Earth Observation for Water Cycle Science 2015
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Assimilation of land surface satellite data for Numerical Weather Prediction at ECMWF

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Introduction: Land Surface for Numerical Weather Prediction (NWP)

Land surfaces:

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

whose high quality forecast is a key objective in NWP

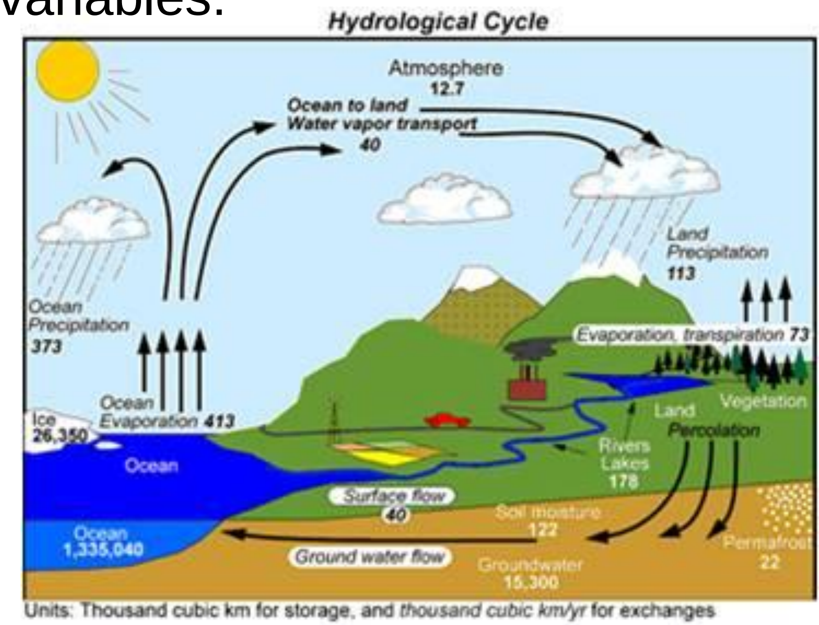
Land Surface Models (LSMs) prognostic variables:

- Soil moisture
- Soil temperature
- Snow mass, temperature, density

Land surface initialization

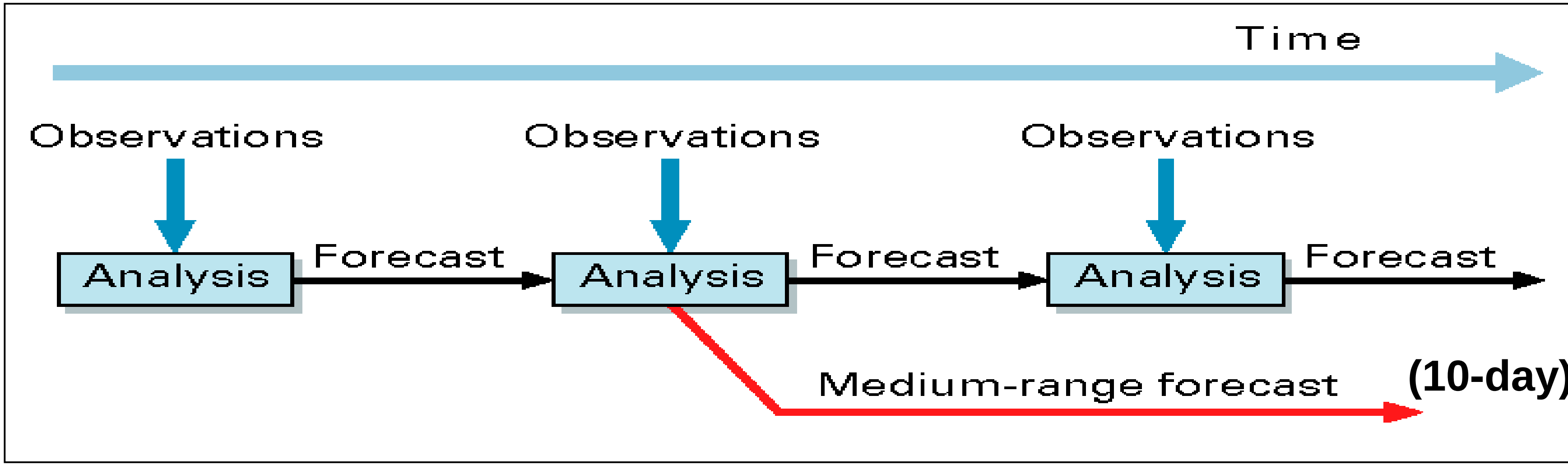
Important for NWP & Seasonal Prediction

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



Trenberth et al. (2007)

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**
  - **Land Data Assimilation System**

Introduction:
Land Surface Data Assimilation (LDAS)

Snow depth

- Methods: Cressman (DWD, ECMWF ERA-I), 2D Optimal Interpolation (OI) (ECMWF, CMC, JMA)
- **Conventional observations**: *in situ* snow depth
- **Satellite data**: **NOAA/NESDIS IMS Snow Cover**

Soil moisture (SM)

- Methods:
  - 1D Optimal Interpolation (Météo-France, ALADIN and HIRLAM)

  Analytical nudging approach (BoM), EnsOI CMC
  - Simplified Extended Kalman Filter (EKF) (DWD, ECMWF, UKMO)
- **Conventional observations**: Analysed SYNOP 2m air relative humidity and air temp.
- **Satellite data**: **EUMETSAT ASCAT soil moisture (UKMO, ECMWF),**

  ESA SMOS brightness temperature development (ECMWF, UKMO, CMC),

  NASA SMAP development

Soil Temperature and Snow Temperature 1D-OI using analysed T2m as observation

Snow data assimilation

Snow Model: Component of H-TESSEL

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

- Snow water equivalent SWE (m), ie snow mass
- Snow density ρs, between 100 and 400 kg/m3

