Evaluation of remotely sensed and modelled soil moisture products using global ground-based in situ observations

C. Albergel(1), P. de Rosnay(1), G. Balsamo(1),J. Muñoz-Sabater(1), C. Gruhier(2), S. Hasenauer(3), L. Isaksen(1), Y. Kerr(2), W. Wagner(3)

[1] European Centre for Medium-Range Weather Forecasts (ECMWF)
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Importance of soil moisture

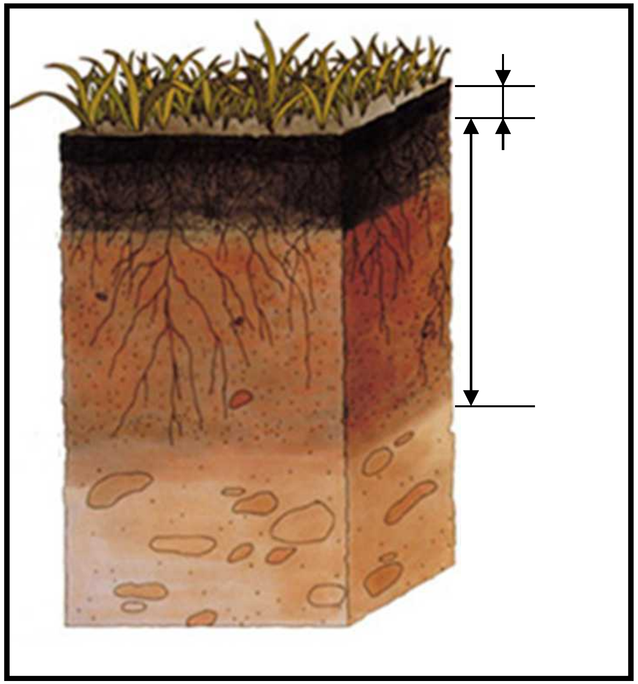
- **Key variable in land surface analysis**
  - Controls hydrological processes (runoff, evaporation, transpiration…)
  - Impacts plants growth and carbon fluxes

- **Obtaining soil moisture estimates**
  - Land surface modelling
  - Remote sensing (e.g. ASCAT, SMOS)
  - Combining land surface modelling and remote sensing through data assimilation

Soil moisture from remote sensing

- Provides quantitative information about the water content of a shallow near surface layer (e.g. ASCAT, SMOS)
- Main variable of interest for applications such as meteorological modelling and hydrological studies is the root-zone soil moisture

