6th National Seminar on Snow on the day of Pyry,
in collaboration with the COST ES1404 Action
2 November 2015, Finnish Meteorological Institute

Snow modelling and data assimilation at ECMWF

P. de Rosnay, L. Isaksen, M. Dahoui, E. Dutra, G. Balsamo and B. Ingleby

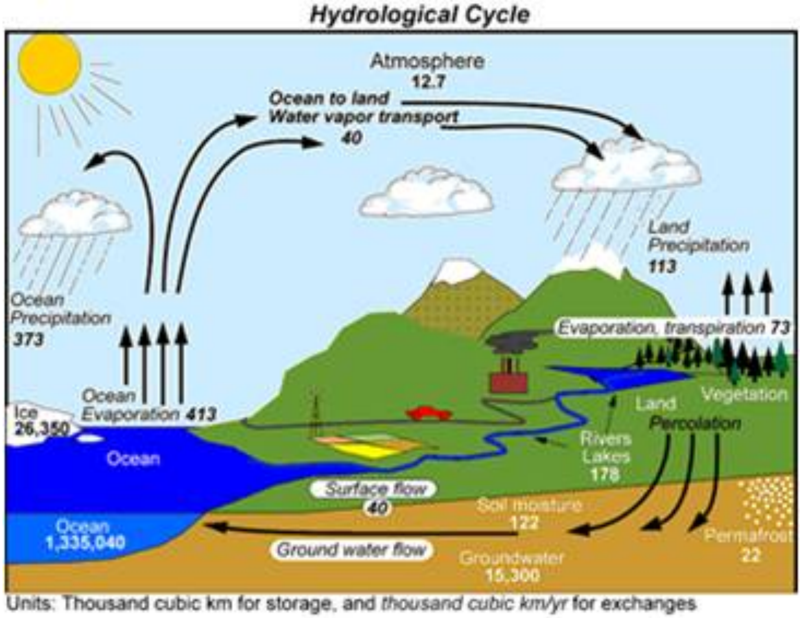
Introduction: Land Surfaces in Numerical Weather Prediction (NWP)

- Processes: Continental hydrological cycle, interaction with the atmosphere on various time and spatial scales
- Boundary conditions at the lowest level of the atmosphere
- Crucial for near surface weather conditions,

whose high quality forecast is a key objective in NWP

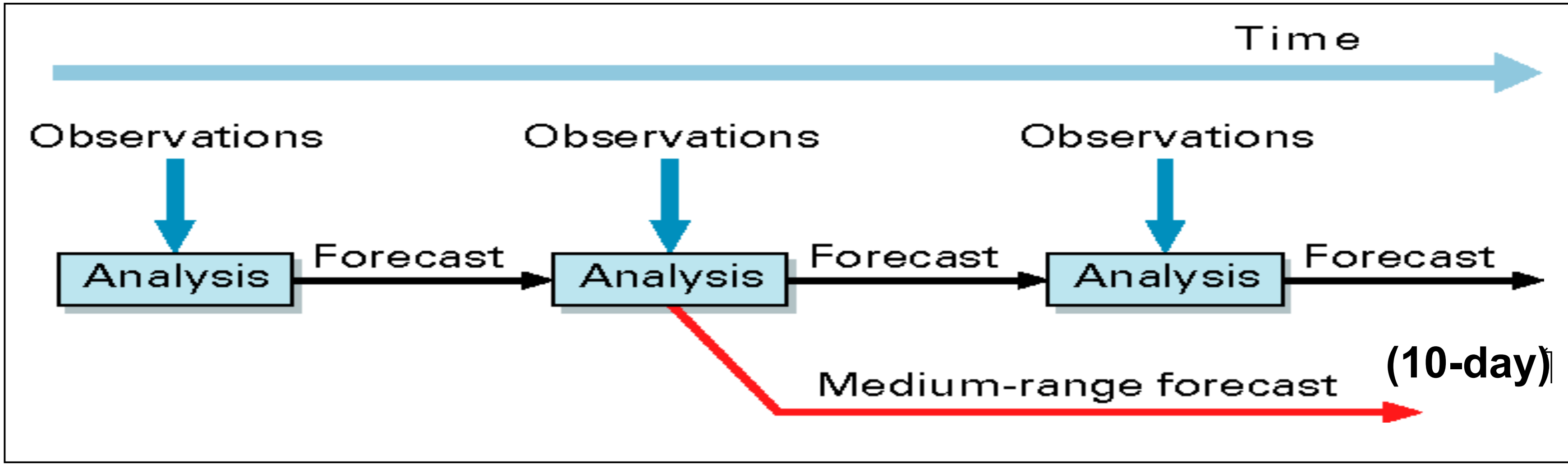
→ **Land surface processes modelling & initialisation are important for NWP at all range (short to seasonal)**

(Beljaars et al., Mon. Wea. Rev, 1996, Koster et al., 2004 & 2011)



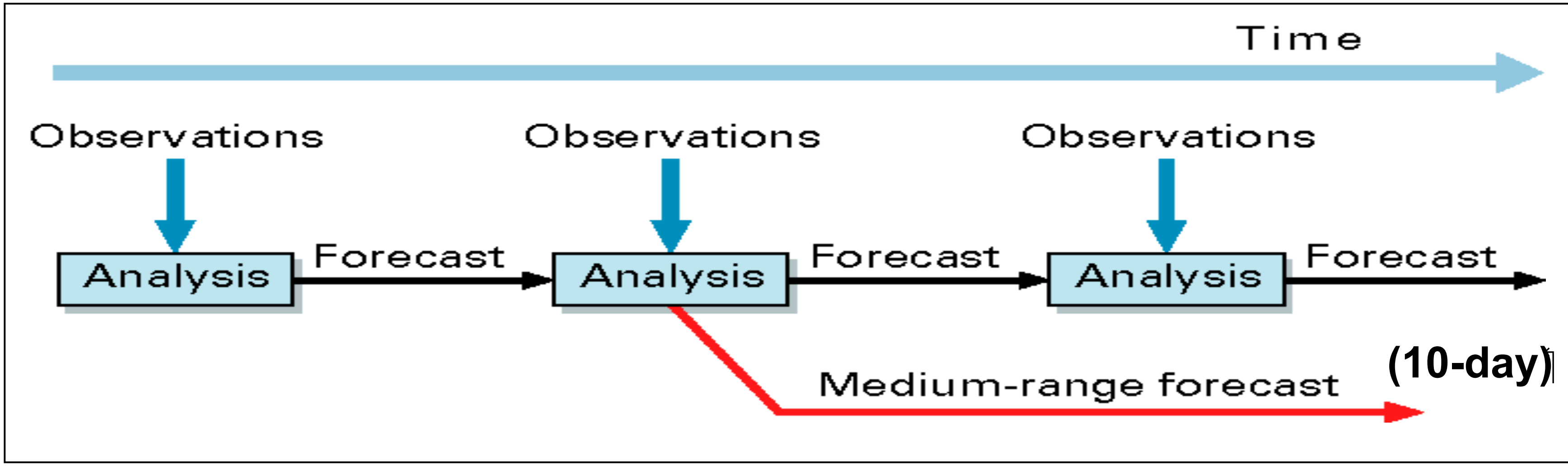
Trenberth et al. (2007)

ECMWF Integrated Forecasting System (IFS)



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

ECMWF Integrated Forecasting System (IFS)



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

Different Systems:

- **NWP (oper):** IFS (with 4D-Var and LDAS), 16km, version 41r1 (2015)
- **ERA-Interim:** IFS (with 4D-Var and LDAS), 79km, version 31r1 (2006)
- **ERA5:** IFS (with 4D-Var and LDAS), 39km, version 41r2 (2016)
- **ERA-Interim-Land:** H-TESSEL LSM simulations (no LDAS), 79km, 37r2 (2011) driven by ERA-I atmospheric cond. corrected by GPCP

ECMWF Land Data Assimilation System (LDAS)

Snow depth

Methods: Cressman for ERA-Interim, 2D Optimal Interpolation (OI) for NWP & for ERA5

Conventional observations: *in situ* snow depth

Satellite data: NOAA/NESDIS IMS Snow Cover Extent (daily product).

