H-SAF /HEPEX Workshops
ECMWF, Reading, UK, 3-7 November 2014

ECMWF Snow modelling and data assimilation

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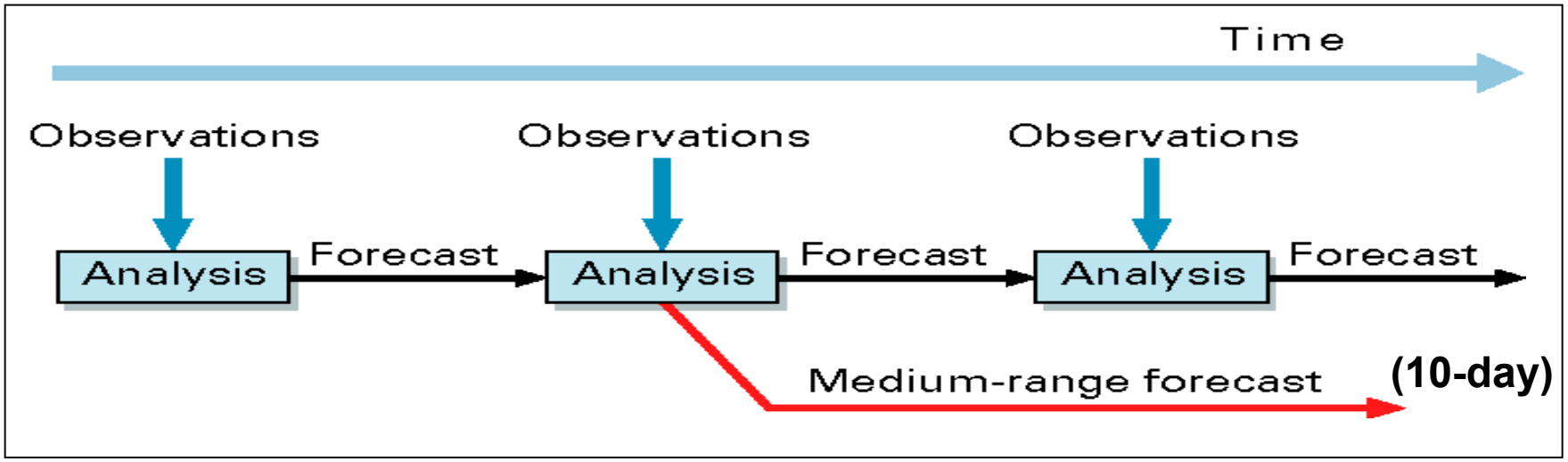
ECMWF Integrated Forecasting System (IFS) for Numerical Weather Prediction (NWP)



- **Forecast Model:** GCM including the H-TESSEL 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-TESSEL

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/m^3
- Snow Albedo between 0.5 and 0.85

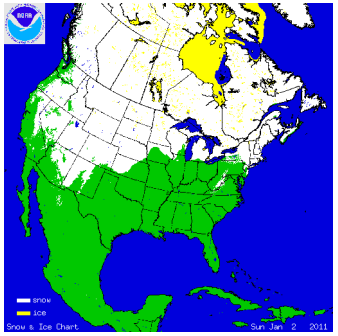
} **Prognostic variables**

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

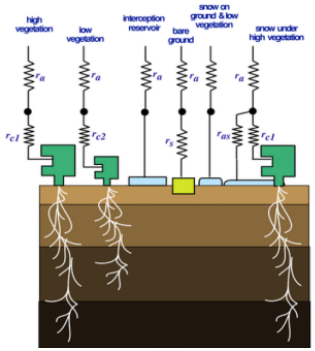


Data Assimilation:

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

de Rosnay et al., Survey of Geophysics 2014

Snow Model



H-TESSEL (Balsamo et al., JHM, 2009**)** accounts for up to 7 surface tiles over land: bare ground, low and high vegetation, interception, lakes and two tiles for snow: exposed snow; shaded snow (under high veg)

Snow model revision in 2009

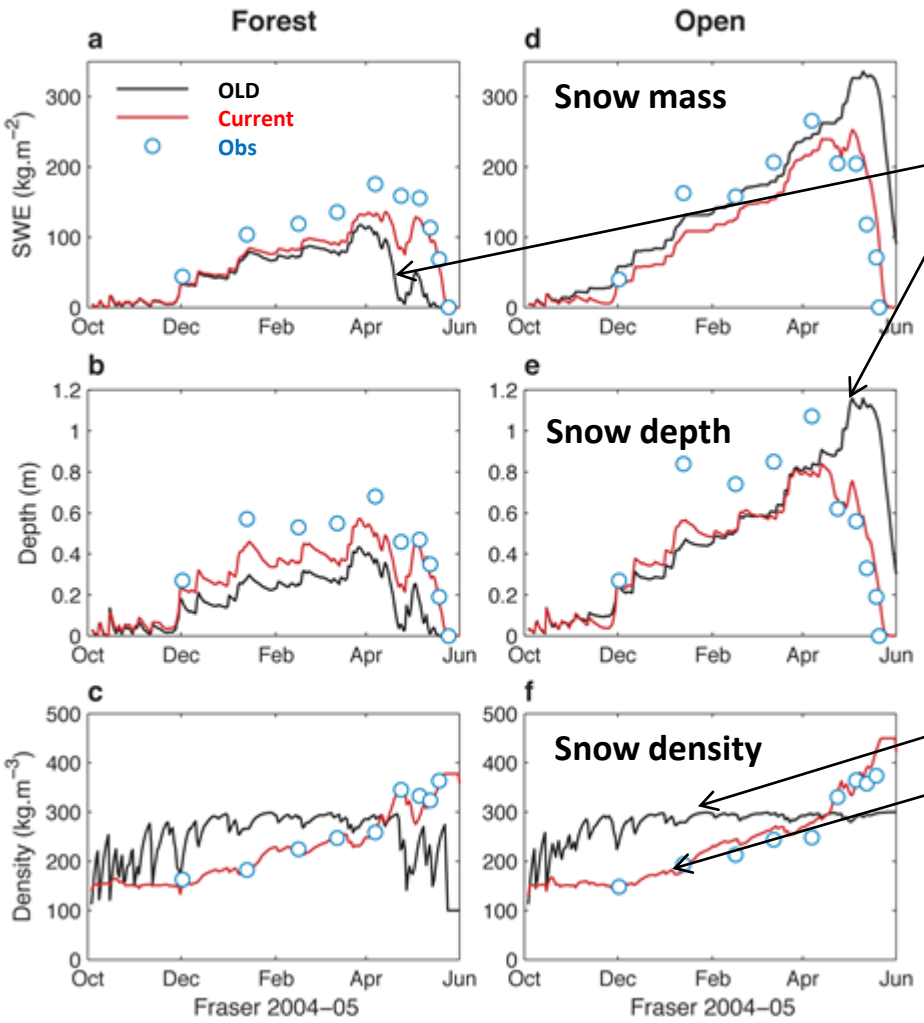
Dutra et al., JHM 2010

	OLD	CURRENT
Liquid water	Dry snow only	- Fraction of liquid water fn of snow mass & temp - Interception of rainfall
Snow Density	Empirical exponential increase and snowfall density constant=100 $kg.m^{-3}$	Physically based (Anderson 1976) and snow fall density fn of temperature & wind speed
Snow Albedo	- Exponential(melting) / Linear decay - Reset to max (0.85) snowfall > 1 mm hr^{-1} - Shaded: constant albedo (0.15)	- Account for liquid water in exponential decay - Continuous reset to max depending on the amount of snowfall (10 mm to full reset) -Shaded : vegetation type dependent (Moody et al. 2007)
Snow fraction	Function of snow mass with a threshold SF=1 for SWE >= 15 mm	Function of snow depth (→ mass and density) with a threshold of SF=1 for SD >= 10 cm