➔ Accurate retrieval requires to account for physical processes



SM-DAS-2 : Root zone retrieval based on Data Assimilation

ASCAT SM data assimilation : SM-DAS-2

ECMWF Atmospheric conditions

SYNOP
T2m RH2m

SM-OBS:
ASCAT
Surface SM

EKF
Soil Moisture
Analysis

SM-DAS-2:
Soil Moisture
Profile

4 layers : 0-7cm, 7-28 cm, 28-100 cm & 100-289cm

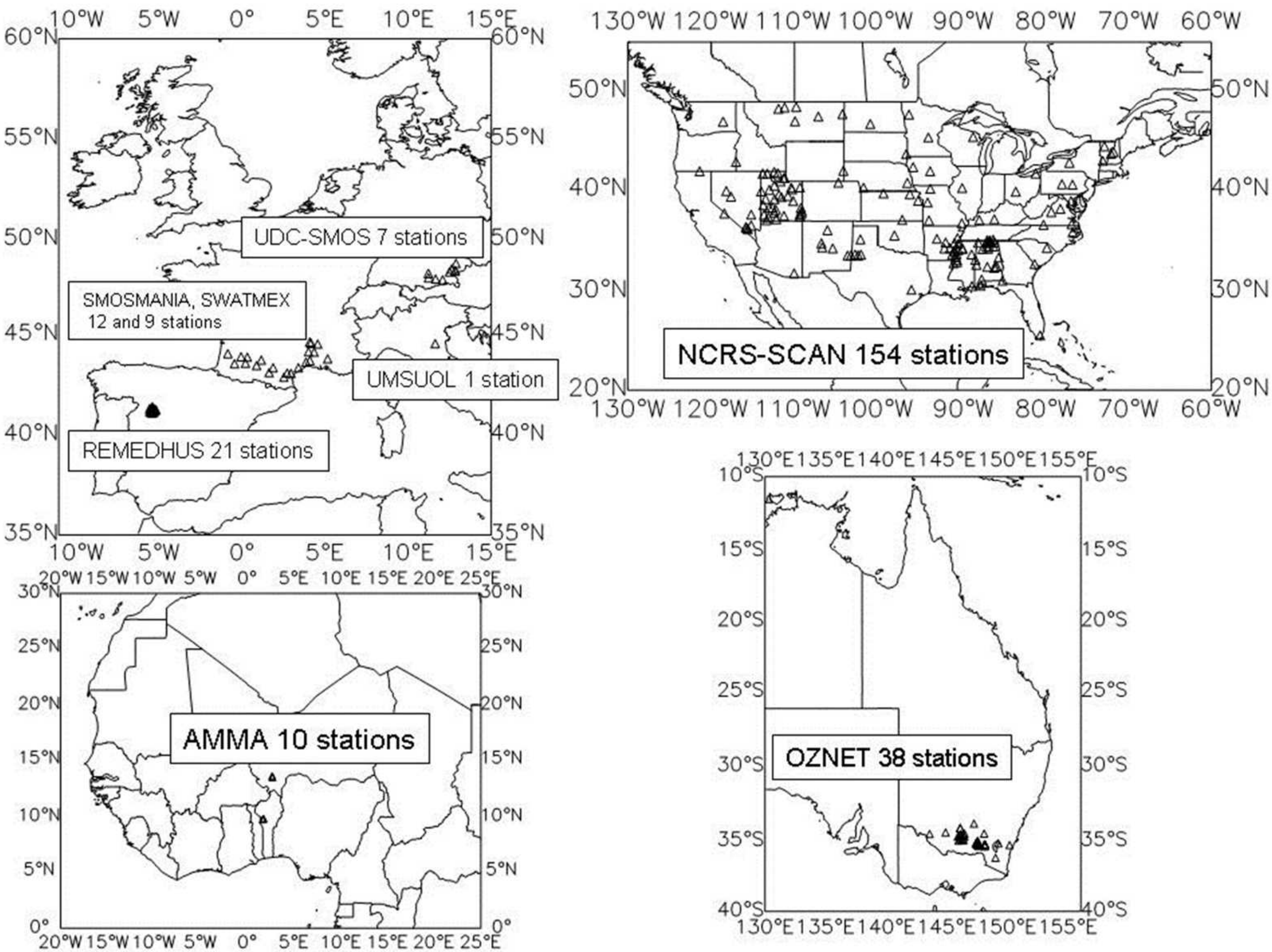
H-SAF CDOP: SM-DAS-2 Production chain

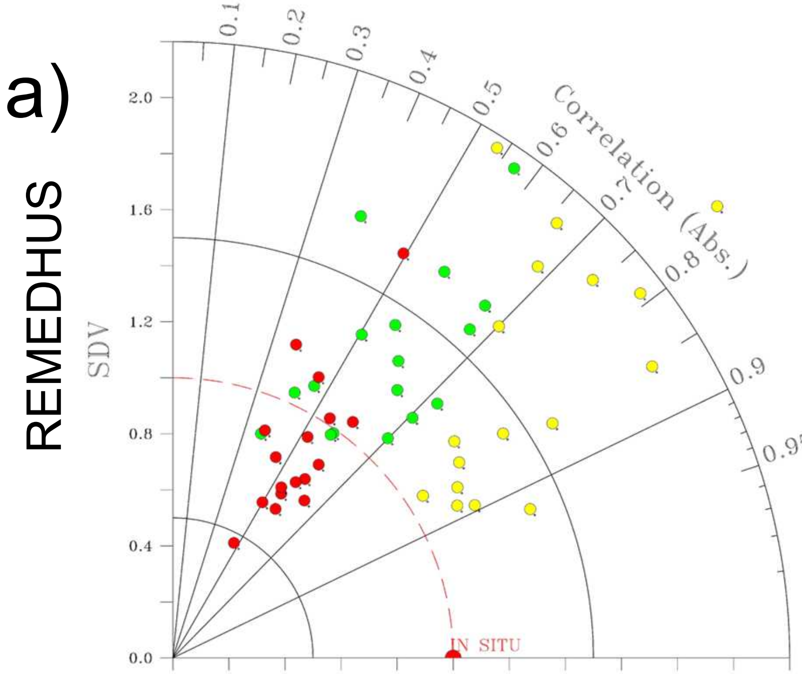
Evaluation of 3 soil moisture products

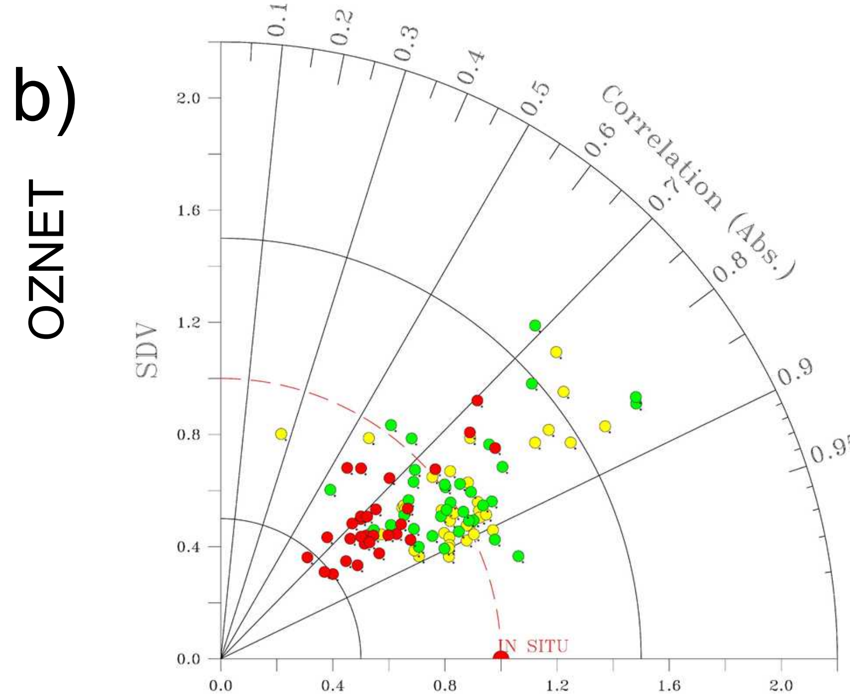
Soil Moisture data set	Type	Soil layer depth (cm)	Spatial resolution	Number of stations
ECMWF SM-DAS-2	NWP analysis	0-7	~25 km (T799)	Global product
ASCAT	Remotely sensed product	C-band, ~0.5-2	~25 km	Global product
SMOS level 2 product	Remotely sensed product	L-band, ~5	~40 km	Global product

