ECMWF Data Assimilation Training course

Land Surface Data Assimilation

Patricia de Rosnay

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ECMWF

ECMWF Data Assimilation Training course

Land Surface Data Assimilation

Patricia de Rosnay

- **Land surface processes**
  - Why it is important in NWP?
  - What are the variables we are analysing?
    - ➔ How do we analyse them?
    - ➔ Which observations are used?

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Outline

Part I (Monday 16 March)

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

Part II (Tuesday 17 March)

- Soil moisture analysis
- Summary and future plans

Introduction: Land Surface in NWP

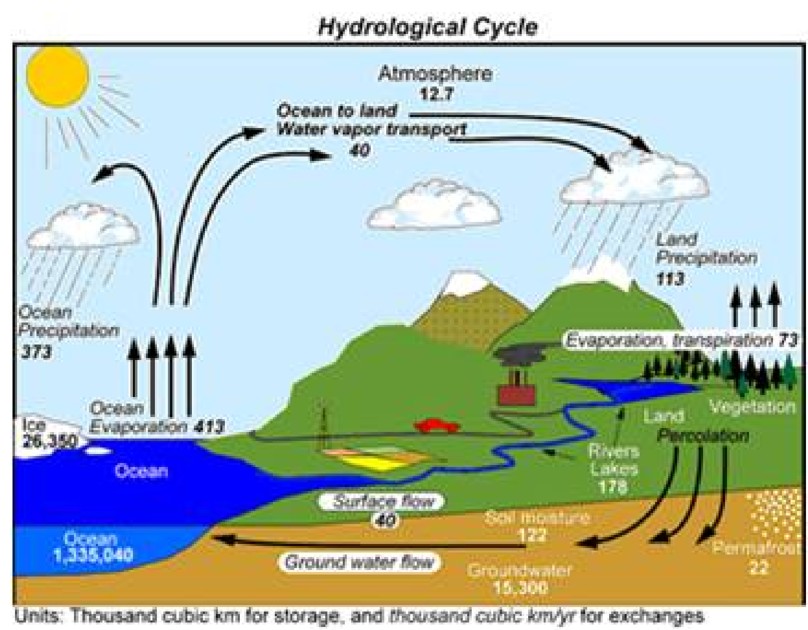
• Land surfaces: Boundary conditions at the lowest level of the atmosphere

• Land surface processes → Continental hydrological cycle, interaction with the atmosphere on various time and spatial scales, strong heterogeneities

• Crucial for near surface weather conditions, whose high quality forecast is a key objective in NWP

• Land Surface Models (LSMs) prognostic variables include:
- Soil moisture
- Soil temperature
- Snow water equivalent, snow temperature, snow density

• Land surface initialization:
Important for NWP & Seasonal Prediction
(Beljaars et al., Mon. Wea. Rev, 1996, Koster et al., 2004 & 2011)



Trenberth et al. (2007)

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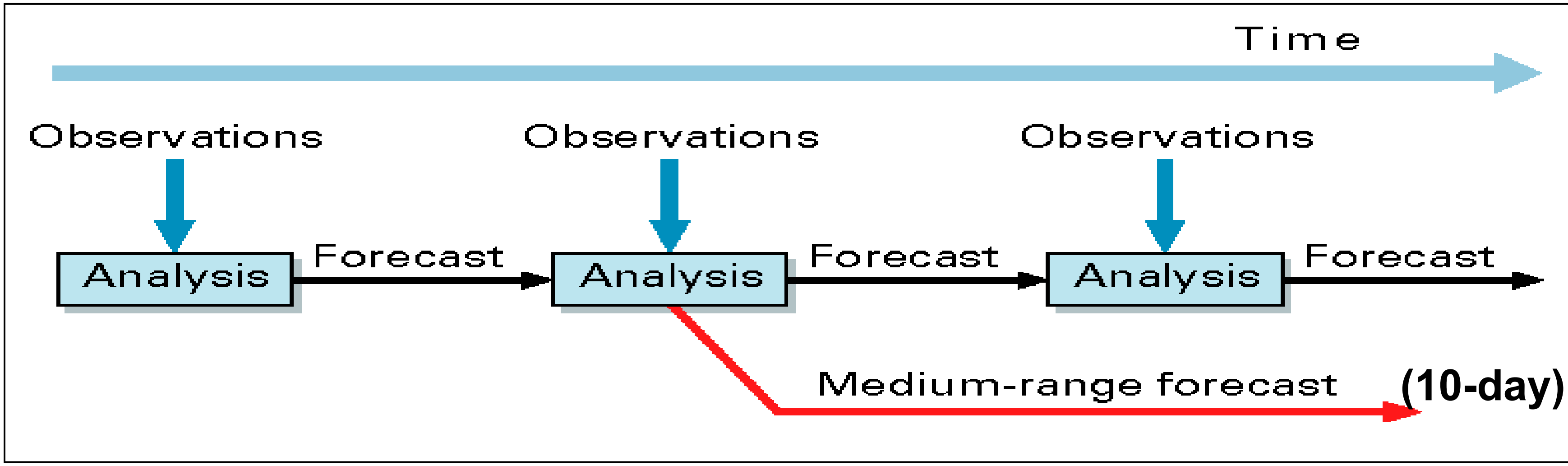
Introduction: ECMWF Integrated Forecasting System (IFS) data assimilation system



Data Assimilation System:
Provides best possible accuracy of initial conditions to the forecast model

- 4D-Var for atmosphere
- Land surface data assimilation
- SST and Sea Ice analysis

→

- **Surface and upper air analyses are running separately in parallel**
- **Feedbacks provided through the first guess forecast initialised with the analysed fields**

→ Surface and Atmospheric DA are weakly coupled

ECMWF

Introduction: Land Surface Data Assimilation (LDAS)

Snow depth analysis

- Approaches: Cressman (DWD, ECMWF ERA-I), 2D Optimal Interpolation (OI) (ECMWF, CMC, JMA)
- Observations: *in situ* snow depth and NOAA/NESDIS IMS Snow Cover

Soil Moisture analysis

- Approaches:
  - 1D Optimal Interpolation (Météo-France, CMC, ALADIN and HIRLAM)
  - Analytical nudging approach (BoM)
  - Simplified Extended Kalman Filter (EKF) (DWD, ECMWF, UKMO)
- Conventional observations: SYNOP data of 2m air relative humidity and air temperature ; **Dedicated 2D OI screen level parameters analysis**
- Satellite data : ASCAT soil moisture (UKMO), SMOS (dvpt ECMWF, UKMO, Env.Canada)

Soil Temperature and Snow temperature also analysed

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

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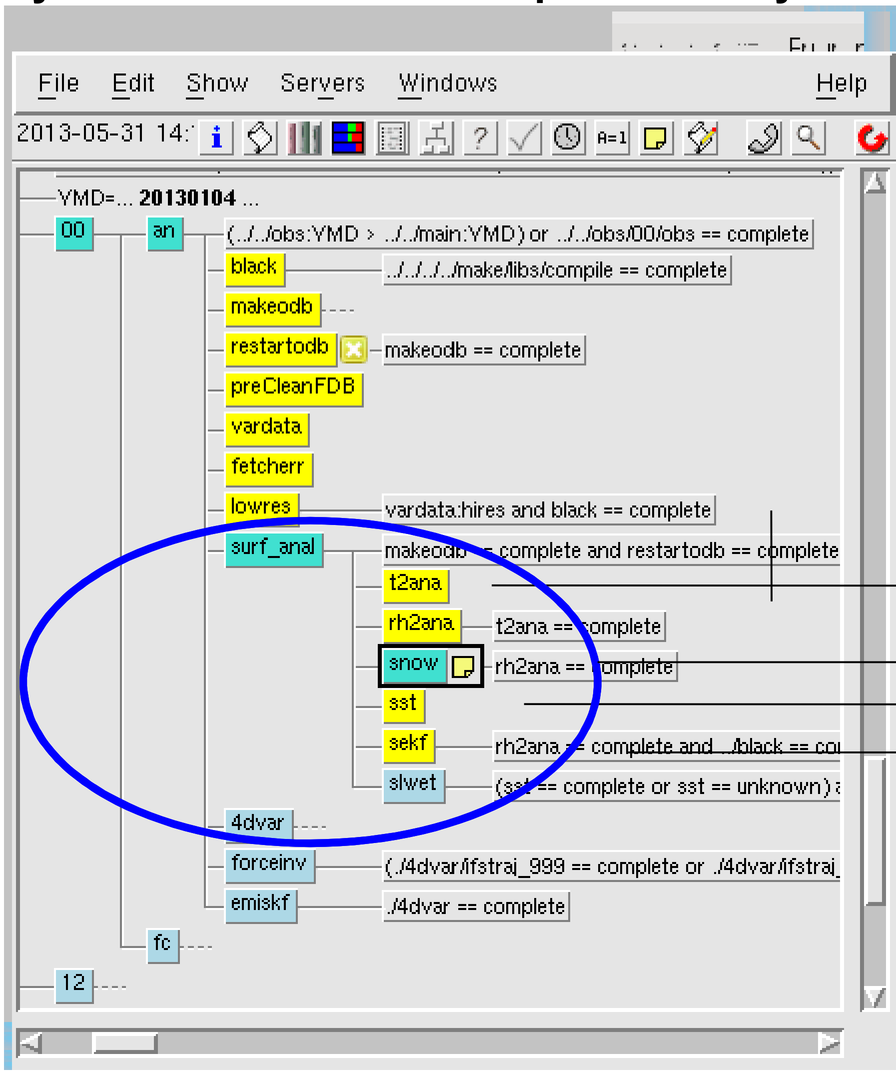
Introduction: LDAS tasks organisation

IFS cycle 40r1 is the current operational cycle



SMS: Supervisor Monitor Scheduler

Different tasks performed

Colour code:
- Yellow: task completed
- Green: running
- Blue: in queue
- Red: failed

Screen level parameters

Snow

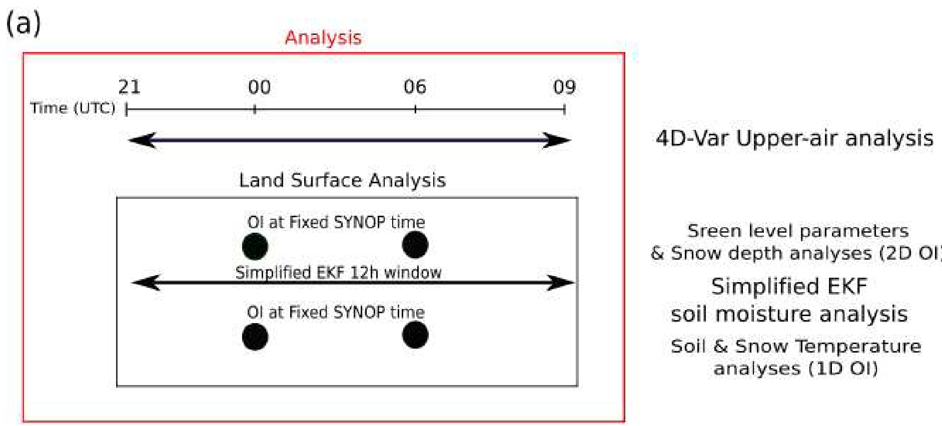
SST and Sea Ice

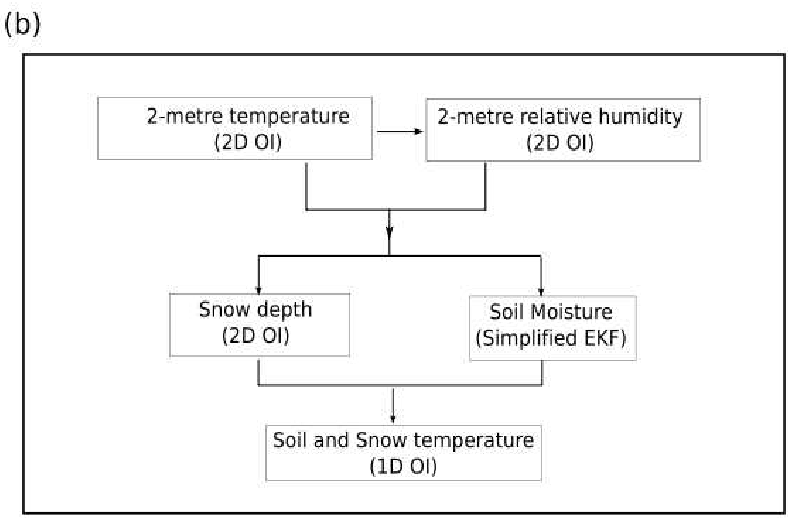
Soil Moisture and Temperature

Surface and and 4D-Var are running separately and in parallel.