Soil moisture

Methods: - 1D OI in ERA-Interim (also used at Météo-France)

- Simplified Extended Kalman Filter (EKF) for NWP and for ERA5

Conventional observations: Analysed SYNOP 2m air relative humidity and air temp.

Satellite data: Scatterometer SM for NWP (ASCAT) & for ERA5 (ERS/SCAT &ASCAT)

ESA SMOS brightness temperature in development, research NASA SMAP

Soil Temperature and Snow Temperature

1D-OI using analysed T2m as observation (NWP, ERA-Interim, ERA5)

Snow in the operational forecasting system

Snow Model: Component of H-TESSEL

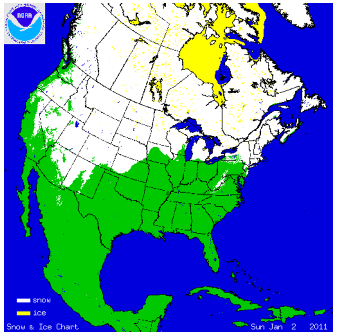
Single layer snowpack

- Snow water equivalent SWE (m), ie snow mass
- Snow Density ρ_s
- Snow Albedo

} **Prognostic variables**

Observations:

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

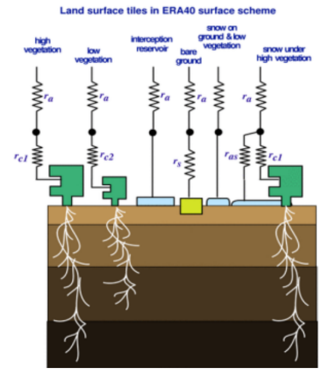


Data Assimilation:

- Optimal Interpolation (OI) in operational IFS
- Analysed variable: SWE, density

Snow Model

HTESSEL 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)



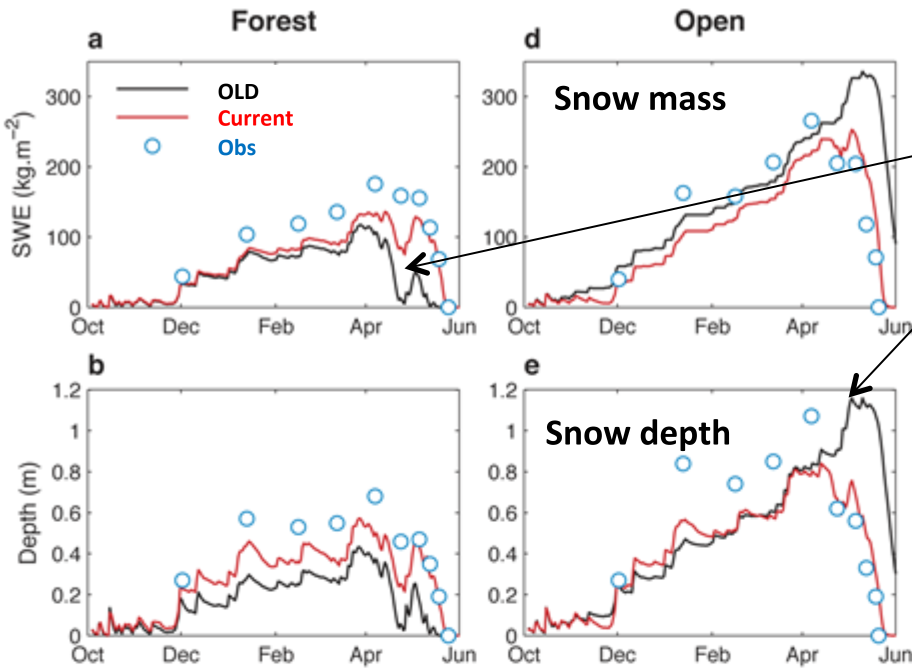
Snow model updated in 2009

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) if 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)
SF: 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 SnowDepth >= 10 cm

Snow Model

Validation against in situ snow observations (SnowMIP2 sites)



<u>Melting period</u>

<u>Old:</u> too early for forests (21days)

too late in open sites (10 days)

