Land Surface Data Assimilation

Patricia de Rosnay

Thanks to: C. Albergel, E. Andersson, G. Balsamo, S. Boussetta, J.-C. Calvet, M. Dahoui, M. Drusch, R. Essery, A. Fouilloux, L. Isaksen, J.-F. Mahfouf, J. Muñoz Sabater, K. Scipal, W. Wagner

ECMWF

Introduction

- Land surfaces:
  - Boundary condition at the lowest level of the atmosphere
- Land surface processes:
  - Essential component of the hydrological cycle
  - Interact with the atmosphere on time sales of hours/weeks/seasons
  - Strong spatial heterogeneities (land cover, soil texture, orography)

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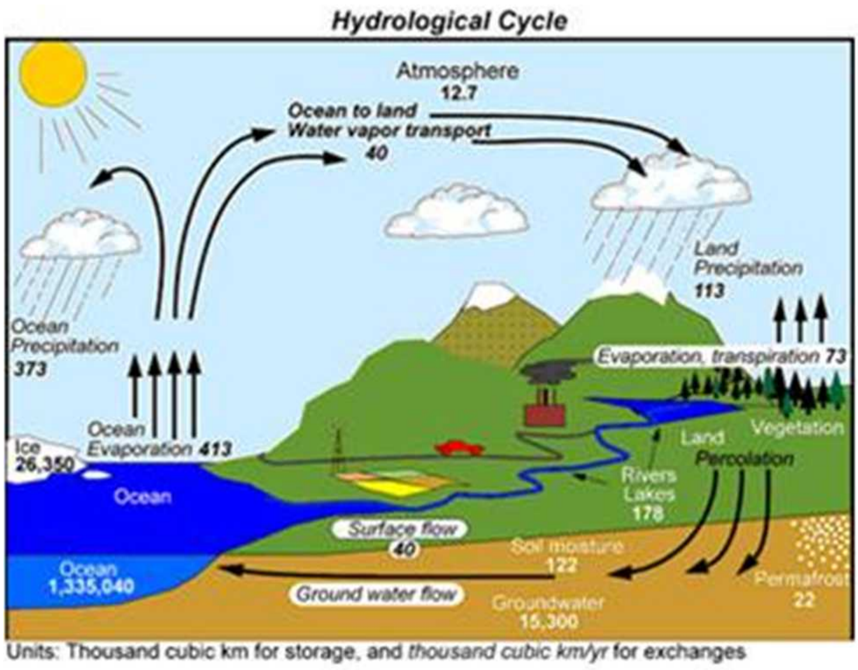


Trenberth et al. (2007)

Introduction: Land Surface Modelling

• **In atmospheric models, Land Surface Models (LSMs) represent the lowest boundary conditions and the surface branch of the continental hydrological cycle**

• **Land Surface Models much improved in the past decade:**

- Multi-layer vertical soil hydrology, accounting for texture, runoff, variable infiltration
- Snow parameterization (density, albedo)
- Vegetation parameters (Leaf Area Index)
- Heterogeneities, sub-grid scale parameterizations
- Lake temperature
- Carbon cycle and link with surface fluxes
- Urban areas, …

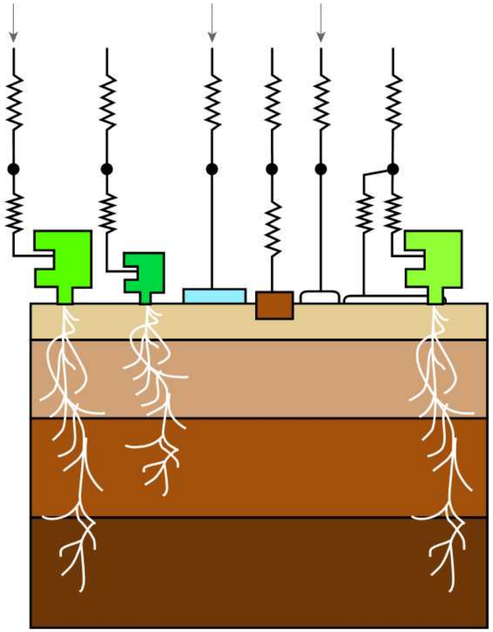
Introduction: Land Surface Modelling

- **Land Surface Models prognostic variables include :**
  - Soil Moisture
  - Soil Temperature

  } Multi-layer in all LSMs

  - Snow mass, temperature, density, albedo

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



ECMWF LSM: H-TESSEL
4 soil layers / 12 prognostic variables
Balsamo et al., JHM 2009

Introduction: Land Surface analysis

Land surface initialization: snow depth, soil moisture, snow and soil temperature

- **Snow depth analysis**
  - Approaches: Cressman (DWD), 2D Optimum Interpolation (ECMWF, CMC, JMA)
  - Observations: SYNOP snow depth and NOAA/NESDIS Snow Cover (ECMWF)
- **Soil Moisture analysis**
  - Approaches:
    - 1D Optimum Interpolation (Météo-France, CMC, ALADIN and HIRLAM)
    - Analytical nudging approach (UKMO, BoM)
    - Simplified Extended Kalman Filter (DWD, ECMWF)
    - Offline LSM using analysed atmospheric forcing (NCEP: GLDAS / NLDAS)
  - 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)

Soil Temperature and Snow temperature also analysed

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

Outline

- Introduction
- **Snow analysis**
- Screen level parameters analysis
- Soil moisture analysis
- Summary and future plans

Snow Analysis

Snow Quantities:

- Snow depth S (m)
- Snow water equivalent SWE (m) – ie mass per m^2
- Snow Density ρ_s, between 100 and 400 kg/m3

Prognostic variables

$$SWE = \frac{SD \times \rho_S}{1000} \quad [m]$$

Background variable used in the snow analysis:

- Snow depth S^b

computed from forecast SWE and density

Observation types:

- Conventional data: SYNOP snow depth (S^O)
- Satellite: Snow cover extent (e.g. NOAA/NESDIS)

operationally available for NWP

ECMWF

NOAA/NESDIS IMS Snow extent data

Interactive Multisensor Snow and Ice Mapping System

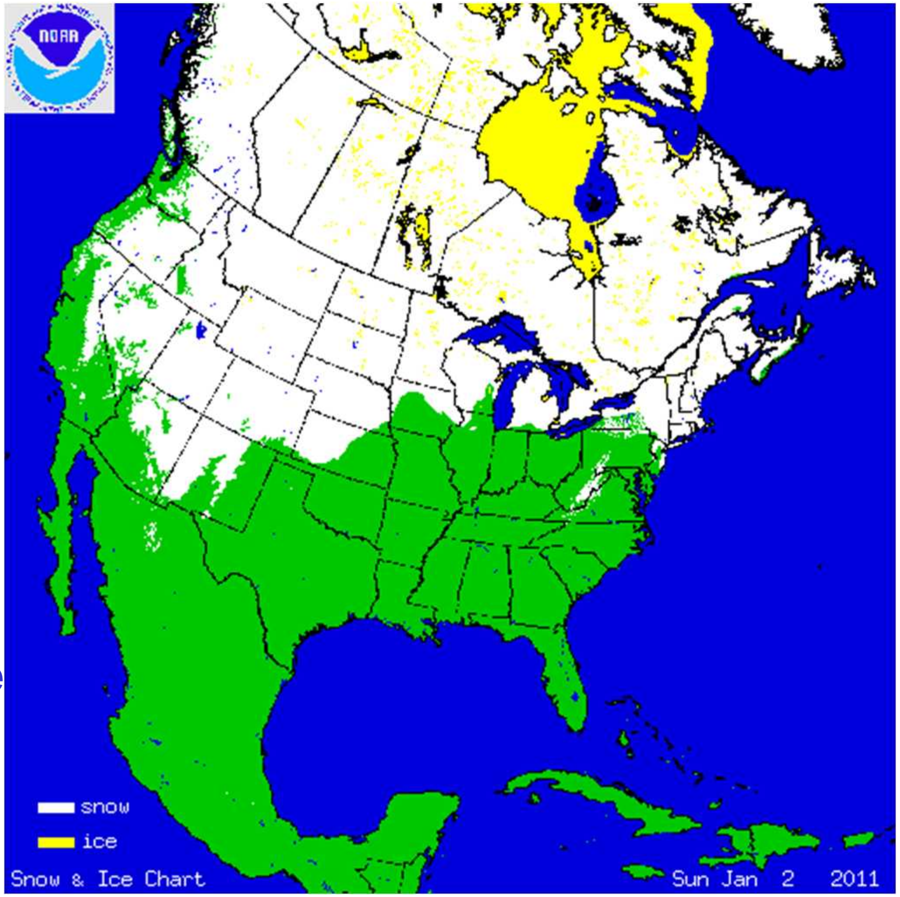
- Time sequenced imagery from geostationary satellites
- AVHRR,
- SSM/I
- Station data

Northern Hemisphere product

- Daily
- Polar stereographic projection

Resolution

- 24 km product (1024 × 1024)
- 4 km product (6044 x 6044)



Information content: Snow/Snow free

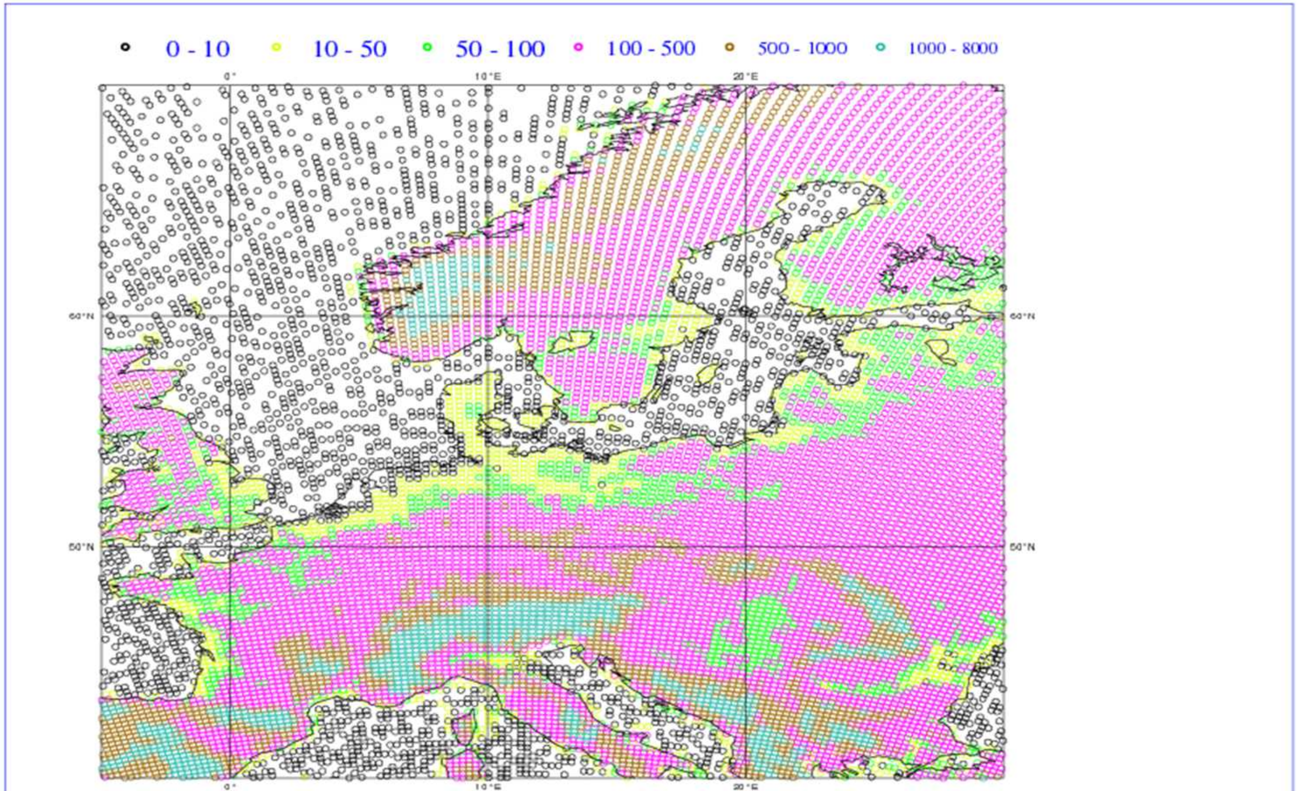
Format:

- 24km product in Grib
- 4 km product in Ascii

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

NOAA/NESDIS Pre-Processing

- NOAA/NESDIS data available daily at 23UTC.
- Pre-processing at ECMWF:
- Conversion to BUFR
- BUFR content: land-sea mask, NESDIS snow extent (snow or snow free),
  and orography, interpolated from the model orograpghy
  on the NESDIS data points.



Orography (m) included in the BUFR

→ used in the snow analysis

ECMWF

Snow Analysis at ECMWF

SYNOP Pre-Processing:

- SYNOP reports converted into BUFR files.
- BUFR data is put into the ODB (Observation Data Base)

Snow depth analysis in two steps: (Drusch et al., J. appl. meteo. 2004)

1- NESDIS data (12UTC only):

- First Guess snow depth compared to NESDIS snow cover

  NOAA snow & First Guess snow free → put 0.1m snow in First Guess

  (First Guess snow free: < 0.01m of snow, ie SWE in [1; 4] mm;
  Update: SD 0.1m, snow density=100kg/m3, SWE=0.01m)

- NESDIS snow free → used as a SYNOP snow free data

2- Snow depth analysis (00, 06, 12, 18 UTC):

- Cressman interpolation: 1987-2010
  Still used in ERA-Interim
- Optimum Interpolation: Used in Operations since November 2010

Cressman Interpolation

$$S^a = S^b + \frac{\sum_{n=1}^{N} w_n \left(S_n^O - S^{b'}\right)}{\sum_{n=1}^{N} w_n}$$

-(Cressman, Mon. Weath. Rev. 1959)

- Used at DWD, ECMWF deterministic (1987-2010) and used in ERA-Interim

- S^O snow depth from SYNOP reports,
- S^b background field estimated from the short-range forecast of snow water equivalent,
- $S^{b'}$ background field at observation location, and
- w_n weight function, which is a function of horizontal r and vertical difference h (model – obs): w = H(r) v(h) with:

$$H(r) = \max\left(\frac{r_{max}^2 - r^2}{r_{max}^2 + r^2}, 0\right)$$

r_{max} = 250 km (influence radius)

$$v(h) = \begin{cases} 1 & \text{if } 0 < h \\ \dfrac{h_{max}^2 - h^2}{h_{max}^2 + h^2} & \text{if } -h_{max} < h < 0 \\ 0 & \text{if } h < -h_{max} \end{cases}$$

Model above observing station

h_{max} = 300 m (model no more than 300m below obs)

Obs point more than 300m higher than model

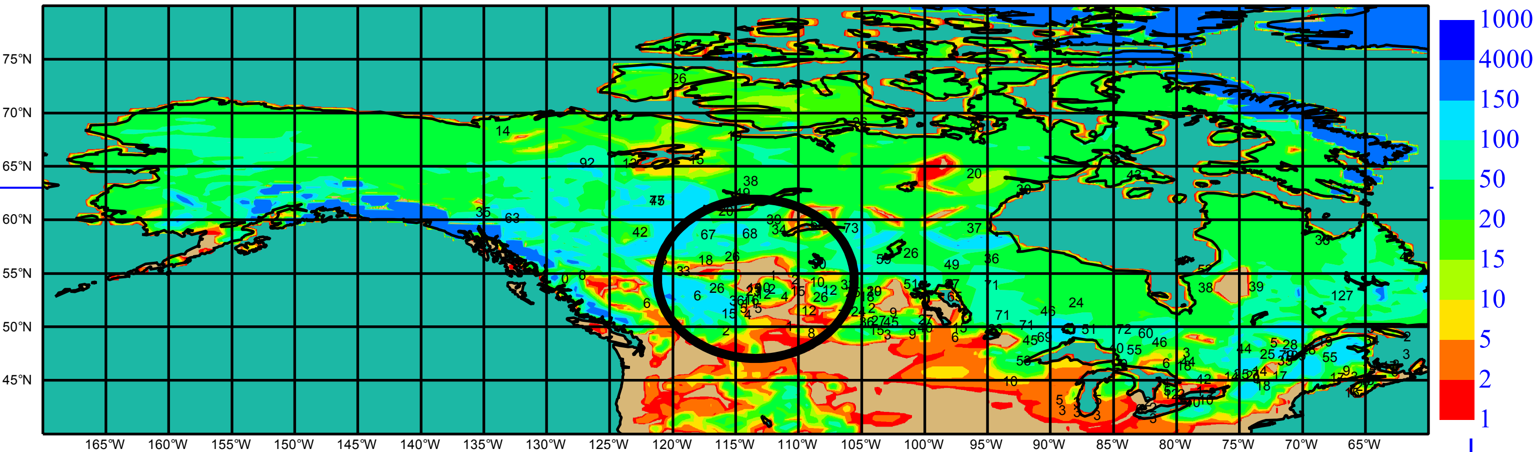
Some issues in the Cressman snow analysis

Winter 2009-2010 highlighted several shortcomings of the snow analysis related to the Cressman analysis scheme and a lack of satellite data in coastal areas, as well as issues in the NESDIS product pre-processing at ECMWF (fixed in flight in operations in February 2010).

