ECMWF Data Assimilation Training course

Land Surface Data Assimilation

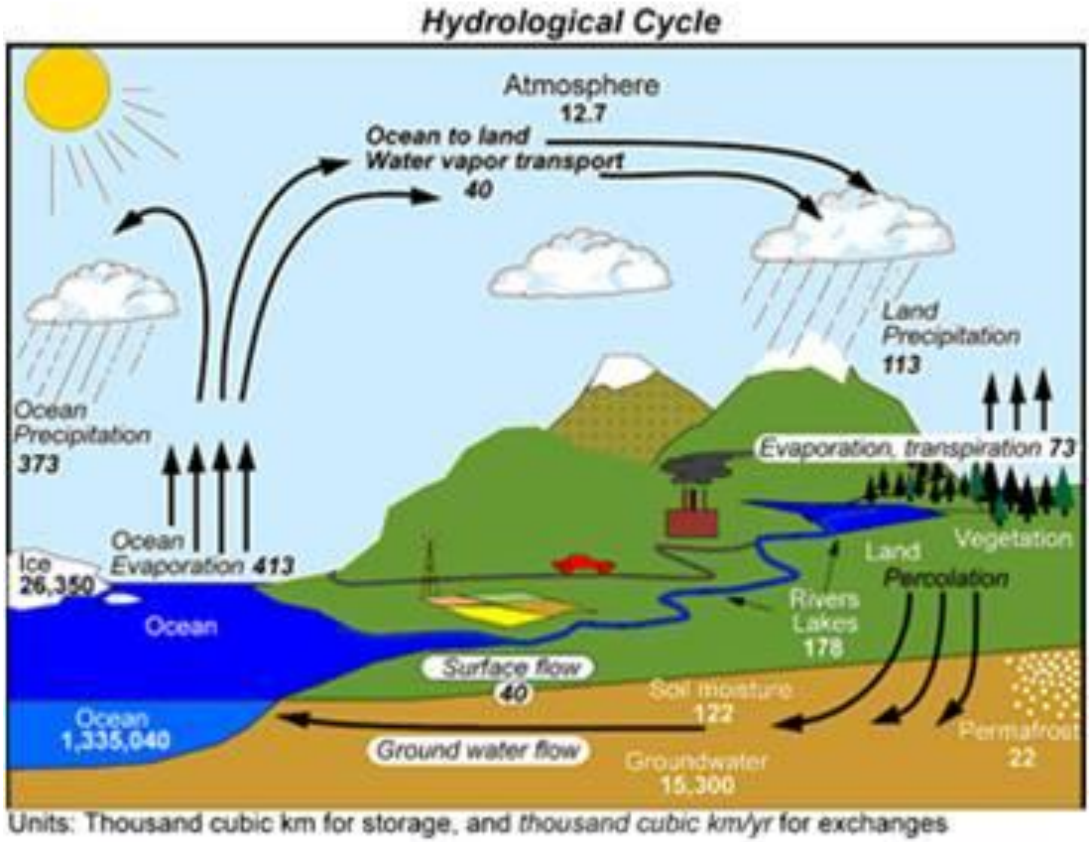
Patricia de Rosnay

Outline

- **Introduction**
- Snow analysis
- Soil moisture analysis
- Summary

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

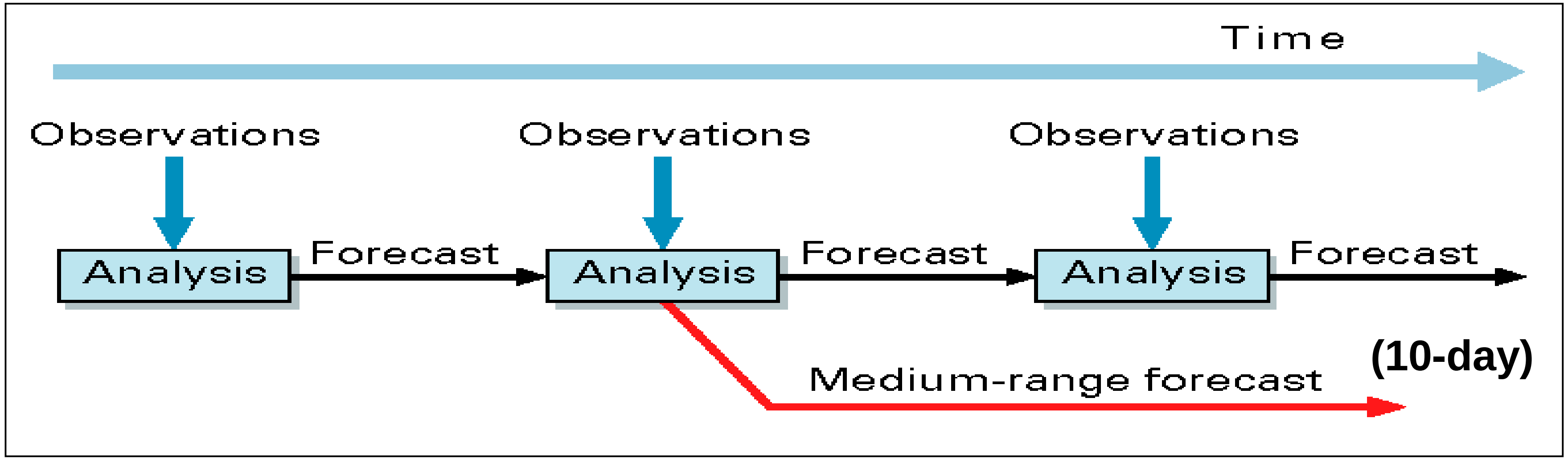


Trenberth et al. J. Hydrometeorol., 2007

→ **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 (coupled)

- **Data Assimilation** → **initial conditions of the forecast model prognostic variables**
  - **4D-Var for atmosphere ; 3D-Var for ocean (for ensemble and seasonal)**
  - **Land Data Assimilation System** → **Weakly coupled land-atmosphere assimilation**

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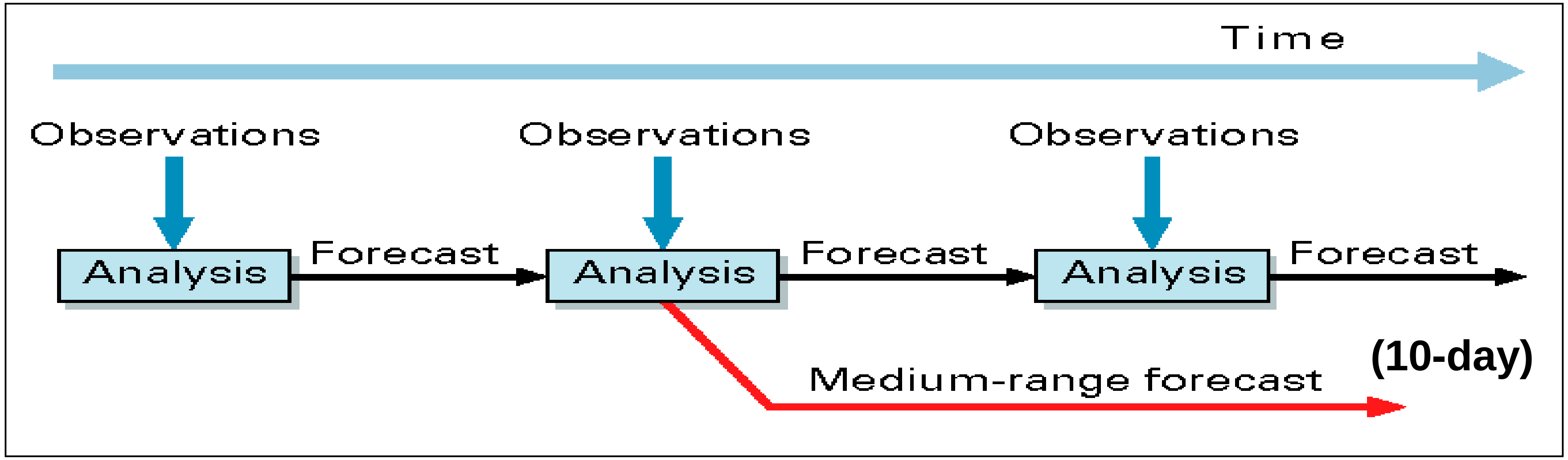

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Different Systems:

NWP (oper):	IFS (with 4D-Var and LDAS), 9km, version 43r1 (2016)
ERA-Interim:	IFS (with 4D-Var and LDAS), 79km, version 31r1 (2006)
ERA5:	IFS (with 4D-Var and LDAS), 32km, version 41r2 (2016)
ERA-Interim-Land:	H-TESSEL offline LSM simulations, with no LDAS, 79km, 37r2 (2011) driven by ERA-I atmosphere corrected by GPCP

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 the ECMWF IFS for NWP

Snow Model: Component of H-TESSEL **(Dutra et al., JHM 2010, Balsamo et al JHM 2009)**

Single layer snowpack

- Snow water equivalent SWE (m)
- Snow Density ρ_s

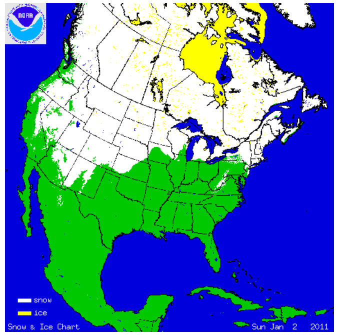
Prognostic variables

Observations: **de Rosnay et al ECMWF Newsletter 2015**

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

Data Assimilation: **de Rosnay et al SG 2014**

- Optimal Interpolation (OI) is used to optimally combine the model first guess, in situ snow depth and IMS snow cover
- The result of the data assimilation is the analysis of SWE and snow density
- It is used to initialize the NWP system.



Snow cover observations

Interactive Multisensor Snow and Ice Mapping System (IMS)

- Time sequenced imagery from geostationary satellites
- AVHRR,
- VIIRS,
- SSM/I, etc.…
- Station data

Northern Hemisphere product

- Daily
- Polar stereographic projection

Information content: Snow/Snow free

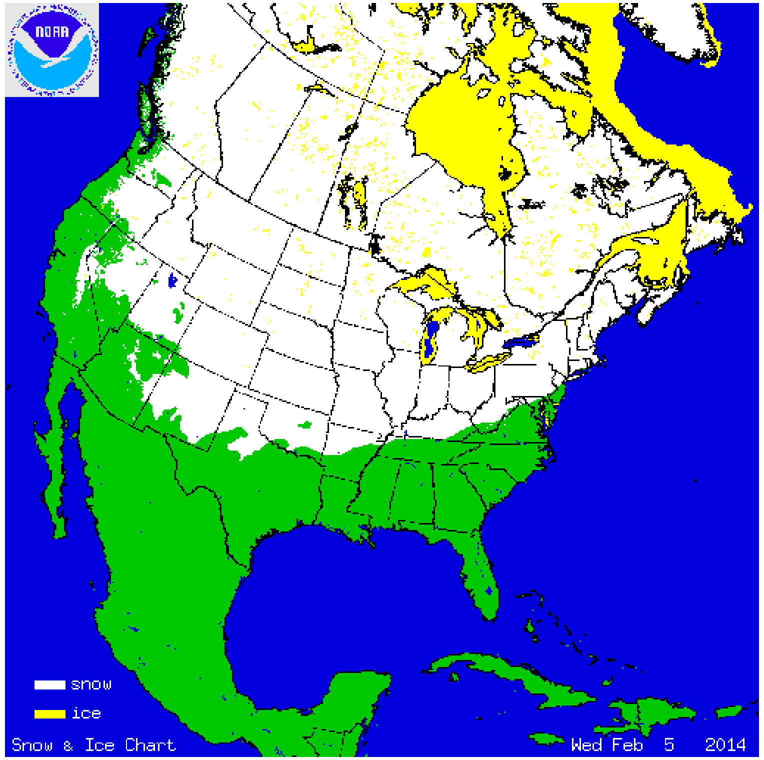
Data used at ECMWF:

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

Latency:

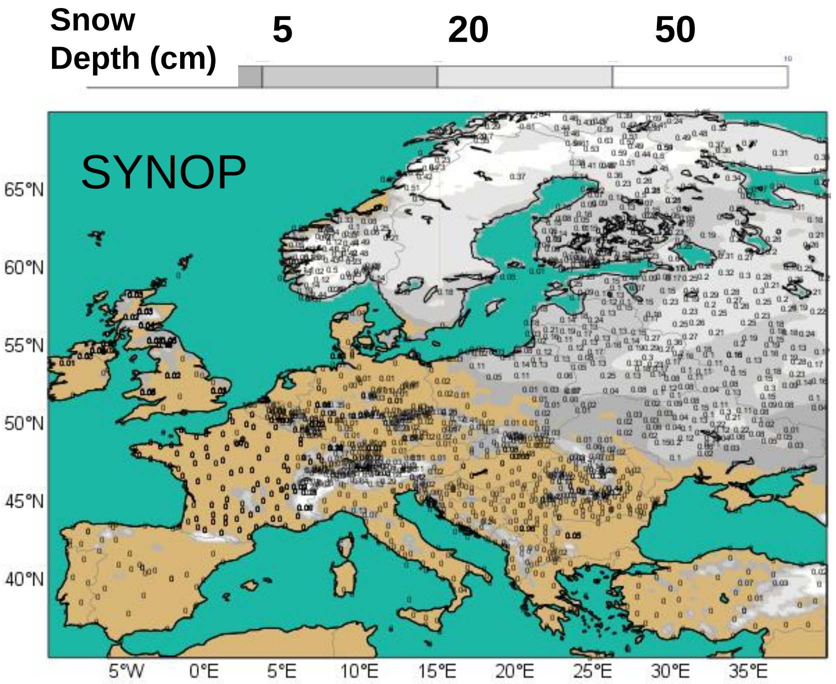
Available daily at 23 UTC. Assimilated in the subsequent analysis at 00UTC