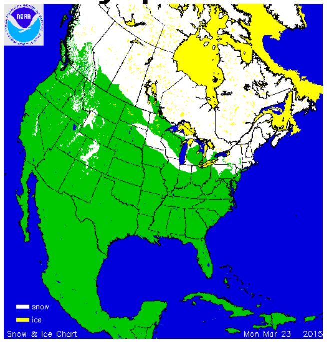
} **Prognostic variables**

Observations:

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

de Rosnay et al, ECMWF News Letter 143, Spring 2015

- Ongoing COST action on snow (HarmoSnow)
- GCW Snow Watch action on snow



IMS Snow Cover 23 Mar 2015

Data Assimilation Approach:

Optimal Interpolation (OI) in oper IFS

de Rosnay et al, Survey of Geophysics 2014

Snow analysis: Forecast impact

Revised IMS snow cover data assimilation

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

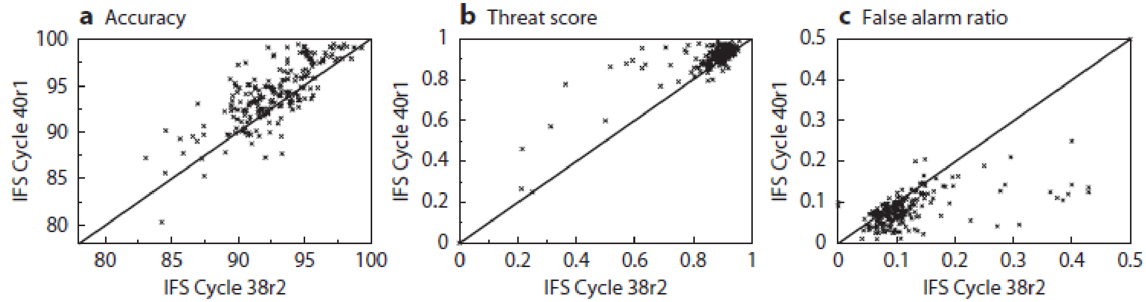


Figure 2 Snow analysis scores for the revised IFS 40r1 snow analysis versus the IFS 38r2 analysis for (a) accuracy, (b) threat score, and (c) false alarm ratio in the period October 2012 to April 2013. Each cross represents the scores computed against 251 independent in situ snow depth observations for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

Impact on atmospheric forecasts

October 2012 to April 2013 (RMSE new-old)

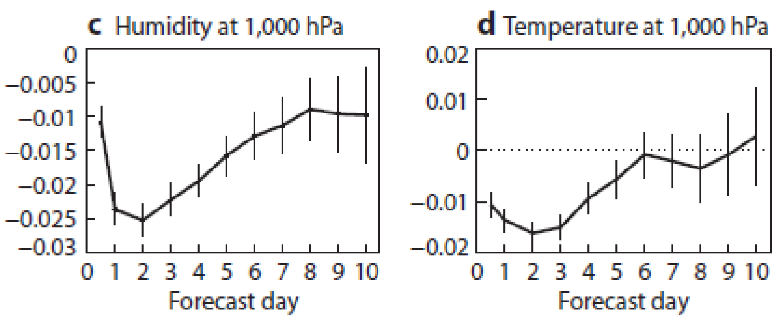


Figure 4 Impact of the revised snow analysis on the normalised root mean square error difference between IFS Cycles 40r1 and 38r2 (40r1 minus 38r2) for (a) humidity forecasts at 850 hPa;

→ Consistent improvement of snow and atmospheric forecasts

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

Operational snow analysis: winter 2014-2015

Snow monitoring:

