Global monitoring of root zone soil moisture from scatterotmeter data assimilation : methodology and validation

C. Albergel, P. de Rosnay, L. Isaken, J. Muñoz-Sabater [(1)]

[(1)]European Centre for Medium Weather Forecast (ECMWF), Reading, UK

Thanks to : A. Al-Yaari, J.-P. Wigneron [(2)], C. Massari, L. Brocca [(3)], P. Laiolo, S. Gabellani, F. Delogu[(4)], P. Struzik[(5)]

[(2)]INRA, UMR1391 ISPA, Bordeaux, France
[(3)]Research Institute for Geo-Hydrological Protection, CNR , Italy
[(4)]CIMA Research Foundation, Savona, Italy
[(5)]Institute of Meteorology and Water Management, Krakow, Poland

H-SAF project of EUMETSAT

The EUMETSAT Network of Satellite Application Facilities

H SAF Support to Operational Hydrology and Water Management

- **Satellite Application Facility on support to operational Hydrology and water management /** CDOP-2 (Feb.2012 – Feb. 2017)

- **Objectives :** to provide and validate new satellite-derived products from existing and future satellites with sufficient time and space resolution to satisfy the needs of operational hydrology

- **Precipitation**

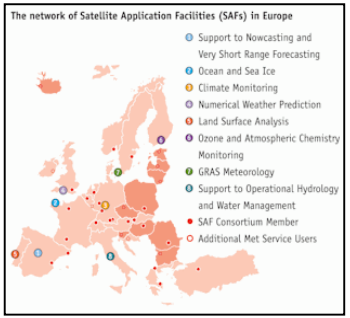
(liquid, solid, rate, accumulated)

- **Soil moisture**

(large-scale, local-scale, surface, in the roots region)

- **Snow**

(detection, cover, melting conditions, water equivalent)



http://hsaf.meteoam.it

Soil moisture: Essential Climate Variable (GCOS)

- **Crucial variable for numerical weather and climate predictions**

➔ Influence weather through its impact on evaporation and other surface energy fluxes

  - Controls the partitioning of Energy (latent / sensible heat fluxes) at the soil-atmosphere interface

- **Key variable in hydrological processes**
  - Controls the partitioning of Precipitation into infiltration/runoff
  - Controls evaporation from bare soil, transpiration from vegetation
- **Impact on plant growth and carbon fluxes**

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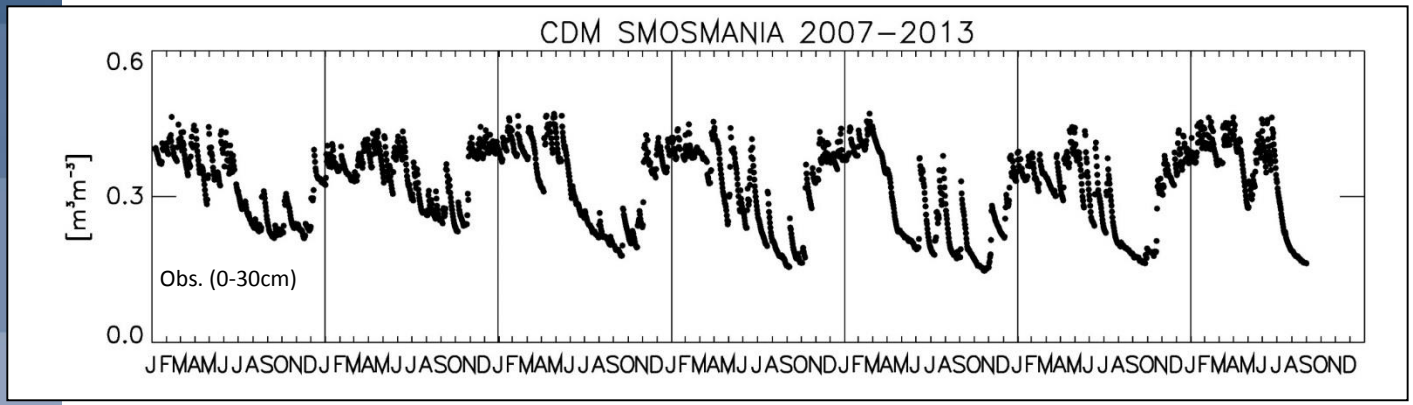
How to obtain soil moisture estimates?

In situ measurements

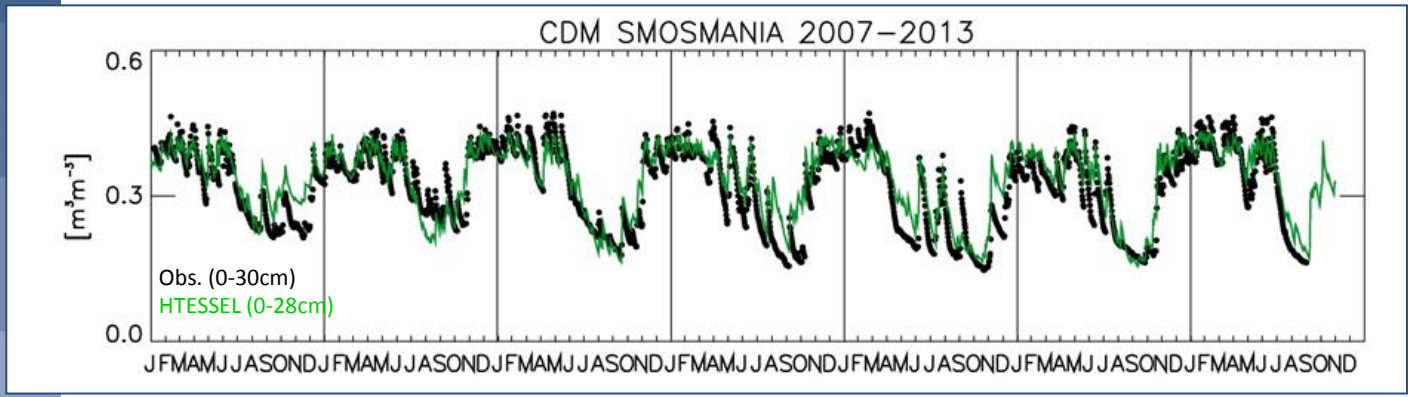


How to obtain soil moisture estimates?

