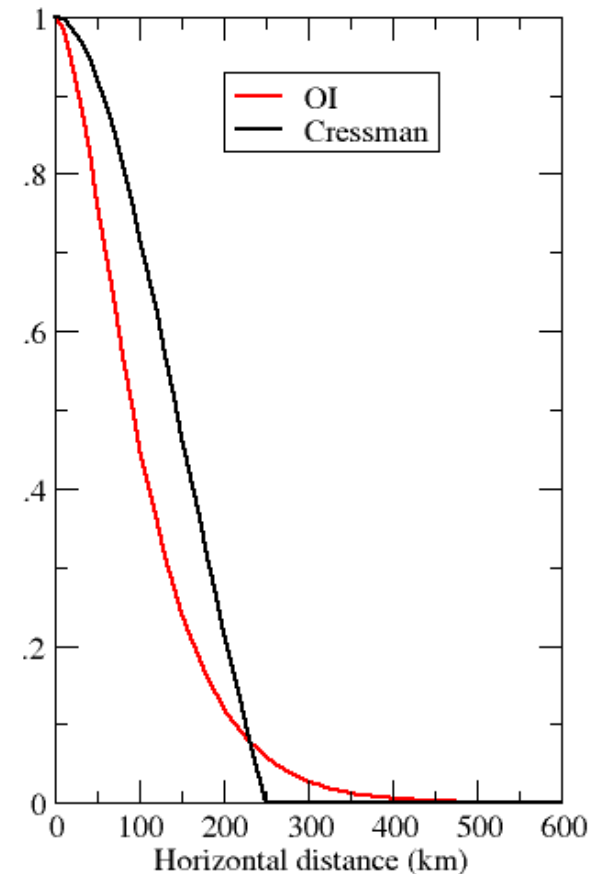
Cressman: ERA-Interim and oper until 2010

Weights are function of horizontal and vertical distances. Do not account for observations and background errors.

Optimal Interpolation (OI): Oper since 2010

Follows Brasnett JAM 1999. The correlation coefficients 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 using error statistics.



de Rosnay et al., Surv. Geophys. 2014

Snow Data assimilation

Validation data: NWS/COOP

- NWS Cooperative Observer Program
- Independent data relevant for validation
- Used to validate a set of numerical experiments considering different assimilation approaches and IMS snow cover

Numerical Experiments	Bias (cm)	R	RMSE (cm)
Cressman, IMS 24 km	1.1	0.66	18.0
OI, IMS 24 km	- 2.0	0.74	10.1
OI, IMS 4km <1500m	- 1.5	0.74	10.1

- Oper until Nov 2010
- ERA-Interim

- Oper since Nov 2010

Validation against ground data

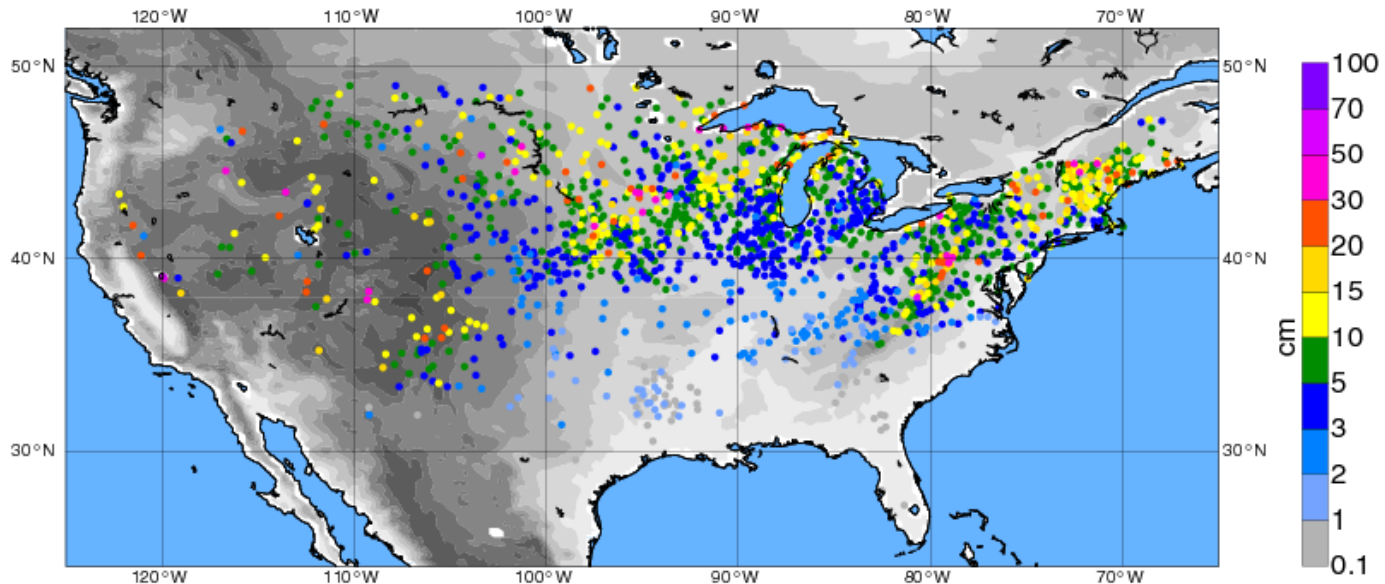
→ Improvement due to the OI compared to Cressman