NOAA/NESDIS
IMS Snow extent data



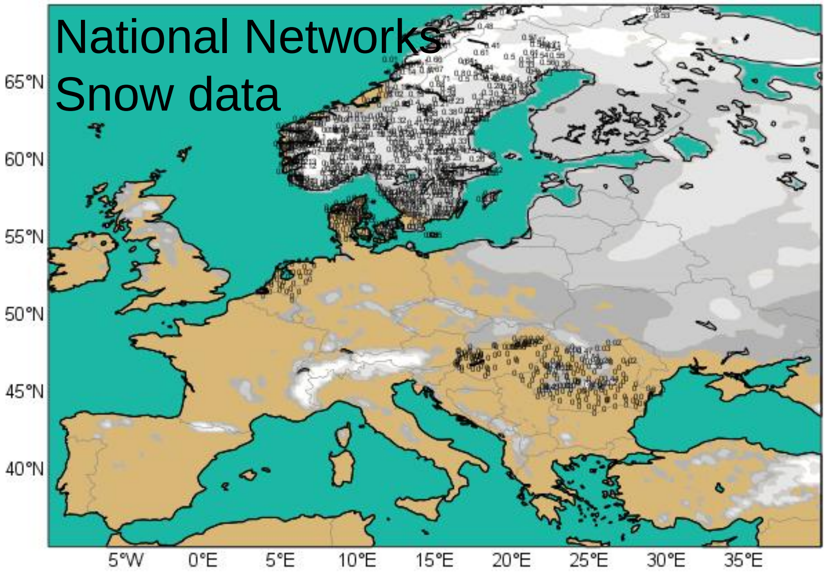
http://nsidc.org/data/g02156.html

Snow Observations
Snow SYNOP and National Network data in Europe



Available on the GTS (Global Telecommunication System)

2016 01 15 at 06UTC



Additional data from national networks from up to 7 countries:
Sweden, Romania, The Netherlands, Denmark, Hungary, Norway, Switzerland.

→ **Dedicated BUFR for additional national data**

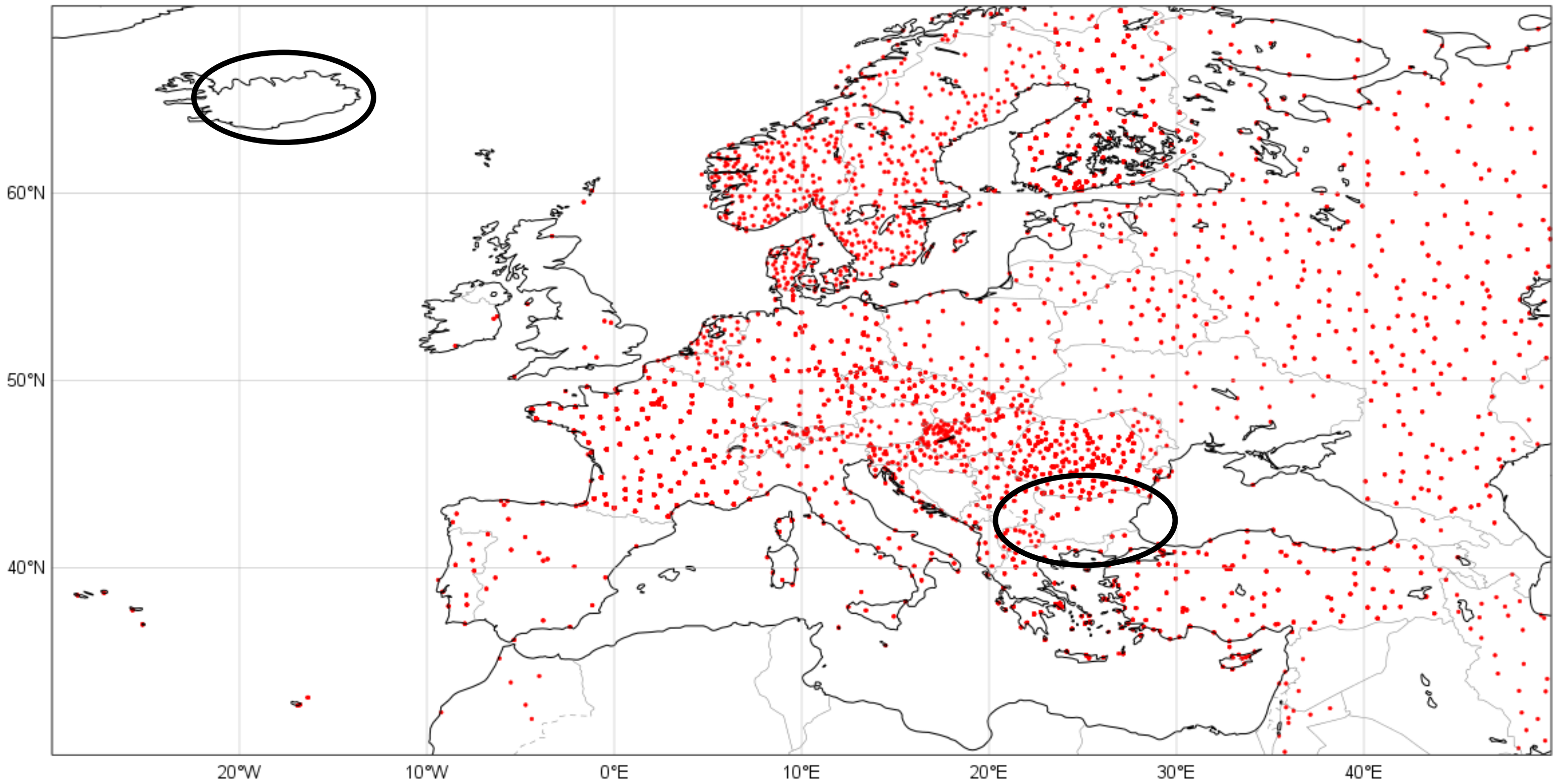
(de Rosnay et al. ECMWF Res. Memo, R48.3/PdR/1139, 2011)

Snow depth observations in Europe

GTS Snow depth availability

SYNOP + national BUFR data

Status on 5 February 2017



In general, good coverage in Europe, but …

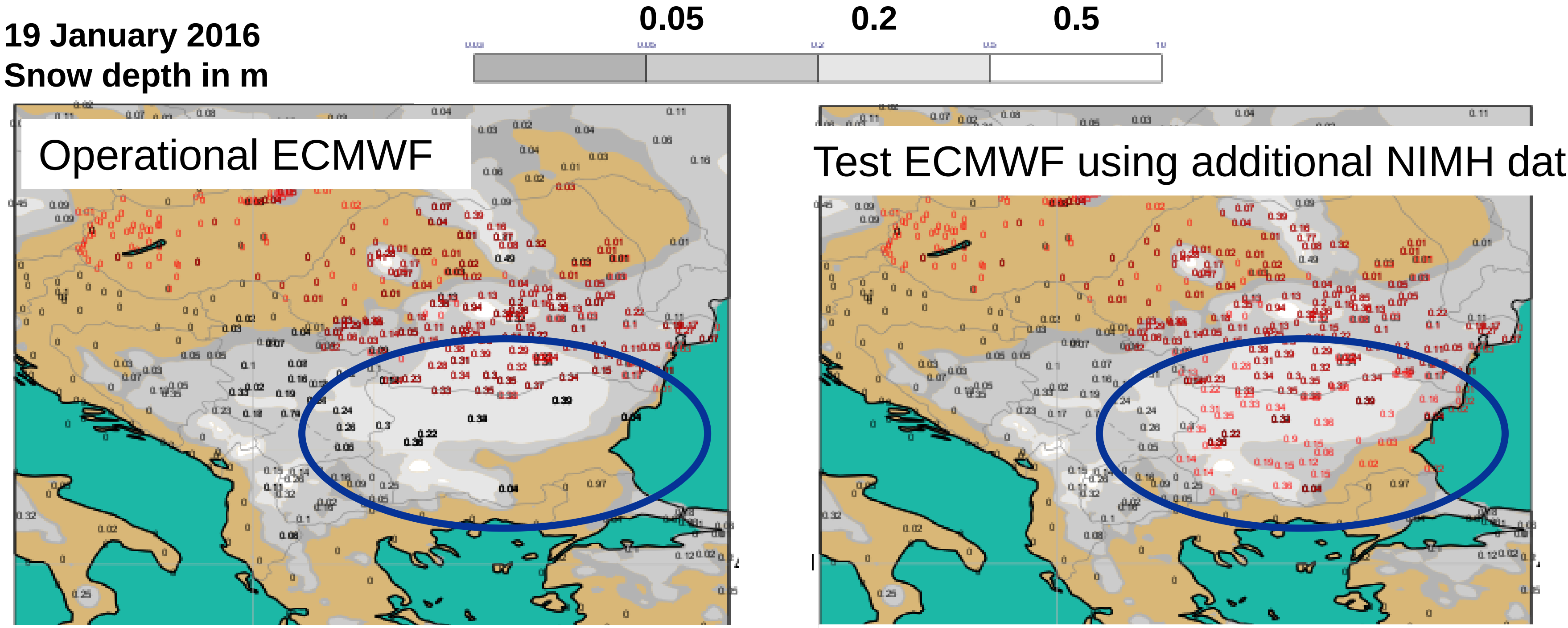
- Iceland : very few snow depth reports on the GTS (none for this date)
- Zero snow depth reporting is still an issue
- Bulgaria: more stations available but not on the GTS

Snow reports from Bulgaria (NIMH)

HarmoSnow COST action → contribute to improve in situ data exchange for NWP

→ NIMH: 39 additional stations (BUFR format, routinely produced)
→ ECMWF data acquisition, 1-month assimilation test
→ Suitable for operational use

19 January 2016
Snow depth in m



Lack of observations in Bulgaria

39 more stations provided by NIMH

de Rosnay et al.,
ECMWF Res Memo
RD16-178, June 2016

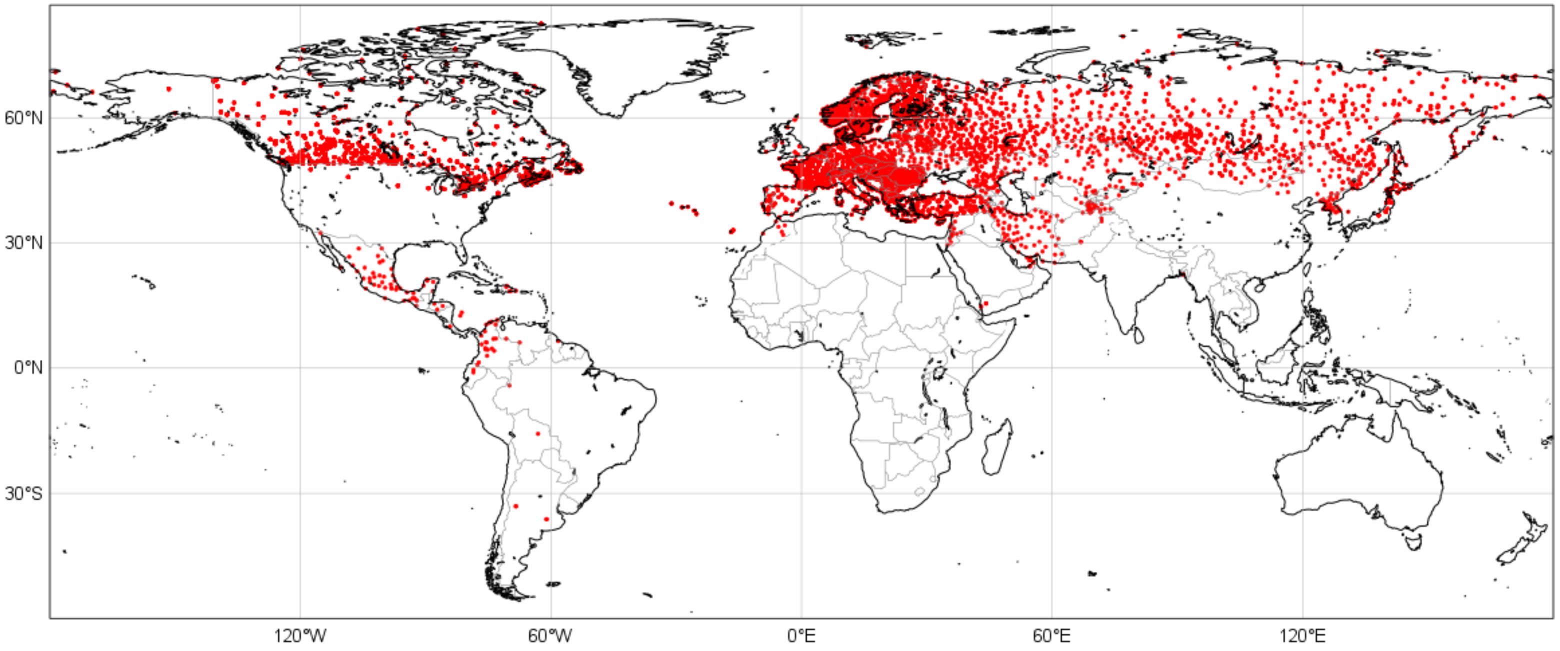
Technical aspects (data format, acquisition, assimilation) solved.
Bulgarian snow observations will be assimilated as soon as allowed by NIMH (data policy)

In situ snow depth observations

GTS Snow depth availability

SYNOP TAC + SYNOP BUFR + national BUFR data

Status on 5 February 2017



- Gap USA: NRT data exist and is available (more than 20000 station in the USA), but it is not on the GTS for NWP applications.
- Recent improvement in China (200 stations in north-East of China)

Snow depth Optimal Interpolation

Based on Brasnett, j appl. Meteo. 1999

1. Observed first guess departure ΔS_n are computed from the interpolated background at each observation location n.

2. Analysis increments ΔS_k^a at each model grid point k are calculated from:

$$\Delta S_k^a = \sum_{i=n}^{N} w_n \times \Delta S_n$$

3. The optimum weights w_n are given for each grid point k by: (**P** + **R**) **w** = **b**

p : **background error vector** between model grid point k and observation n (dimension of N observations) $p(n) = \sigma^2_{b\,.}\ \mu(n,k)$

P : correlation coefficient matrix of background field errors between all pairs of observations (N × N observations); $P(n_1,n_2) = \sigma^2_b \times \mu(n_1,n_2)$ with the correlation coefficients $\mu(n_1,n_2)$ and σ_b = 3cm the standard deviation of background errors.