In situ measurements

Land Surface Model

HTESSEL forced by ERA-Interim near-surface meteorology



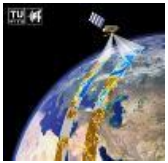
How to obtain soil moisture estimates?

In situ measurements

Land Surface Model

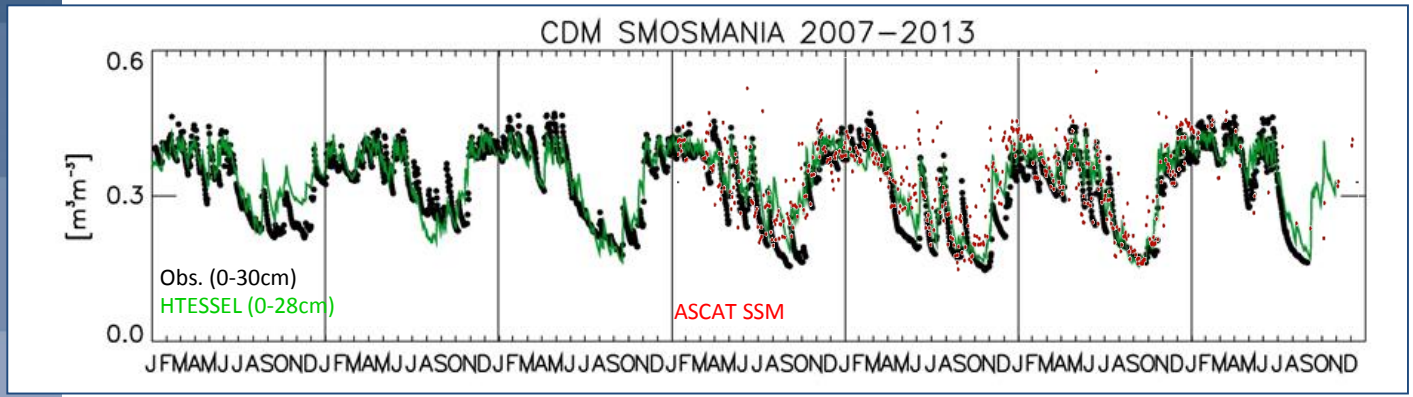
HTESSEL forced by ERA-Interim near-surface meteorology

Surface Soil moisture from space



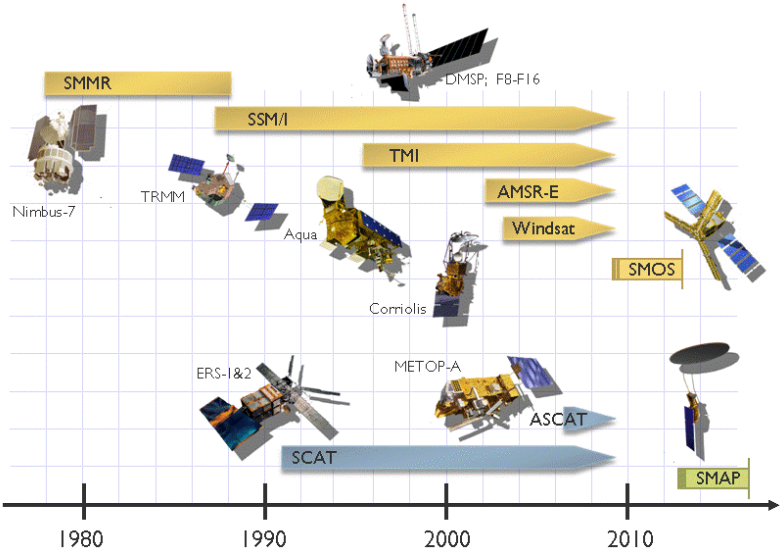
ASCAT

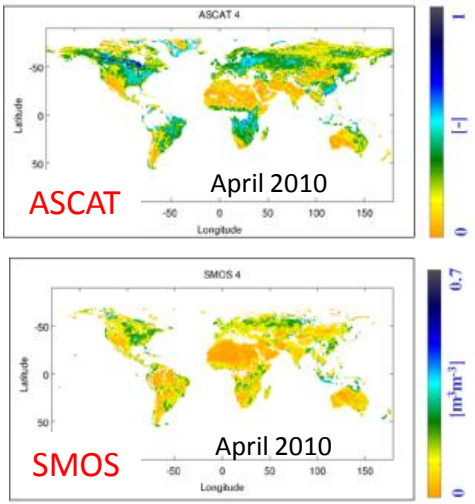
SMOS



How to obtain soil moisture estimates?

- **Spatial Remote Sensing :** unique opportunity to observe SM at a global scale





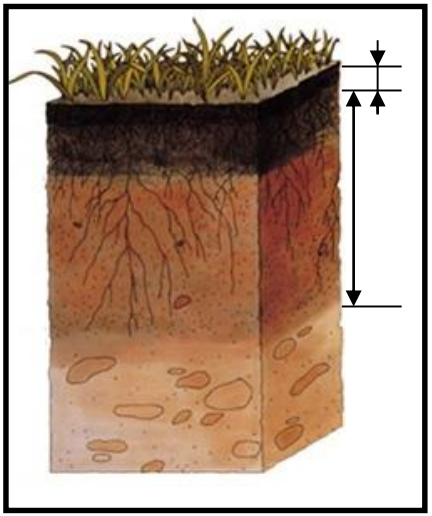
(Figure from : http://www.esa-soilmoisture-cci.org)

Soil moisture analysis

- **Remote Sensing :** provides quantitative information about the water content of a shallow near surface layer

- Main variable of interest for applications such as meteorological modelling, hydrological studies : root-zone soil moisture

- **Assimilation algorithms :**



➔ Soil Moisture Analysis
- Combines observations and model trajectory
- Propagates information from surface observations into deeper layers
- Provides values when there is no satellite data (from the model propagation)

HSAF Project at ECMWF

- Contributor to the core H-SAF soil moisture products
- ➔ Our H-SAF activities are centred around the development of surface and root zone soil moisture based on scatterometer data assimilation