Snow Model

Validation against in situ snow observations (SnowMIP2 sites)

Dutra et al., JHM 2010



Melting period

Old: too late in open sites

too early for forests

Current: Albedo improved open sites

Rain interception improve forest

Snow density:

OLD: overestimated compaction

Current: Closer to observations

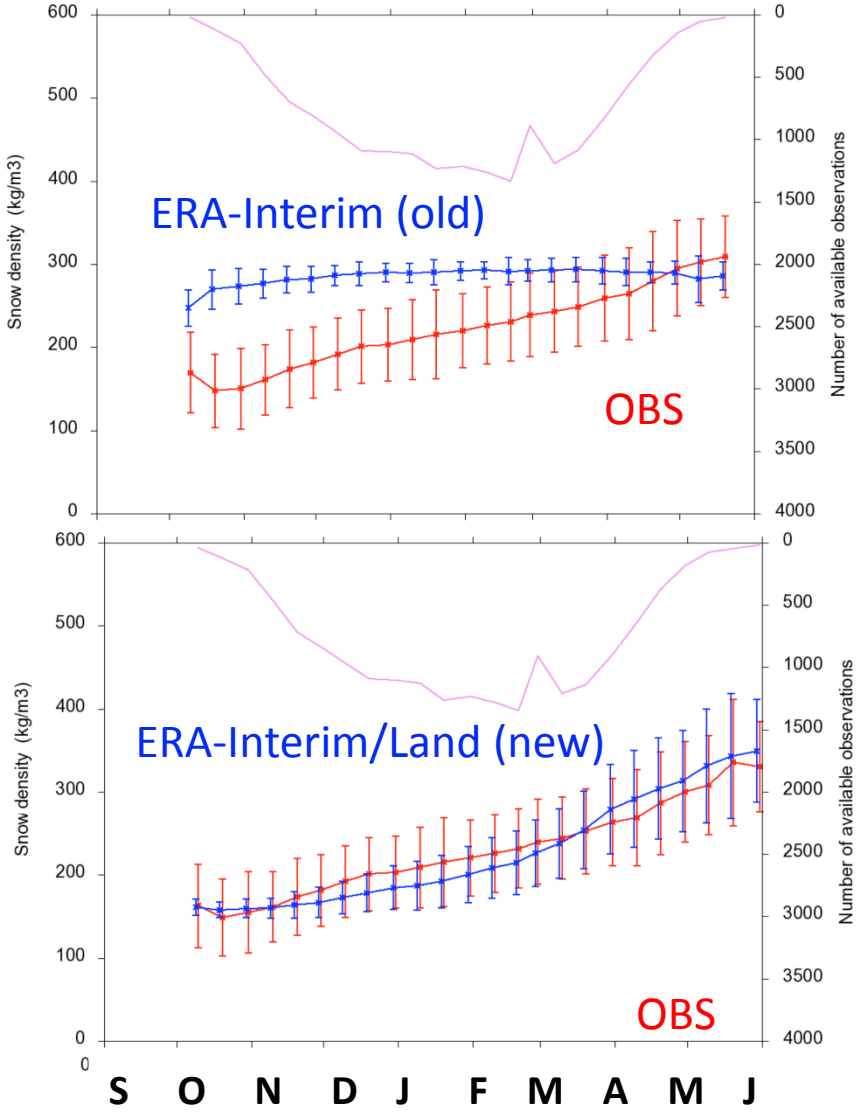
Decreased snow density

→ Increased thermal insulation

→ Reduce negative soil temperature bias

Snow Model

Comparing ERA-Interim (Old snow) with ERA-Interim/Land (New snow)



Snow density evolution (data from the former Soviet Union Hydrological Snow Surveys)
Mean seasonal cycle (1979-1993)

Old model overestimates density

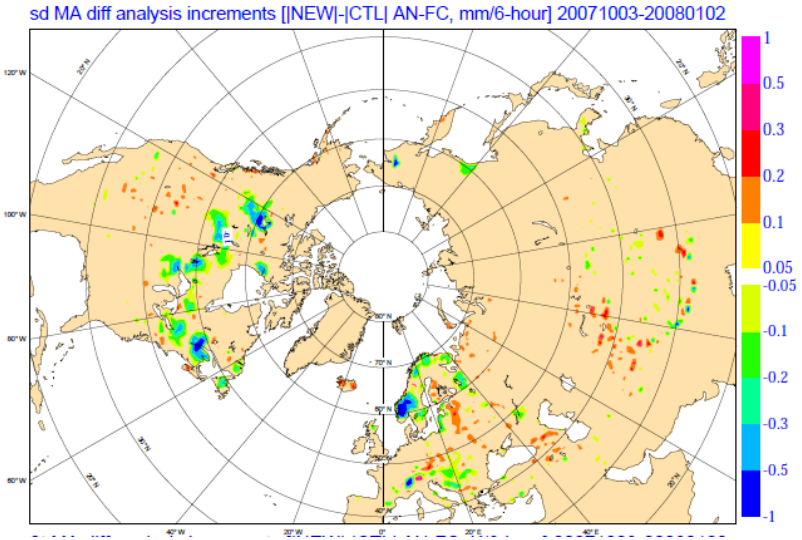
Current snow density formulation improves significantly the match with observations ERA-Interim/Land

A correct snow density simulation is very important to link SWE to Snow depth measurements

(Balsamo et al. HESSD 2014)

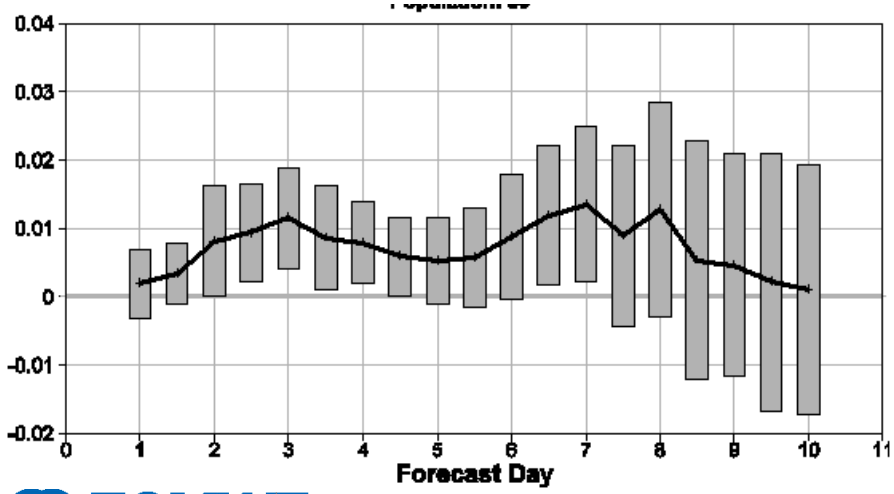
Snow Model

Snow mass analysis increments:
|NEW| - |OLD|



Effects of snow model improvements on snow data assimilation

Cold colors show reduction of assimilation increments → Short range forecast closer to observations



