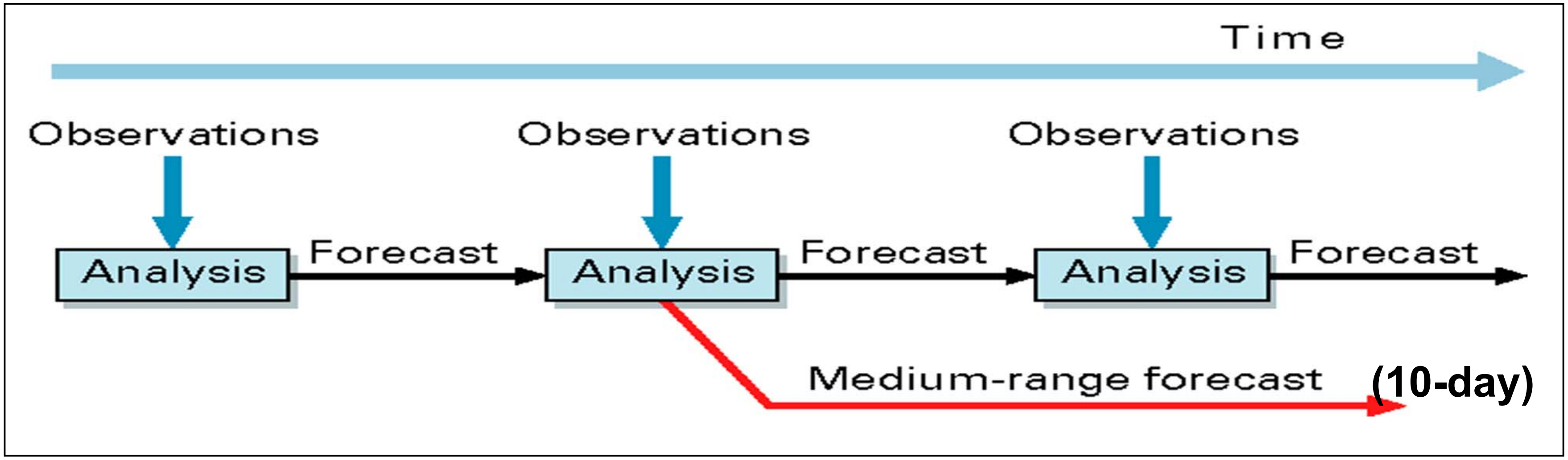
1st International Surface Working Group
19-20 July 2017, Monterey, CA

Assimilation of land surface satellite data for Numerical Weather Prediction at ECMWF

P. de Rosnay, G. Balsamo, C. Albergel, S. Boussetta, S. English, D. Fairbairn, H. Hersbach, L. Isaksen,
J. Muñoz Sabater, N. Rodríguez-Fernández,

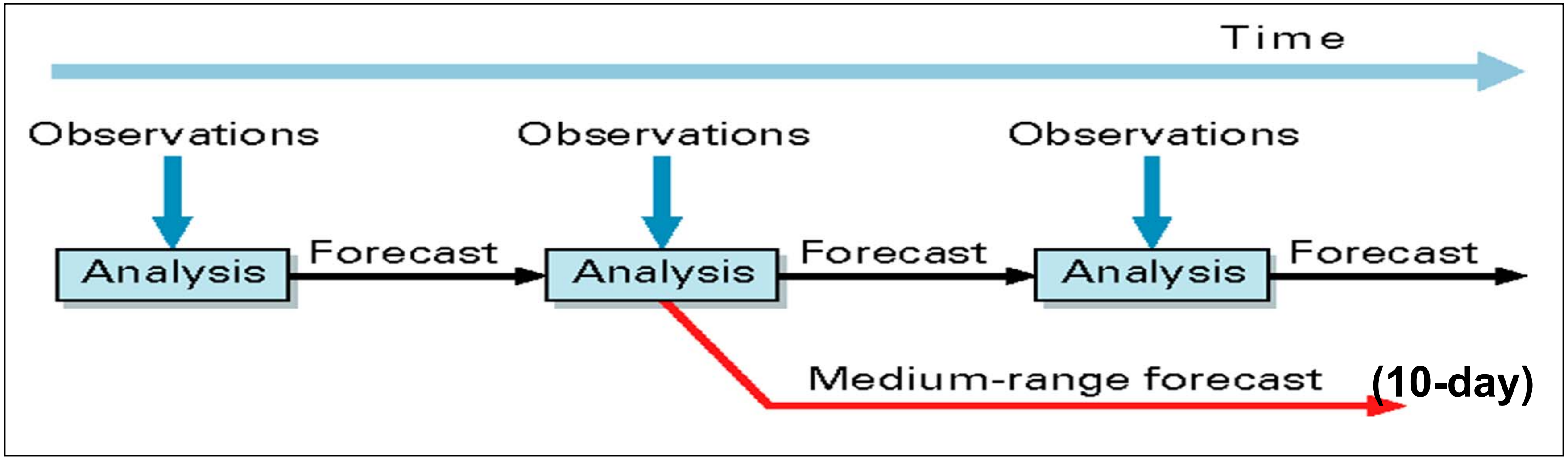
ECMWF Integrated Forecasting System (IFS)



- **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 (LDAS)**

ECMWF Integrated Forecasting System (IFS)



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Land assimilation in ECMWF systems:

- **NWP**: IFS (with 4D-Var, **LDAS**), 9km, 43r1
- **ERA-Interim**: IFS (with 4D-Var, **LDAS**), 79km, 31r1 (2006)
- **ERA5**: IFS (with 4D-Var, **LDAS**), 31km, 41r2
- **ERA-Interim-Land:** H-TESSEL forced by ERA→ LSM model only: no DA
- **CERA-20C** IFS (with 4D-Var,NEMOVAR), 130km, 41r2 (no LDAS)
- **CERA-SAT** IFS (with 4D-Var, NEMOVAR and **LDAS**), 62km, 42r1
- **ENS** IFS (with 4D-Var, NEMOVAR and **LDAS**), 16/32km, 43r1

ECMWF Land Data Assimilation System (LDAS)

Snow depth

Methods: Cressman for ERA-Interim, 2D Optimal Interpolation (OI) for NWP & for ERA5

Conventional observations: *in situ* snow depth

Satellite data: NOAA/NESDIS IMS Snow Cover Extent (daily product).

Soil moisture (SM)

Methods: - 1D Optimal Interpolation in ERA-Interim (also used at Météo-France, ECCC)

- Simplified Extended Kalman Filter for NWP, ERA5 (also at UKMO)

Conventional observations: Analysed SYNOP 2m air relative humidity and air temp.

Satellite data: Scatterometer SM for NWP (ASCAT) & for ERA5 (ERS/SCAT &ASCAT)

ESA SMOS brightness temperature in development, research NASA SMAP

Soil Temperature and Snow Temperature

1D-OI using analysed T2m as observation (NWP, ERA-Interim, ERA5)

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

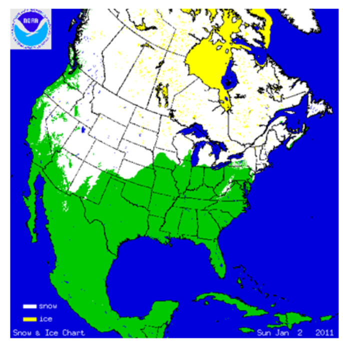
} **Prognostic variables**

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) in operational IFS
- The result of the data assimilation is the analysis of SWE and snow density



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

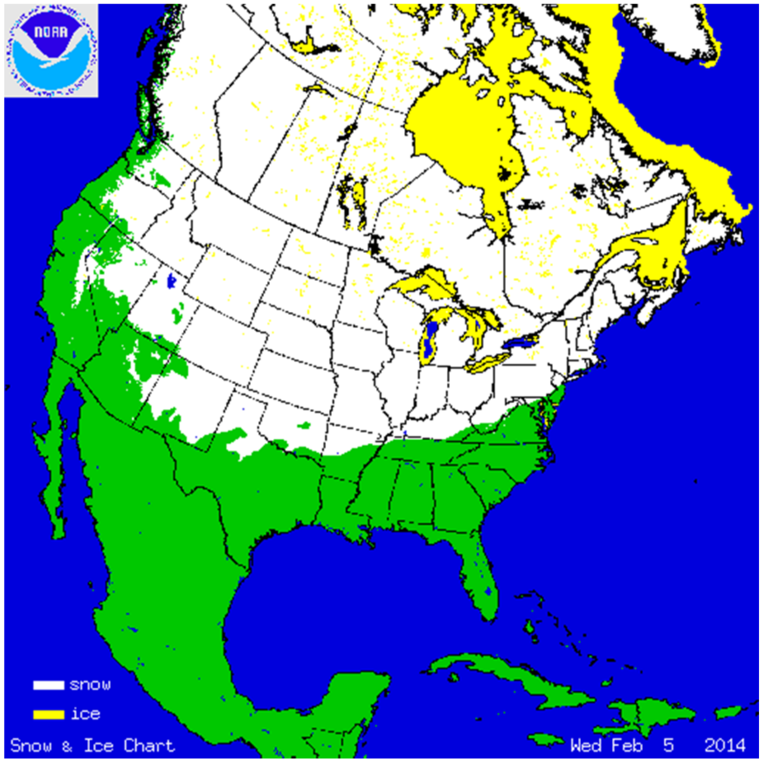
Information content: Snow/Snow free

Data used at ECMWF:

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

NOAA/NESDIS

IMS Snow extent data



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

Latency:

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

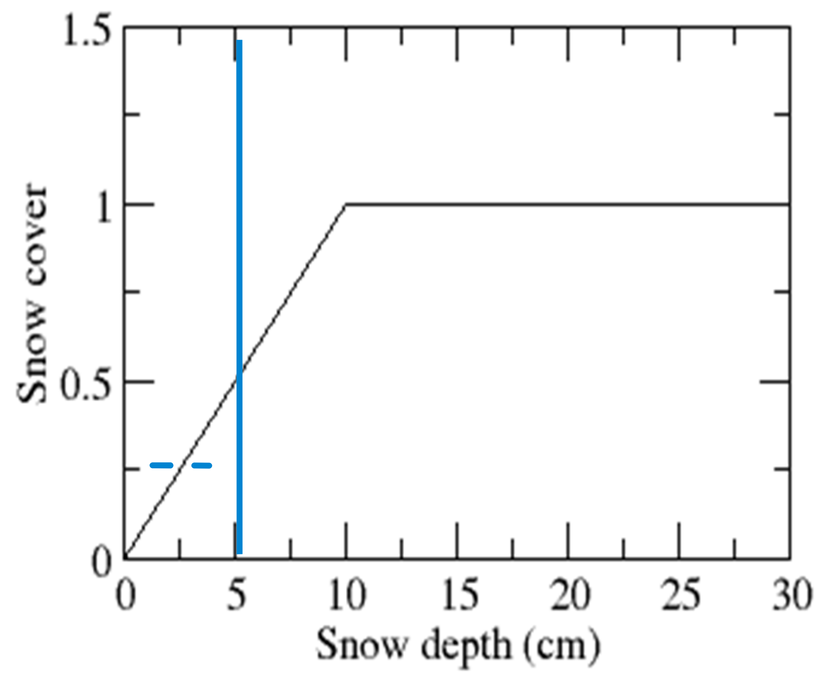
Revised NESDIS/IMS snow cover DA

- 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
- IFS revision: assimilate IMS & account for observation error

Fst / Guess NESDIS IMS	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

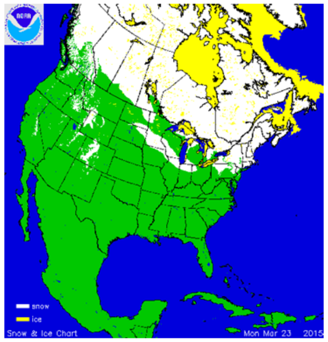
IMS has snow(SC>=50%)
→ Model snow depth >= 5cm



Model relation between Snow Cover (SC) and Snow Depth (SD)

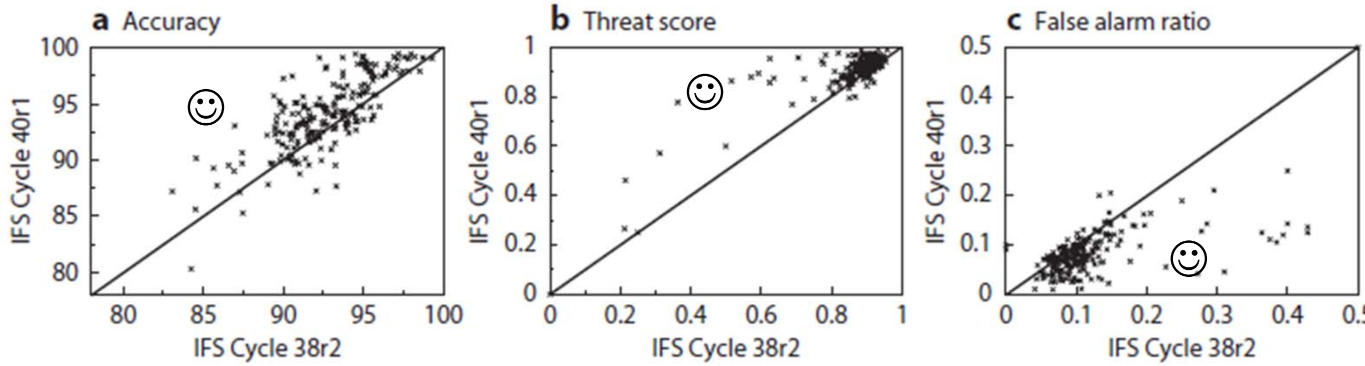
Snow analysis: Forecast impact

Revised IMS snow cover data assimilation (2013)



Impact on snow October 2012 to April 2013

(using 251 independent *in situ* observations)



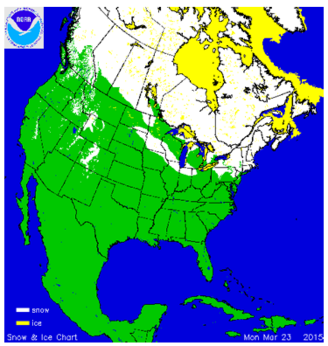
	Snow observed	No snow observed
Snow in analysis	a Hits	b False alarm
No snow in analysis	c Misses	d Correct no snow

The following scores are used for the evaluation:

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

Snow analysis: Forecast impact

Revised IMS snow cover data assimilation (2013)



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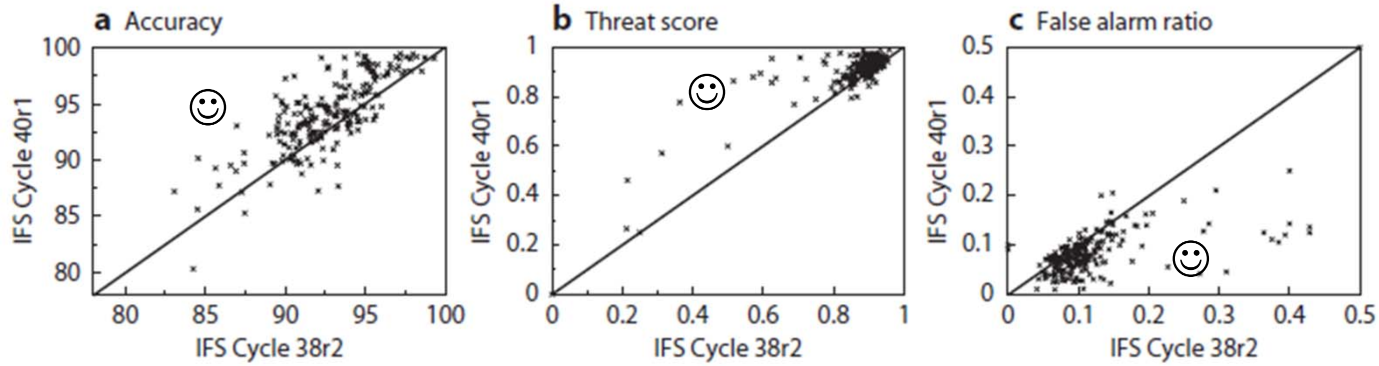
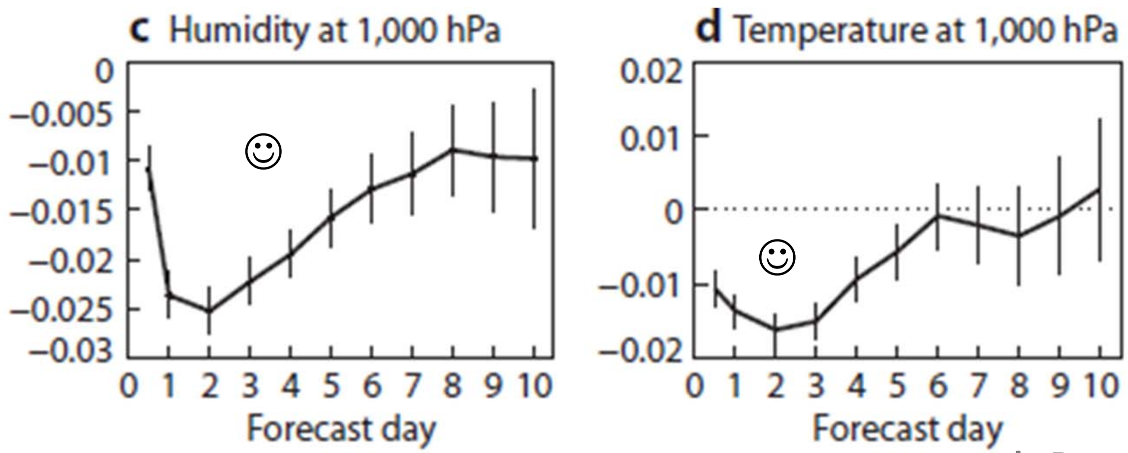


Impact on atmospheric forecasts

October 2012 to April 2013 (RMSE new-old)



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

Simplifed EKF soil moisture analysis

For each grid point, analysed soil moisture state vector x_a:

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

x background soil moisture state vector,

$\mathcal{H}$ non linear observation operator

y observation vector

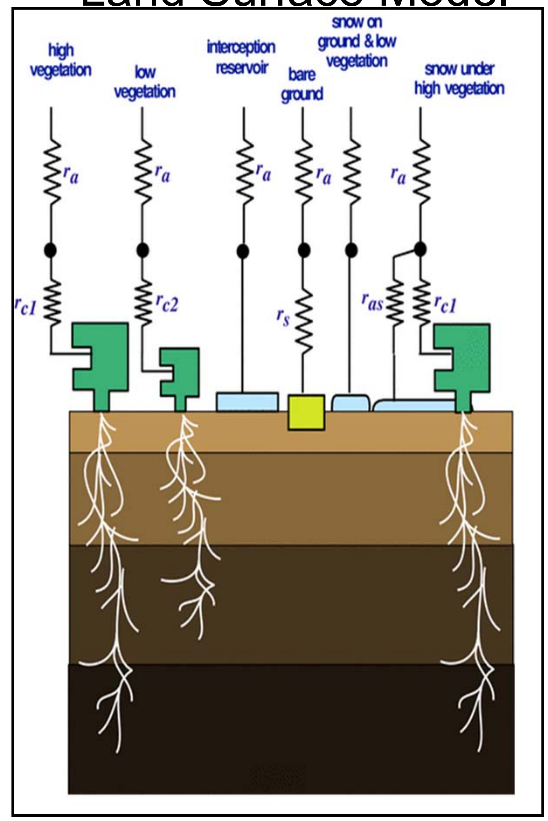
K Kalman gain matrix, fn of
H (linearsation of $\mathcal{H}$), **P** and **R** (covariance matrices
of background and observation errors).