- **SM-DAS-2 (H14), operational since 07/2012**
  - Surface and root zone liquid soil moisture index
  - Based on physical soil freezing processes representation, expressed into liquid soil moisture index by normalizing using the saturated soil moisture value (function of soil texture)

- **SM-DAS-3 (H27), end of CDOP-2**
  - Re-analysis of SM-DAS-2
  - ➔ Provide long time series of the liquid root zone soil moisture index (covering 1992-2014)

SM-DAS-2 (H14) liquid root zone soil moisture index

operational from Jul. 2012

ECMWF Atmospheric conditions

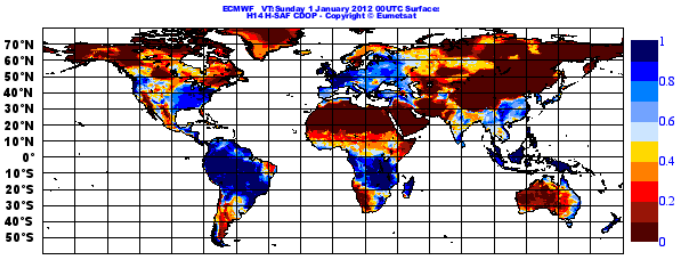
SYNOP
T2m RH2m

ASCAT
Surface SM
METOP-A & B

EKF
Soil Moisture
Analysis

SM-DAS-2:
Soil Moisture
Profile

~25km



EKF corrects the trajectory of the Land Surface Model (HTESSEL)

0-7cm, 7-28cm, 28-100cm, 100-289cm

http://hsaf.meteoam.it/soil-moisture.php

SM-DAS-2 (H14) liquid root zone soil moisture index

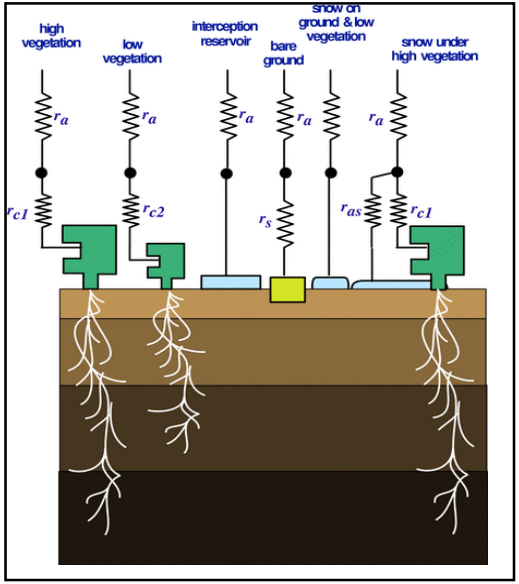
Simplified Extended Kalman Filter soil moisture analysis
(*de Rosnay et al., QJRMS, 2013*)

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

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

$\boldsymbol{x}_b$ background state vector,
$\mathcal{H}$ non linear observation operator
$\boldsymbol{y}$ observation vector
$\boldsymbol{K}$ Kalman gain matrix, function of **H** (linearization of $\mathcal{H}$), **B** and **R** (covariance matrices of background and observation errors)

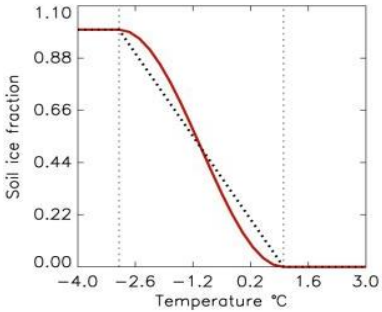
Observations used :
Conventional SYNOP observations (T2m, RH2m)
ASCAT surface soil moisture (METOP-A, B)

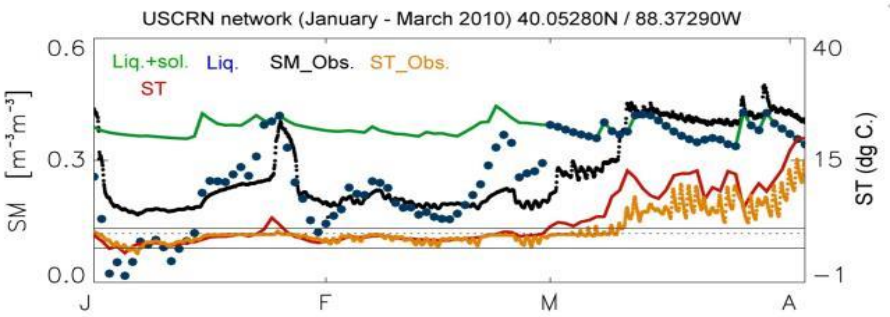


LSM : HTESSEL
0-7cm, 7-28cm, 28-100cm, 100-289cm
(*Balsamo et al., JHM, 2009*)

SM-DAS-2 (H14) liquid root zone soil moisture index

- **Rational for having a liquid product :**

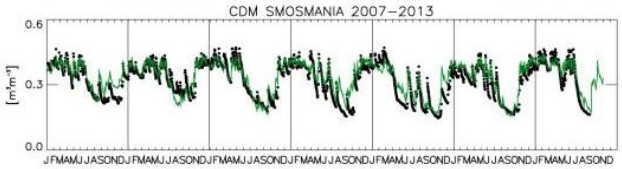


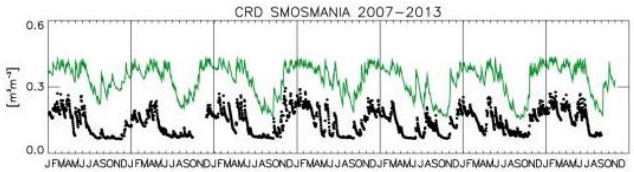


2010-2013	Scores	Liq.+sol.	Liq.
USCRN (US) 1 station	R	0.72	0.74
	R Anomalies	0.56	0.57
	RMSD	0.074	0.069
	Bias	-0.024	-0.005

SM-DAS-2 (H14) liquid root zone soil moisture index

- **Rational for having an index [0-1] :** Spatial variability of SM is very high, differences in soil properties ➔ difference in the mean and variance