Impact of snow model on NWP:

RMSE forecast (OLD-Current) N. Hemisphere 1000hPa Temperature at 00UTC

Significant improvement of near surface temperature

(01-10-2007-30-04-2008)

Snow Observations

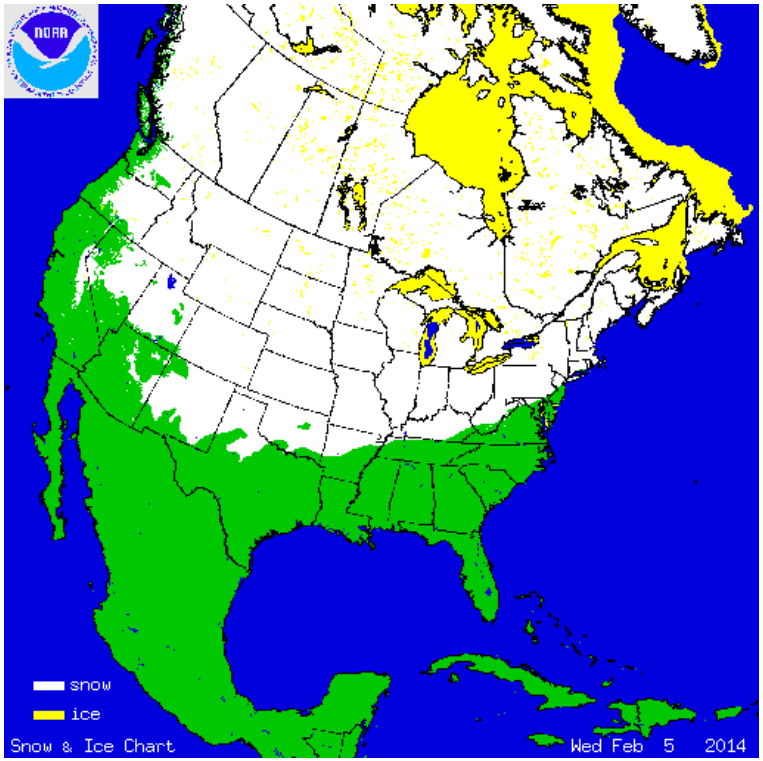
Interactive Multisensor Snow and Ice Mapping System (IMS)

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

Northern Hemisphere product

- **Daily, no time stamp**
- Polar stereographic projection

NOAA/NESDIS
IMS Snow extent data



IMS Snow Cover 5 Feb. 2014

Information content: Snow/Snow free

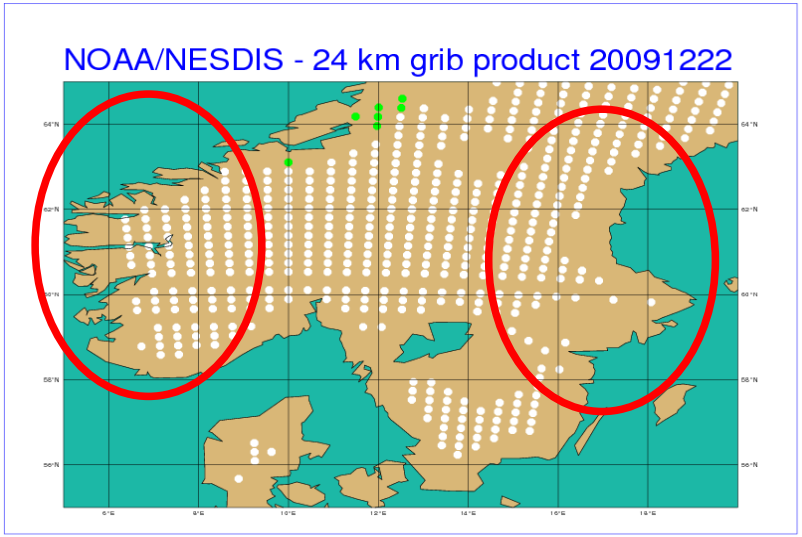
Data used at ECMWF:

- **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)

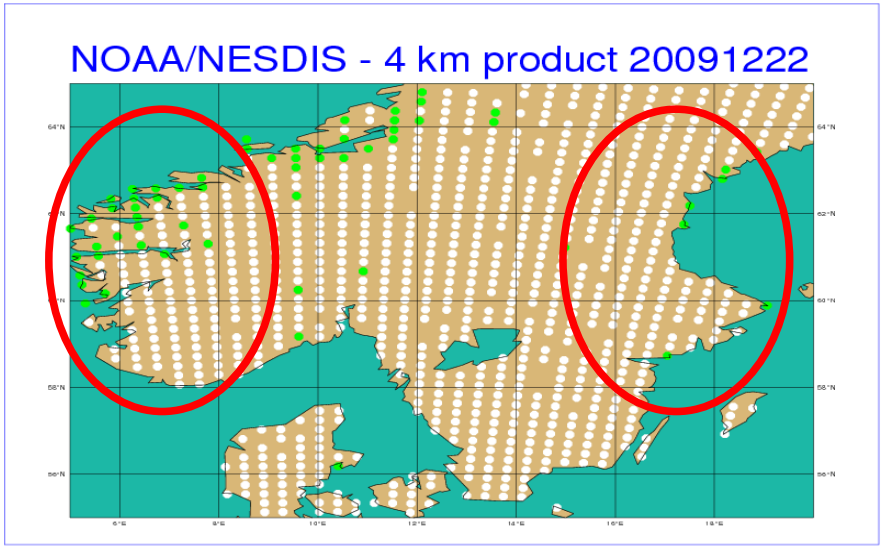
More information at: http://nsidc.org/data/g02156.html

Snow Observations

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



Used in ERA-Interim



Used for NWP (since 2010)