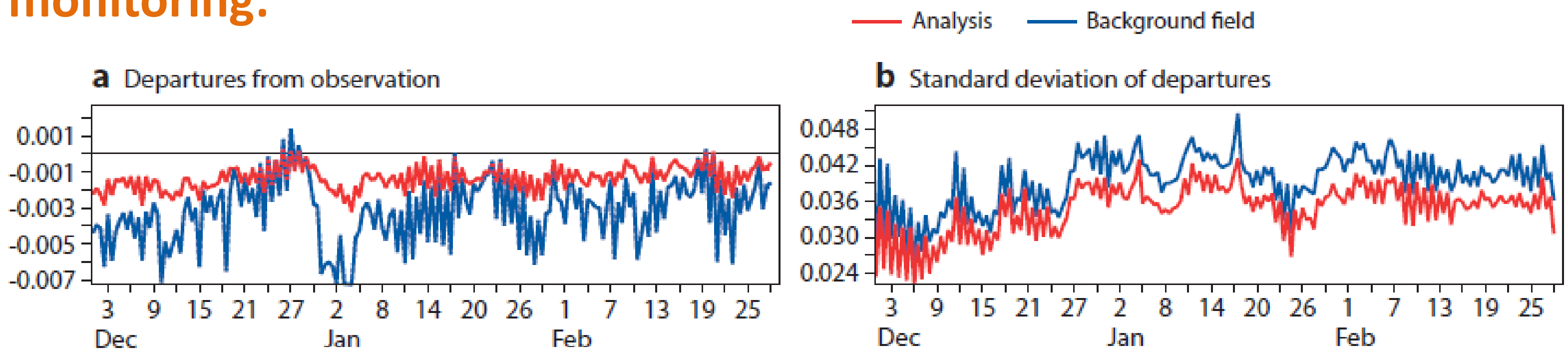
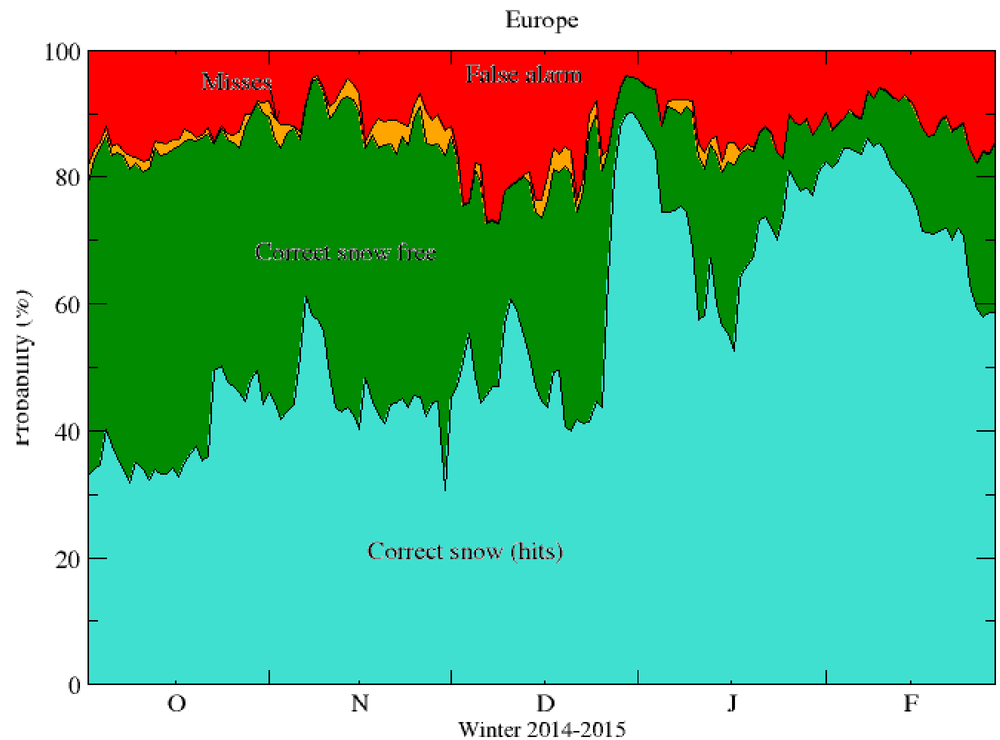
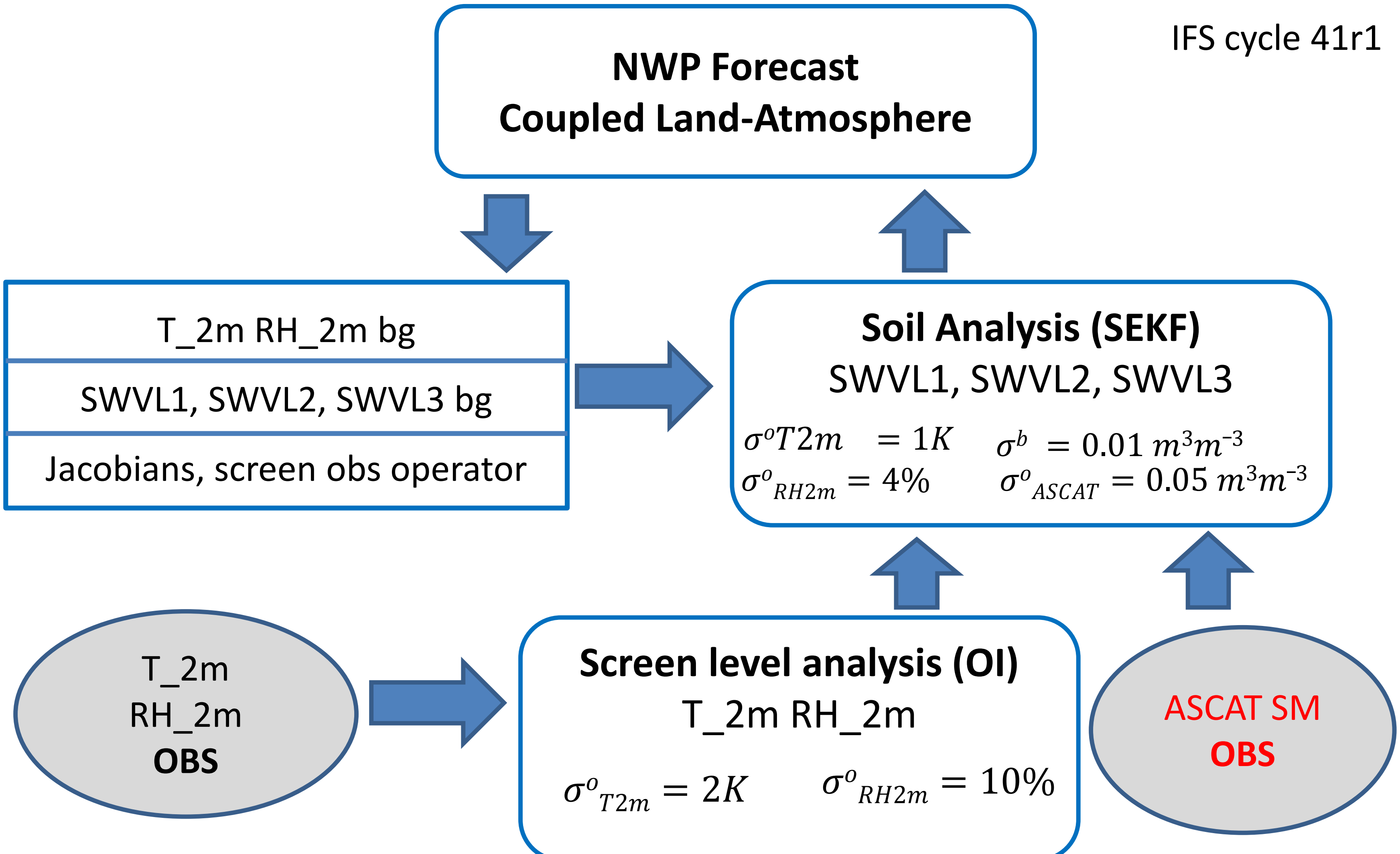