Some issues in the Cressman Snow analysis

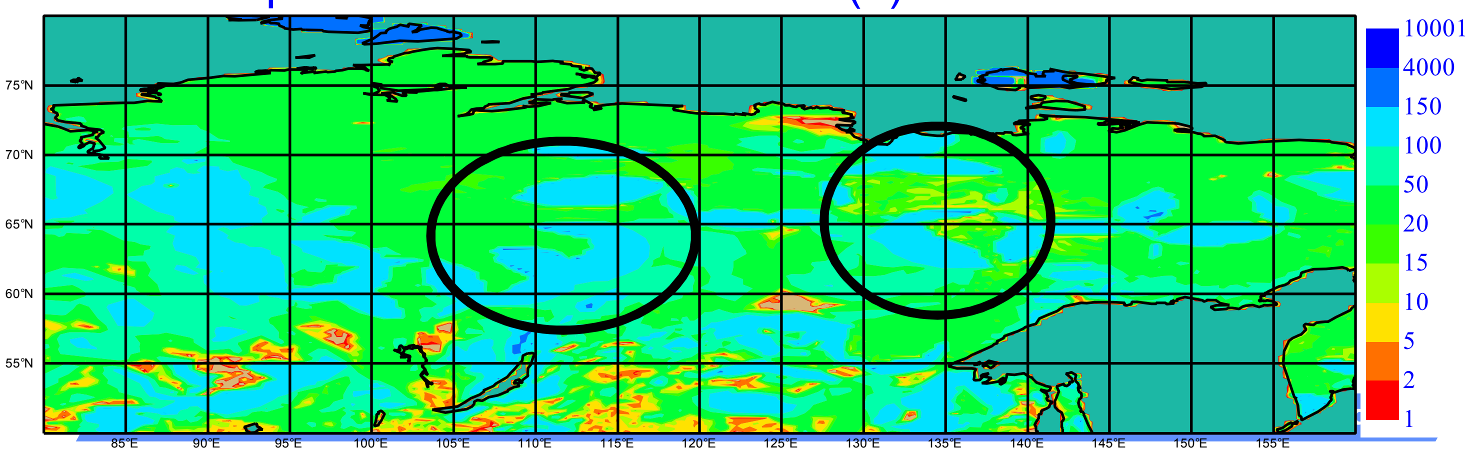
"Bull's eyes" (or "PacMan") Snow Patterns where observations are scarce
Due to the Cressman interpolation (as indicated in Kalnay, 2003)

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



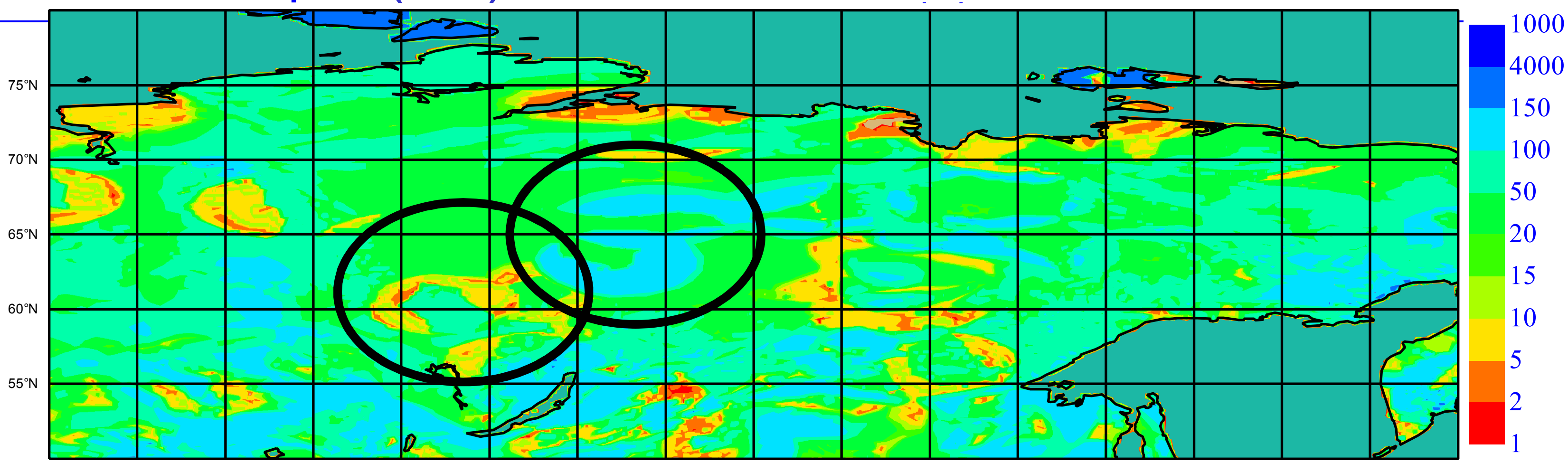
Siberia 2007

ECMWF

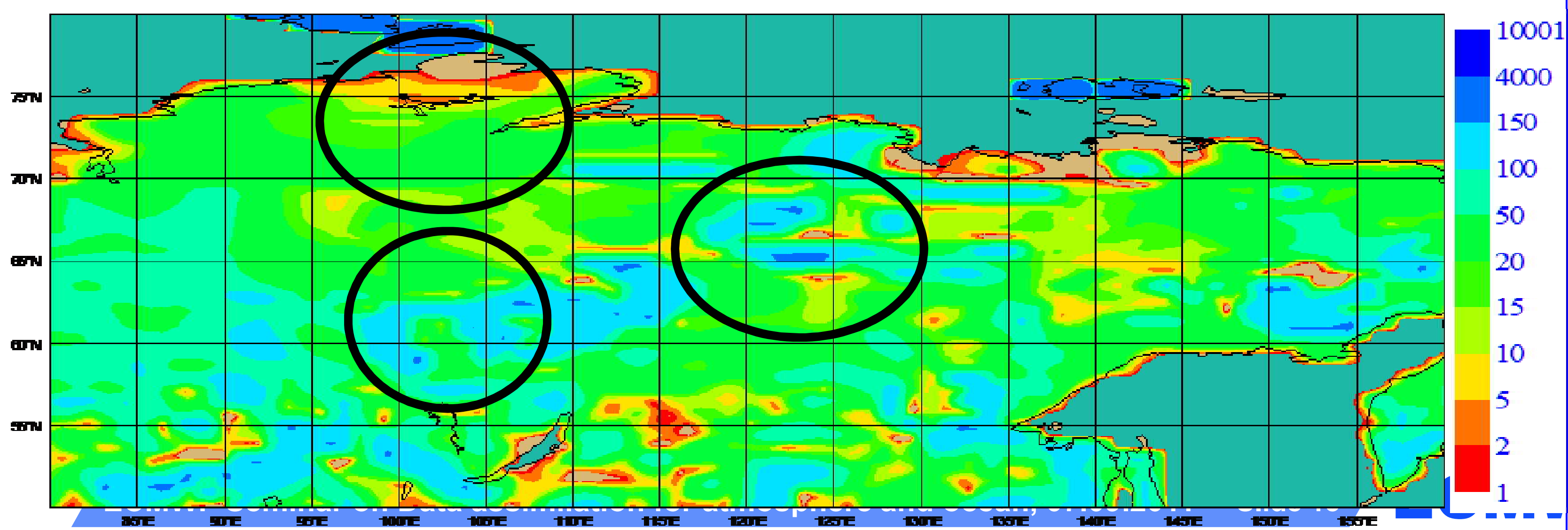
Snow Patterns: bull’s eyes (“PacMan”) issues due to Cresmman Interpol. Example on 23 Feb 2010

Deterministic Analysis, T1279 (16km)

SNOW Depth (cm) Integrated Forecasting System IFS cycle 36r1



ERA-Interim re-analysis, T255 (80km), IFS cycle 31r1



Revised snow analysis

Winter 2009-2010 highlighted several shortcomings of the snow analysis related to the Cressman analysis scheme and a lack of satellite data in coastal areas, as well as issues in the NESDIS product pre-processing at ECMWF (fixed in flight in operations in February 2010).

<u>Revised snow analysis from Nov. 2010:</u>

- **OI:** New Optimum Interpolation Snow analysis, using weighting functions of Brasnett, J. Appl. Meteo. (1999). The OI makes a better use of the model background than Cressman.
- **NESDIS:** NOAA/NESDIS 4km ASCII snow cover product (substituting the 24 km GRIB product) implemented with fixes in geometry calculation. The new NESDIS product is of better quality with better coverage in coastal areas.
- **QC:** Introduction of blacklist file and rejection statistics. Monitoring capabilities.

Snow depth Optimum Interpolation

Used at CMC, JMA, ECMWF

Based on Brasnett, j appl. Meteo. 1999

1. Observed Increments from the interpolated background ΔS_i are estimated 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) = σ^2_b . X μ(i,,j)

B : **error covariance matrix of the background field** (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.

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

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

O = σ^2_o × **I** with σ_o = 4cm the standard deviation of obs. Errors

Lz; vertical length scale: 800m, **Lx:** horizontal length scale: 55km

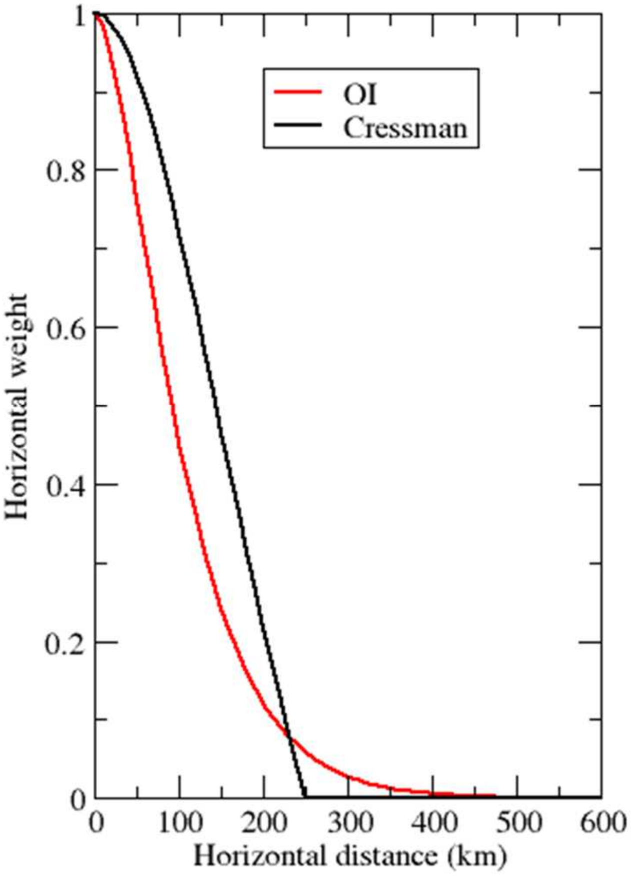
Quality Control: if $\Delta S_i > \text{Tol}\,(\sigma_b^2 + \sigma_o^2)^{1/2}$; Tol = 5

ECMWF

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.

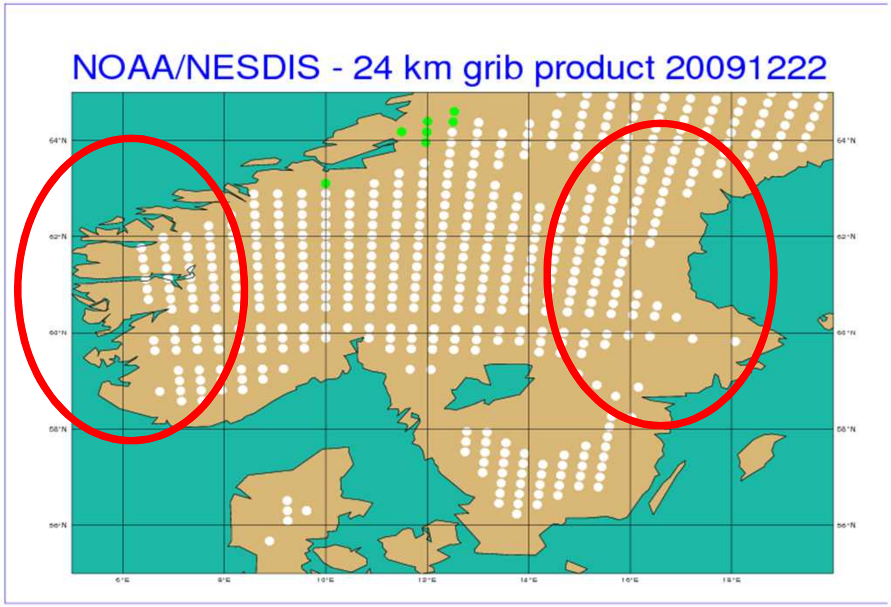


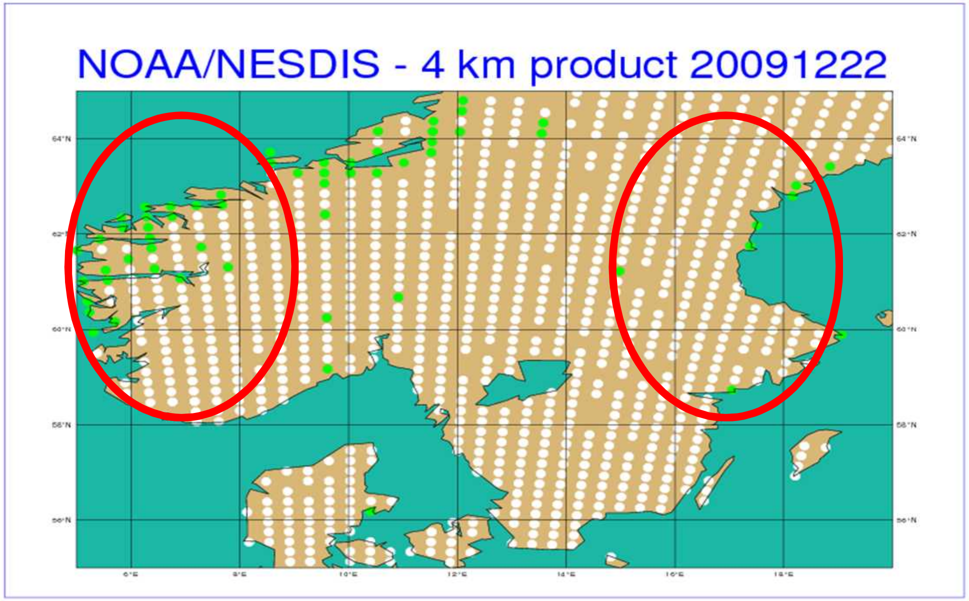
OI: The correlation coefficients of B and b follow a second-order autoregressive horizontal structure and a Gaussian for the vertical elevation differences.