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

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

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

Snow depth Optimal Interpolation

Correlation coefficients $\mu(n_1,n_2)$ (structure function):

$$\mu(n_1,n_2) = \left(1+\frac{r_{n_1 n_2}}{Lx}\right)\exp\left(-\left[\frac{r_{n_1 n_2}}{Lx}\right]\right).\exp\left(-\left[\frac{z_{n_1 n_2}}{Lz}\right]^2\right)$$

Lz; vertical length scale: 800m, **Lx:** horizontal length scale: 55km
$r_{n1,n2}$ and $Z_{n1,n2}$ the horizontal and vertical distances between points n_1 and n_2

Quality Control: reject observation if $\Delta S_n > Tol\,(\sigma_b^2 + \sigma_o^2)^{1/2}$ 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 :

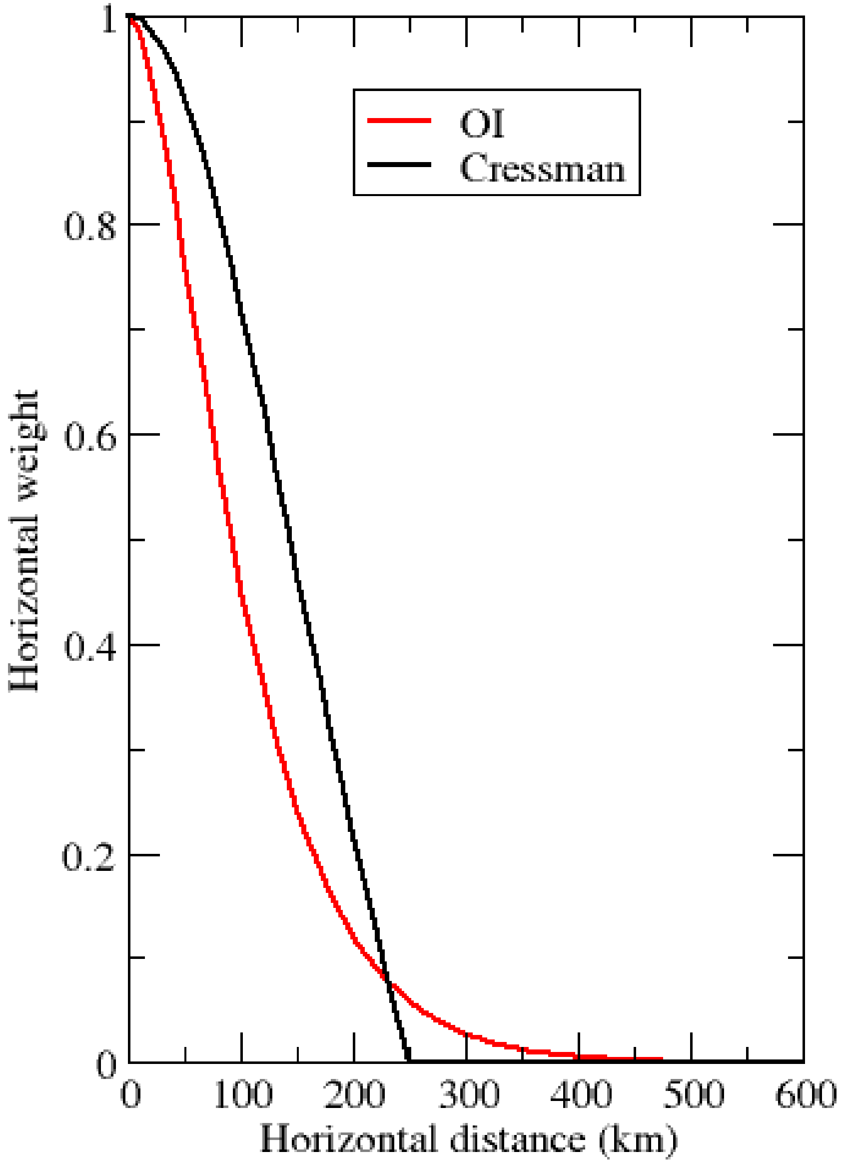
$$\Delta\ S_k^a = \sum_{n=1}^{N} w_n \times \Delta S_n$$

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

OI: The correlation coefficients of P and p 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



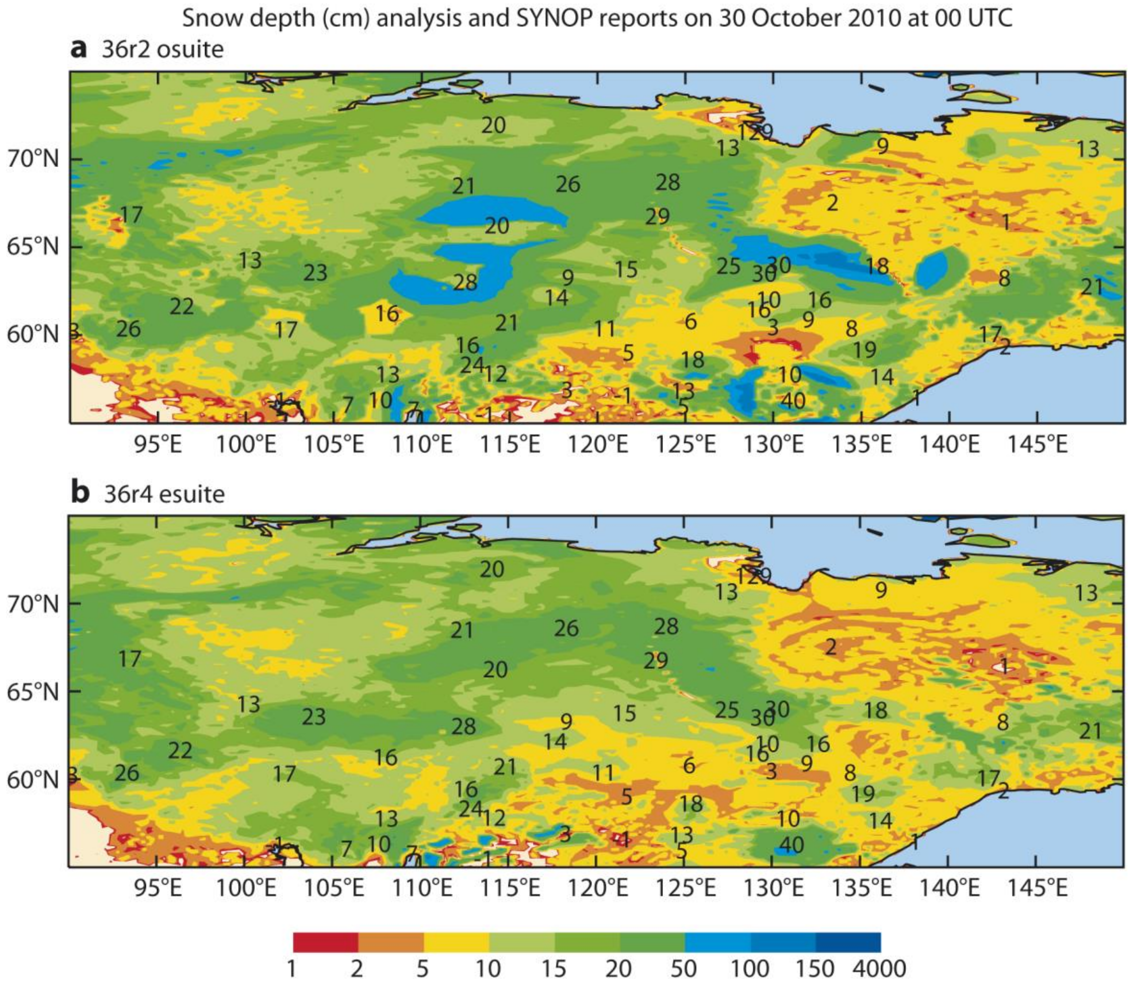
Snow Data assimilation

New snow analysis improves

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

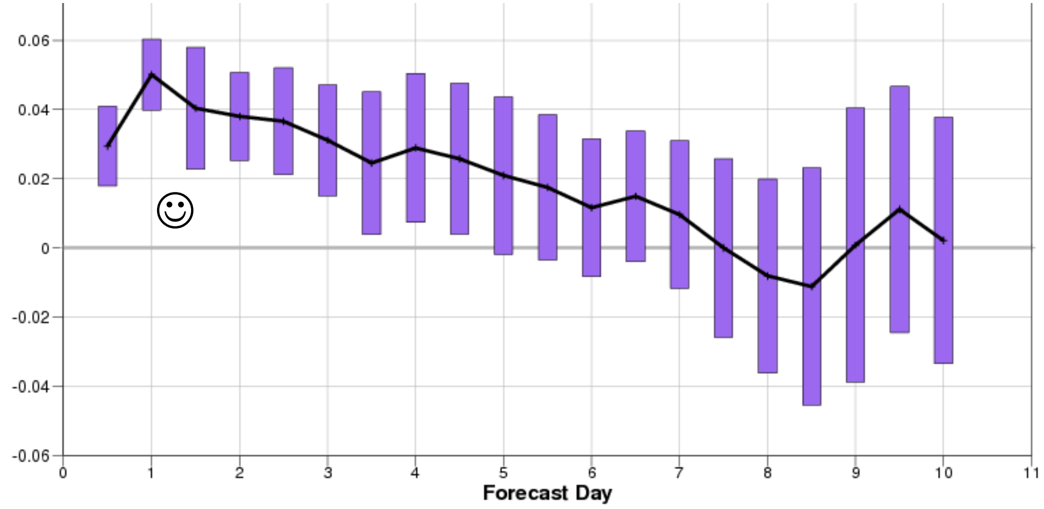
Old (before 2010):
Cressman+ IMS 24km

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)

