5th SALGEE Workshop 2017
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ECMWF Soil Moisture products for NWP, hydrology and drought applications

Patricia de Rosnay

Thanks to: Souhail Boussetta, Gianpaolo Balsamo, Clément Albergel, David Fairbairn, Joaquín Muñoz-Sabater, Nemesio Rodríguez-Fernández, Hans Hersbach, Emanuel Dutra, H-SAF & ECMWF colleagues

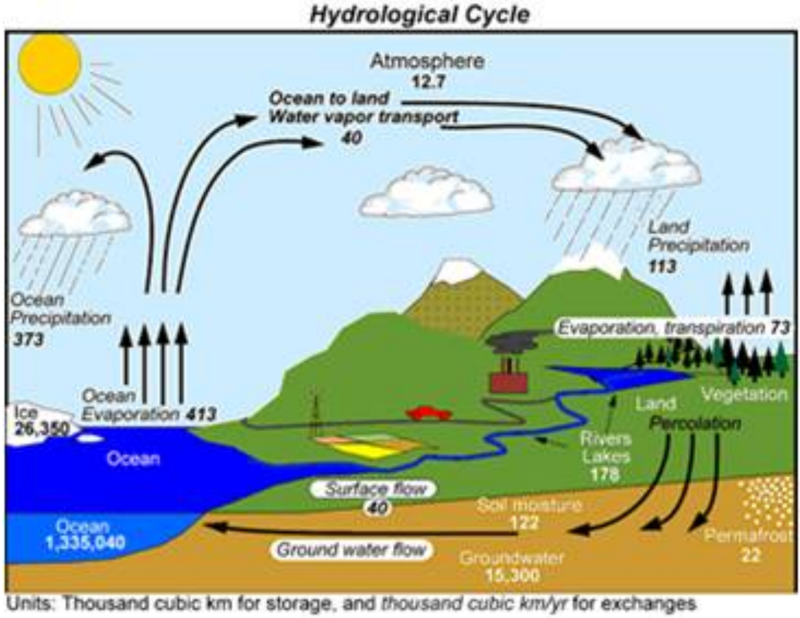
Introduction: Land Surface for Numerical Weather Prediction (NWP)

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
- Strong influence on near surface weather conditions, whose high quality forecast is a key objective in NWP

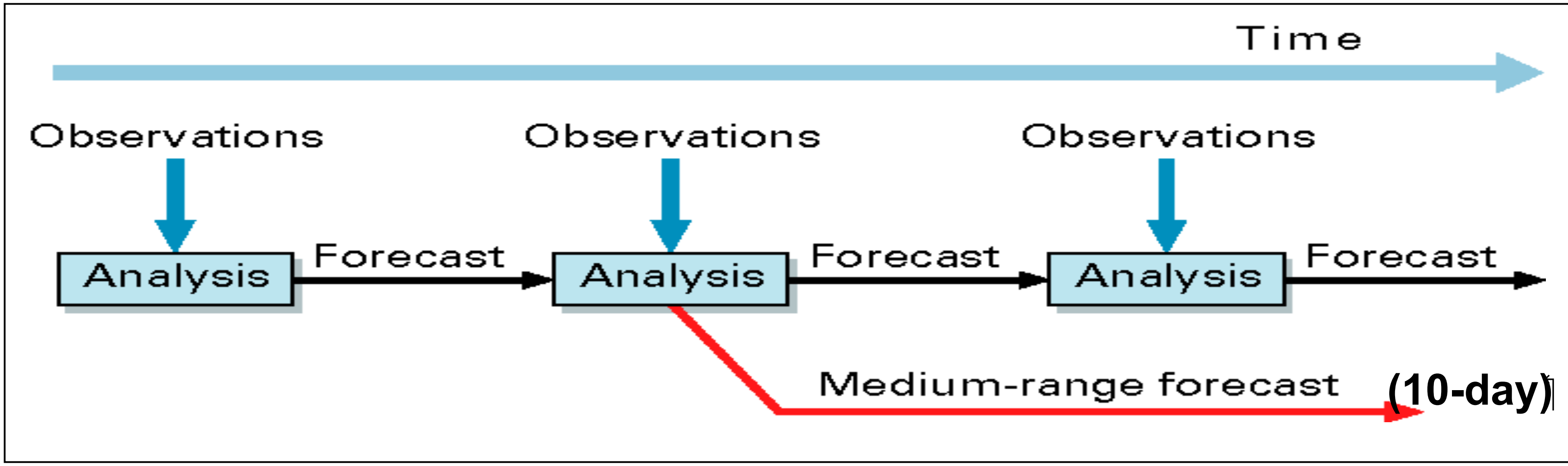
→ **Land surface processes modelling & initialization are important for NWP at all range (short to seasonal)**

(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 ; 3D-Var for ocean (for ensemble and seasonal)**
  - **Land Data Assimilation System (LDAS)**

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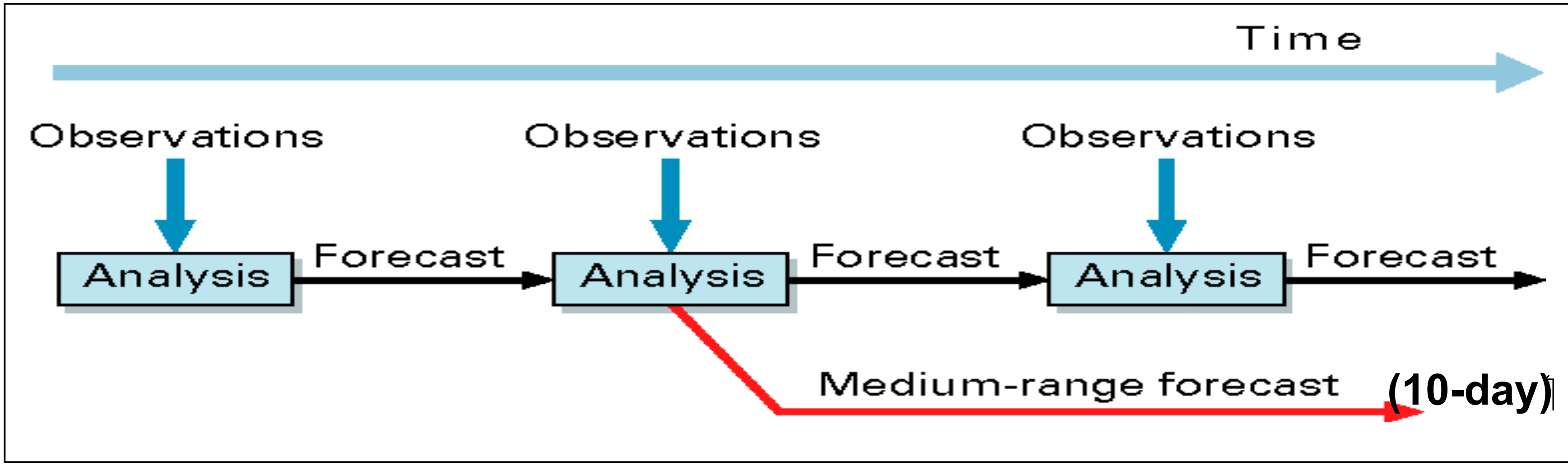

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Land assimilation in ECMWF systems for NWP:

- **NWP (oper):** IFS (with 4D-Var, **LDAS**), 9km, 43r3 (2017)
- **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

ECMWF Land Data Assimilation System (LDAS)

Soil moisture (SM)