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

NESDIS 24km vs 4km product

- Data thinning to 24 km -> same data quantity, improved quality
- 4km data more local than 24km -> better consistency with the way it is used (in Cressman and OI)
- Better coverage of pre-processed data in coastal area

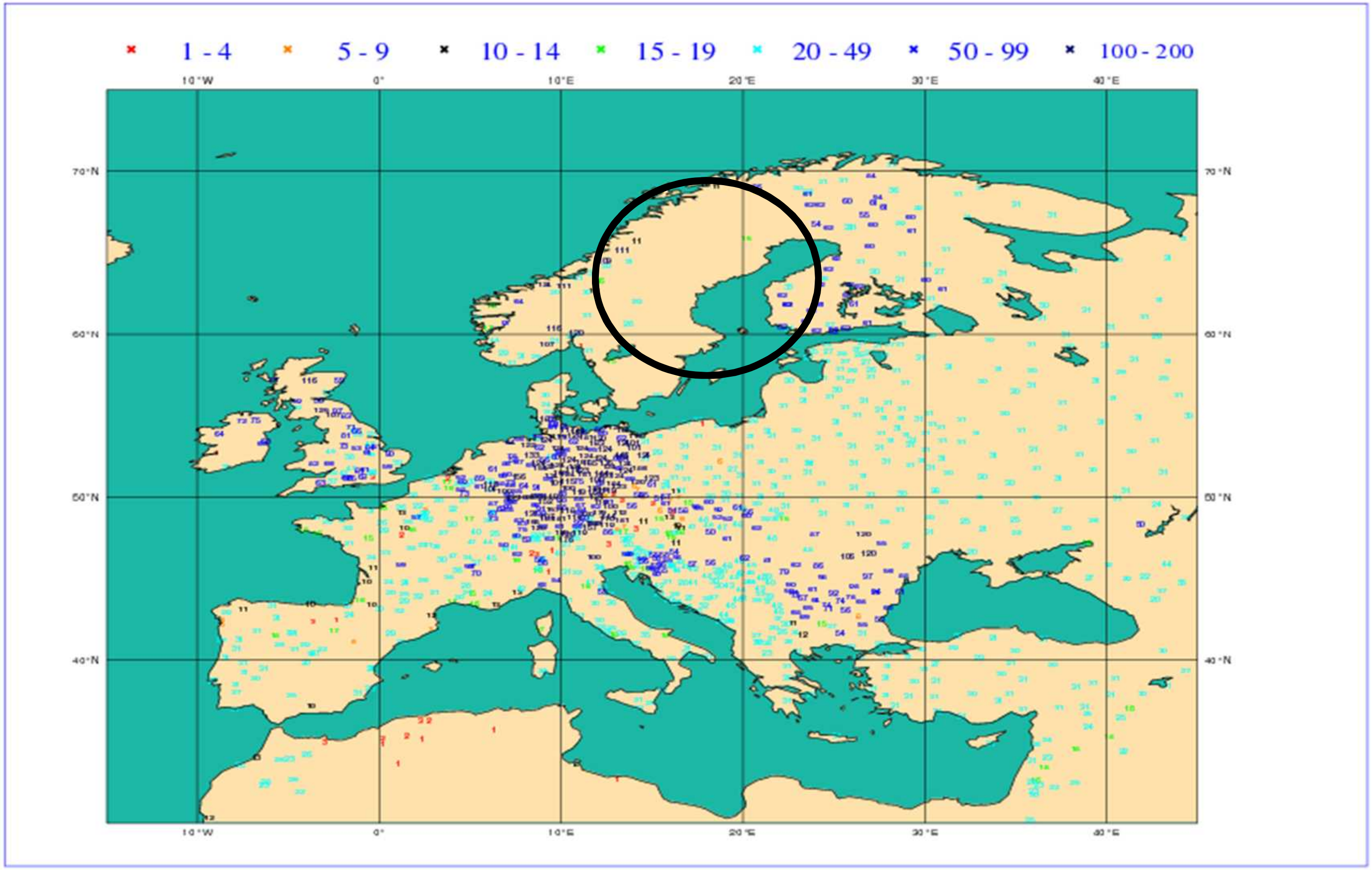




Snow analysis

QC and monitoring possibilities

Number of SYNOP reports used in January 2010

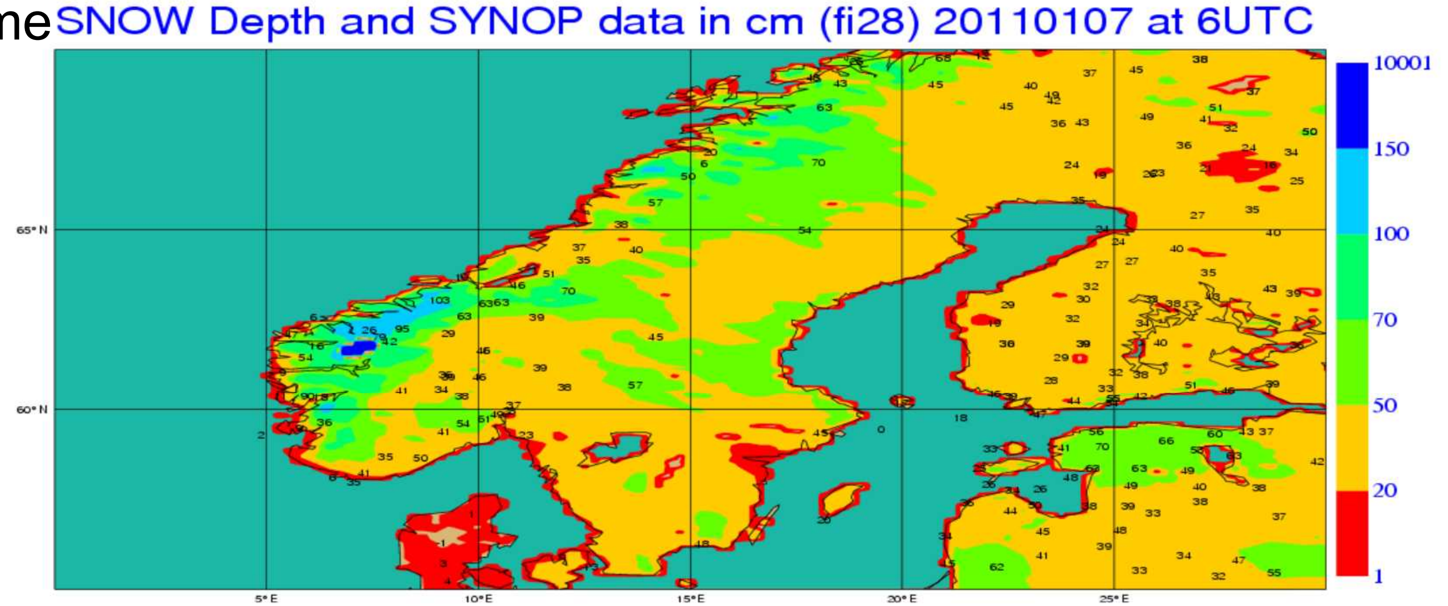


→ **Lack of SYNOP Snow depth data in Sweden**

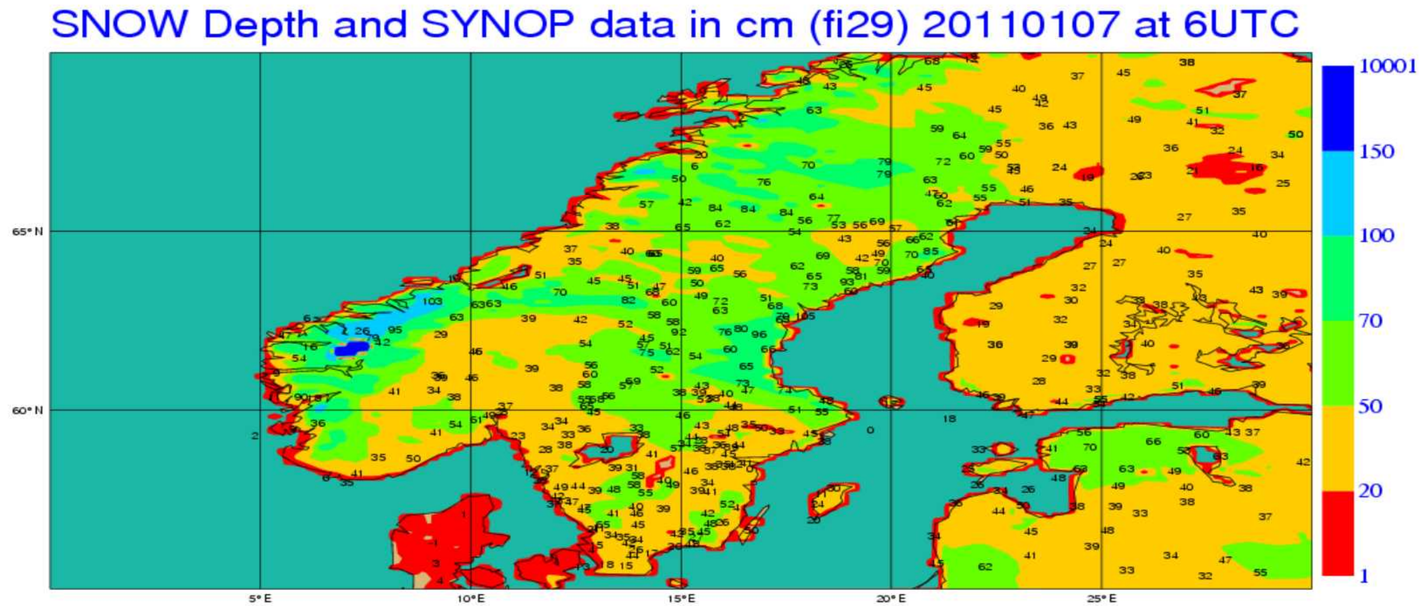
Use of Additional Snow depth data

→Since December 2010, Sweden has been providing additional snow depth Data, Near Real Time (06 UTC)
through the GTS

Snow depth analysis using SYNOP data



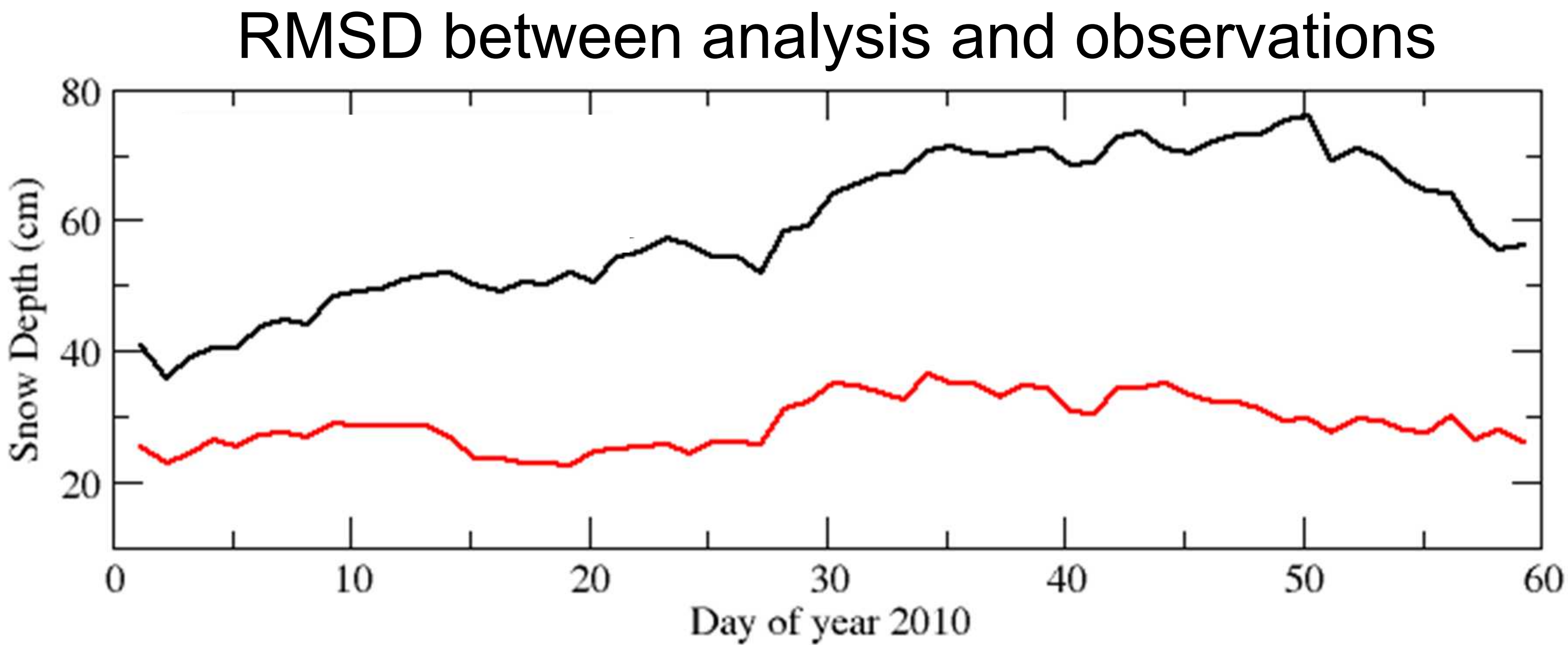
Snow depth analysis using SYNOP data + additional snow data



Implemented as a new report type, in flight from 29 March 2011

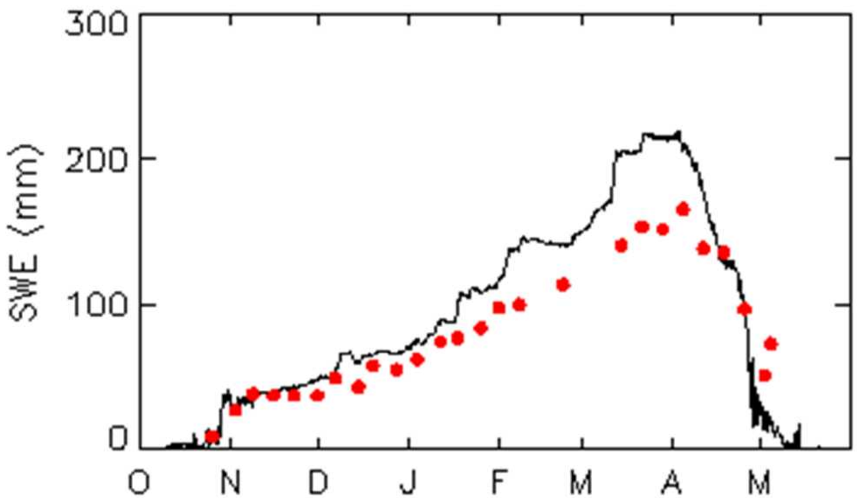
Comparison against SYNOP data

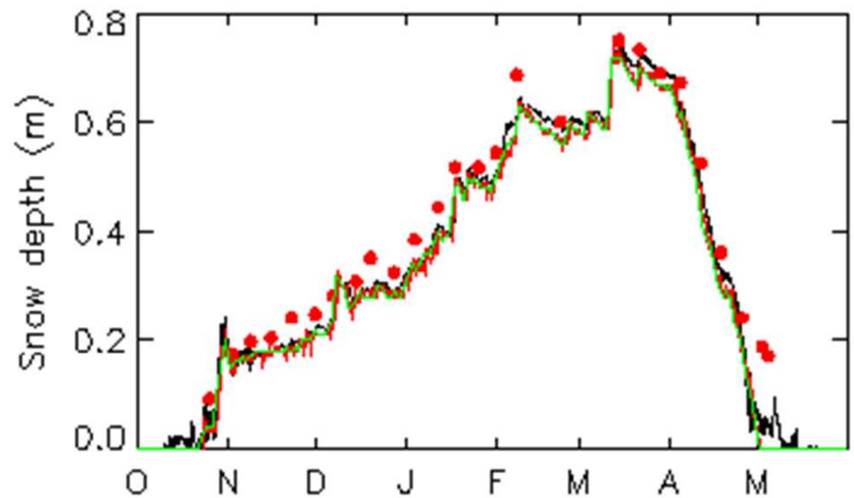
Old analysis (Cressman and NESDIS 24km)
New analysis (OI and NESDIS 4km)