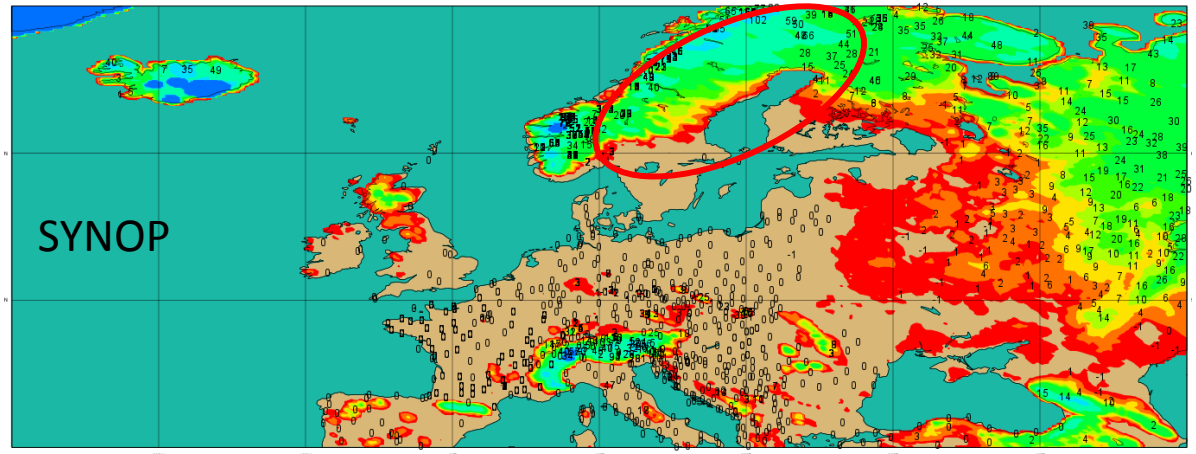
IMS Products after pre-processing at ECMWF

- 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 Observations

2014 01 01 at 06UTC

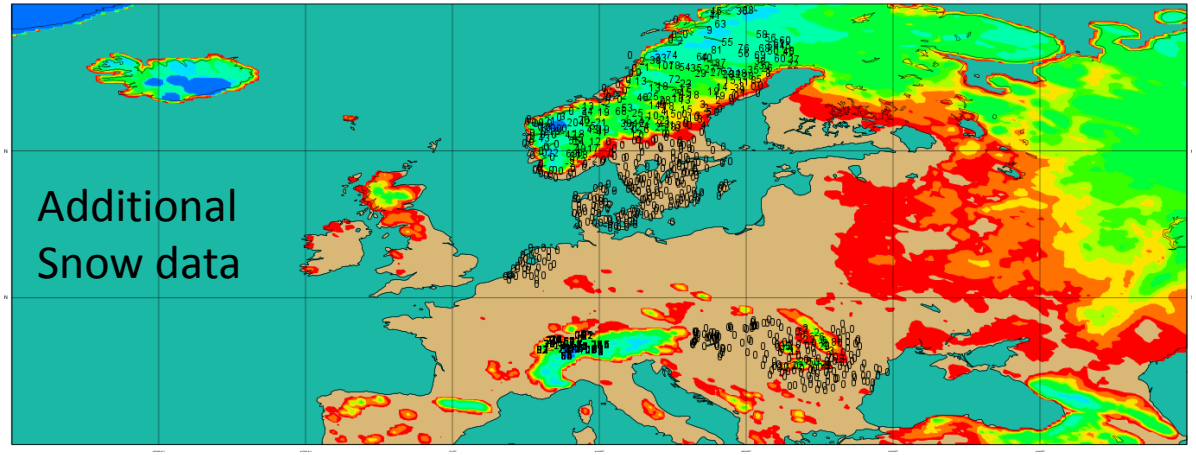
Snow SYNOP and National Network data



Data available on the GTS (Global Telecommunication System)

Snow Depth (cm)

2 5 10 15 20 50 100 150 4000



Additional data from national networks (7 countries):

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

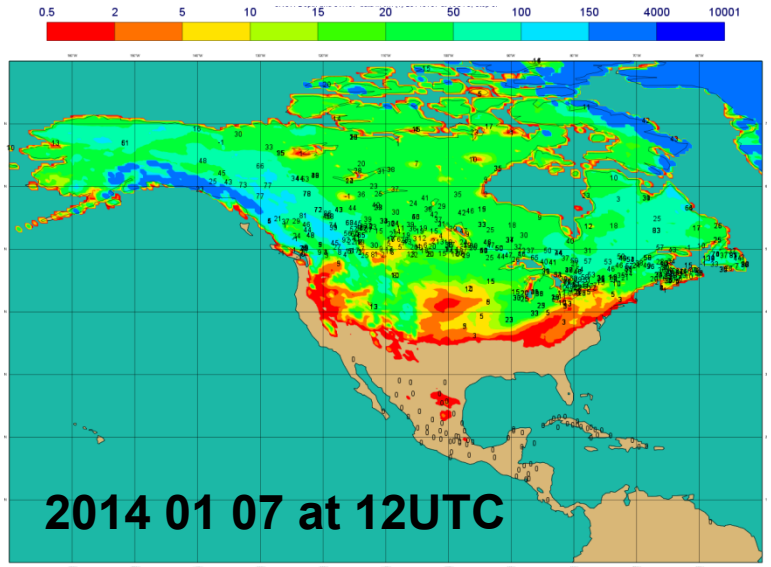
→ **Dedicated BUFR (2011)**

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

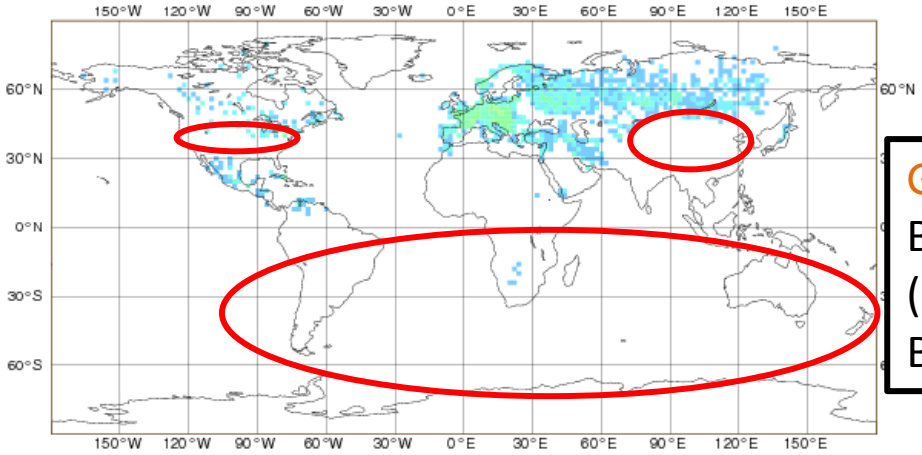
Snow Observations

SYNOP Snow depth availability

Data available on the GTS
(Global Telecommunication System)



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



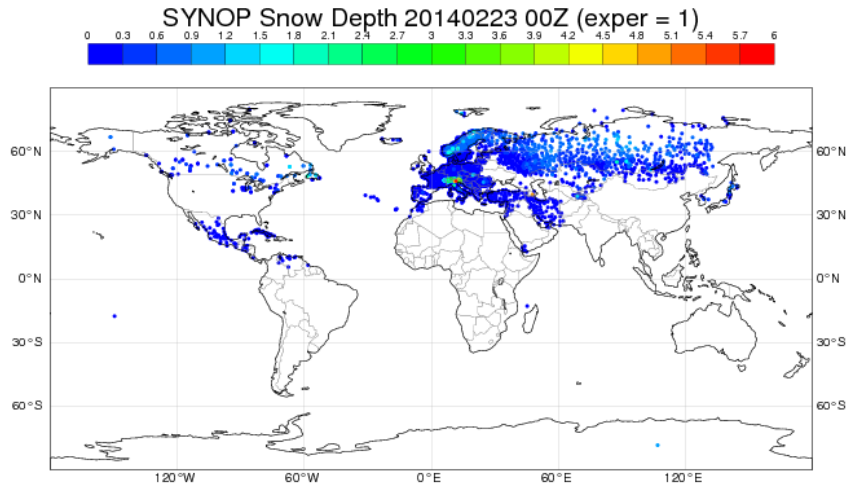
Gap in USA, China and southern hemisphere
But NRT data exist and is available,
(e.g . >20000 station in USA)
But it is not on the GTS for NWP applications.

