ECMWF Data Assimilation Training course

Land Surface Data Assimilation – Part 1

Patricia de Rosnay

Outline

Part I (Monday 7 March)

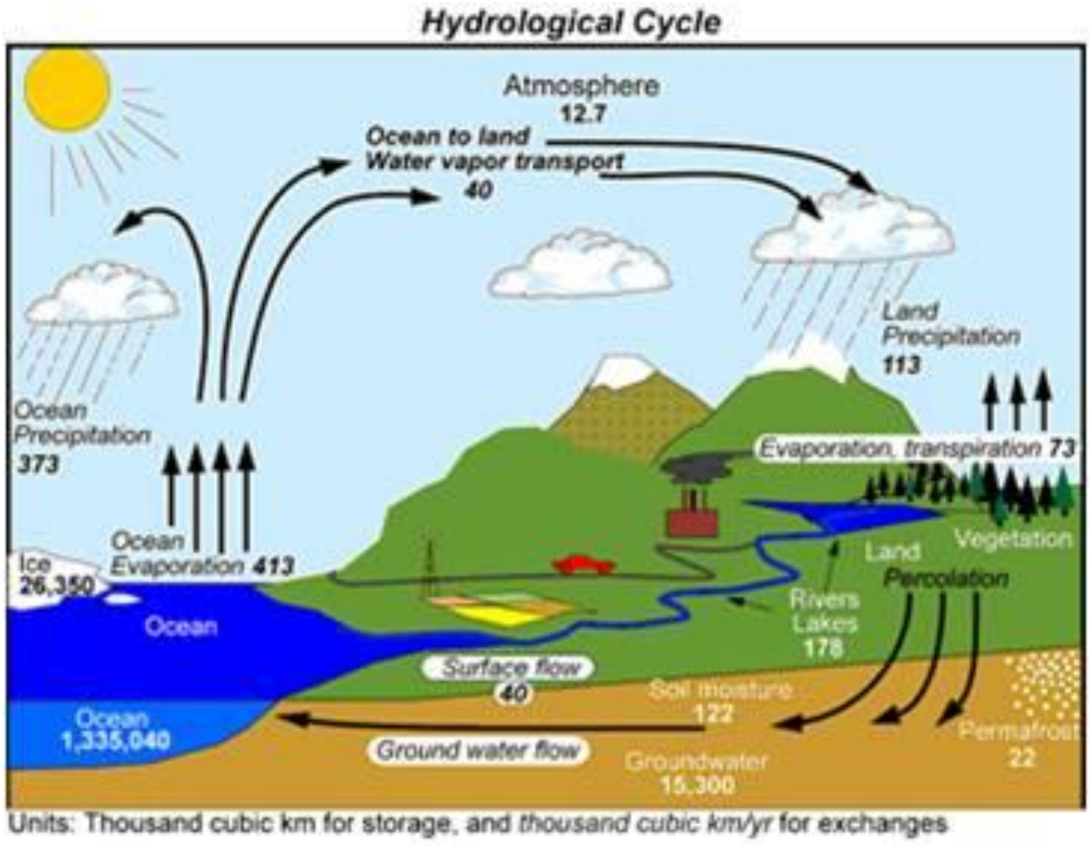
- **Introduction**
- Snow analysis
- Screen level parameters analysis

Part II (Tuesday 8 March)

- Soil moisture analysis
- Summary and future plans

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

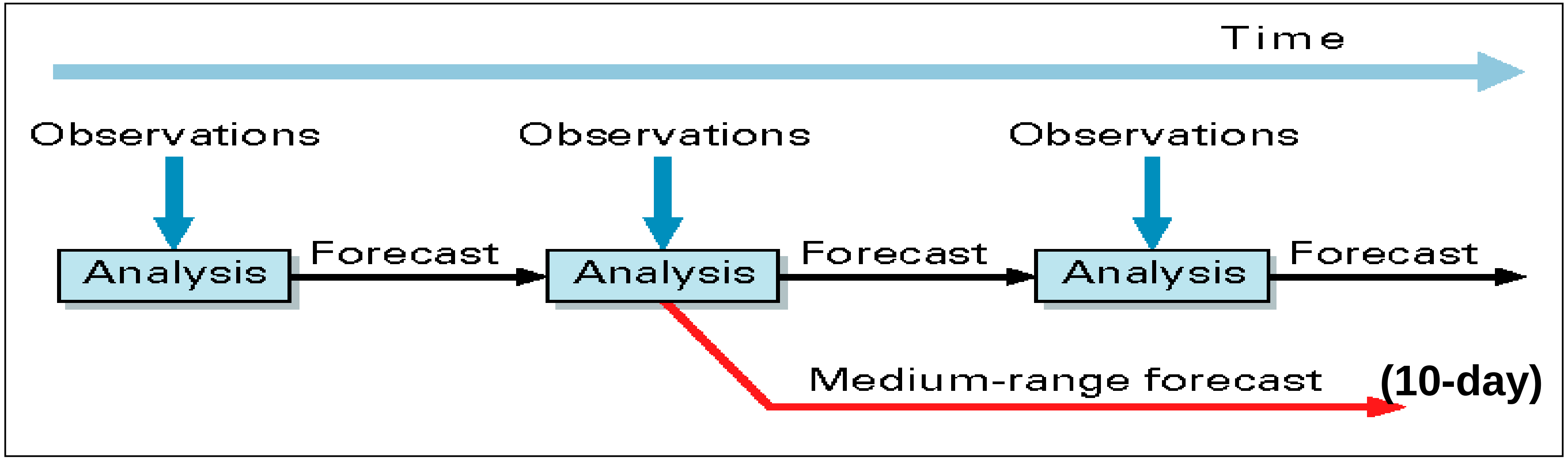


Trenberth et al. J. Hydrometeorol., 2007

→ **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., Science 2004, Koster et al. J Hydrometeorol. 2011)

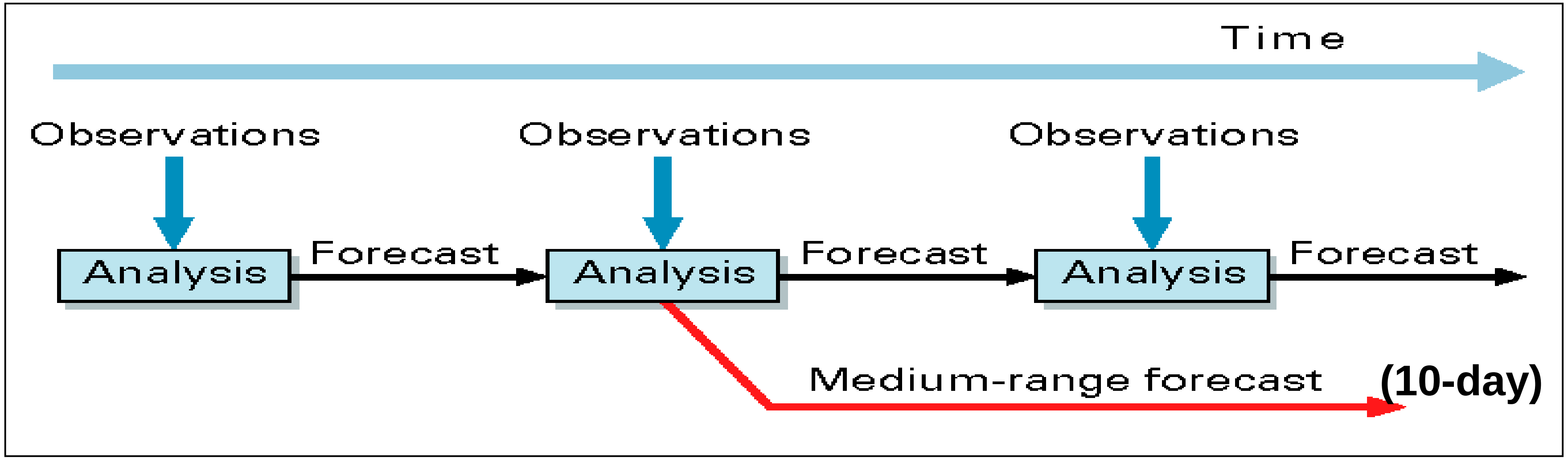
ECMWF Integrated Forecasting System (IFS)



- **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 (LDAS)**

ECMWF Integrated Forecasting System (IFS)



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  - **Land Data Assimilation System (LDAS)**

Several 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)

} Weakly coupled DA

- **ERA-Interim-Land:** **79km**
- **ERA5-Land:** **39 km**

H-TESSEL LSM simulations forced by ERA→ model only: no LDAS

Introduction: Land Surface Data Assimilation (LDAS)

Snow depth

- Methods: Cressman (DWD, ECMWF ERA-I), 2D Optimal Interpolation (OI) (ECMWF operational and ERA5, Env. Canada)
- Conventional Observations: *in situ* snow depth
- Satellite data: NOAA/NESDIS IMS Snow Cover Extent (ECMWF), H-SAF snow cover (UKMO in dvpt)

Soil Moisture

- Methods:
  - 1D Optimal Interpolation (Météo-France, Env. Canada, ALADIN and HIRLAM)
  - Simplified Extended Kalman Filter (EKF) (DWD, ECMWF, UKMO)
- Conventional observations: Analysed SYNOP 2m air relative humidity and temperature, **from 2D OI screen level parameters analysis**
- Satellite data : ASCAT soil moisture (UKMO, ECMWF), SMOS (dvpt ECMWF, UKMO, Env.Canada)

Soil Temperature and Snow temperature

- 1D OI for the first layer of soil and snow temperature (ECMWF, Météo-France)

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Snow in operational forecasting systems

Example of the ECMWF system:

Snow Model: Component of H-TESSEL ; Single layer snowpack

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

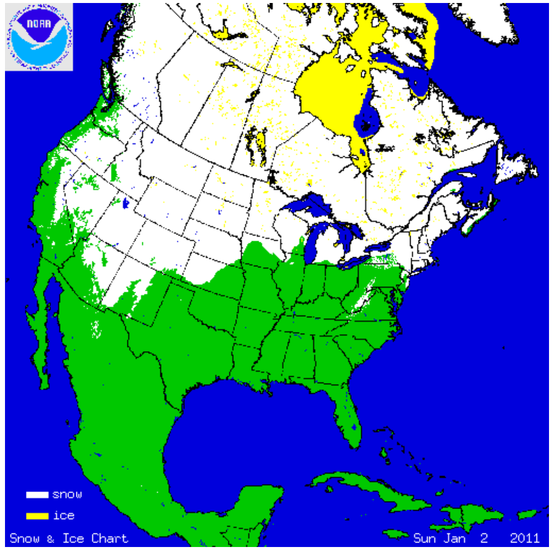
Prognostic variables

Snow depth (SD) is diagnostic: $SD = SWE \cdot \rho_w / \rho_s$

with ρ_w water density

Observations:

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

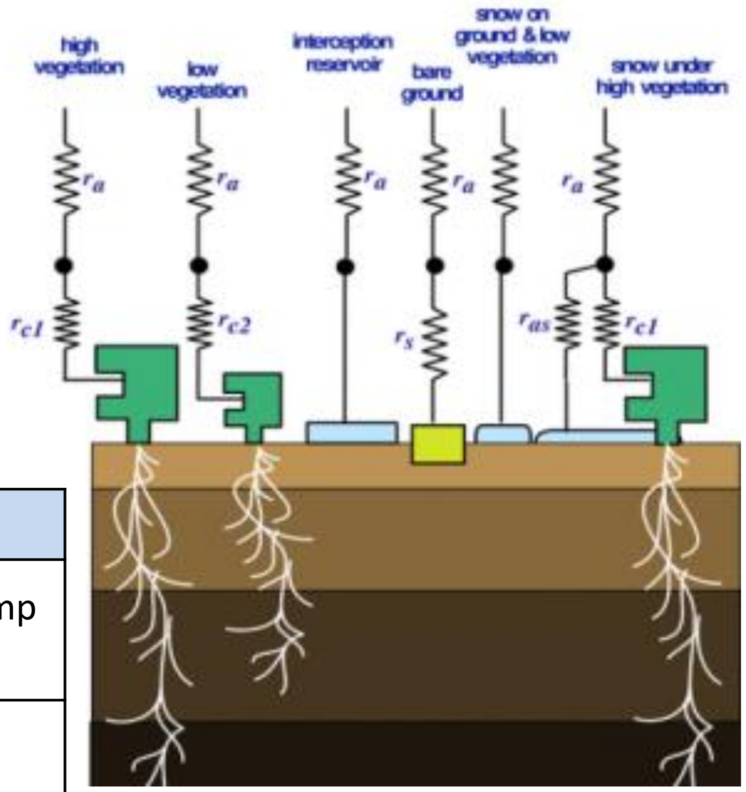


Data Assimilation:

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

Snow Model

H-TESSEL 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)



H-TESSEL Land surface model
Balsamo et al J. Hydrometeorol. 2009

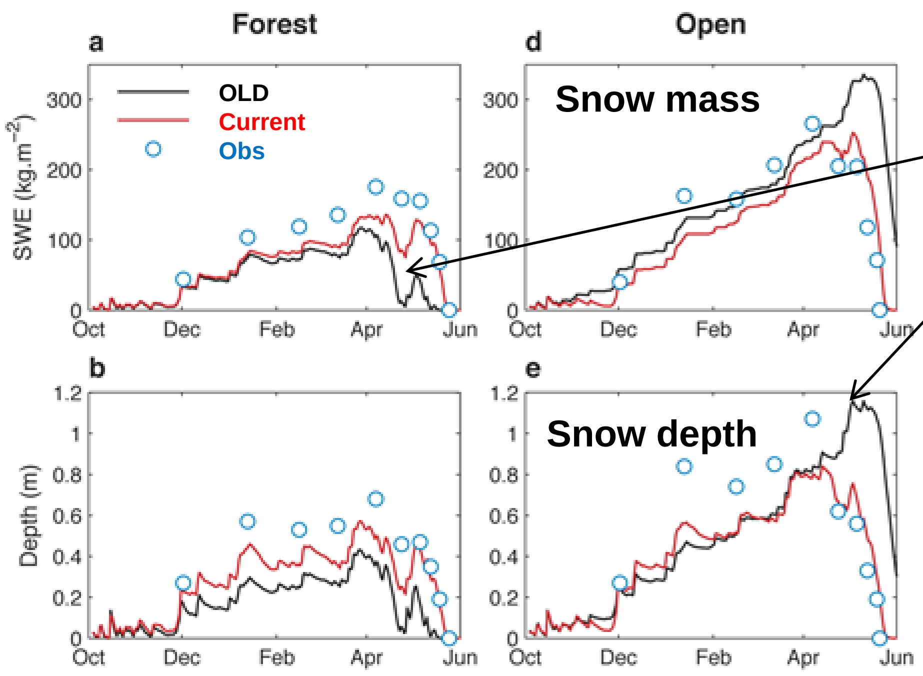
Snow model updated in 2009

Dutra et al., J. Hydrometeorol., 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 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. Remote Sens. Environ. 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>

Old: too early for forests (21days)

too late in open sites (10 days)

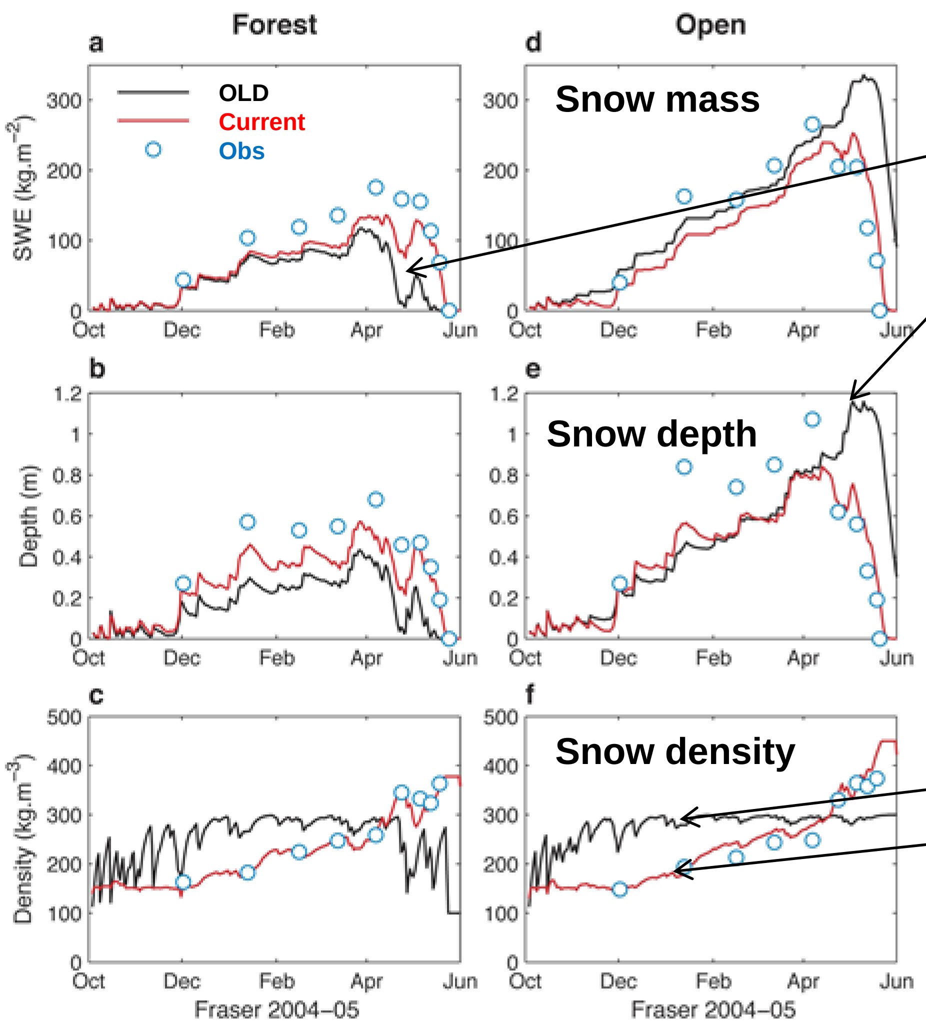
Current: Albedo → improves open sites

Rain interception → improves forest

Dutra et al., JHM 2010

Snow Model

Validation against in situ snow observations (SnowMIP2 sites)



Dutra et al., JHM 2010

<u>Melting period</u>

Old: too early for forests (21days)

too late in open sites (10 days)

Current: Albedo → improves open sites

Rain interception → improves forest

<u>Snow density:</u>

OLD: overestimated compaction

Current: Closer to observations

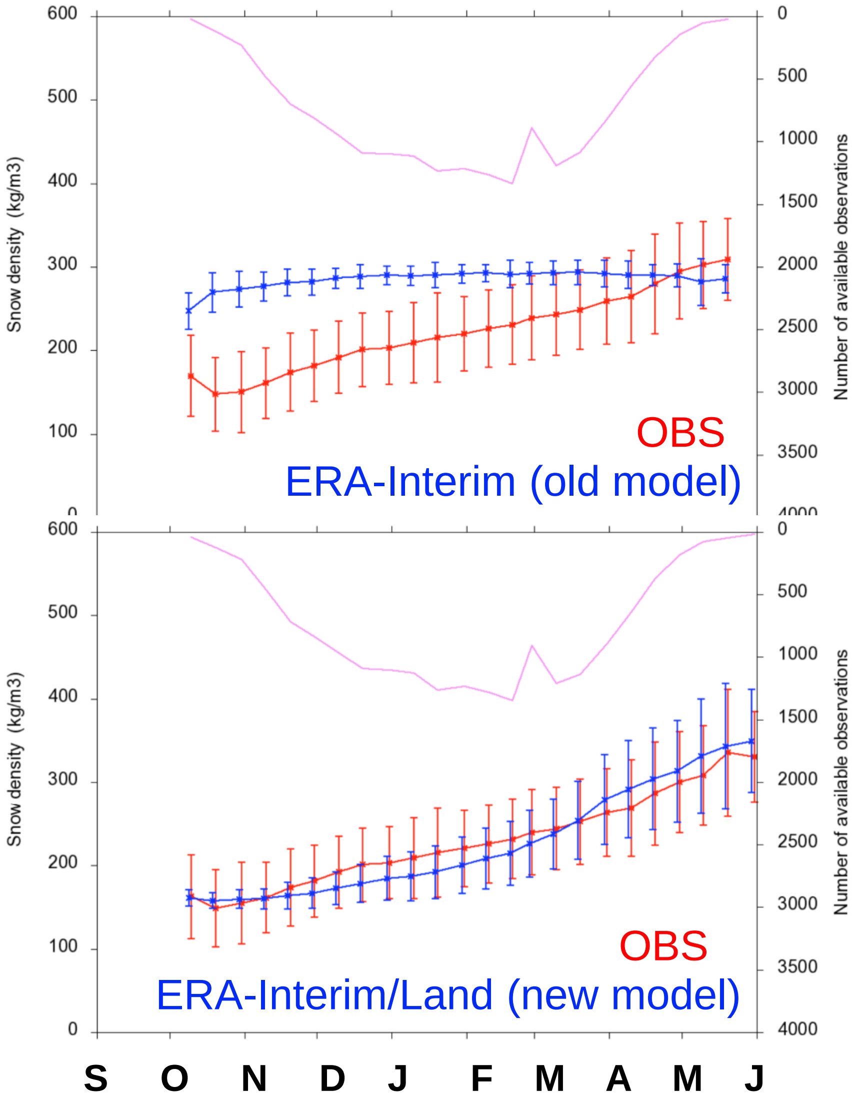
Decreased snow density

→ Increased thermal insulation

→ Reduce negative soil temperature bias

Snow Model

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



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

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 (model variable) to snow depth measurements (observations that enter the analysis)

(Balsamo et al. HESS 2015)

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

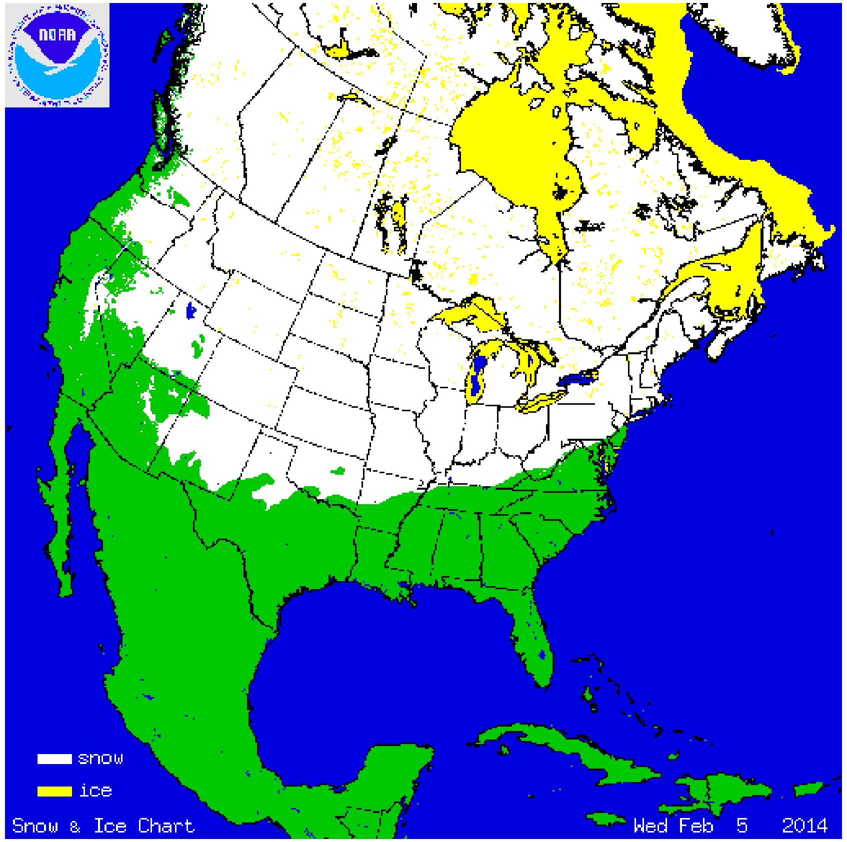
Information content: Snow/Snow free

Data used at ECMWF:

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

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

NOAA/NESDIS
IMS Snow extent data



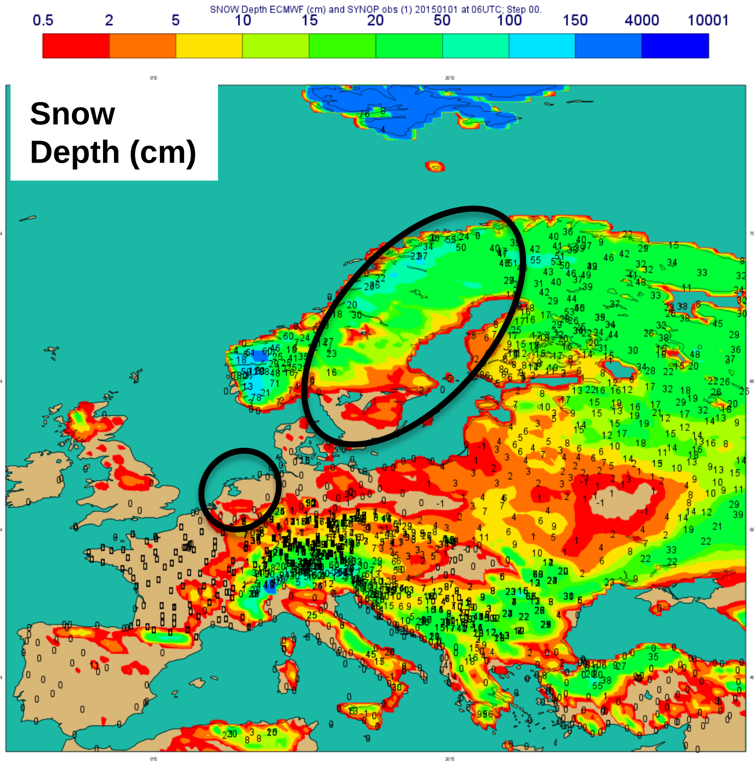
IMS Snow Cover 5 Feb. 2014

Snow Observations: SYNOP and National Networks

For NWP purpose: observations are exchanged in near real time (NRT) using the co-ordinated Global Telecommunication System (GTS)

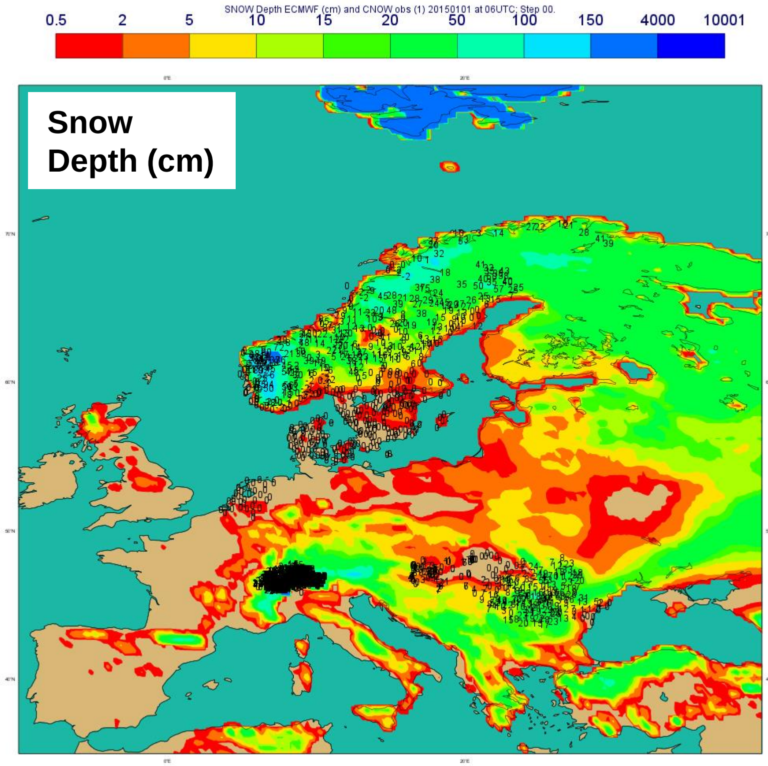
Snow observations available on the GTS

2015 01 01 at 06UTC



SYNOP (BUFR&TAC)

Additional National Networks



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

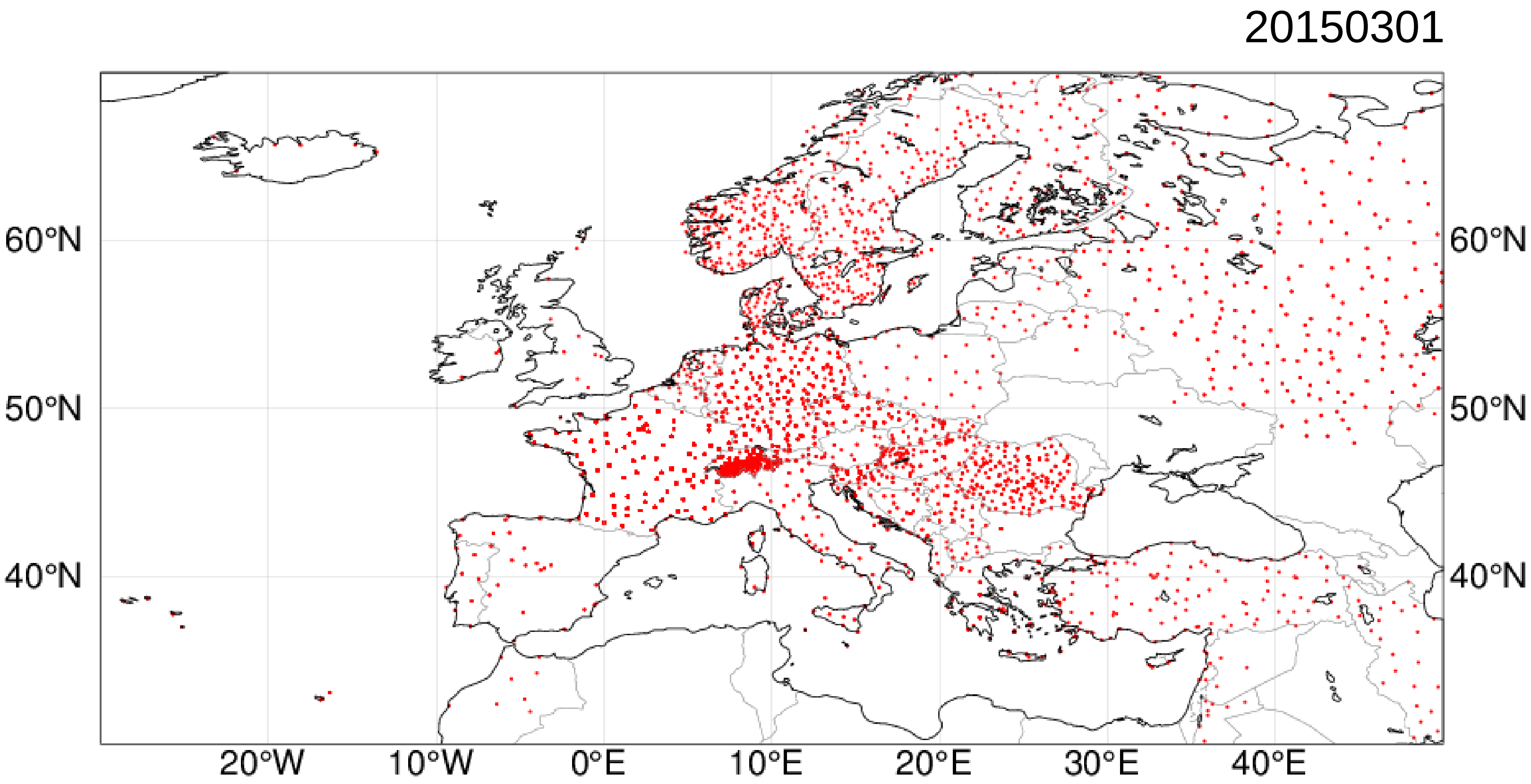
→ **Dedicated BUFR for additional national data**

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

Snow Observations in Europe

GTS SYNOP Snow depth availability

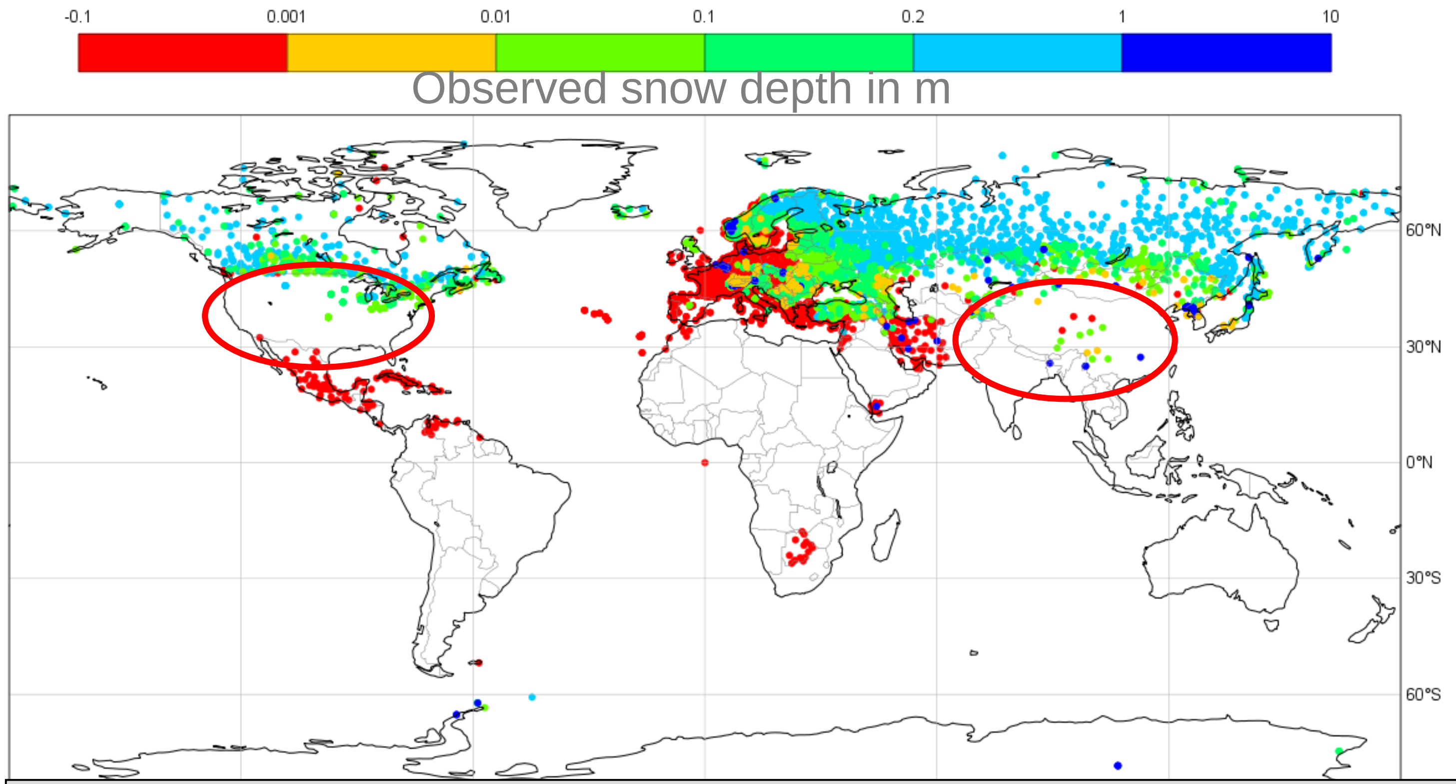
Operational snow observations monitoring
(SYNOP TAC + SYNOP BUFR + national BUFR data):



Snow Observations: GTS SYNOP Snow depth availability

Status in January 2015

Operational snow observations monitoring (SYNOP TAC + SYNOP BUFR + national BUFR data):
http://www.ecmwf.int/en/forecasts/charts/obstat/?facets=Category,Conventional%20Data%3BParameter,%20Snow%20depth



Gaps 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.