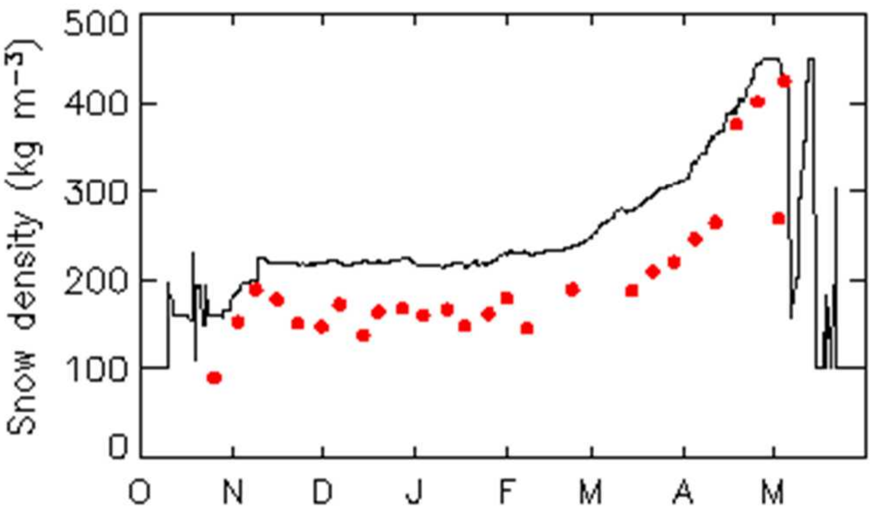


Independent validation

Sodankylä, Finland (67.368N, 26.633E) **Winter 2010-2011**





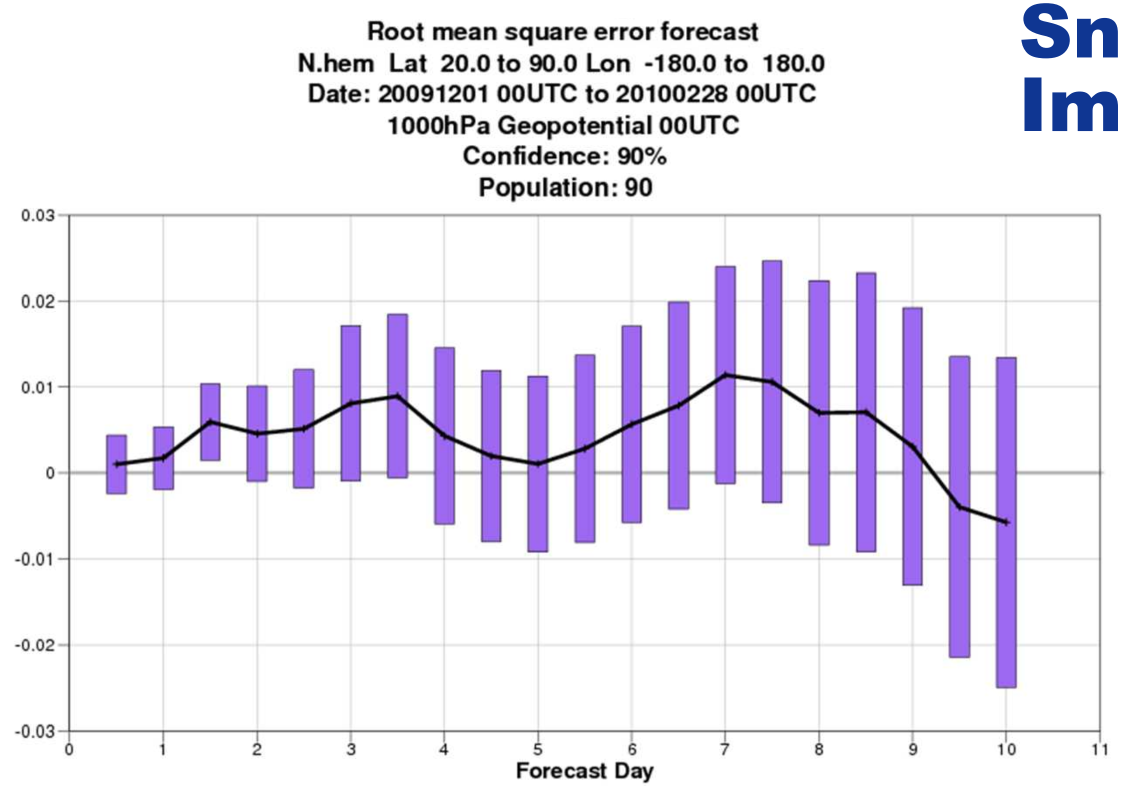


- ECMWF deterministic analysis
- SYNOP snow depths
- FMI-ARC snow pit and ultrasonic depth gauge

Figures produced by
R. Essery, Univ Edinburgh

ECMWF

Snow analysis Impact (North Hem.)

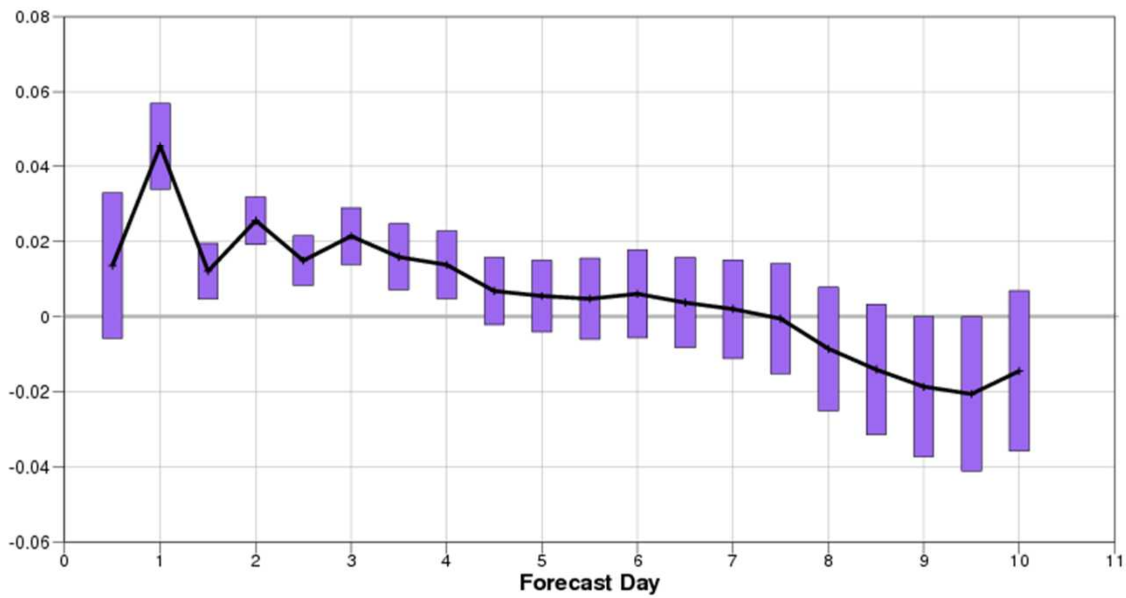


RMSE FC (Cressman –OI)

1000hPa Geopotental

Positive → improved by OI

Impact of OI vs Cressman (both use NESDIS 24km)



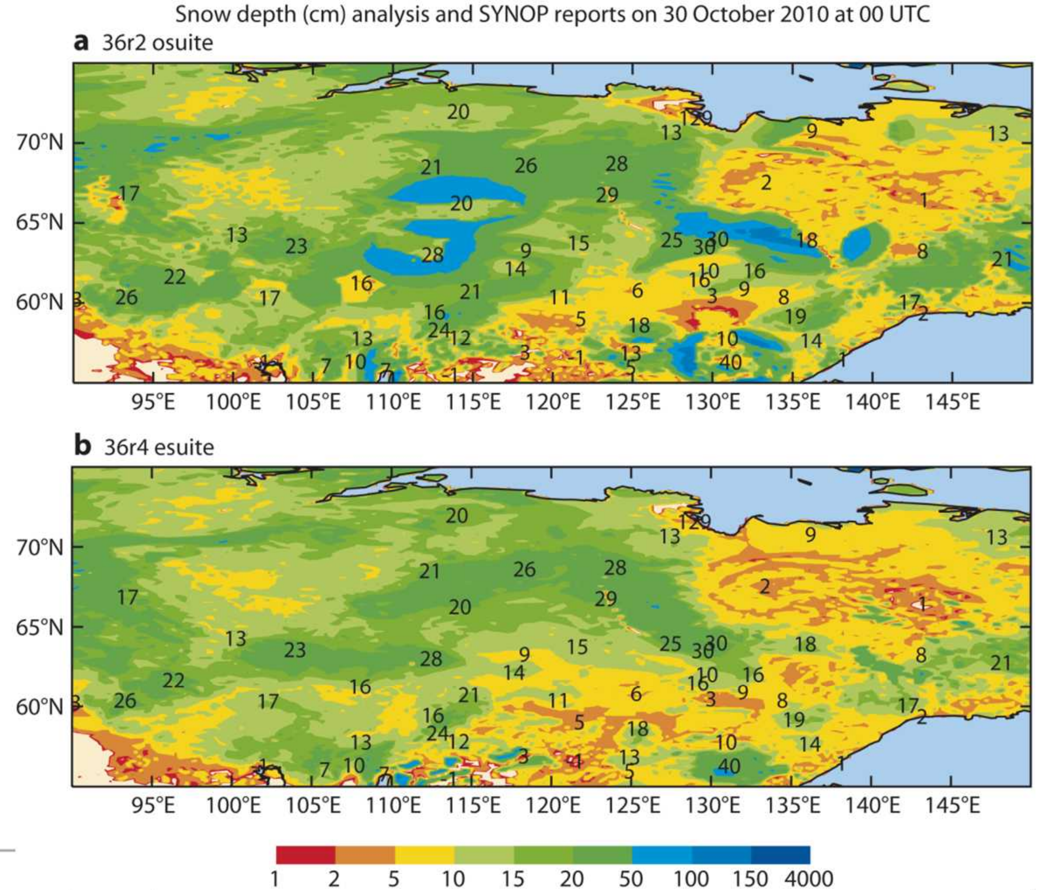
Overall Impact of OI NESDIS 4km vs Cressman NESDIS 24 km

ECMWF

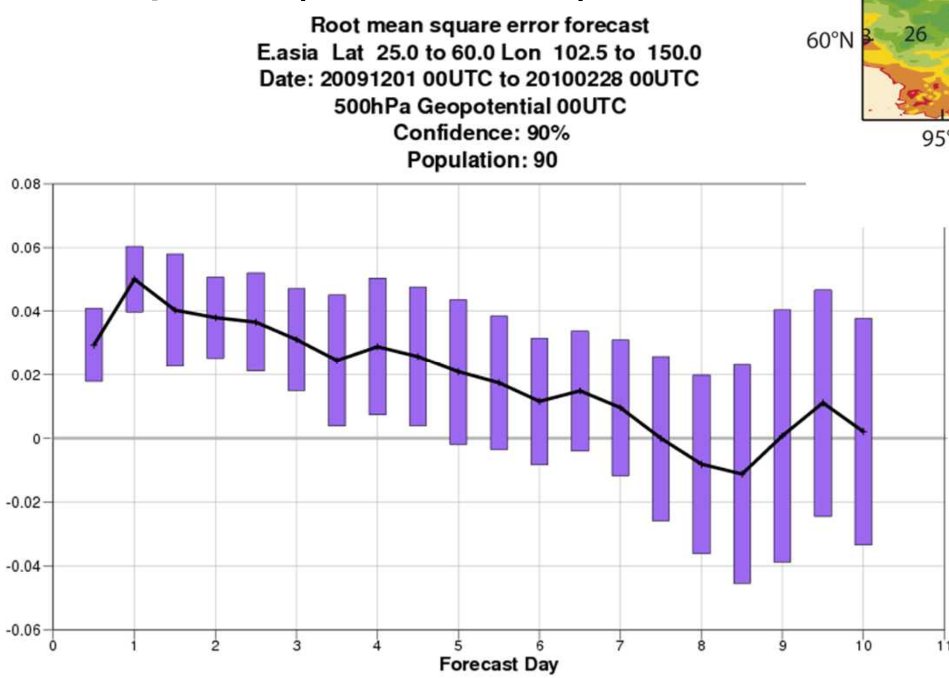
New snow Analysis in Operations

Old: Cressman
NESDIS 24km

New: OI
NESDIS 4km



FC impact (East Asia):



- OI has longer tails than Cressman and considers more observations.

- Model/observation information optimally weighted by an error statistics.

Summary on Snow Analysis

- Snow analysis based on Cressman (DWD, ECMWF ERA-Interim) and OI (CMC, JMC, ECMWF deterministic)
- Based on OI at CMC, JMA, ECMWF (Nov. 2010)
- OI has longer tails than Cressman and considers more observations.
- Positive impact of OI on NWP

- Use of SYNOP snow depth
- ECMWF flexible to use non-SYNOP reports (new report codetype)
- Snow cover data used (NOAA/NESDIS IMS product)
- **No** use of Snow Water Equivalent product in NWP

- Introduction
- Snow analysis
- **Screen level parameters analysis**
- Soil moisture analysis
- Summary and future plans

Screen Level parameters analysis

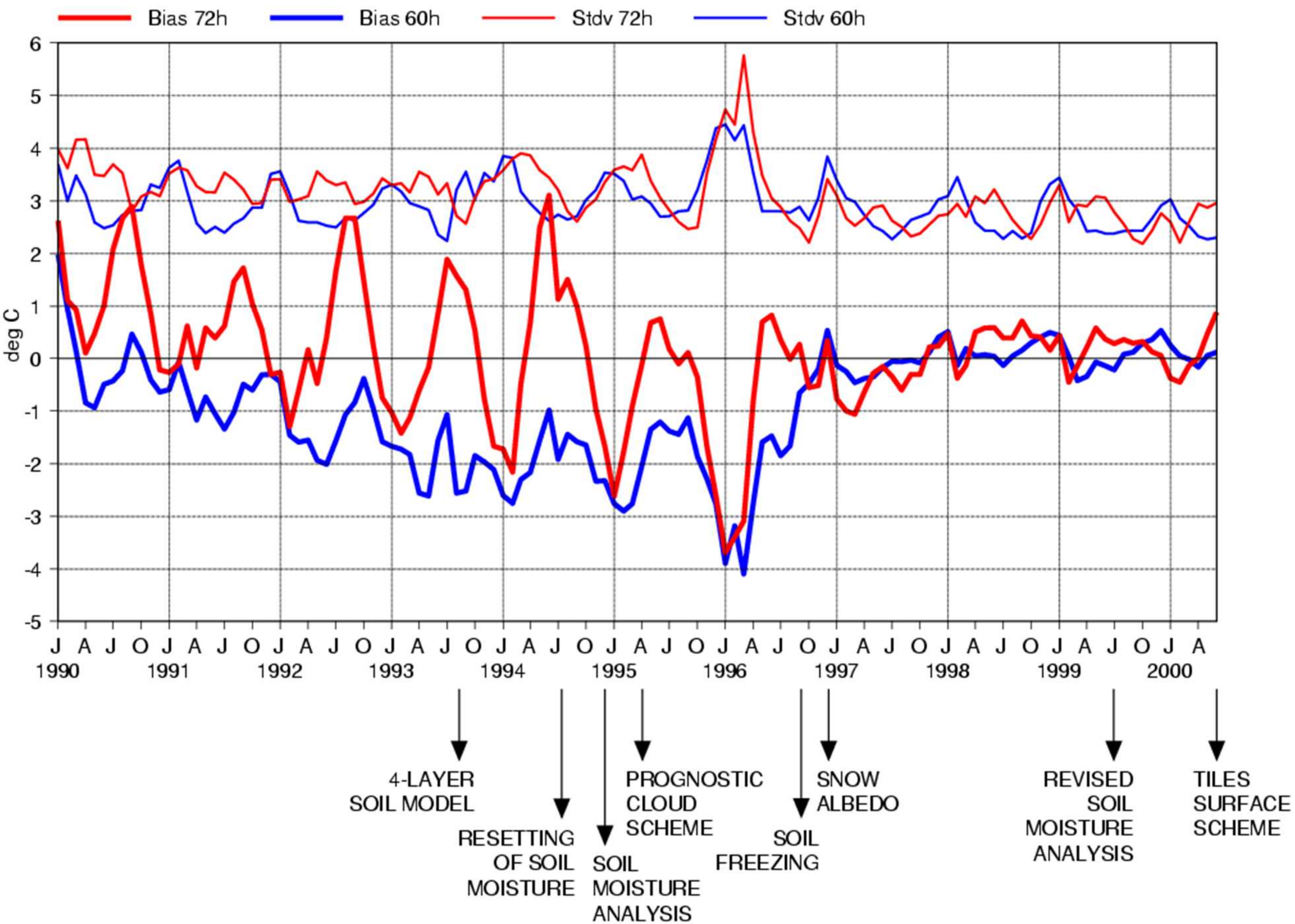
- Screen level variables: 2m Air Temperature (T) and air Relative humidity (RH), both diagnostic variables.
- Analysis based on an Optimum Interpolation using SYNOP observations, every six hours: 00UTC, 06UTC, 12UTC, 18UTC.