Methods: - 1D Optimal Interpolation in ERA-Interim

- Simplified Extended Kalman Filter (EKF) for NWP and for ERA5

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

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

SMOS brightness temperature, research NASA SMAP

Snow depth

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

Observations: *in situ* snow depth and NOAA/NESDIS IMS Snow Cover

Soil Temperature and Snow Temperature

1D-OI using T2m analysis increments

Simplifed EKF soil moisture analysis

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

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

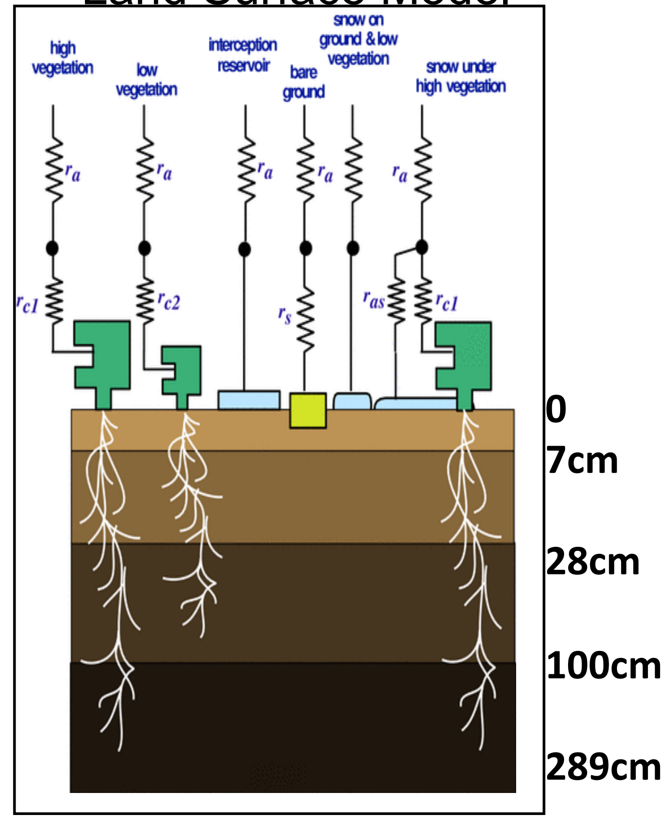
$\boldsymbol{x}$ background soil moisture state vector,
$\mathcal{H}$ non linear observation operator
$\boldsymbol{y}$ observation vector
$\boldsymbol{K}$ Kalman gain matrix, fn of
H (linearsation of $\mathcal{H}$), **P** and **R** (covariance matrices
of background and observation errors).

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

Observations used at ECMWF:

- 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)

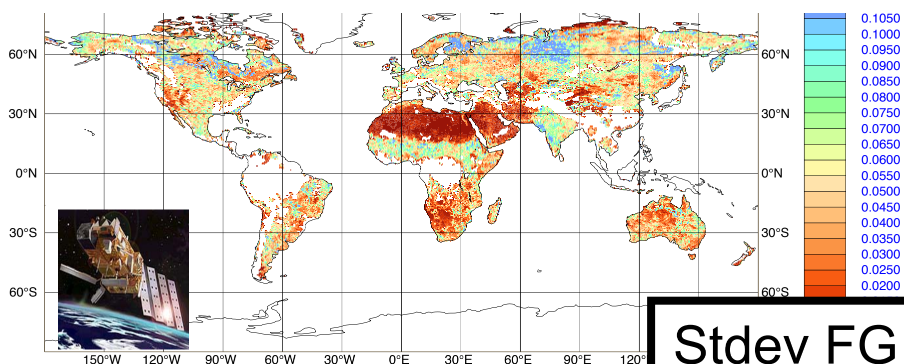
NRT Brightness Temperature

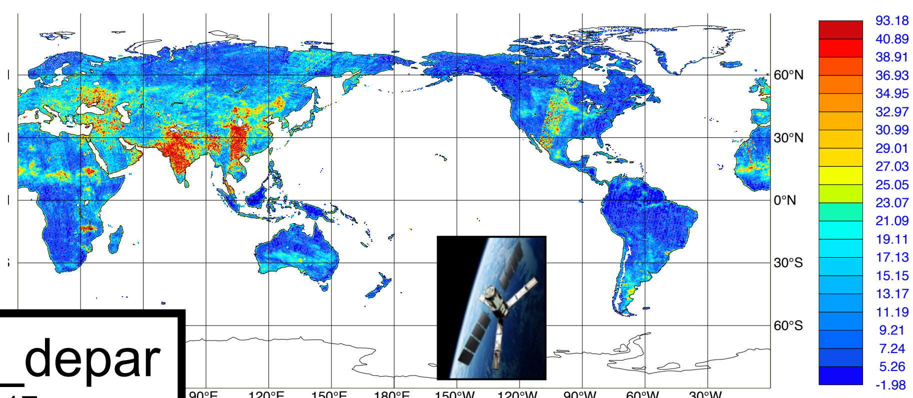
Dedicated soil moisture mission

→ Best sensitivity to soil moisture

Operational monitoring of surface soil moisture satellite data:

ASCAT/A soil moisture (m^3m^{-3}) 40° SMOS TB (K)