Snow Data assimilation

Validation data: NWS/COOP

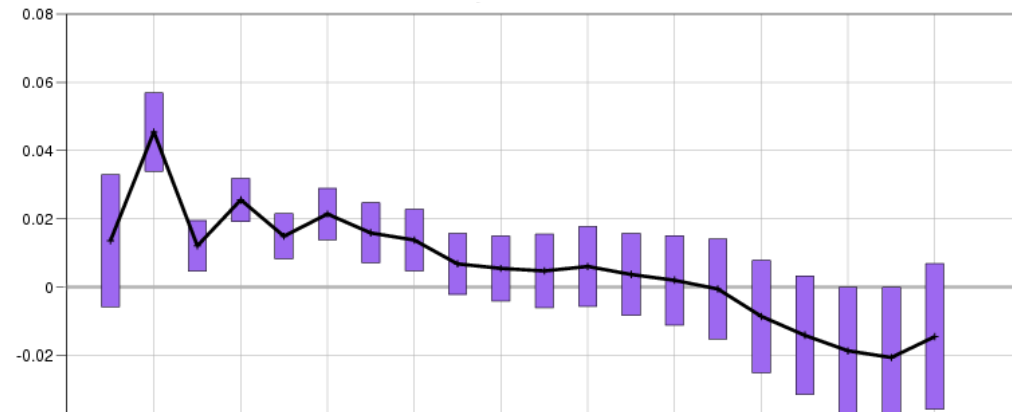
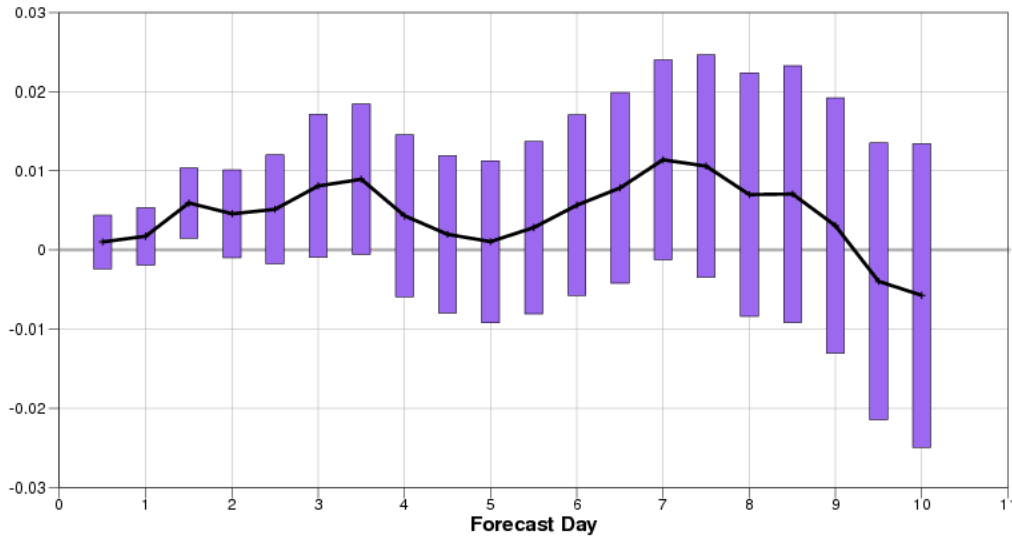
- National Weather Service Cooperative Observer Program
- Independent data relevant for validation

**RMSE (cm) for the new snow analysis, winter 2010
(OI, IMS 4km except in mountainous areas)**



Snow Data assimilation

Impact on the Atmospheric Forecasts RMS 1000hPa Geopotential height Northern Hemisphere DJF 2009-2010