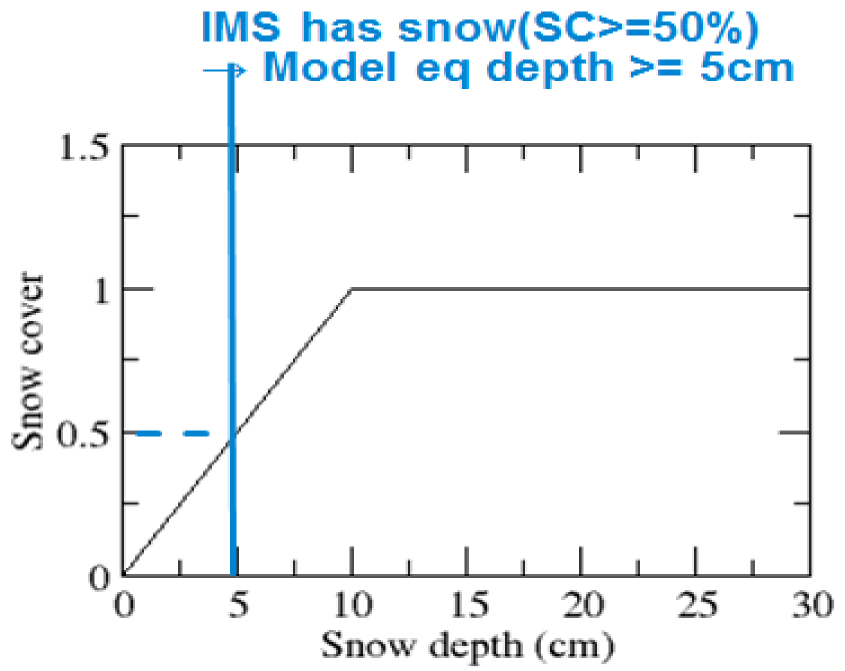
Assimilation of IMS snow cover

- 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

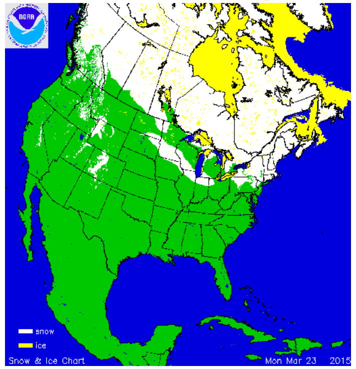


Model relation between SC and SD

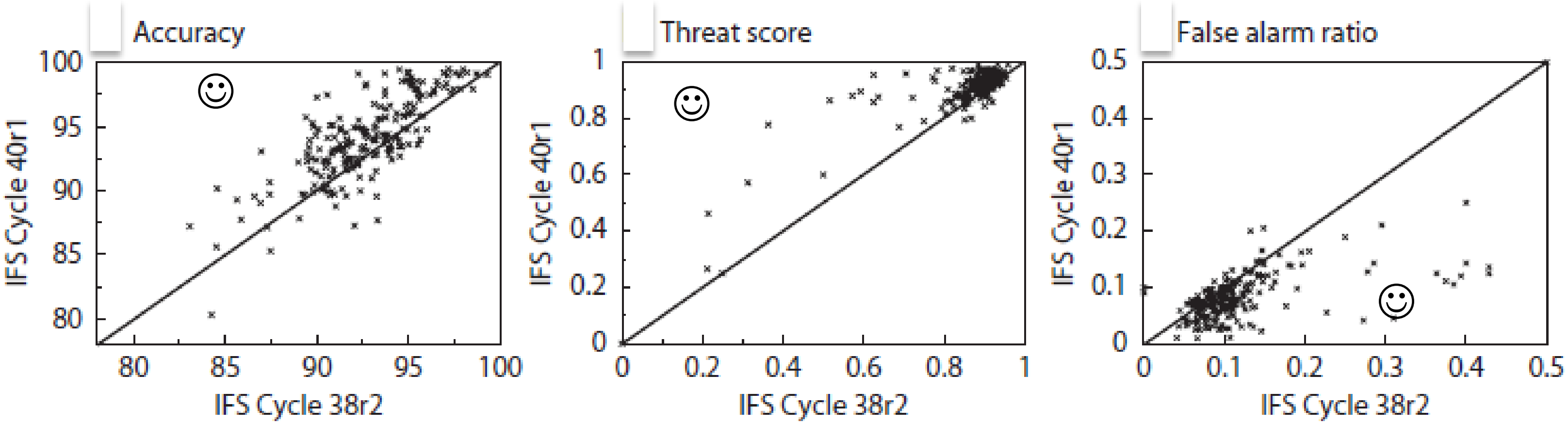
de Rosnay et al, ECMWF Newsletter 143, Spring 2015

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

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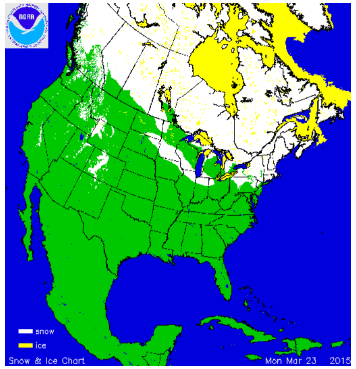

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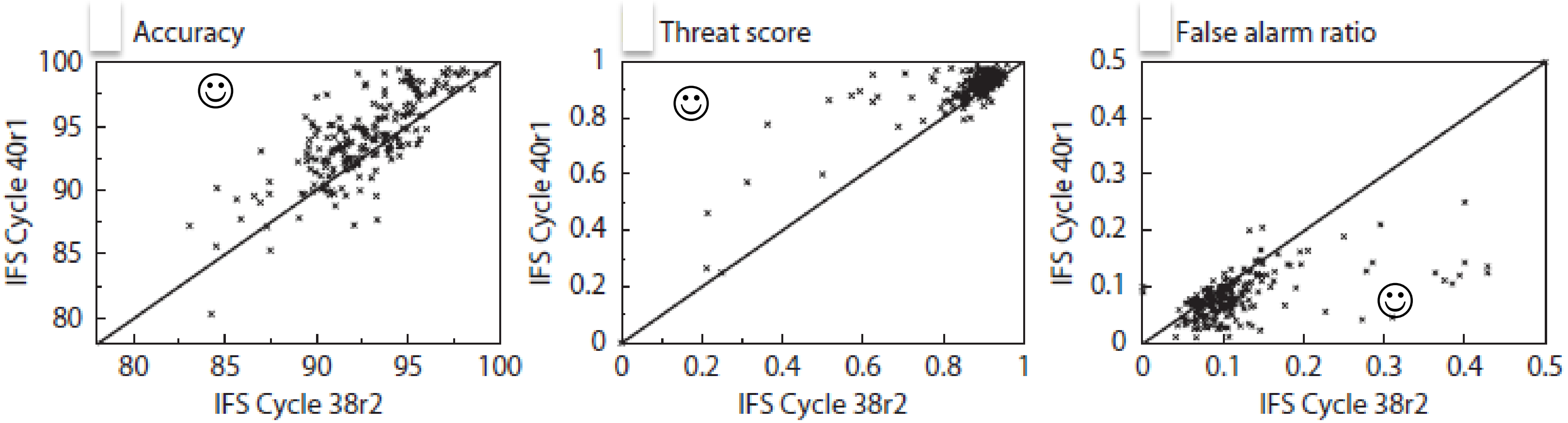
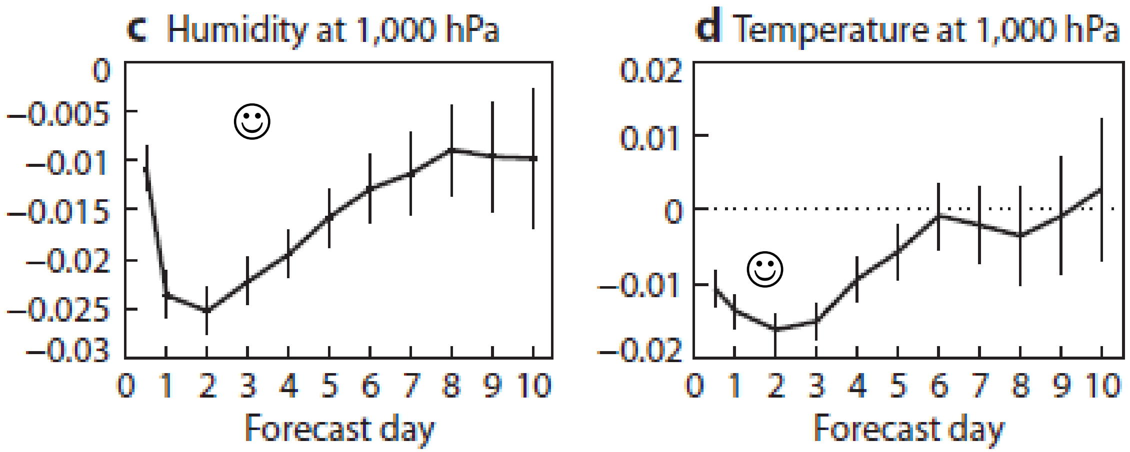


Impact on atmospheric forecasts

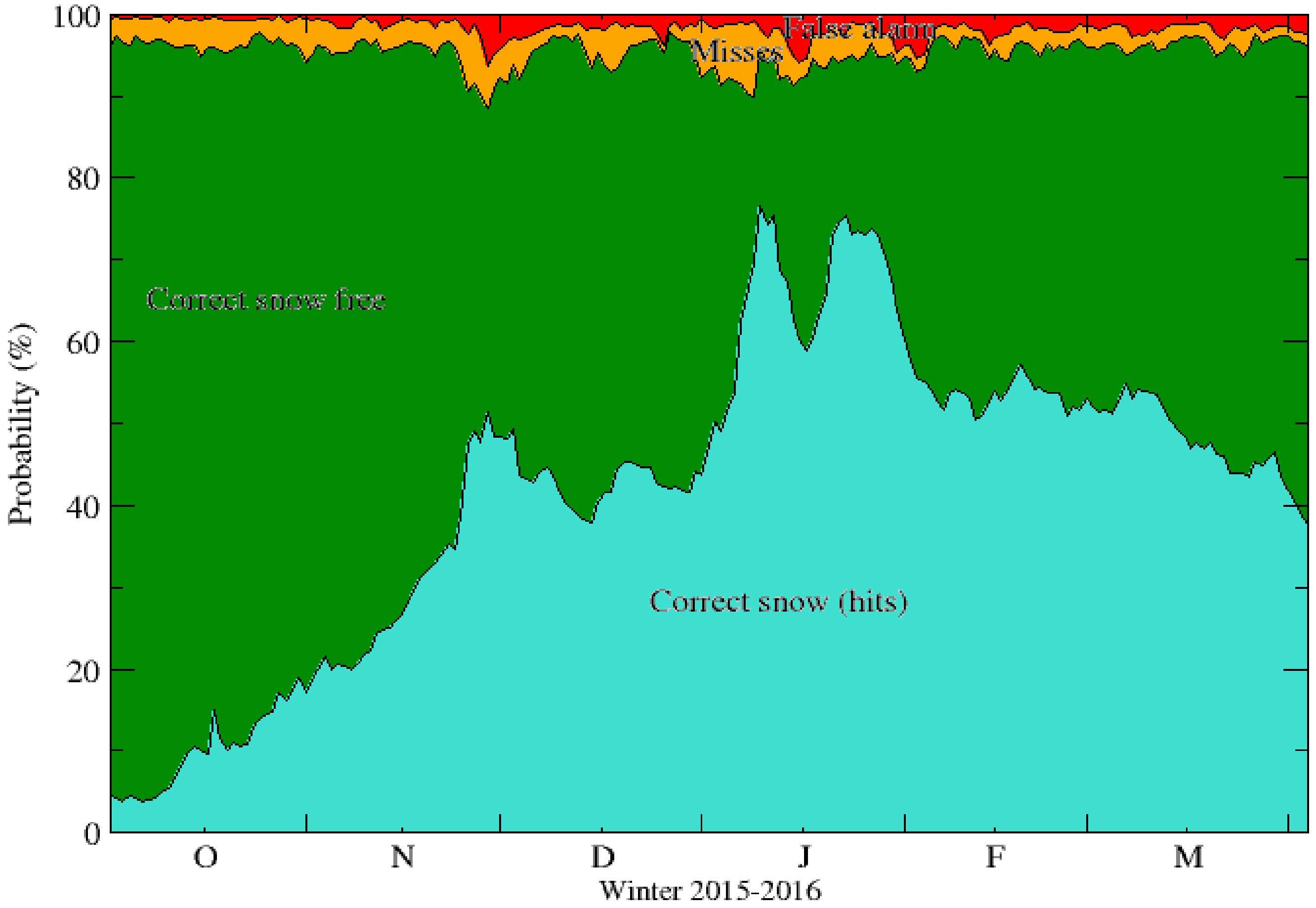
October 2012 to April 2013 (RMSE new-old)



→ Consistent improvement of snow and atmospheric forecasts

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

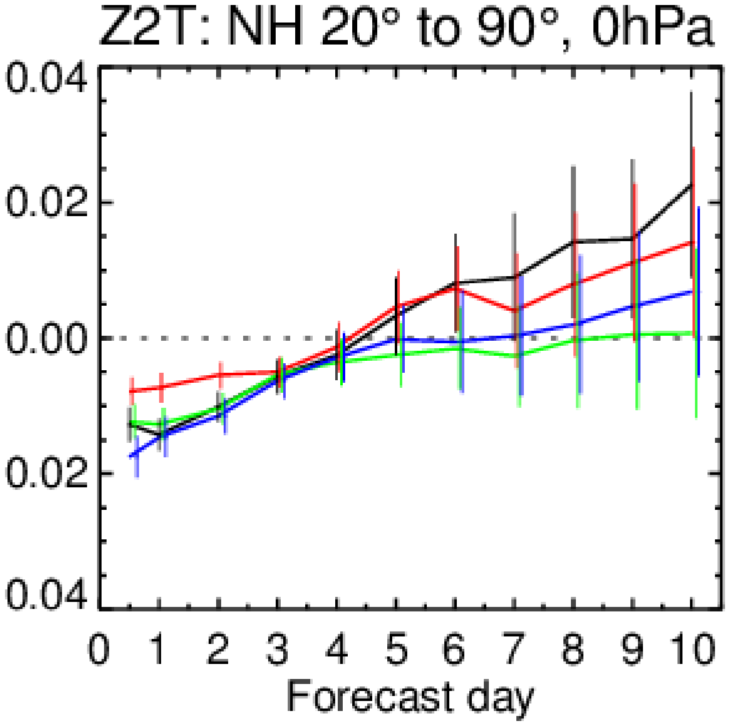
Operational snow analysis evaluation against in situ stations
North Hemisphere - winter 2015-2016



Observing System Experiments

Winter 2014-2015 (December to April) - Assess the impact of the snow observing system

Expts	SYNOP	National Data	IMS snow cover
0- OL (no snow data assimilation)			
1- Snow DA: SYNOP+IMS	✓		✓
2- Snow DA: SYNOP+Nat (all in situ)	✓	✓	
3- Snow DA SYNOP+Nat+IMS (all)	✓	✓	✓