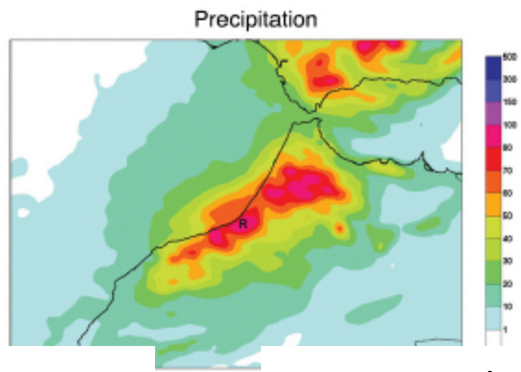
Stdev FG_depar

June 2017

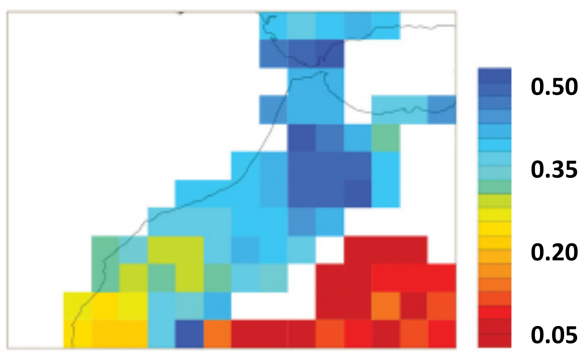
SMOS and ASCAT monitoring

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

Flash flood in Morocco 23 February 2017

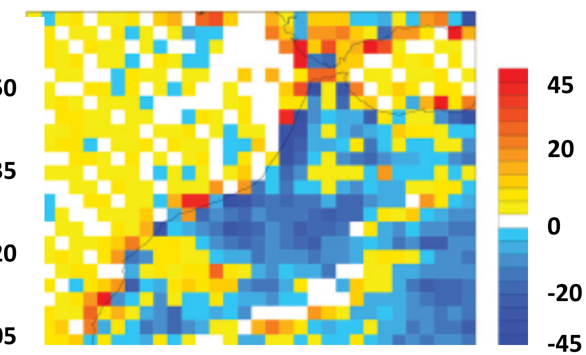


ASCAT Soil Moisture



ASCAT Soil Moisture in m^3/m^3
(red is dry / blue is wet)
→ Saturated

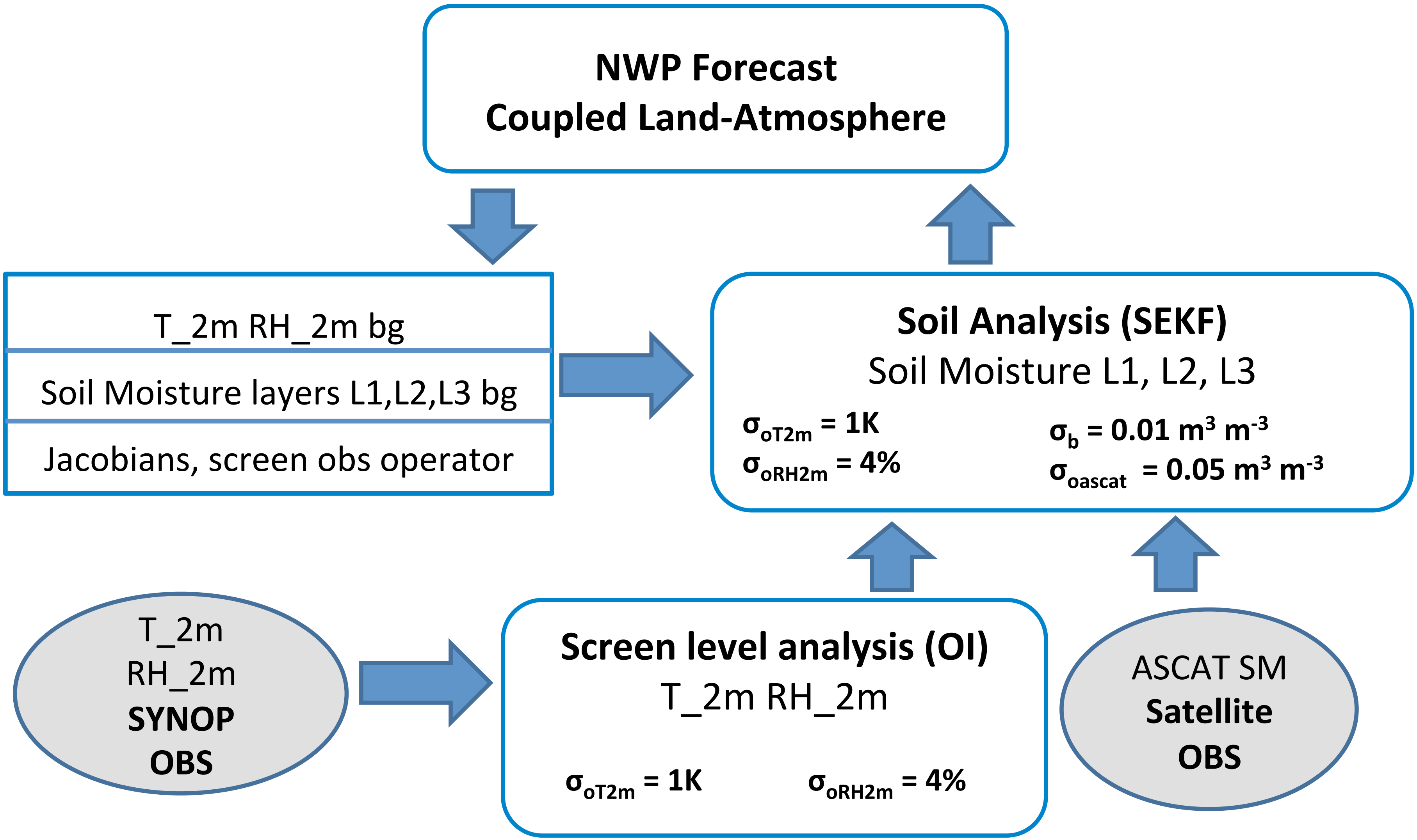
SMOS Brightness Temp



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

SMOS colder/wetter than FG
-> ECMWF FG drier than observations

Soil Analysis in the IFS

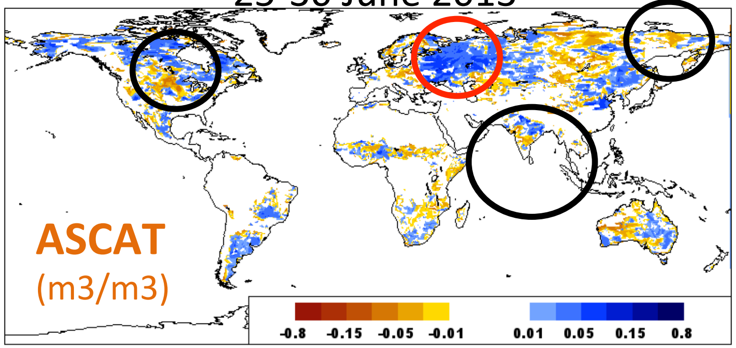


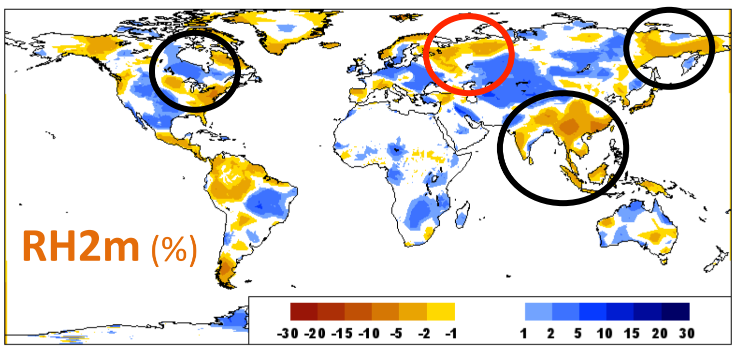
→ Operational soil moisture data assimilation: combines SYNOP and satellite data

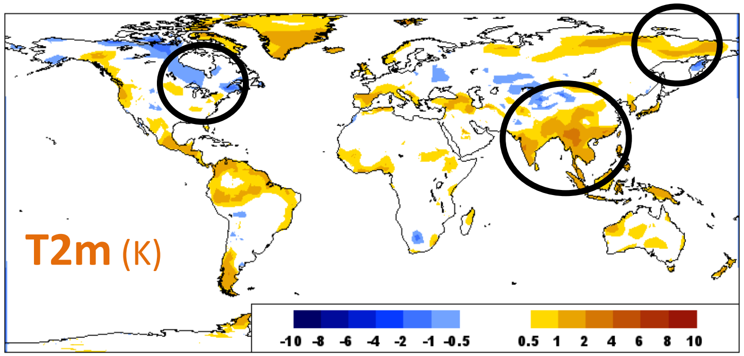
ASCAT Soil Moisture data assimilation

Innovation (Obs- model)