ECMWF

LDAS components and tasks organisation





LDAS & 4D-Var are run separately

LDAS

- 2D OI: Screen-level for T and humidity, Snow depth
- SEKF: Soil moisture
- 1D OI: Snow & soil temperature

Analysed surface fields: used as initial conditions for the next forecast

➔Influence the forecast which will be used as first guess for the next data assimilation window, for both 4D-Var and LDAS

➔Feedback to the atmosphere

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Snow data assimilation

Snow Model: Component of H-TESSEL

(Balsamo et al., JHM 2009, Dutra et al., 2010)

- Snow depth S (m) (diagnostic)
- Snow water equivalent SWE (m), ie snow mass
- Snow Density ρ_s, between 100 and 400 kg/m^3

} **Prognostic variables**

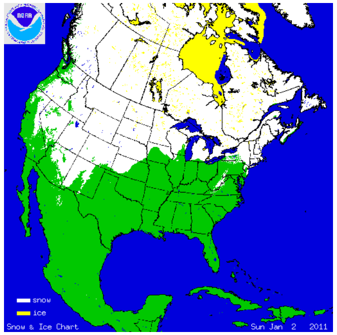
$$S = \frac{1000.SWE}{\rho_s}\ [m]$$

Observations types used:

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

Drusch et al. JAM, 2004 ; de Rosnay et al, SG 2013

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



Data Assimilation Approaches:

- Cressman Interpolation in ERA-Interim
- Optimal Interpolation in operations

de Rosnay et al, Survey of Geophysics 2013

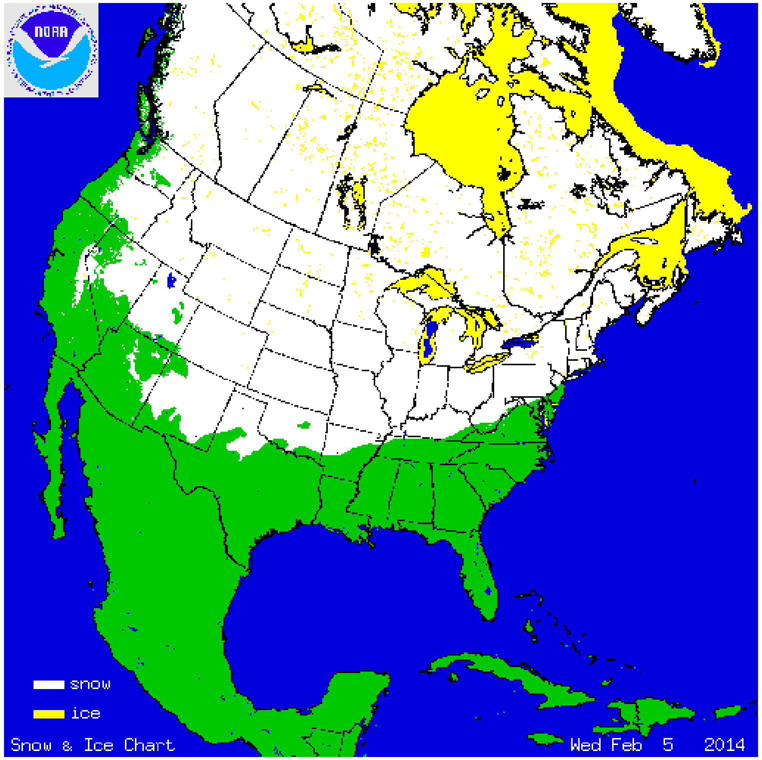
NOAA/NESDIS IMS Snow extent data

Interactive Multisensor Snow and Ice Mapping System

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

Northern Hemisphere product

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



IMS Snow Cover 5 Feb. 2014

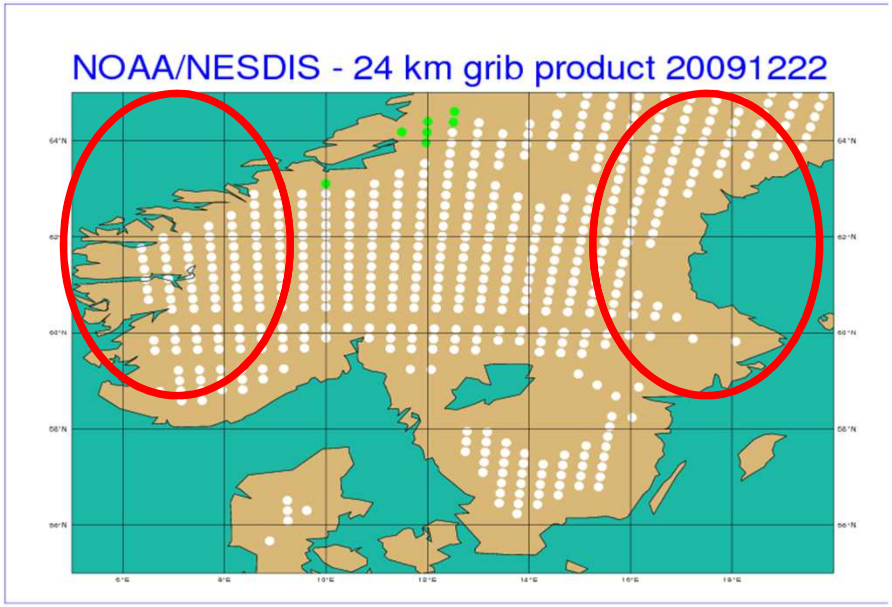
Information content: Snow/Snow free

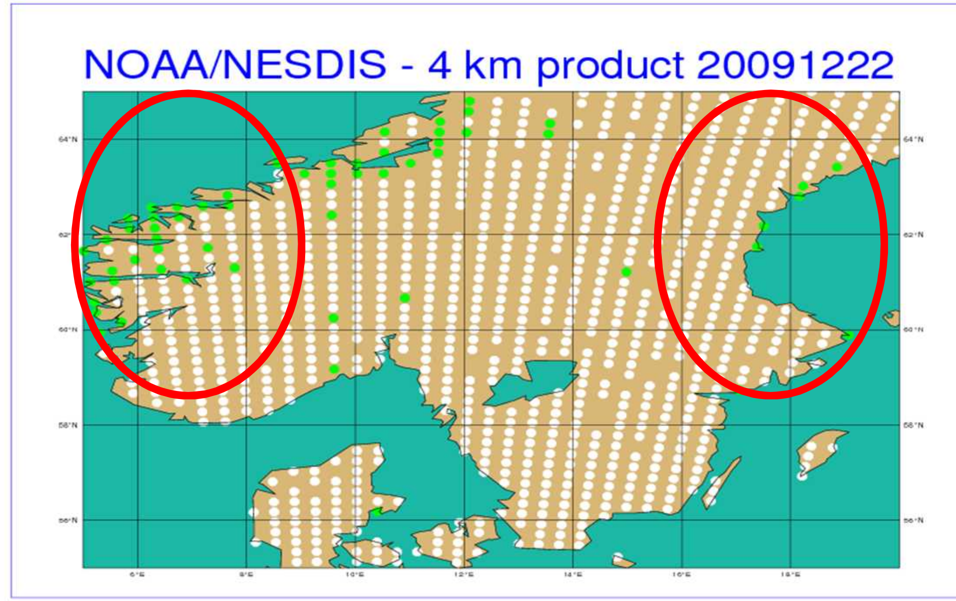
Data used at ECMWF:

- **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 Cover 24km vs 4km product





IMS Products after pre-processing at ECMWF

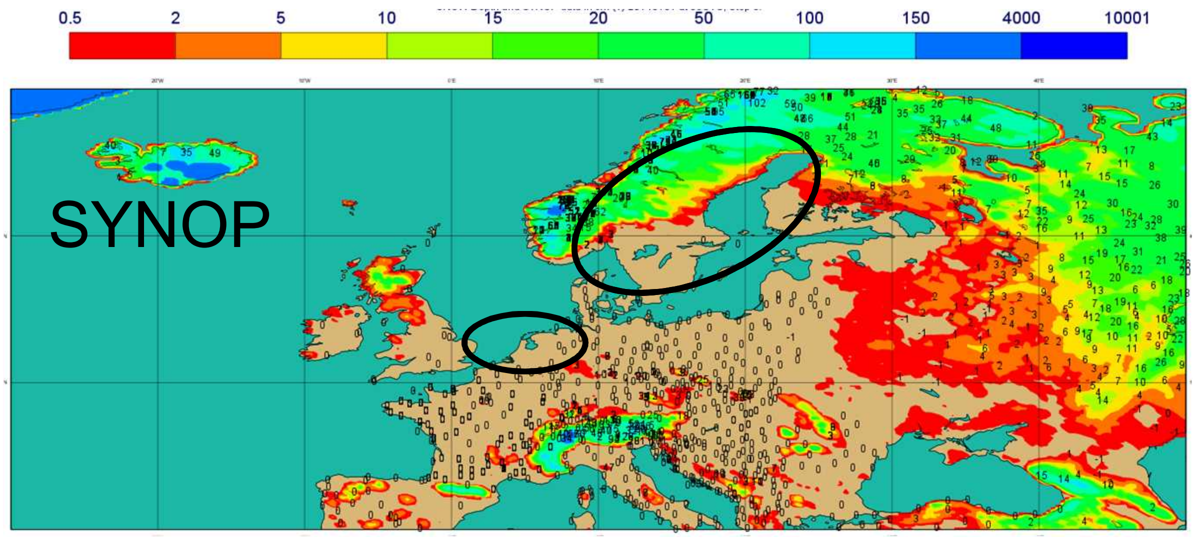
- Coast mask applied in the 24km product (lack of geolocation information in the grib product)
- Data thinning (1/36) of the 4km product -> same data quantity, improved quality

4km product provides more local information than 24km product

→ consistent with the way IMS is used in the data assimilation system

Snow SYNOP

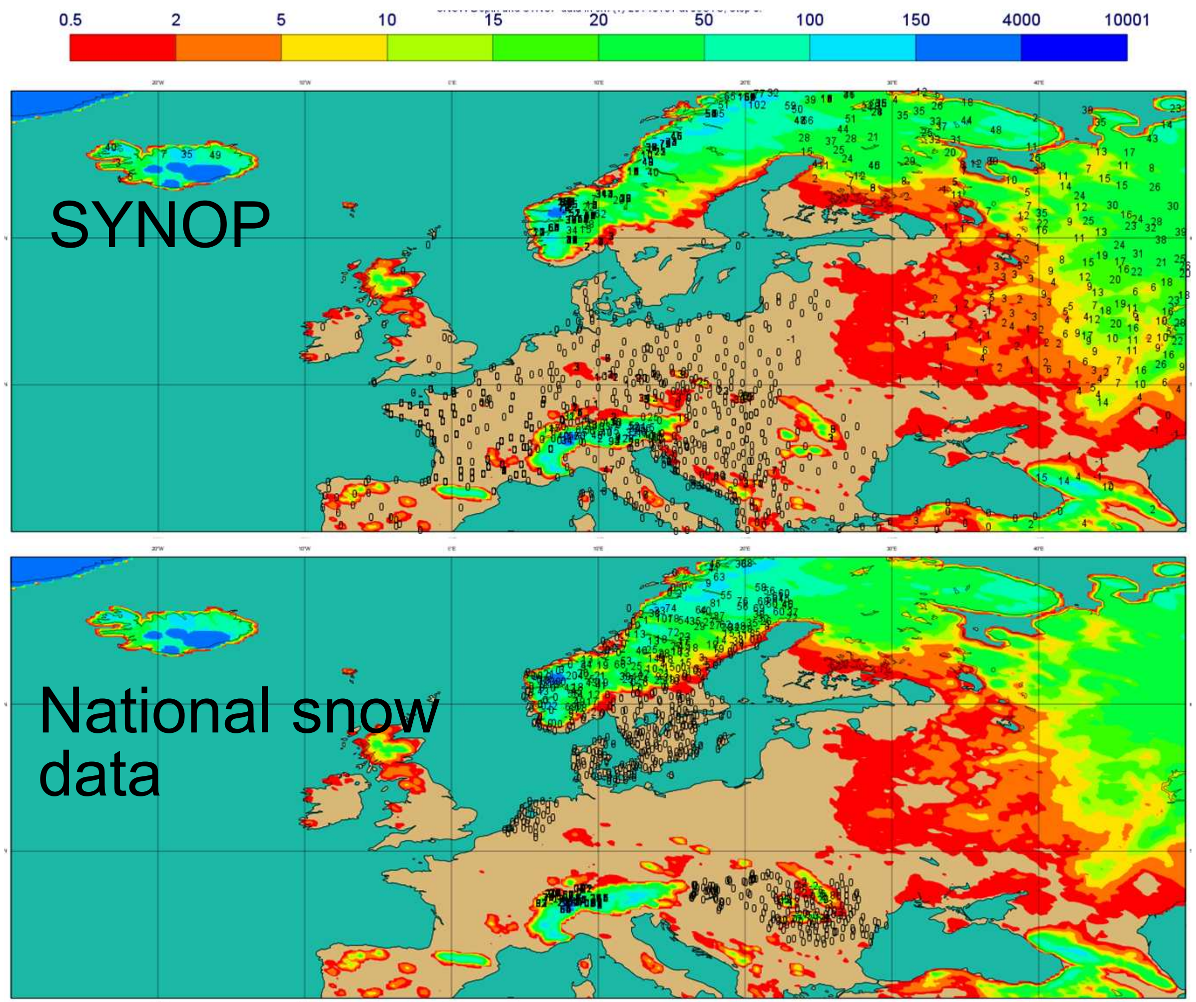
2014 01 01 at 06UTC



ECMWF

Snow SYNOP and National Network data

2014 01 01 at 06UTC



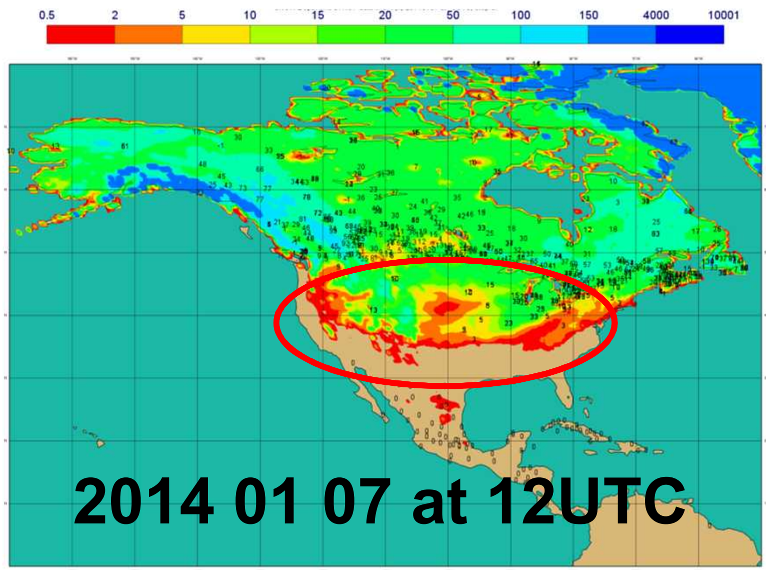
Additional data from national networks from 7 countries:

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

→ Dedicated BUFR

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

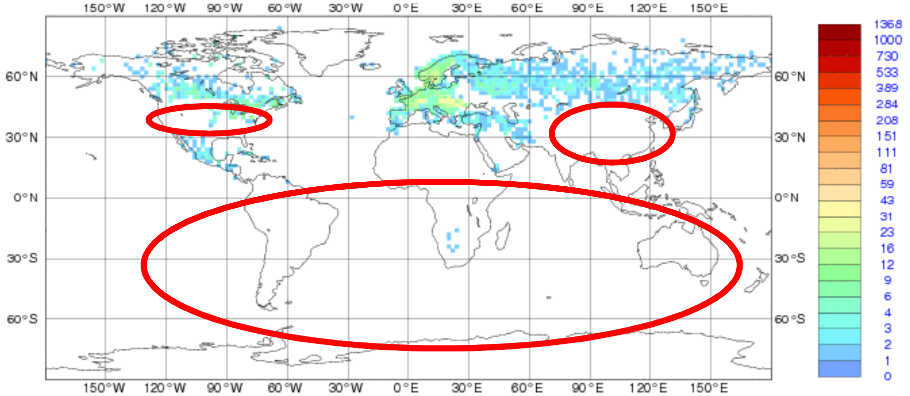
SYNOP Snow depth availability



ECMWF Operational monitoring of SYNOP snow depth: number of observations on 2014 01 04 at 00UTC (21-09 UTC):
observations gap in USA, China and southern hemisphere

GCW Snow Watch initiative to improve in situ snow depth data access (NRT and rescue), Brun et al 2013

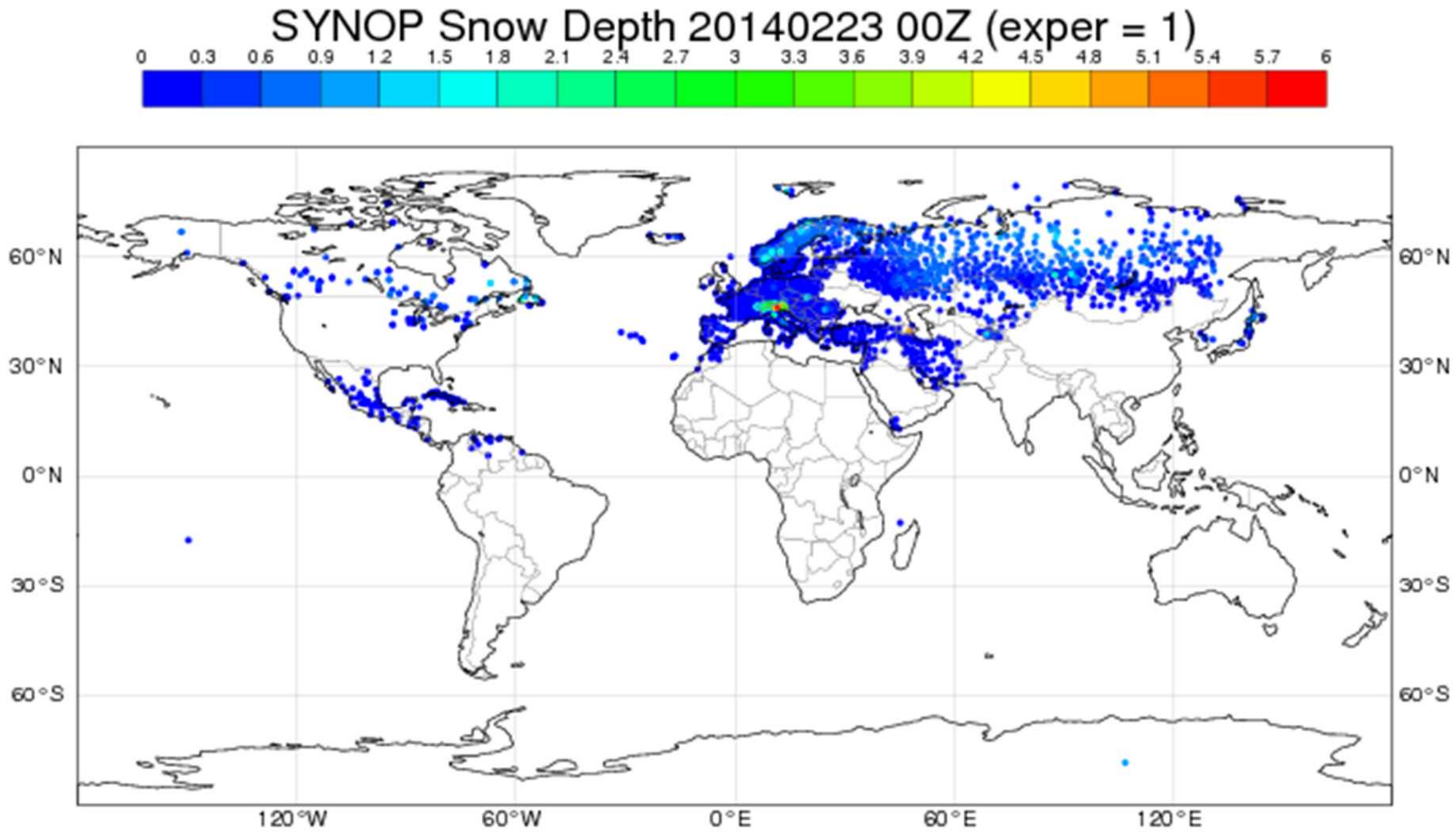
http://www.ecmwf.int/products/forecasts/d/charts/monitoring/conventional/snow/



ECMWF

Snow depth observations

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



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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: Operations: 1987-2010
  Still used in ERA-Interim
- Optimal Interpolation (OI): Operational since November 2010

(de Rosnay et al; SG 2013)

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

NESDIS: \ 1st Guess:	Snow	No Snow
Snow	x	**DA** 5cm
No Snow	DA	DA

enter the analysis with a snow depth of 0 cm (snow free) or 5 cm (snow covered, used only if the model first guess is snow free)

Background error:
σ_b= 3cm

Observation errors:
SYNOP σ_{SYNOP}=4cm
IMS σ_{ims}=8cm

Snow depth Optimal Interpolation

Used at CMC, JMA, ECMWF

Based on Brasnett, j appl. Meteo. 1999

- Observed first guess departure (obs.-fg), [ΔS_i] are computed from the interpolated background at each observation location [i]
- The analysis increments [ΔS_j^a] at each model grid-point [j] are then expressed as :

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

- The optimum weights [w_i] are given for each grid point j by $\mathbf{w} = (\mathbf{B} + \mathbf{R})^{-1} \times \mathbf{b}$

- **b** ; the vector of correlation coefficients of the background field error between the observations and the grid point
- **B** ; the correlation coefficient matrix of background field errors between all pairs of observations
- **R** ; the covariance matrix of observational errors

σ_b the standard deviation of background errors (3cm), σ_o that of observation errors (4cm in situ, 8cm IMS)

Snow depth Optimal Interpolation

Used at CMC, JMA, ECMWF

Based on Brasnett, j appl. Meteo. 1999

- The correlation coefficients of **B** and **b** are vital to the method and are assumed to have the form (structure function)

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

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

- 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

(use a maximum of 50 observations per grid point)

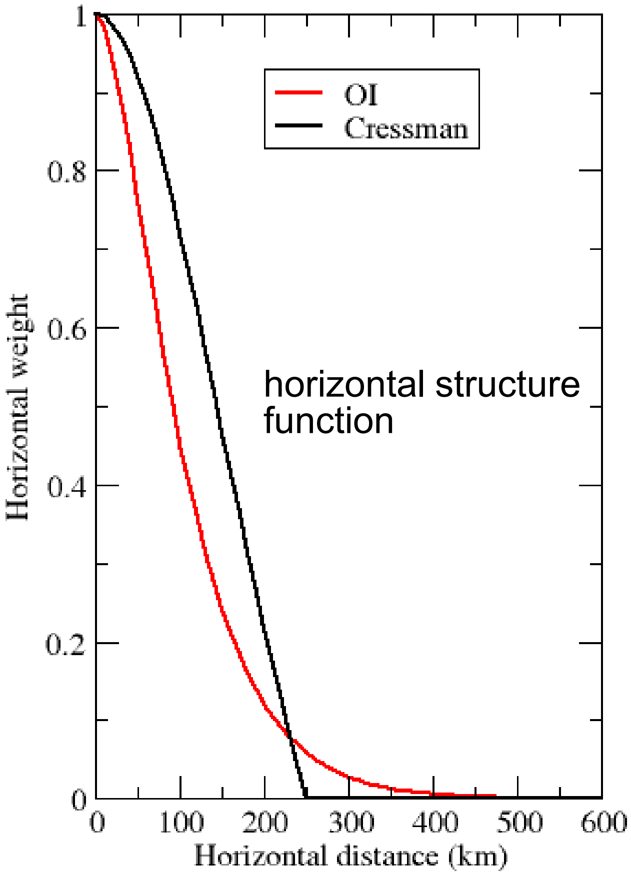
OI vs Cressman

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. 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.

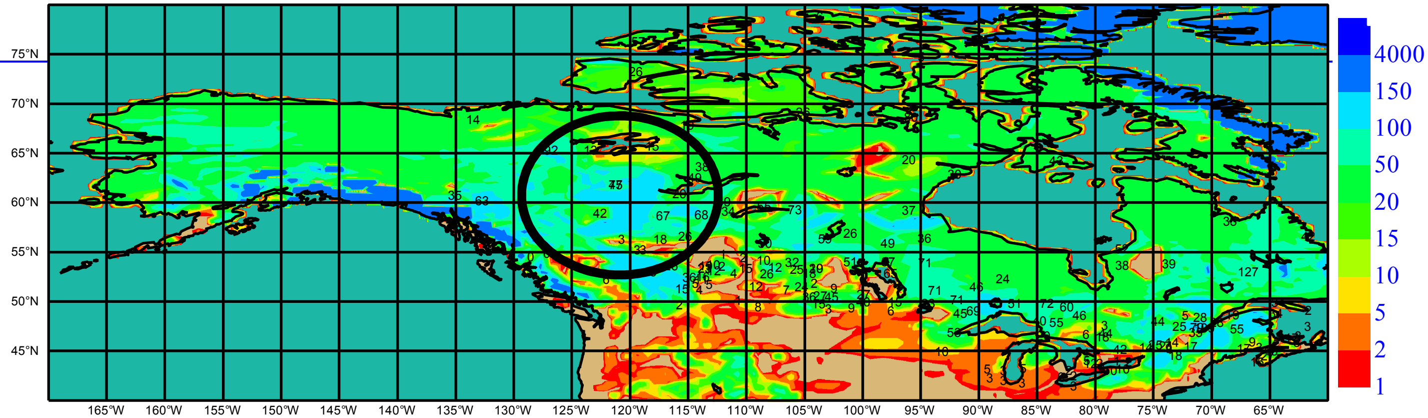


ECMWF

Some issues in the Cressman Snow analysis

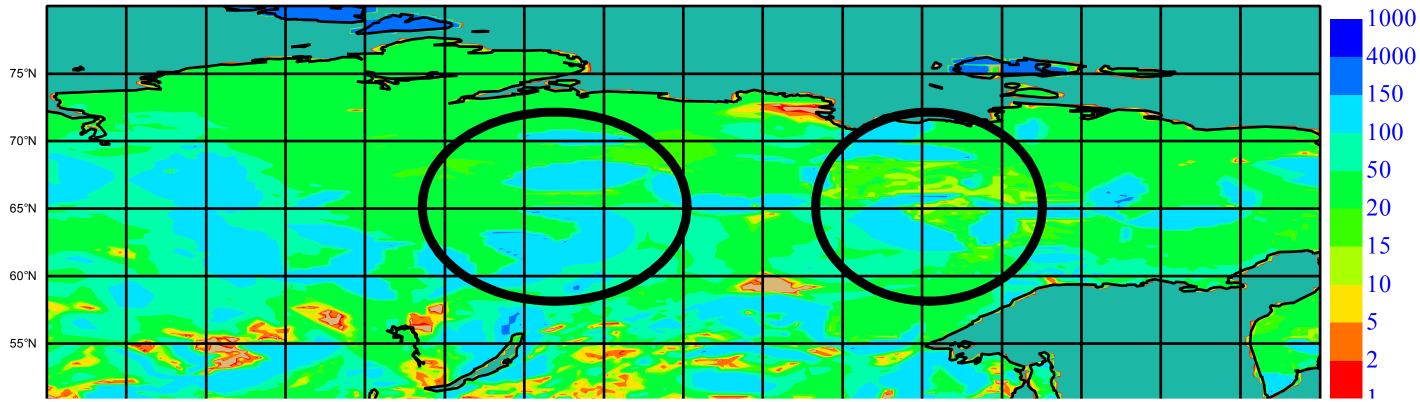
"Bull's eyes" (or "PacMan") Snow Patterns where observations are scarce
Due to the Cressman interpolation (as indicated in Kalnay, 2003)