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

Observations used at ECMWF:

- Conventional SYNOP pseudo observations (analysed T2m, RH2m)
- Satellite MetOp-A/B ASCAT soil moisture
- SMOS TB Data at 30, 40, 50 degrees

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



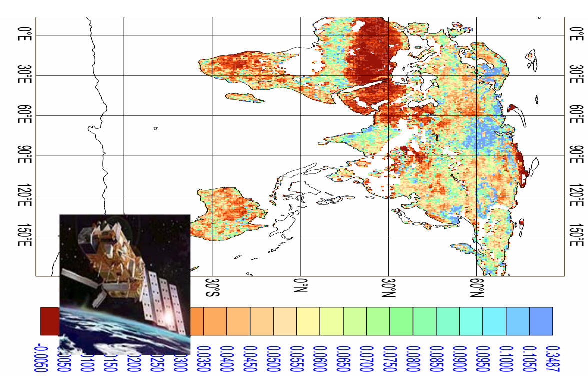
Drusch et al., GRL, 2009
de Rosnay et al., ECMWF News Letter 127, 2011
de Rosnay et al., QJRMS, 2013

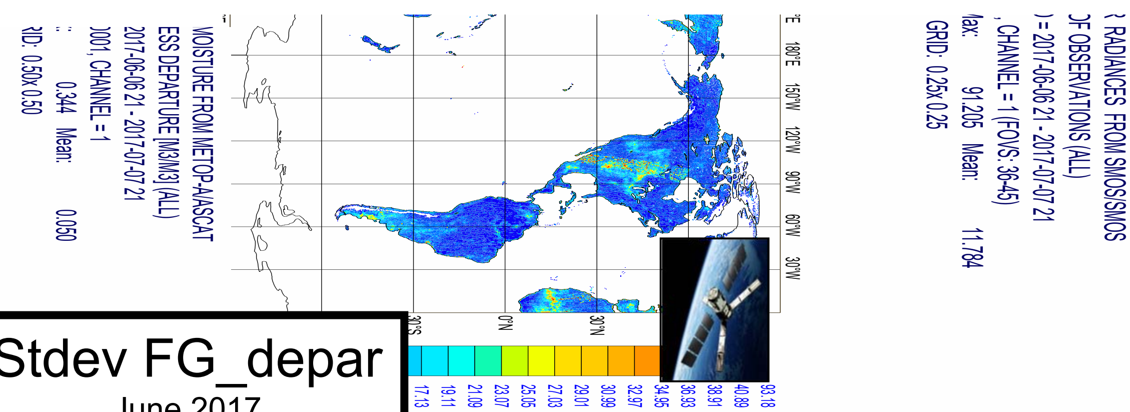
Satellite data monitoring for NWP

Active microwave data:
ASCAT MetOP-A /B C-band (5.6GHz)
NRT Surface soil moisture
Operational product
→ operational continuity

Passive microwave data:
SMOS, SMAP L-band (1.4 GHz)
NRT Brightness Temperature
Dedicated soil moisture mission
→ Best sensitivity to soil moisture

Operational monitoring of surface soil moisture satellite data:
ASCAT/A soil moisture (m^3m^{-3}) 40^o SMOS TB (K)



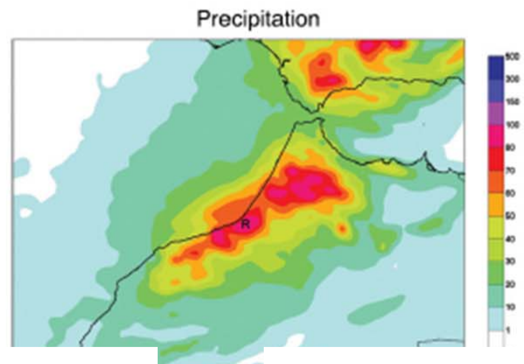


Stdev FG_depar
June 2017

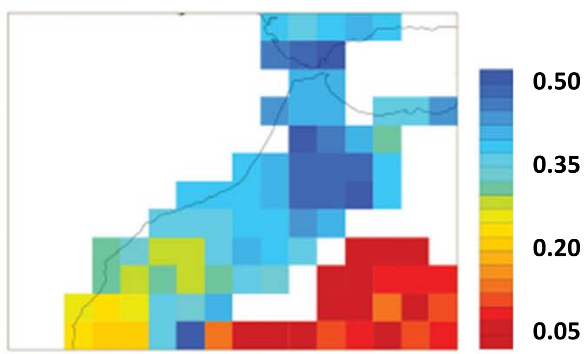
SMOS and ASCAT monitoring

Case study that illustrates the relevance of SMOS and ASCAT to monitor soil moisture in extreme conditions

Flash flood in Morocco 23 February 2017

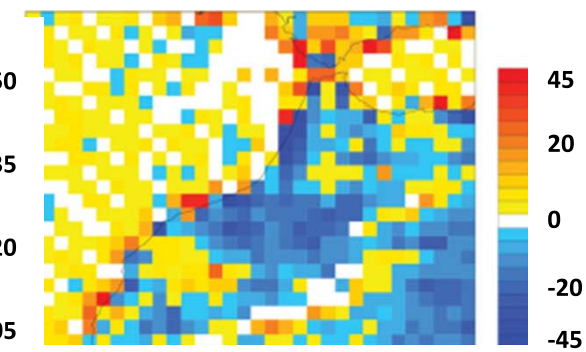


ASCAT Soil Moisture



ASCAT Soil Moisture in m³/m³
(red is dry / blue is wet)
→ Saturated

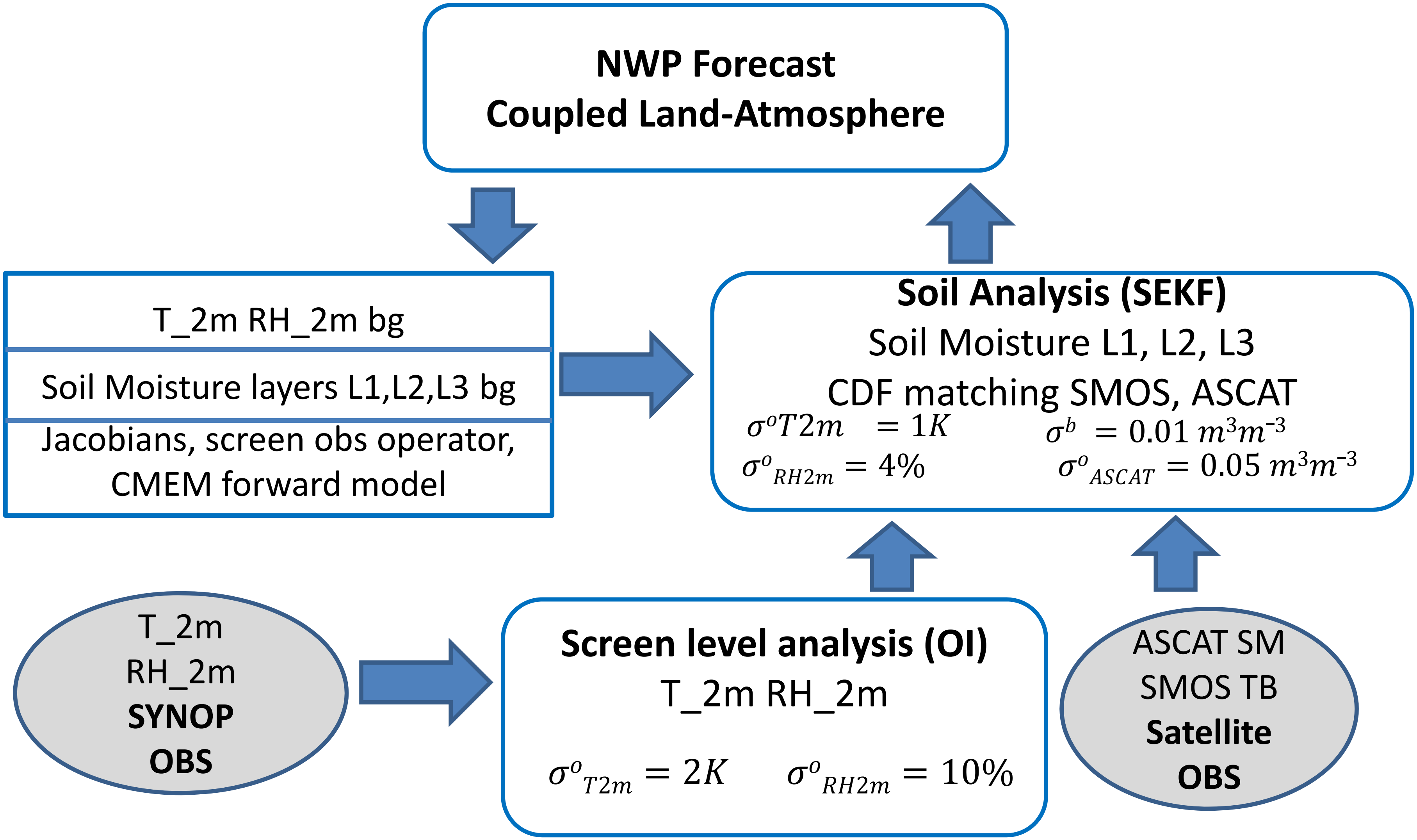
SMOS Brightness Temp



FG_depar in K
(Blue means SMOS is wetter than ECMWF)