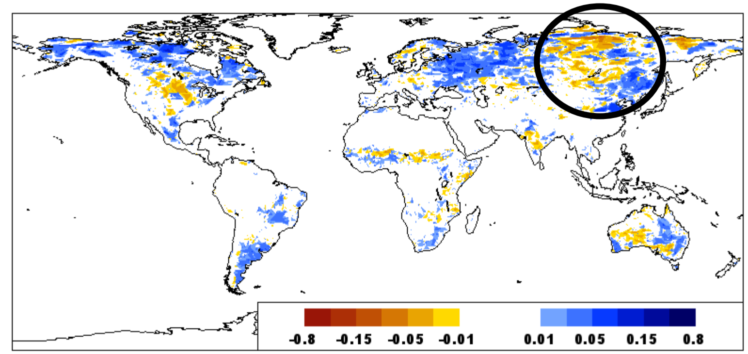
25-30 June 2013



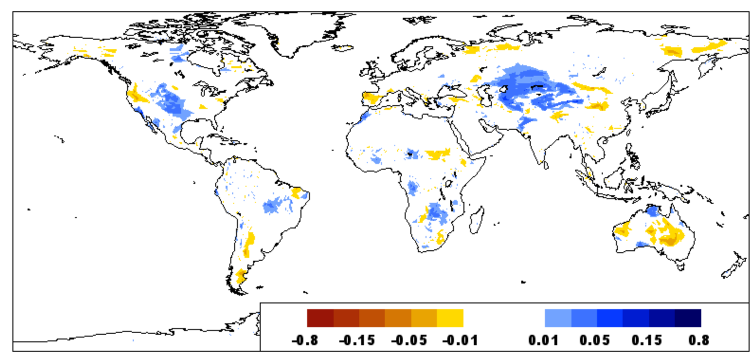




Accumulated Increments (m^3/m^3) in top soil layer (0-7cm)



Due to ASCAT



Due to SYNOP T2m and RH2m

Complementarity: both in situ and satellite contribute to soil moisture increments

ECMWF Re-analysis (ERA5)

Assimilation of Scatterometer soil moisture data ERS/SCAT and MetOpA/B ASCAT

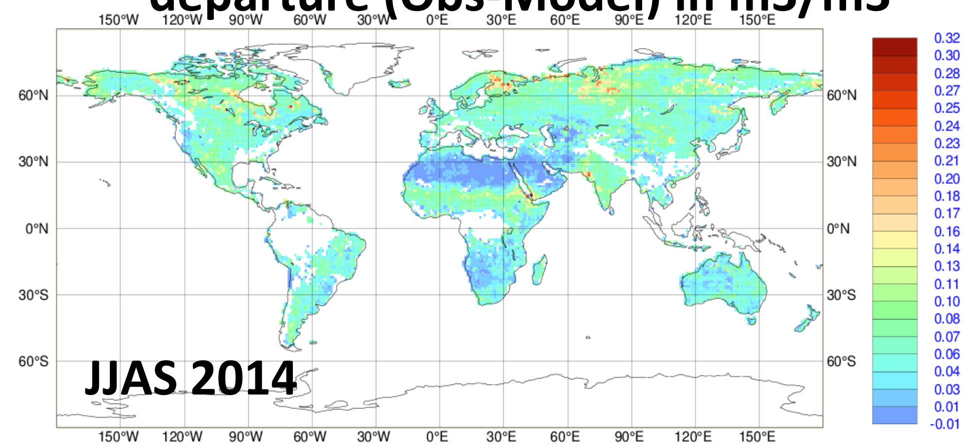
Use of EUMETSAT ASCAT-A reprocessed data (25km sampling)

	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

ASCAT surface soil moisture first guess departure (Obs-Model) in m3/m3



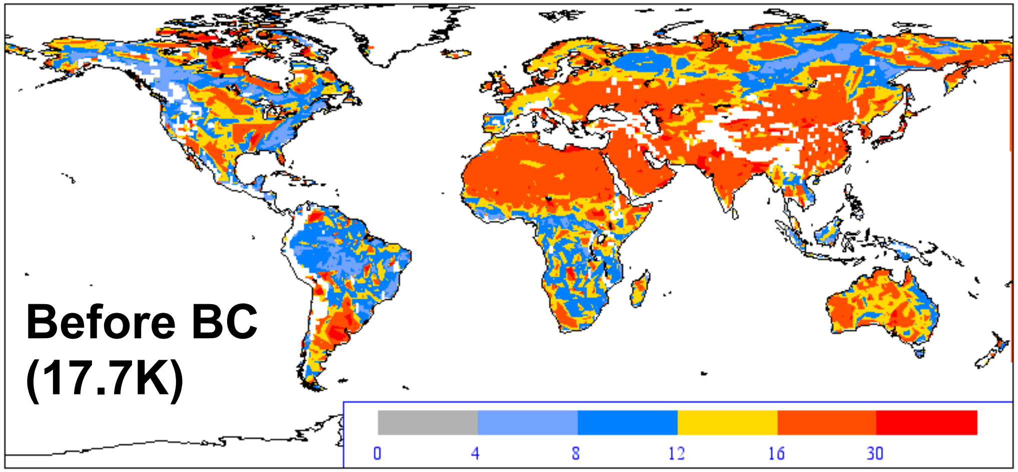
ERA5 production (C3S) on-going
2010-2016 released
1979-2009 Q2 2018

ECMWF L-band TB Bias correction

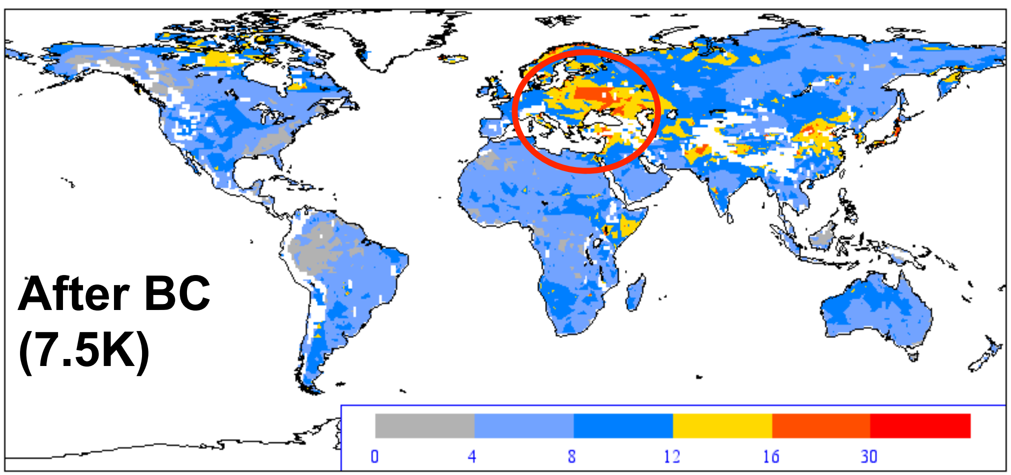
RMSD between SMOS Obs and ECMWF TBxx, 40 degrees

2012

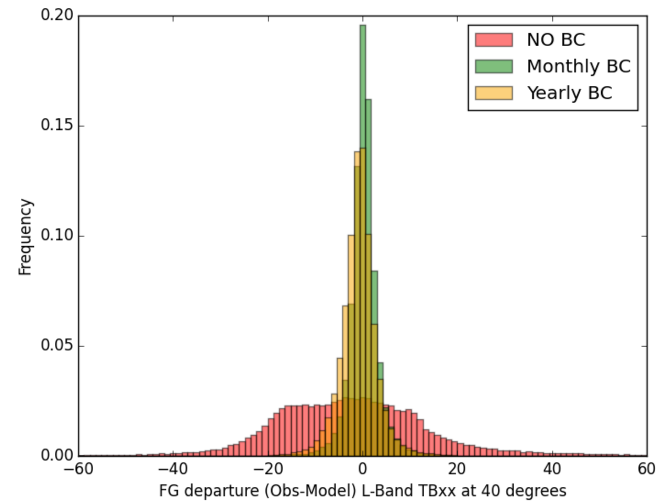
RMSD (K)