World Meteorological Organization (WMO): Members States encouraged to report snow depth on the GTS

- BUFR template for national data approved by WMO in April 2014
- WMO GCW (Global Cryosphere Watch): **Snow Watch** initiative on snow reporting

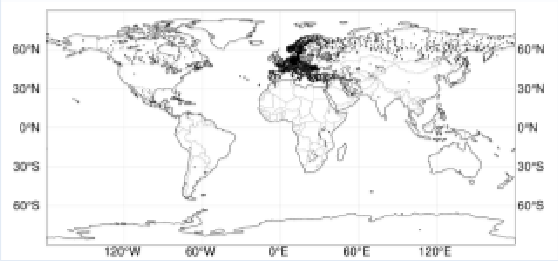
GCW Snow Watch Activity on Snow reporting

World Meteorological Organization
Global Cryosphere Watch

Snow Reporting

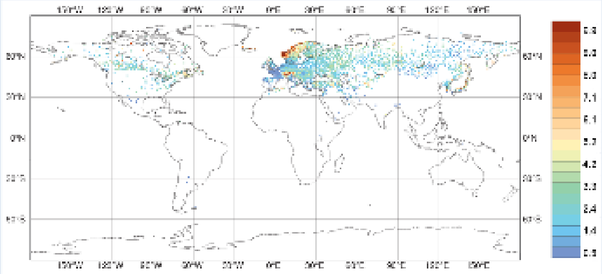
A GCW Snow Watch Activity

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.

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

European COST Action on Snow

- COST is an intergovernmental framework for European Cooperation in Science and Technology . It supports networking activities within the COST action.

- COST Action on Snow (ES1404): 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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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

→ Better connection between snow measurements and models, between snow observers, researchers and forecasters

→ Contribute to improve snow observation availability for NWP and research, far data assimilation and validation.

http://www.harmosnow.eu/

Snow Analysis at ECMWF

Pre-Processing:

- SYNOP reports converted into BUFR files.
- IMS converted to BUFR (and orography added)
- SYNOP BUFR data is put into the ODB (Observation Data Base)

Snow depth analysis at 00, 06, 12, 18 UTC :

- Cressman interpolation (Mon. Wea. Rev. 1959): Operationaly used at ECMWF for 1987-2010; Used in ERA-Interim, used at DWD.
- Optimal Interpolation (OI): Operational at ECMWF since November 2010

(de Rosnay et al; Surv Geophys. 2014)

Use NESDIS IMS data in the OI (00 UTC):

NESDIS: \ 1stGuess:	Snow	No Snow
Snow	x	**DA** 5cm
No Snow	DA	DA

Errors sepcification

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

Snow depth Optimal Interpolation

Used at Env. Canada, ECMWF

Based on Brasnett, j appl. Meteo. 1999

1. Observed first guess departure ΔS_i are computed from the interpolated background 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) $b(i) = \sigma^2_b \, . \, \mu(i,j)$

B : correlation coefficient matrix of background field errors between all pairs of observations (N × N observations); $B(i_1,i_2) = \sigma^2_b \times \mu(i_1,i_2)$ with the correlation coefficients $\mu(i_1,i_2)$ and σ_b = 3cm the standard deviation of background errors.

O : **covariance matrix of the observation error** (N × N observations):

$\mathbf{O} = \sigma^2_o \times \mathbf{I}$

with σ_o the standard deviation of observation errors (4cm in situ, 8cm IMS)

Snow depth Optimal Interpolation

Used at Env. Canada, ECMWF

Based on Brasnett, j appl. Meteo. 1999

Correlation coefficients $\mu(i_1,i_2)$ (structure function):

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

Lz; vertical length scale: 800m, **Lx:** horizontal length scale: 55km
$r_{i1,i2}$ and $Z_{i1,i2}$ the horizontal and vertical distances between points i_1 and i_2

Quality Control: reject observation if $\Delta S_i > Tol\ (\sigma_b^2 + \sigma_o^2)^{1/2}$ with Tol = 5
→Observation rejected if first guess departure larger than 25 cm

Redundancy rejection: use observation reports closest to analysis time
And use a maximum of 50 observations per grid point)

OI vs Cressman

In both cases, snow depth increments computed as :

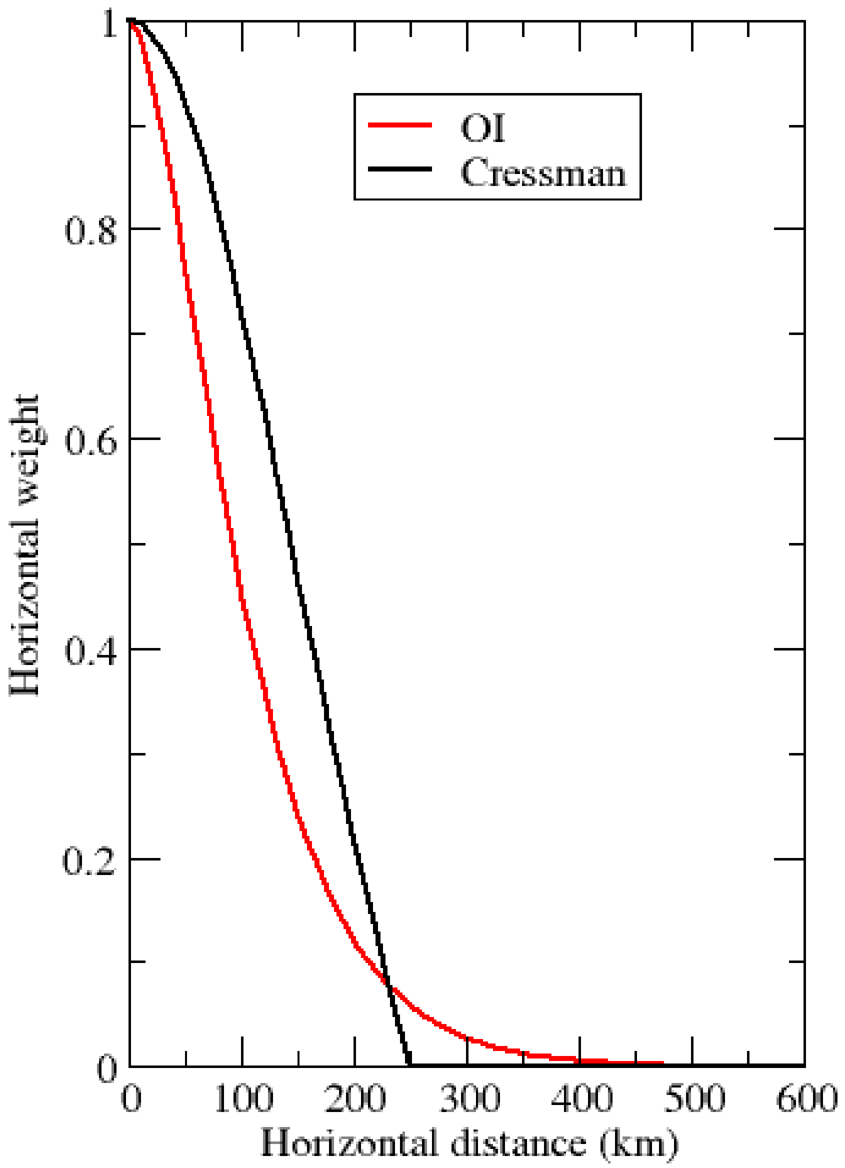
$$\Delta S_j^a = \sum_{i=1}^{N} w_i \times \Delta S_i$$

Cressman: weights are function of horizontal and vertical distances. Do not account for observations and background errors.

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

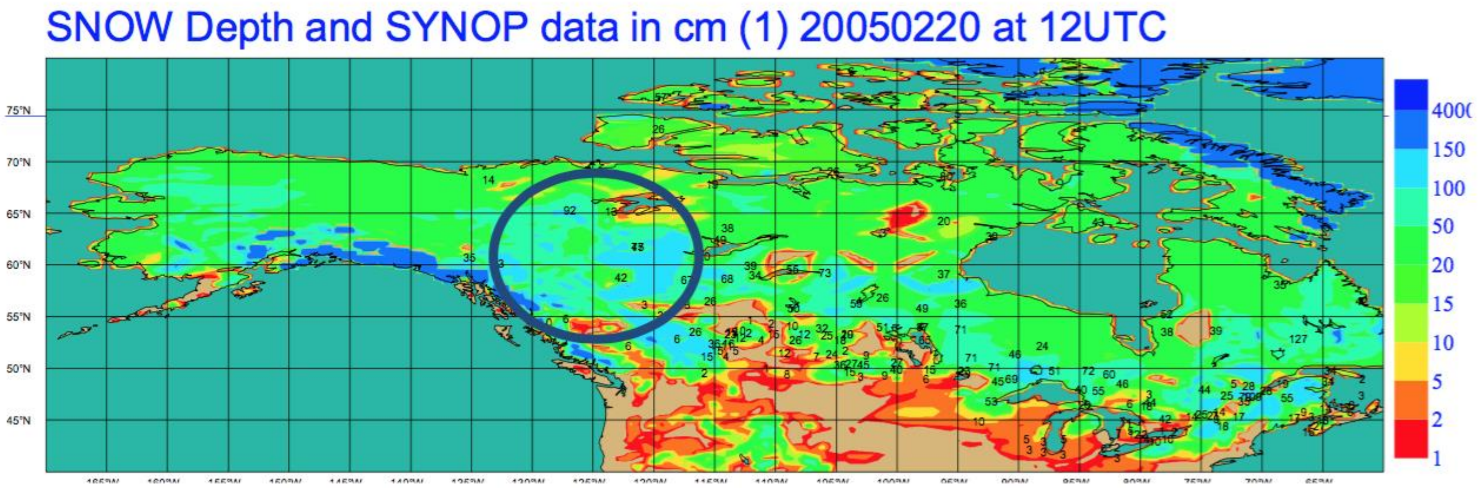
OI has longer tails than Cressman and considers more observations. Model/observation information optimally weighted using error statistics.