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

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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	- 2.1	0.73	10.3
OI, IMS 4km <1500m	- 1.5	0.74	10.1

- Oper until Nov 2010
- ERA-Interim

- Oper since Nov 2010

Validation against ground data
→ Main improvement due to the OI compared to Cressman

Validation data: NWS/COOP

- NWS Cooperative Observer Program
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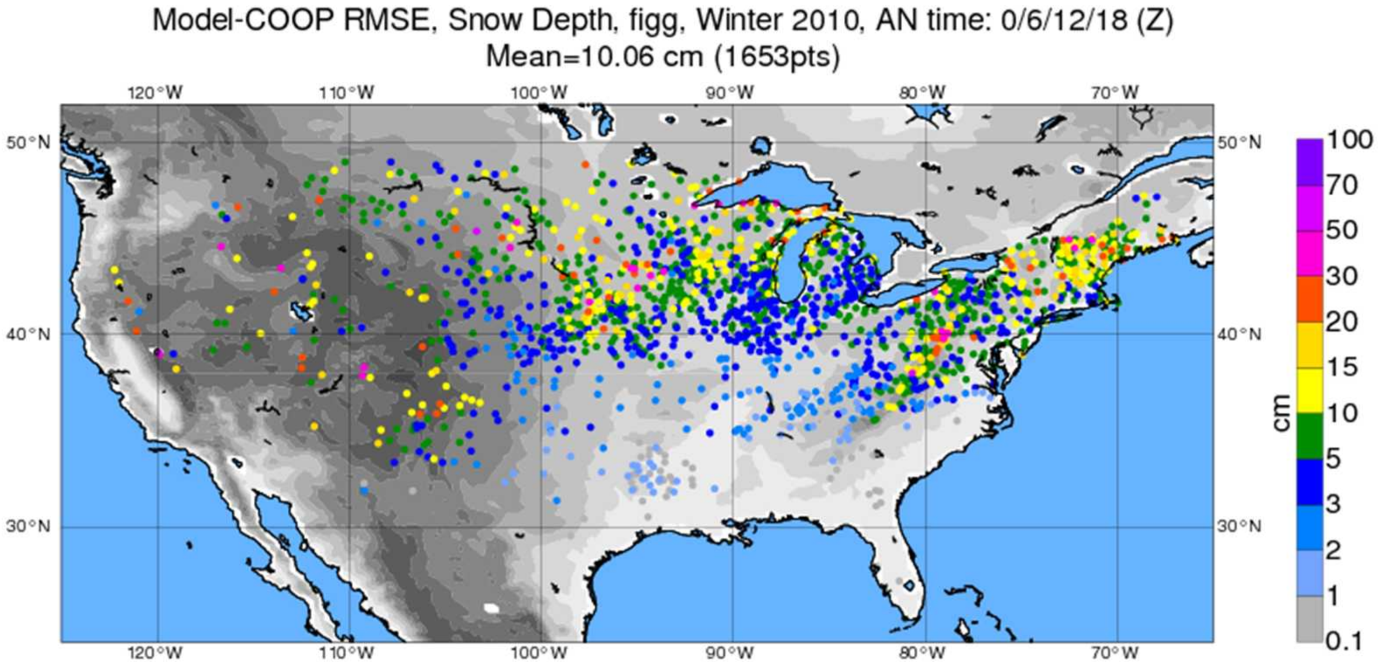
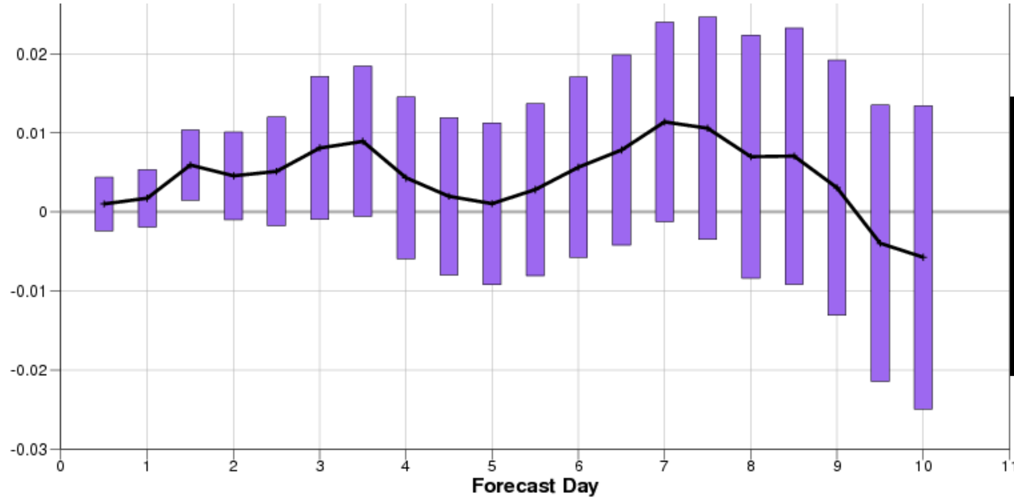
RMSE (cm) for the new snow analysis
(OI, IMS 4km except in mountainous areas)



ECMWF

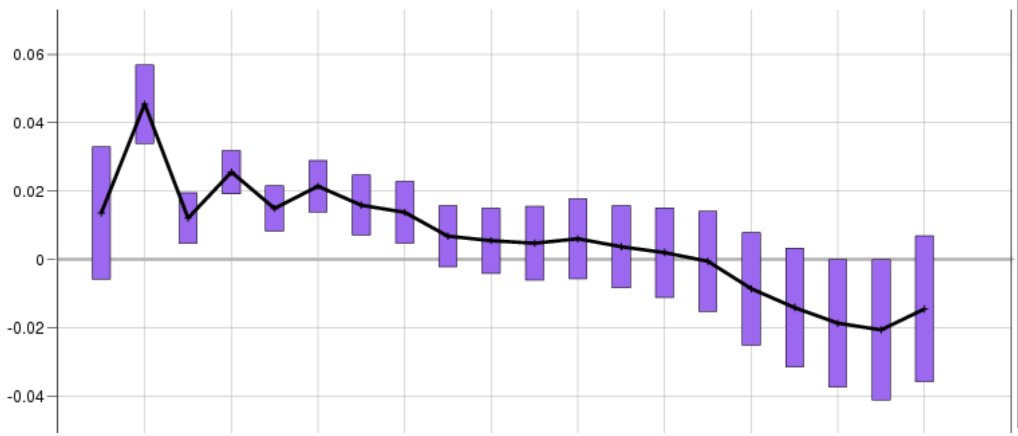
Impact on the Atmospheric Forecasts

RMS 1000hPa Geopotential height
Northern Hemisphere
DJF 2009-2010



Top: OI vs Cressman impact
(both use IMS 24km)

Positive means OI improves



Bottom: Overall impact

New OI,IMS 4km
vs Cressman, IMS 24km

Positive means new analysis improves

Validation with atmospheric forecasts
→ Main improvement due to the IMS 4km and pre-processing

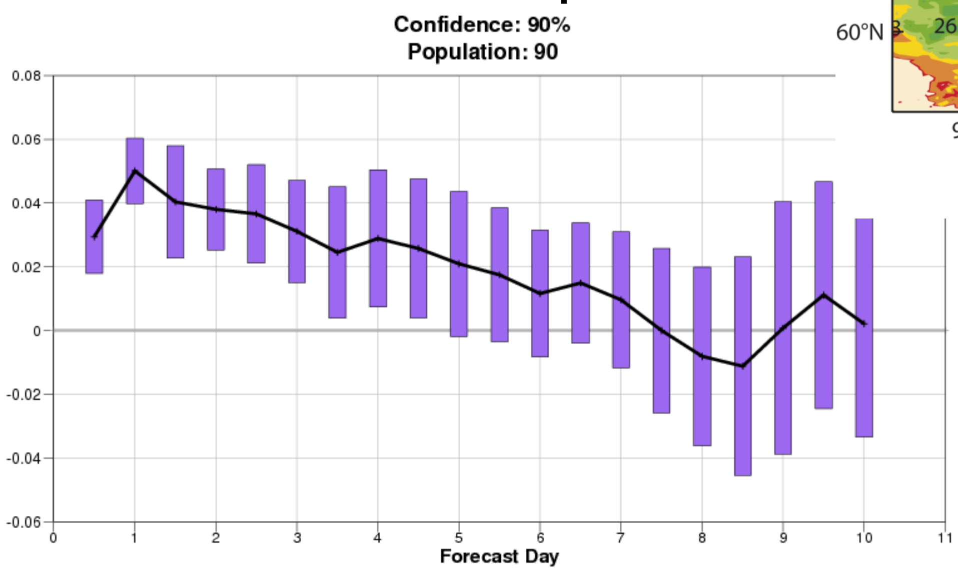
ECMWF

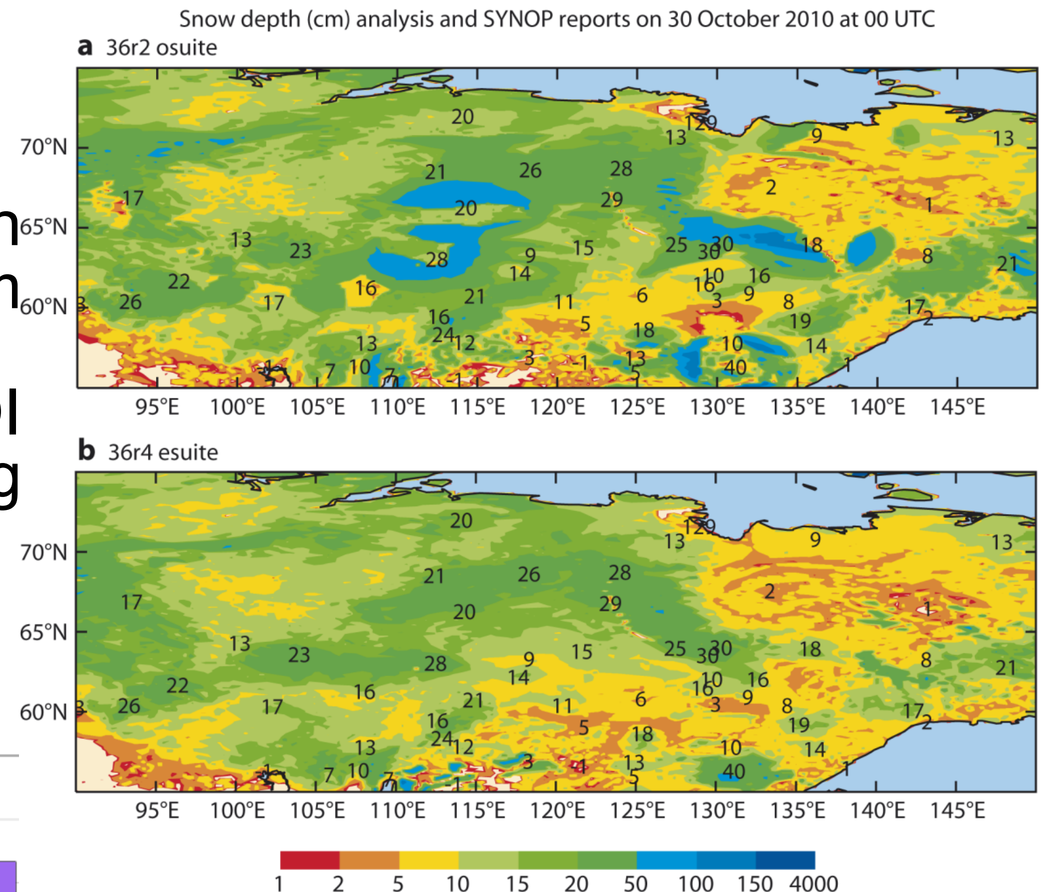
OI snow Analysis in Operations From Nov 2010

Old: Cressman
IMS 24km

New: OI
IMS 4km & new preprocessing

FC impact (East Asia)
RMSE 500 hPa Geopot H





New snow analysis improves both the snow depth patterns and the atmospheric forecasts

ECMWF

Snow Analysis latest improvements

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

- 2013: further improvement in the ECMWF snow analysis in 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

Snow Analysis latest improvements

Improved use of NESDIS/IMS snow cover data

Current version:

Cycle 40r1:

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

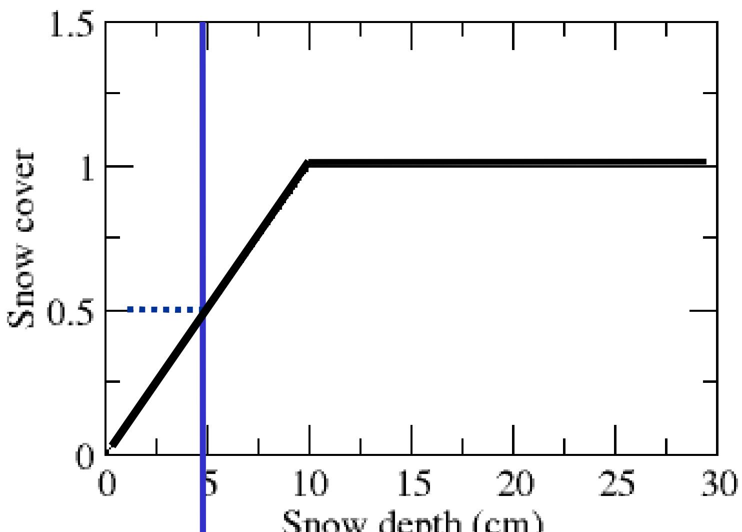
OI

40r1 errors:

BG: $\sigma_b = 3cm$

SYNOP $\sigma_{SYNOP} = 4cm$

IMS $\sigma_{ims} = 8cm$



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

ECMWF

Snow Analysis latest improvements

Improved use of NESDIS/IMS snow cover data

Previous version: IFS Cycle 38r2

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

OI

Previous cycles errors:
BG: σ_b= 3cm
OBS: σ_{SYNOP}=4cm

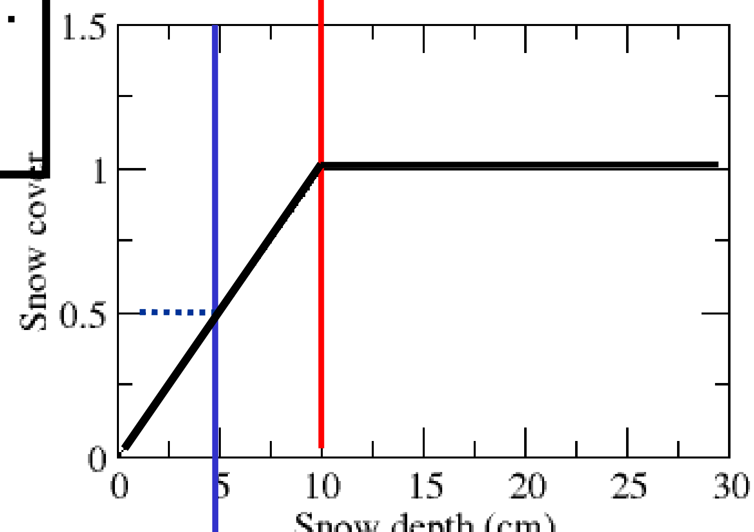
38r2:
- BG overwritten
- SC=1 → SD=10cm

Current version: Cycle 40r1:

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

OI

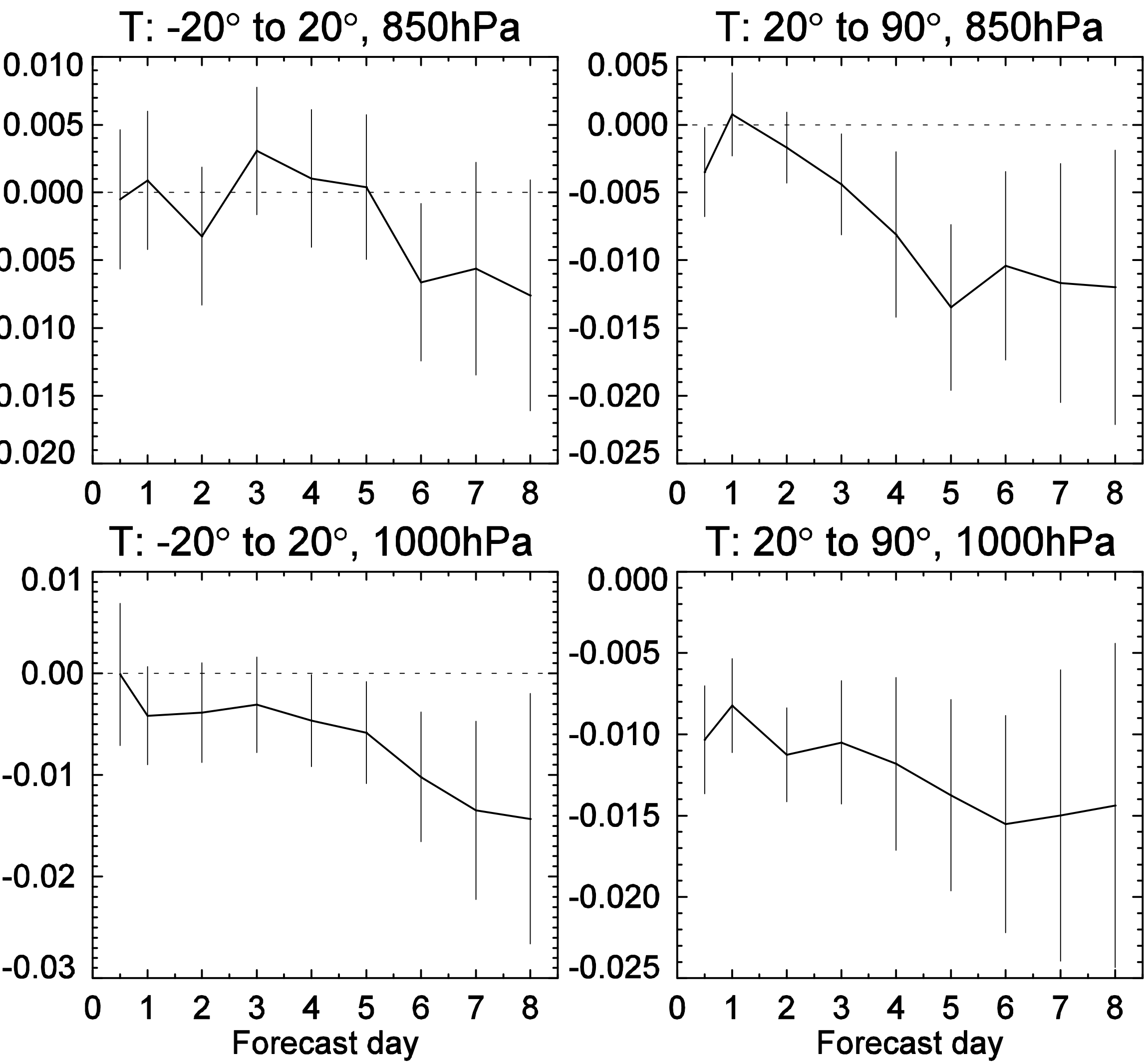
40r1 errors:
BG: σ_b = 3cm
SYNOP σ_{SYNOP}= 4cm
IMS σ_{ims} = 8cm



40r1:
- Obs assimilated
- SC=1 → SD=5cm

Snow analysis latest improvements: Temperature FC verification

Tropics NH extra-tropics



Temp FC RMSE
Verified against own analysis
(20 Dec 12 – 08 Mar 13)

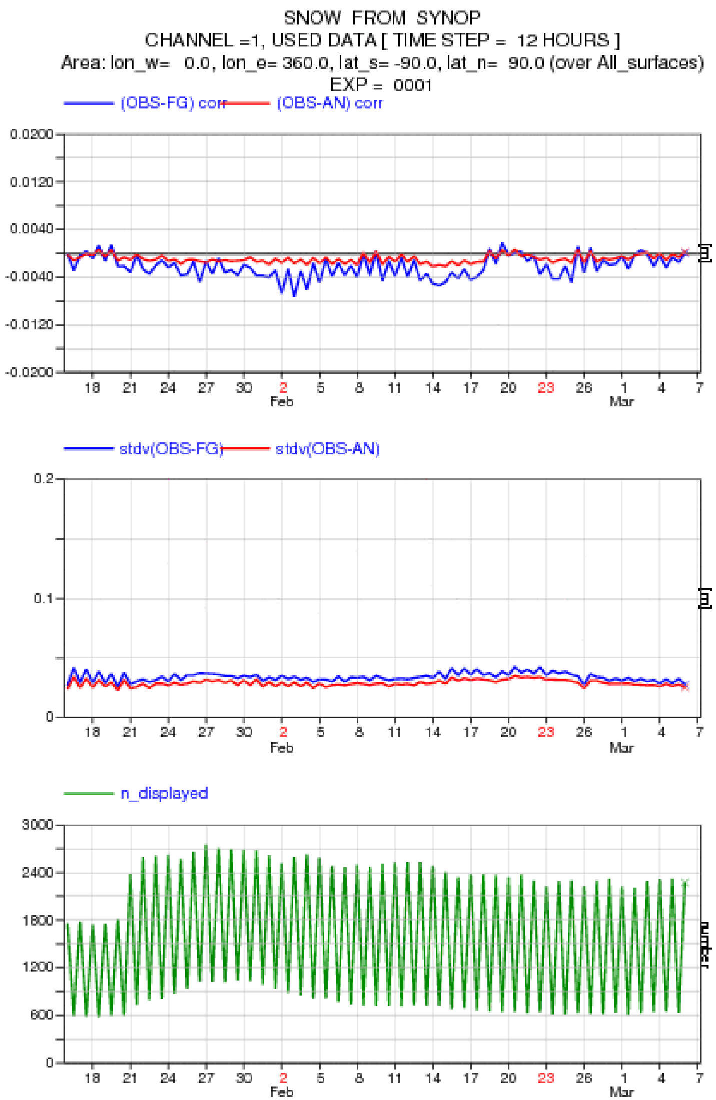
40r1-38r2 (current-previous cycle)

Improved use of IMS snow cover → Significant impact on the atmosphere and error reduction in forecasts

de Rosnay et al. in prep 2014

ECMWF

Snow observations monitoring



2014

Global first guess departure

Global analysis departure

Standard deviation of departure statistics

Number of in situ observations used:
~600 to 2500 per 12 hours

ECMWF

Summary on Snow Analysis

- Large sensitivity of atmospheric forecasts to snow data assimilation (DA method, observations pre-processing, error specification)
- Current snow analysis based on 2D-OI (CMC, JMC, ECMWF), old approach was based on Cressman (still used in ERA-Interim)

- Importance of in situ snow depth data availability
- Scarce snow depth observations in some areas → European initiative (new BUFR for additional snow data) – action to extend it to WMO Member States
- Snow cover data used (NOAA/NESDIS IMS product)
- **No** use of Snow Water Equivalent product in NWP
- Future investigations on using satellite radiances

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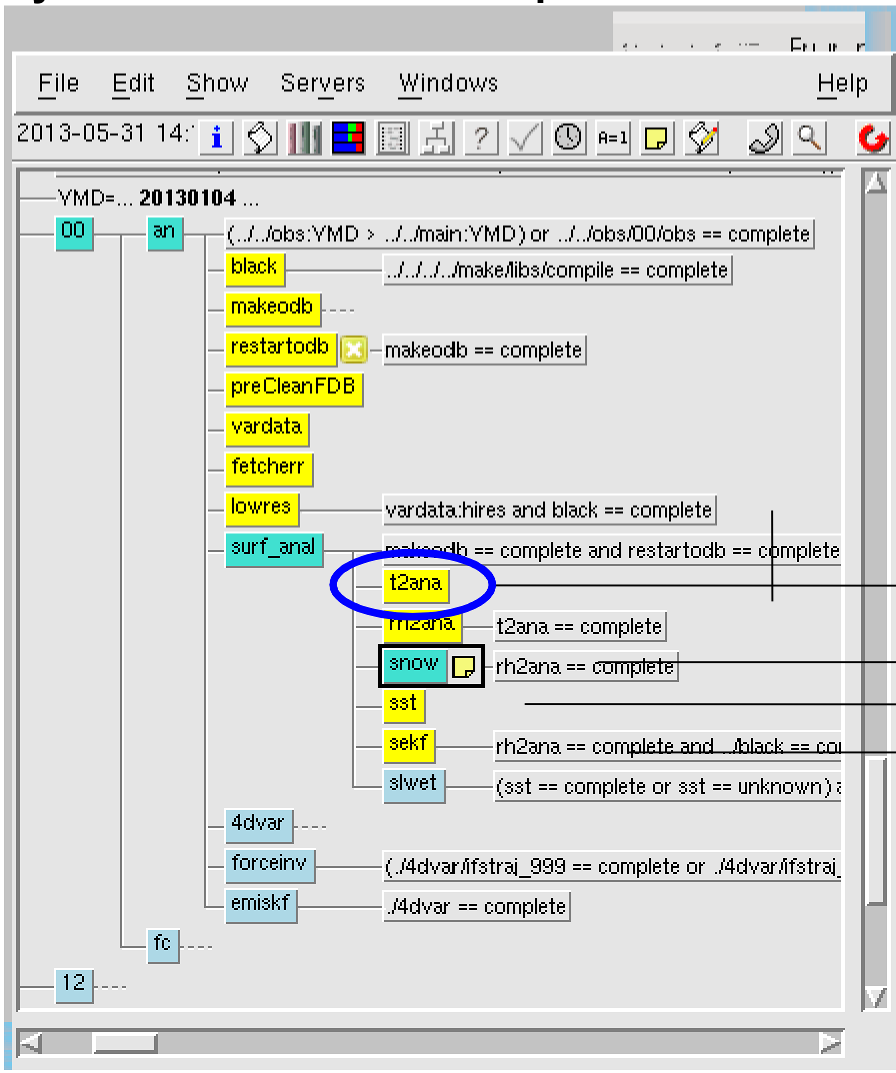
- **Screen level parameters analysis**