e 40

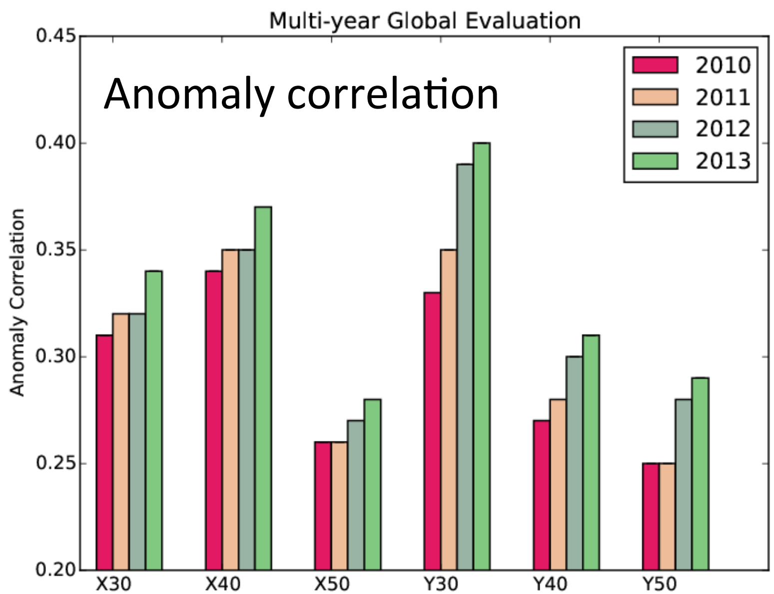


Low residual RMSD, except in RFI areas

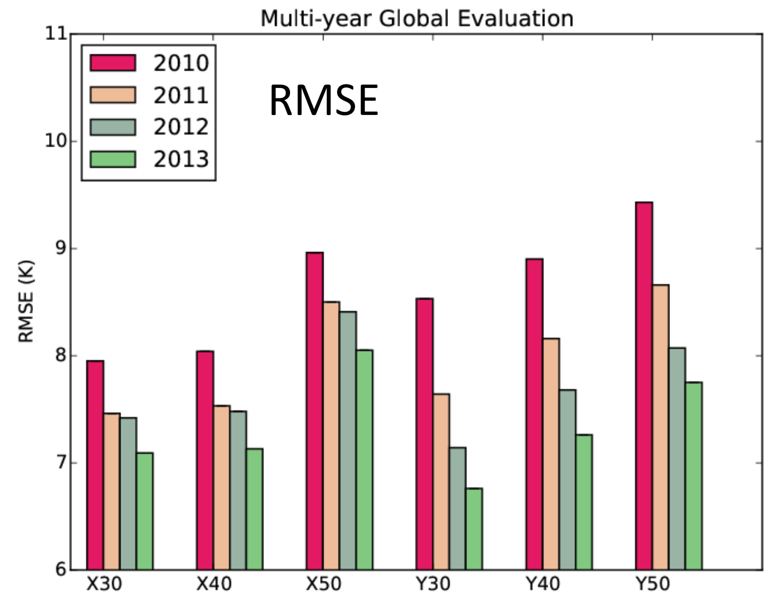


SMOS Forward modelling and Bias correction

- CMEM: ECMWF Community Microwave Emission Modelling Platform. Used ERA-Interim forcing, H-TESSEL and CMEM to simulate forward ECMWF SMOS TB for 2010-2013.
- → Comparison between ECMWF TB and SMOS NRT TB
- **Consistent improvement of SMOS data at Pol xx and yy, for incidence angles 30, 40, 50 degrees**



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



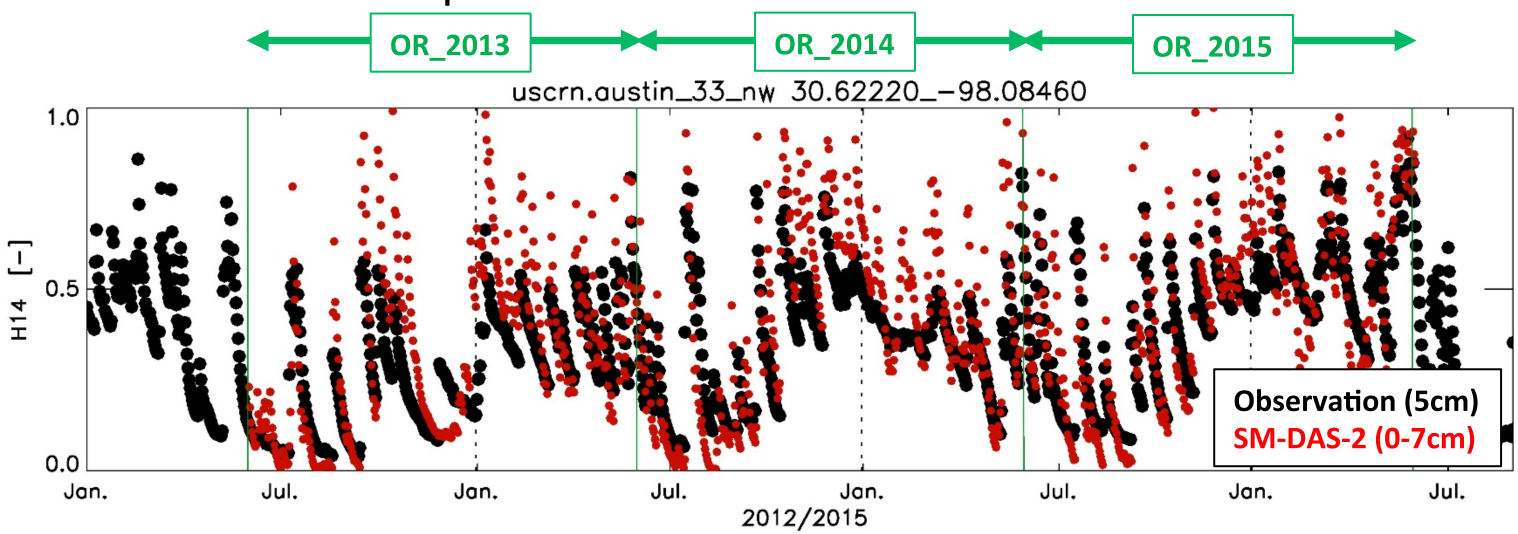
Polarisation (xx or yy) and incidence angle (30, 40, 50)

EUMETSAT H-SAF soil moisture

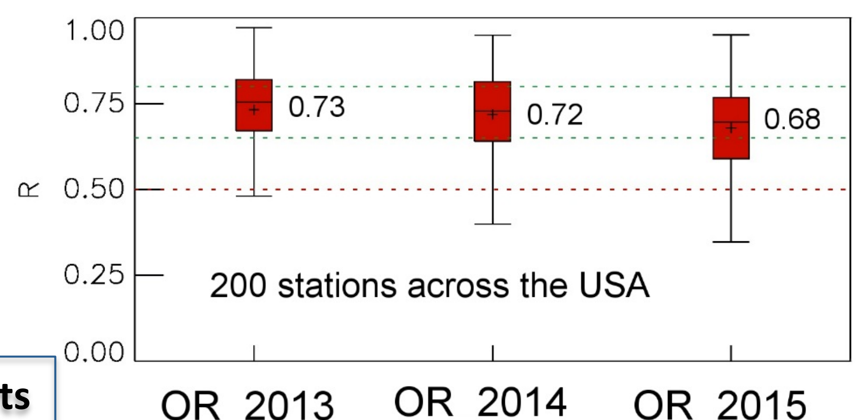
Scatterometer root zone soil moisture products based on data assimilation in a dedicated LDAS suite