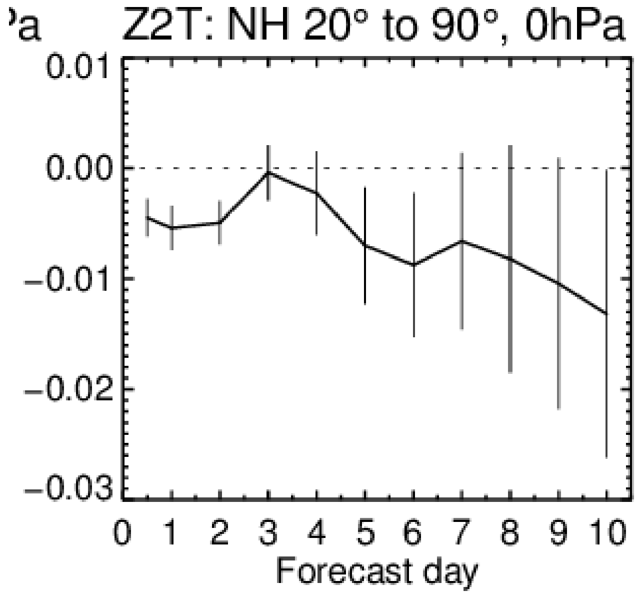


Impact on T2m Forecasts:
Normalized RMSE for T2m FC difference compared to the reference (OL)

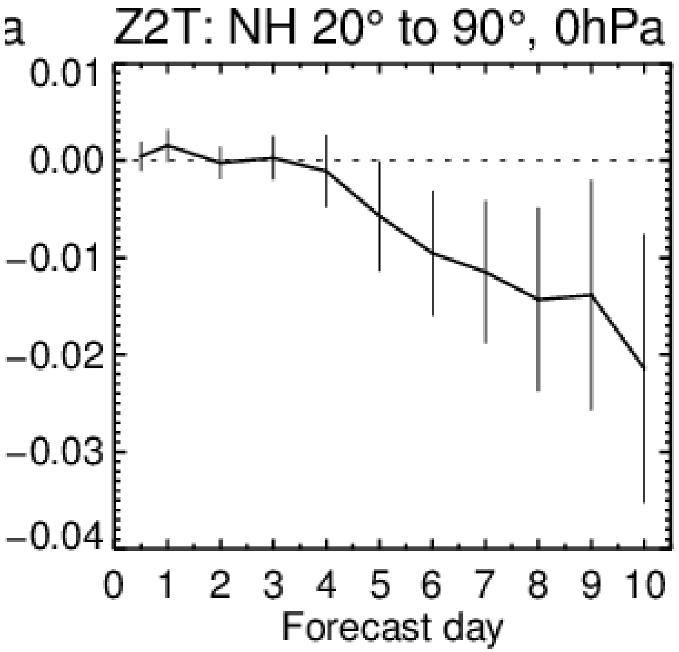
— SYNOP+IMS (1-0)
— SYNOP+Nat (2-0)
— SYNOP+Nat+IMS (3-0) -> oper

Best T2m Forecast when all observations, combining in situ and IMS, are assimilated.

Impact of IMS snow cover assimilation (case 3-2)



All data assimilated (Synop+Nat+IMS)
compared to all in situ data assimilated (SYNOP+Nat)
-> Further T2m forecasts error reduction,
significant at short range



Impact of National data (case 3-1)

All data assimilated (SYNOP+Nat+IMS)
compared to SYNOP+IMS assimilation
-> Further T2m forecasts error reduction at medium range

Contribution & complementarities of each observation types to improve T2m forecasts at short and medium ranges

Summary on Snow analysis

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

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

3. DA of *in situ* snow depth and snow cover (IMS used at ECMWF)
   - In situ snow depth reporting: issues on availability and reporting practices
   - National Met services encouraged to improve snow depth reports availability on the Global Telecommunication System (GTS)

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Soil Moisture – Atmosphere interactions

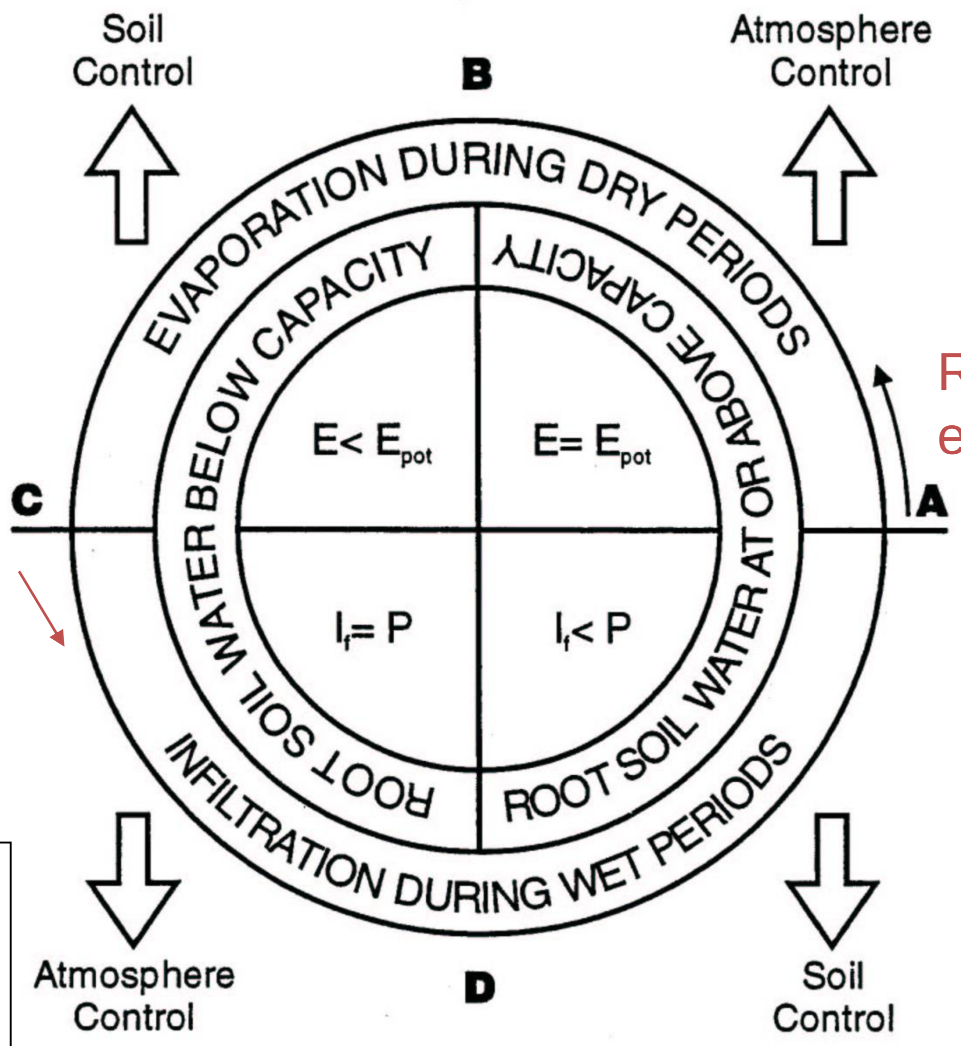
The hydrological ‘Rosette’ (P. Viterbo, PhD thesis, «The representation of surface processes in General Circulation Models » ECMWF, 1996)

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.



Rain ends

Rain starts

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

A history of soil moisture analysis at ECMWF

- **Nudging scheme (1995-1999): soil moisture increments Δx (m^3m^{-3}):**

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

D: nudging coefficient (constant=1.5g/Kg), Δt = 6h, q specific humidity
Uses upper air analysis of specific humidity
Prevents soil moisture drift in summer

- **Optimal interpolation 1D OI (1999-2010)**

$$\Delta x = \alpha \left(T^a - T^b\right) + \beta \left(Rh^a - Rh^b\right)$$

Mahfouf, ECMWF News letter 2000,
Douville et al., Mon Wea. Rev. 2000

α and β: optimal coefficients
OI soil moisture analysis based on a dedicated screen level parameters (T2m Rh2m) analysis

- **Simplified Extended Kalman Filter (EKF), Nov 2010**

Drusch et al., GRL, 2009
de Rosnay et al., QJRMS 2013

  - Motivated by better using T2m, RH2m
  - Opening the possibility to assimilate satellite data related to surface soil moisture.

Soil moisture related observations

1- Satellites

Active microwave data:
ASCAT: Advanced Scatterometer
On MetOP-A (2006-), MetOP-B (2012-)
C-band (5.6GHz)
NRT Surface soil moisture

Operational product
→ ensured operational continuity

Passive microwave data:
SMOS: Soil Moisture & Ocean Salinity
2009-
L-band (1.4 GHz)
NRT Brightness Temperature

Dedicated soil moisture mission
→ Strongest sensitivity to soil moisture

Active and Passive:
SMAP
L-band TB 2015-
Dedicated
soil moisture mission

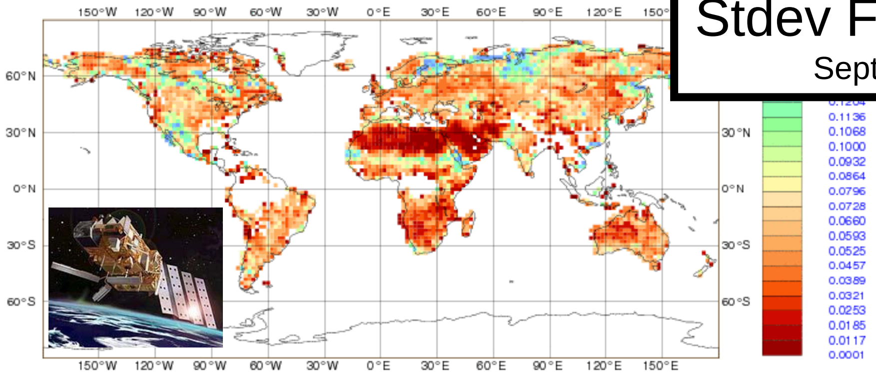
STATISTICS FOR SOIL MOISTURE FROM METOP-B/ASCAT

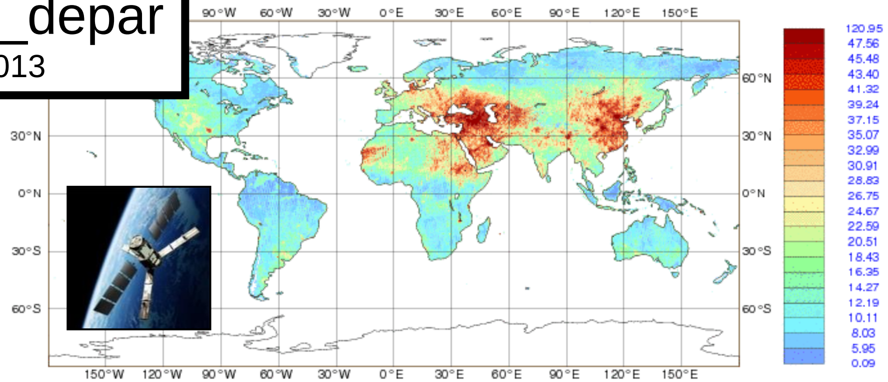
STATISTICS FOR RADIANCES FROM FROM SMOS

Operational Monitoring of surface soil moisture related satellite data:

ASCAT soil moisture (m^3m^{-3}) SMOS Brightness temperature (K)

Stdev FG_depar
Sept. 2013



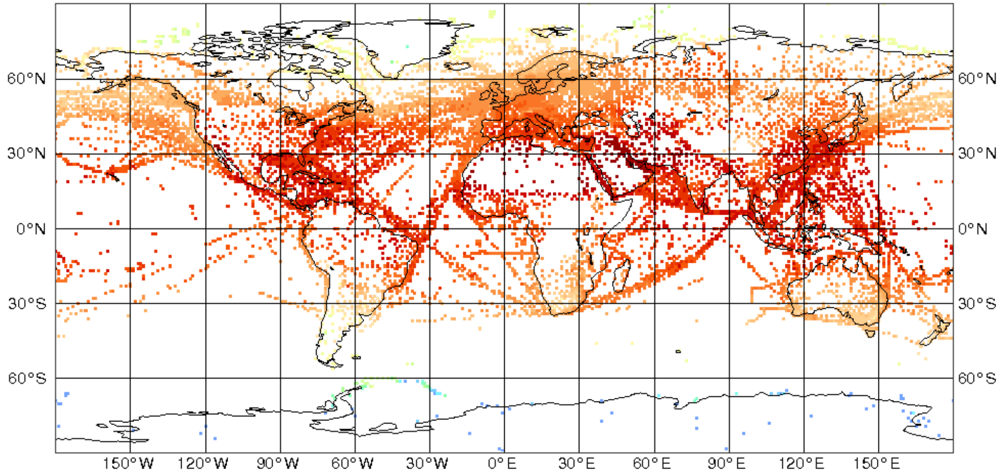


2- In situ:

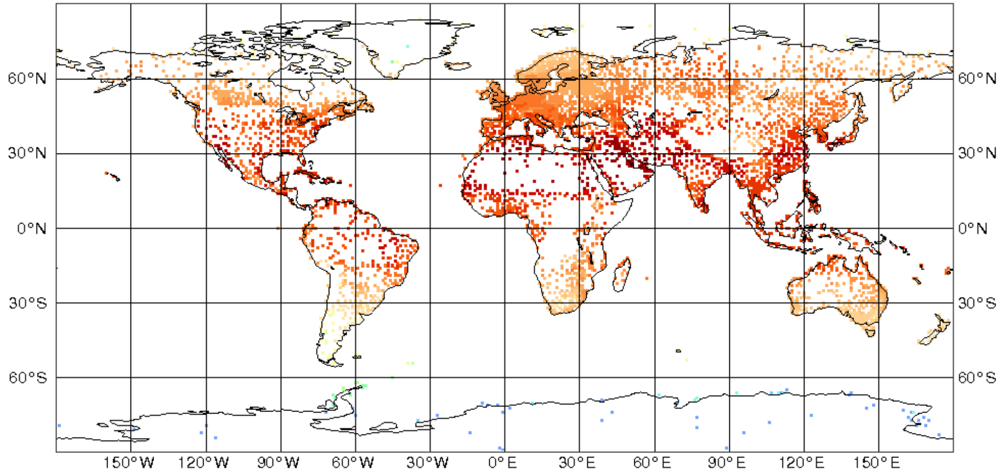
SYNOP two-meter Air temperature Relative humidity, T2m, RH2m