Structure function



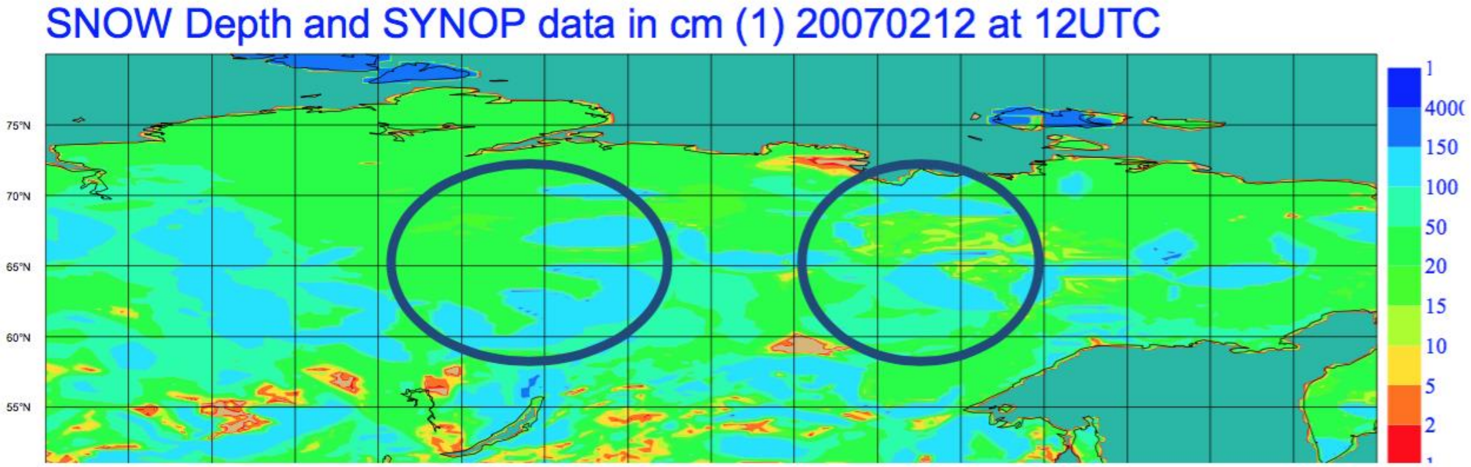
Snow Data assimilation

Cressman shows spurious snow patterns where observations are scarce (Kalnay, Cambridge Univ. Press 2003)



ERA-Interim snow analysis

North America 2005



Siberia 2007

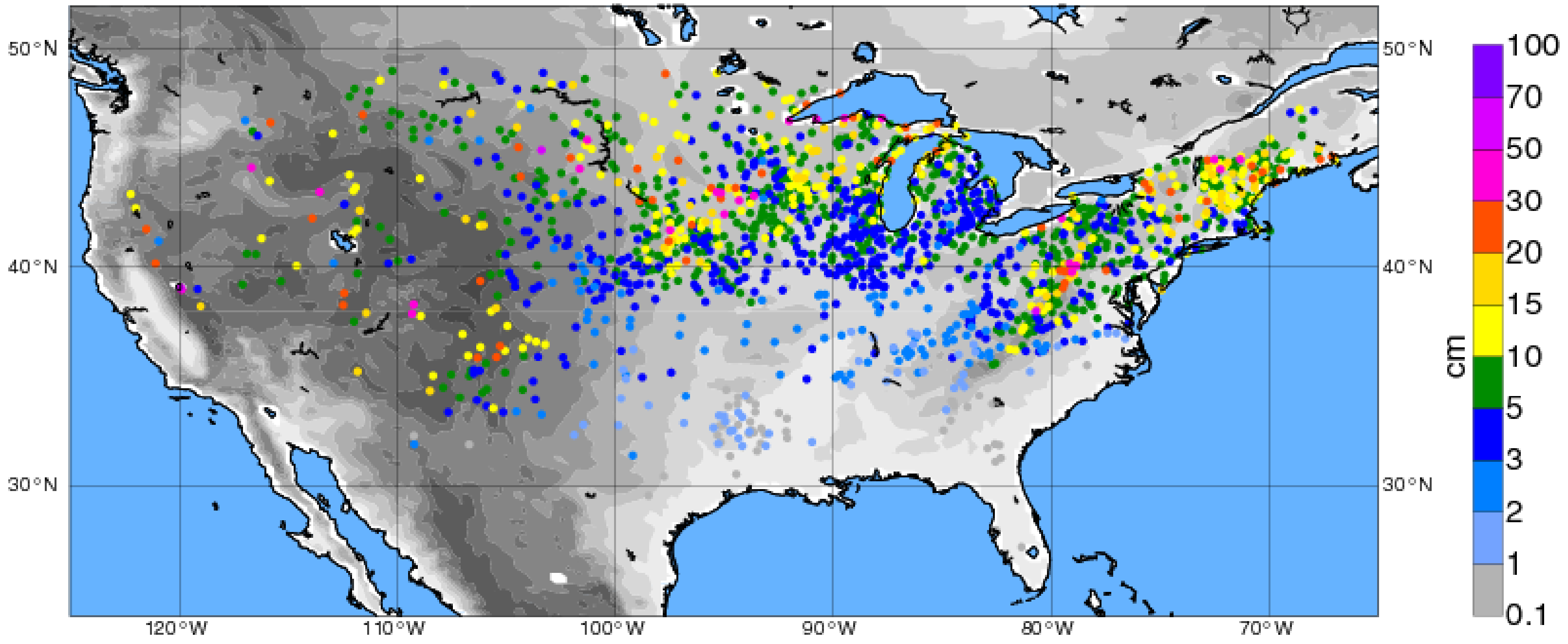
Cressman (Mon. Wea. Rev. 1959)
→ Issues with Bull's eyes as already indicated in Kalnay, Cambridge Univ. Press 2003

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

Validation data: NWS/COOP

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 in snow depth due to the OI compared to Cressman

ECMWF

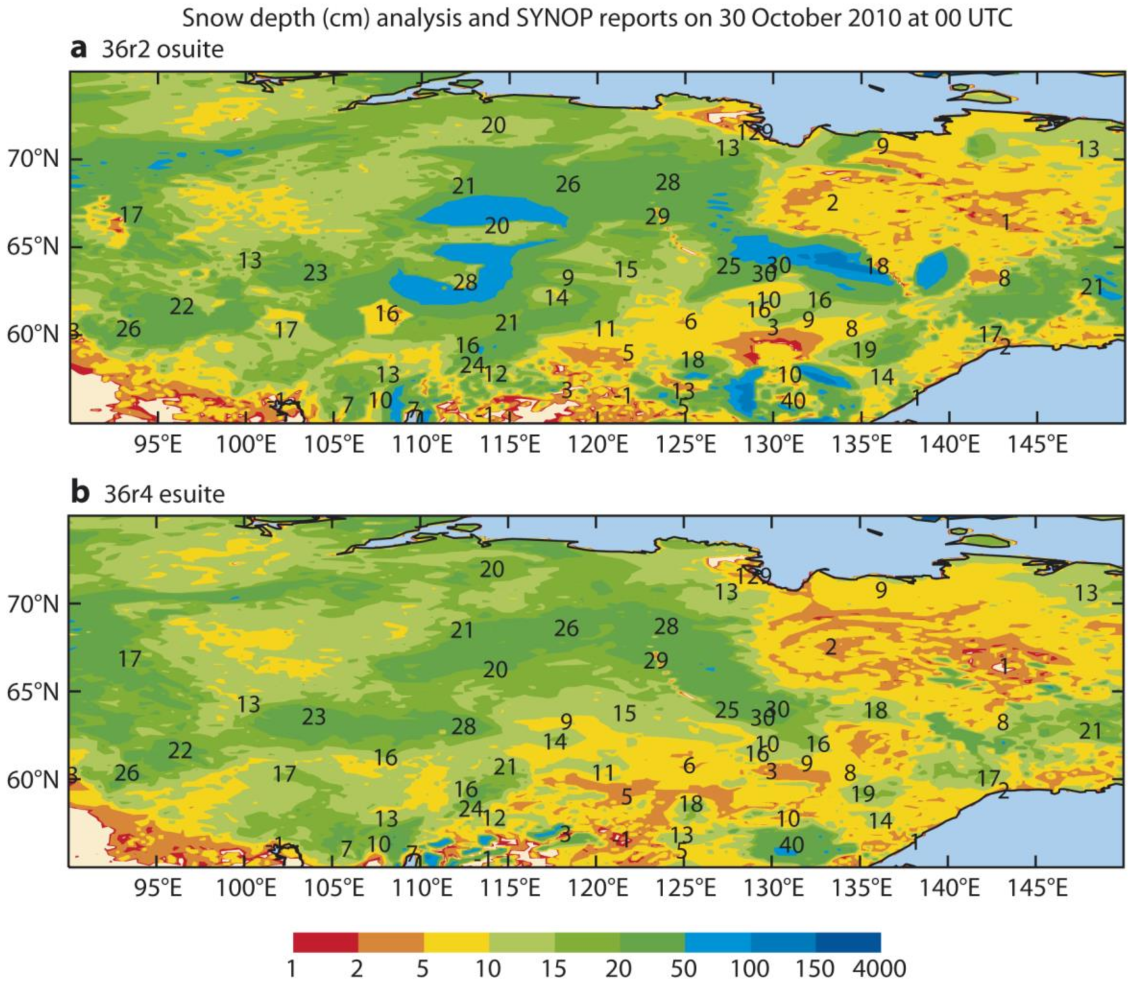
Snow Data assimilation

New snow analysis improves

- Snow depth patterns (OI impact)
- Atmospheric forecasts (IMS 4km+QC impact)

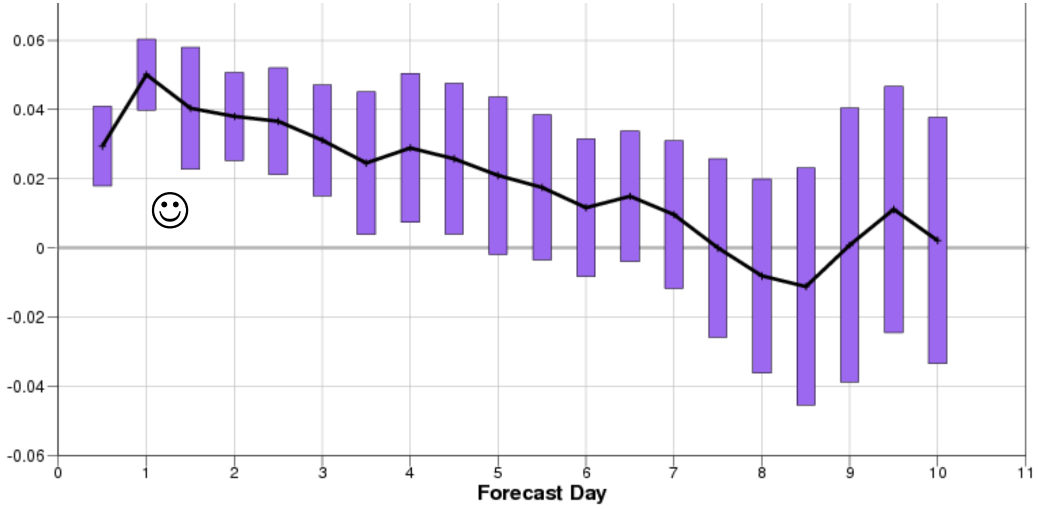
Old (before 2010):
Cressman+ IMS 24km

New (from 2010):
OI+ IMS 4km



FC impact (East Asia) for DJF 2009-2010

RMSE Diff (Old – New) 500 hPa Geopot Height



(de Rosnay et al Survey of Geophysics, 2015)

Snow Analysis improvements at ECMWF

- 2010: replace Cressman by OI and improved IMS use (4km data and revised preprocessing)

- 2013: further improvement in the ECMWF snow analysis (IFS 40r1):

  - Revised observations error specification for IMS snow cover and assimilation of 5cm of snow instead of direct insertion,
  - Generic snow blacklist,
  - Revised surface analysis code and Observation data base (ODB) feedback
  - New Land surface observations monitoring for conventional and IMS data