Evaluation of SM-DAS-2/H14

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



H-SAF H14 Validation reports (Albergel et al)

EUMETSAT H-SAF soil moisture

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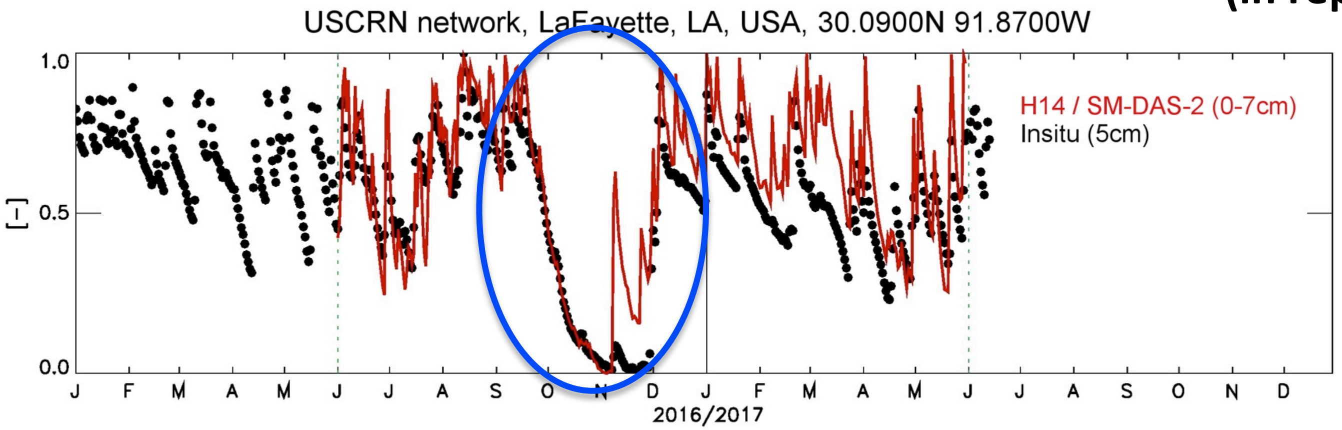
Surface and root zone liquid soil moisture content

Fairbairn, Albergel et al H14 2017 validation report (in rep)



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

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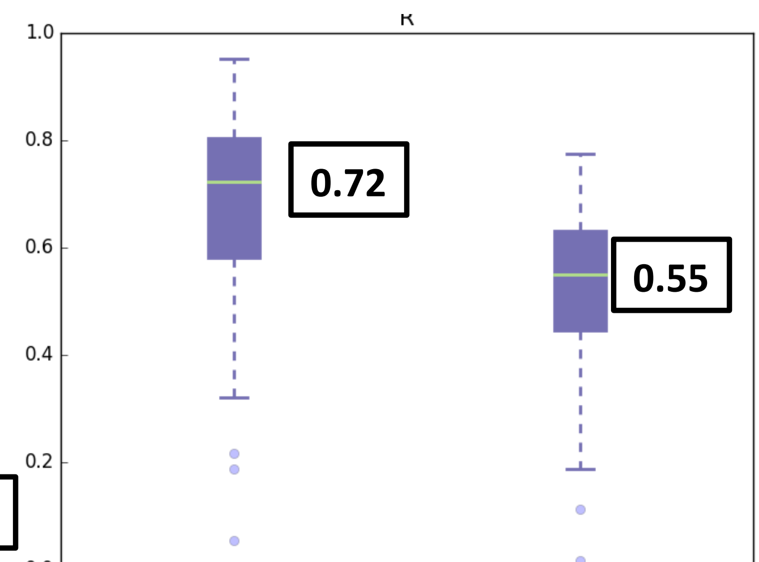


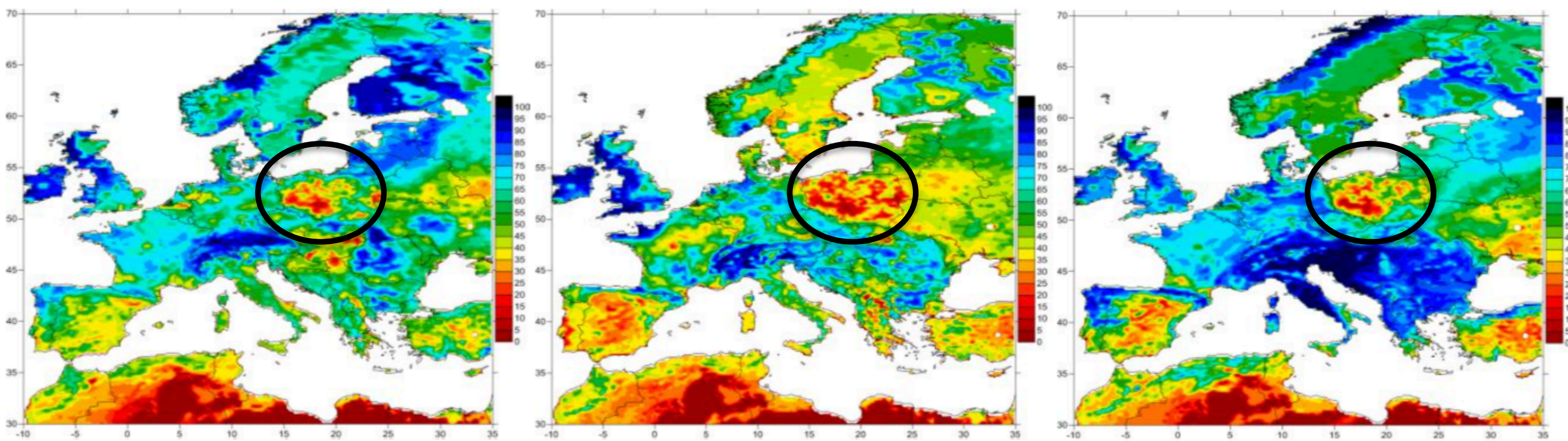
USCRN, 102 stations used

EUMETSAT H-SAF soil moisture

H14 ASCAT Root zone soil moisture index

2015 severe drought in Poland

Piotr Struzik & M. Kepinska-Kasprzak (proceedings EUMETSAT conf 2016)



15.05.2015 25.08.2015 15.10.2015

H14 used by Institute of Meteorology and Water Management in Poland for agriculture applications