SMOS colder/wetter than FG
-> ECMWF FG drier

Soil analysis in the IFS

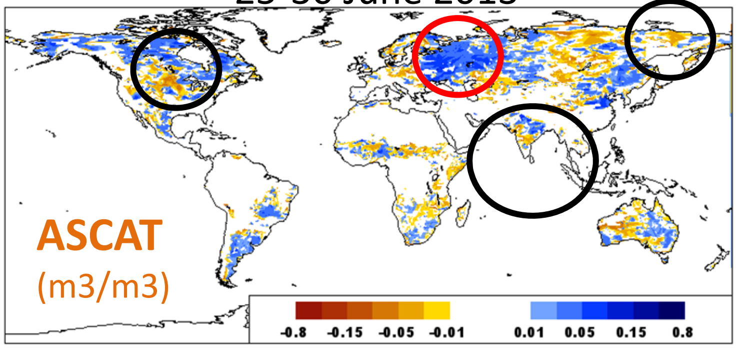


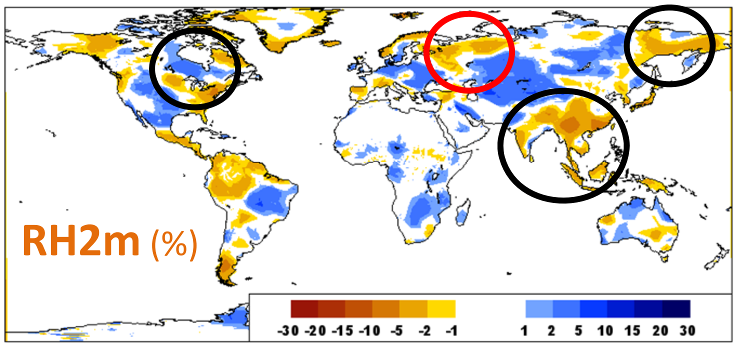
→ Operational soil moisture data assimilation: combines SYNOP and satellite data

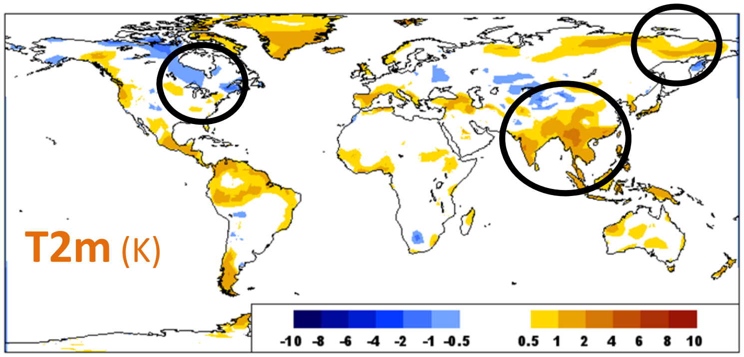
ASCAT Soil Moisture data assimilation

Innovation (Obs- model)

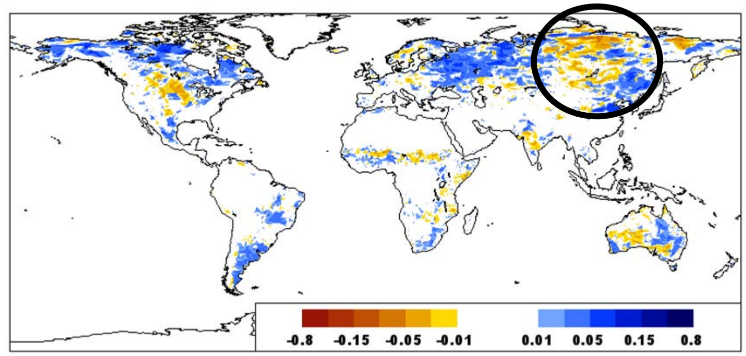
25-30 June 2013



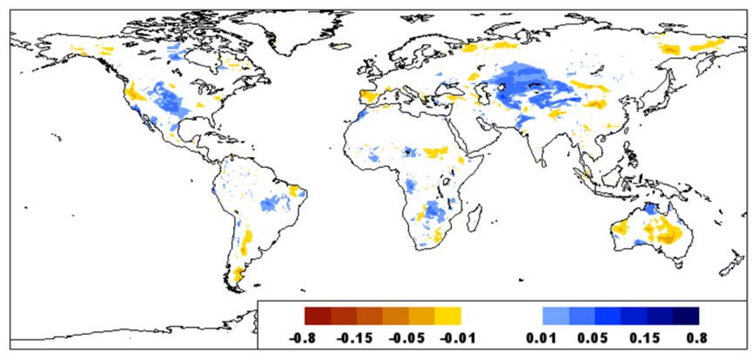




Accumulated Increments (m^3/m^3) in top soil layer (0-7cm)

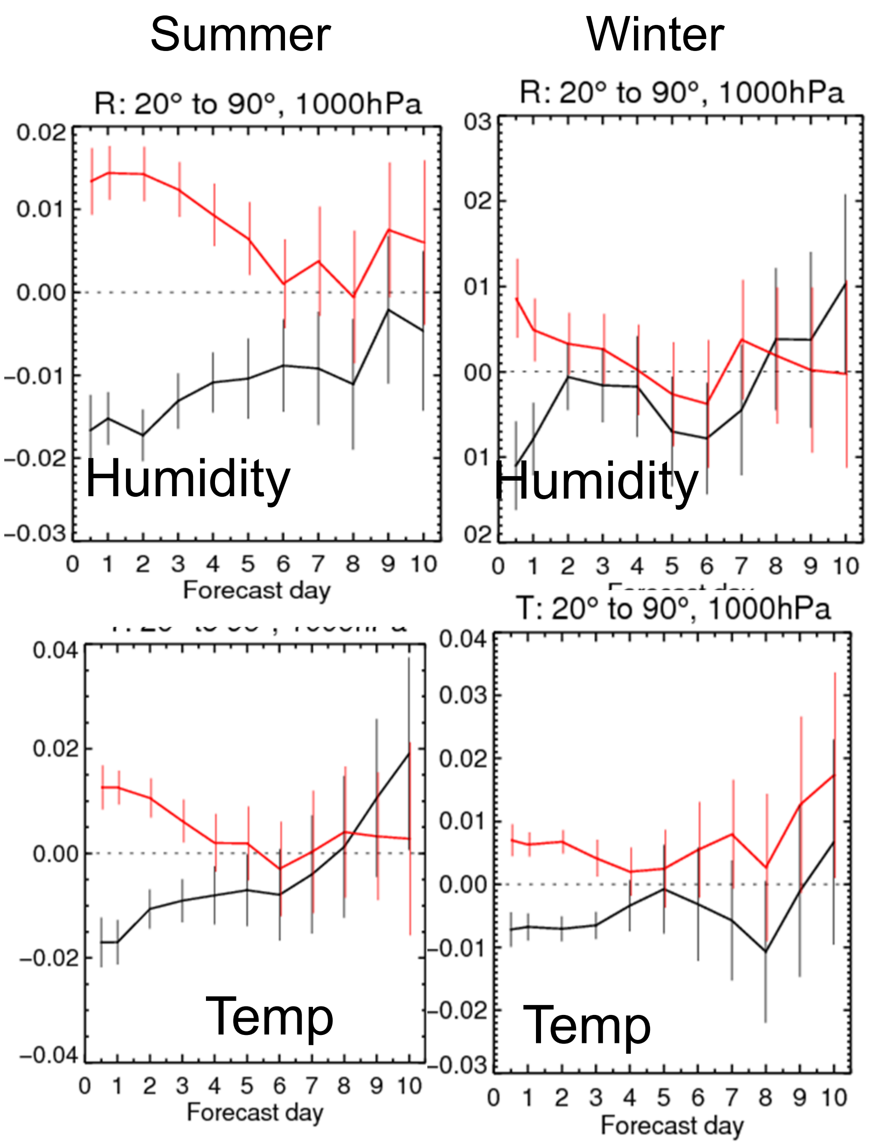


Due to ASCAT



Due to SYNOP T2m and RH2m

Soil Analysis for NWP: Impact on the forecast ?