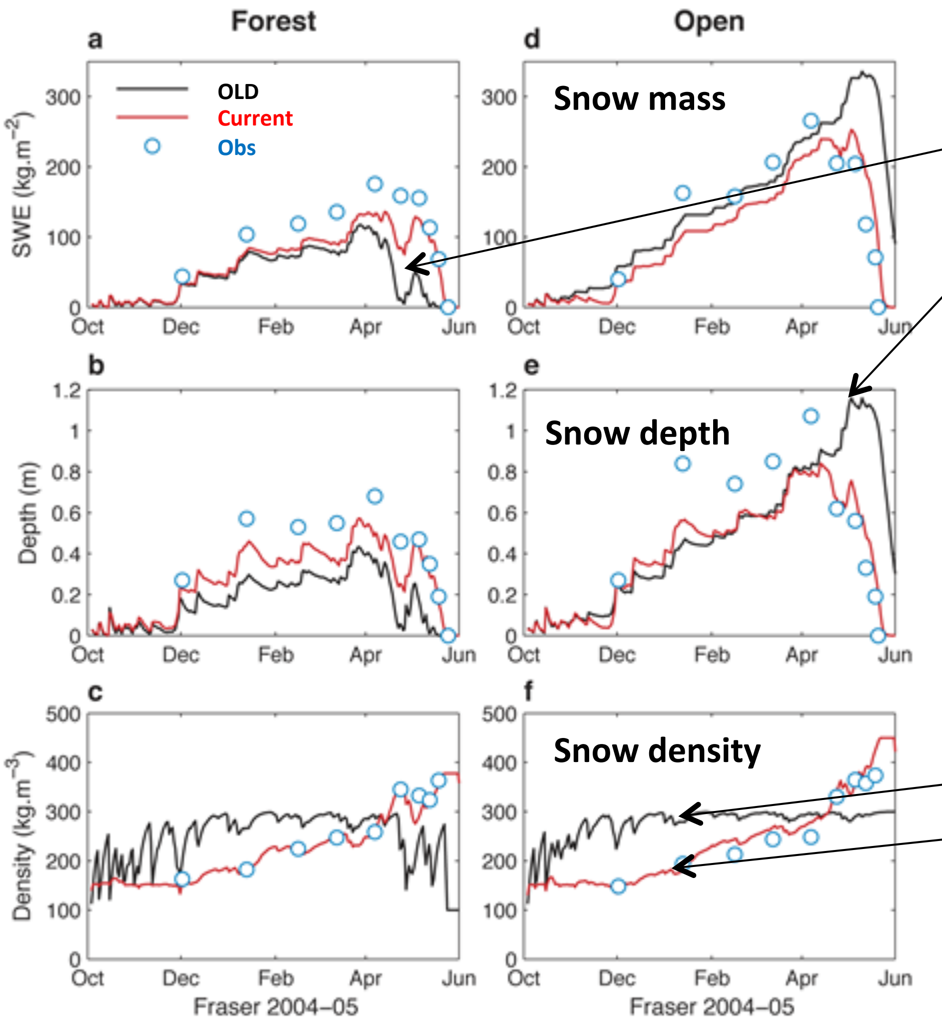
Current: Albedo → improves open sites

Rain interception → improves forest

Dutra et al., JHM 2010

Snow Model

Validation against in situ snow observations (SnowMIP2 sites)



Melting period
Old: too early for forests (21days)
too late in open sites (10 days)

Current: Albedo → improves open sites
Rain interception → improves forest

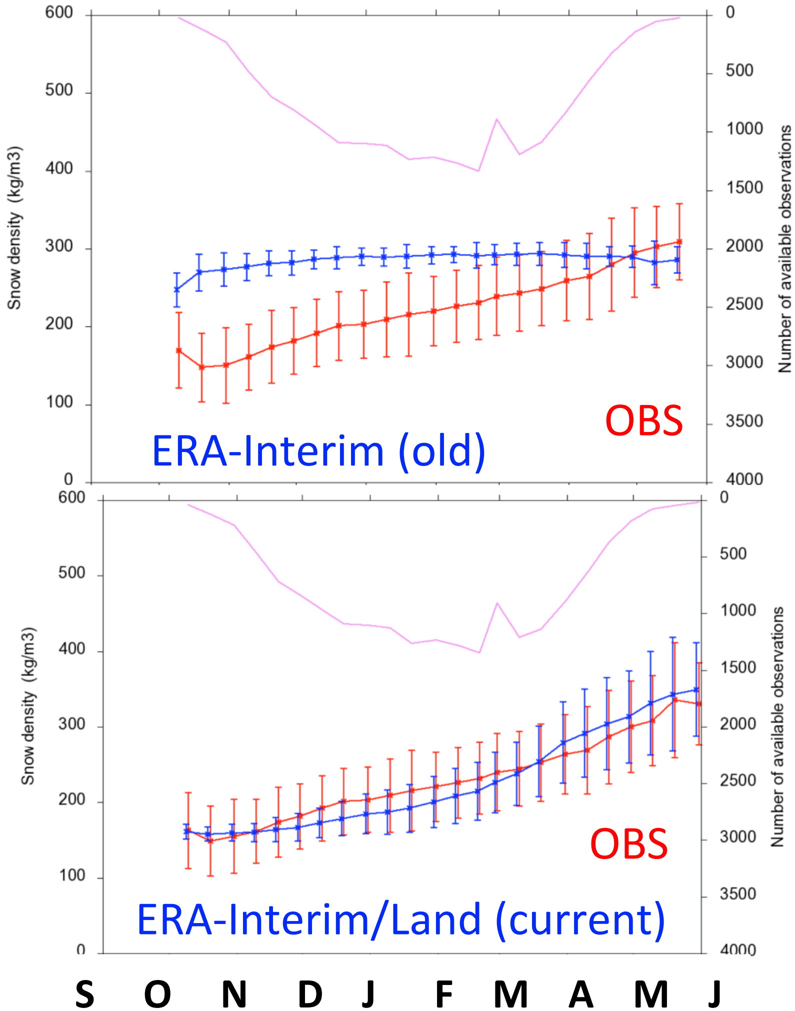
Snow density:
OLD: overestimated compaction
Current: Closer to observations

Decreased snow density
→ Increased thermal insulation
→ Reduce negative soil temperature bias

Dutra et al., JHM 2010

Snow Model

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



Snow density evolution (data from the former Soviet Union Hydrological Snow Surveys)

Old model overestimates snow density

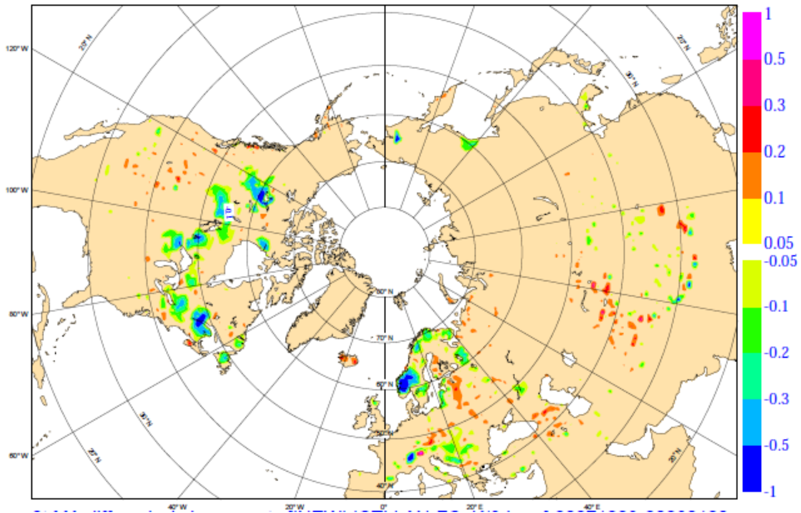
Current snow density formulation improves significantly the match with observations ERA-Interim/Land

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

(Balsamo et al. HESS 2015)

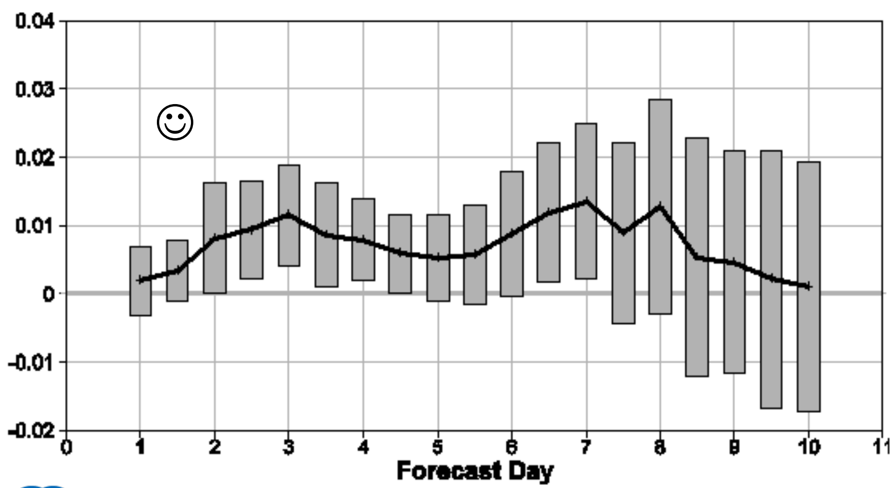
Snow Model

Snow mass analysis increments:
|Current| - |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