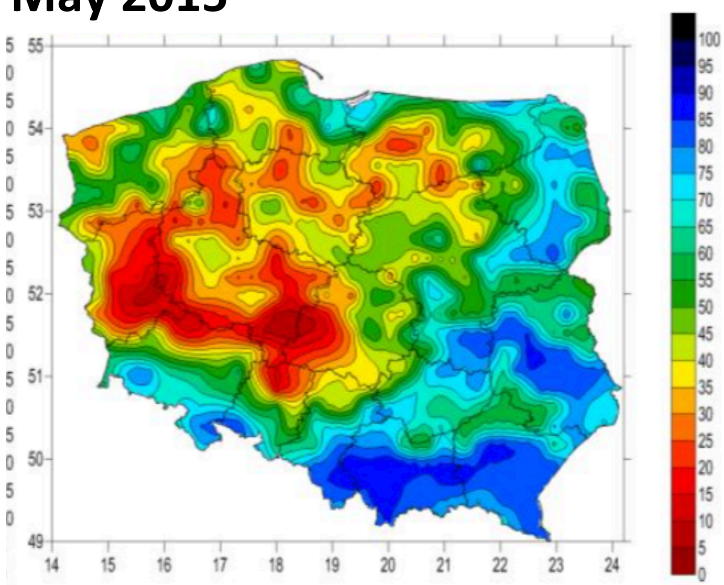
EUMETSAT H-SAF soil moisture

H14 ASCAT Root zone soil moisture index

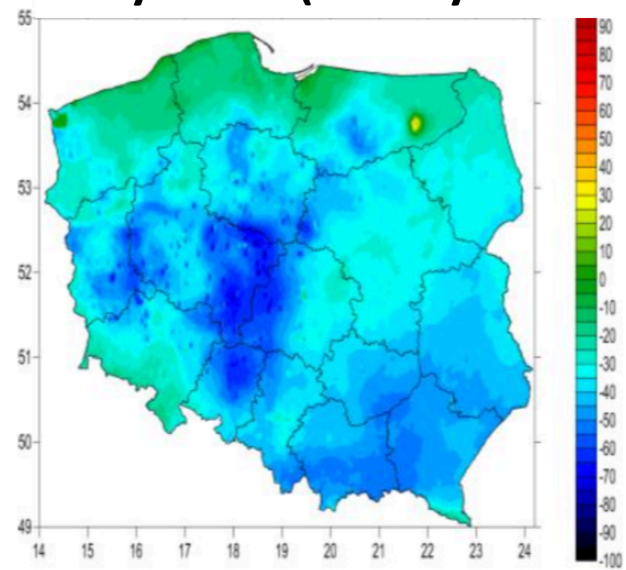
2015 severe drought in Poland

Piotr Struzik & M. Kepinska-Kasprzak (proceedings EUMETSAT conf 2016)

H-SAF H14 7-28cm depth
May 2015



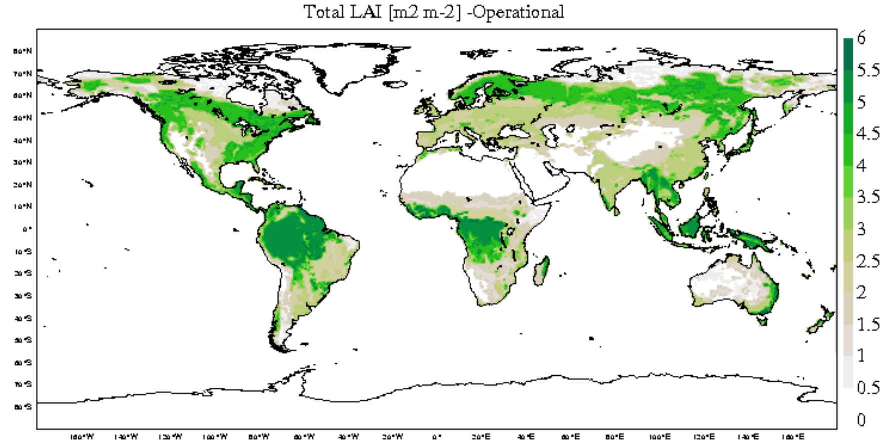
LSA-SAF ET anomaly
May 2015 (vs May 2010-2014)

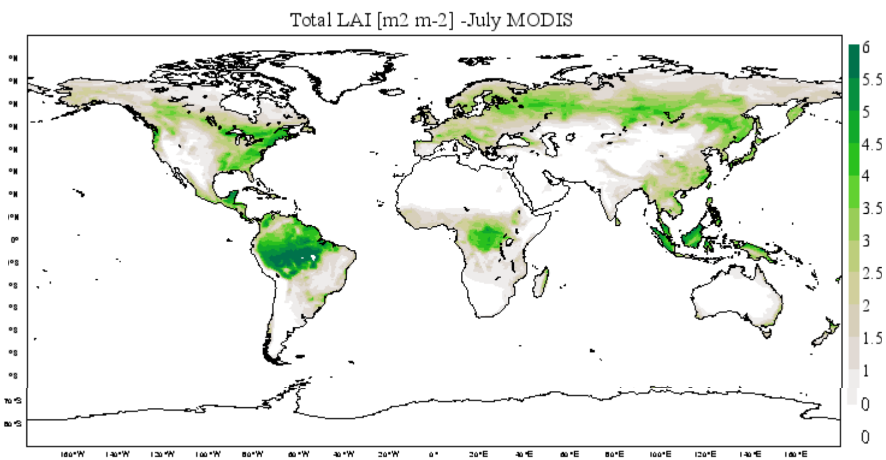


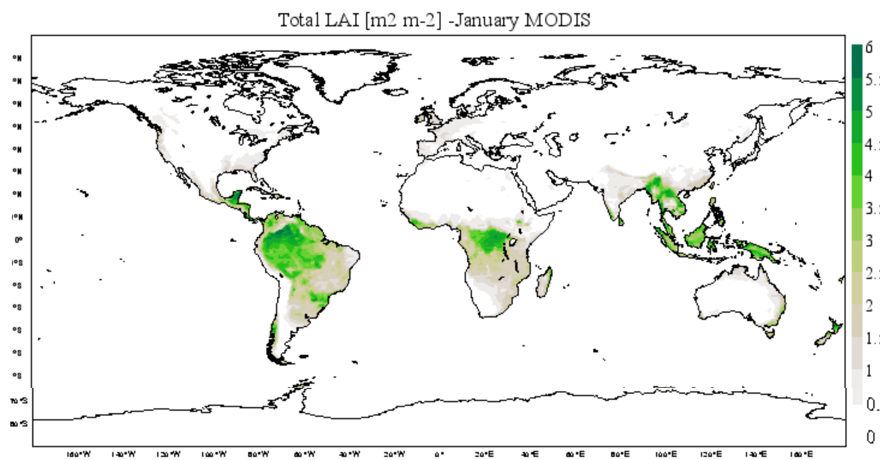
- Consistency between H-SAF H14 soil wetness and LSA-SAF ET products
- Drought event very well captured by both products (against in situ)

Seasonal Varying Leaf Area Index

Boussetta et al., IJRS, 2013





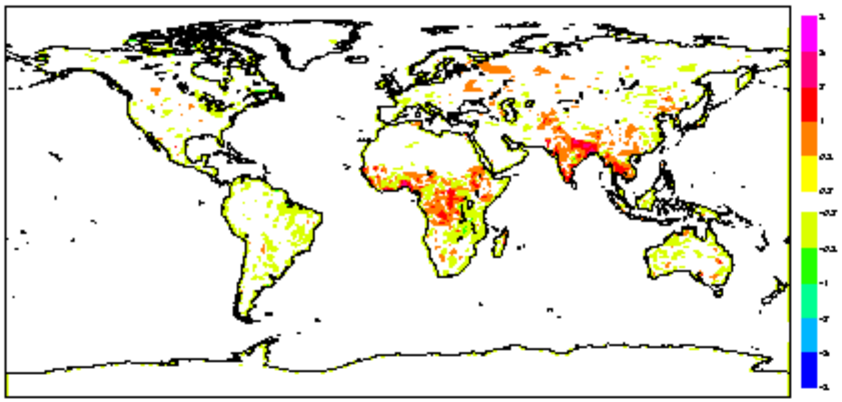


derived 8years (2000-2008) climatological time series from MODIS S5 products

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

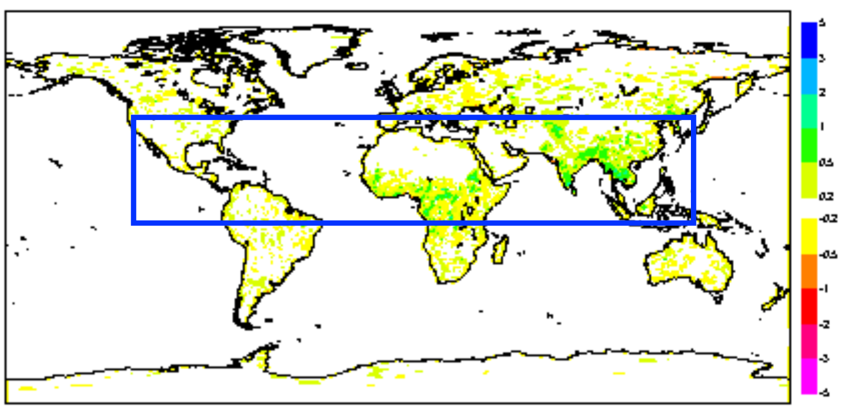
Sensitivity T2m (New-Old)