Figure 7 Monitoring time series from December 2014 to February 2015 of the ECMWF operational IFS Cycle 40r1 suite for conventional snow depth showing (a) mean departures of background field and analysis from observations, in metres (b) standard deviation of background field and analysis departures from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

Operational snow analysis evaluation Europe (2014-2015):



Soil Analysis in the IFS



ASCAT operational implementation

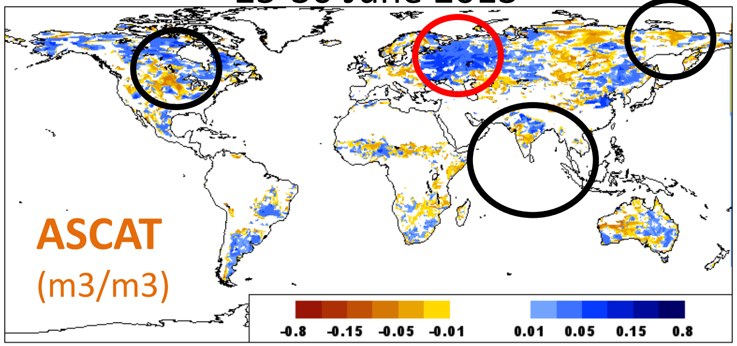
→ Operational soil moisture data assimilation: combines SYNOP and satellite data

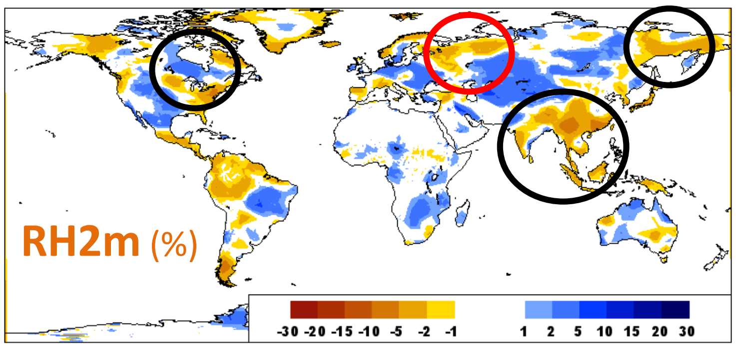
Note: Only two NWP centres use satellite soil moisture in operations (UKMO and ECMWF)

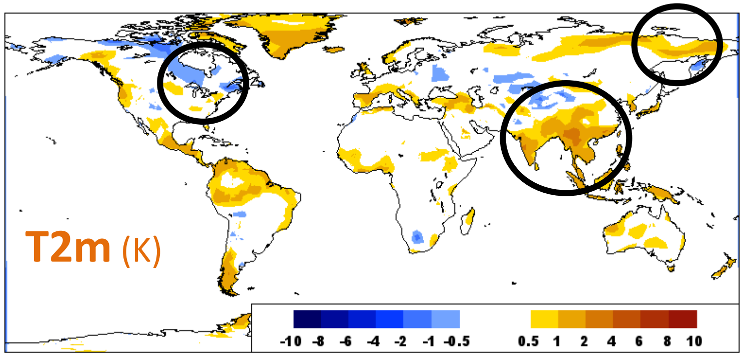
ASCAT Soil Moisture data assimilation

Innovation (Obs- model)

25-30 June 2013

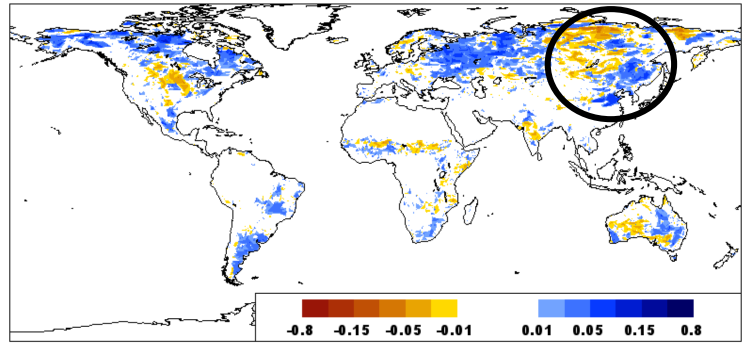




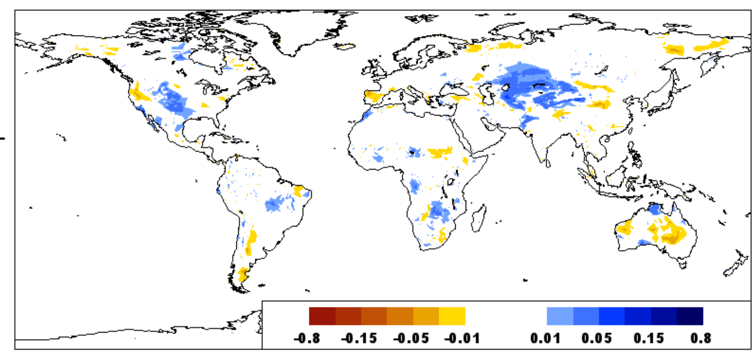


Accumulated Increments (m^3/m^3)

in top soil layer (0-7cm)