Part II (Tuesday)

- Soil moisture analysis
- Summary and future plans

IFS cycle 40r1 is the current operational



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Screen level parameters

Snow

SST and Sea Ice

Soil Moisture and Temperature

ECMWF

Screen Level parameters analysis

- Screen level variables: 2m Air Temperature (T2m) and air Relative humidity (RH2m), both diagnostic variables.
- 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.
- Relevance of screen level analysis for evaluation purposes

OI Screen Level parameters analysis

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

Same approach as snow analysis:

- Observed first guess departure (obs.-fg), [ΔS_i] are computed from the interpolated background at each observation location [i]
- The analysis increments [ΔS_j^a] at each model grid-point [j] are then expressed as :

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

- The optimum weights [w_i] are given for each grid point j by **w** = (**B** + **R**)$^{-1}$ x **b**
- **b** ; the vector of correlation coefficients of the background field error between the observations and the grid point
- **B** ; the correlation coefficient matrix of background field errors between all pairs of observations
- **R** ; the covariance matrix of observational errors

σ_b the standard deviation of background errors (1.5 K / 5 % RH)
σ_o that of observation errors (2 K / 10 % RH)

OI Screen Level parameters analysis

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

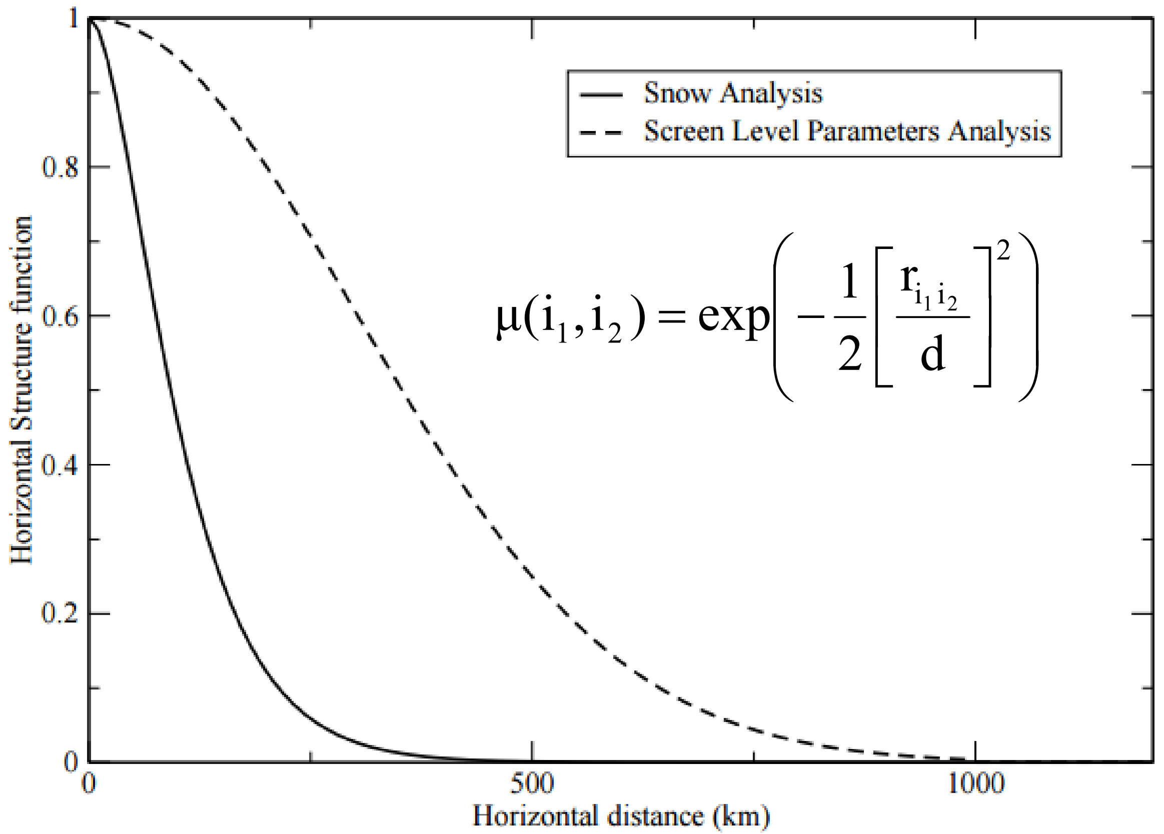


Figure 9.3 *Horizontal structure functions used in the Optimum Interpolation scheme for the screen level parameters and snow depth analyses.*

Screen Level parameters analysis

Quality control:

- Number of observations N = 50, horizontal length parameter 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:

  Observation is rejected if :

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

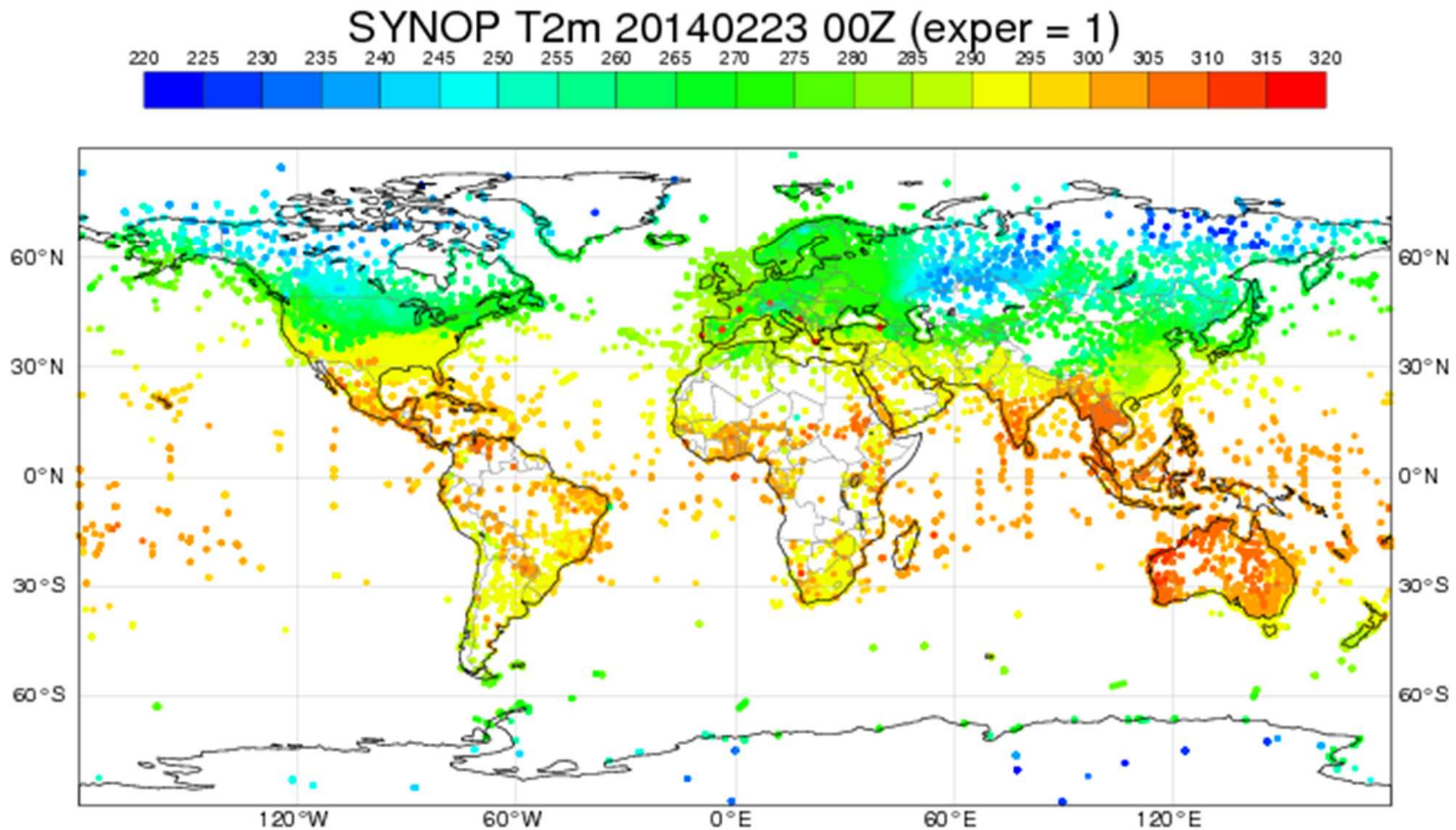
  $$|\Delta X_i| > \gamma\sqrt{\sigma_o^2 + \sigma_b^2}$$

  with γ = 3 (tolerance)

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

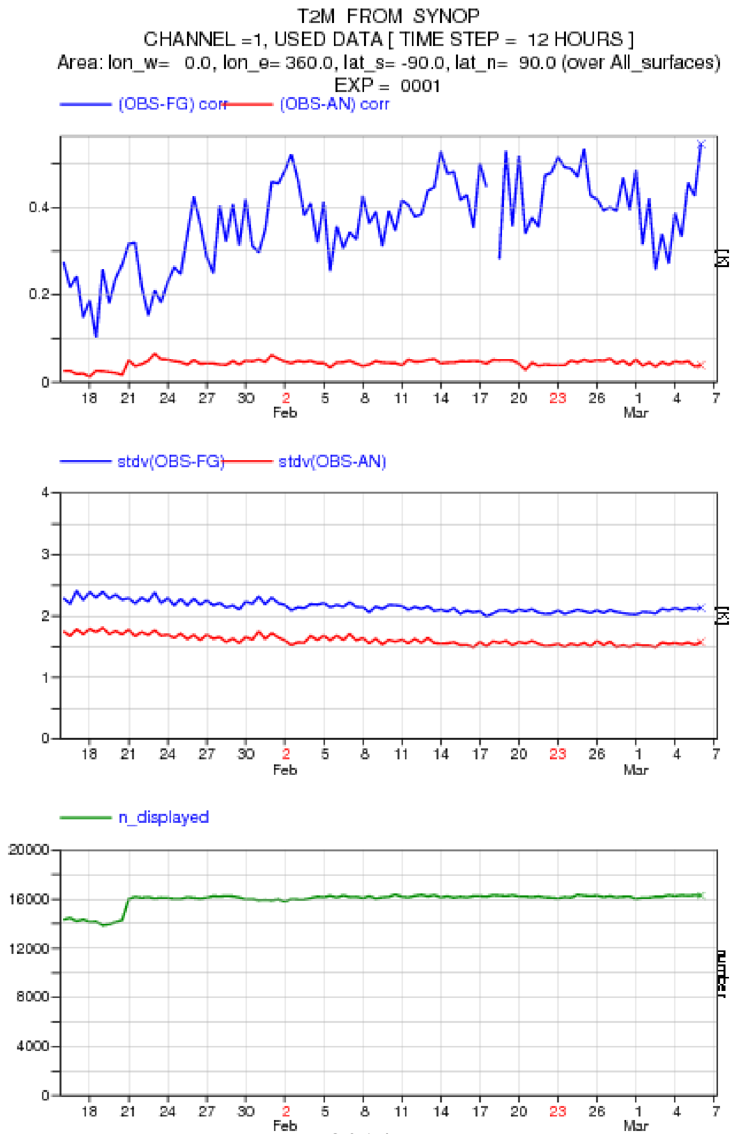
Screen level observations

All T2m observations available (>180000 per day)