— No soil Analysis

---- zero line (ref): old obs error (till 2015)

— New screen level obs error (since 2015)

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

ECMWF new Re-analysis (ERA5)
Assimilation of Scatterometer soil moisture data
ERS/SCAT and MetOpA/B ASCAT

Use of EUMETSAT ASCAT-A reprocessed data (25km sampling)

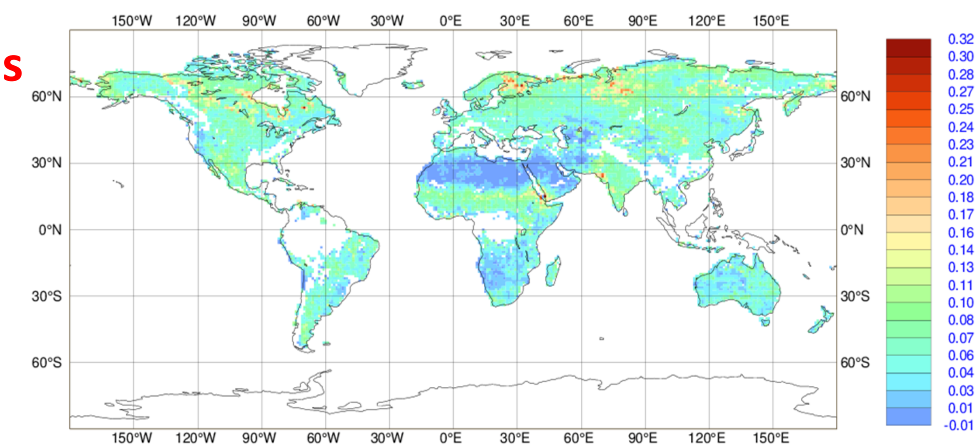
	FG departure Mean m^3m^{-3}	FG departure StDev m^3m^{-3}
Using NRT ASCAT	0.013	0.05
Using Reproc ASCAT	0.006	0.044

(FMA 2010)

→ Reprocessed ASCAT has reduced background departure statistics both in mean and Stdev

ERA5 on-going production (Copernicus C3S)

ASCAT surface soil moisture STDev First guess departure (Obs-Model) in m3/m3 for JJAS 2014



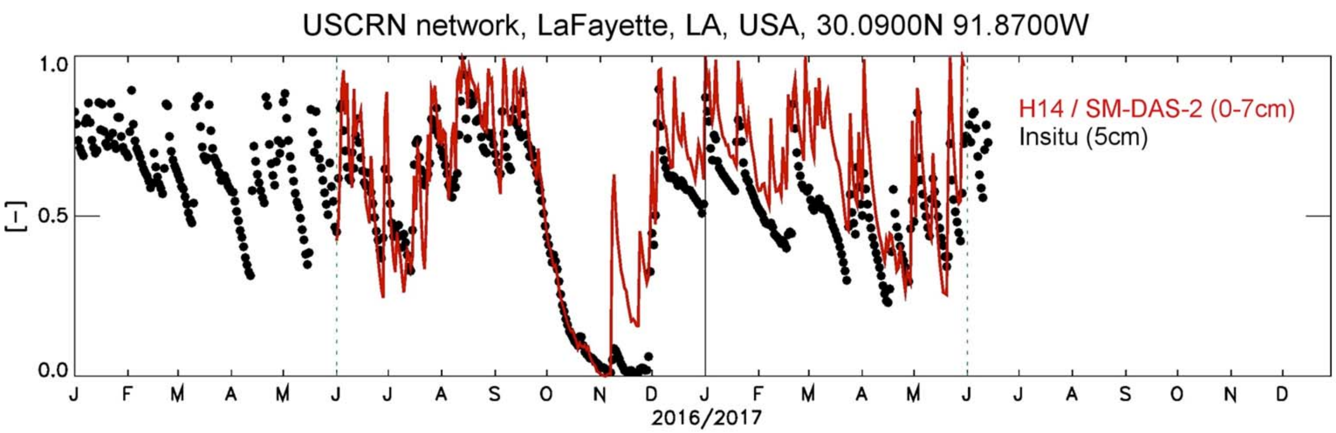
EUMETSAT H-SAF soil moisture

Scatterometer root zone soil moisture based on data assimilation

Fairbairn, Albergel et al.

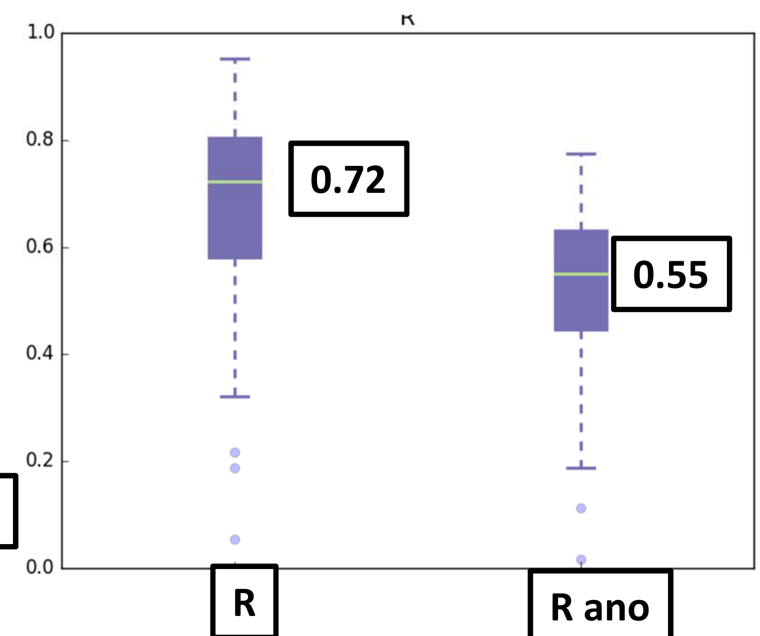
Evaluation of SM-DAS-2/H14

Surface and root zone liquid soil moisture content



Observation (5cm)
H14/SM-DAS-2 (0-7cm)

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



USCRN, 102 stations used

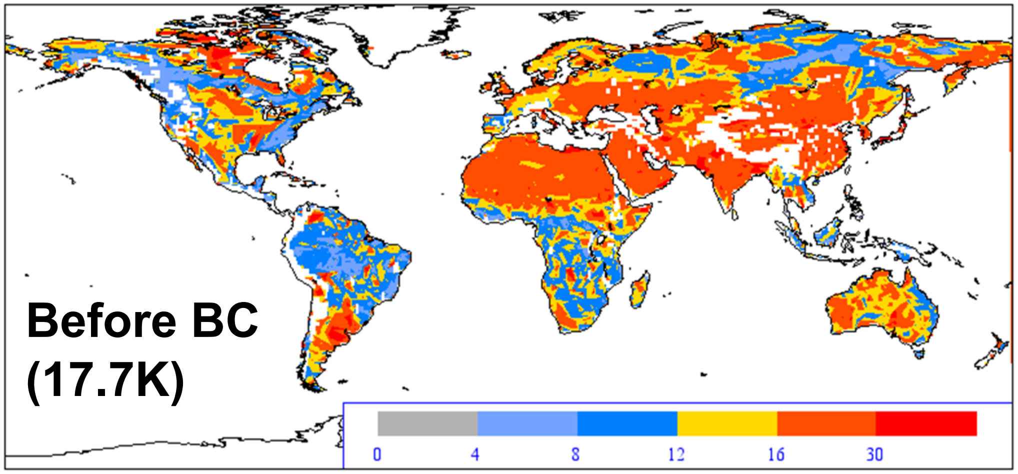
The EUMETSAT Network of Satellite Application Facilities
H SAF Support to Operational Hydrology and Water Management

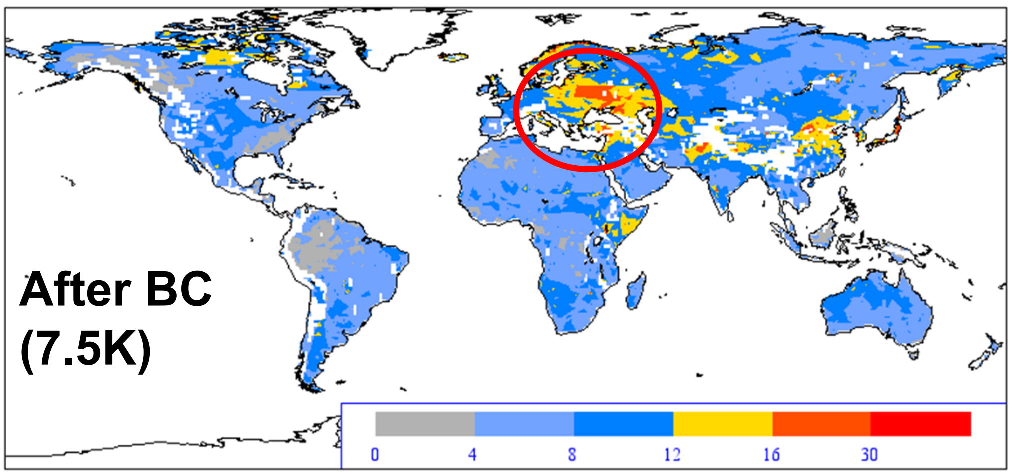
ECMWF L-band TB Bias correction

RMSD between SMOS Obs and ECMWF TBxx, 40 degrees

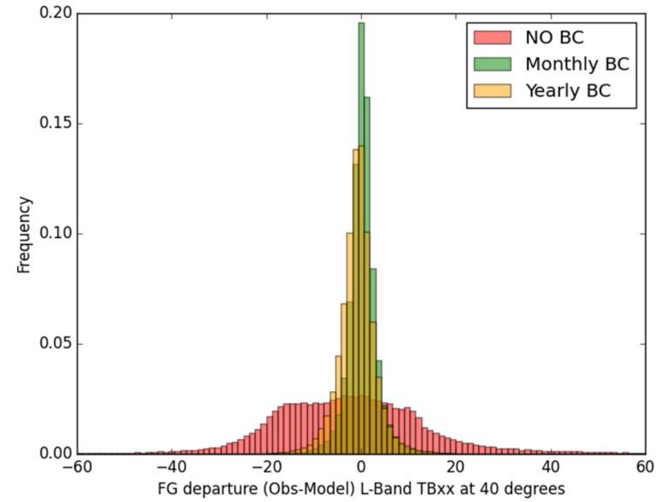
2012

RMSD (K)