Due to ASCAT

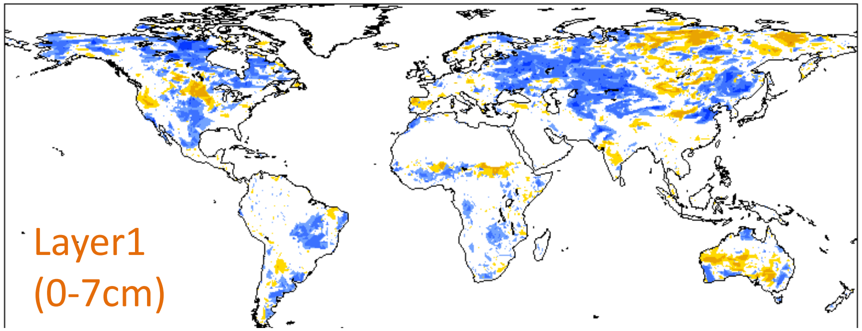


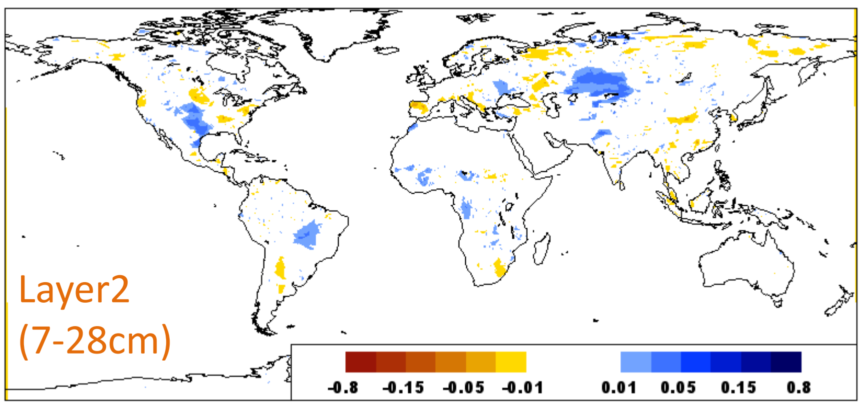
Due to SYNOP T2m and RH2m

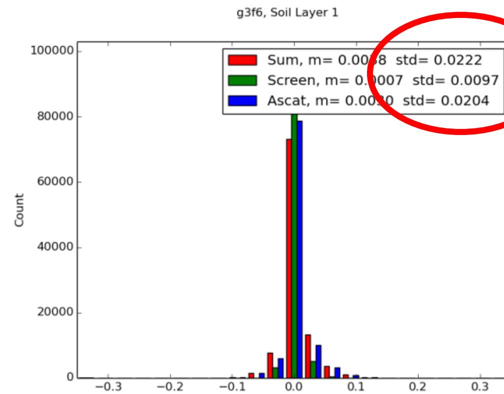
ASCAT Soil Moisture data assimilation

25-30 June 2013

Volumetric Soil Moisture increments (m^3/m^3) (accumulated)

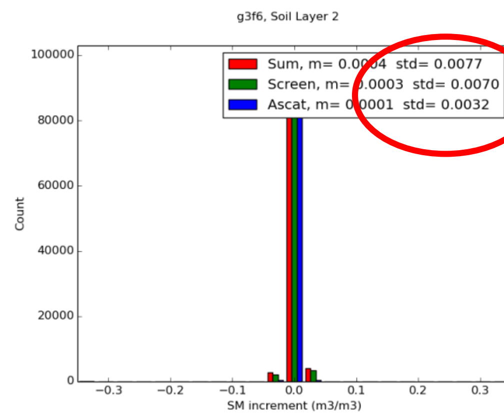






(m^3/m^3)

Layer1:
Most increments due to ASCAT



Layer2:
Most increments due to SYNOP T2m & RH2m

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

ERA5 preparation
Assimilation of ASCAT reprocessed SM data

Surface data assimilation in the future reanalysis ERA5
Preparatory tests using operational and reprocessed data sets

	FG departure Mean m^3m^{-3}	**FG departure StDev** m^3m^{-3}
CTRL	0.013	0.05
REPROC	0.006	0.044

(FMA 2010)

→ Reprocessed ASCAT soil moisture:
Reduced background departure statistics both in mean and Stdev

Ongoing tests to use ERS reprocessed soil moisture DA
→ ERA5 will assimilate scatterometer soil moisture for 1991-present

Also use the reprocessed IMS snow cover 4km product (2004-present)

EUMETSAT H-SAF soil moisture

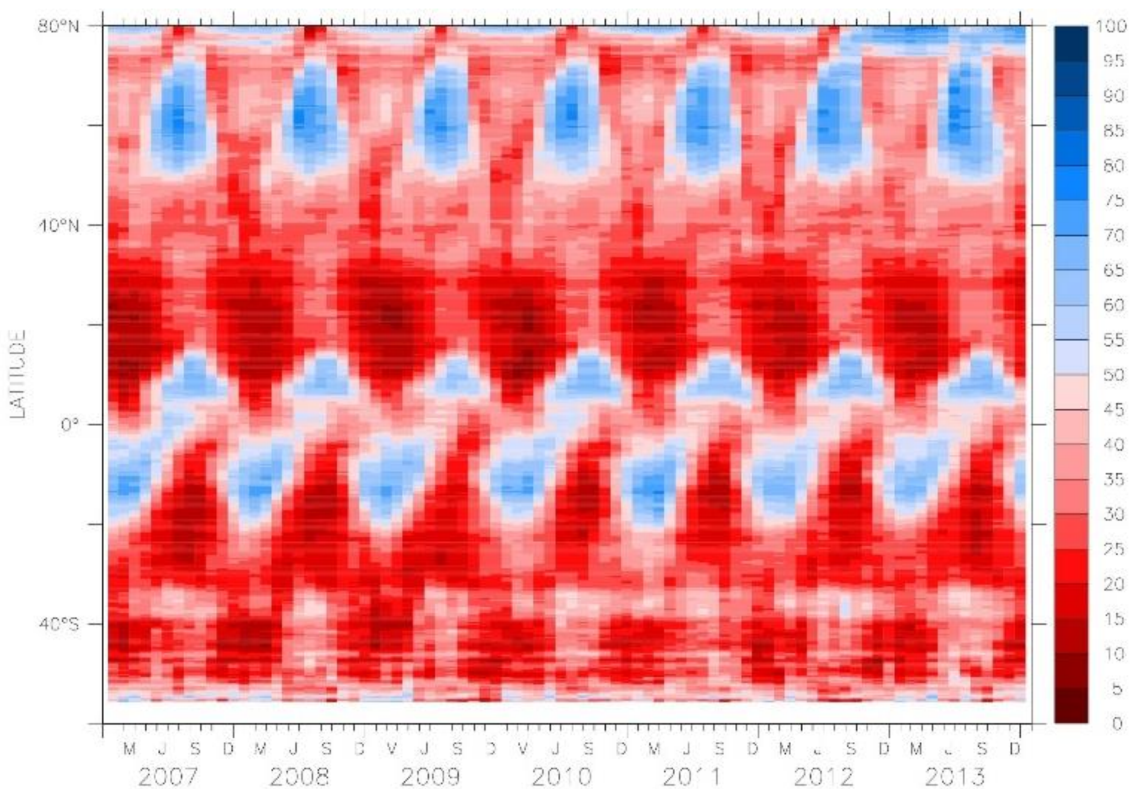
Scatterometer root zone soil moisture based on data assimilation