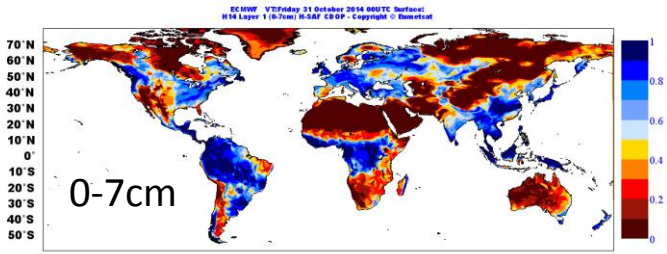


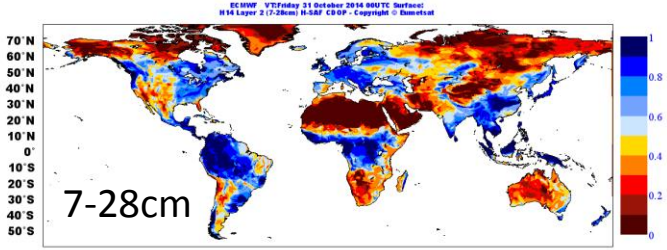
Obs. (0-30cm)
HTESSEL (0-28cm)

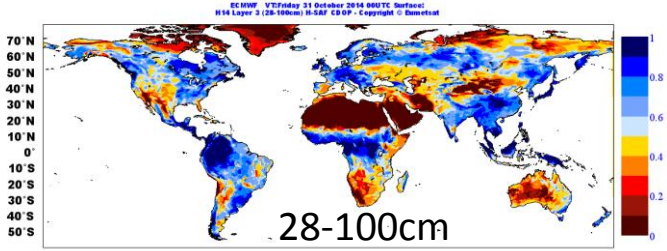
- True information of modelled/analysed soil moisture does not necessarily relies on their absolute magnitudes but instead on their time variations

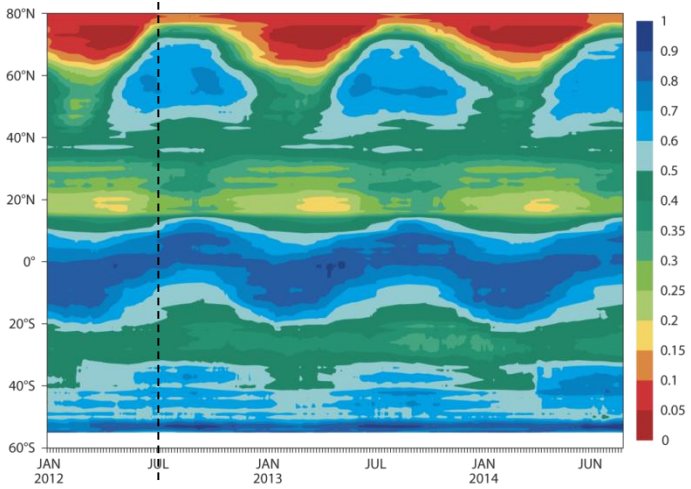
➔ Represents the time-integrated impacts of antecedent meteorological forcing on the hydrological state of the soil system within the model

SM-DAS-2 (H14) liquid root zone soil moisture index

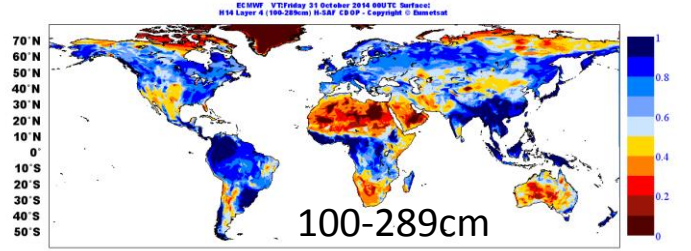








SM-DAS-2 (0-100cm [-]), land-only zonal mean

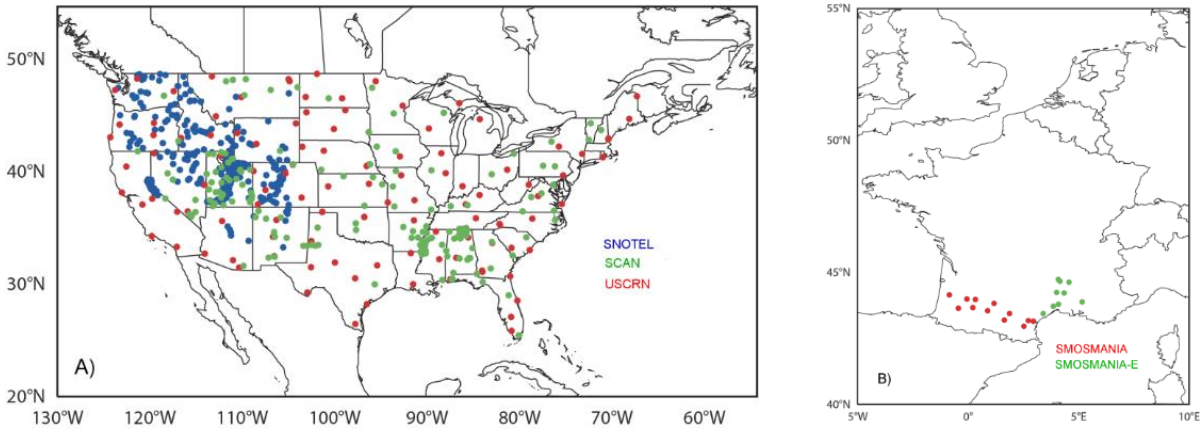


http://hsaf.meteoam.it/soil-moisture.php

SM-DAS-2 (H14) : Evaluation

Accuracy requirements for product SM-DAS-2 (H14) : Correlations values (R)