- **ASCAT : NRT data and disseminated to NWP community via EUMETSAT**
- **SMOS : level 2 product, i.e. SSM, produces at CESBIO**

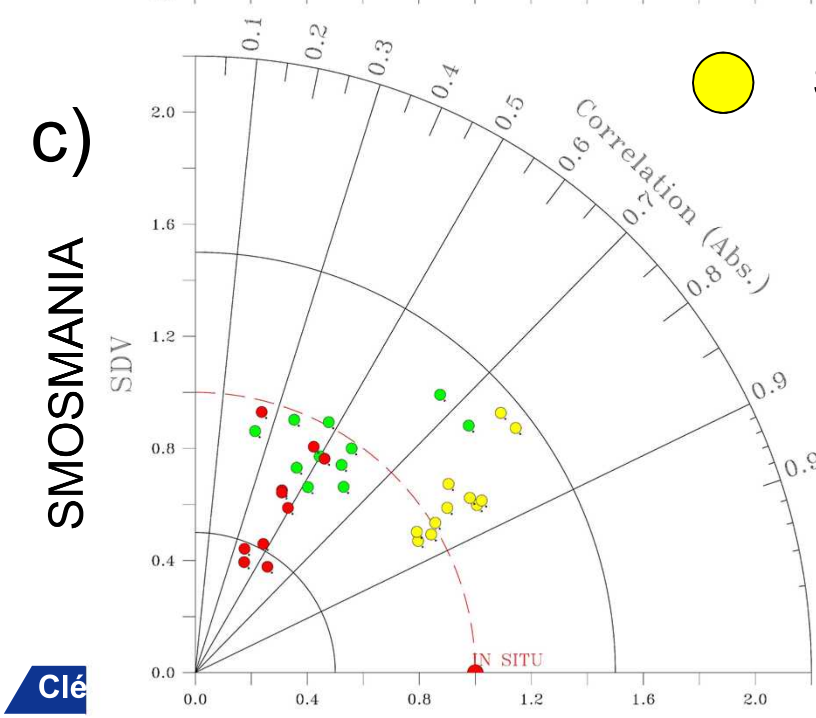
In situ SSM : 252 stations available in 2010







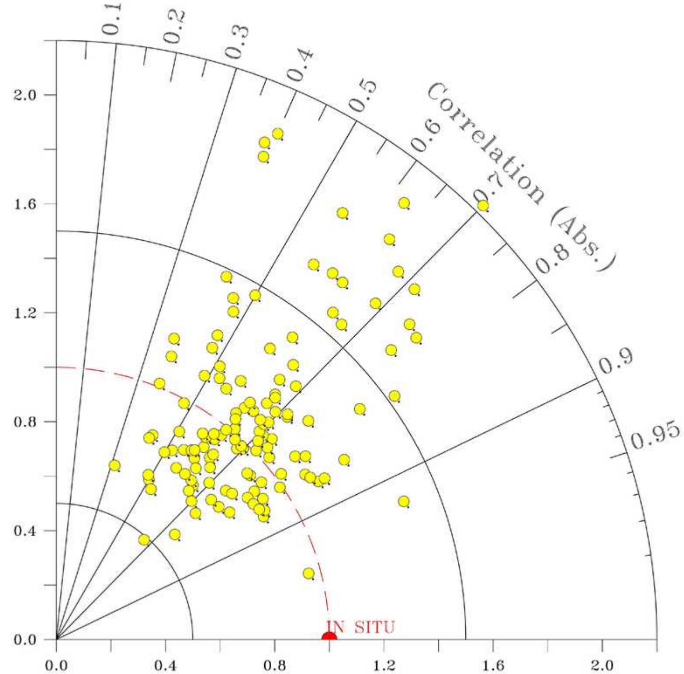
SM-DAS-2 ASCAT SMOS



Soil Moisture data set	Correlation [-]		
	SM-D	*ASC*	*SMO*
REMEDHUS (Spain)	**0.79**	**0.57**	**0.52**
OZNET (Australie)	**0.82**	**0.80**	**0.74**
SMOSMANIA (France)	**0.83**	**0.52**	**0.44**