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

Assimilation of IMS snow cover

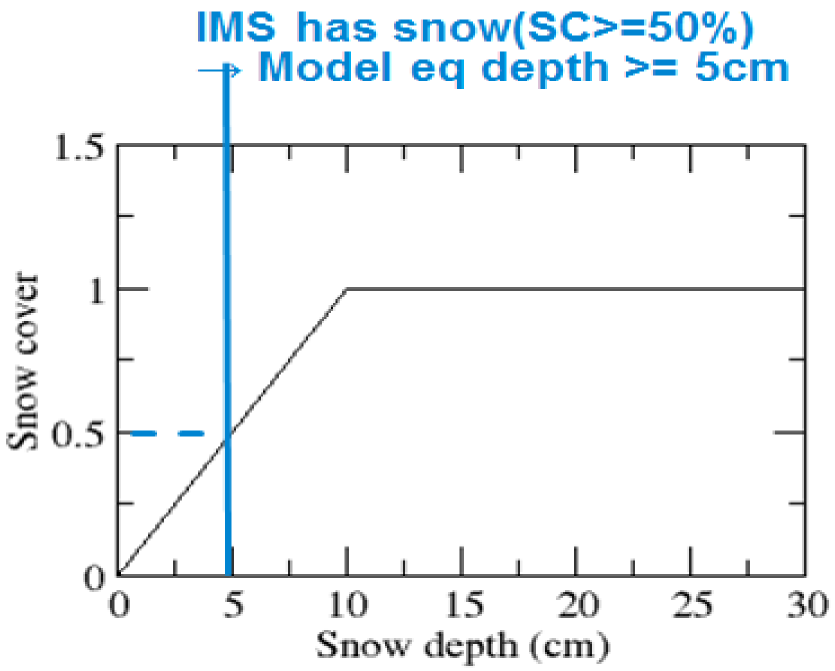
- IMS snow cover (SC) means SC>50%
- But no quantitative information on snow depth
- Relation snow cover (SC)/Snow Depth (SD): SC=50% corresponds to SD=5cm
- Previously: direct insertion of 10cm when IMS has snow & model has no snow
- Issues with overestmated snow
- IFS revision for current cycle: assimilate IMS and account for IMS observation error

Revised Nov 2013 (IFS 40 r1 and 41r1)

Fst Guess / NESDIS	Snow	No Snow
Snow	x	**DA** 5cm
No Snow	DA	DA

Error specifications:

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

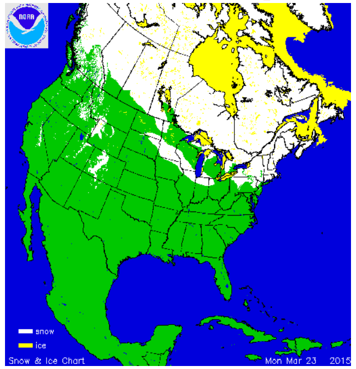


Model relation between SC and SD

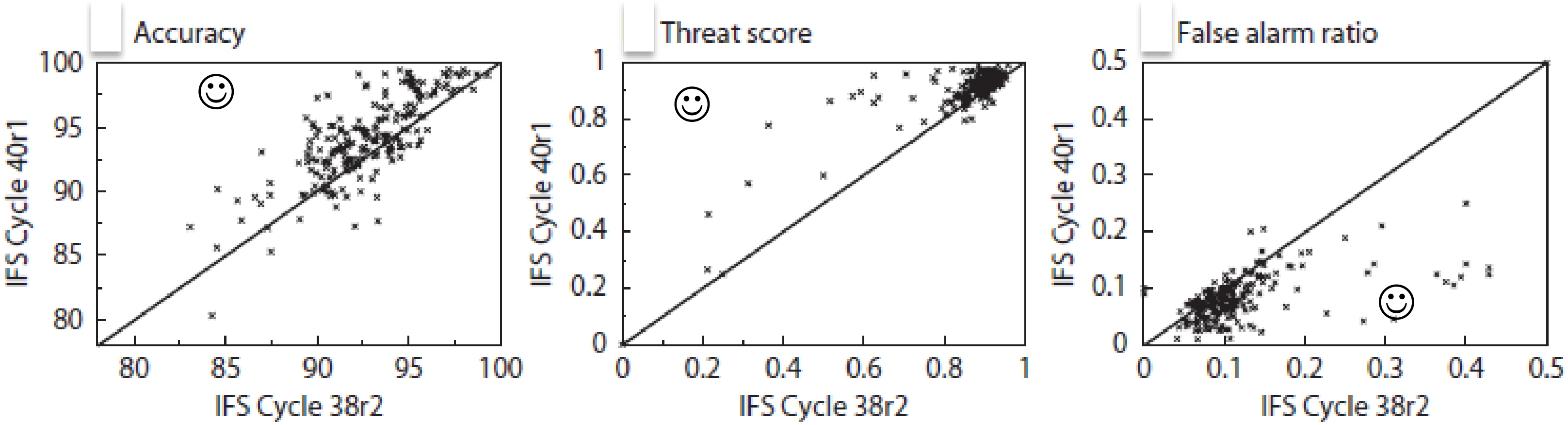
de Rosnay et al, ECMWF Newsletter 143, Spring 2015

Snow analysis: Forecast impact

Revised IMS snow cover data assimilation (2013)



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



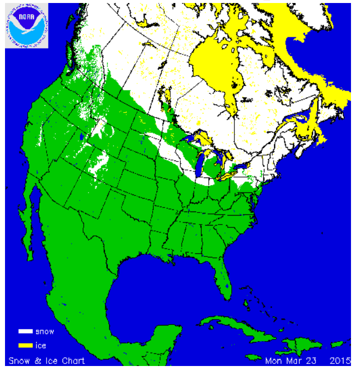
	Snow observed	No snow observed
Snow in analysis	a Hits	b False alarm
No snow in analysis	c Misses	d Correct no snow

The following scores are used for the evaluation:

- Accuracy = a+d / (a+b+c+d)
- False alarm ratio = b / (a+b)
- Threat score = a / (a+b+c)

Snow analysis: Forecast impact

Revised IMS snow cover data assimilation (2013)



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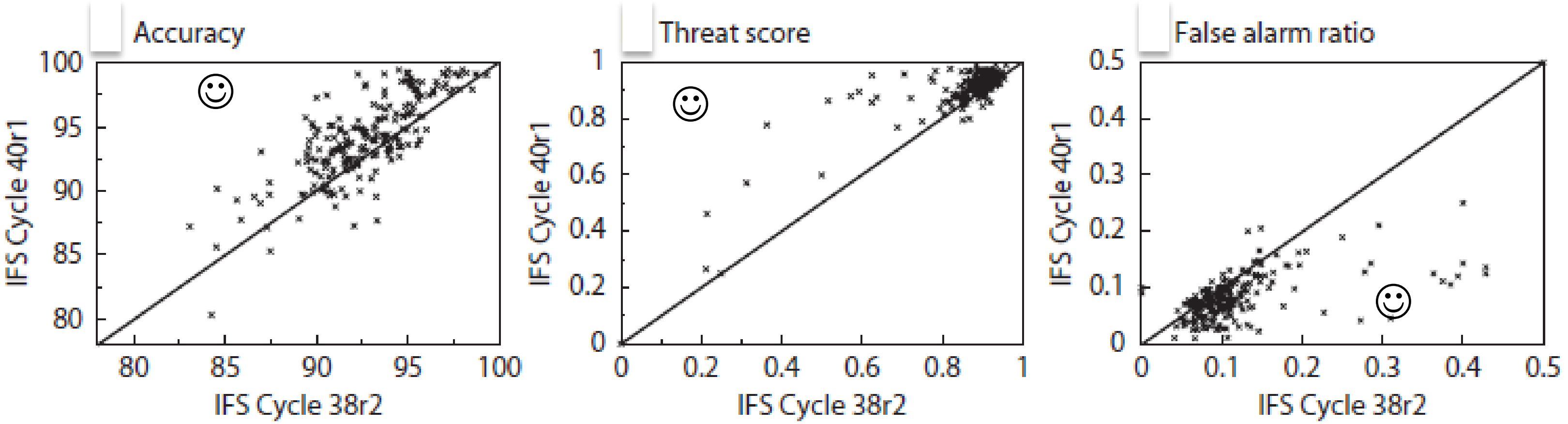
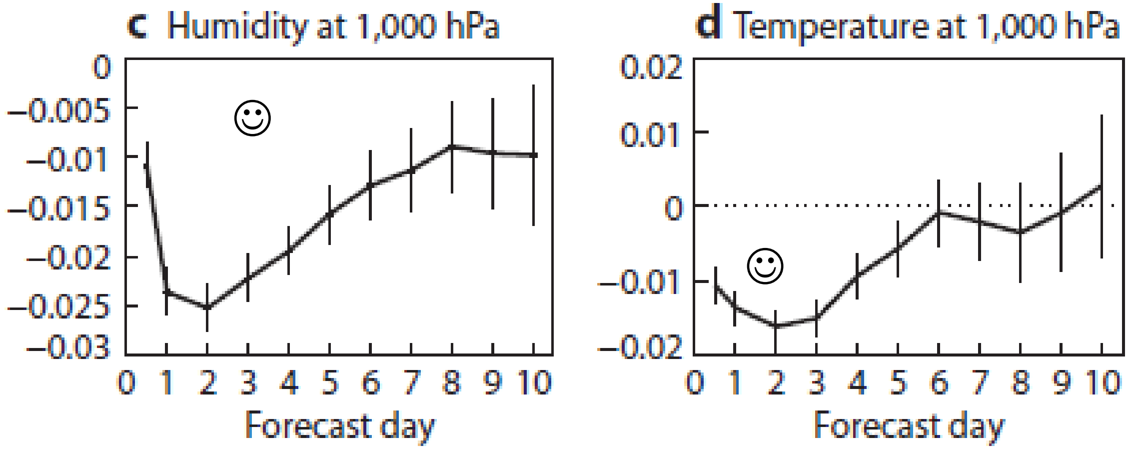