Top: Cressman -OI impact (both use IMS 24km)
Positive : OI improves

Bottom: Overall impact (Old-New)
New: OI+IMS 4km
Old: Cressman+ IMS 24km
Positive: new improves

→ Main impact of snow data assimilation on atmospheric forecasts due to the IMS 4km and revised QC

Snow Data assimilation

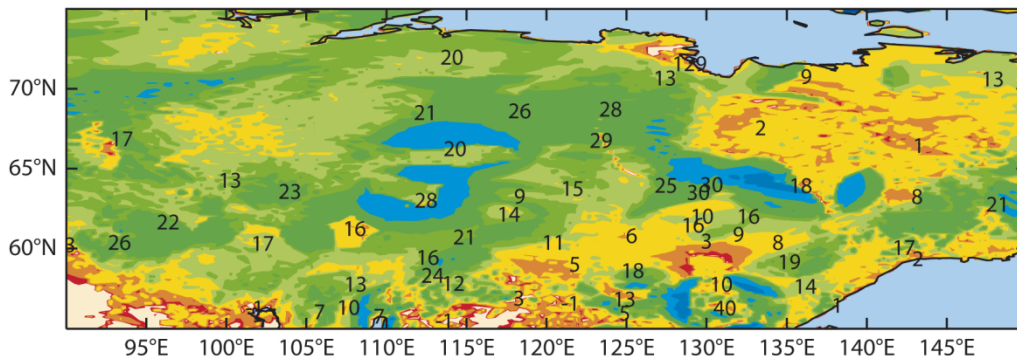
Snow depth (cm) analysis and SYNOP reports on 30 October 2010 at 00 UTC

Old:
Cressman+ IMS 24km

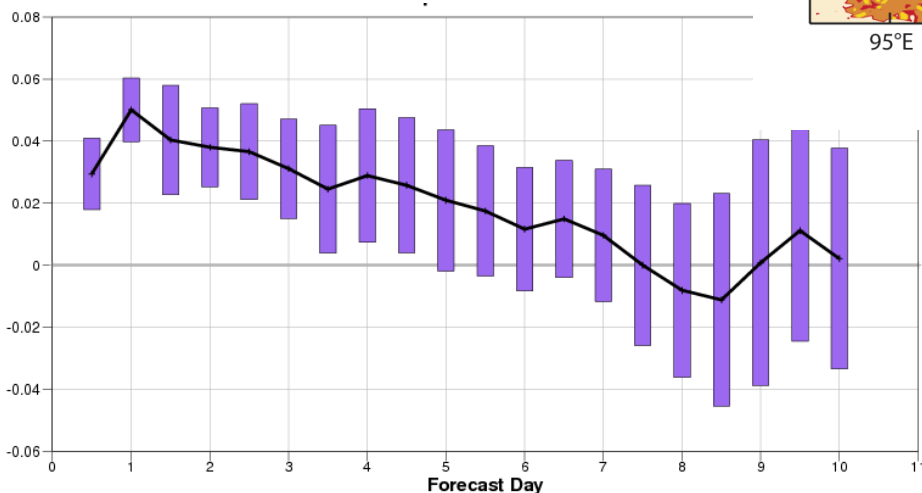
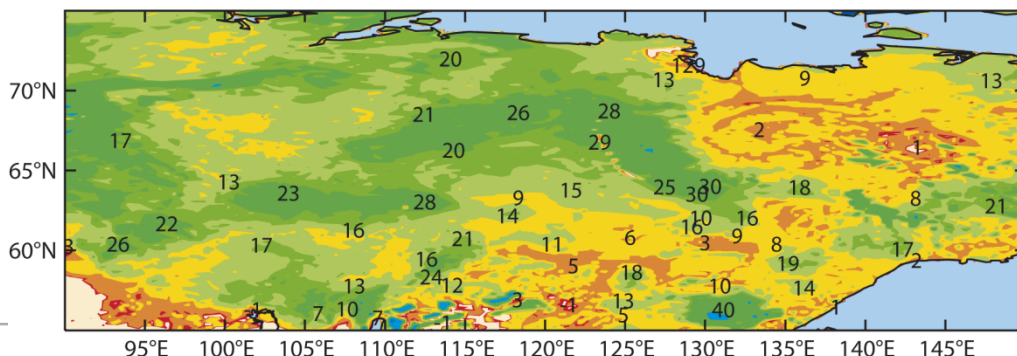
New:
OI+ IMS 4km