- 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)

- Indirect effect on atmosphere through the soil variables

- Relevance of screen level analysis for evaluation purposes

History of ECMWF 2m T errors



OI Screen Level parameters analysis

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

1. Increments ΔX_i are 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)
$B(i_1,i_2) = \sigma^2_b \times \mu(i_1,i_2)$ with the horizontal correlation coefficients $\mu(i_1,i_2)$ and σ_b = 1.5 K / 5 % rH the standard deviation of background errors.

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

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

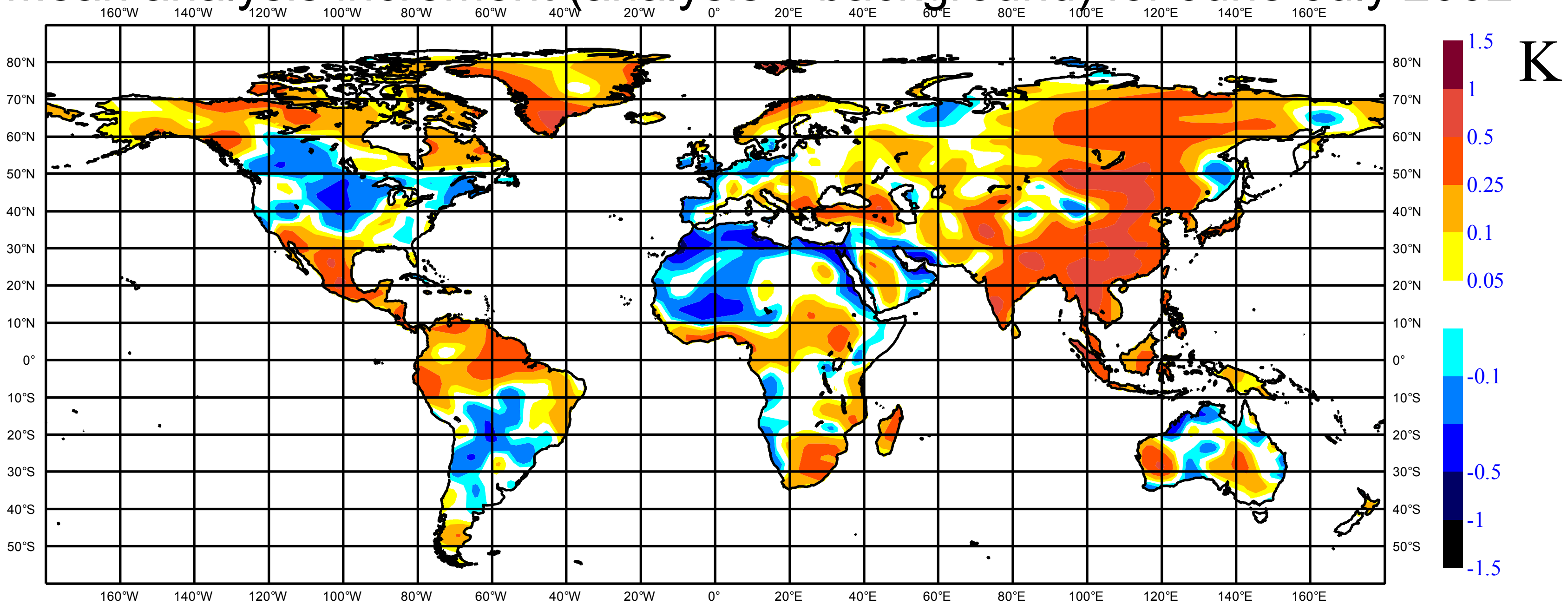
Screen Level parameters analysis

- Number of observations N = 50, d = 300 km, scanned radius 1000km.
- Gross quality checks as rH $\in$ [2,100] and T > $T_{dewpoint}$
- Observation points that differ more than 300 m from model orography are rejected.
- Observation is rejected if it satisfies: $|\Delta X_i| > \gamma\sqrt{\sigma_o^2 + \sigma_b^2}$ with γ = 3 (tolerance)
- Number of used observations ~ 6000 (40% of the available observations) every 6 hours.

Screen Level parameters analysis

Implemented in 1999 at ECMWF

Mean analysis increment (analysis – background) for June-July 2002



-Large differences in many areas of the world:

- Positive (negative) increments ie too cold (too warm) forecast compared to the analysis and observations.

→Forecasts model has systematic errors in the short-range forecast which are corrected in the analysis.

ECMWF

- Introduction
- Snow analysis
- Screen level parameters analysis
- **Soil moisture analysis**
- Summary and future plans

Interaction between Soil Moisture and Atmosphere

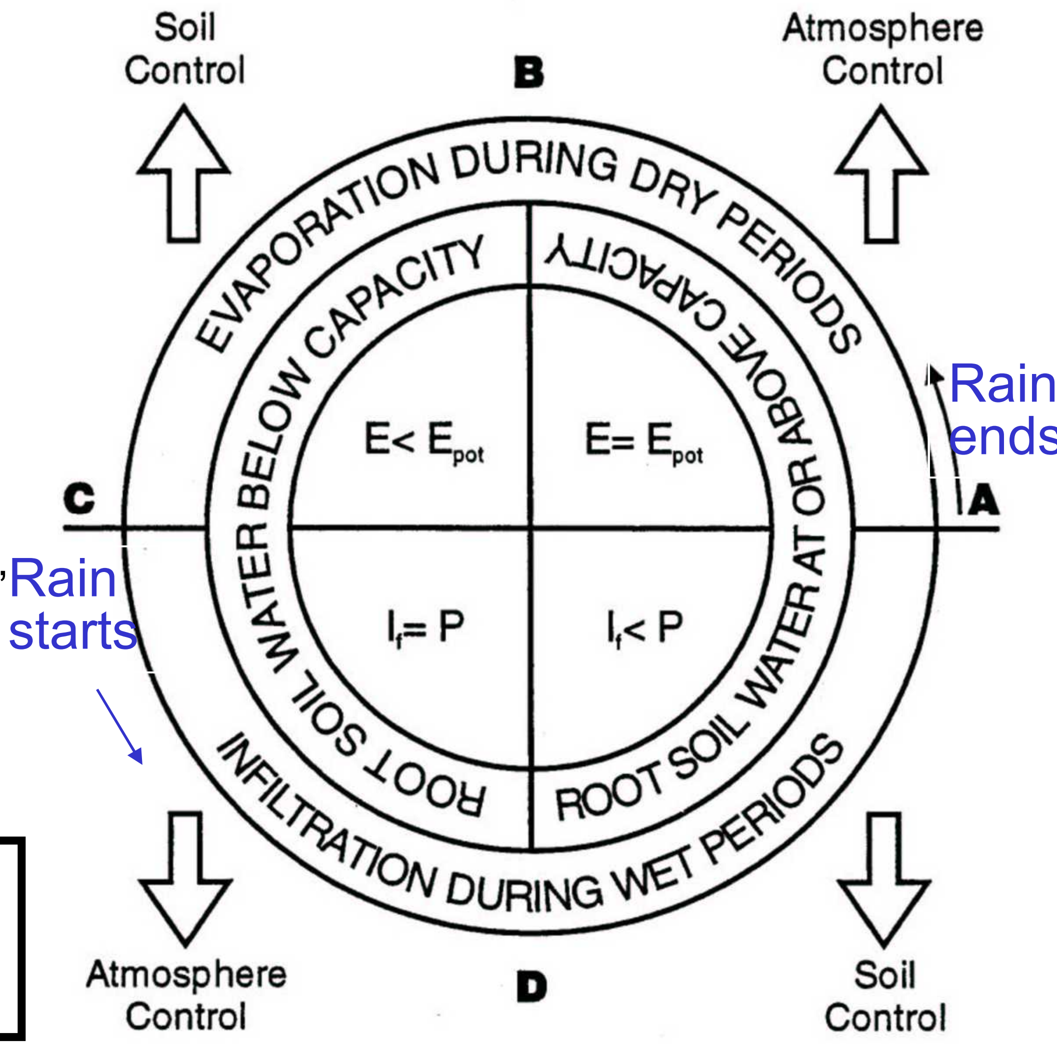
The hydrological 'Rosette' (P. Viterbo, PhD thesis, «The representation of surface processes in General Circulation Models » ECMWF, 1996)

A → B: After rain,
Evaporation at potential rate,
Atmospheric control.

B → C: Below field capacity soil moisture,
Limitation of root extraction,
Soil control.

C → D: Precipitation & relatively dry soils,
High infiltration rate I,
Atmospheric control.

D → A: Precipitation and soil near saturation,
Soil infiltration is reduced.
Excess goes in runoff,
Soil control.



Simple representation, but illustrates how soil-plant-atmosphere interactions are controlled by different processes depending on the conditions.

Interaction between Soil Moisture and Atmosphere

Based on a multi-model approach: characterization of the strength of the coupling between surface and atmosphere.

(Koster et al, Science 2004).

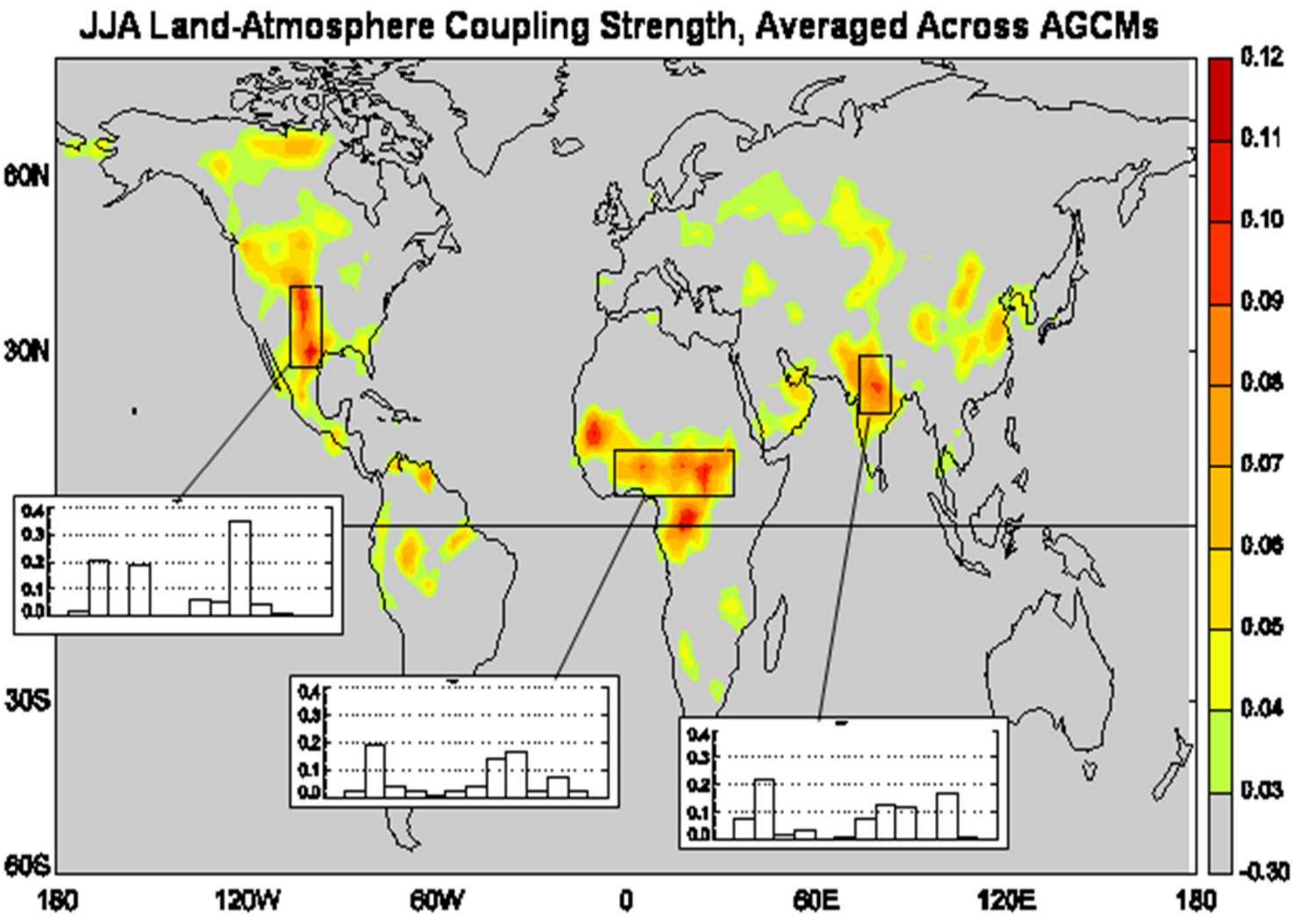
SM, variable of interface

Partition LE/H

Vegetation phenology,

Soil respiration,

Biogeochemical cycle



Hot spot areas → strong feedback of soil moisture on precipitation

A short history of soil moisture analysis at ECMWF

- **Nudging scheme (1995-1999)**

$$\Delta\Theta = \Delta t \, D \, C_v \left(q^a - q^b\right)$$

D: nudging coefficient (constant), Dt = 6h, q specific humidity
Uses upper air analysis of specific humidity
Prevents soil moisture drift in summer

- **Optimum interpolation 1D OI (1999-2010)** **(Mahfouf, ECMWF News letter 2000, Douville et al., Mon Wea. Rev. 2000)**

$$\Delta\Theta = a \left(T^a - T^b\right) + b \left(Rh^a - Rh^b\right)$$

a and b: optimal coefficients

OI soil moisture analysis based on a dedicated screen level parameters (T2m Rh2m) analysis

Drusch and Viterbo, Mon. Weath. Rev., 2007 showed that the OI using screen level variables improves fluxes but degrades soil moisture → requirement to use future satellite soil moisture data (more direct SM information)

- **Simplified Extended Kalman Filter (since November 2010)** **(Drusch et al., GRL, 2009 de Rosnay et al., ECMWF News letter 2011)**

Why an EKF soil moisture analysis ?