Improvement of near surface temperature

(Oct-Nov 2007)

Snow Observations

Interactive Multisensor Snow and Ice Mapping System (IMS)

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

Northern Hemisphere product

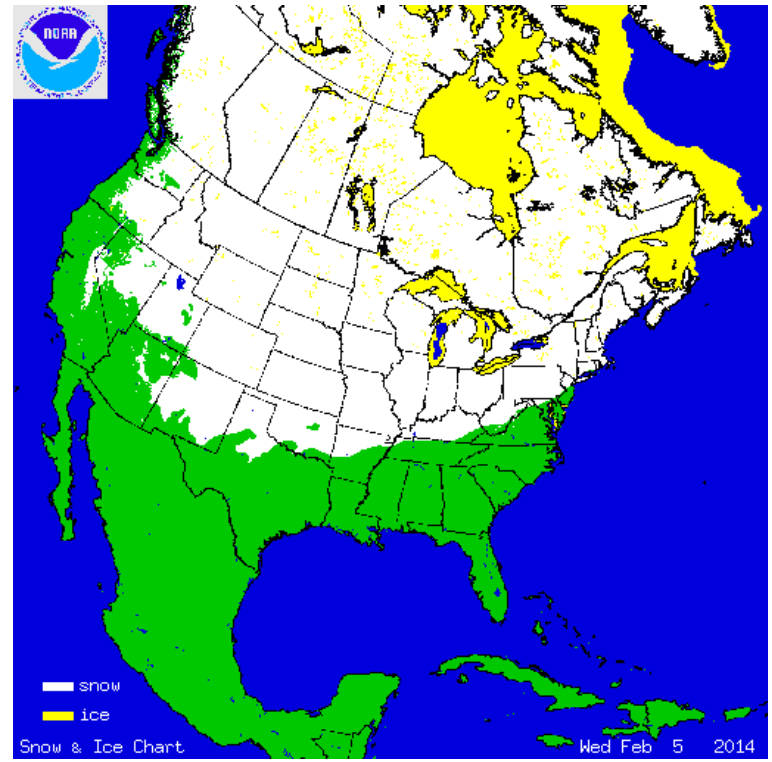
- Daily
- Polar stereographic projection

Information content: Snow/Snow free

Data used at ECMWF:

- **24km product** (ERA-Interim)
- **4 km product** (operational NWP, ERA5)

NOAA/NESDIS
IMS Snow extent data

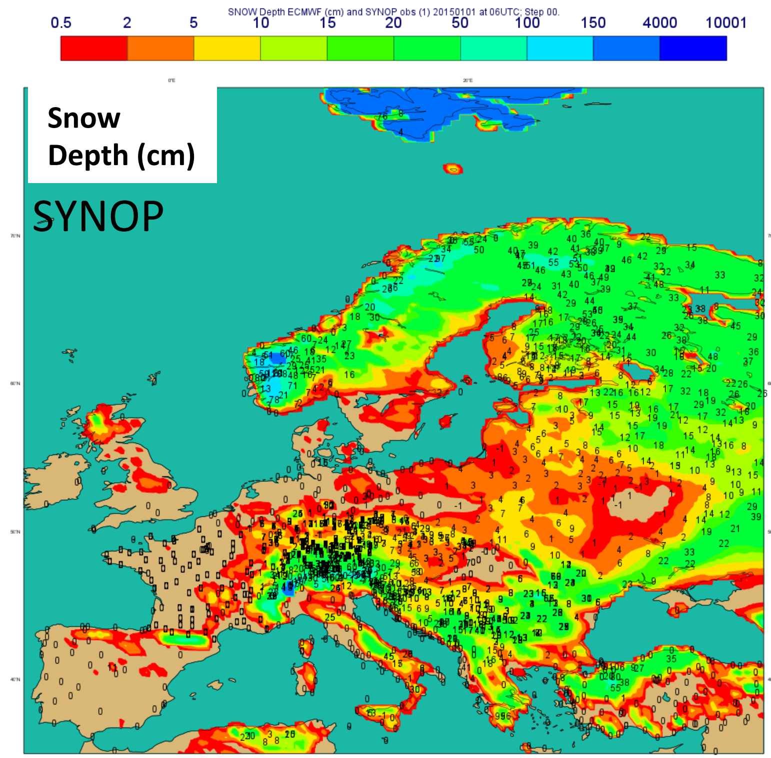


IMS Snow Cover 5 Feb. 2014

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

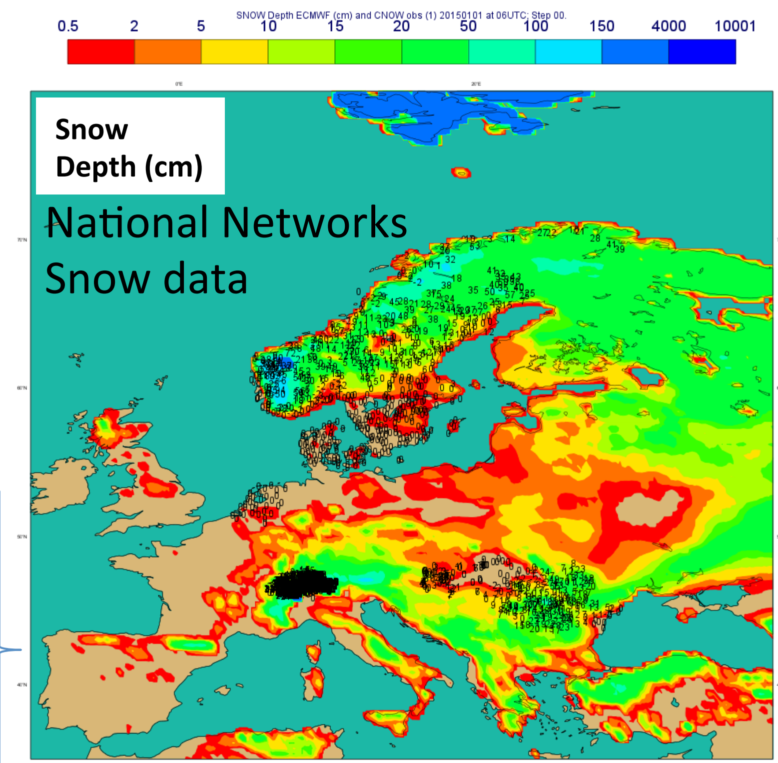
Snow Observations

Snow SYNOP and National Network data



Available on the GTS (Global Telecommunication System)

2015 01 01 at 06UTC



Additional data from national networks (7 countries):
Sweden (>300), Romania(78), The Netherlands (33), Denmark (43), Hungary (61), Norway (183), Switzerland (332).