SYNOP T2m, RH2m in situ data assimilated in a 2D-OI

Ocean and Land observations



Used for Land Data Assimilation



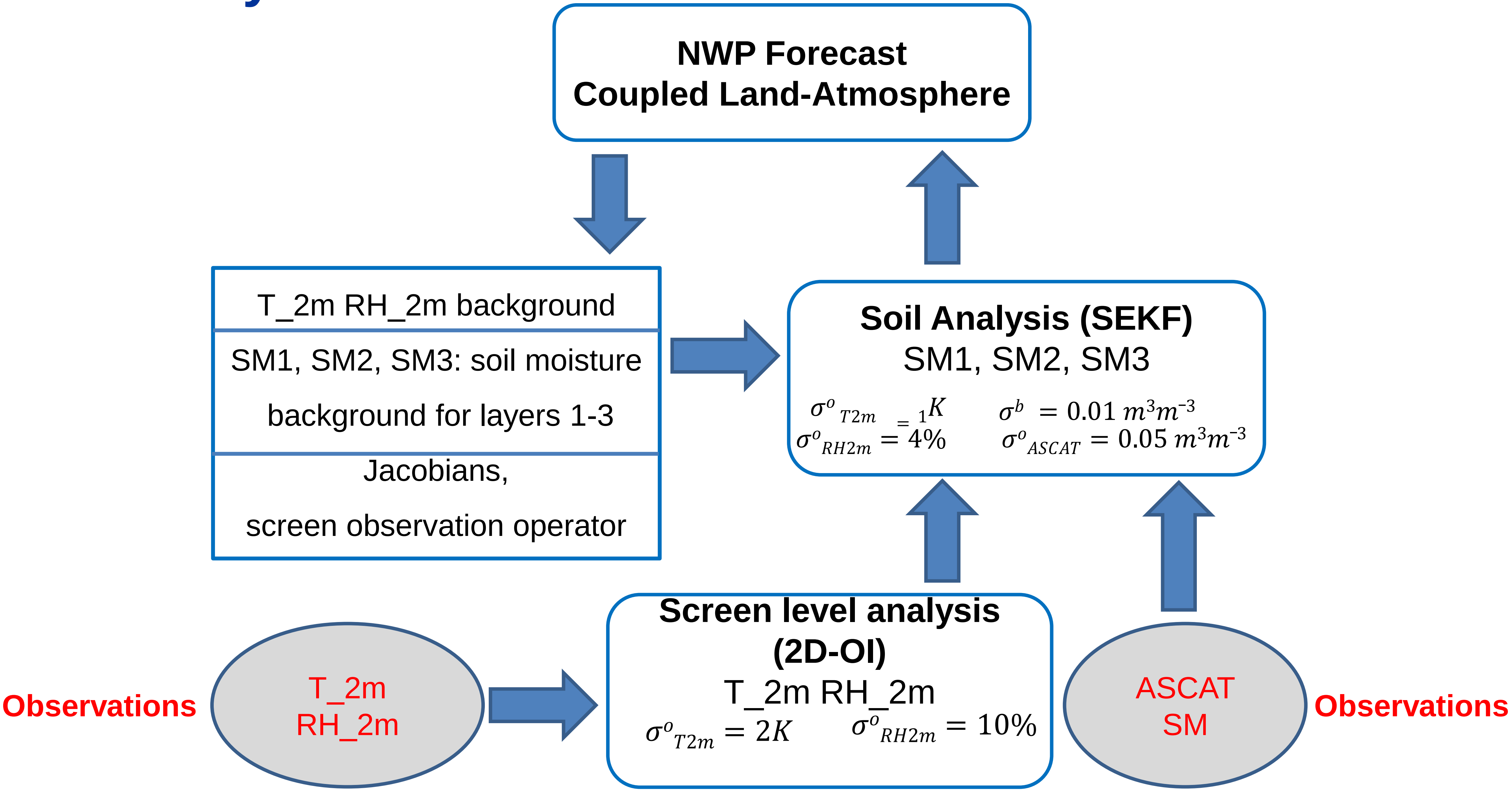
Screen level observations are: two meter temperature and relative humidity. Observations are available on the GTS:

Diversity of Report types:

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

Analysed T2m, RH2m (output of the 2D-OI) is used as input of the soil analysis

Soil Analysis for NWP



NWP Forecast
Coupled Land-Atmosphere

T_2m RH_2m background

SM1, SM2, SM3: soil moisture background for layers 1-3

Jacobians, screen observation operator

Soil Analysis (SEKF)
SM1, SM2, SM3

$\sigma^{o}{}_{T2m} = 1K$ $\quad \sigma^{b} = 0.01\ m^{3}m^{-3}$

$\sigma^{o}{}_{RH2m} = 4\%$ $\quad \sigma^{o}{}_{ASCAT} = 0.05\ m^{3}m^{-3}$

Screen level analysis (2D-OI)
T_2m RH_2m

$\sigma^{o}{}_{T2m} = 2K$ $\quad \sigma^{o}{}_{RH2m} = 10\%$

Observations

T_2m
RH_2m

ASCAT
SM

Observations

Simplifed EKF soil moisture analysis

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

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

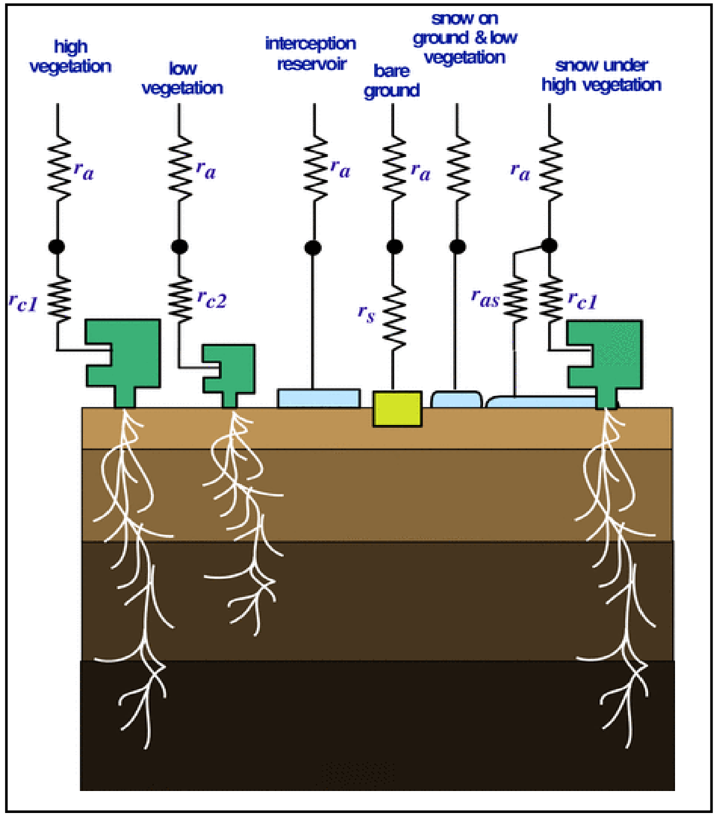
$\boldsymbol{x}$ background soil moisture state vector,
$\mathcal{H}$ non linear observation operator
$\boldsymbol{y}$ observation vector
$\boldsymbol{K}$ Kalman gain matrix, fn of
H (linearsation of $\mathcal{H}$), **P** and **R** (covariance matrices of background and observation errors).

Used at ECMWF (operations and ERA5), DWD, UKMO

Observations used at ECMWF:
For operational NWP:

- Conventional SYNOP pseudo observations (analysed T2m, RH2m)
- Satellite MetOp-A/B ASCAT soil moisture
- SMOS brightness temperature

The simplified EKF is used to corrects the soil moisture trajectory of the Land Surface Model



Drusch et al., GRL, 2009
de Rosnay et al., ECMWF News Letter 127, 2011
de Rosnay et al., QJRMS, 2013

Simplifed EKF soil moisture analysis

$$X_t^a = x_t^b + K\,(y_t - \mathcal{H}[x_t^b])$$

Elements of the SEKF for each individual grid point in the case of assimilation of T2m, RH2m, ASCAT:

Control vector

$$\boldsymbol{x}b_{(t)} = \begin{bmatrix} SM_{l1(t)} \\ SM_{l2(t)} \\ SM_{l3(t)} \end{bmatrix}$$

Observations vector

$$y_{(tobs)} = \begin{bmatrix} T_{2m} \\ RH_{2m} \\ ASCAT_{sm} \end{bmatrix} \begin{matrix} [\mathrm{K}] \\ [\%] \\ [\mathrm{m}^3/\mathrm{m}^3] \end{matrix}$$

Observations operator

$$\mathcal{H}[x_b^t]) = \begin{bmatrix} T_{2m} \\ TH_{2m} \\ SM_{top} \end{bmatrix}$$

SM: volumetric soil moisture of the model layers in m3/m3

Background error

$$\mathbf{P} = \begin{bmatrix} 0.01^2 & 0 & 0 \\ 0 & 0.01^2 & 0 \\ 0 & 0 & 0.01^2 \end{bmatrix}$$

Observation error

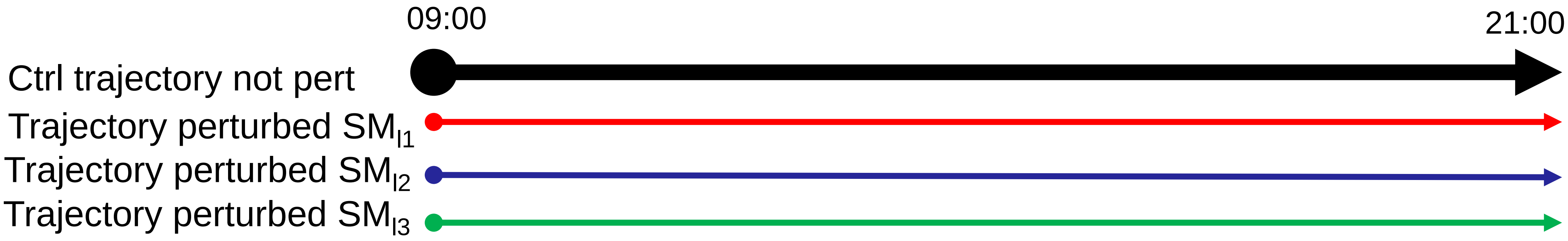
$$\mathbf{R} = \begin{bmatrix} 1^2 & 0 & 0 \\ 0 & 4^2 & 0 \\ 0 & 0 & 0.05^2 \end{bmatrix}$$

Simplifed EKF soil moisture analysis

Jacobians computation

Estimated by finite differences by perturbing individually each component x_j of the control vector **x** by a small amount δx_j . One perturbed model trajectory is computed for each control valriable

In the ECMWF soil analysis the perturbation size is set to $0.01 m^3 m^{-3}$



09:00

21:00

Ctrl trajectory not pert

Trajectory perturbed SM_{l1}

Trajectory perturbed SM_{l2}

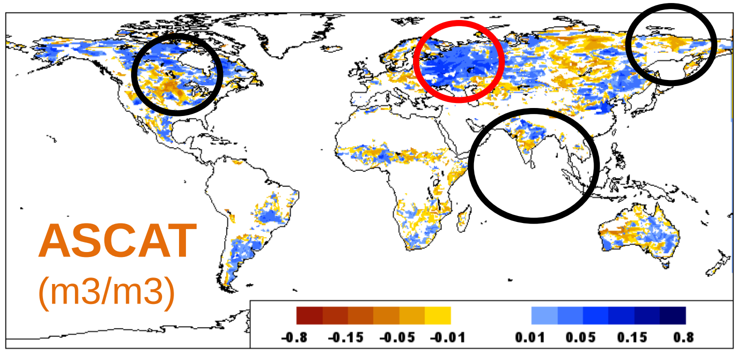
Trajectory perturbed SM_{l3}

$$H=\begin{bmatrix} \frac{T_{2m}pert1-T_{2m}}{\delta SM_{l1}} & \frac{T_{2m}pert2-T_{2m}}{\delta SM_{l2}} & \frac{T_{2m}pert3-T_{2m}}{\delta SM_{l3}} \\ \frac{RH_{2m}pert1-RH_{2m}}{\delta SM_{l1}} & \frac{RH_{2m}pert2-RH_{2m}}{\delta SM_{l2}} & \frac{RH_{2m}pert3-RH_{2m}}{\delta SM_{l3}} \\ \frac{SM_{l1}pert1-SM_{l1}}{\delta SM_{l1}} & \frac{SM_{l1}pert2-SM_{l1}}{\delta SM_{l2}} & \frac{SM_{l1}pert3-SM_{l1}}{\delta SM_{l3}} \end{bmatrix}$$