Impact on atmospheric forecasts

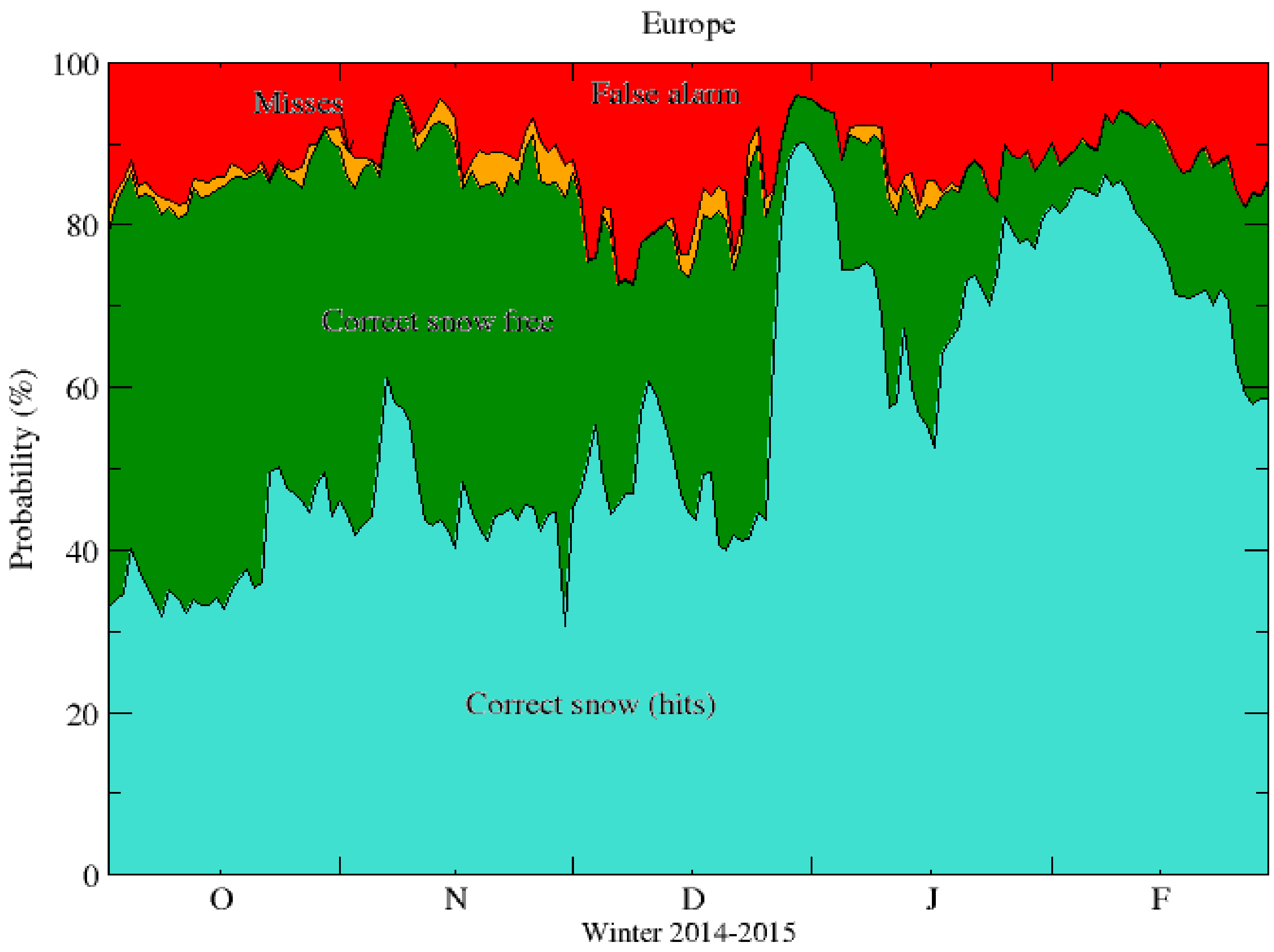
October 2012 to April 2013 (RMSE new-old)



→ Consistent improvement of snow and atmospheric forecasts

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

Operational snow analysis: winter 2014-2015



	Snow observed	No snow observed
Snow in analysis	a Hits	b False alarm
No snow in analysis	c Misses	d Correct no snow

Operational snow analysis: winter 2014-2015

Operational snow monitoring

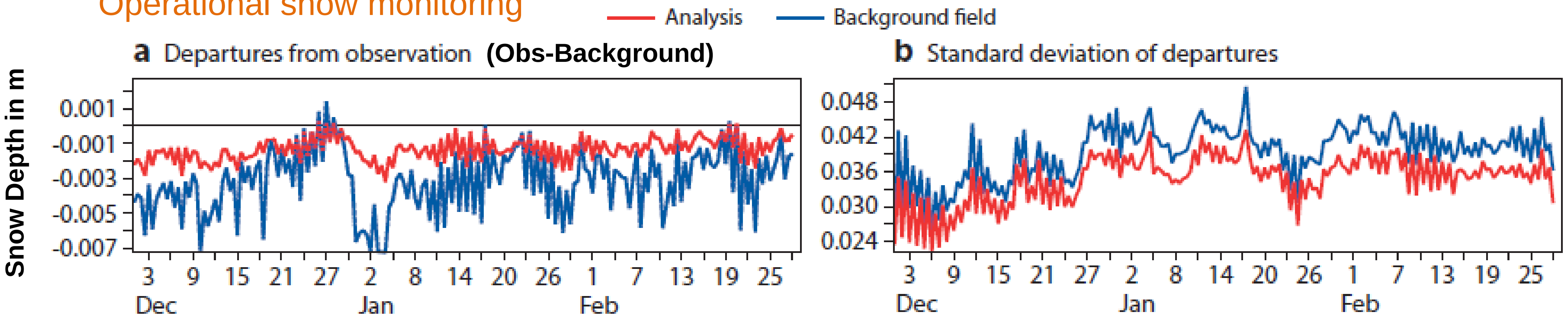


Figure 7 Monitoring time series from December 2014 to February 2015 of the ECMWF operational IFS Cycle 40r1 suite for conventional snow depth showing (a) mean departures of background field and analysis from observations, in metres (b) standard deviation of background field and analysis departures from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

1. Not all NWP systems have a snow analysis
   Snow data assimilation systems relies on relatively simple approaches (Cressman,OI)

2. Mostly DA of *in situ* snow depth and the IMS multi sensor snow cover
   - 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

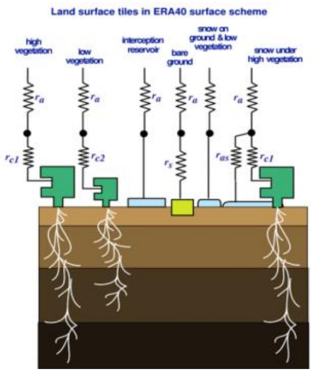
     → National Met services encouraged to improve snow depth reports availability on the GTS

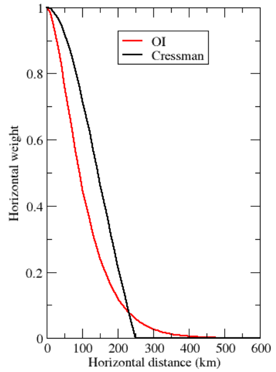
3. Challenges in retrieving snow mass from satellite measurements → Novel mission concepts required for snow water equivalent

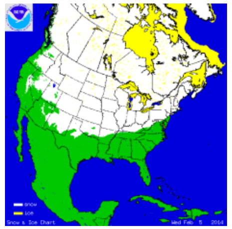
4. Snow initialisation has a large impact on Numerical Weather Forecast

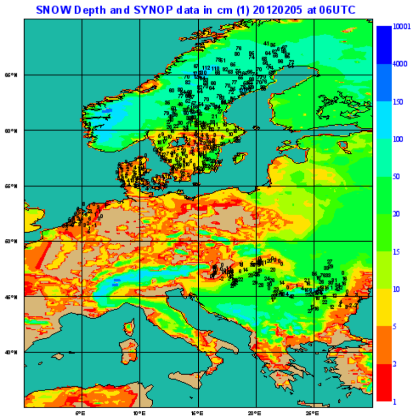
Snow in the ECMWF IFS history

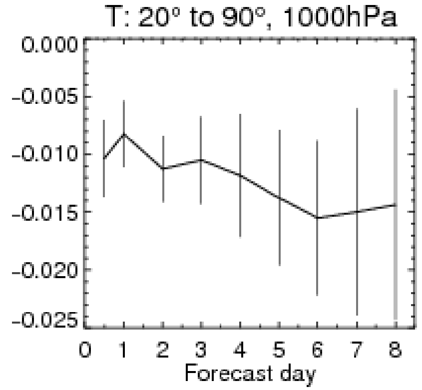
2009 | 2010 | 2011 | ….. | 2013 | 2015











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

Future:
Multi-layer snow model
Future snow missions?
RT modelling

Dutra et al., J. hydrometeorol. 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

Outline

Part I (Monday)

- Introduction
- Snow analysis
- **Screen level parameters analysis**

Part II (Tuesday)

- Soil moisture analysis
- Summary and future plans

Screen Level parameters analysis

- Screen level variables: 2m Air Temperature (T2m) and air Relative humidity (RH2m)
- Analysis based on an Optimal Interpolation using SYNOP observations, every six hours: 00UTC, 06UTC, 12UTC, 18UTC
- Screen level analysis increments are used for the soil moisture analysis (OI system, e.g. at Météo-France and ECMWF ERA-Interim)
- Screen level analysis fields are used as input of the SEKF soil moisture analysis (ECMWF)
- T2m and RH2m are diagnostic variables of the model, so their analysis only has an indirect effect on atmosphere through the soil and snow variables.
- Screen level analysis reliable for evaluation purposes

OI Screen Level parameters analysis

Mahfouf, J. Appl. Meteo. 1991, & ECMWF News Lett. 2000

1. First guess departure ΔX_i estimated at each observation location i from the observation and the interpolated background field (6 h or 12 h forecast).

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

$$\Delta X_j^a = \sum_{i=1}^{N} w_i \times \Delta X_i$$

3. The optimum weights w_i are given by: (**B** + **O**) **w** = **b**

2D-OI like for snow analysis

b : error covariance between observation i and model grid point j (dimension of N observations)

B : error covariance matrix of the background field (N × N observations)
$B(i_1,i_2) = \sigma_b^2 \times \mu(i_1,i_2)$ with the horizontal correlation coefficients $\mu(i_1,i_2)$
and σ_b = 1.5 K for T2m and 5 % RH2m is the standard deviation of background errors.

$$\mu(i_1,i_2) = \exp\left(-\frac{1}{2}\left[\frac{r_{i_1 i_2}}{d}\right]^2\right)$$

O : covariance matrix of the observation error (N × N observations):
O = σ_o^2 × **I** with σ_o = 2.0 K for T2m and10 % RH2m is ths standard deviation of obs. errors

Screen Level parameters analysis

Quality control:

- Number of observations N = 50, d = 300 km, scanned radius 1000km.
- Gross quality checks as rH $\in$ [0,100] and T > $T_{dewpoint}$
- Observation points that differ more than 300 m from model orography are rejected.
- First-guess check:

$$|\Delta X_i| = \gamma\sqrt{\sigma_o^2 + \sigma_b^2}$$

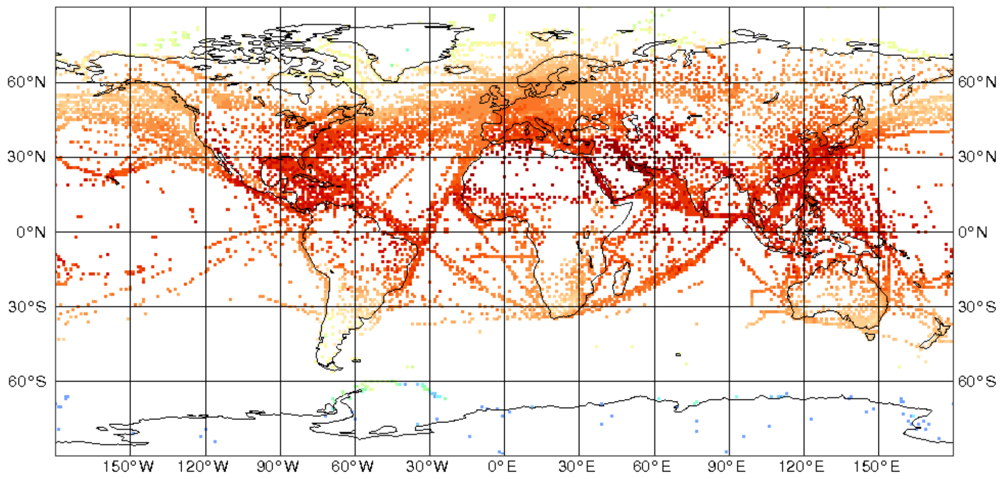
  Observation is rejected if : with γ = 3 (tolerance)

- Redundancy rejection

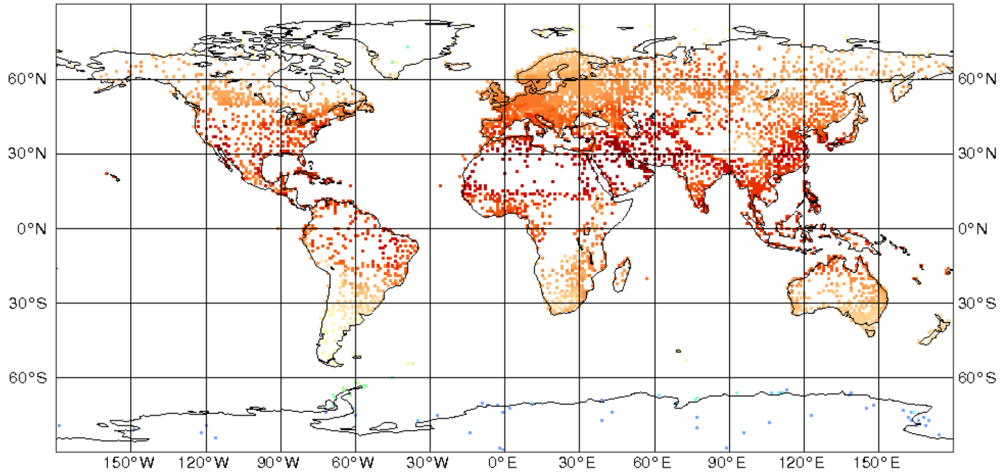
- Number of active observations > 16000 per 12 hour (less than 20% of the available observations).