Warming
Cooling

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

Impact T2m MEA Old – New

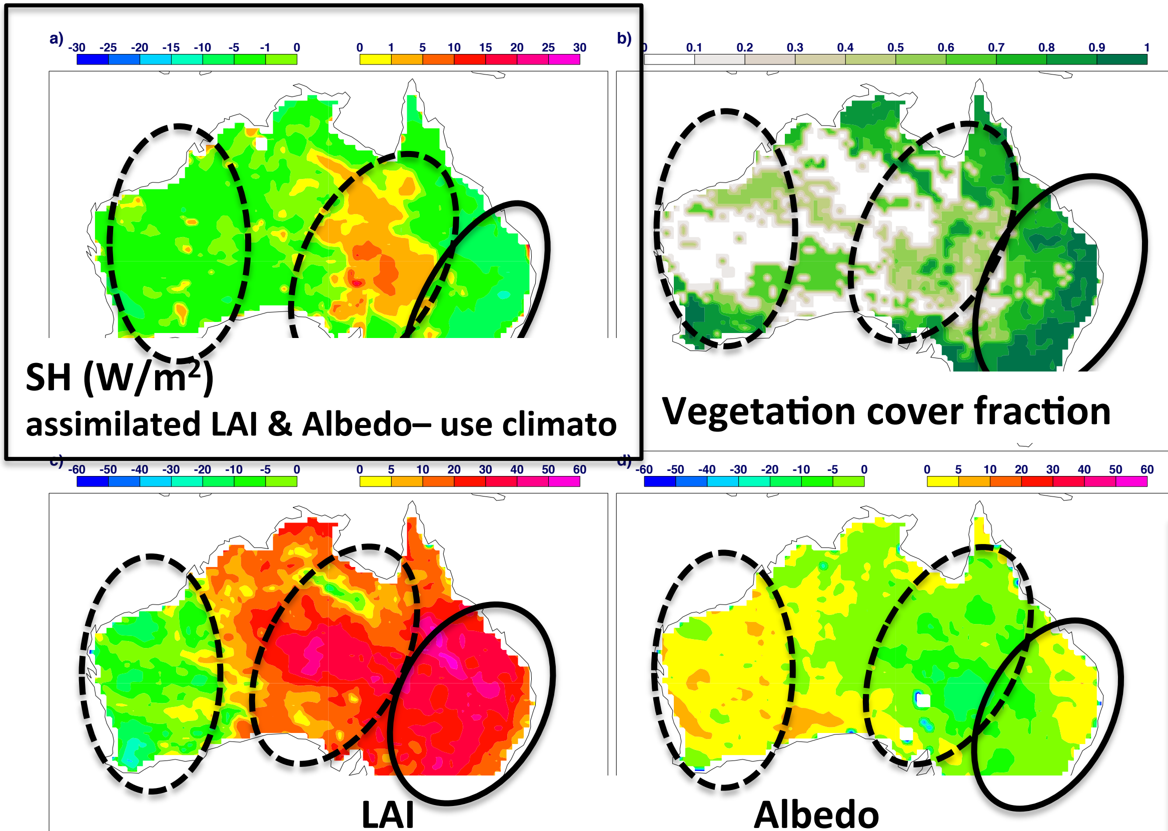


Forecasts Improvement

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**

Impact of LAI and albedo assimilation on surface processes



November 2010 anomaly (reference 1999-2013)

Boussetta et al, RSE, 2015
Calvet et. al. Elsevier, Oxfd, ISBN :9781785481048, 2016

East and Centre: Rain after drought
LAI + anom (+50%)
Albedo – anom (-20%)

West: drought
LAI – anom
Albedo + anom

East and Centre: after rain period → LAI positive anomaly and abledo negative anomaly
East: High cover → more ETR → LH positive anom & SH negative anomaly (by 20W/m²) → LAI effect
Centre: Scattered cover → Albedo decrease → more energy leads to SH increase → Albedo effect

West: drought→ positive albedo anomaly →less energy, less SH → Albedo effect dominates

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

Designed by CESBIO/Estellus, Implemented by ECMWF

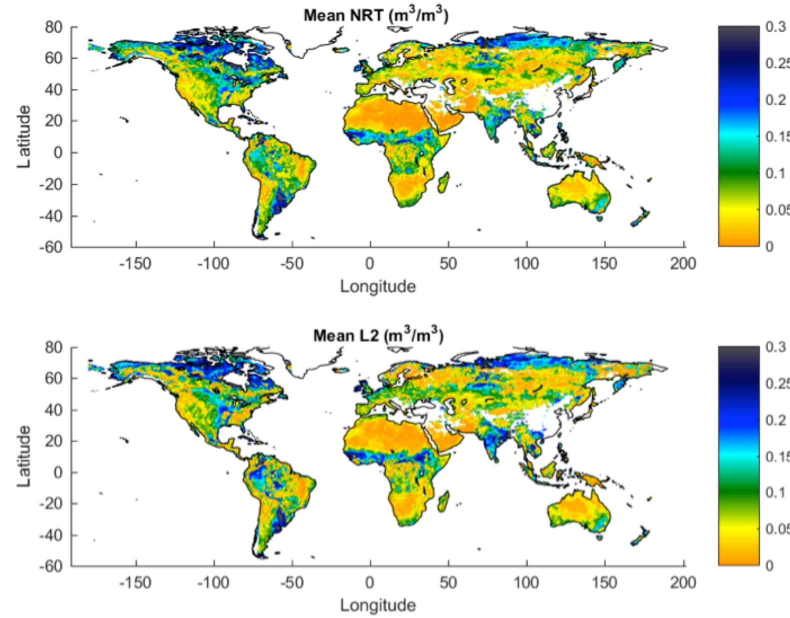
- Neural Network used to retrieve SMOS L2 SM from NRT brightness temperature
- Trained on SMOS L2 Soil moisture

→ 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)
→ median correlation of 0.71

Rodriguez-Fernandez et al, HESS 2017

Summary

- ECMWF soil moisture based on data assimilation of in situ (screen level) observations and satellite surface soil moisture → NWP, ERA5
- EUMETSAT H-SAF ASCAT root zone products: H14 (NRT) and H27 Climate data record, based on H-SAF retrieval suites
- ESA SMOS surface soil moisture product in near real time

- Importance of LAI and albedo conditions on energy partition
- ECMWF and EUMETSAT H-SAF products capture drought conditions (H-SAF PVR H24 and H27, 2017, Struzik et al 2016)
- Ongoing developments that will benefit drought monitoring: soil moisture vertical resolution increase in HTESSEL, ensemble-based soil moisture analysis

Thank you for your Attention!

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