- Possible to investigate the use of new generation of satellite data:
    - SM active microwave (MetOp/ASCAT, L-band SMAP)
    - SM passive microwave (L-band SMOS, SMAP)
- Makes it possible to combine different sources of information

SYNOP **ASCAT** **SMOS**

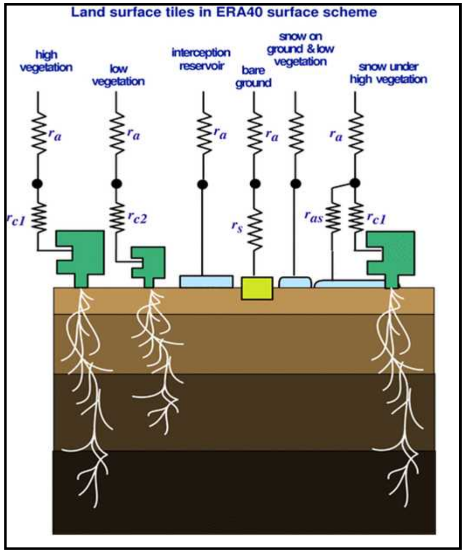
- Dynamical estimates of the Jacobian Matrix that quantify accurately the physical relationship between observations and soil moisture
- Flexible to account for the land surface model evolution

Simplifed EKF soil moisture analysis

For each grid point, Analysed soil moisture state vector $\boldsymbol{\theta}_a$:

$$\boldsymbol{\theta}_a = \boldsymbol{\theta}_b + \boldsymbol{K}\,(\boldsymbol{y} - \mathcal{H}[\boldsymbol{\theta}_b])$$

SEKF corrects the trajectory of the Land Surface Model



$\boldsymbol{\theta}$ background soil moisture state vector,
$\mathcal{H}$ non linear observation operator
$\boldsymbol{y}$ observation vector
$\boldsymbol{K}$ Kalman gain matrix, fn of
H (linearsation of $\mathcal{H}$), **B** and **R** (covariance matrices of background and observation errors).

Observations:

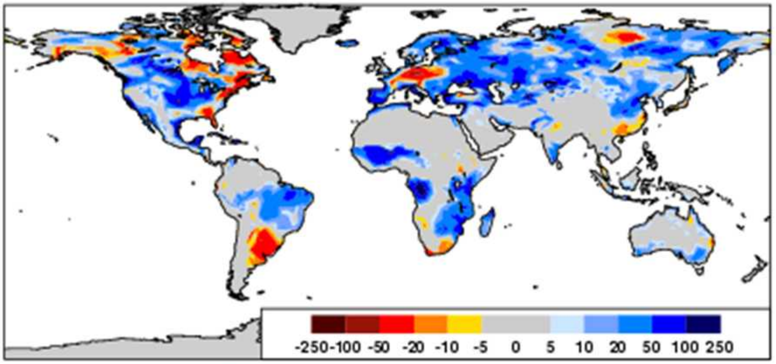
- Used in operations:
  Conventional observations (T2m, RH2m)

- Developments at ECMWF, Météo-France, BoM to use Satellite data related to soil moisture (ASCAT product, SMOS and AMSR-E Brightness temperature) in a SEKF.

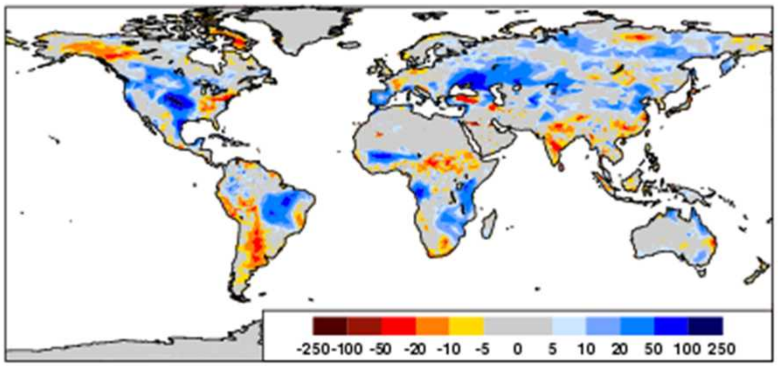
SEKF evaluation

0-1m Soil Moisture increments for July 2009 (mm)

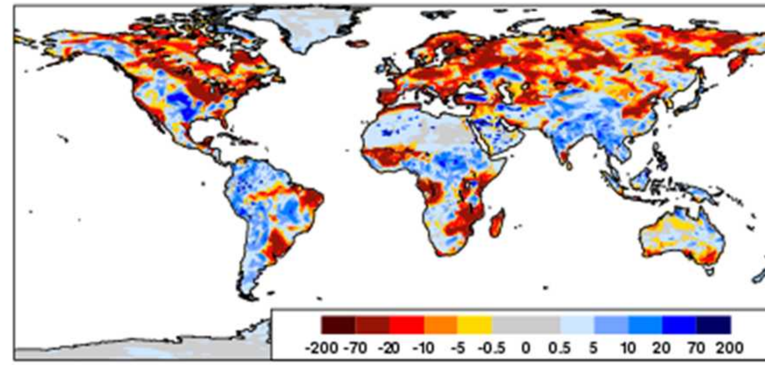
|SEKF|-|OI|



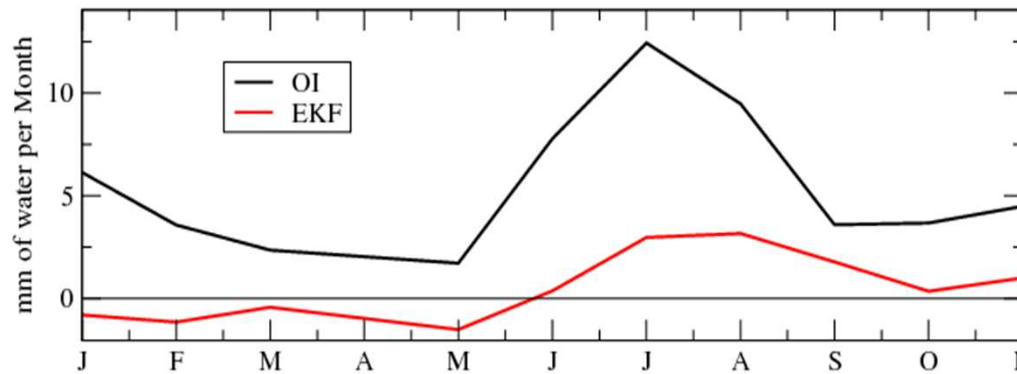
OI



SEKF



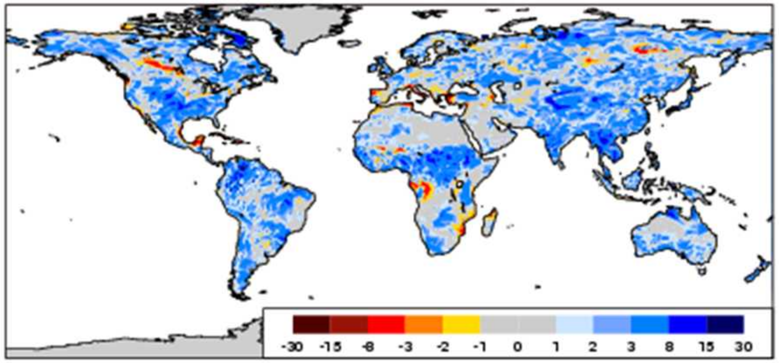
Global Soil Moisture Increments (1st meter of soil)



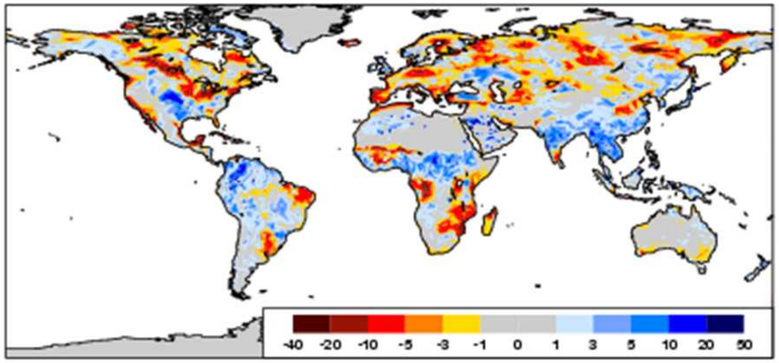
-Two 1-year analysis experiments using the OI and the SEKF
- Reduced increment with the SEKF compared to the OI
- EKF accounts for (non-linear) control on the soil moisture increments (meteorological forcing and soil moisture conditions)
- **SEKF prevents undesirable and excessive soil moisture corrections**

SEKF evaluation

Profile of Soil Moisture increments difference |SEKF|-|OI| July 2009

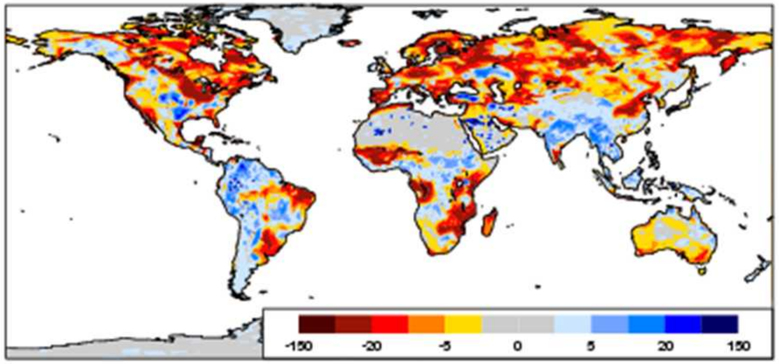


Layer 1 (0-7cm)



Layer 2 (7-28cm)

Increments reduction: mainly at depth

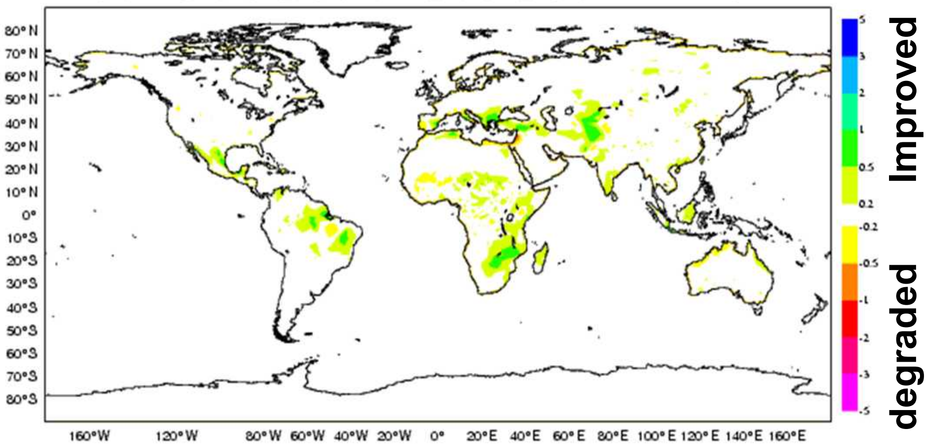


Layer 3 (100-289 cm)

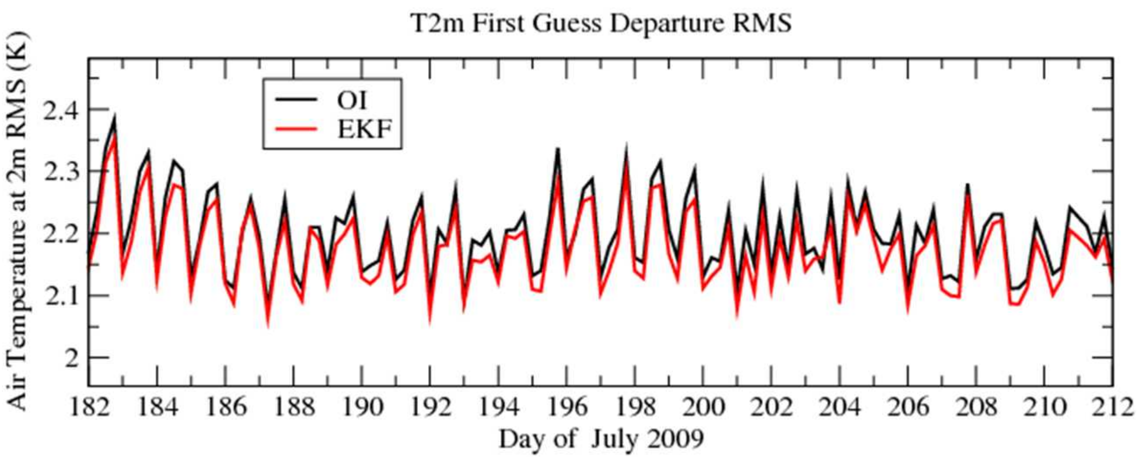
Impact on 2-meter Temperature

Compared to the OI, the SEKF consistently improves T2m

T2m error (OI-SEKF) 48h fc
→ EKF improves T2m



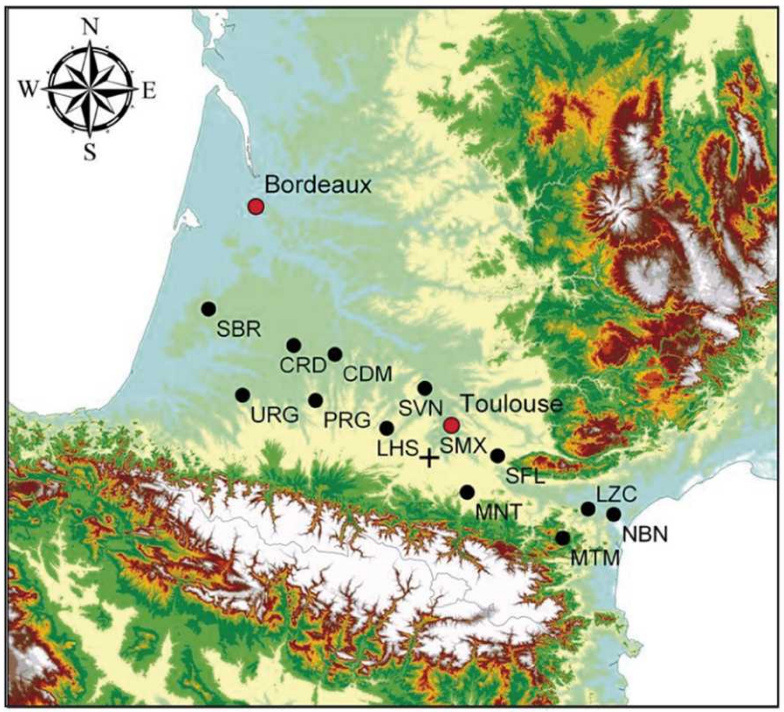
Global mean RMS (against SYNOP)