Low residual RMSD, except in RFI areas

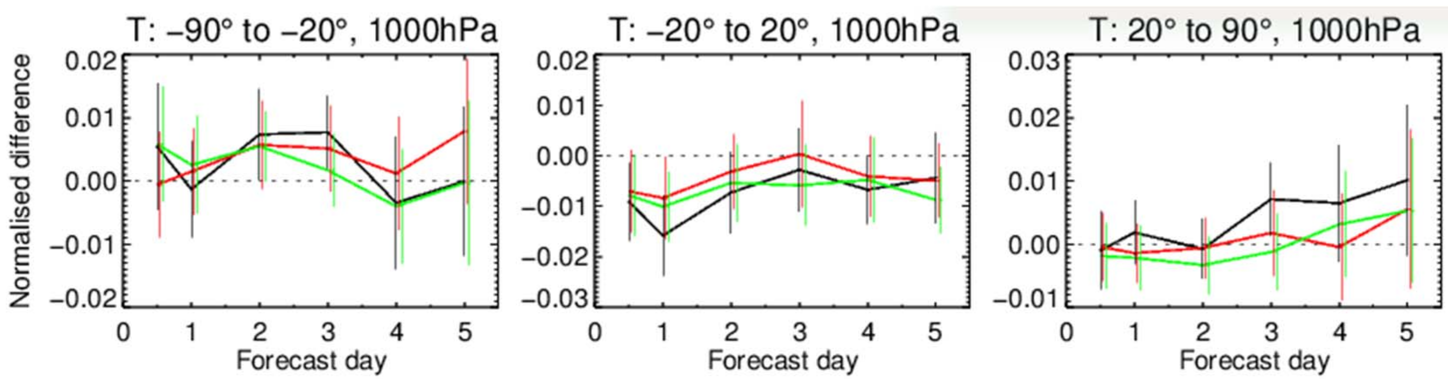


SMOS data assimilation impact on atmospheric scores

Muñoz-Sabater et al.

Normalized change in rms of fc error:

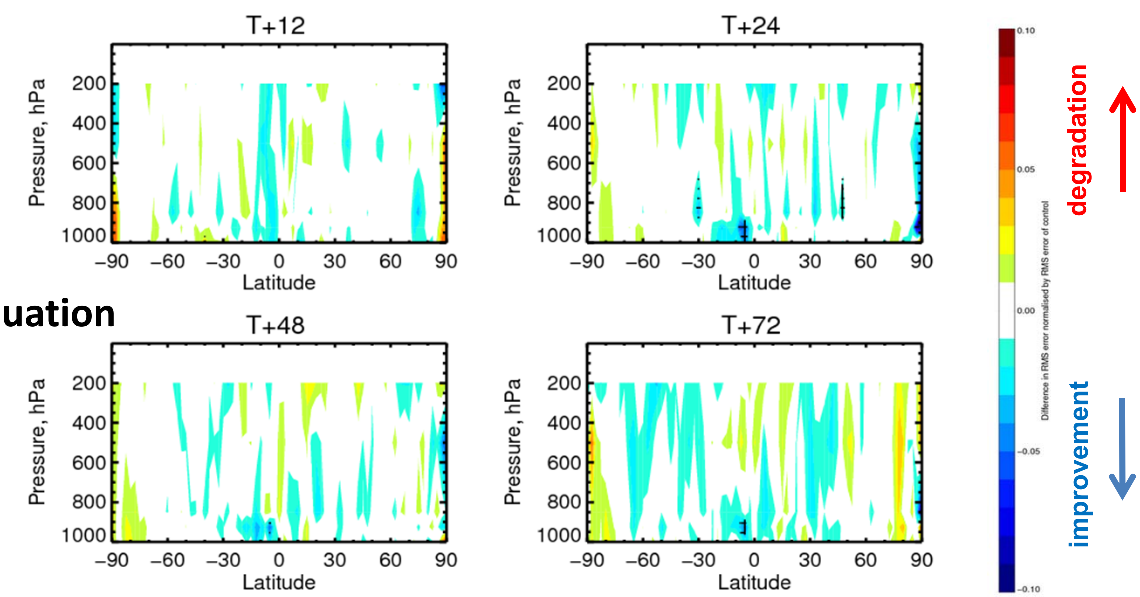
Config.1
Config.2
Config.3



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

Configuration 3

Based on short experiments
Longer experiment under evaluation

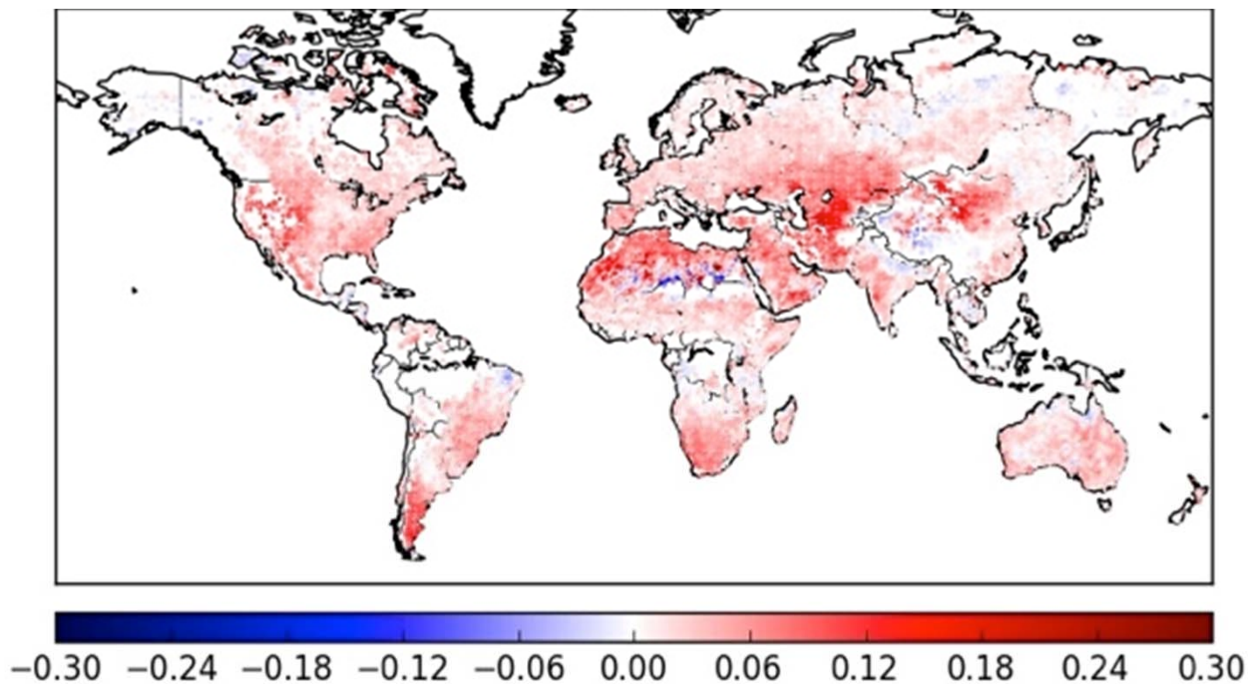


Impact of soil vertical resolution for satellite soil moisture

Tests with H-TESSEL soil resolution increased: top layer 0-7cm replaced by 3 layers 0-1cm, 1-3cm, 3-7cm

Impact on Anomaly Correlation with ESA-CCI satellite soil moisture

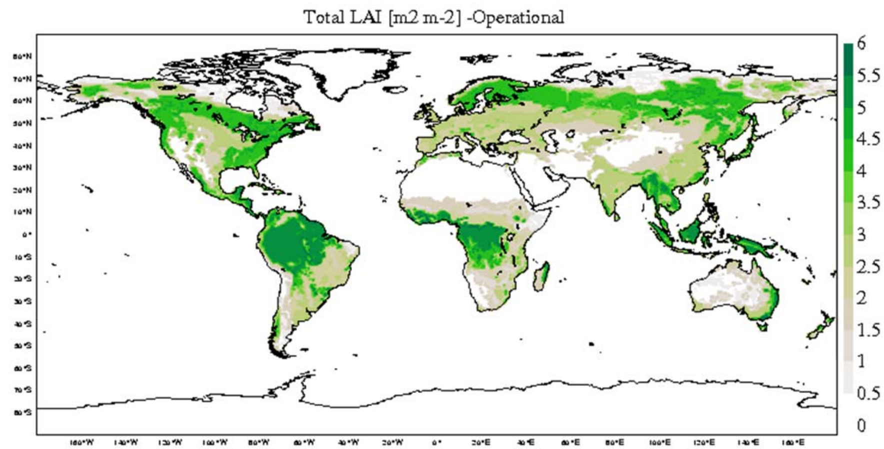
(Albergel, Balsamo)



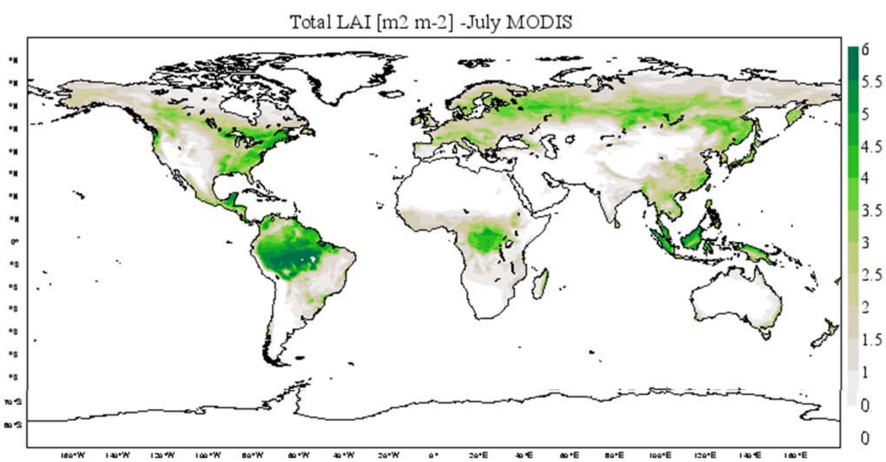
Globally Improved match to satellite soil moisture (shown is ΔACC calculate on 1-month running mean)