Screen level DA: Observation usage Land/Sea surface data in the OI

Ocean and Land observations



Used for Land Data Assimilation



Screen level observations are: two meter temperature and relative humidity. Observations are available on the GTS:

Diversity of Report types:

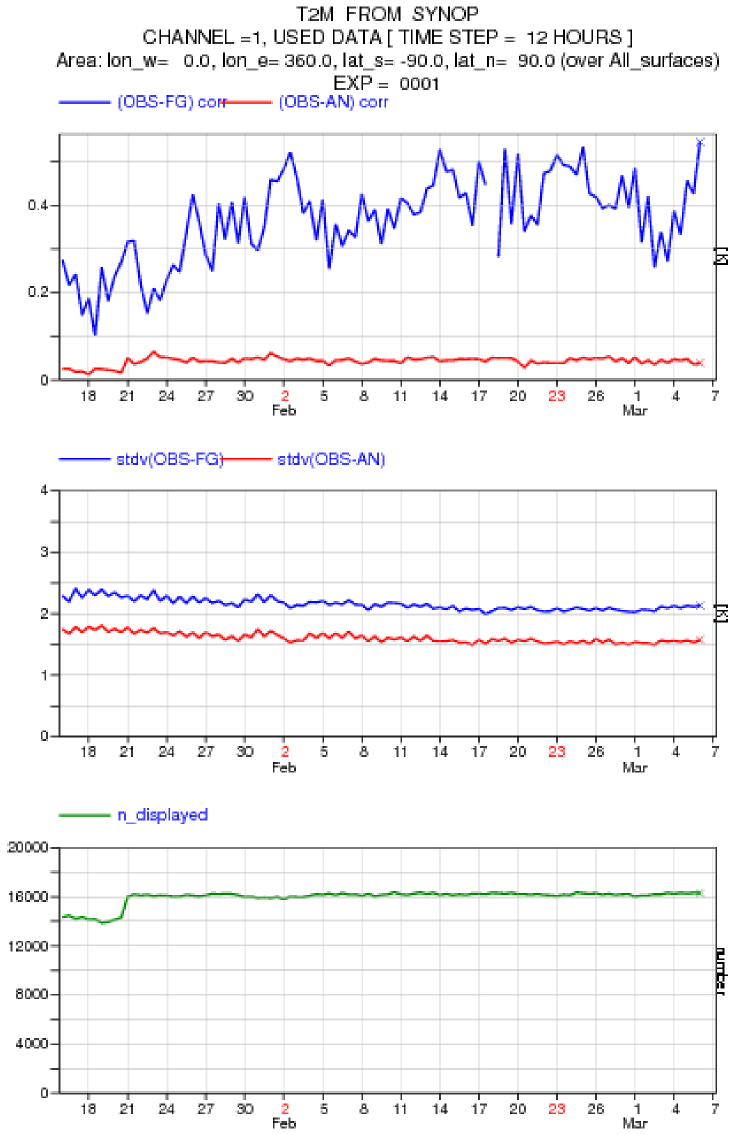
- Drifting buoys, automatic and manual stations on ships, etc..
- Automatic and manual SYNOP stations, METAR (METeorological Airport Reports), etc…

For soil moisture analysis purpose, only Land observations are relevant

In coastal areas it is important to select land only report types for model land points (match with the land sea-mask).

→ only land report types enter the screen level analysis.

Screen level observations monitoring



2014

http://www.ecmwf.int/en/forecasts/charts/obstat/?facets=Category,Conventional%20Data%3BParameter,%202m%20temperature

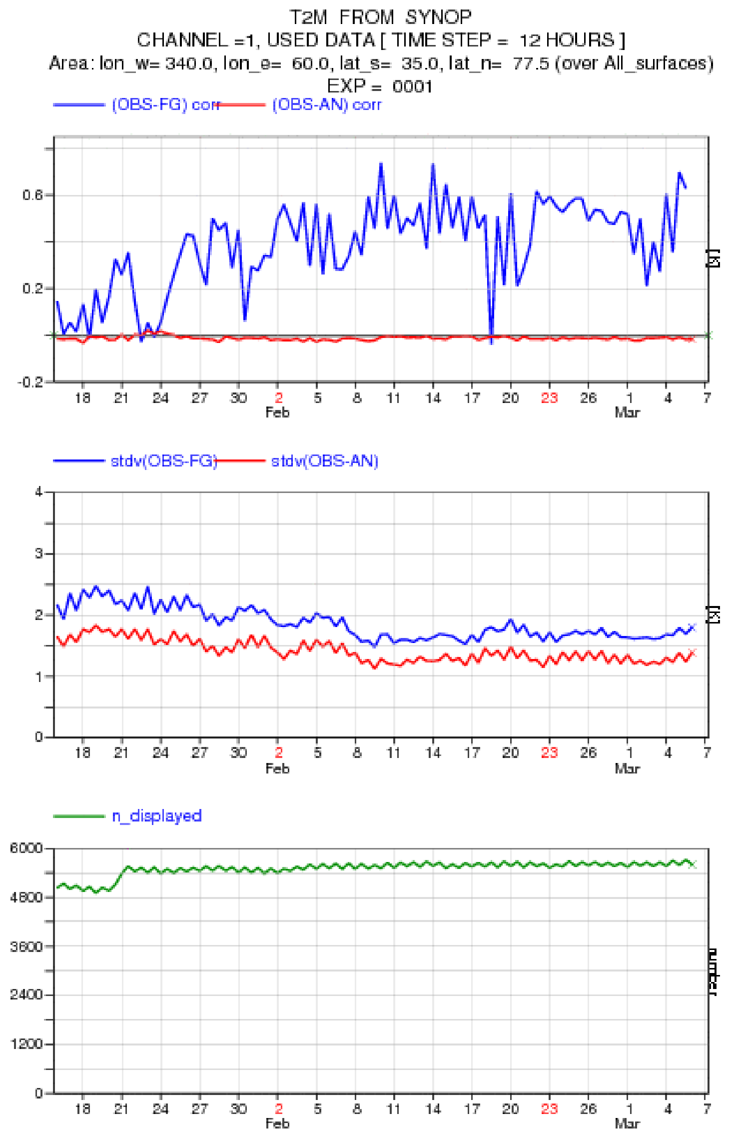
Global first guess departure

Global analysis departure

Standard deviation of departure statistics

Number of observations used:
>16000 per 12 hours

Screen level observations monitoring



Feb-Mar 2014

http://www.ecmwf.int/en/forecasts/charts/obstat/?facets=Category,Conventional%20Data%3BParameter,%202m%20temperature

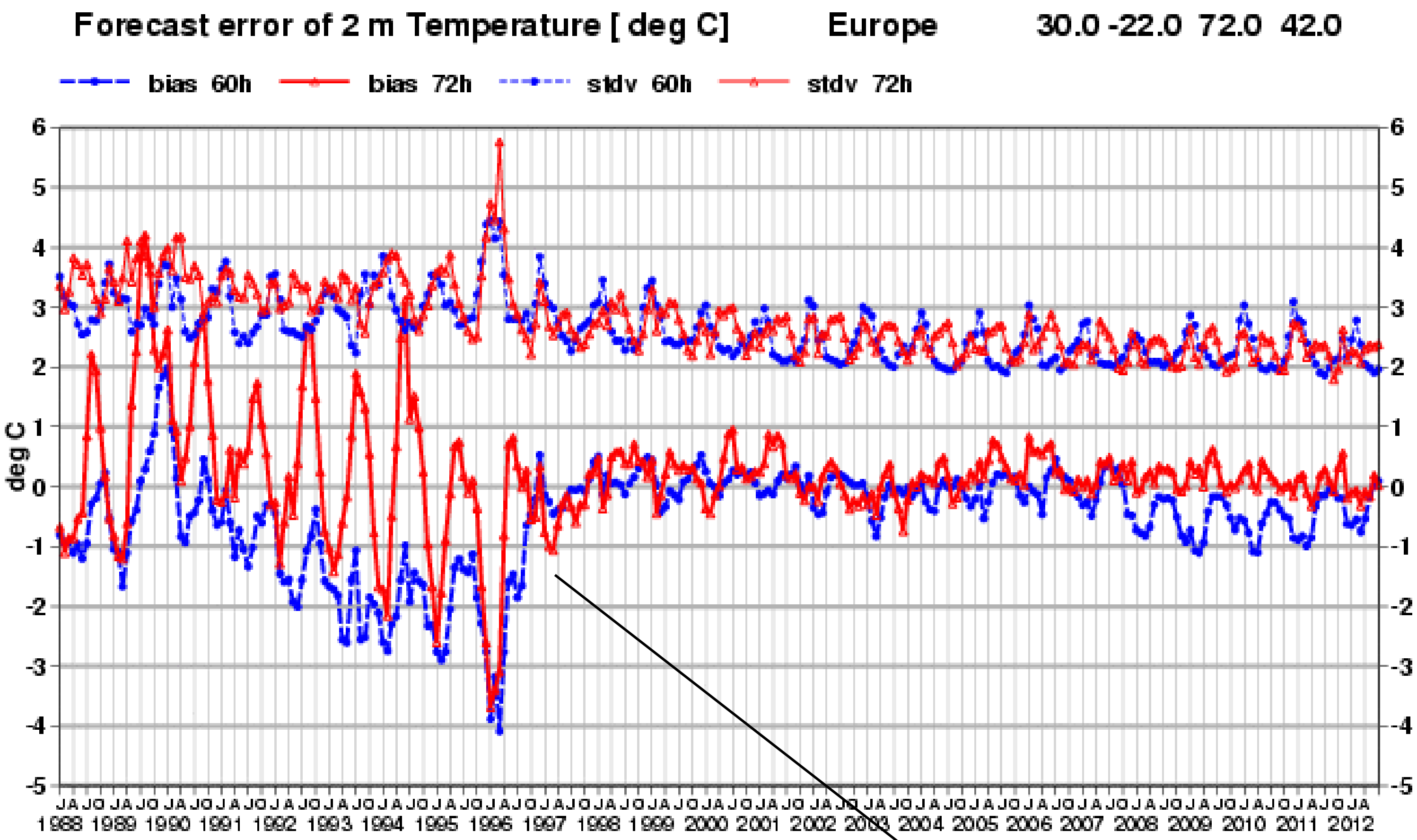
Europe first guess departure (Obs-Background, in K)

Europe analysis departure (Obs-Background, in K)

Standard deviation of departure statistics

Number of observations used over Europe:
~5000 per 12 hours

Screen level analysis: 2m temperature forecast verification



Soil freezing parameterisation
Snow albedo parameterisation

Verification for 60h (night time) and 72h (day time)

From Richardson et al., 2012, ECMWF Tech. Memo 688