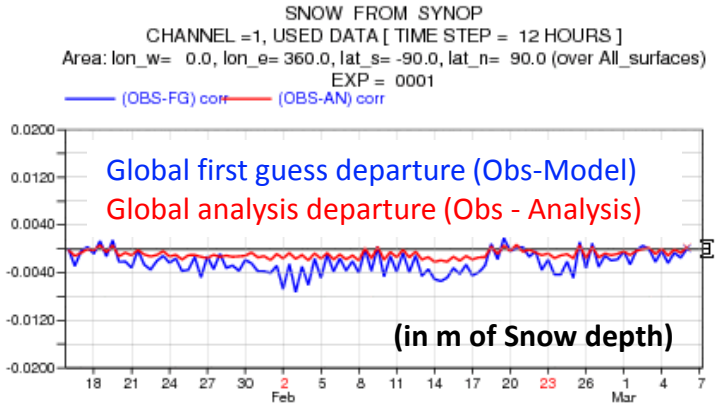
- WMO GCW Snow Watch initiative to improve in situ snow depth data access (NRT and rescue), Brun et al 2013
- Dedicated BUFR template (WMO approved 2014) or SYNOP report

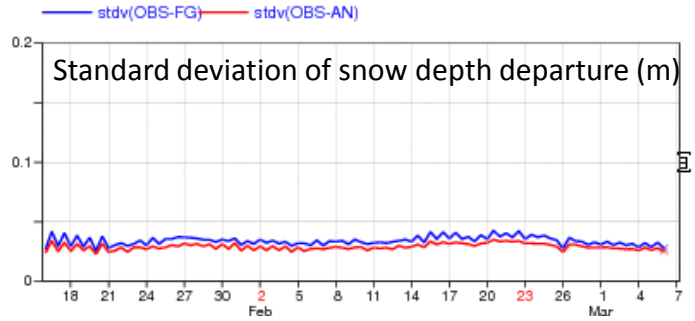
→ WMO Members States encouraged to put on the GTS their snow depth data

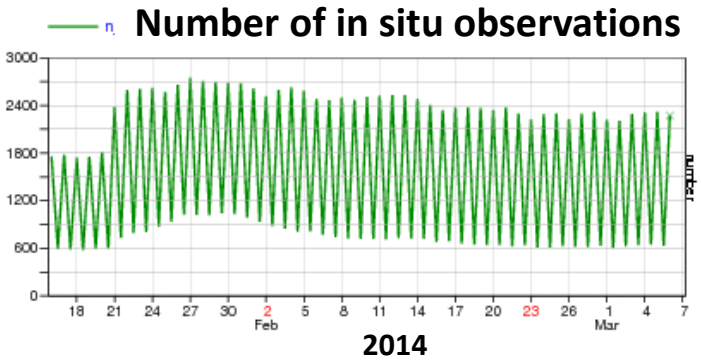
Snow Observations

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









2014

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 Data assimilation

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

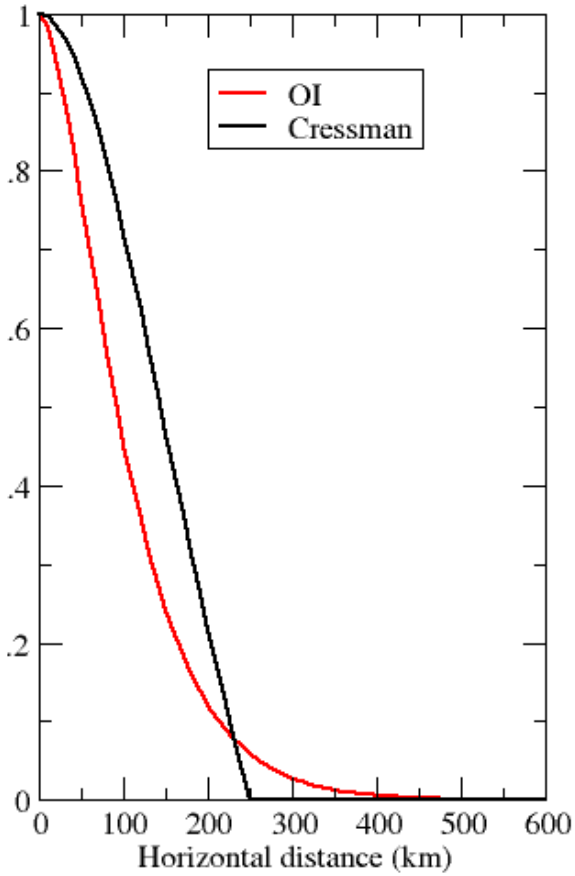
Cressman: ERA-Interim and oper until 2010

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

Optimal Interpolation (OI): Oper since 2010

The correlation coefficients follow a second-order autoregressive horizontal structure and a Gaussian for the vertical elevation differences.

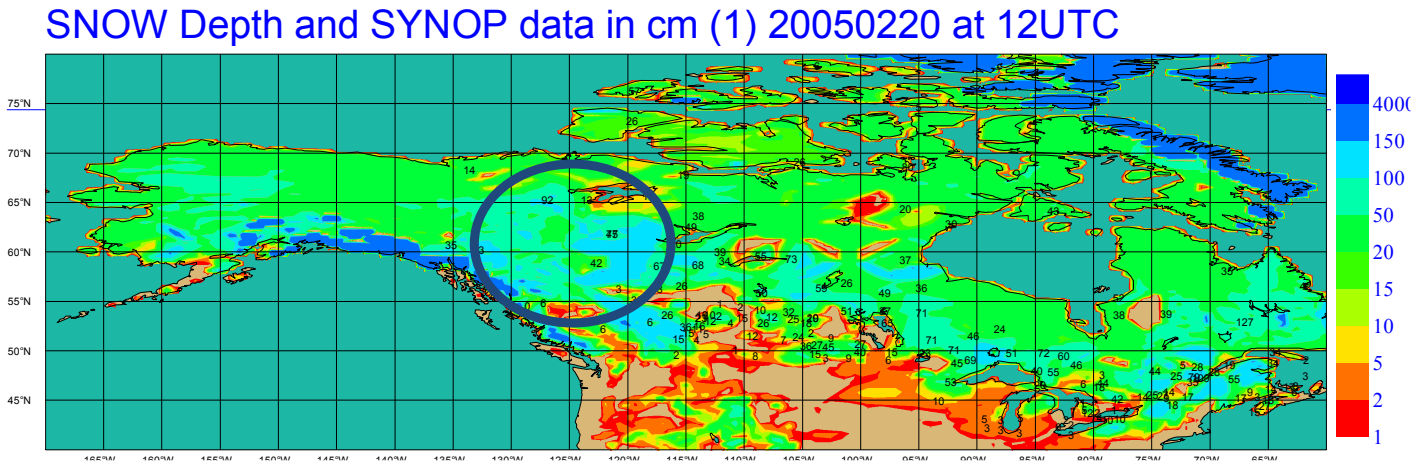
OI has longer tails than Cressman and considers more observations. Model/observation information optimally weighted using error statistics.