ECMWF

Screen level observations monitoring



2014

Global first guess departure

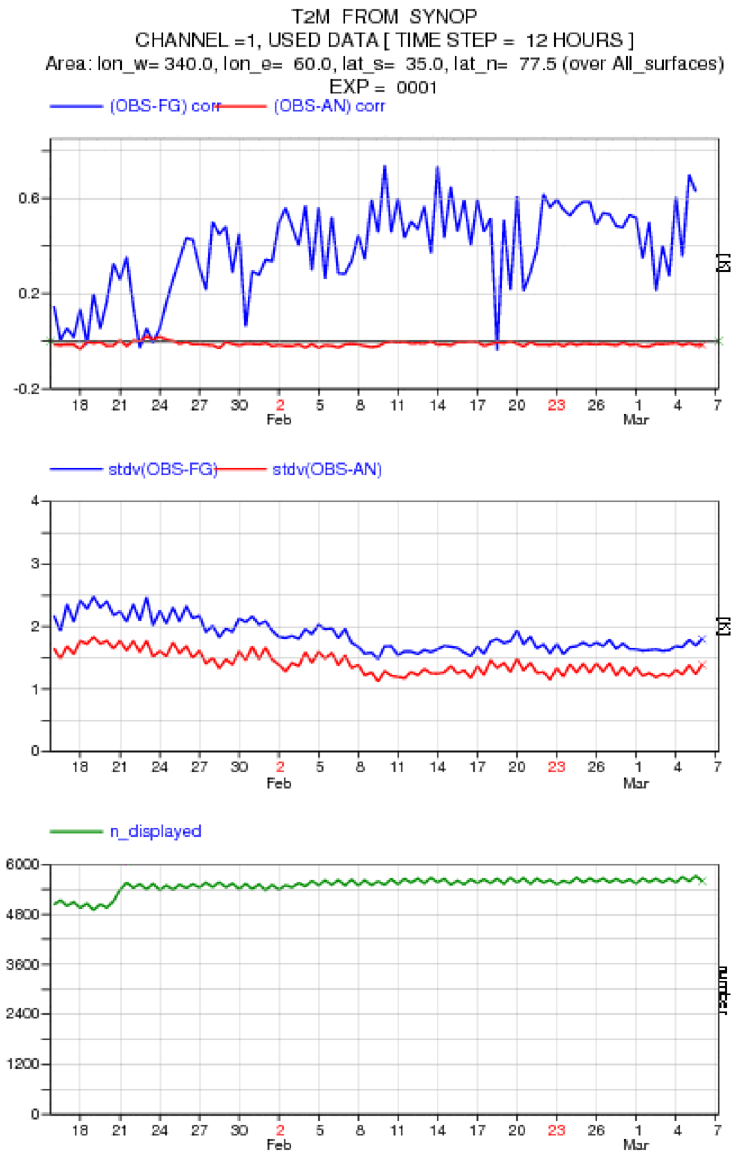
Global analysis departure

Standard deviation of departure statistics

Number of observations used:
>16000 per 12 hours

ECMWF

Screen level observations monitoring



Europe first guess departure

Europe analysis departure

Standard deviation of departure statistics

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

ECMWF

1D OI soil and snow temperature analysis

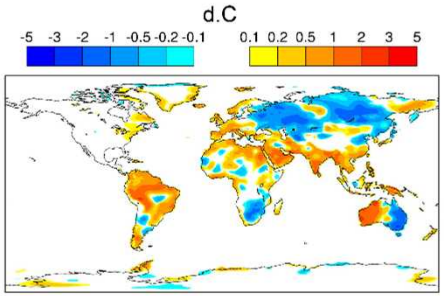
- **Analysis increments from 2-m temperature analysis are used to produce increments for the first layer soil temperature and snow temperature** $\Delta T = c(T_a - T_b) \qquad c = (1 - F_1)F_3$

The analysis increments **c** relies on two empirical functions that account for (F_1,) the cosine of the mean solar zenith angle (μ_M) and (F_3) the model orography (to reduce the increments over mountainous areas where observations are considered less reliable)

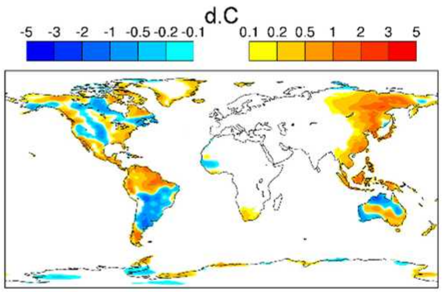
$$F_1 = \frac{1}{2}\{1 + \tanh[\lambda(\mu_M - 0.5)]\}, \qquad \lambda = 7$$

$$F_3 = \begin{cases} 0 \ \ if\ Z > Z_{max} \\ \left(\frac{Z - Z_{max}}{Z_{min} - Z_{max}}\right)^2 \ \ if\ Z_{min} < Z < Z_{max} \\ 1\ if\ Z < \ Z_{min} \end{cases}$$

Where Z is the model orography, Z_{min}=500m and Z_{max}=3000m.



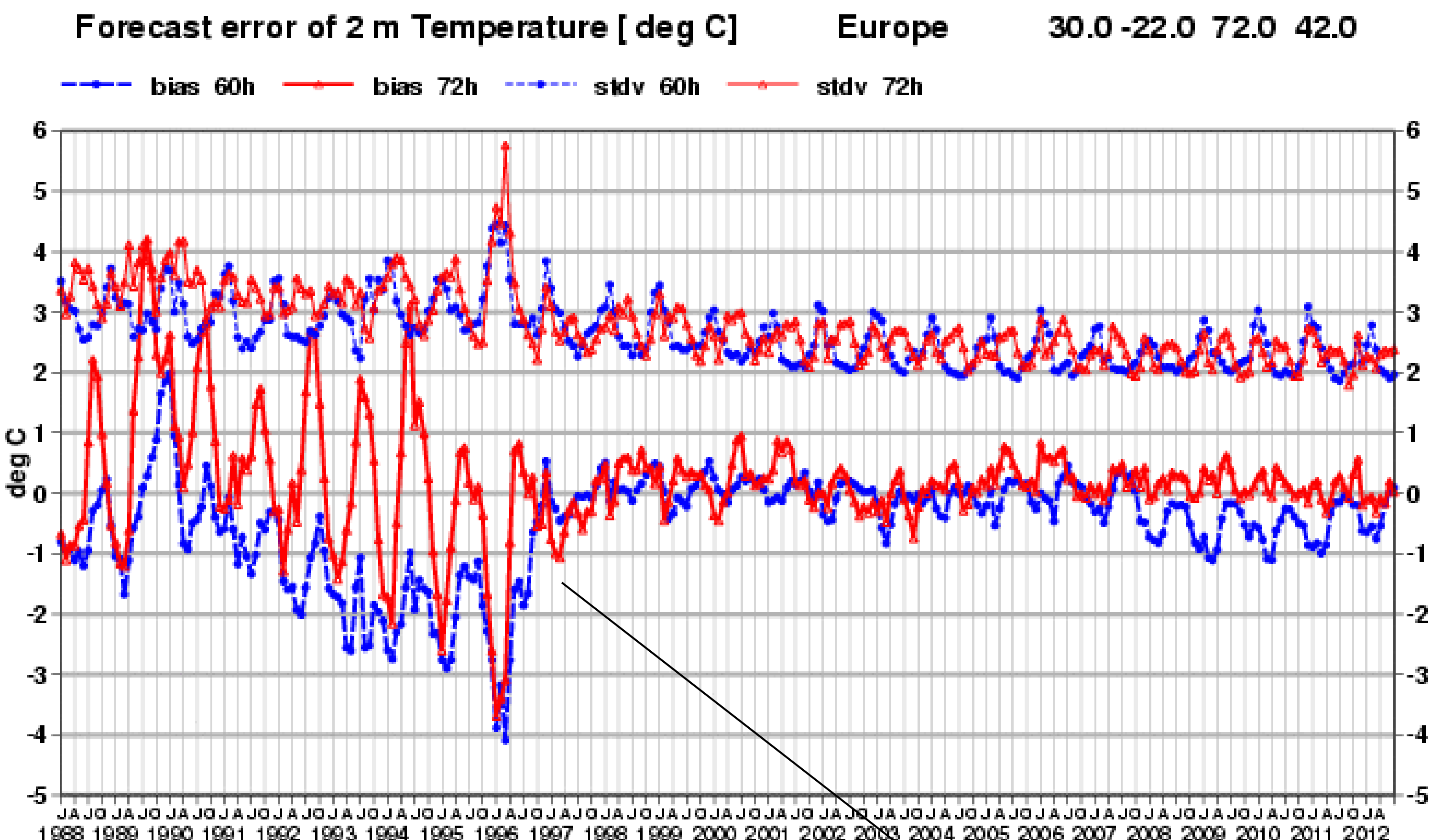
Soil temperature (first layer 0-7cm) analysis increments 01/06/2013 00:00 UTC



Soil temperature (first layer 0-7cm) analysis increments 01/06/2013 12:00 UTC

c is constructed such that the analysis of soil temperatures is more effective during night and in winter when the temperature errors are less likely to be related to soil moisture

Screen level analysis: 2m temperature forecast verification



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

Soil freezing parameterisation
Snow albedo parameterisation

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

ECMWF

Outline

Part I (Monday)

- Introduction
- Snow analysis
- Screen level parameters analysis

Part II (Tuesday)

- Soil moisture analysis
- Summary and future plans

ECMWF

LDAS: “Bring home” messages

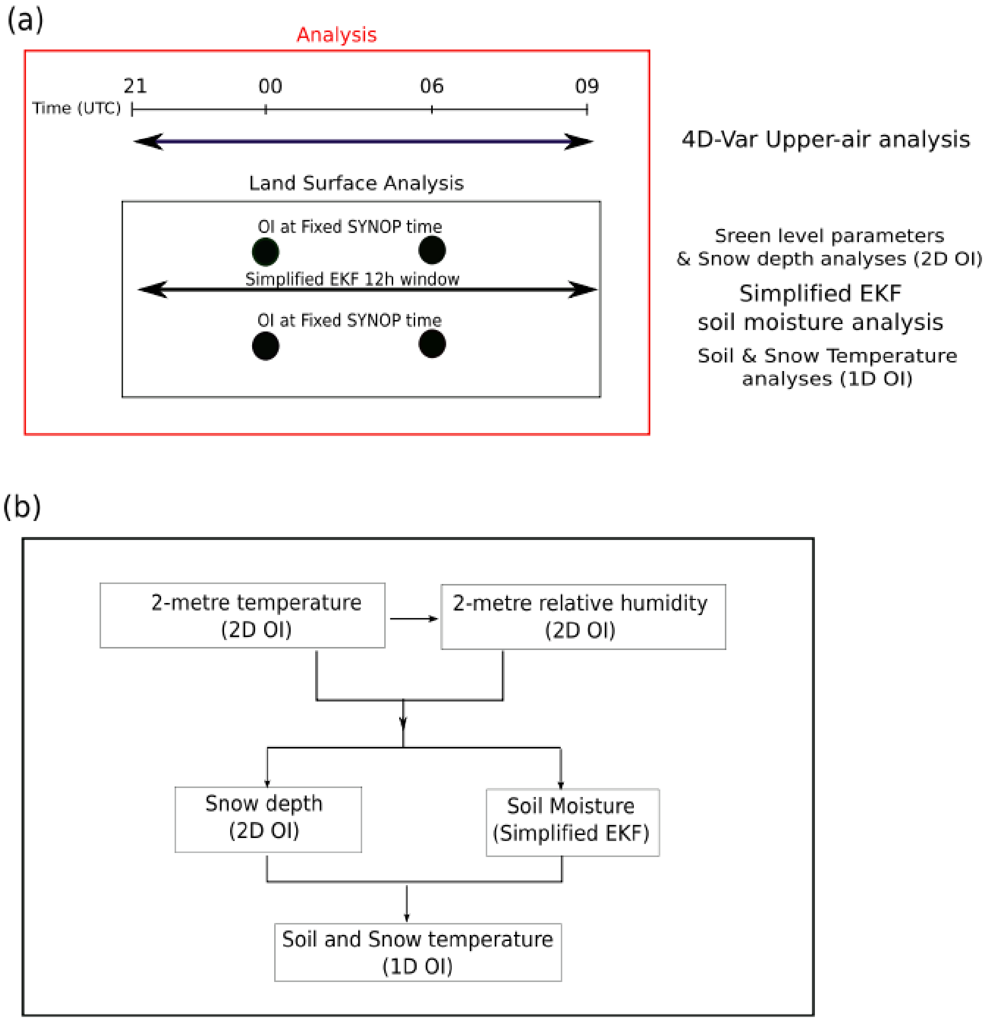
- **Land surface processes**
  - Boundary conditions at the lowest level of the atmosphere
  - Crucial for numerical weather and climate predictions

- **Analysed surface fields**
  - Used as initial conditions for the next forecast
  - ➔ Influence the fc be used as first guess for the next DA window

- **Snow analysis:** *2D-OI for snow depth*
  - Conventional snow depth data: SYNOP and National networks
  - Snow cover extent: NOAA NESDIS/IMS daily product (4km)

- **Screen Level analysis:** *2D-OI for T2m, RH2m*
  - Analysis fields used as input of the SEKF soil moisture analysis
  - T2m increments: inputs of the 1D-OI soil & snow temperature analysis

Introduction: LDAS tasks organisation



LDAS:
- 2D OI:
  - Screen-level for T and humidity
  - Snow depth
- EKF
  - Soil moisture
- 1D OI:
  - Snow & soil temperature

Analysed surface fields: used as initial conditions for the next forecast.

→ Influence the forecast which will be used as first guess for the next data assimilation window, for both 4D-Var and LDAS

→ Feedback surface-atmosphere.

ECMWF

Snow depth Optimal Interpolation

Used at CMC, JMA, 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) $b(i) = \sigma^2_b \cdot \mu(i,j)$

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 horizontal 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)

ECMWF

Snow depth Optimal Interpolation

Used at CMC, JMA, 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 i1 and i2

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 Screen Level parameters analysis

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

Same approach as snow analysis:

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**

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 / 5 % rH the standard deviation of background errors.