FC impact (East Asia)
RMSE 500 hPa Geopot H

a 36r2 osuite



b 36r4 esuite



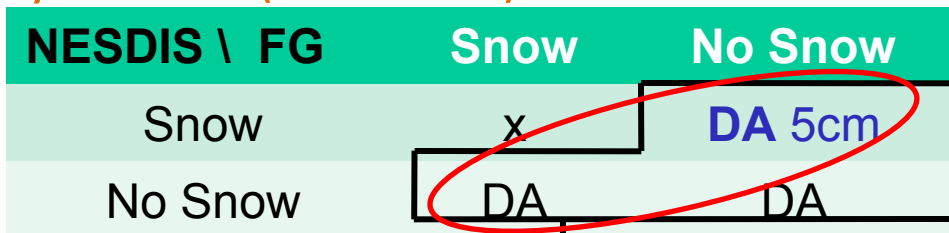
New snow analysis improves both the snow depth patterns (OI impact) and the atmospheric forecasts (IMS 4km+QC impact)

Snow Data Assimilation: latest improvements

NESDIS/IMS snow cover data DA

Current version:

Cycle 40r1 (Nov 2013):



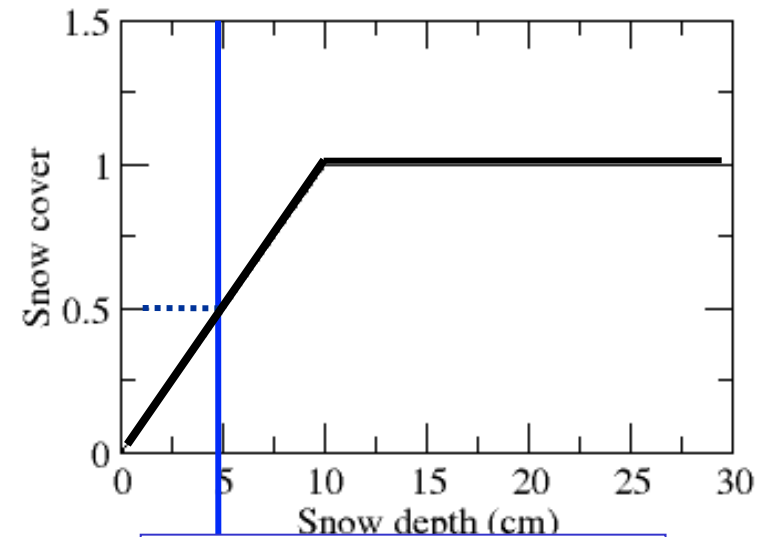
OI

40r1 errors:

BG $\sigma_b = 3\text{cm}$

SYNOP $\sigma_o = 4\text{cm}$

IMS $\sigma_{ims} = 8\text{cm}$



40r1:

- Obs assimilated

- SC=1 \rightarrow SD=5cm

Snow Data Assimilation: latest improvements

NESDIS/IMS snow cover data DA

Previous version: IFS Cycle 38r2

NESDIS \ FG	Snow	No Snow
Snow	x	BG: 10cm
No Snow	DA	DA

OI

IFS 38r2 errors:
 BG $\sigma_b = 3\text{cm}$
 OBS $\sigma_o = 4\text{cm}$

Current version:

Cycle 40r1 (Nov 2013):

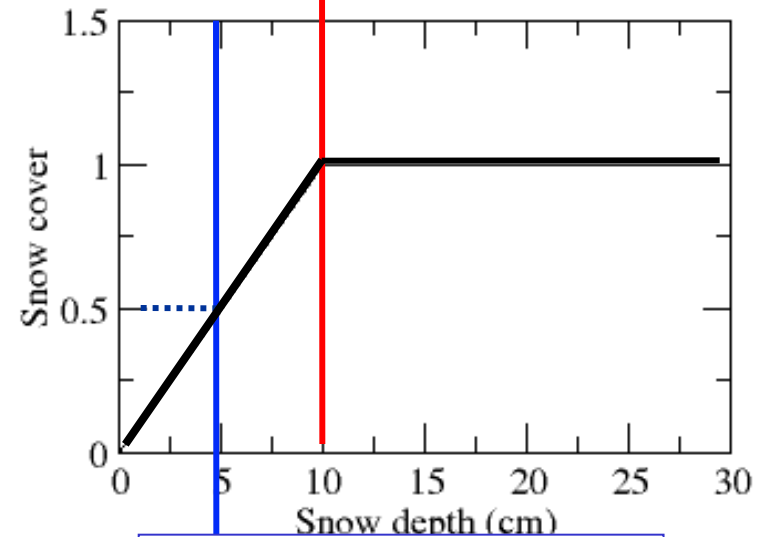
NESDIS \ FG	Snow	No Snow
Snow	x	DA 5cm
No Snow	DA	DA