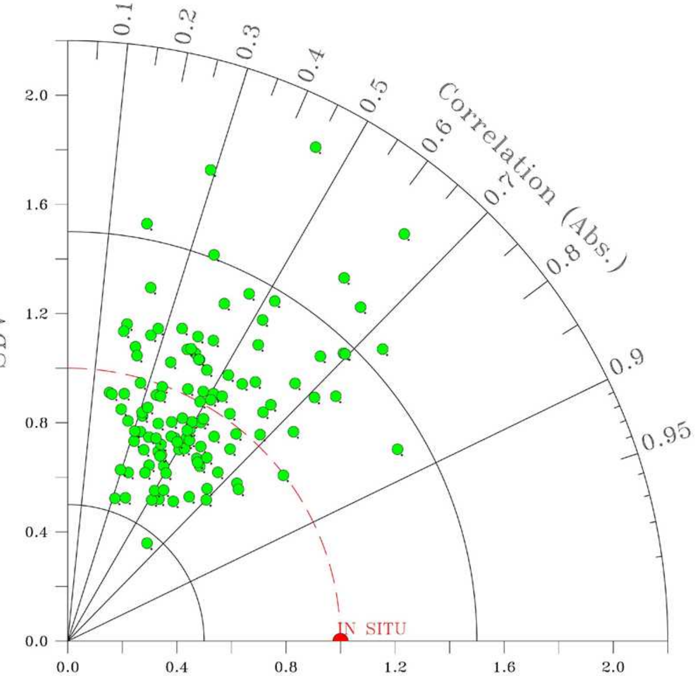
a)

NCRS-SCAN



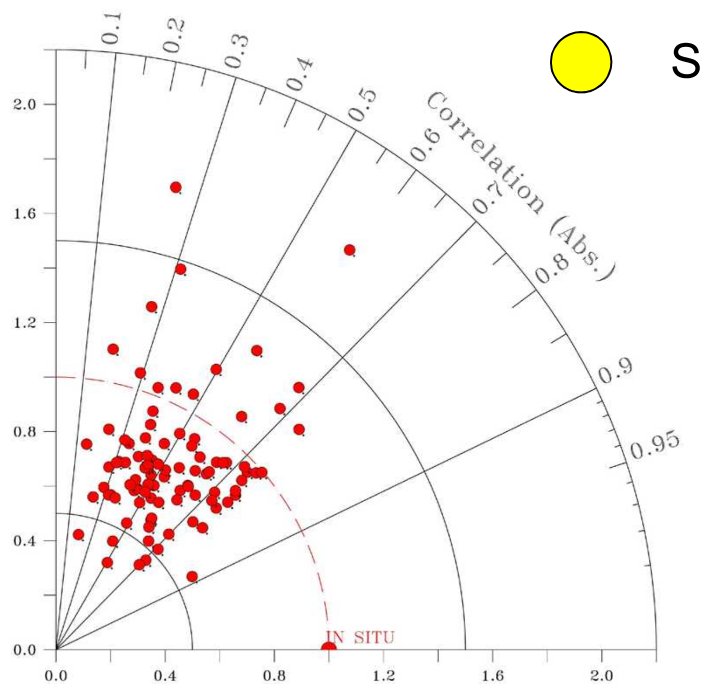
b)

NCRS-SCAN



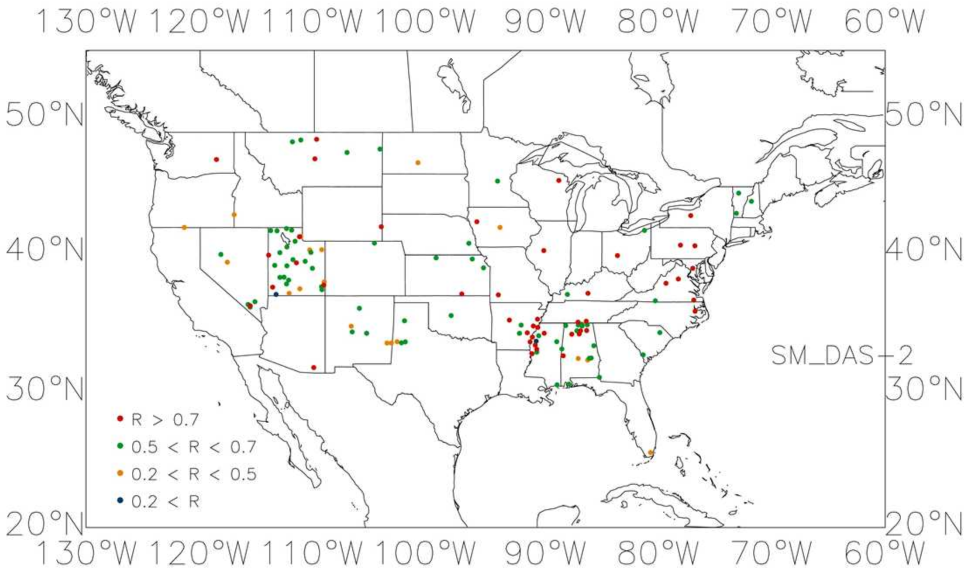
c)