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

Horizontal correlation coefficients (structure functions)

O : covariance matrix of the observation error (N × N observations):
O = σ_o^2 × **I** with σ_o = 2.0 K / 10 % rH the standard deviation of obs. errors

Summary on Snow Analysis

- The snow analysis is a 2-D OI performed every 6 hours, at 00 UTC, 06 UTC, 12 UTC and 18 UTC
- The snow-depth background S (m) is estimated from the shortrange forecast of snow water equivalent (m of water equivalent) and snow density (units: kgm^{-3})
- Analysis is performed using snow-depth observations, the snow-depth background field, and the high resolution (4km) NOAA/NESDIS snow extent
- Snow depth observations include conventional snow depth reports from SYNOP stations as well as additional national snow depth observations reported by several member states

Summary on Snow Analysis

- the satellite derived snow extent is used once per day, for the 00 UTC analysis
- It is converted in the Observation Data Base into a quantitative snow depth information

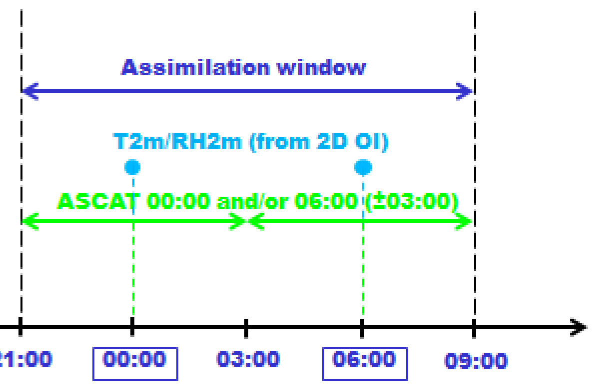
➔ To this end the model relation between snow extent and snow depth is used as observation operator, with 5 cm of snow depth where binary snow cover is one and 0 cm snow depth where binary snow cover is zero

- The latter observations enter the analysis whatever the first guess conditions are
- In contrast the 5 cm snow depth derived from the snow cover observations enter the analysis only where the model first guess indicates snow free conditions

Soil Moisture analysis at 00:00, 06:00, 12:00, 18:00

First guess departure quality check (i.e. no analysis if) :

($T2M_{obs}$-$T2M_{mod}$) > 5K
($RH2M_{obs}$-$RH2M_{mod}$) > 20%
(SM_{obs}-SMM_{mod}) > $0.01 m^3 m^{-3}$



Model first guess for analysis at 00:00 (d) ➔ Fc 18:00 (d-1) step 6
Model first guess for analysis at 06:00 (d) ➔ Fc 18:00 (d-1) step 12
[…]

Schematic depiction of the interaction between the soil hydrology and the atmosphere: illustrates the behaviour of the soil and the atmosphere within a complete cycle (wet period followed by a dry period) [Dooge 1992]

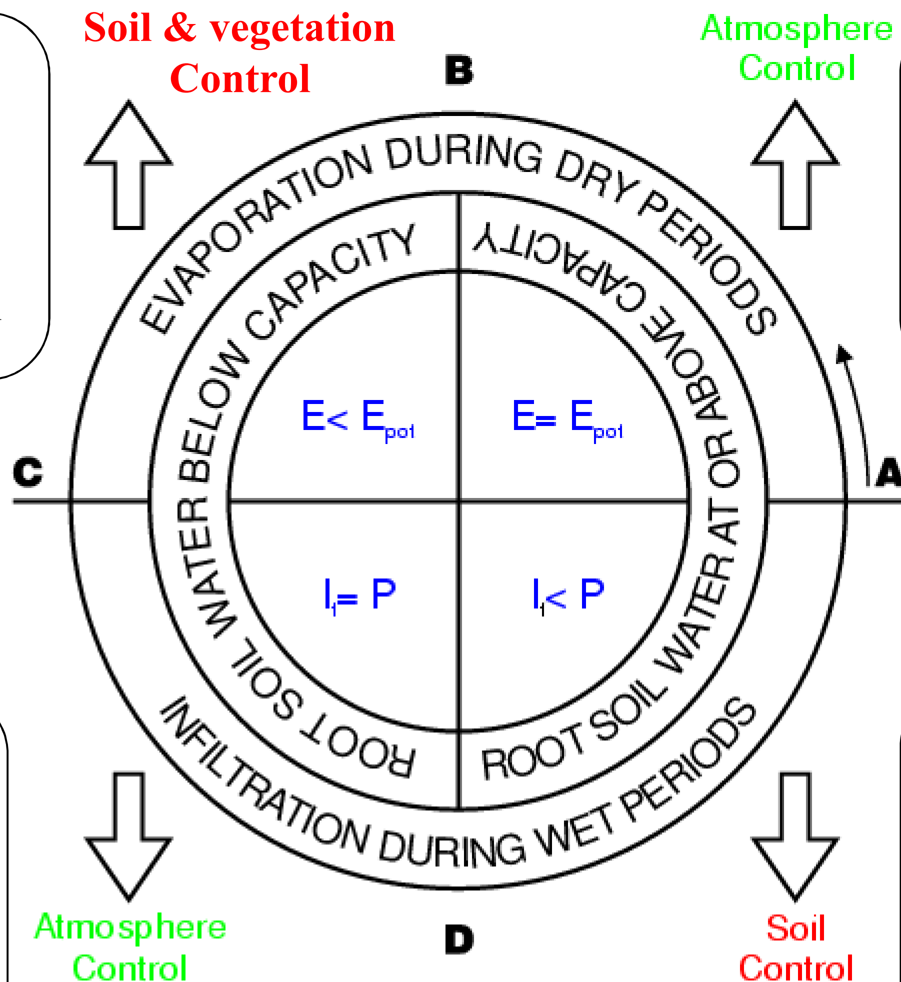
B-C : SM has decreased below a certain level

- E limited by plant-physiological mechanism
- E drops below its maximal value ($E<E_{po}$)

A-B : after a long episode of rainfall

- Soil saturated with water
- SM is determined by E
- Atmosphere controls E rate (at $E=E_{pot}$)

Rain starts



Rain ends

C-D : Precipitation starts again

- Dry soil is taking up water
- Infiltration equals precipitation ($I_f=P$)

D-A : Maximum soil water level is reached

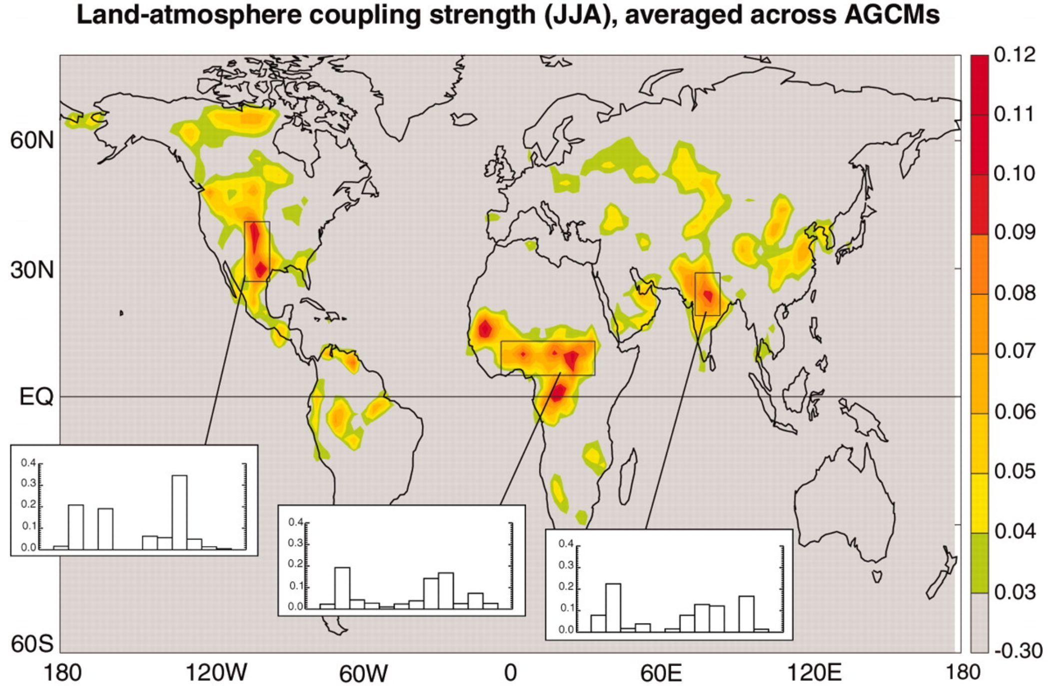
- Soil's ability to take up precipitation ↓
- Part of the precipitation goes into runoff ($I_f<P$)

Impact of soil moisture on precipitation : Koster et al., Science, 2004

The GLACE Team: *Regions of Strong Coupling Between Soil Moisture and Precipitation*. **Science** 20 August 2004: Vol. 305 no. 5687 pp. 1138-1140 DOI: 10.1126/science.1100217

Multimodel estimation of land atmosphere coupling strength :

A global initialization of soil moisture may enhance precipitation prediction skill during Northern Hemisphere summer (*in the transition zones between wet and dry climates*)



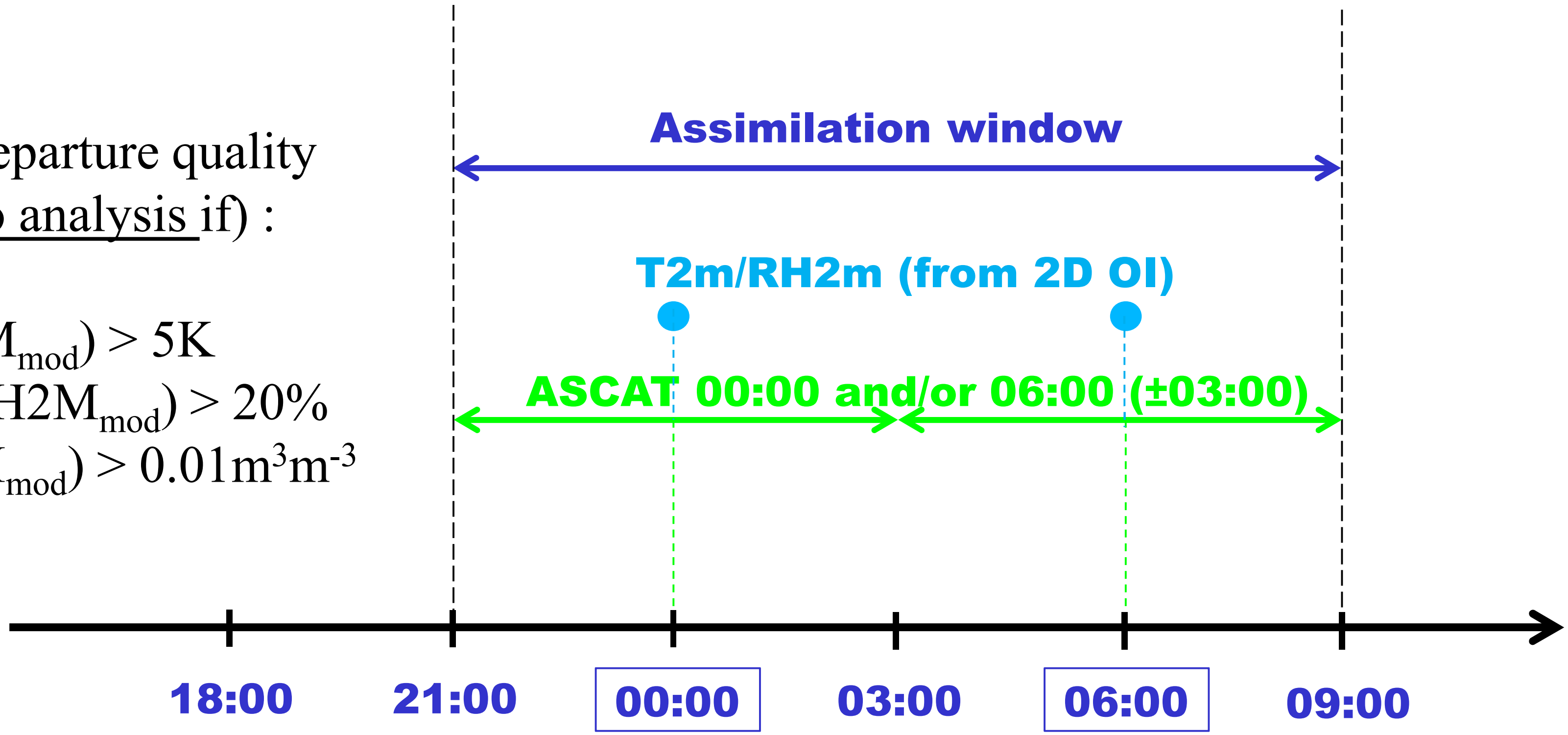
Multimodel estimation of the regions on Earth where precipitation is affected by soil moisture anomalies during Northern Hemisphere summer [*Koster et al., Science, 2004*]

ECMWF

Soil Moisture analysis at 00:00, 06:00, 12:00, 18:00

First guess departure quality check (i.e. no analysis if) :

$(T2M_{obs}-T2M_{mod}) > 5K$
$(RH2M_{obs}-RH2M_{mod}) > 20\%$
$(SM_{obs}-SMM_{mod}) > 0.01 m^3 m^{-3}$



Model first guess for analysis at 00:00 (d) ➔ Fc 18:00 (d-1) step 6
Model first guess for analysis at 06:00 (d) ➔ Fc 18:00 (d-1) step 12
[…]