OI

IFS 40r1 errors:
 BG $\sigma_b = 3\text{cm}$
 SYNOP $\sigma_o = 4\text{cm}$
 IMS $\sigma_{ims} = 8\text{cm}$

Previously (38r2):

- BG overwritten
- SC=1 \rightarrow SD=10cm



Current (40r1):

- Obs assimilated
- SC=1 \rightarrow SD=5cm

Revised snow analysis: Forecast impact

Temp FC RMSE (20 Dec 12 – 08 Mar 13)

IFS 40r1-38r2 (New-Old)

Improved use of IMS snow cover

→ Relevant for snow line update

→ Significant impact on the atmosphere

→ **Forecast error reduction**

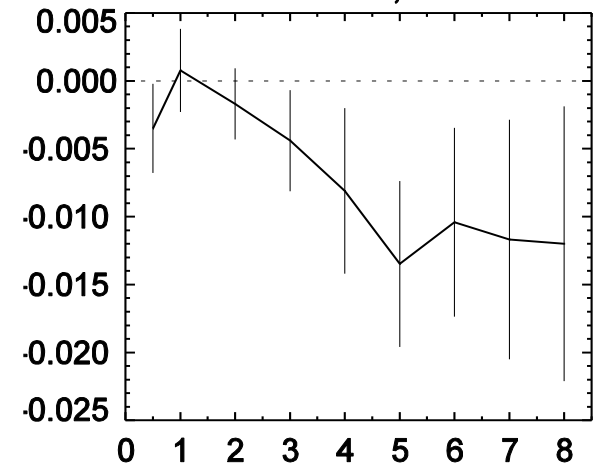
Other improvements in the ECMWF snow analysis from Nov 2013:

- Technical developments for conventional and IMS Observation Data Bases (ODBs)
- New Land surface observations NRT monitoring for conventional snow depth, and for IMS snow cover observations:

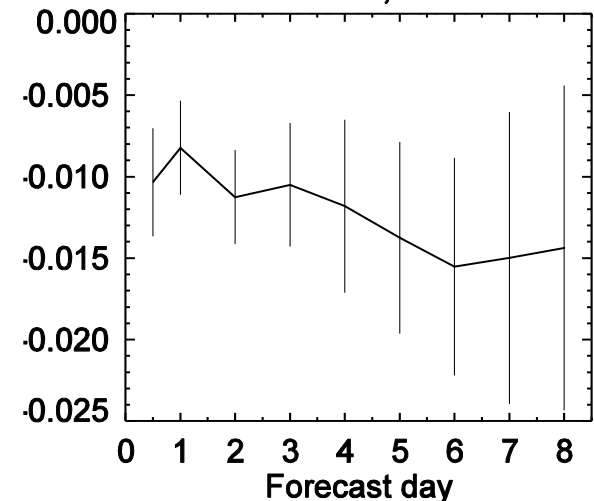
<https://software.ecmwf.int/wiki/display/LDAS/Land+Surface+Observations+monitoring>