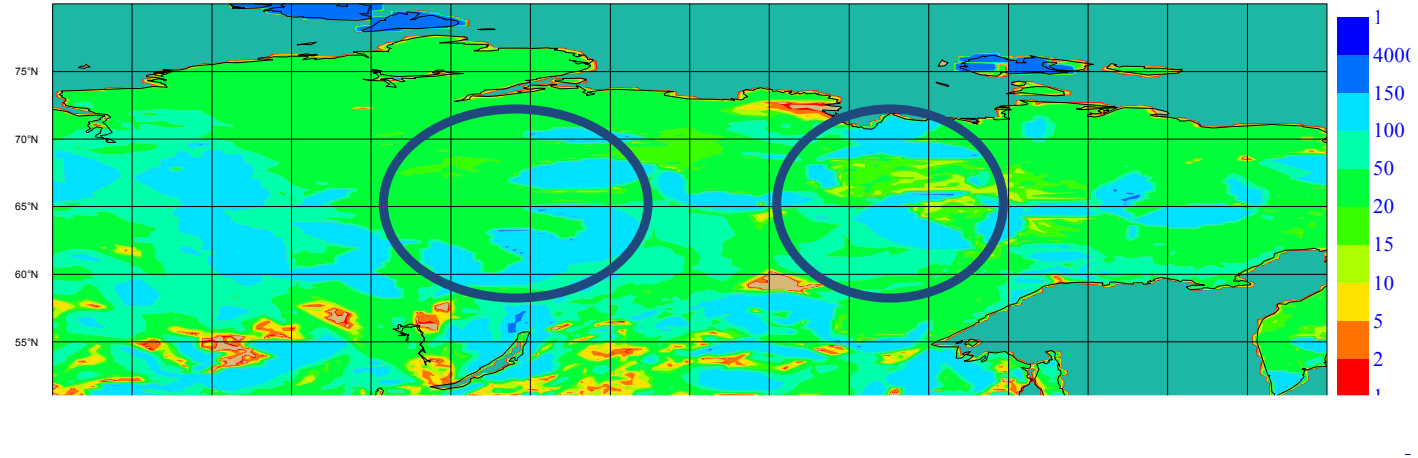
de Rosnay et al., Surv. Geophys. 2014

Snow Data assimilation

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



North America 2005



Siberia 2007

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

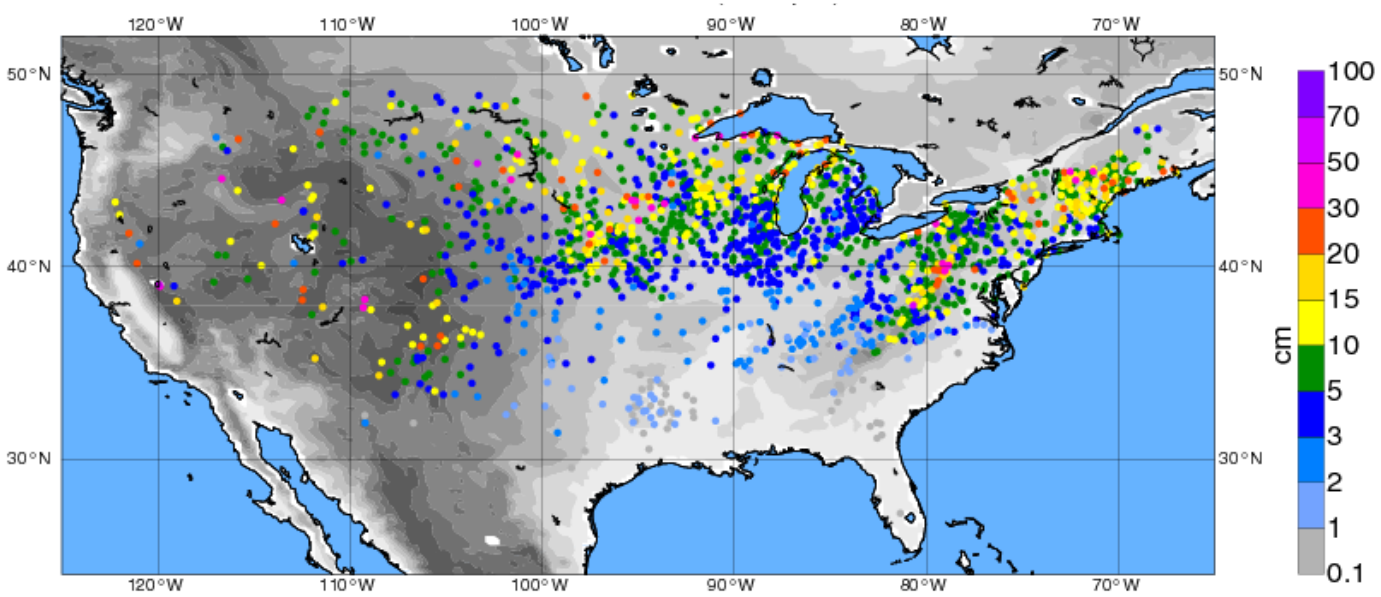
→ Improvement due to the OI compared to Cressman

Snow Data assimilation

Validation data: NWS/COOP

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

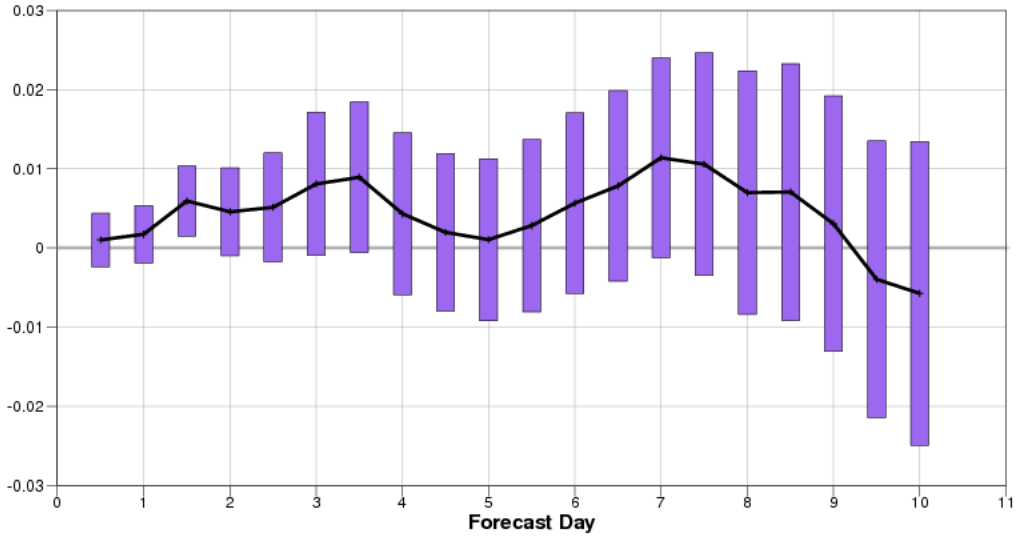
RMSE (cm) for the new snow analysis, winter 2010
(OI, IMS 4km except in mountainous areas)