→ **Dedicated BUFR for additional national data**

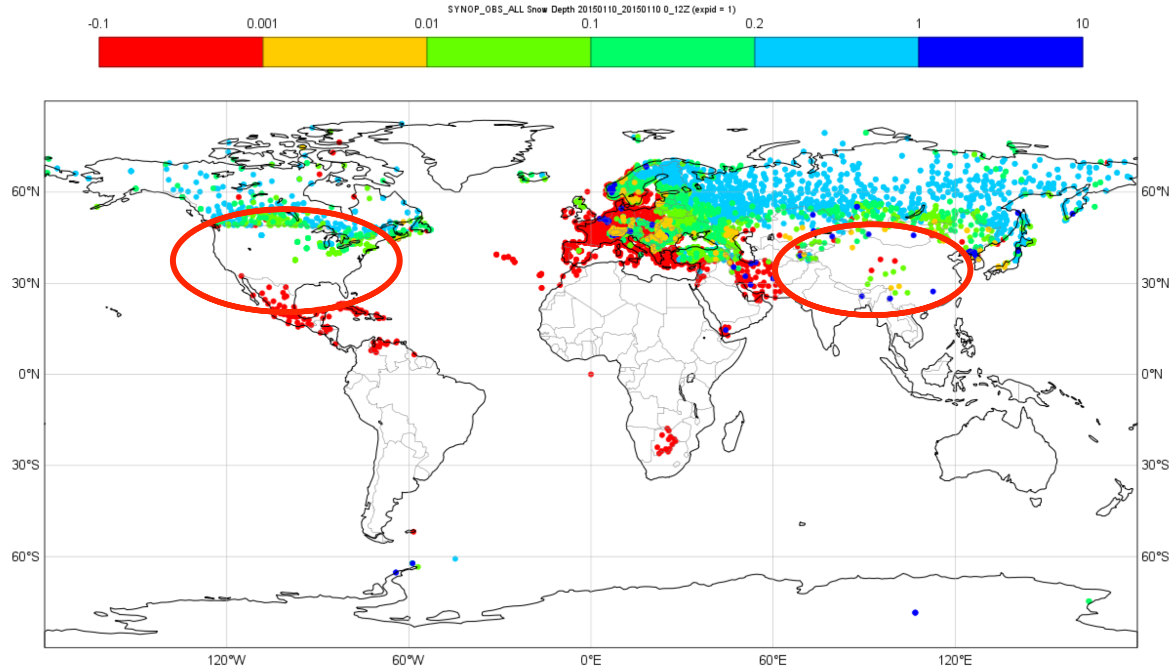
(de Rosnay et al. ECMWF Res. Memo, R48.3/PdR/1139, 2011)

Snow Observations

GTS SYNOP Snow depth availability

Status in January 2015

Operational snow observations monitoring
(SYNOP TAC + SYNOP BUFR + national BUFR data):
http://old.ecmwf.int/products/forecasts/d/charts/monitoring/conventional/snow/



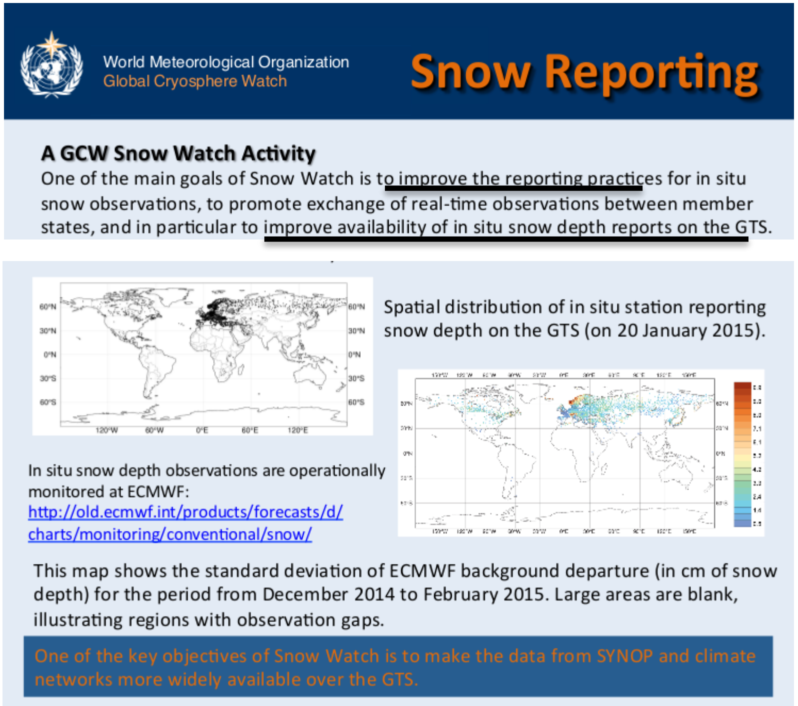
Gap in USA, China and southern hemisphere
NRT data exist and is available (more than 20000 station in the US)
But it is not on the GTS for NWP applications.

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

- BUFR template for national data approved by WMO in April 2014
- WMO GCW **Snow Watch** initiative on snow reporting, (Brun et al 2013)

International initiatives that address snow observations

GCW Snow Watch Activity on Snow reporting



World Meteorological Organization
Global Cryosphere Watch

Snow Reporting

A GCW Snow Watch Activity
One of the main goals of Snow Watch is to improve the reporting practices for in situ snow observations, to promote exchange of real-time observations between member states, and in particular to improve availability of in situ snow depth reports on the GTS.

Spatial distribution of in situ station reporting snow depth on the GTS (on 20 January 2015).

In situ snow depth observations are operationally monitored at ECMWF: http://old.ecmwf.int/products/forecasts/d/charts/monitoring/conventional/snow/

This map shows the standard deviation of ECMWF background departure (in cm of snow depth) for the period from December 2014 to February 2015. Large areas are blank, illustrating regions with observation gaps.

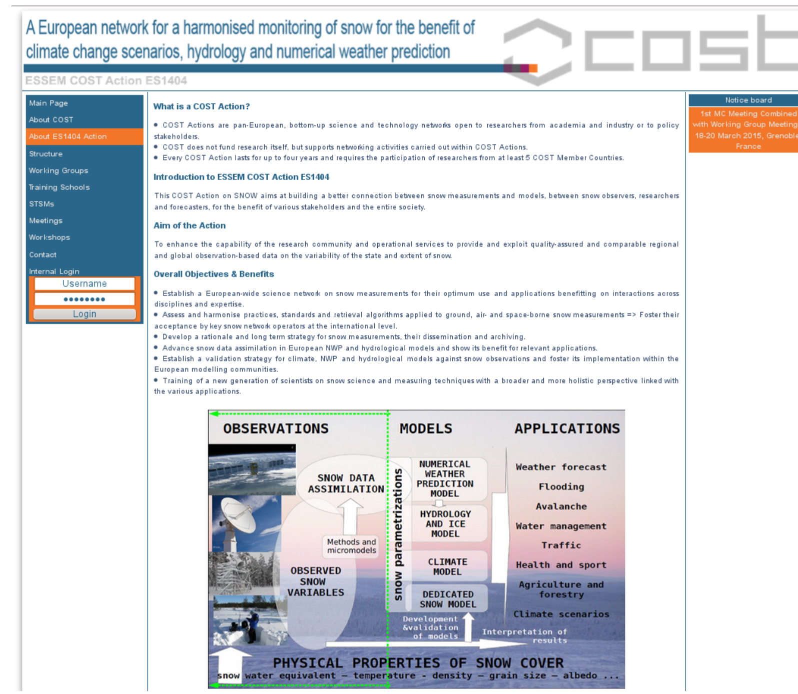
One of the key objectives of Snow Watch is to make the data from SYNOP and climate networks more widely available over the GTS.