H14/SM-DAS-2: NRT product operational since July 2012

H27/SM-DAS-3: Thematic Data Record SCAT root zone soil moisture for 1992-2014

Albergel et al.

→ Based on Surface-only Land Data Assimilation System :
Assimilation of ASCAT reprocessed data and screen level analysed T2M, RH2M



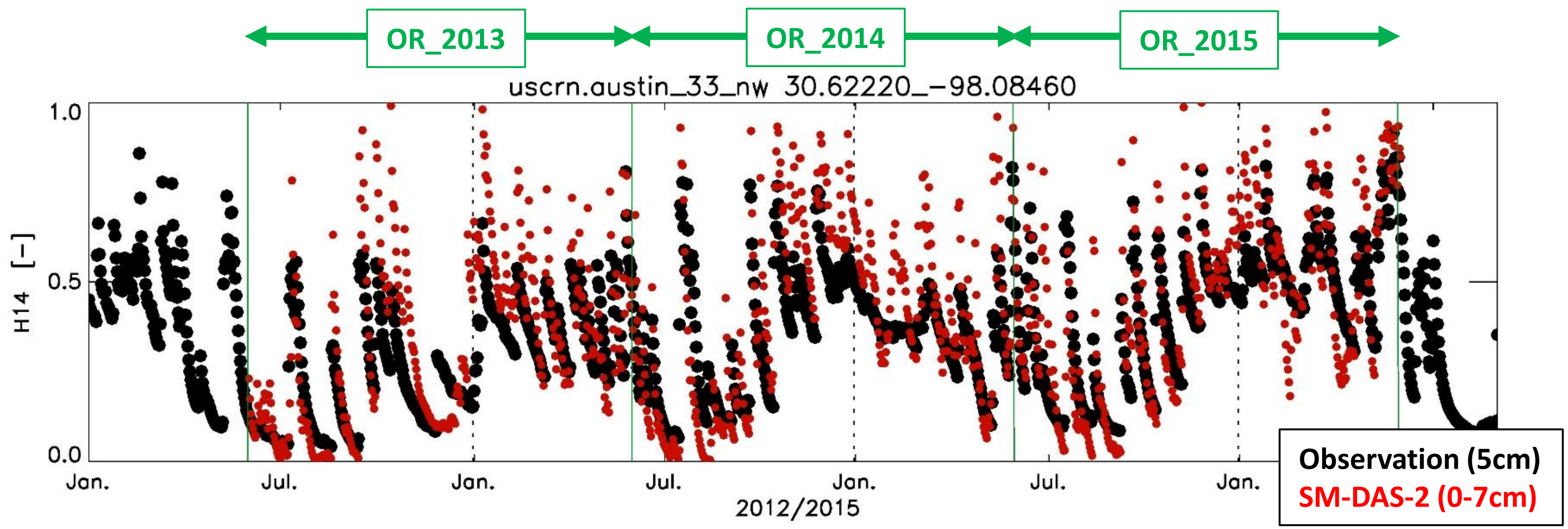
The EUMETSAT Network of Satellite Application Facilities
H SAF
Support to Operational Hydrology and Water Management

EUMETSAT H-SAF soil moisture

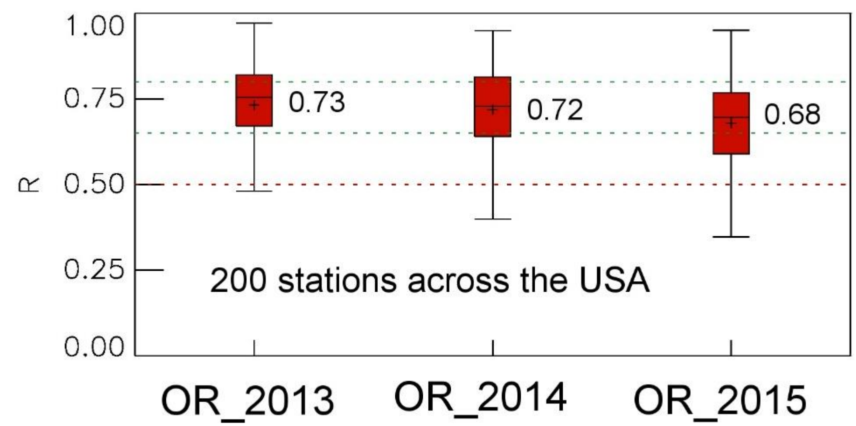
Evaluation of SM-DAS-2/H14

Albergel et al.