Snow Data assimilation

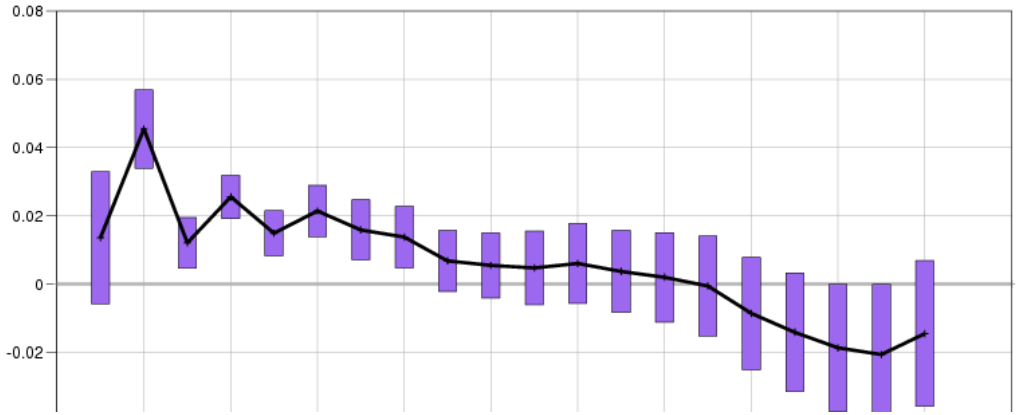
Impact on the Atmospheric Forecasts

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

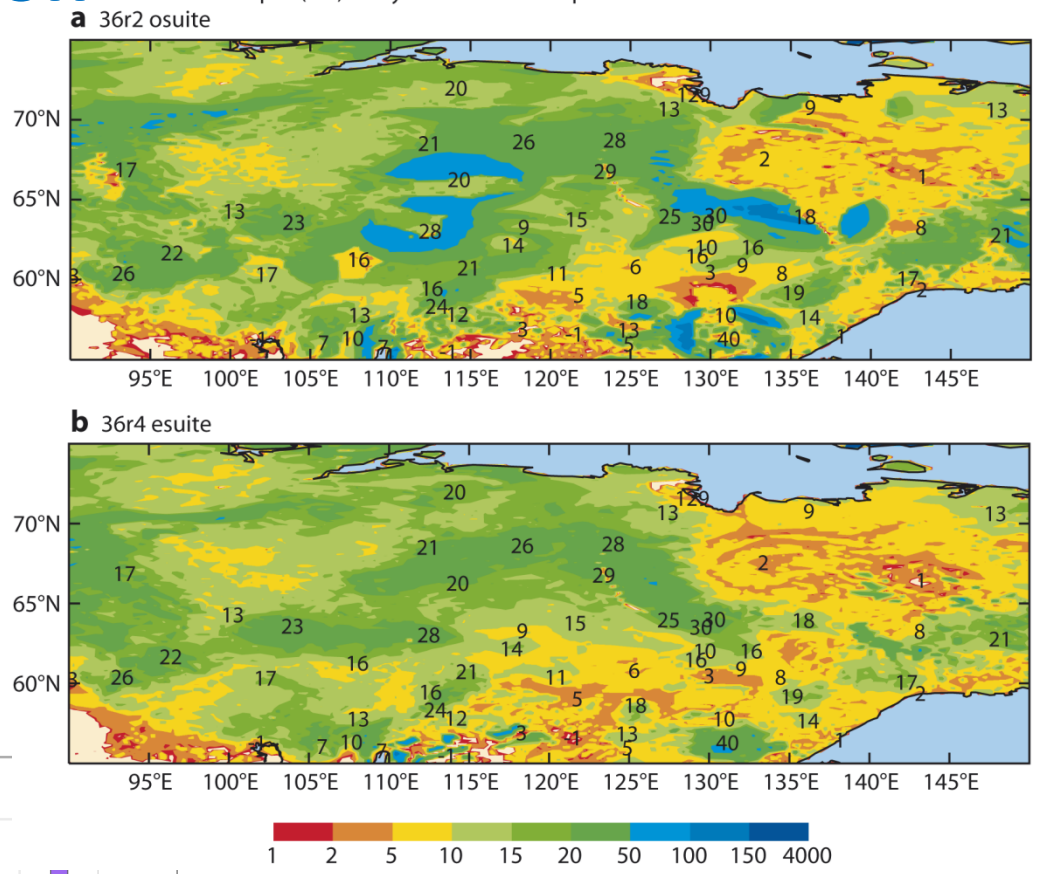
Positive: new improves

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

Snow Data assimilation

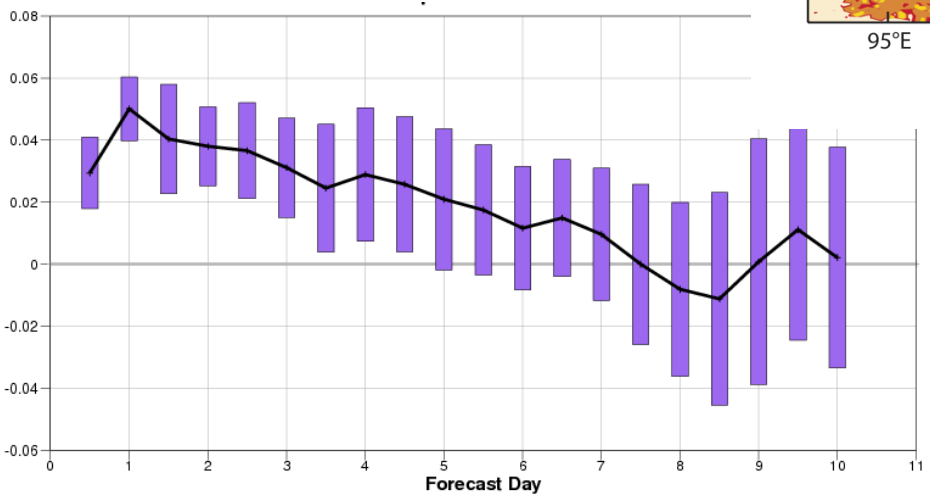
Old:
Cressman+ IMS 24km

New:
OI+ IMS 4km



FC impact (East Asia)

RMSE 500 hPa Geopot H



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:

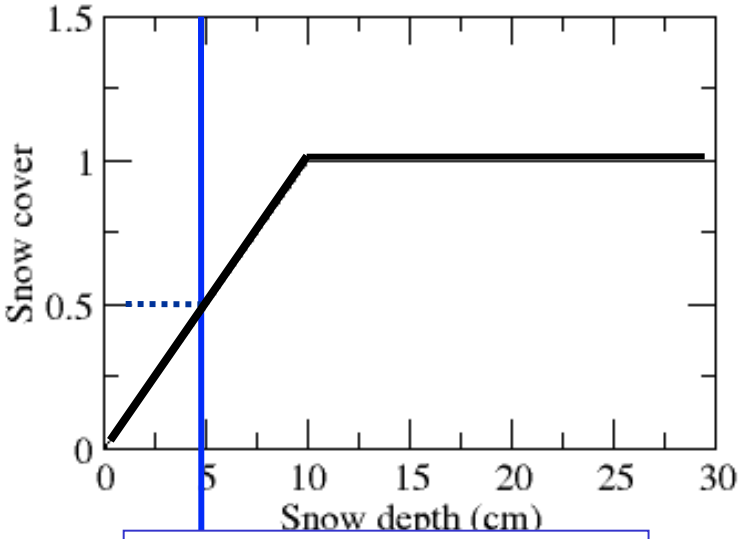
Cycle 40r1 (Nov 2013):

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

OI

40r1 errors:

BG	σ_b = 3cm
SYNOP	σ_o = 4cm
IMS	σ_{ims} = 8cm



40r1:

- Obs assimilated

- SC=1 → 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	σ_b = 3cm
OBS	σ_o = 4cm

Current version: Cycle 40r1 (Nov 2013):

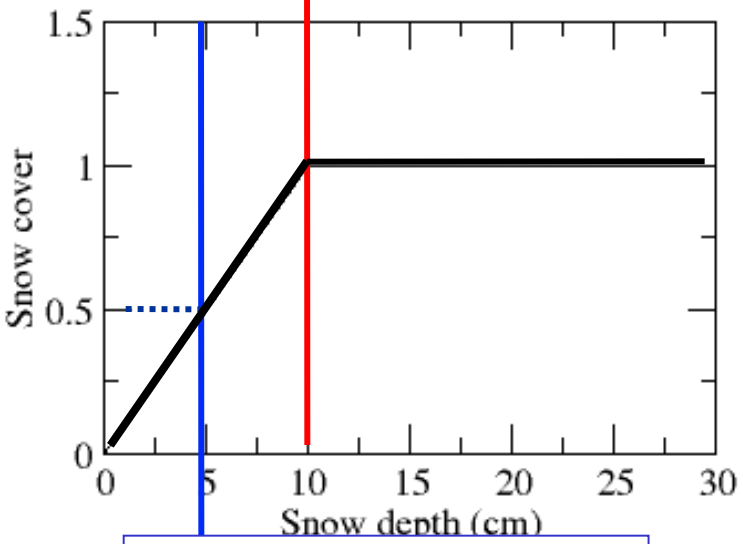
NESDIS \ FG	Snow	No Snow
Snow	x	**DA** 5cm
No Snow	DA	DA

OI

IFS 40r1 errors:

BG	σ_b = 3cm
SYNOP	σ_o = 4cm
IMS	σ_{ims} = 8cm

Previously (38r2):
- **BG overwritten**
- **SC=1 → SD=10cm**



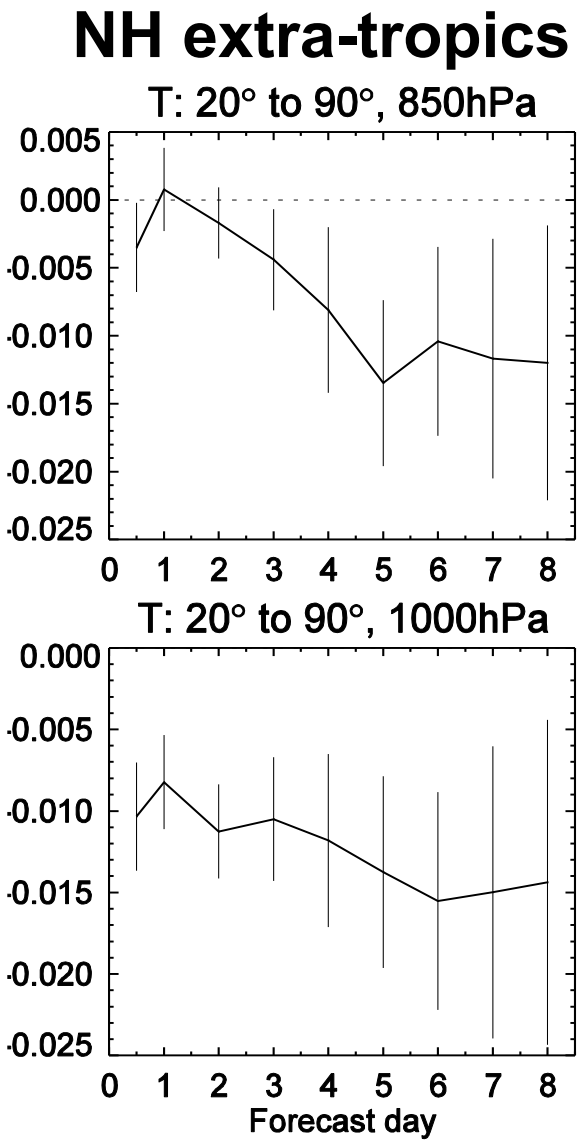
Current (40r1):
- **Obs assimilated**
- **SC=1 → SD=5cm**

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**



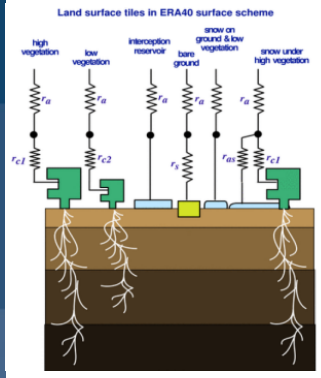
Other improvements in the ECMWF snow analysis from Nov 2013:

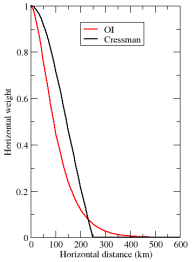
- Technical developments for conventional and IMS Observation Data Bases (ODBs)
- New Land surface observations NRT monitoring for conventional snow depth, and for IMS snow cover observations:

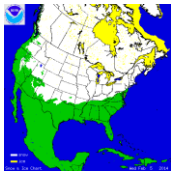
https://software.ecmwf.int/wiki/display/LDAS/Land+Surface+Observations+monitoring

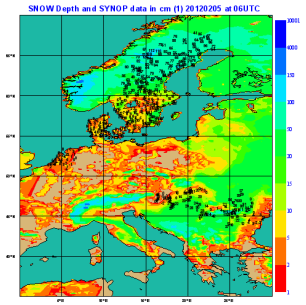
Snow in the IFS Summary

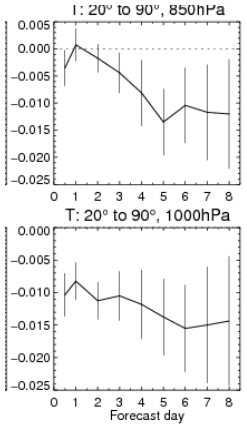
2009 2010 2011 2012 2013 2014 …











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 & DA

. 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