Unit	Threshold	Target	Optimal
Dimensionless	0.50	0.65	0.80



Period considered: June-2012 to May-2013

SM-DAS-2 (H14) : Evaluation

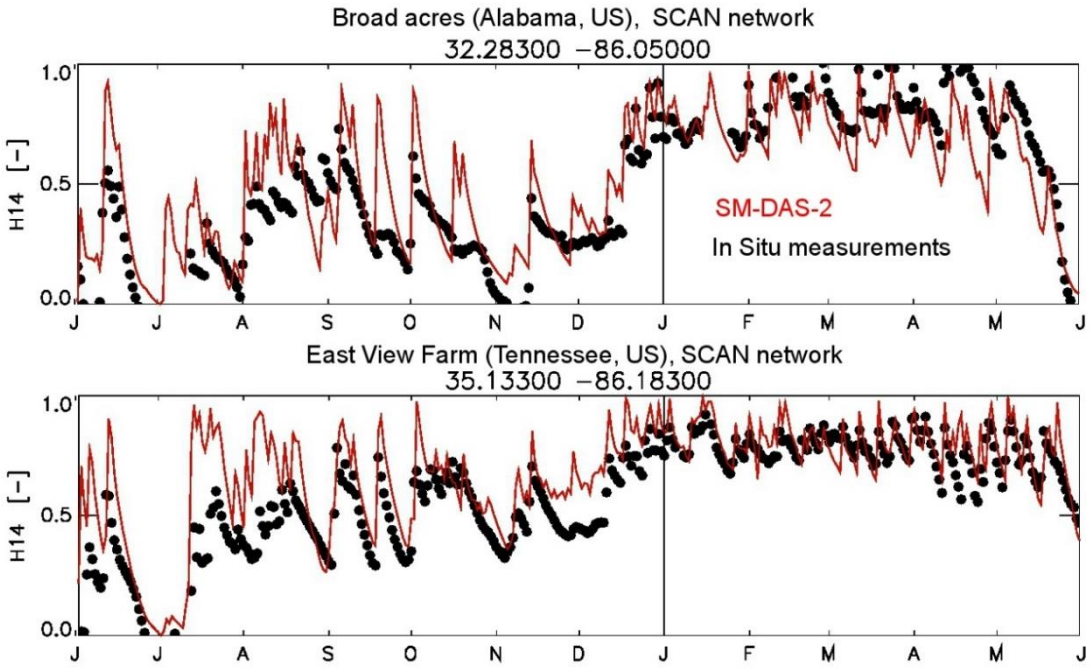


Illustration of soil moisture products time series, in situ data are in black, H14 / SM-DAS-2 is in red. Stations belong to the NRCS-SCAN network, in the US

SM-DAS-2 (H14) : Evaluation

Period considered : June-2012 to May-2013

Country	Region (N stations*)	Bias (-)	Standard deviation (-)	RMSD (-)/[m3m-3]	R
France	SMOSMANIA-W (12 stations)	0.081	0.264	0.197 / 0.049	0.86
France	SMOSMANIA-E (9 stations)	-0.004	0.299	0.236 / 0.060	0.72
USA	NRCS-SCAN (79 stations)	-0.034	0.209	0.213 / 0.051	0.72
USA	NRCS-SNOTEL (144 stations)	-0.080	0.243	0.233 / 0.058	0.72
USA	NRCS-USCRN (80 stations)	0.020	0.231	0.215 / 0.053	0.72
Average weighted by the number of stations	326 stations	-0.036	0.234	0.222 / 0.055	0.73

Considering all the stations, the averaged R value of 0.73 is above the target accuracy of 0.65

* Cases with pvalue <0.05 are considered, only

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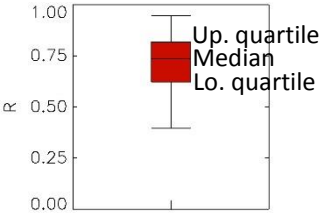
USA	NRCS-USCRN (82 stations)	0.007	0.236	0.206 / 0.045	0.71



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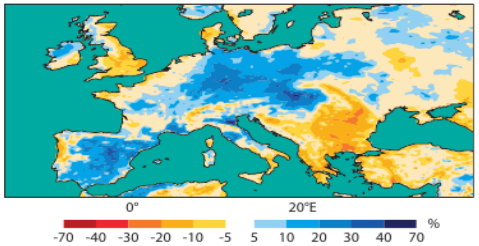
SM-DAS-2 (H14) : Flood in Central europe

" ***[…] Another key factor in determining whether flooding is likely to take place is how saturated the soils are. […] As part of EUMETSAT's Satellite Application Facility on Support to Operational Hydrology and Water Management (H-SAF), ECMWF has been producing the root zone soil moisture product (H14/SM-DAS-2).***"

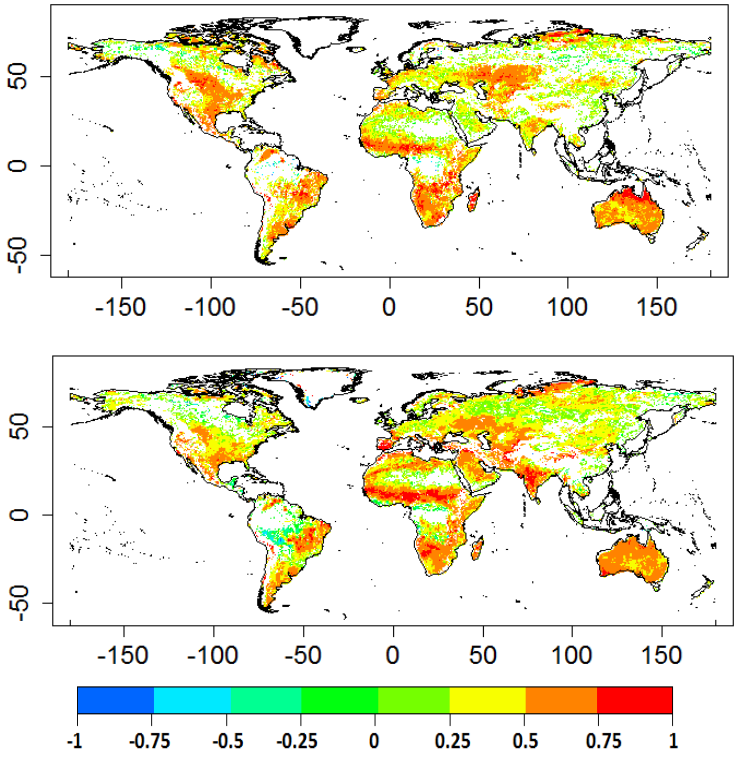


2: Difference in soil moisture saturation between 2013 and 2012 over Europe. EUMETSAT H-SAF root zone (0–1 m) soil moisture difference, 2013 minus 2012, for 20 May to 3 June based on ASCAT data assimilation in the ECMWF Land Data Assimilation System.