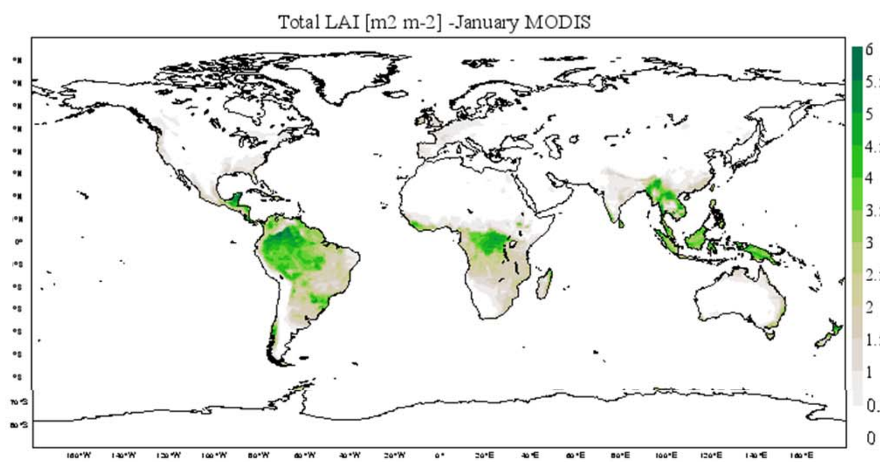
Anomaly correlation (1988-2014) measured with ESA-CCI soil moisture remote sensing (multi-sensor) product.
→ Provides a global validation of the usefulness of increase soil vertical resolution.

Seasonal Varying Leaf Area Index



Boussetta, Balsamo et al



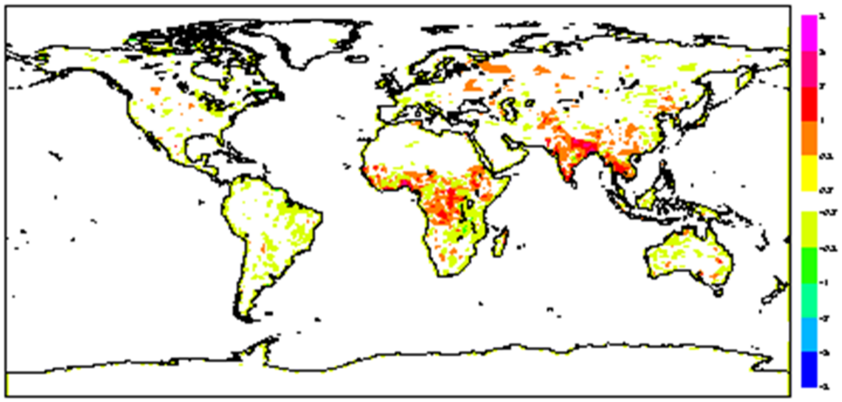


derived 8years (2000-2008) climatological time series from MODIS S5 products

Satellite-based LAI climatology introduce a more realistic seasonal variability of the vegetation state compared to the constant LAI map which used to overestimate LAI especially in winter and during the transition periods of spring and autumn

Seasonal Varying Leaf Area Index: Impact on T2m forecasts

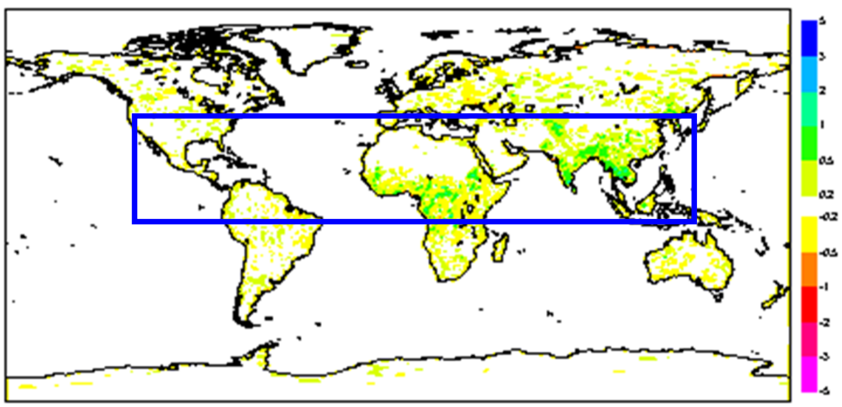
Sensitivity T2m (New-Old)



Warming
Cooling

Experiments Feb-Sept 2008
- Old (fixed LAI)
- New (LAI seasonal)

Impact T2m MEA Old – New



Forecasts
Improvement

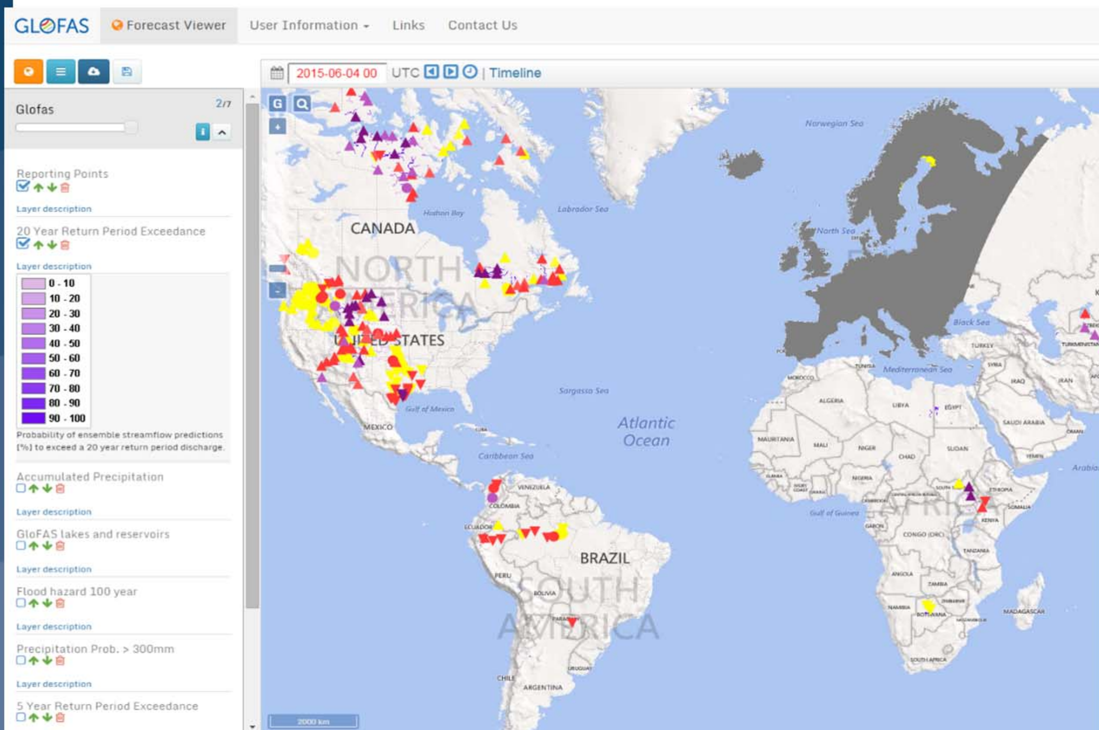
Degradation

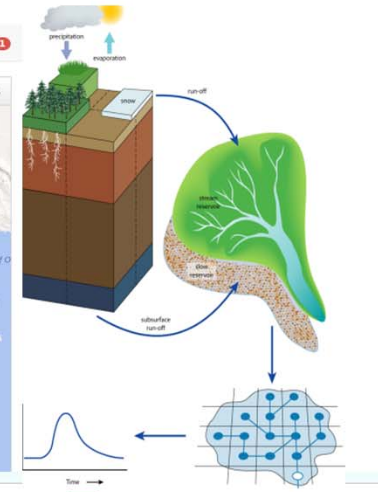
- **Satellite LAI → a consistent warming seen in FC36h (12UTC) due to reduction of LAI in spring (reduced ET).**
- **Beneficial impact on near surface temperature forecast by reducing t2m bias by ~0.5degree**

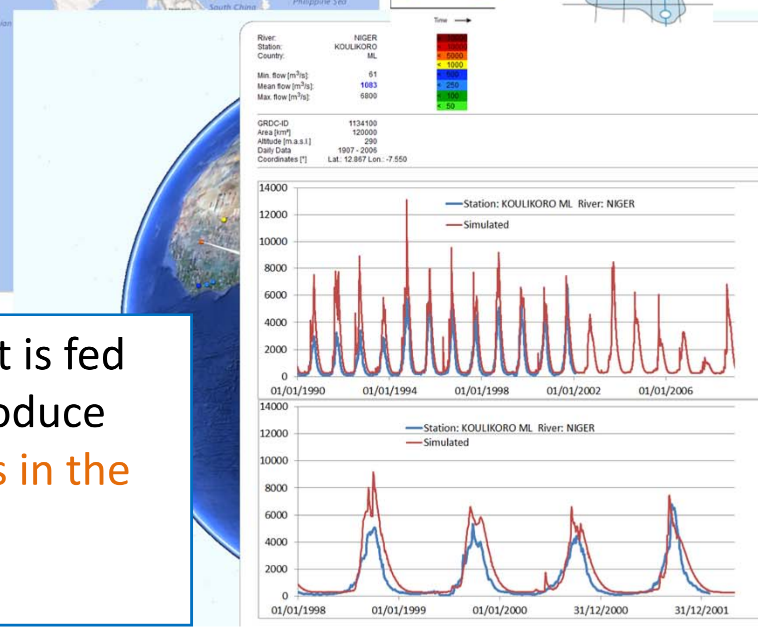
The Global Flood Awareness System

www.globalfloods.eu

florian.pappenberger@ecmwf.int







Output from global ECMWF NWP land-surface forecast is fed into a routing model (Simplified LISFLOOD (JRC)) to produce flood forecasts – benefiting from all the improvements in the ECMWF Integrated Forecasting System (model and assimilation)!