Surface and root zone liquid soil moisture content



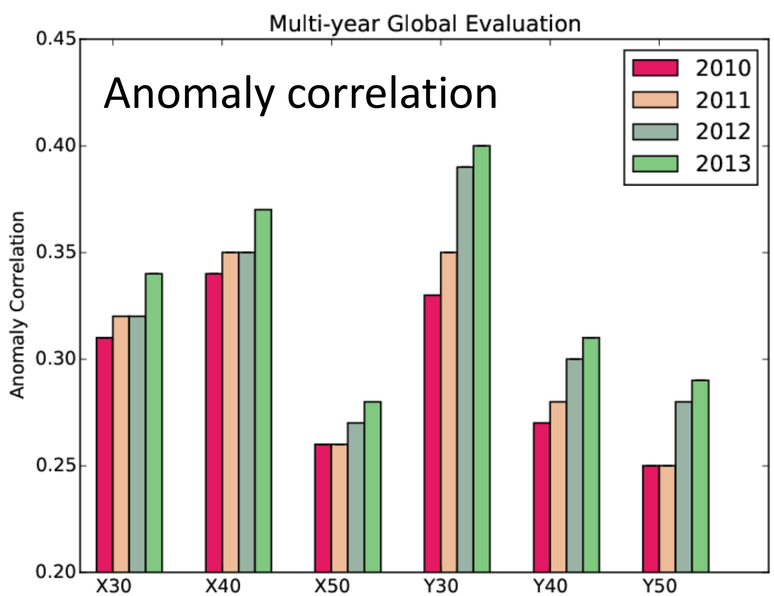
Accuracy requirements for product SM-DAS-2 [R]			
Unit	Threshold	Target	Optimal
Dimensionless	0.50	0.65	0.80



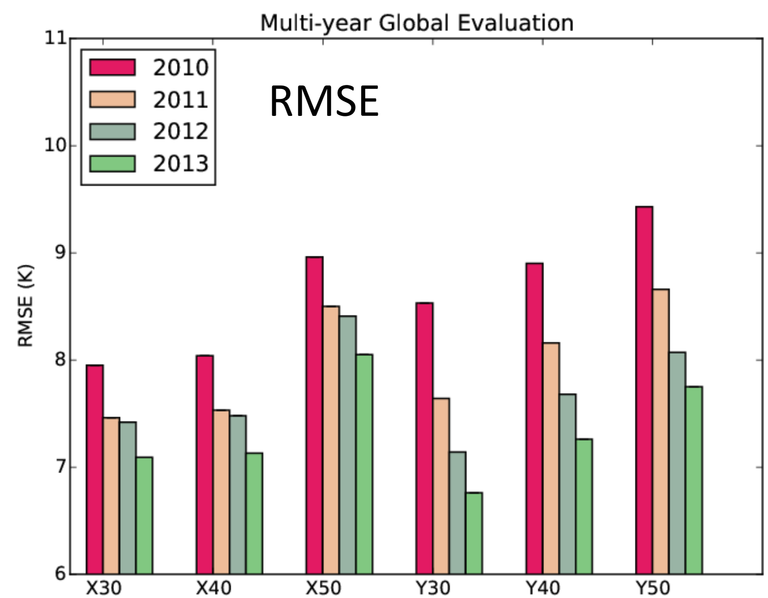
SMOS Forward modelling and Bias correction

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

de Rosnay et al, in prep RSE



Polarisation (x or Y) and incidence angle (30, 40, 50)



Polarisation (x or Y) and incidence angle (30, 40, 50)

Preparation for operational assimilation of SMOS T_B

CTRL (operational system) : T^{2m}, RH^{2m}, ASCAT

Observation error (**R**):

Muñoz-Sabater et al.

- T^{2m} ➔ $\sigma(T_{2M})$= 1 K; RH^{2m} ➔ $\sigma(RH_{2M})$= 4%;
- ASCAT ➔ $\sigma(SM_{ASCAT})$= 0.05 m^3m^{-3}
- SMOS T_B ➔ $\sigma(T_B)$= 6 + p·rad_acc K

Background error (**B**):

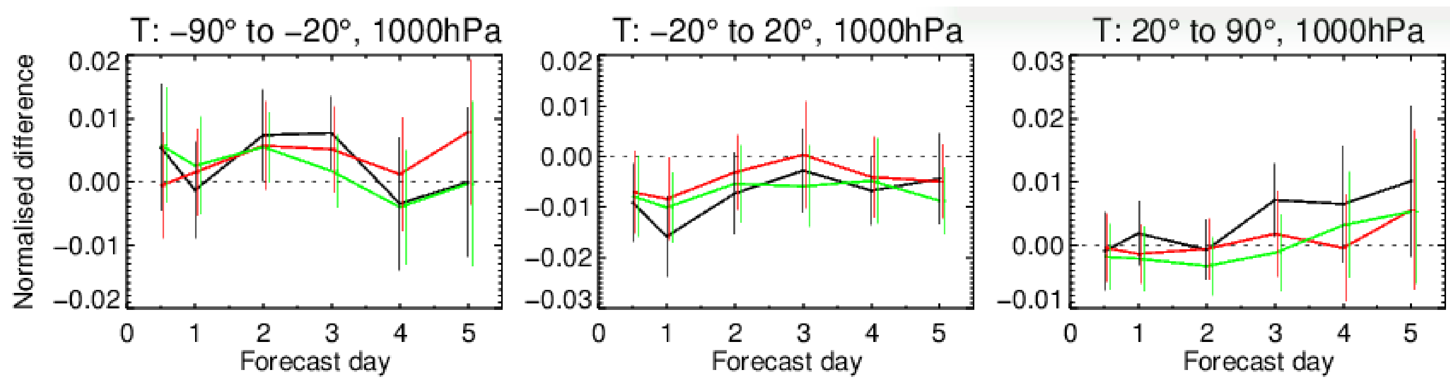
Depth	Config.1 (p=1 ~ [8.5-10] K)	Config.2 (p=1 ~ [8.5-10] K)	Config.3 (p=3 ~ [13.5-18] K)
0-7 cm	ε = 20% WHC [0.03-0.08] m^3m^{-3}	ε = 10% WHC [0.015-0.04] m^3m^{-3}	ε = 10% WHC [0.015-0.04] m^3m^{-3}
7-28 cm	ε = 10% WHC [0.015-0.04] m^3m^{-3}	ε = 5% WHC [0.008-0.02] m^3m^{-3}	ε = 5% WHC [0.008-0.02] m^3m^{-3}
28-72 cm	ε = 5% WHC [0.008-0.02] m^3m^{-3}	ε = 5% WHC [0.008-0.02] m^3m^{-3}	ε = 5% WHC [0.008-0.02] m^3m^{-3}