F. Pappenberger, F. Wetterhall, C. Albergel, L. Alfieri, G. Balsamo, K. Bogner, T. Haiden, T. Hewson, L. Magnusson, P. de Rosnay, J. Muñoz-Sabater & I. Tsonevsky : *Floods in Central Europe in June 2013*. ECMWF newsletter 136, summer 2013, 9-11pp

http://www.ecmwf.int/publications/newsletters/

Satellite-based passive microwave soil moisture dataset comparative study



SMOSL3 Vs. SM-DAS-2

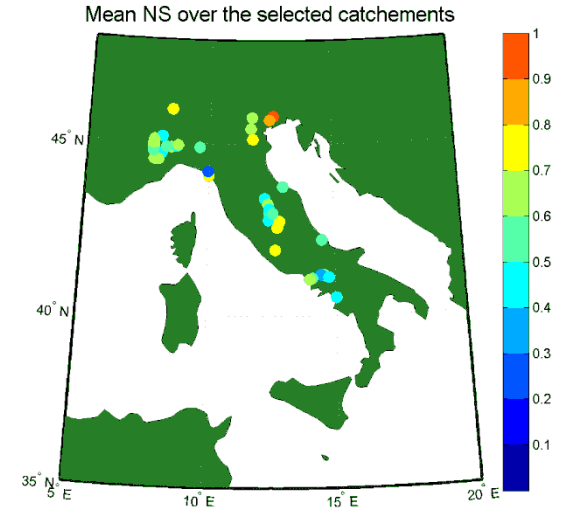
AMSR-VUA Vs. SM-DAS-2

Both (SMOS and AMSR-VUA) successfully captured the seasonal SSM variations present in SM-DAS-2 **Al-Yaari et al., 2014 (RSE)**

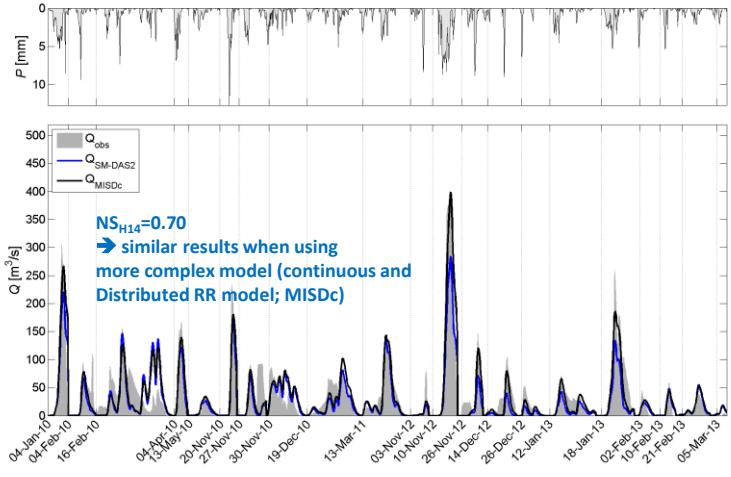
Slides provided by A. Al-Yaari, J.-P. Wigneron, INRA, France

- **H14 used for initializing simple event based rainfall-runoff model**

➔ **“Simplified Continuous Rainfall Runoff” model**
(SCRRM, Massari et al. 2014, HESS)



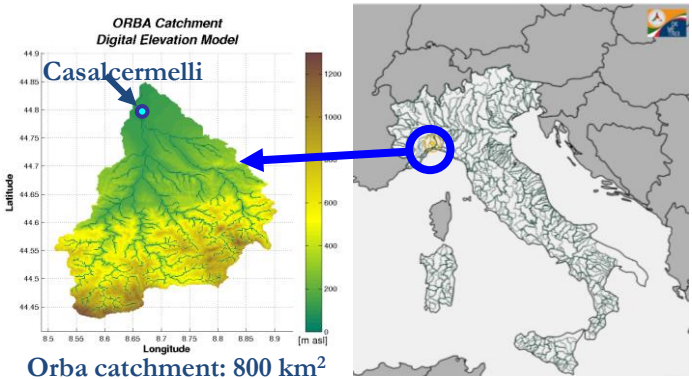
Tiber River at Santa Lucia Area=840 km²



Application of the model to 35 Italian catchments 2010-2013…

Yesterday 17:00-17:30	Assimilation of H-SAF soil moisture products for hydrological modelling in Mediterranean catchments	Christian Massari (CNR/IRPI)

Slide provided by C. Massari, L. Brocca, Research Institute for Geo-Hydrological Protection, CNR , Italy

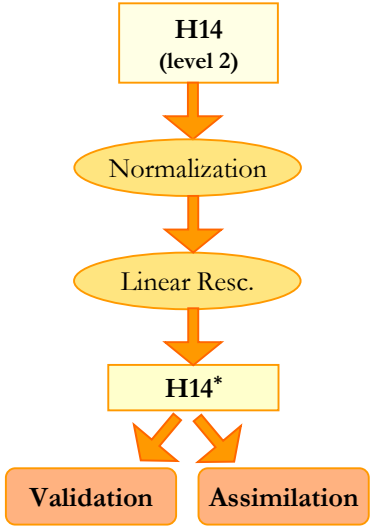


Orba catchment: 800 km^2

For the period July 2012 – June 2013

Validation of H14 using Continuum model

Assimilation of H14 into Continuum model



Hydrol. Earth Syst. Sci., 17, 39–62, 2013
www.hydrol-earth-syst-sci.net/17/39/2013/
doi:10.5194/hess-17-39-2013

Hydrology and Earth System Sciences

Continuum model (Silvestro et al., 2013) → Distributed and physically-based hydrological model