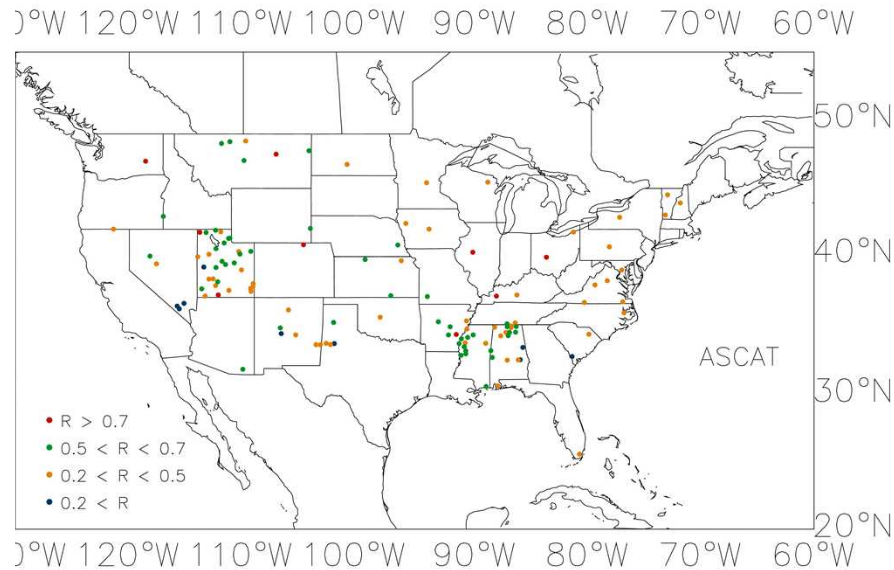
NCRS-SCAN



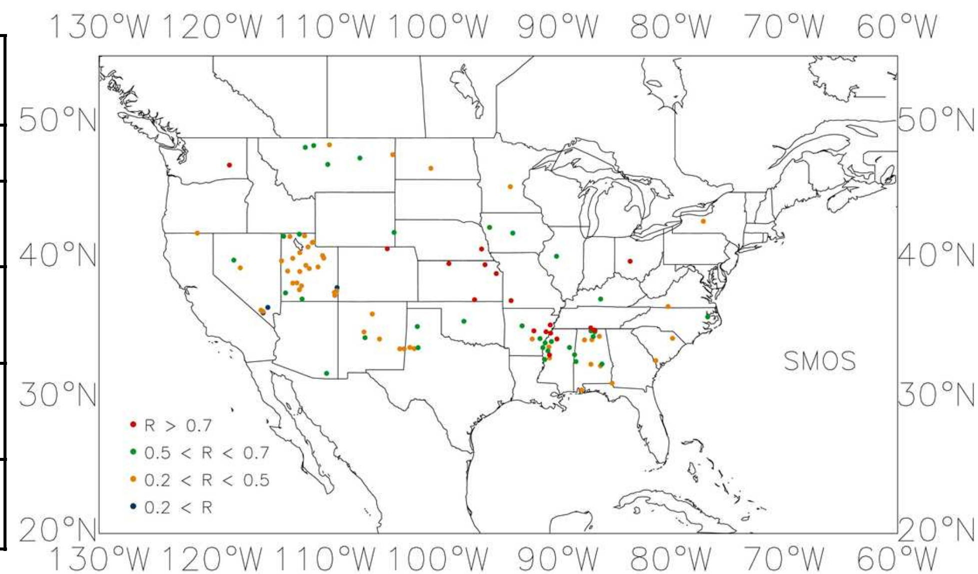
SM-DAS-2 ASCAT SMOS

Soil Moisture data set	Correlation [-]		
	SM-D	***ASC***	***SMO***
NCRS-SCAN (US)	**0.65**	**0.48**	**0.51**

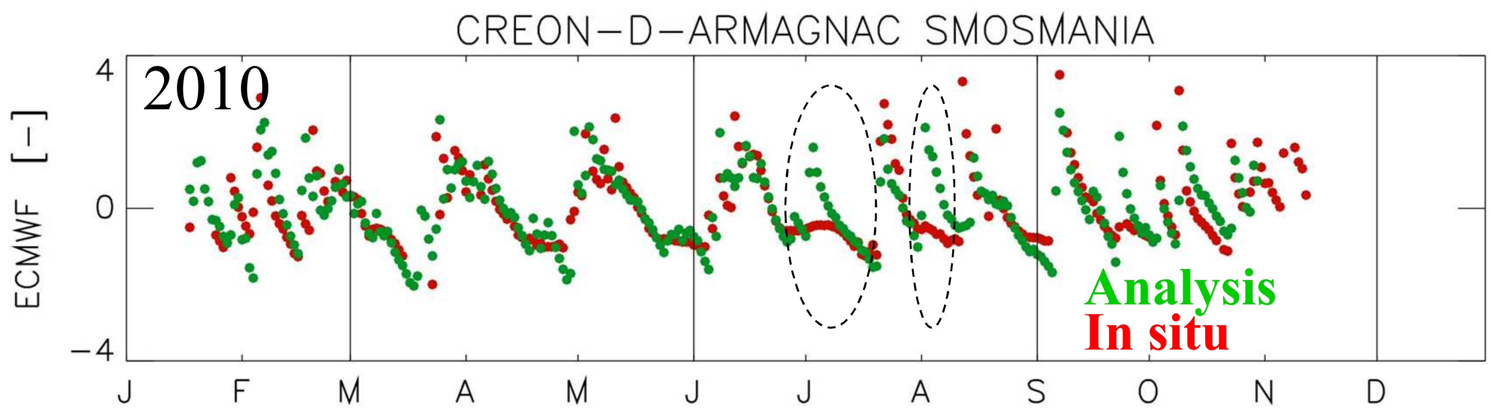




Level of correlation	NCRS-SCAN		
	SM-D	***ASC***	***SMO***
Inadequate (%) R<0.2	**2**	**7**	**3**
Poor (%) 0.2<R<0.5	**14**	**47**	**48**
Fair (%) 0.5<R<0.7	**50**	**39**	**32**
Good (%) R>0.7	**34**	**7**	**17**