SMOS data assimilation impact on atmospheric scores

Muñoz-Sabater et al.

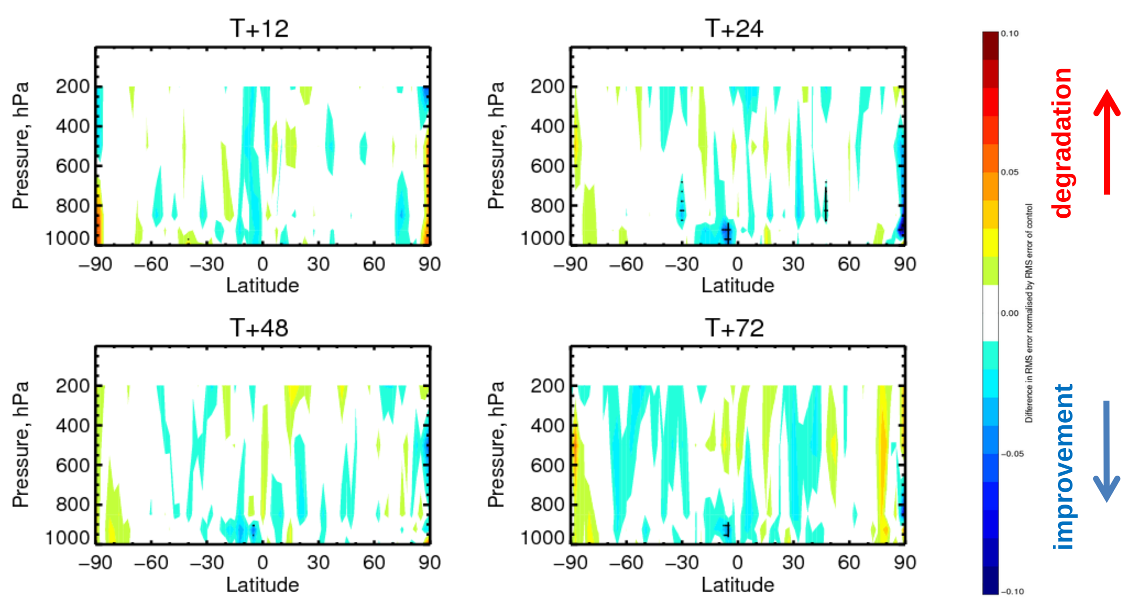
Normalized change in rms of fc error:

Config.1 (black)
Config.2 (red)
Config.3 (green)



SH- extratropics ***Tropics*** ***NH- extratropics***

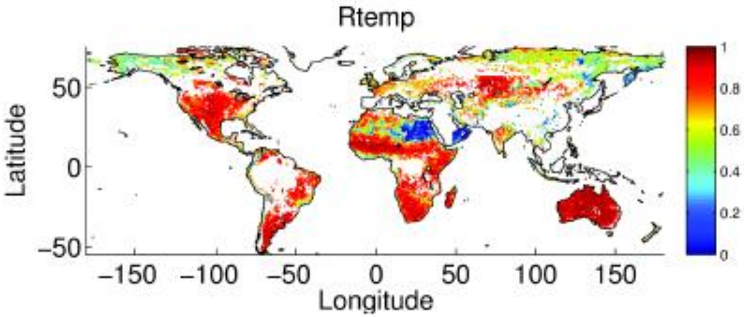
Configuration 3



EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

An official ESA Near-Real-Time product based on Neural Networks

NRT prototype designed and evaluated by CESBIO **(Rodriguez-Fernandez et al.)**



SMOS NRT SM vs SMOS L3 SM:
Average temporal correlation = 0.8

Input	STD	R	Bias
NN	**0.049**	**0.55**	-0.024
SMOS L3	0.064	0.50	-0.026

Average stats vs USDA SCAN in situ measurements better than SMOS L3

NRT operational implementation in progress at ECMWF **(Muñoz-Sabater et al.)**

- A SM product very similar to the current operational one but in Near-Real-Time
- ESA product distributed by GTS and EUMETCAST

More information in the poster by Rodriguez-Fernandez et al.

Summary

- Most NWP centres analyse soil moisture and/or snow depth
- Satellite data used for snow cover and soil moisture analyses
- Snow: NOAA NESDIS/IMS 4km snow cover data (multi-sensor product). No Snow Water Equivalent products used for NWP (yet)
- Soil moisture: ASCAT operational since May 2015 at ECMWF.
- SMOS TB: preparation and tests for NWP, SMAP developments
- SMOS SM: NRT processor implementation
- Observation latency : crucial for NWP applications (<3h)
- Longer term development for satellite observations usage:
  - Use of MW data to analyse snow depth
  - Integrated hydrological variables such as river discharges

Thank you for your Attention!

Contact: Patricia.Rosnay@ecmwf.int

Useful links:

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

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