NH extra-tropics

T: 20° to 90°, 850hPa

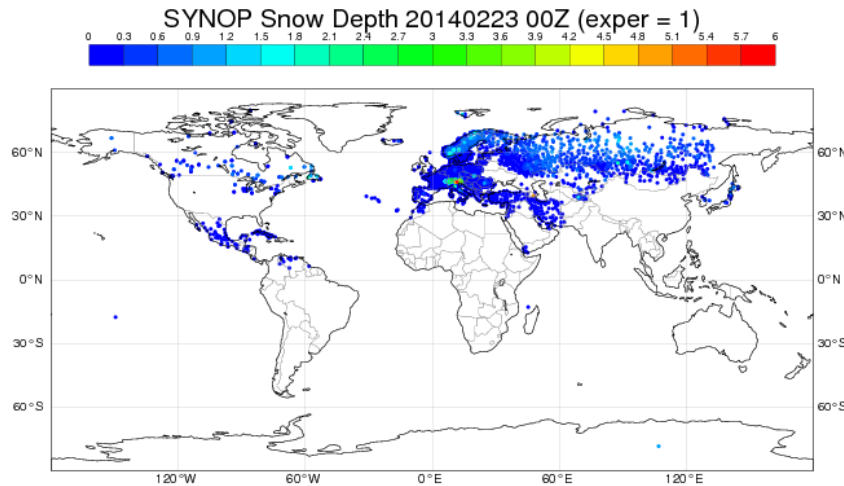


T: 20° to 90°, 1000hPa



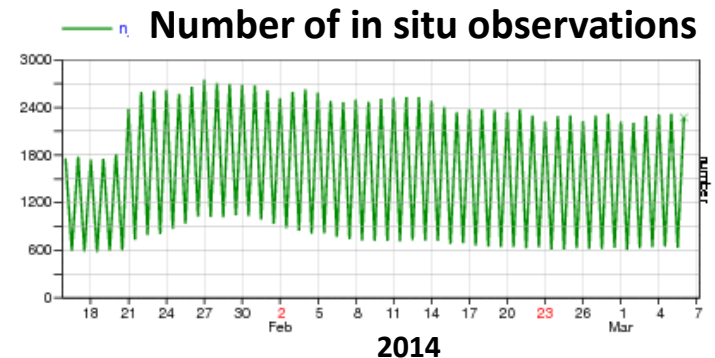
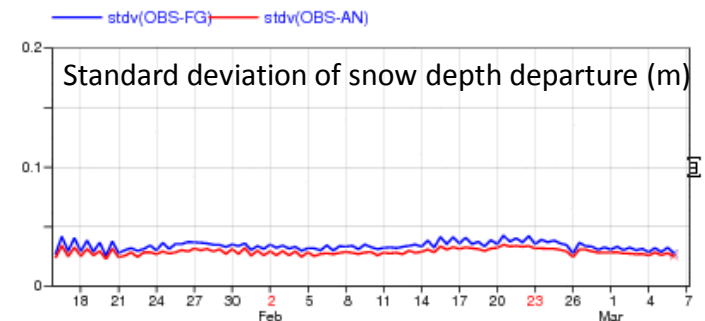
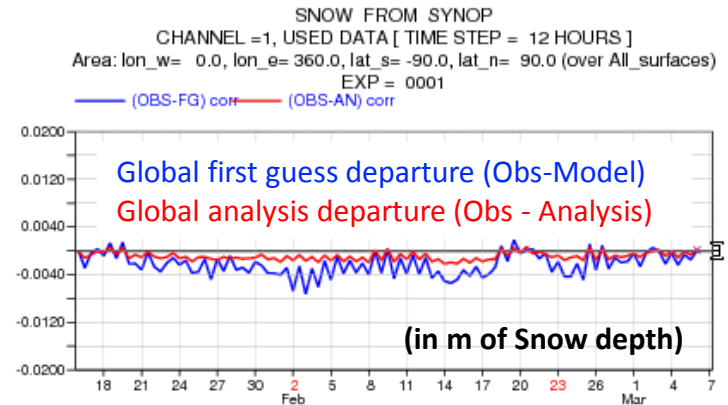
Snow Observations

Snow depth observations available
(>4500 per day in winter time)



Data assimilation system
developments to enable monitoring
of snow observations:
From November 2013 (IFS cycle 40r1)

<http://old.ecmwf.int/products/forecasts/d/charts/monitoring/conventional/snow>



Snow Observations

- Four types of reports, three different formats (two BUFR and TAC).
- TAC reports (manual and automatic) converted into BUFR.
- All BUFR converted into conventional data ODB (Observation Data Base)
- For TAC data state of the ground used before conversion for BUFR to put zero snow depth when the state of the ground indicates snow free conditions.

- ODB used as input of the data assimilation. Information currently used in data assimilation: lat,lon, elevation, date, time, station identifier, report type and codetype, SD, Tair.

- Relevant information to include in the ODB when available: snow density, SWE, state of the ground (for non-TAC reports).

Snow in the IFS Summary

2009

2010

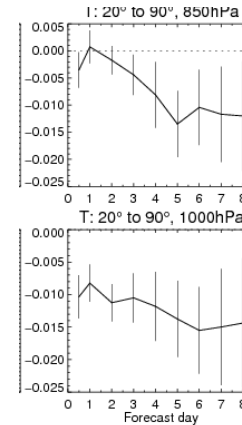
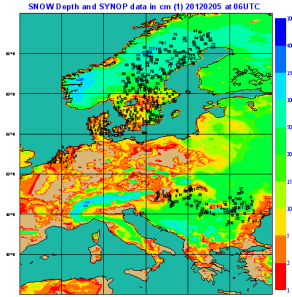
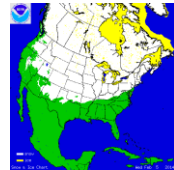
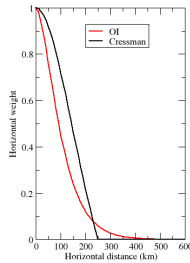
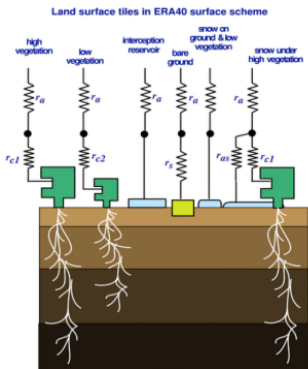
2011

2012

2013

2014

...