Exploiting remote sensing land surface temperature in distributed hydrological modelling: the example of the Continuum model

F. Silvestro[1], S. Gabellani[1], F. Delogu[1], R. Rudari[1], and G. Boni[1,2]
[1]CIMA research foundation, Savona, Italy
[2]DIBRIS, University of Genova, Genova, Italy

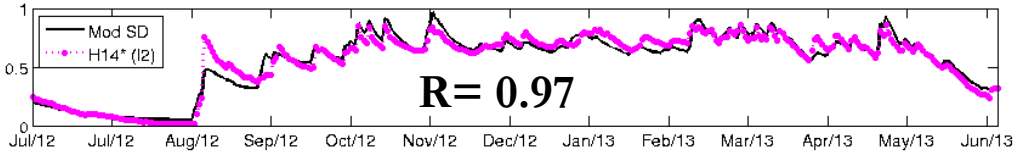
Correspondence to: F. Silvestro (francesco.silvestro@cimafoundation.org)

Received: 24 May 2012 – Published in Hydrol. Earth Syst. Sci. Discuss.: 14 June 2012
Revised: 12 December 2012 – Accepted: 20 December 2012 – Published: 11 January 2013

Slides provided by P. Laiolo, S. Gabellani, F. Delogu, CIMA Research Fundation, Italy

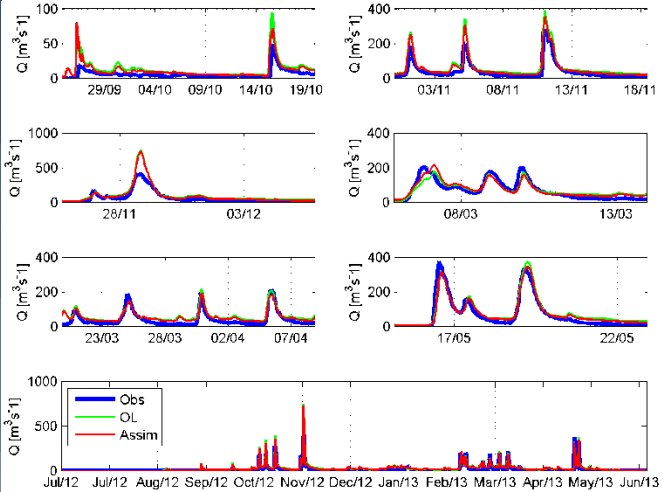
09:30-10:00	Assimilation of satellite soil moisture data in a distributed hydrological model: impact on the hydrological cycle in some Italian basins	Simone Gabellani (CIMA foundation)

Validation results



Mean values at basin scale

Assimilation results



MAE, RMSE, NS – Annual analysis			
Experiment	**MAE**	**RMSE**	**NS**
OL	17.4	25.3	0.63
Assim H14	15.2	22.5	0.70

NS coefficient – Seasonal analysis				
Experiment	**Summer**	**Autumn**	**Winter**	**Spring**
OL	-2.64	0.57	0.52	0.78
Assim H14	-1.14	0.69	0.54	0.83

Slides provided by P. Laiolo, S. Gabellani, F. Delogu, CIMA Research Fundation, Italy

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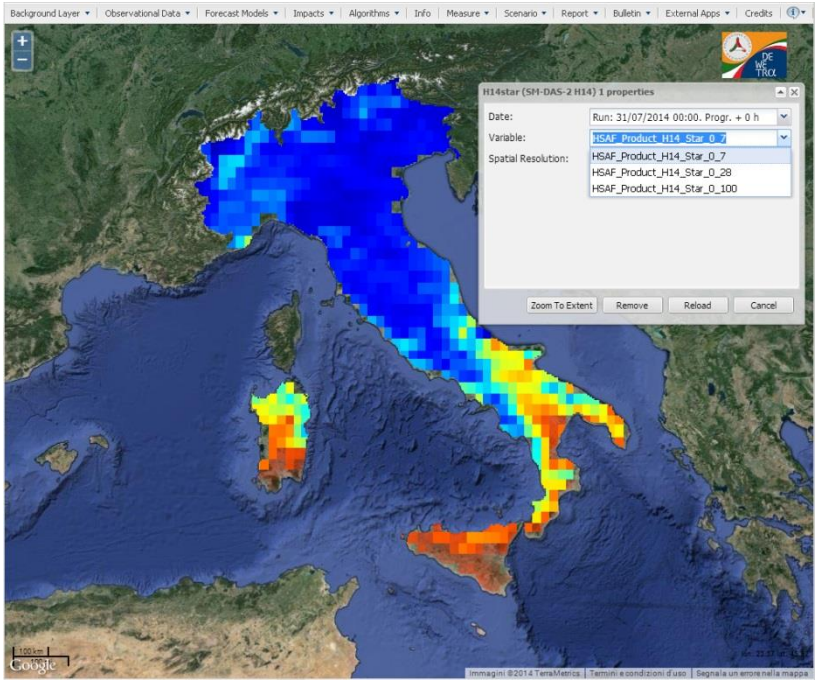
SM-DAS-2 (H14) liquid root zone soil moisture index



SM-DAS-2 product is operationally used by Italian Civil Protection and published on Dewetra platform

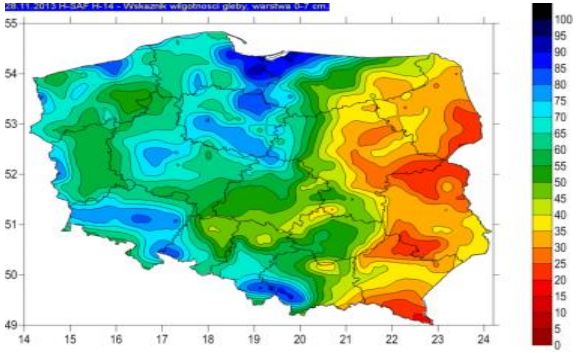
Real-time integrated system for hydro-meteorological and wildfire risk forecasting (monitoring and prevention)

Based on the rapid availability of different data to help establishing risk scenarios