Comparison of the Anomaly time-series



Soil Moisture data set	Correlation [-]		
	SM-D	*ASC*	*SMO*
Winter	0.70	0.71	0.55
Spring	0.65	0.56	0.51
Summer	0.53	0.46	0.46
Autumn	0.62	0.50	0.45

- Representativeness of local rainfall could induce discrepancies when compared to coarse resolution products
- Assimilation of rain-gauge rainfall accumulation is an ongoing activity

Global evaluation

- **Good performances of the three products to capture surface soil moisture annual cycle as well as short term variability**

Soil Moisture data set	Correlation [-]			Bias [-]			RMSD [-]		
	SM-D	*ASC*	*SMO*	*SM-D*	*ASC*	*SMO*	*SM-D*	*ASC*	*SMO*
All stations	**0.70**	**0.53**	**0.54**	**-0.050**	**-0.068**	**0.120**	**0.235**	**0.255**	**0.243**

- **Results particularly encouraging over the Oznet network**
  - **does not seem to be affected by RFI**
  - **dense vegetation canopies → reduced sensitivity to soil moisture**
  - **land use is predominantly agricultural →significant fraction of bare soil and/or of dry vegetation**

Towards a root zone soil moisture product

- ECMWF SSM, good correlations, high biases and RMSD
- Spatial variability of in situ SSM very high and differences in soil properties could imply difference in the mean and the variance on SSM

→ The true information content of modelled SSM not relies in their absolute magnitudes but in their time variation, i.e. the time-integrated impact of antecedent meteorological forcing

Good level of correlation of ECMWF SSM is supportive of the development of a root zone soil moisture index

Use of ASCAT within the EKF

- Small/Neutral impact of ASCAT SSM assimilation
- ASCAT required that the data are rescaled to the model climatology (CDF matching, Scipal et al., 2008)

➔ Improved CDF matching is expected, with H-TESSEL corrected from precipitation errors

- New ASCAT data processed by EUMETSAT (lower product noise level, 18/08)

There is room for improvement!

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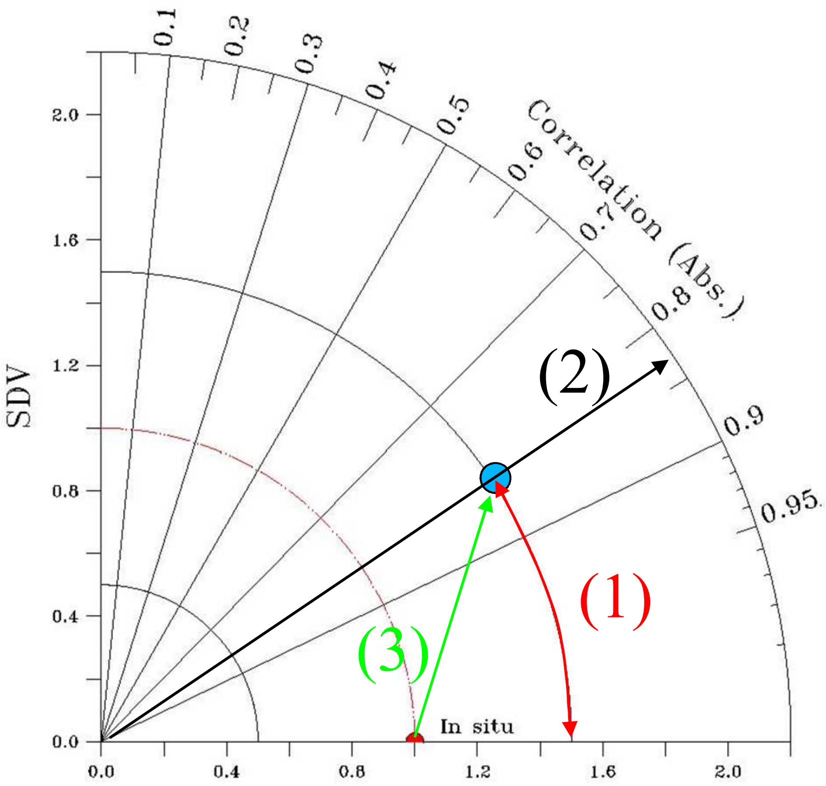
Statistical comparison

- ‘Classic’ scores: R, bias, RMSD
- Normalised standard deviation $SDV = \sigma_{analyse} / \sigma_{in\ situ}$
- Centred RMSD normalised by in situ standard deviation $E^2 = \left(rmsd^2 - Bias^2\right) / \sigma^2{}_{in\ situ}$
- R, SDV and E are usually represented on Taylor diagram

(Taylor, 2001)