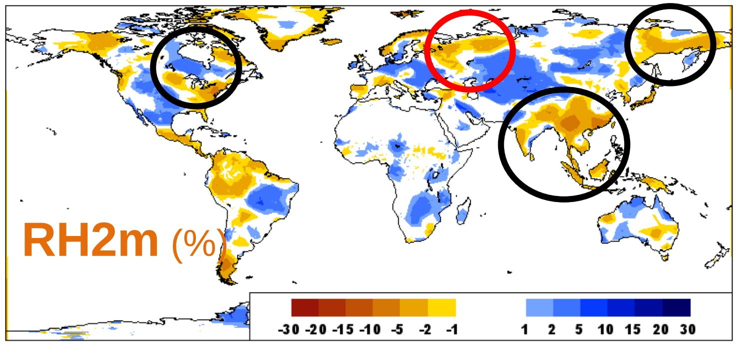
Soil Moisture data assimilation for NWP

Innovation (Obs- model)

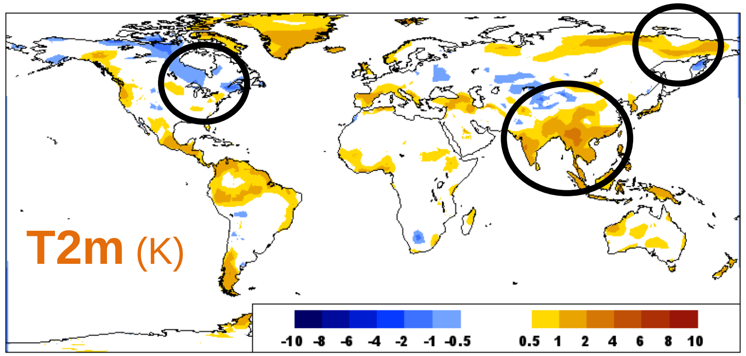
25-30 June 2013



ASCAT (m3/m3)



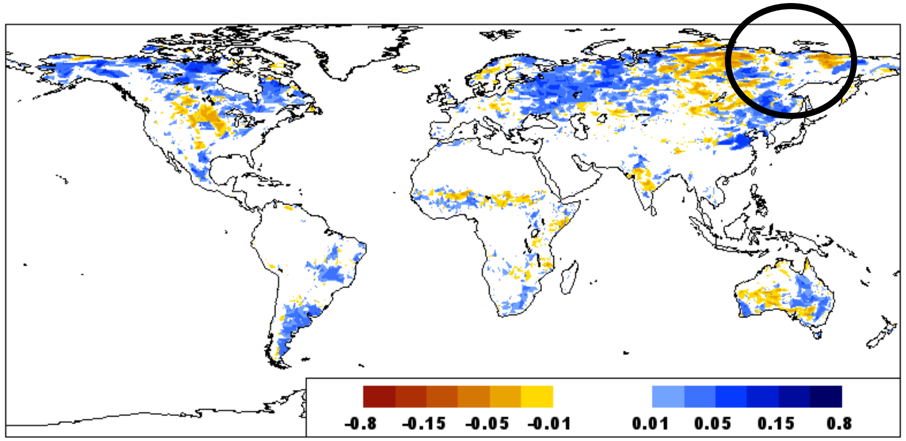
RH2m (%)



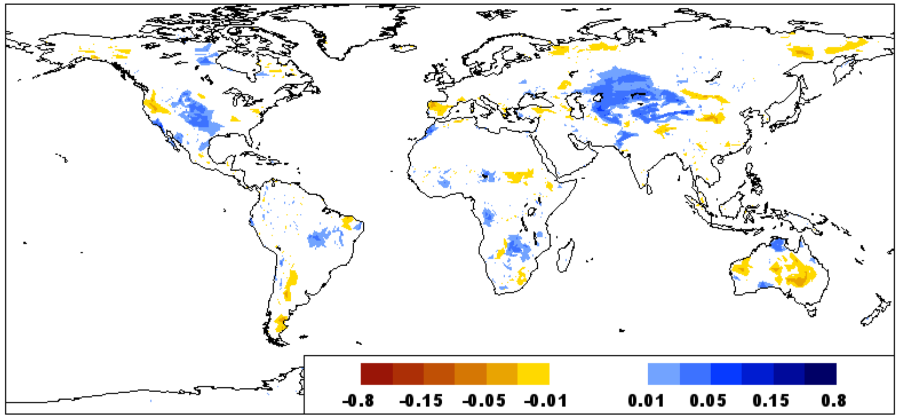
T2m (K)

Accumulated Increments (m^3/m^3)

in top soil layer (0-7cm)



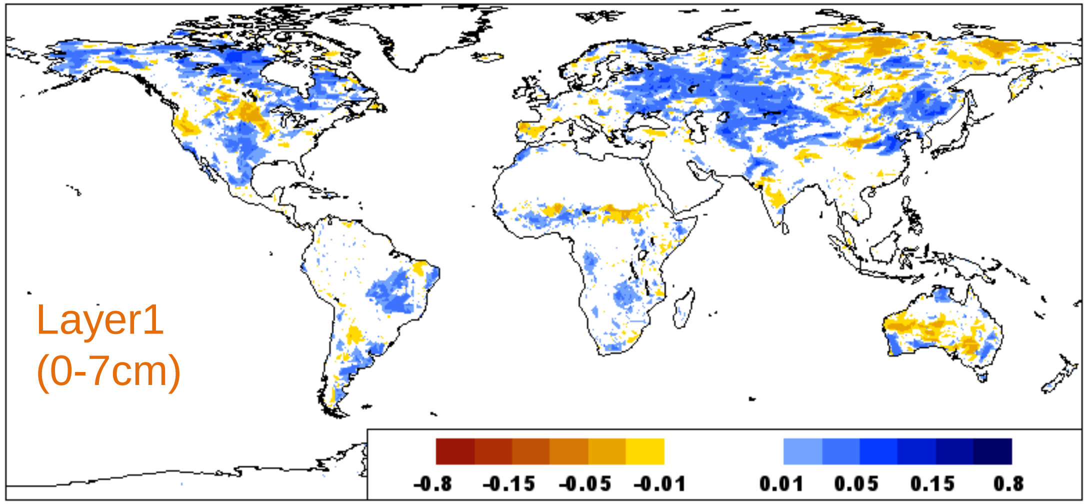
Due to ASCAT

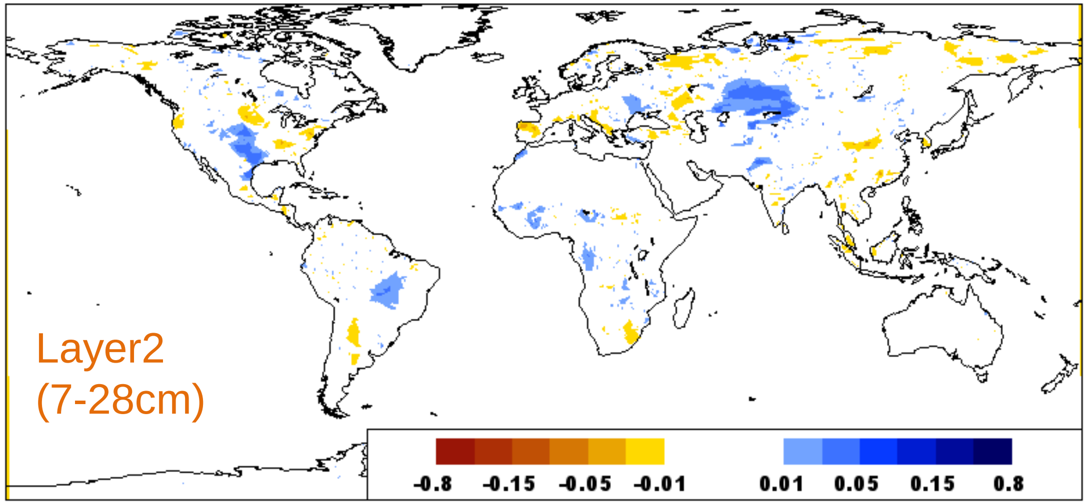


Due to SYNOP T2m and RH2m

ASCAT Soil Moisture data assimilation for NWP

Volumetric Soil Moisture increments (m^3/m^3) (accumulated) 25-30 June 2013



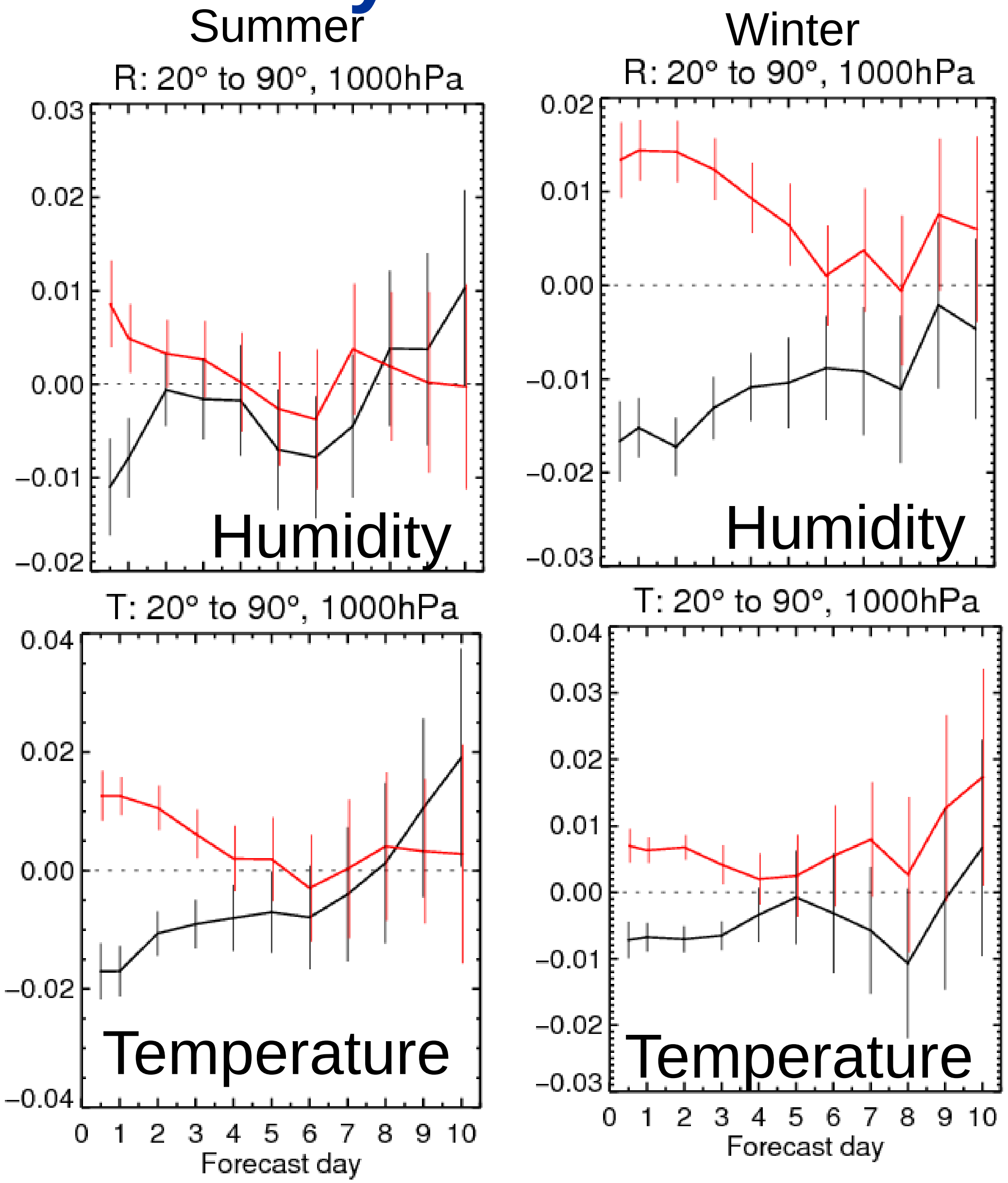


Vertically integrated Soil Moisture increments (stDev in mm)

	SYNOP	ASCAT
Layer 1	0.68	**1.43**
Layer 2	**1.48**	0.68
Layer 3	**4.28**	0.46

ASCAT more increments than SYNOP at surface
SYNOP give more increments at depth
→ For 12h DA window, link obs to root zone stronger for T2m,RH2m than for surface soil moisture observations

Soil Analysis for NWP: Impact on the forecast ?