Snow Model

- . Liq. Water
- . Density
- . Albedo
- . Fraction

Snow Obs and DA

- . OI
- . 4km IMS
- . Obs preproc/QC
- . IMS latency/acquisition

- . Additional in situ obs
- . New BUFR template
- . WMO/SnowWatch action
- . IMS data assimilation
- . obs error revision

Snow Model & Data Assimilation

- . Multi-layer model
- . Snow cover Fract
- . BUFR SYNOP
- . RT modelling
- . Snow COST action

Dutra et al., JHM 2010

de Rosnay et al., Res Memo 2010, 2011

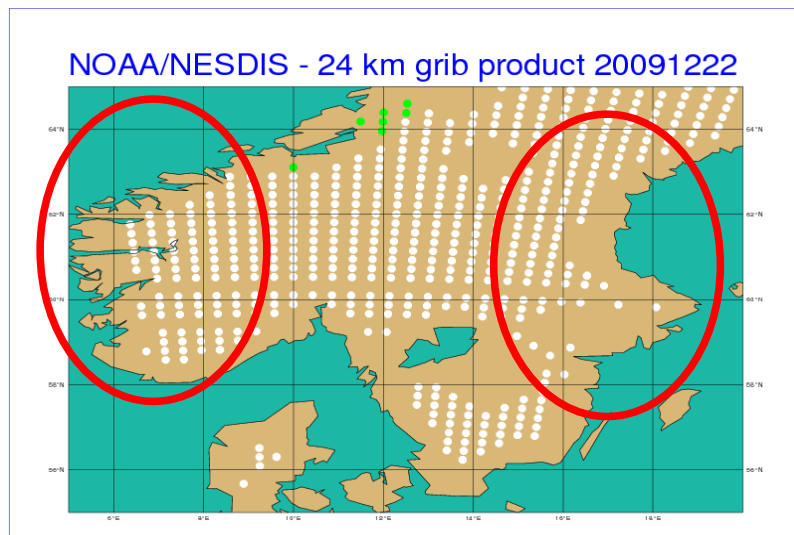
Brun et al., Snow Watch 2013

de Rosnay et al., Surv. Geophys 2014

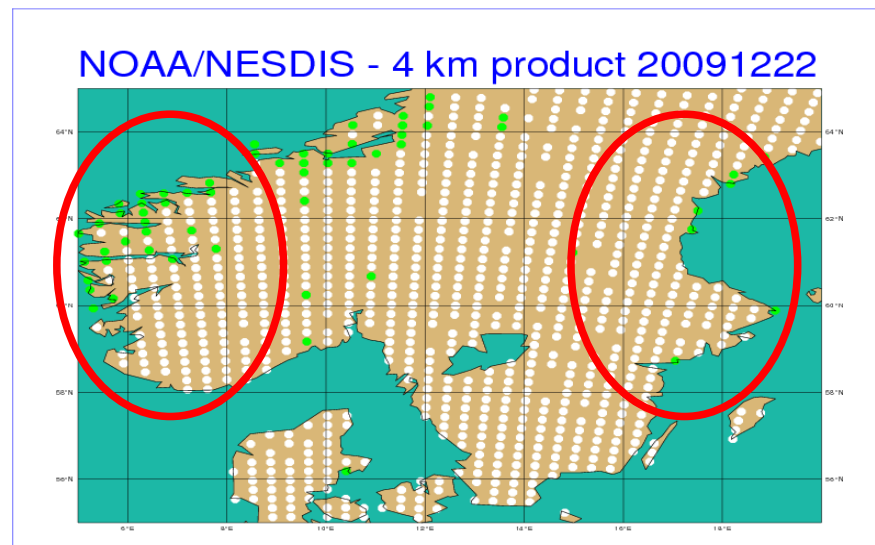
ECMWF Land Data Assimilation System:
<https://software.ecmwf.int/wiki/display/LDAS/LDAS+Home>