Summary (1/2)

Satellite data used for snow and soil moisture in the ECMWF IFS

- Snow: NOAA NESDIS/IMS 4km snow cover data (multi-sensor product). No use of Snow Water Equivalent products used for NWP
- Soil moisture: ASCAT-A/B IFS DA operational
- L-band TB: SMOS IFS Monitoring operational, SMAP Early Adopter
- SMOS SM: NRT (NN) processor implementation, offline NN SM DA tests
- Reanalyses: ERA5 use of Scatterometer series ERS/SCAT and Metop ASCAT
- Root zone retrieval from ASCAT (H-SAF): H14 (NRT) and H27 Climate data record

Summary (2/2)

- Flood forecasts: benefits from overall improvements in the ECMWF IFS, including soil and snow data assimilation.

- Current developments:
  - Hybrid EDA-SEKF analysis for stronger land-atmosphere assimilation coupling (Quasi SCDA)
- Future
  - SEKF in OOPS
  - Use of MW data to analyse snow depth
  - LST DA in the SEKF
  - Future WCOM mission relevant for both SWE and SM
  - Integrated hydrological variables such as river discharges
- Observation latency : crucial for NWP applications (<3h)
- In situ data: essential for DA (snow,T2m, etc) and evaluation (SM)

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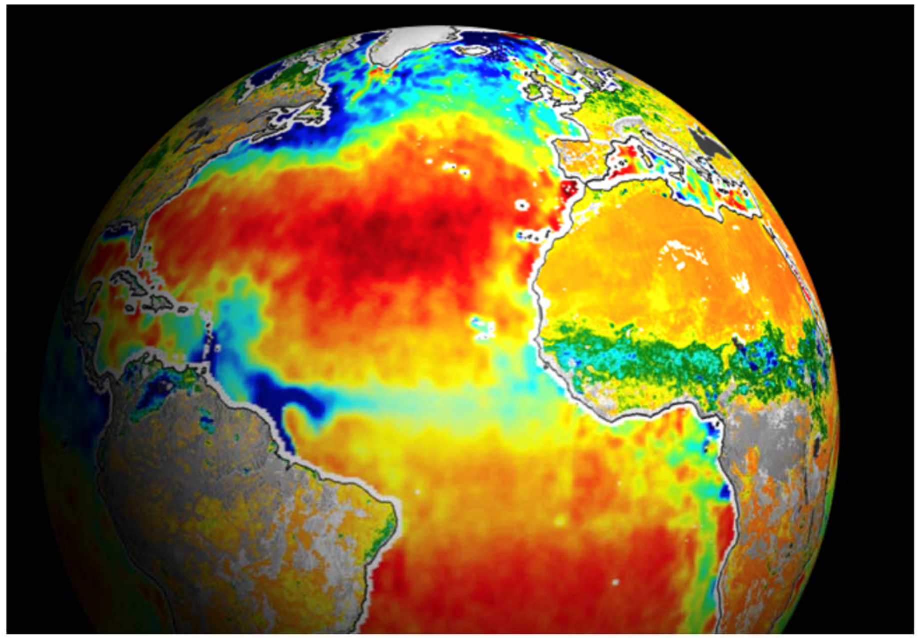
ECMWF/ESA Workshop on Using Low Frequency Passive Microwave Measurements in Research and Operational Applications

- Learning homepage
- Training
- Workshops
  - Poster guidelines
  - Past workshops
- Seminars
- Education material

ECMWF | Reading | 4-6 December 2017



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Programme (to follow)

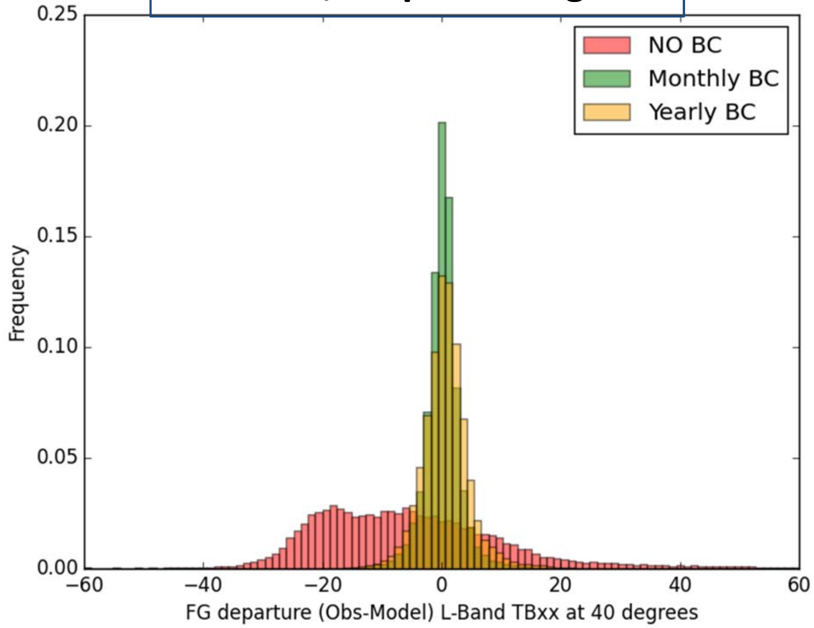
Local information

https://www.ecmwf.int/en/learning/workshops/workshop-using-low-frequency-passive-microwave-measurements-research-and-operational-applications

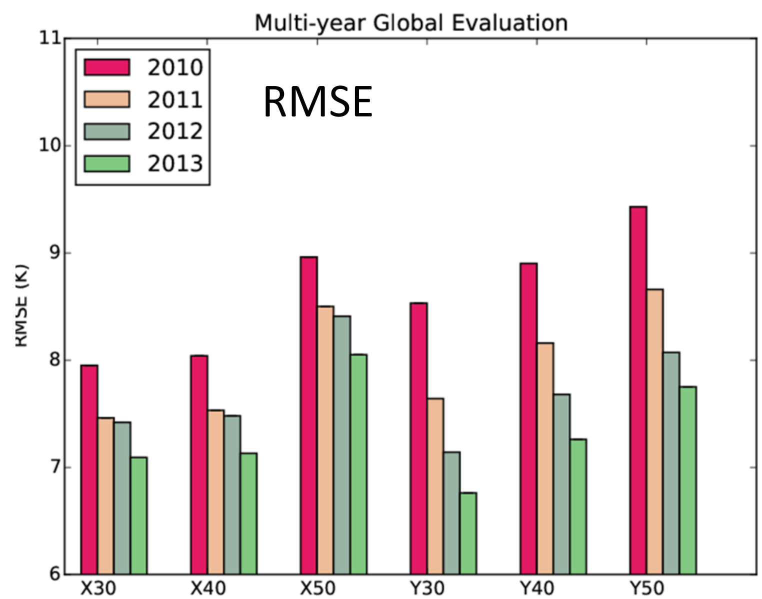
SMOS Forward modelling and Bias correction

- 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**

SMOS FG departure (O-B)
Jan 2013, XX pol 40 degrees



de Rosnay et al, in prep



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

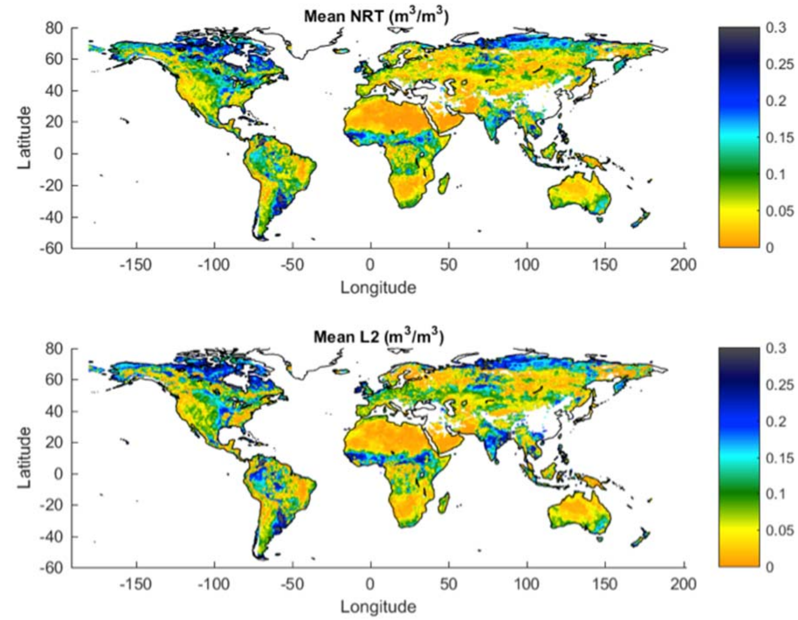
New level 2 SMOS NRT Soil Moisture product based on Neural Networks

Designed by CESBIO/Estellus, Implemented by ECMWF (Rodriguez et al, HESS 2017)

- Neural Network used to retrieve SMOS L2 SM from NRT brightness temperature
- Trained on SMOS L2 Soil moisture

→ NRT (4h latency) SMOS L2 SM

- Available in NetCDF, since March 2016 on ESA SMOS Online Dissemination service*https://smos-ds-02.eo.esa.int/oads/access*
  also on EUMETCAST and GTS



Comparison between L2 NRT and L2 v6.20 soil moisture

Evaluation against in situ stations (USCRN and SCAN)

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

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