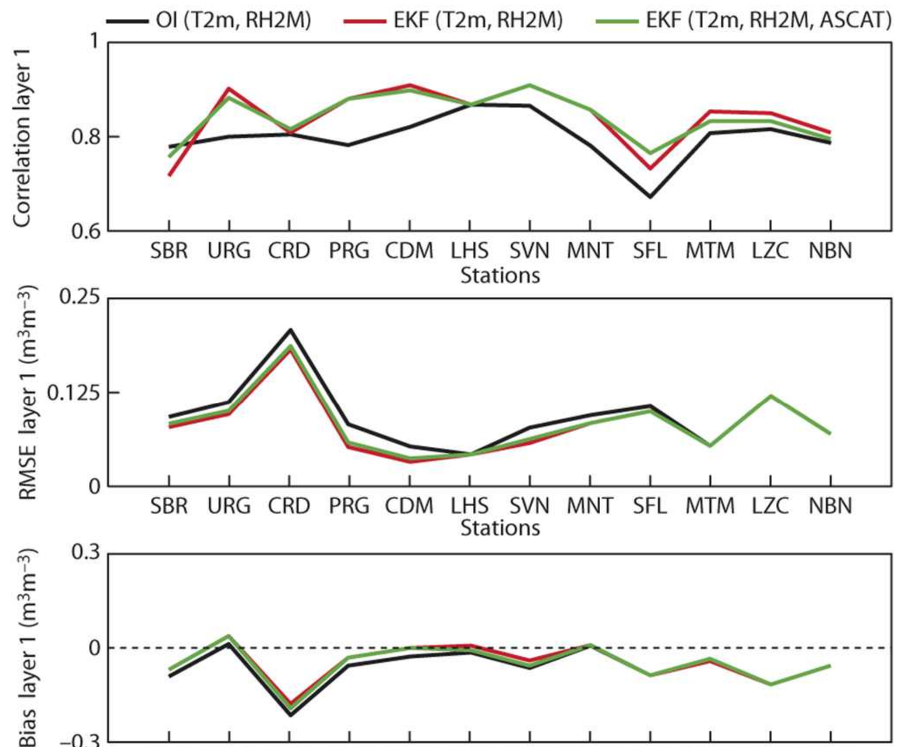


Soil Moisture Analysis verification

Validated for several sites across Europe (Italy, France, Spain, Belgium)

Verification of ECMWF SM over the SMOSMANIA Network





→ **SEKF improves Soil Moisture, improves screen level parameters and opens the possibility to use satellite data**

Active microwave data: ASCAT

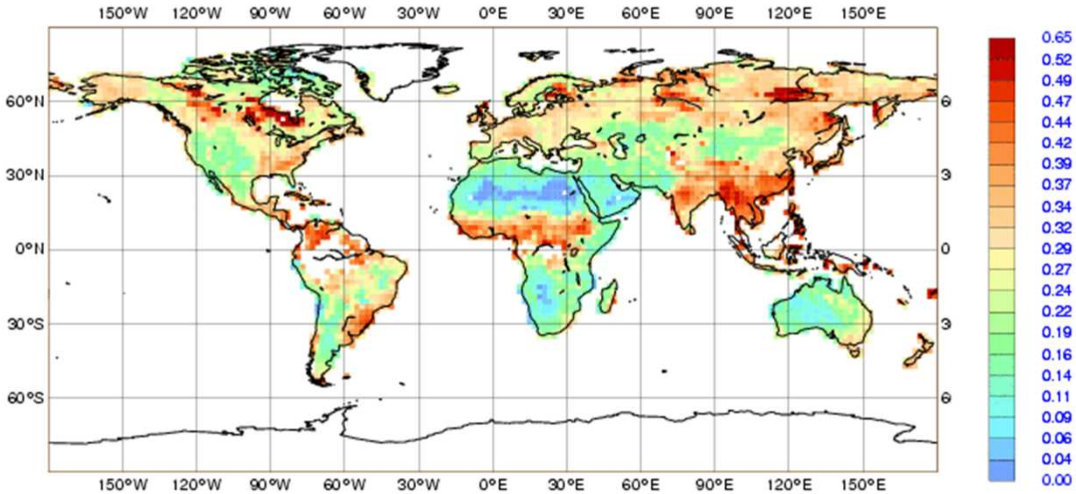
Advanced Scatterometer on MetOP (launched in 2006)
Continuity of ERS/SCAT (1-1992; 2-1996)

Active microwave instruments operating at C-band (5.6GHz)

Surface soil moisture index (ms) based on the
TUWien retrieval scheme (Wagner et al. 1999)

ASCAT operational SM product (EUMETSAT)

Soil Moisture Monitoring
Aug. 2011



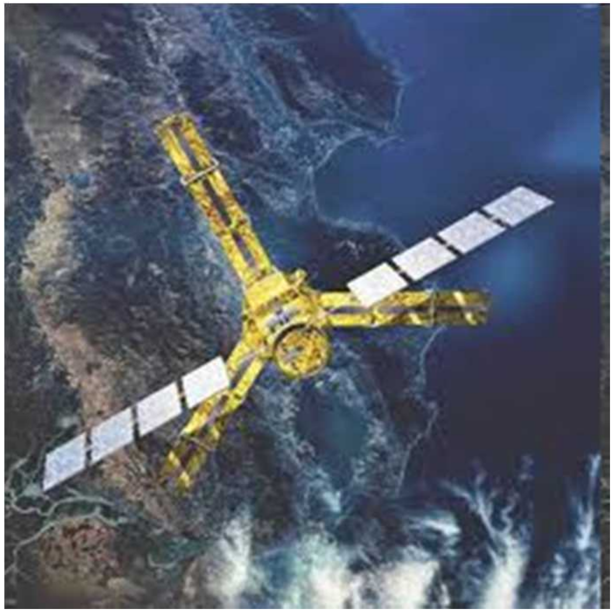
Passive microwave data: SMOS

Soil Moisture and Ocean Salinity (launched in 2009)

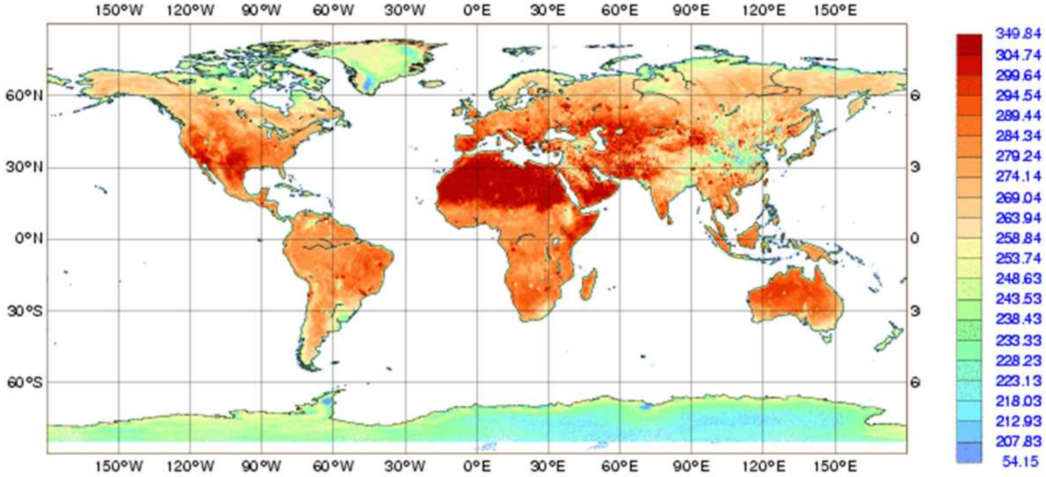
Passive microwave interferometric radiometer operating at L-band (1.4 GHz)

Based on Multi-angular measurements
of Brightness Temperature (TB) (Kerr et al., 2010)

SMOS Earth Explorer mission at ESA
NRT TB product available



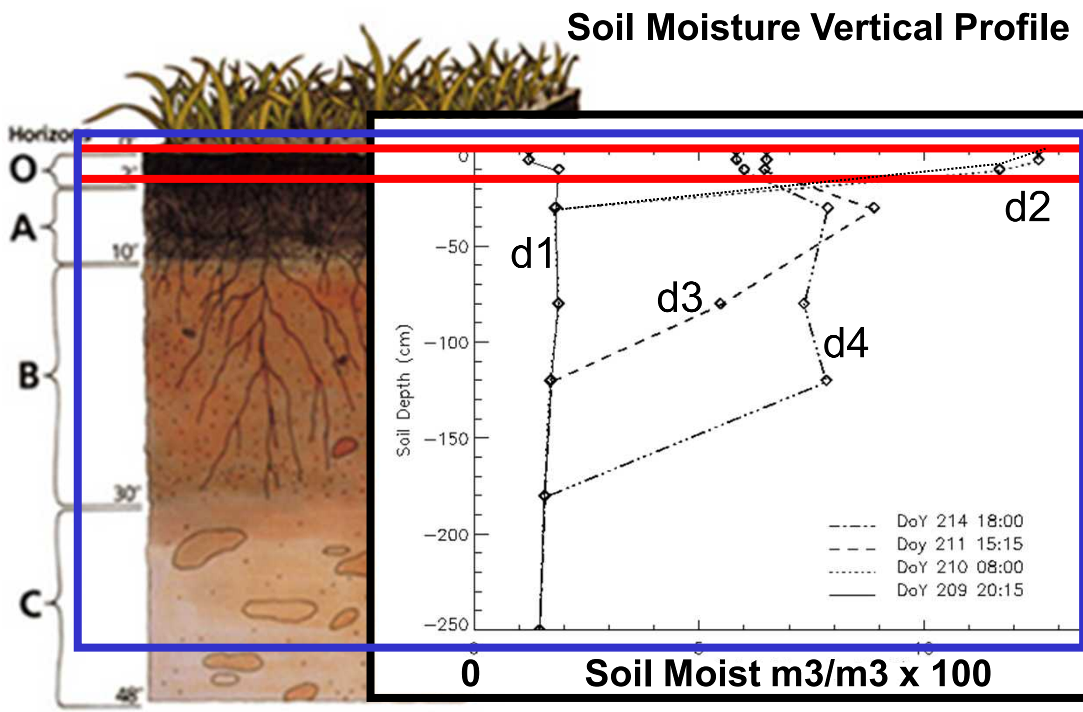
Brightness Temperature (K) Monitoring
Aug. 2011



Soil Moisture remote sensing

→ Surface Soil Moisture

Top soil moisture sampling depth: 0-2cm ASCAT, 0-5cm SMOS



Root Zone SM Profile

Variable of interest for Soil-Plant-Atm interaction, Climate, NWP and hydrological applications

Root Zone SM Profile: Accurate retrieval requires to account for physical processes

→ Space agencies retrieval of level 3 / level 4 products approaches rely on data assimilation approaches.

Use of Active microwave data: ASCAT

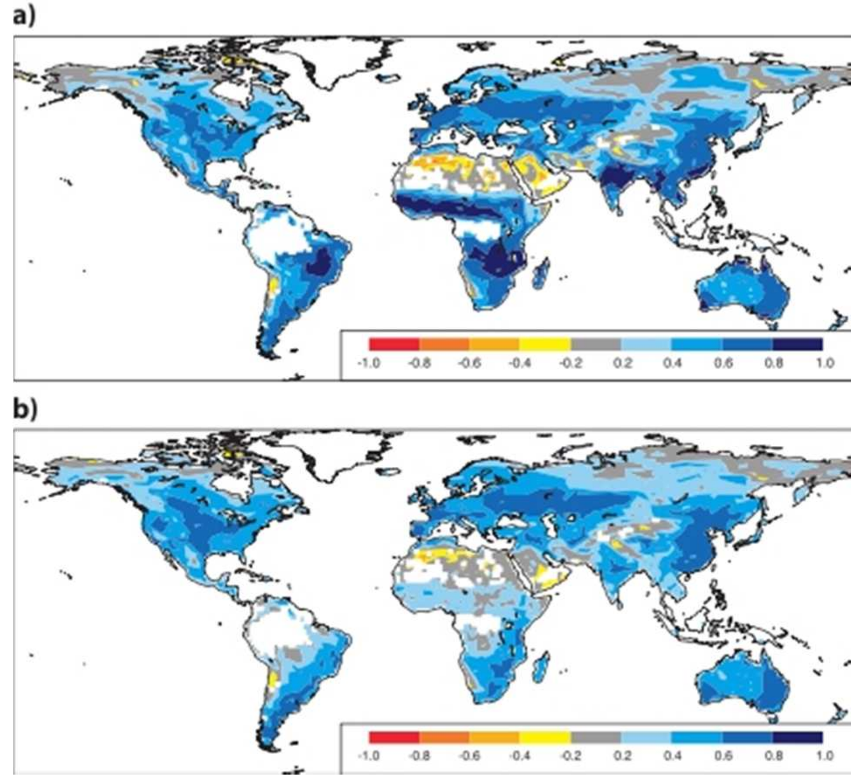
Correlation of ERS and ERA-40 SM values and anomalies

Good agreement between ERS and ERA-40 soil moisture products.

For 85% of the land points, correlation is significant at the 0.05 level.

High correlation where strong SM seasonal cycle (e.g. monsoon regions).

Relatively low correlation in the eastern part of the North America (high amount of biomass).



ASCAT provides good SM information in semi-arid and moderately vegetated area.

Scipal et al., ADWR 2008

ASCAT CDF matching

- ASCAT soil moisture is an Index (ms)
- Model soil moisture θ is volumetric (m^3/m^{-3})

→ ASCAT index has to be converted to volumetric soil moisture and bias corrected

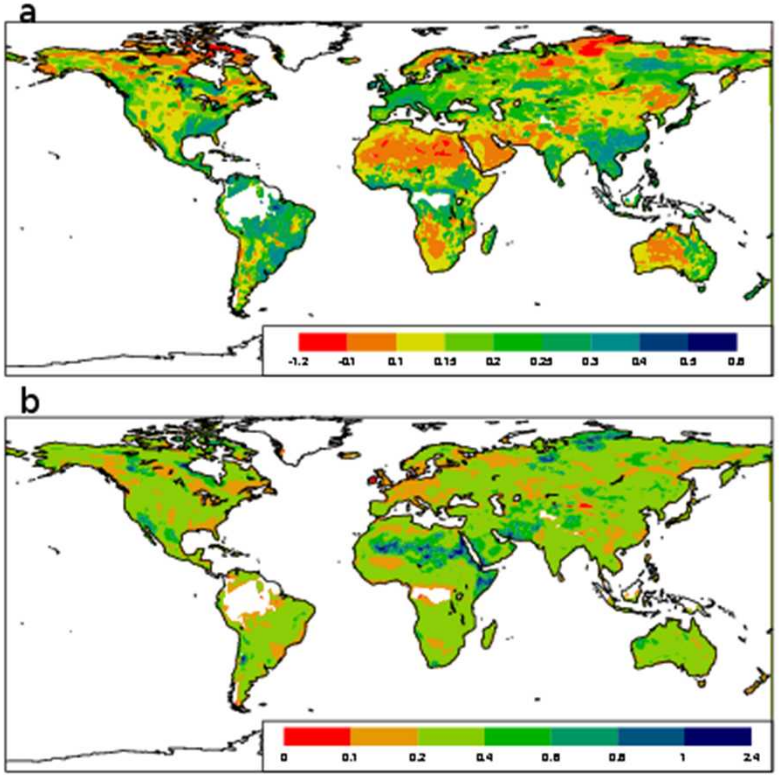
→ Simple Cumulative Distribution Function (CDF) matching (Scipal et al., 2008)

$$\boldsymbol{\theta}_{ASCAT} = a + b * ms$$

a and b are CDF matching parameters computed on each model grid point separately

$$a = \overline{\theta_{ERA}} - \overline{ms}\ .\ [var(\theta_{ERA}) / var(ms)]^{1/2}$$

$$b = [var(\theta_{ERA}) / var(ms)]^{1/2}$$



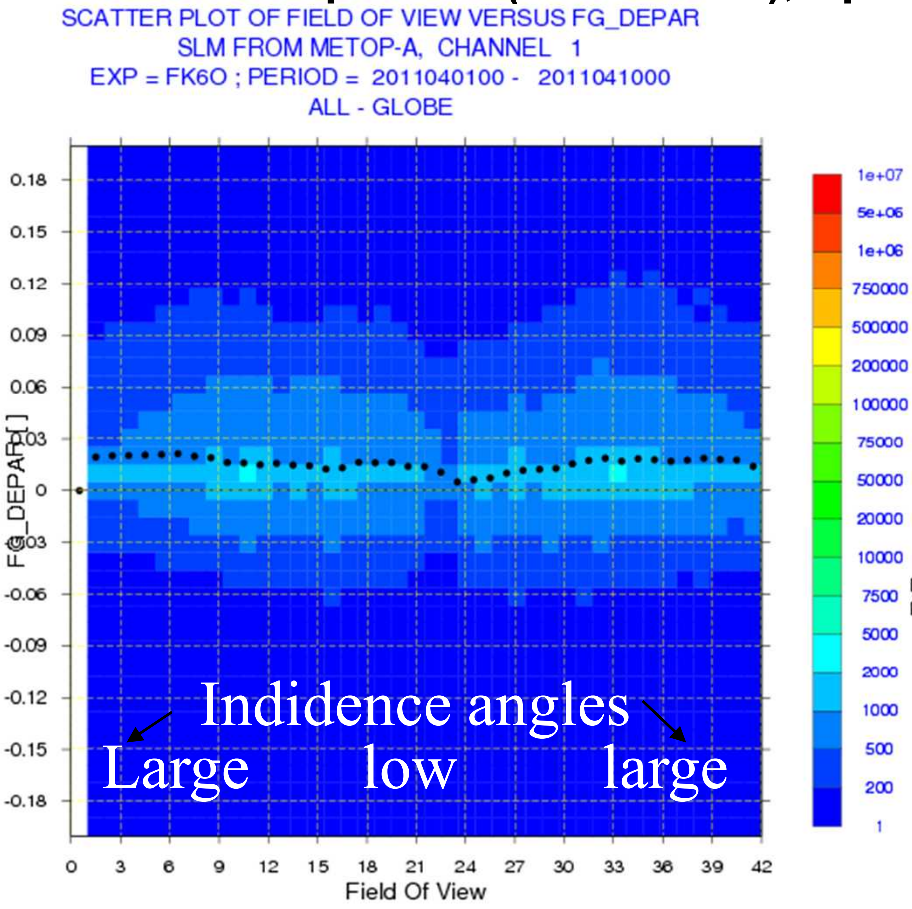
T1279 (16km) resolution ASCAT CDF matching parameters