Slides provided by P. Laiolo, S. Gabellani, F. Delogu, CIMA Research Fundation, Italy

SM-DAS-2 (H14) liquid root zone soil moisture index

- Use soil moisture product H-SAF H-14 for operational monitoring of the area of Poland
- To be used in agrometeorological service
- To be implemented as an input to hydrological model



http://agrometeo.pogodynka.pl/obrazysatelitarne

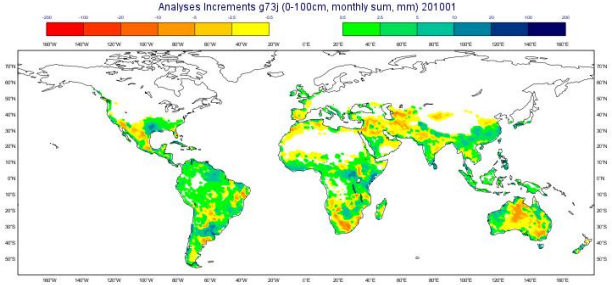
Visualisation from IMGW internal web page; in winter " *[…]* frozen surfaces are well detected as dry upper layer"

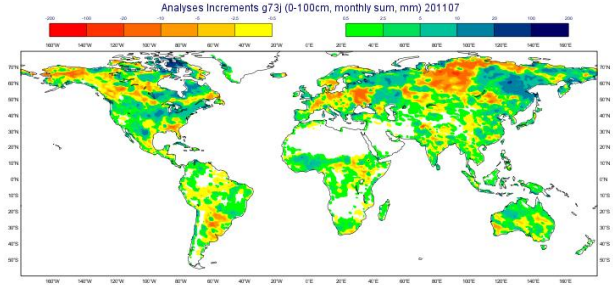
dr inż. Piotr Struzik
(personal communication, Jan.-2014)

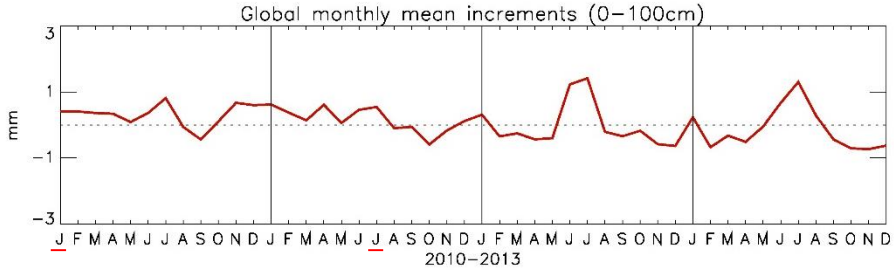
SM-DAS-3 (H27) liquid root zone soil moisture index

- **Re-analysis of SM-DAS-2**

➔ Provide long time series of the liquid root zone soil moisture index (covering 1992-2014, 16km) using ASCAT, ERS-1&2 and screen level variables





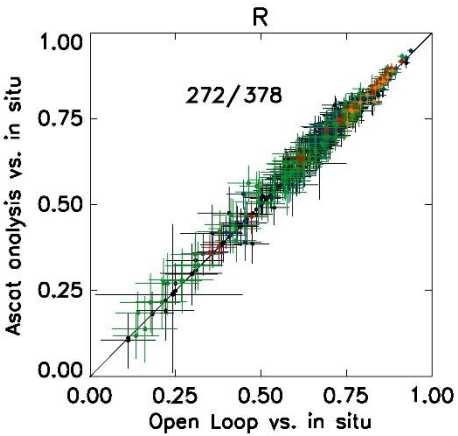


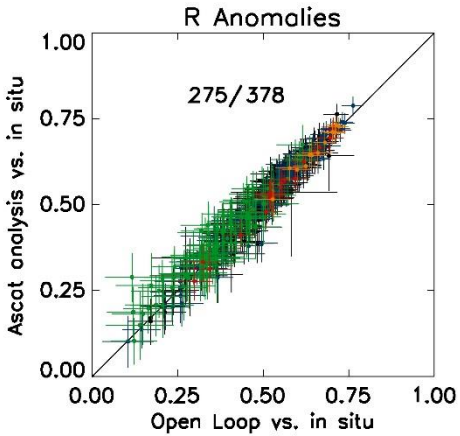
SM-DAS-3 (H27) liquid root zone soil moisture index

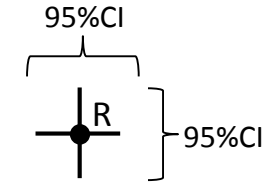
- **Re-analysis of SM-DAS-2**

➔ Provide long time series of the liquid root zone soil moisture index (covering 1992-2014, 16km) using ASCAT, ERS-1&2 and screen level variables

➔ Preliminary evaluation vs. in situ data (2011-2013)







SCAN (USA)
USCRN (USA)
PBO_H2O (USA)
REMEDHUS (Sp.)
SMOSMANIA (Fr.)

Summary

- **SM-DAS-2 (H14), operational since 07/2012**
  - Very good ability to reproduce soil moisture variability
  - ➔ Used as a benchmark for satellite-derived soil moisture products
  - Positive impact when used in hydrological modelling
  - Operationally used by the Italian Civil Protection, Polish agromet. service

Albergel, C., de Rosnay, P., Gruhier, C., Muñoz-Sabater, J., Hasenauer, S., Isaksen, L., Kerr, Y. & Wagner, W.: **Evaluation of remotely sensed and modelled soil moisture products using global ground-based in situ observations**. *Remote Sensing of Environment*, 118, 215-226, 2012.

- **SM-DAS-3 (H27), end of CDOP-2**
  - Re-analysis of SM-DAS-2 using consistent production algorithm and observations to provide long time series of the liquid root zone soil moisture index (covering 1992-2014)

http://hsaf.meteoam.it
http://hsaf.meteoam.it/soil-moisture.php

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

Global monitoring of root zone soil moisture from scatterotmeter data assimilation : methodology and validation

Thank you for your attention!

Contact : clement.albergel@ecmwf.int

http://hsaf.meteoam.it (/soil-moisture.php)

H14 Liquid Root Zone Soil Moisture index