Snow Watch reporting Handout (ECMWF/UKMO)

http://globalcryospherewatch.org/reference/documents/

COST action on Snow: HarmoSnow

"A European network for a harmonised monitoring of snow for the benefit of climate change scenarios, hydrology and numerical weather prediction".



A European network for a harmonised monitoring of snow for the benefit of climate change scenarios, hydrology and numerical weather prediction

ESSEM COST Action ES1404

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About ES1404 Action
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Training Schools
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Login

What is a COST Action?

- COST Actions are pan-European, bottom-up science and technology networks open to researchers from academia and industry or to policy stakeholders.
- COST does not fund research itself, but supports networking activities carried out within COST Actions.
- Every COST Action lasts for up to four years and requires the participation of researchers from at least 5 COST Member Countries.

Introduction to ESSEM COST Action ES1404

This COST Action on SNOW aims at building a better connection between snow measurements and models, between snow observers, researchers and forecasters, for the benefit of various stakeholders and the entire society.

Aim of the Action

To enhance the capability of the research community and operational services to provide and exploit quality-assured and comparable regional and global observation-based data on the variability of the state and extent of snow.

Overall Objectives & Benefits

- Establish a European-wide science network on snow measurements for their optimum use and applications benefitting on interactions across disciplines and expertise.
- Assess and harmonise practices, standards and retrieval algorithms applied to ground, air- and space-borne snow measurements => Foster their acceptance by key snow network operators at the international level.
- Develop a rationale and long term strategy for snow measurements, their dissemination and archiving.
- Advance snow data assimilation in European NWP and hydrological models and show its benefit for relevant applications.
- Establish a validation strategy for climate, NWP and hydrological models against snow observations and foster its implementation within the European modelling communities.
- Training of a new generation of scientists on snow science and measuring techniques with a broader and more holistic perspective linked with the various applications.

Notice board
1st MC Meeting Combined with Working Group Meetings: 18-20 March 2015, Grenoble, France

http://www.cost.eu/COST_Actions/essem/Actions/ES1404

http://costsnow.fmi.fi/

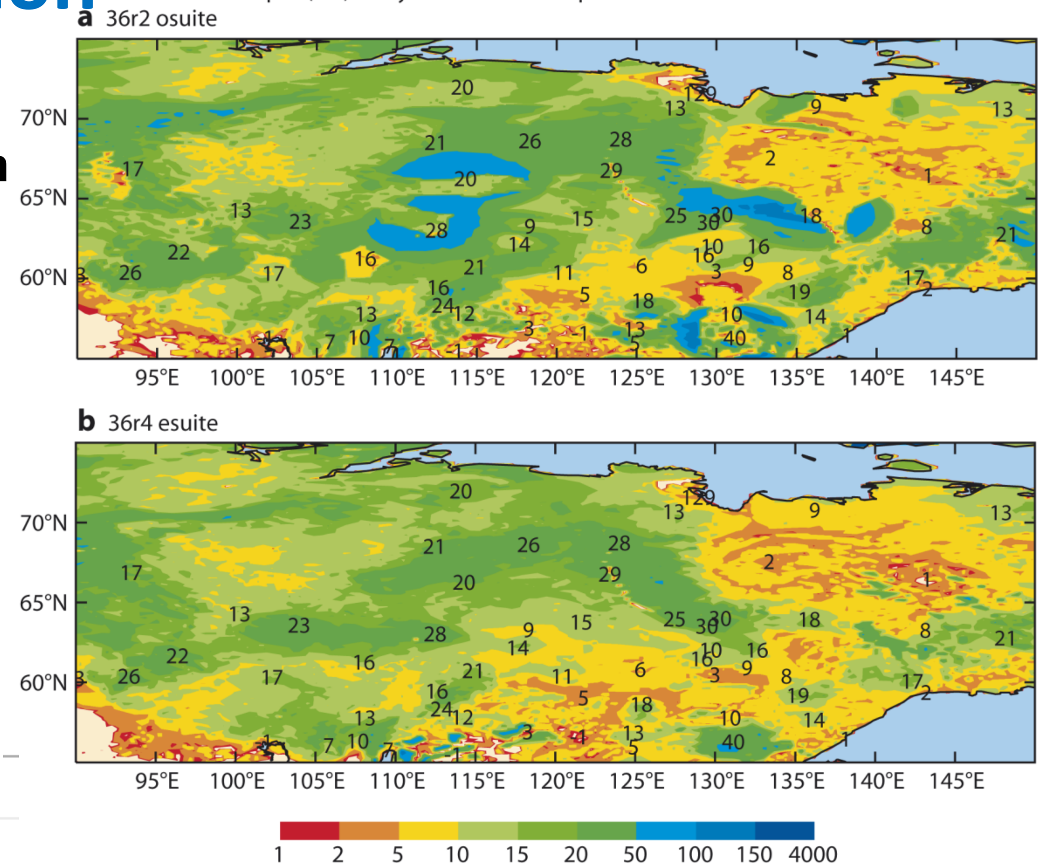
Snow Data assimilation

Updated 2010

Old:
Cressman+ IMS 24km

New:
OI+ IMS 4km

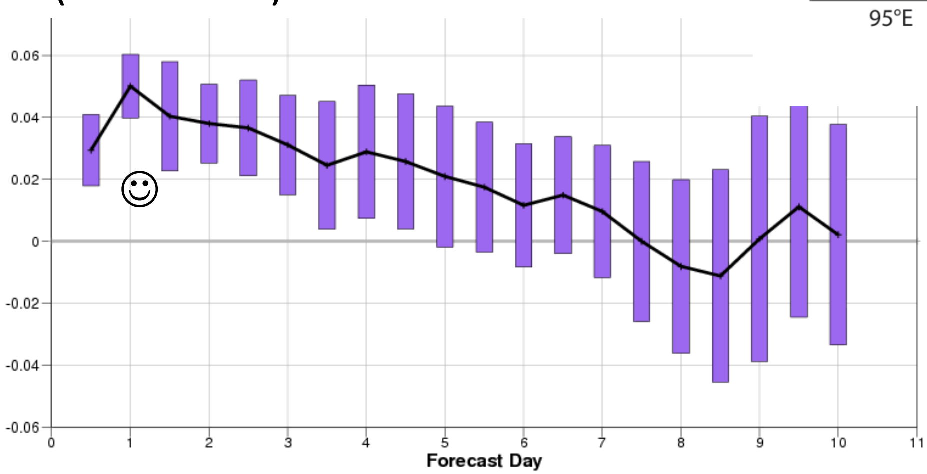
Snow depth (cm) analysis and SYNOP reports on 30 October 2010 at 00 UTC



FC impact (East Asia)

RMSE 500 hPa Geopot Height

(Old – New)

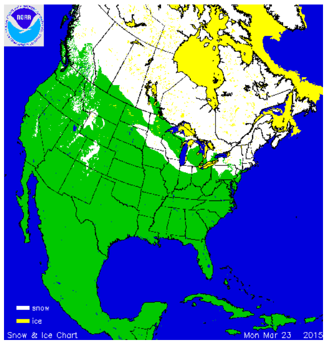


New snow analysis improves both the snow depth patterns (OI impact) and the atmospheric forecasts (IMS 4km+QC impact)