Taylor Diagram

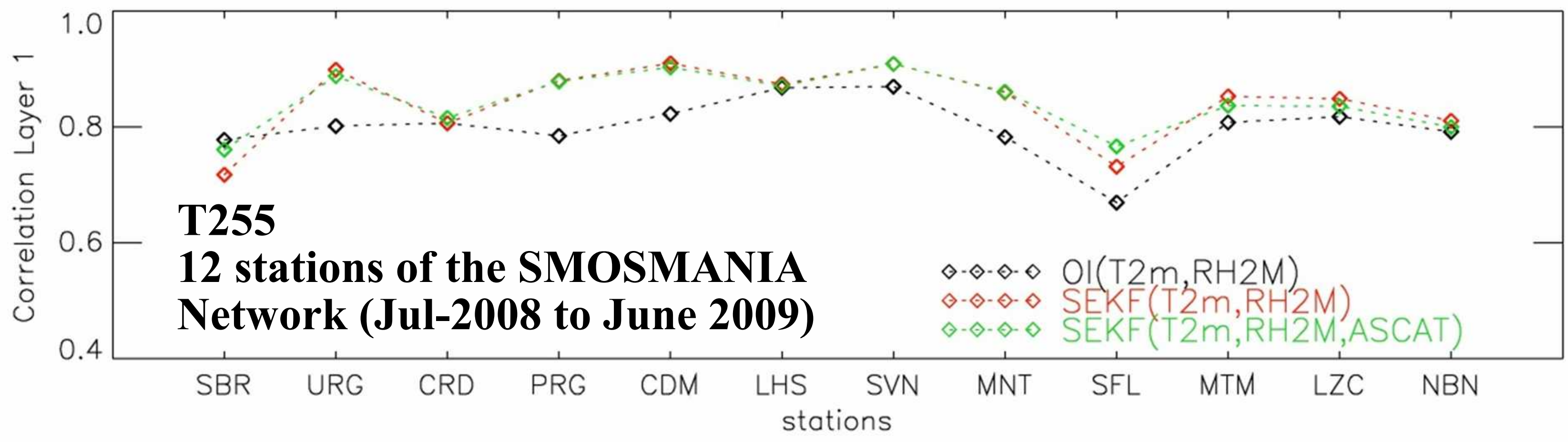


- SDV is displayed as a radial distance **(1)**
- R as an angle in the polar plot (2)
- E is the distance to the 'In situ' point **(3)**

ECMWF

Implementation of the EKF (1)

- Using the EKF instead of OI significantly improved the soil moisture analysis
- The use of ASCAT SSM does not show any improvements



Land surface model evolution

2000/06	2007/11	2009/03	2009/09	2010/2011

TESSEL

Van den Hurk et al. (2000)
Viterbo and Beljaars (1995)
Viterbo et al (1999)
Up to 8 tiles (binary Land-Sea mask)
GLCC veg. (BATS-like)
ERA-40 and ERA-I scheme

Hydrology-TESSEL

Balsamo et al. (2009)
van den Hurk and Viterbo (2003)
Global Soil Texture (FAO)
New hydraulic properties
Variable Infiltration capacity & surface runoff revision

NEW SNOW

Dutra et al. (2010)

Revised snow density
Liquid water reservoir
Revision of Albedo and sub-grid snow cover

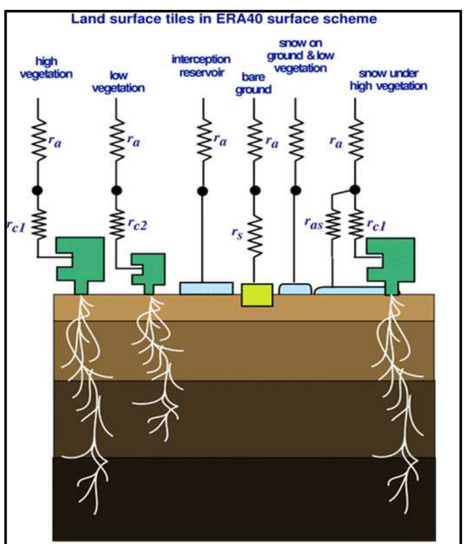
NEW LAI

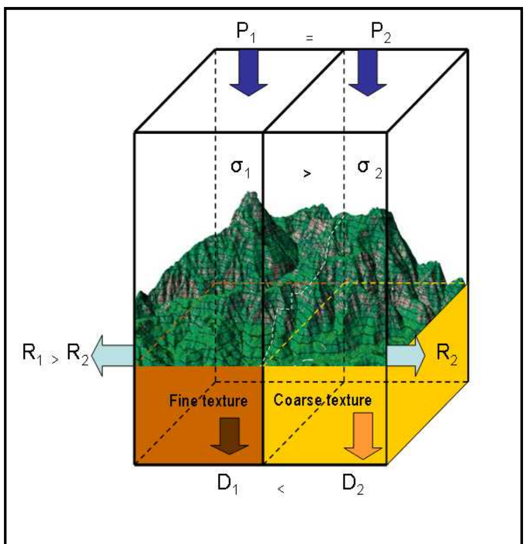
Boussetta et al. (2010)

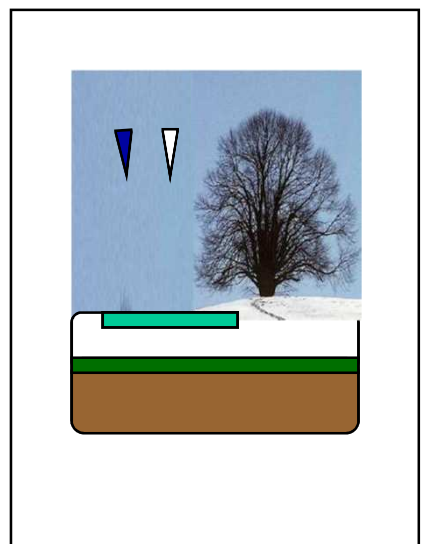
BARE GROUND EVAPORATION

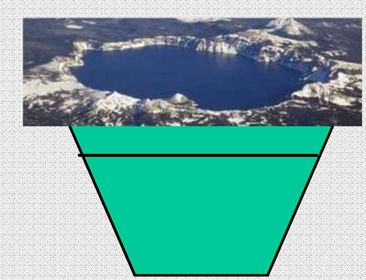
FLAKE

Mironov et al (2010),
Dutra et al. (2010),
Balsamo et al. (2010)
Extra tile (9) to account for sub-grid lakes