— **No soil Analysis**

----- **zero line (ref): IFS cycle 40r1 (2013)**

— **IFS cycle 41r1 (2015)**
(revised soil analysis observation errors)

→ Very large impact of soil moisture initialisation on near-surface weather forecast

Soil moisture related observations

1- Satellites

Active microwave data:

ASCAT: Advanced Scatterometer

On MetOP-A (2006-), MetOP-B (2012-)

C-band (5.6GHz)

NRT Surface soil moisture

Operational product

→ ensured operational continuity

Passive microwave data:

SMOS: Soil Moisture & Ocean Salinity

2009-

L-band (1.4 GHz)

NRT Brightness Temperature

Dedicated soil moisture mission

→ Strongest sensitivity to soil moisture

Active and Passive:

SMAP

L-band TB 2015-

Dedicated

soil moisture mission

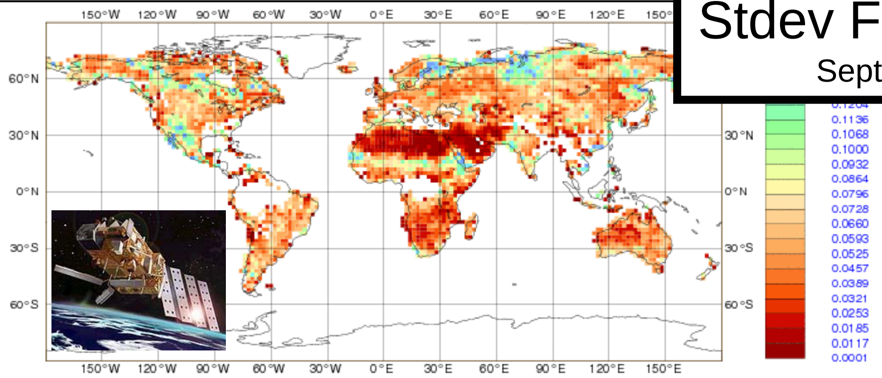
Operational Monitoring of surface soil moisture related satellite data:

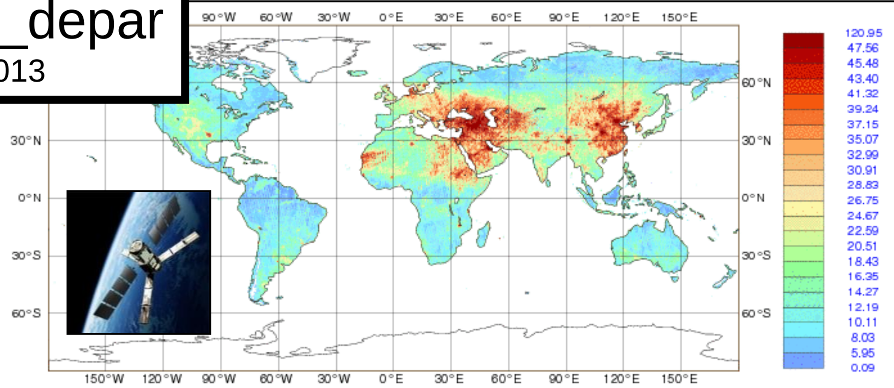
ASCAT soil moisture (m^{3}m^{-3})

SMOS Brightness temperature (K)

Stdev FG_depar

Sept. 2013





2- In situ:

SYNOP two-meter

Air temperature

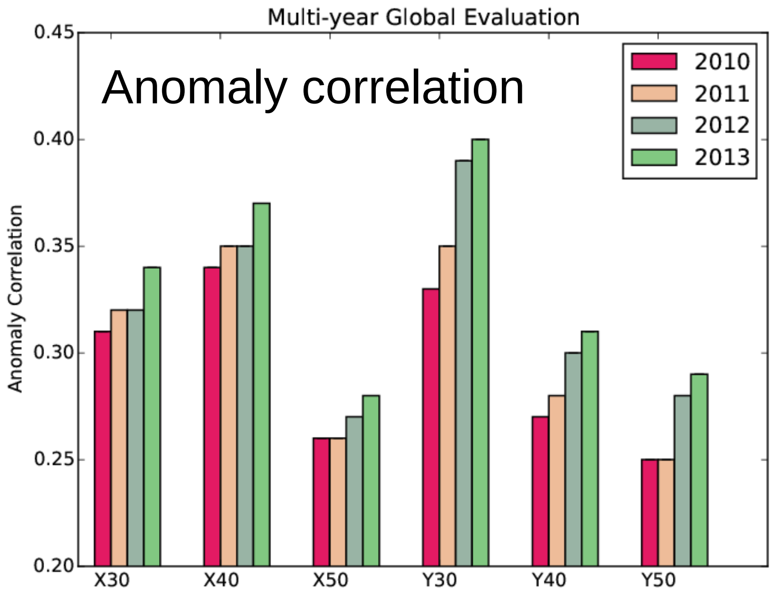
Relative humidity,

T2m, RH2m

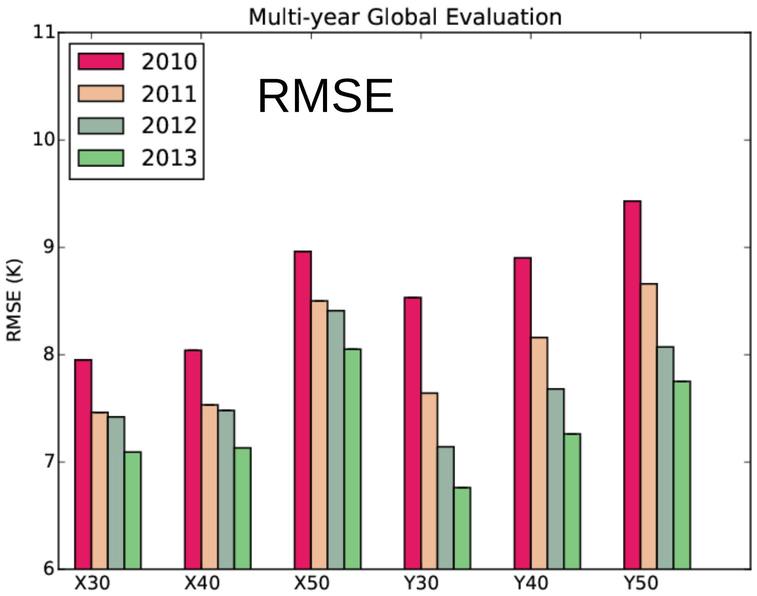
Use of Brightness Temperatures
→ SMOS Forward modelling

- CMEM: ECMWF Community Microwave Emission Modelling Platform
  → produce reprocessed ECMWF SMOS TB for 2010-2013
- Comparison between ECMWF TB and SMOS NRT TB (both reprocessed)
- **Consistent improvement of SMOS data at Pol xx and yy, for incidence angles 30, 40, 50 degrees**

Comparison between forward ECMWF and observed SMOS brightness temperatures



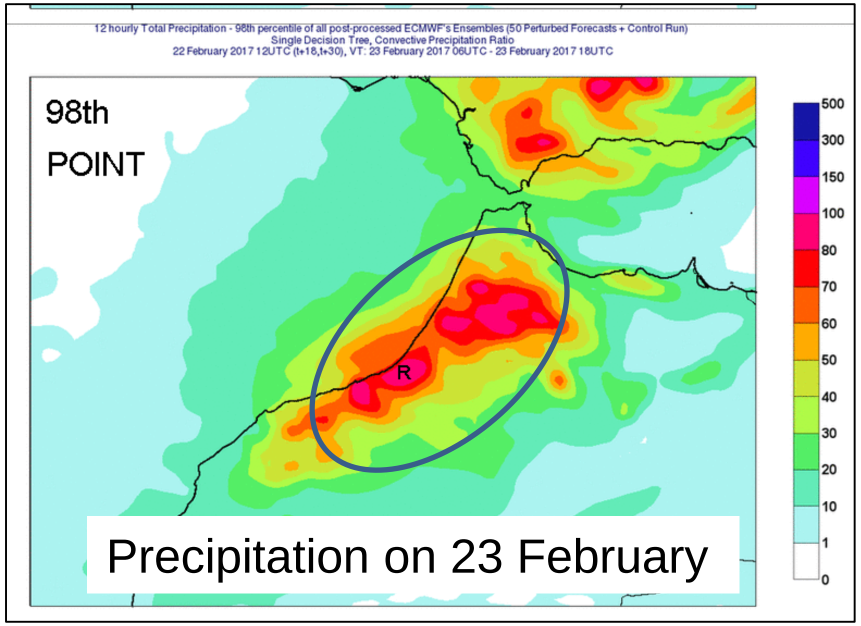
Polarisation (xx or yy) and incidence angle (30, 40, 50)



Polarisation (xx or yy) and incidence angle (30, 40, 50)

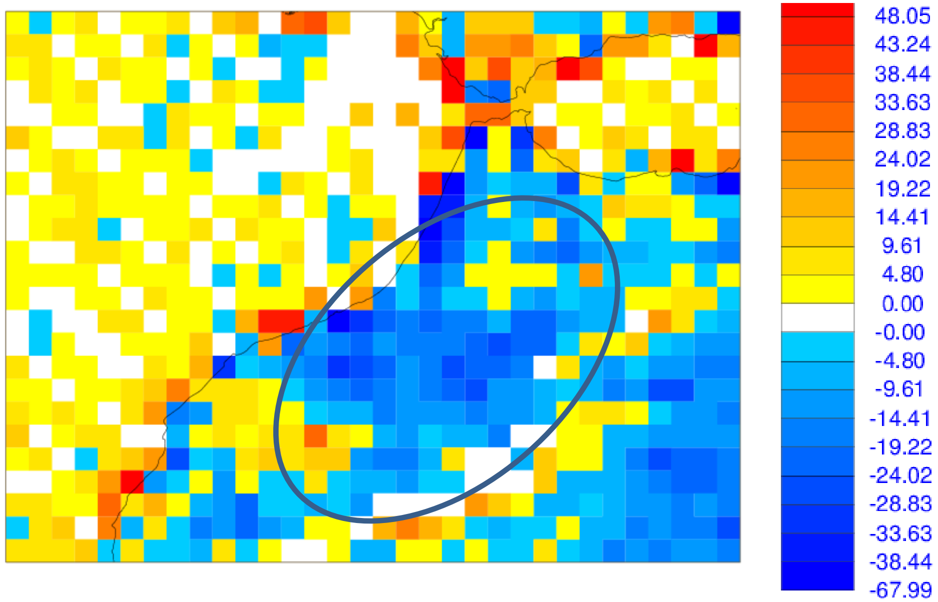
SMOS in the IFS

Moroccan flood February 2017

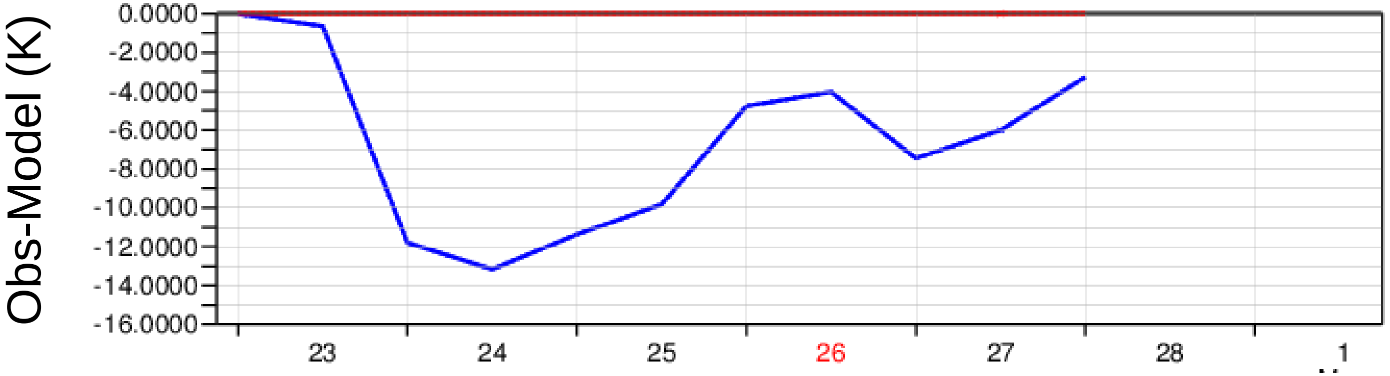


Precipitation on 23 February

SMOS TBh (30degrees) 23-28 Feb
Mean First Guess departure: Obs-Model (K)



Blue indicates that ECMWF is **too dry**, according to SMOS.



First guess departure (Obs-Model) Morocco, 23-28 Feb 2017

Summary

- ➢ Most NWP centres analyse soil moisture and/or snow depth
- ➢ Land Data Assimilation Systems: run separately from the atmospheric data assimilation, but first guess forecast is coupled → weakly coupled assimilation
- ➢ Variety of approaches for snow and soil moisture

- ➢ **Operational snow analysis systems:**
  - Rely on simple analysis methods (Cressman, 2D-OI, or climatology)
  - Uses in situ snow depth data (SYNOP and national networks) and NOAA/NESDIS snow cover data
  - No Snow Water Equivalent products used for NWP (yet)

Summary

Operational Soil Moisture analysis systems for NWP:

- **Approaches**: **1D-OI** (Météo-France, CMC, ALADIN, HIRLAM, ECMWF ERA-I); **EKF** (DWD, ECMWF, UKMO); **Offline Land Surface Model (LSM)** using analysed atmospheric forcing (NCEP: GLDAS / NLDAS)

- **Data**: Most Centres rely on screen level data (**T2M and RH2m**) through a dedicated OI analysis, **ASCAT** (UKMO, ECMWF NWP & EUMETSAT H-SAF)

- Compared to the OI, the EKF analysis improves both Soil Moisture and T2m:

→ Relevance of screen level parameters to analyse soil moisture (ECMWF,CMC)

→ Consistency in the Land surface models between soil moisture and screen level parameters

Summary and future plans

- Developments of multi-variate and ensemble approaches (ECMWF, CMC, Météo-France)
- Continuous developments to assimilate ASCAT soil moisture and SMOS brightness temperature in NWP systems
- Ongoing development to use of new satellites, e.g. NASA SMAP (launched January 2015)
- Assimilation of vegetation parameters (Leaf Area Index)
- Increase coupling between land and atmospheric assimilation

- Long term perspectives:
    - Importance of horizontal processes (river routing)
    - Assimilation of integrated hydrological variables such as river discharges: e.g. Surface Water Ocean Topography (e.g. SWOT 2020)

Thank you for your Attention!

Useful links:

ECMWF LDAS: https://software.ecmwf.int/wiki/display/LDAS/LDAS+Home

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