(de Rosnay et al Survey of Geophysics, 2015)

Snow analysis: Forecast impact

Revised IMS snow cover data assimilation (2013)



Impact on snow October 2012 to April 2013 (using 251 independent in situ observations)

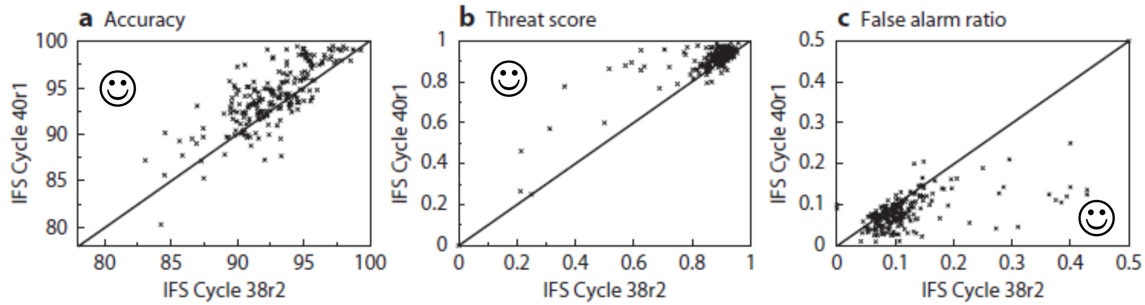
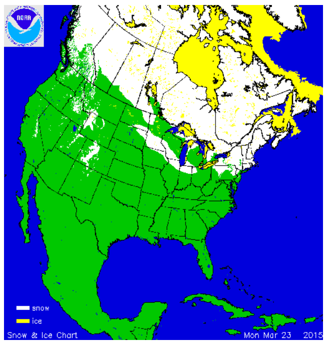


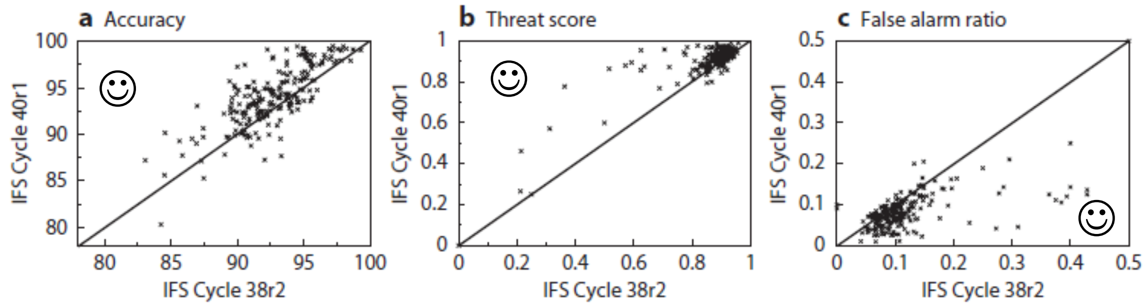
Figure 2 Snow analysis scores for the revised IFS 40r1 snow analysis versus the IFS 38r2 analysis for (a) accuracy, (b) threat score, and (c) false alarm ratio in the period October 2012 to April 2013. Each cross represents the scores computed against 251 independent in situ snow depth observations for a given date. The scatter plots show the results for each of the 212 days from 1 October 2012 to 30 April 2013. The black line represents the one-to-one line.

Snow analysis: Forecast impact

Revised IMS snow cover data assimilation (2013)



Impact on snow October 2012 to April 2013 (using 251 independent *in situ* observations)



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Impact on atmospheric forecasts

October 2012 to April 2013 (RMSE new-old)

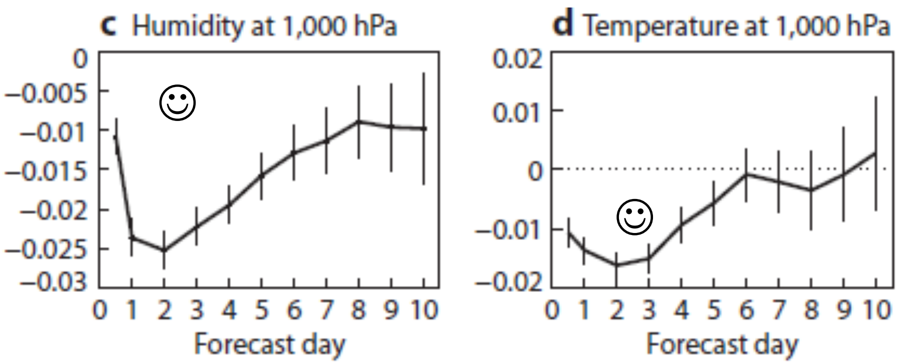


Figure 4 Impact of the revised snow analysis on the normalised root mean square error difference between IFS Cycles 40r1 and 38r2 (40r1 minus 38r2) for (a) humidity forecasts at 850 hPa;

→ Consistent improvement of snow and atmospheric forecasts

de Rosnay et al., ECMWF NL 143, Spring 2015

Operational snow analysis: winter 2014-2015

Operational snow monitoring

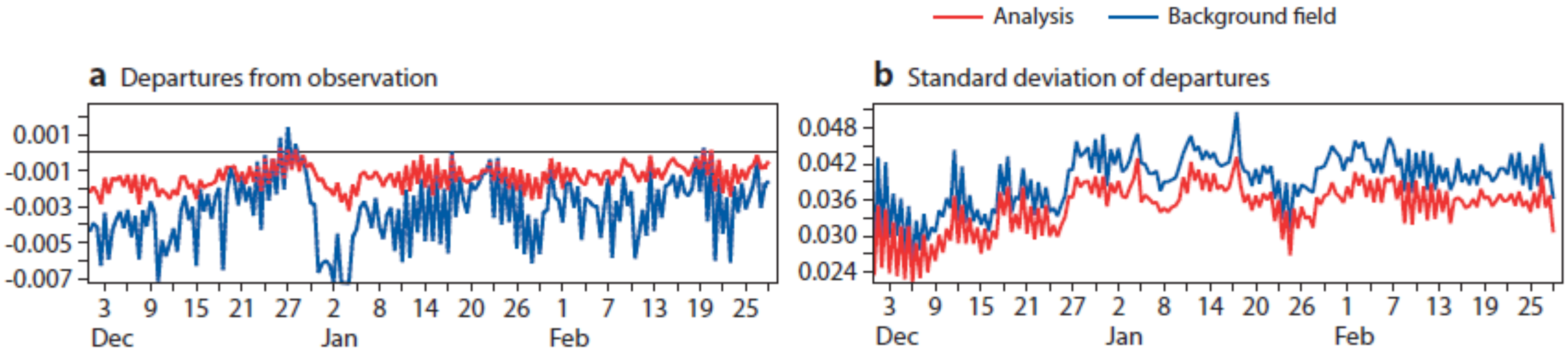


Figure 7 Monitoring time series from December 2014 to February 2015 of the ECMWF operational IFS Cycle 40r1 suite for conventional snow depth showing (a) mean departures of background field and analysis from observations, in metres (b) standard deviation of background field and analysis departures from observations, in metres.