Land surface data assimilation evolution

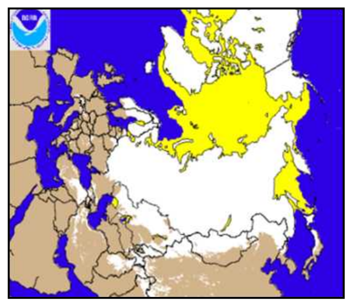
1999/07	2004/03	2008/09 2010/2011

OI screen level analysis

Douville et al. (2000)
Mahfouf et al. (2000)
Soil moisture analysis based on Temperature and relative humidity analysis

Revised snow analysis

Drusch et al. (2004)
Cressman snow depth analysis using SYNOP data improved by using NOAA / NSEDIS Snow cover extend data

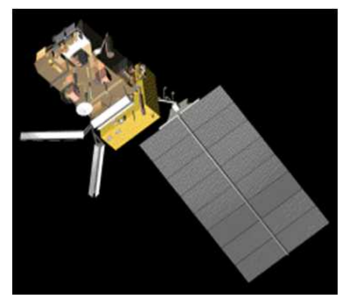


Structure Surface Analysis

OI snow analysis and high resolution NESDIS data (4km)

SEKF Soil Moisture analysis
Simplified Extended Kalman Filter
Drusch et al. (2009), de Rosnay et al. (2011)

METOP-ASCAT



SMOS

- SEKF (Simplified Extended Kalman Filter) surface analysis
- Use of active microwave data (ASCAT soil moisture product)
- Use of passive microwave SMOS data (Brightness Temperature product)
- New snow analysis and use of NOAA/NESDIS 4km snow cover product

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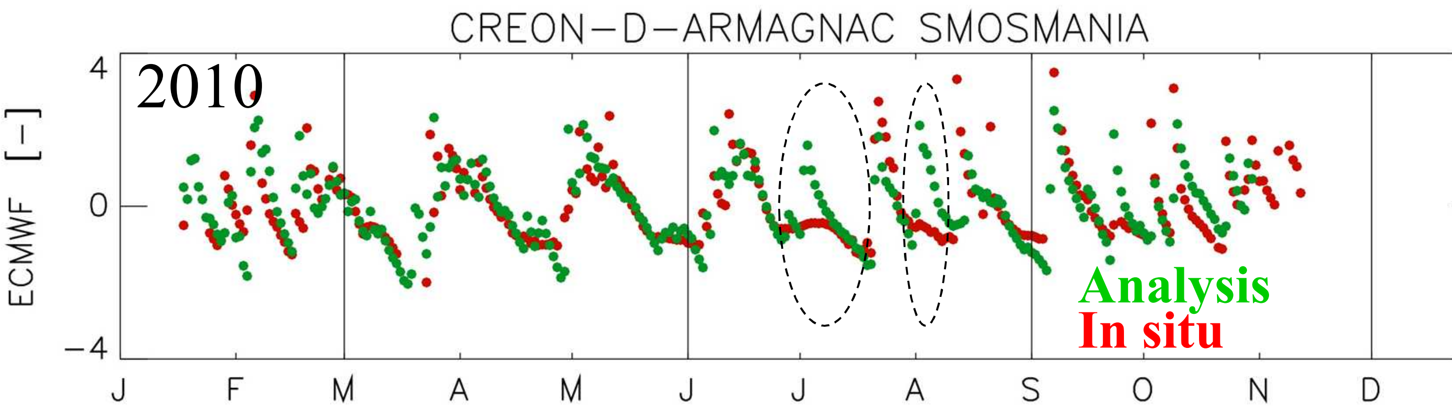

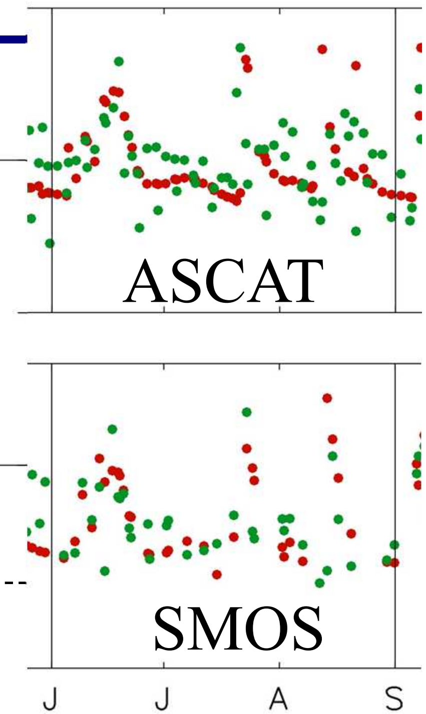

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ECMWF