Snow Observations

NOAA/NESDIS IMS Snow Cover 24km vs 4km product



Used in ERA-Interim



Used for NWP (since 2010)

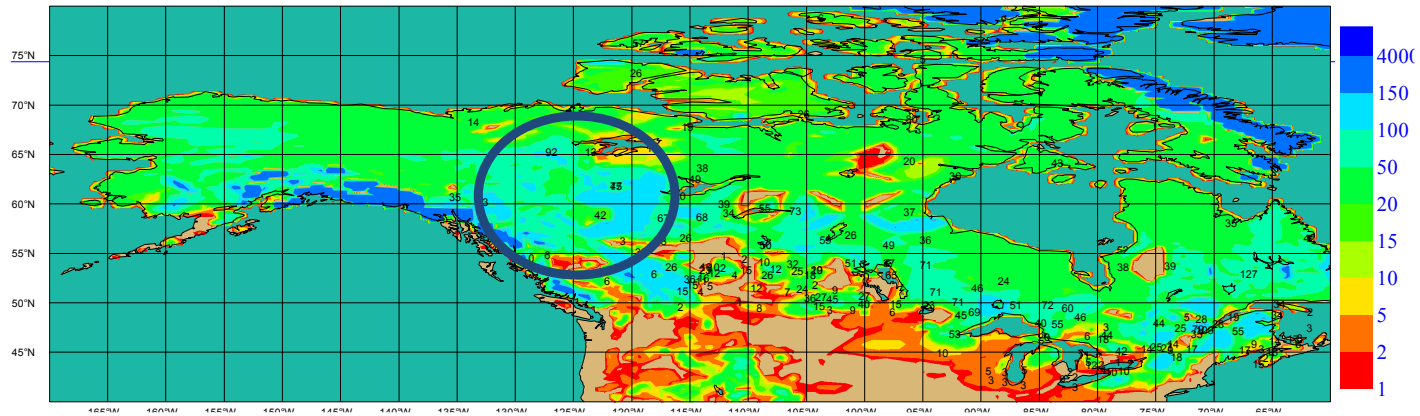
IMS Products after pre-processing at ECMWF

- Coast mask applied in the 24km product (inaccurate geolocation information in the grib product)
- Data thinning (1/36) of the 4km product -> same data quantity, improved quality
- 4km product provides more local information than 24km product

Snow Data assimilation

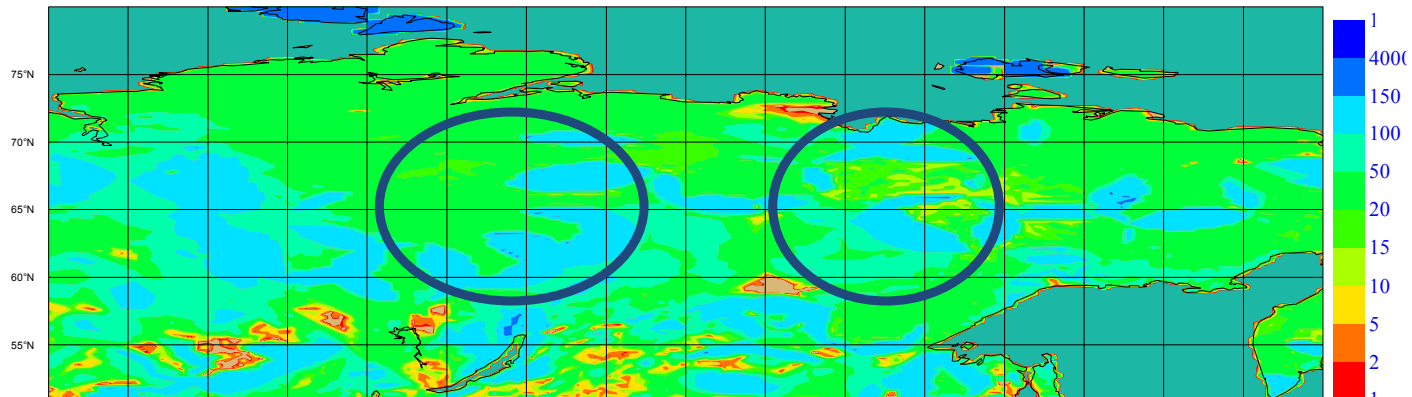
Cressman shows spurious snow Patterns where observations are scarce (Kalnay, 2003)

SNOW Depth and SYNOP data in cm (1) 20050220 at 12UTC



North
America
2005

SNOW Depth and SYNOP data in cm (1) 20070212 at 12UTC



Siberia
2007