Others technical work in 41r2 (Q1 2016):

- BUFR SYNOP in LDAS
- New blacklist for LDAS conv obs
- Model improved treatment of
  - snow depth update after snowfall
  - Sub-grid scale energy partition affecting snow fraction

Summary

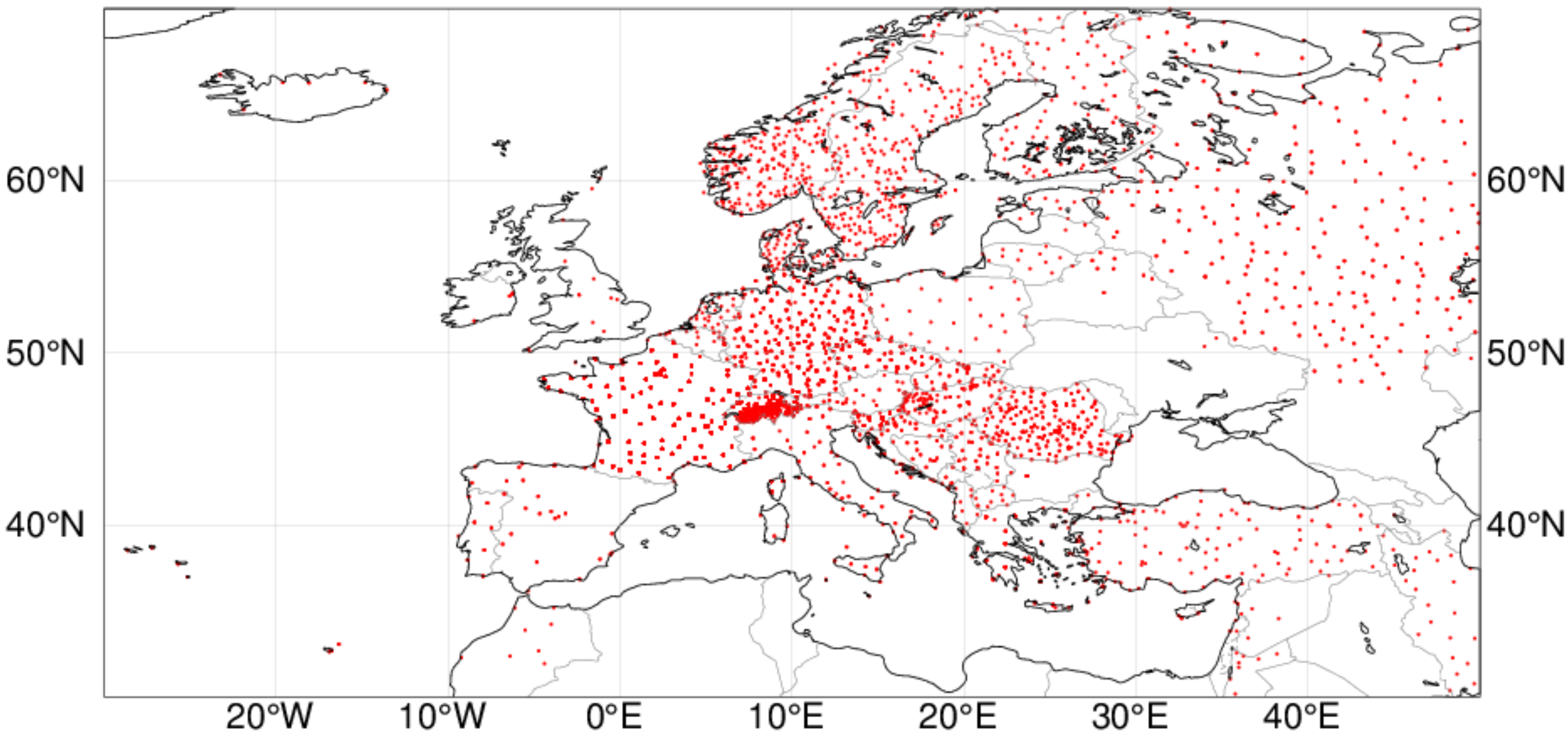
- Major developments in the ECMWF snow model and data assimilation (DA) for NWP in the past few years
- Snow has a large impact on Numerical Weather Forecast
- DA of *in situ* snow depth and the IMS multi sensor snow cover
- Challenges in retrieving snow mass from satellite measurements → Novel mission concepts required for SWE (ESA-GEWEX EO4water conference 2015)
- In situ snow depth reporting: issues on availability and reporting practices
- International initiatives to address snow reporting (harmonization and practices):
  - Snow Watch snow reporting activity
  - HarmoSnow COST action ES1404
- National Met services encouraged to improve snow depth reports availability on the GTS

Snow Observations in Europe

GTS SYNOP Snow depth availability

Operational snow observations monitoring
(SYNOP TAC + SYNOP BUFR + national BUFR data):
http://old.ecmwf.int/products/forecasts/d/charts/monitoring/conventional/snow/

20150301



Thank you for your Attention!

Useful links:

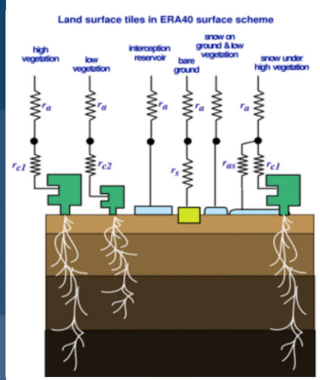
ECMWF LDAS: https://software.ecmwf.int/wiki/display/LDAS/LDAS+Home
Snow Watch: http://globalcryospherewatch.org/reference/documents/

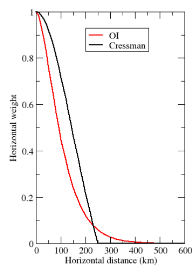
HarmoSnow COST Action: http://www.cost.eu/COST_Actions/essem/Actions/ES1404
http://costsnow.fmi.fi/

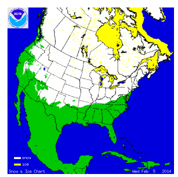
ECMWF Land Surface Observation monitoring:
https://software.ecmwf.int/wiki/display/LDAS/Land+Surface+Observations+monitoring

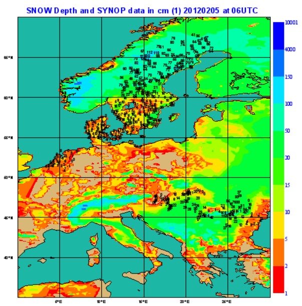
Snow in the ECMWF IFS

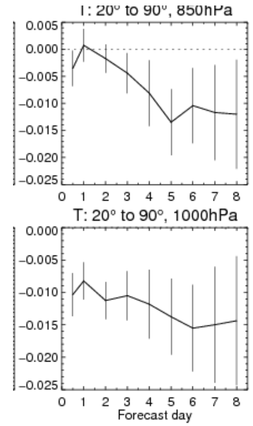
2009 2010 2011 2012 2013 2014 2015











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

Ongoing

. BUFR SYNOP
. Snow COST action
. Snow Watch
. MultiLayer model

Future:
RT modelling

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

de Rosnay et., ECMWF Newsletter 143, Spring 2015

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.