CDF matching fits the data mean and variance on that of the model.
At ECMWF, matching based on ERA-Interim and ERS/SCAT data set (1992-2000).
CDF matching also used at UKMO and Météo-France

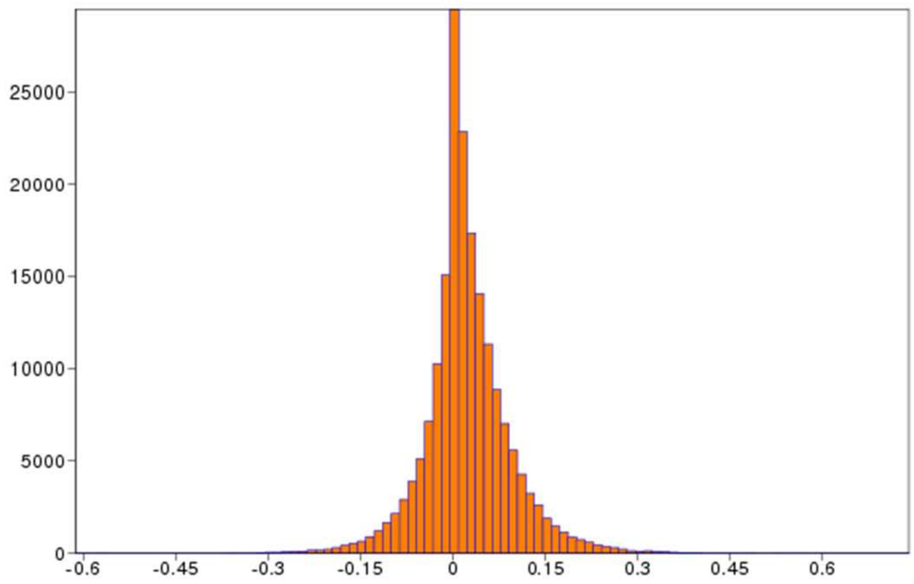
ASCAT Monitoring

ASCAT operational monitoring at ECMWF

ASCAT Soil Moisture Global
First Guess Departure (Obs-Model), April 2011:



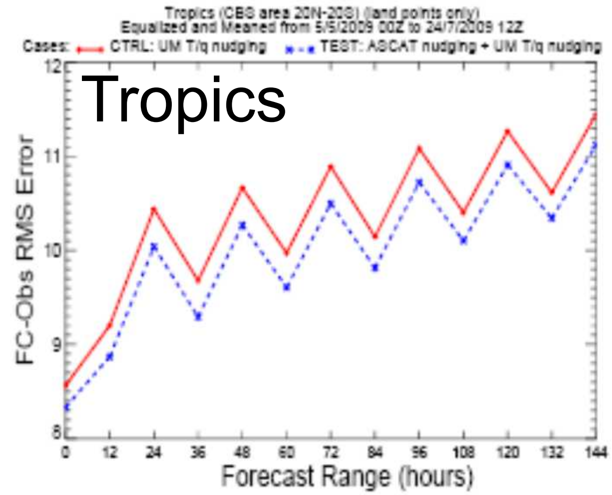
Mean 0.017 m^3/m^{-3}
SDT 0.071 m^3/m^{-3}



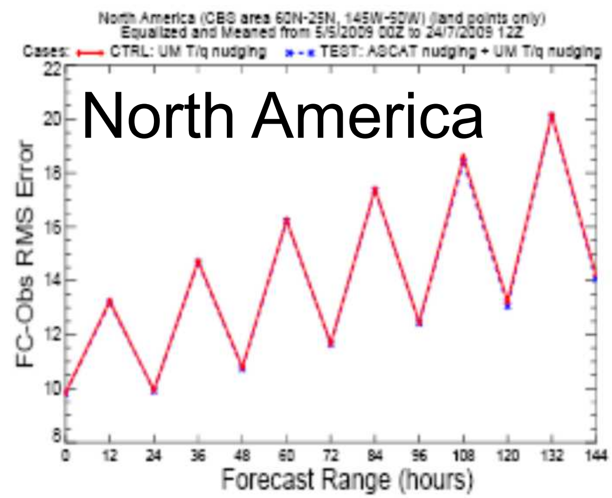
ASCAT data assimilation

T2m impact

- UKMO: ASCAT data assimilated along with screen level parameters in a **nudging scheme** at the UKMO, → **operational** since summer 2010
(Dharssi et al., HESS, 2011)



- Méteo-France, ECMWF: **Research DA** of ASCAT soil moisture in a **multi-variate SEKF**
(Draper et al., HESS 2011
de Rosnay et al., ECMWF News letter 2011)



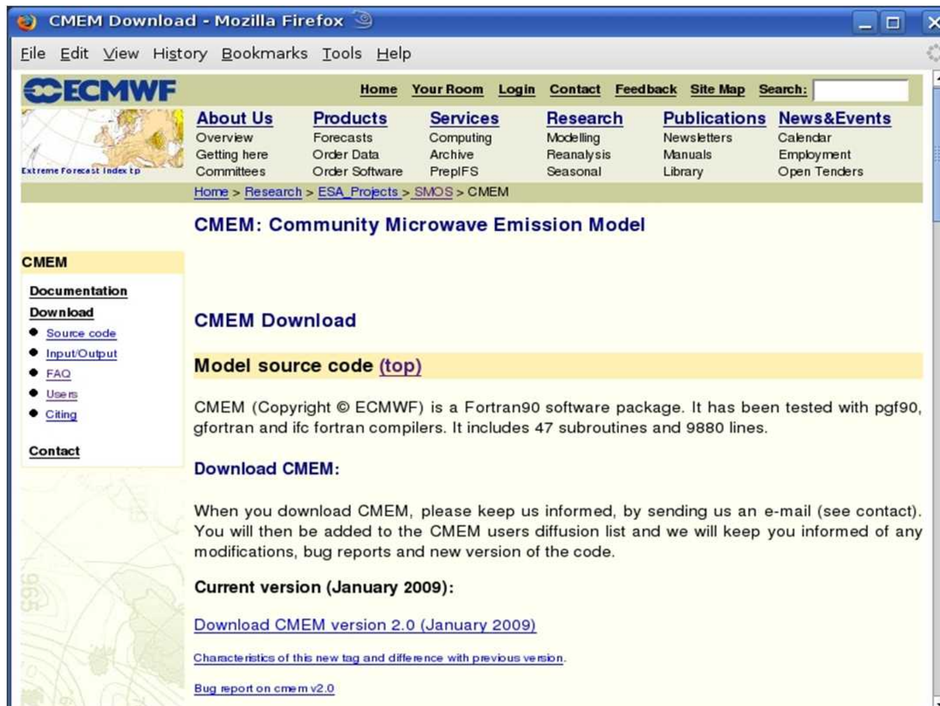
Importance of pre-procesing, revision of bias correction at ECMWF (seasonal correction)

Use of passive microwave data: SMOS

- **SMOS measures L-band TB**
- **Forward operator: microwave emission model**
- **ECMWF Community Microwave Emission Model (CMEM)**
- I/O interfaces for the Numerical Weather Prediction Community.
- Web interface available

http://www.ecmwf.int/research/ESA_projects/SMOS/cmem/cmem_index.html

Also used at CMC, CSIRO, GSFC, and others centres



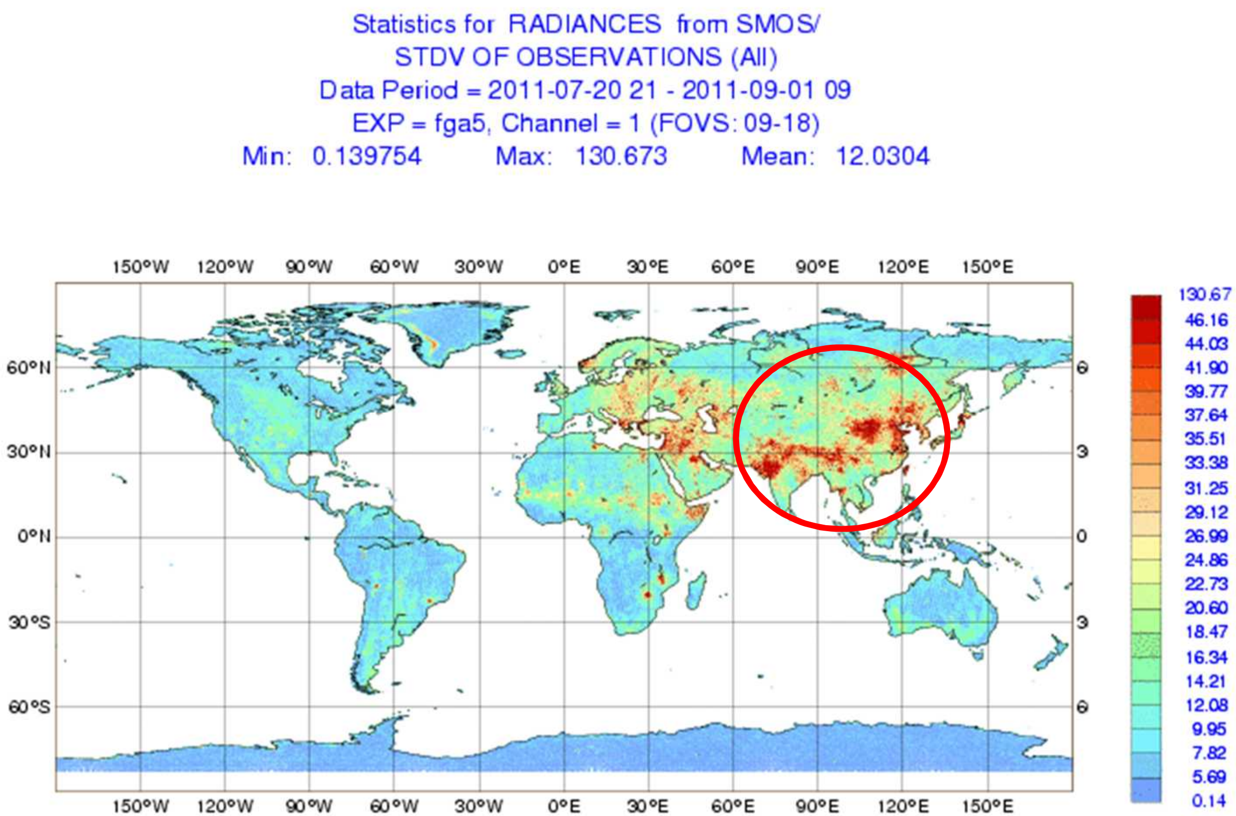
References:
Drusch et al. JHM, 2009
de Rosnay et al. JGR, 2009
Muñoz Sabater et al., IJRS 2011

SMOS Monitoring

(Muñoz Sabater et al. ECMWF News Letter 2011)

STD of First Guess Departure over land (Obs – Model), July-Aug 2011

RFI (Radio Frequency Interference) issues → impact on FG departures STD is large; Lots of RFI sources switched off in Europe, still an important issue in Asia.



- Continuous improvement of the data quality since the end of the commissioning phase

- August 2011: availability of a reprocessed SMOS TB data set of consistent quality

SMOS Challenges

- Objective of the Earth Explorer mission: to investigate multi-angular L-band data to access soil moisture information. L-band is optimal for soil moisture remote sensing. High potential of SMOS.
- New type of observation: multi-angular L-band data
- Data volume, data thinning, noise filtering
- RFI issues, detecting and mitigation approaches under development (ESA)
- For NWP applications:
  - Multi-angular monitoring implemented in Near Real Time
  - New forward operator (CMEM) developed (used at ECMWF, CMC, GSFC, and others)
  - Bias correction and forward operator calibration have to be investigated based on long enough time series of consistent quality.
  - Ongoing SMOS data implementation in the ECMWF SEKF and at CMC

Summary and future plans

- Most NWP centres analyse soil moisture and/or snow depth

- **Operational snow analysis:**
  - Rely on simple analysis methods (Cressman, OI, or climatology)
  - Uses SYNOP data, NOAA/NESDIS snow cover
  - No Snow Water Equivalent products used for NWP (yet)

Summary and future plans

- **Operational Soil Moisture analysis:**
  - Various approaches used: 1D-OI (Météo-France, CMC, ALADIN, HIRLAM); SEKF (DWD, ECMWF); Nudging (UKMO); Offline LSM using analysed atmospheric forcing (NCEP: GLDAS / NLDAS)
  - Most use Screen level data (T2M and RH2m) through a dedicated OI analysis
  - ASCAT (assimilated UKMO, monitored ECMWF)

- Land Surface Analysis approaches are under development to investigate the use of multi-variate approaches (ECMWF, CMC, Météo-France, BoM)
- Compared to the OI, the SEKF analysis improves both Soil Moisture and T2m:

→ Relevance of screen level parameters to analyse soil moisture

→ Consistency in the LSM between soil moisture and screen level parameters

- Developments to use ASCAT soil moisture and SMOS brightness temperature data assimilation in NWP

Summary and Future plans

• Land surface processes involve long time scales. Testing periods of several months/seasons are required (ECMWF SEKF implemetations tests based on 1-year analysis experiments)

• Surface heterogeneities → high resolution data assimilation systems relevant for analysis and re-analysis activities.

• Experience of the land surface modelling community in intercomparison exercises – Preparation of a Project for Intercomparison of Land Data Assimilation Systems (PILDAS) coordinated by NASA/GSFC and Météo-France with ECMWF participation

→ Importance of developing and maintaining modular land data assimilation systems that enables consistent NWP initialisation and offline experimentation

Summary and Future plans

- Use of future satellites: NASA SMAP (Soil Moisture Active and Passive, 2014), continuity with SMOS and ASCAT and exploitation of the synergy between active and passive measurements
- Assimilation of vegetation parameters (Leaf Area Index) and surface characteristics (albedo)

- Long term perspectives:
    - Consistent evolution of LDAS and LSM evolution.
    - Importance of horizontal processes (river routing)
    - Assimilation of integrated hydrological variables such as river discharges: Surface Water Ocean Topography (SWOT) mission (2019)