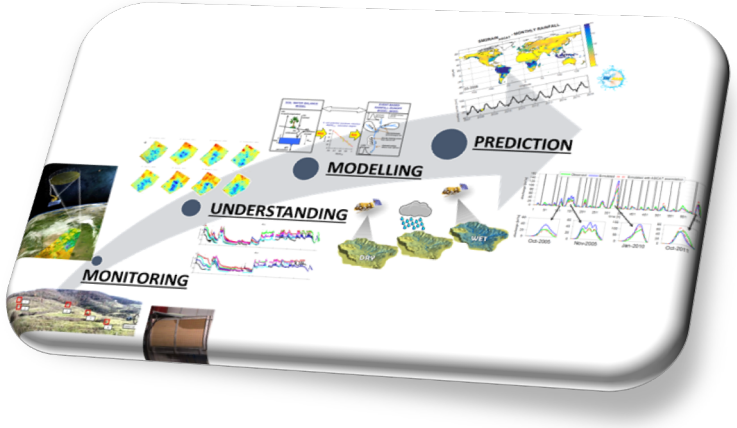
Soil Moisture Week

Webminar 06/11/2019

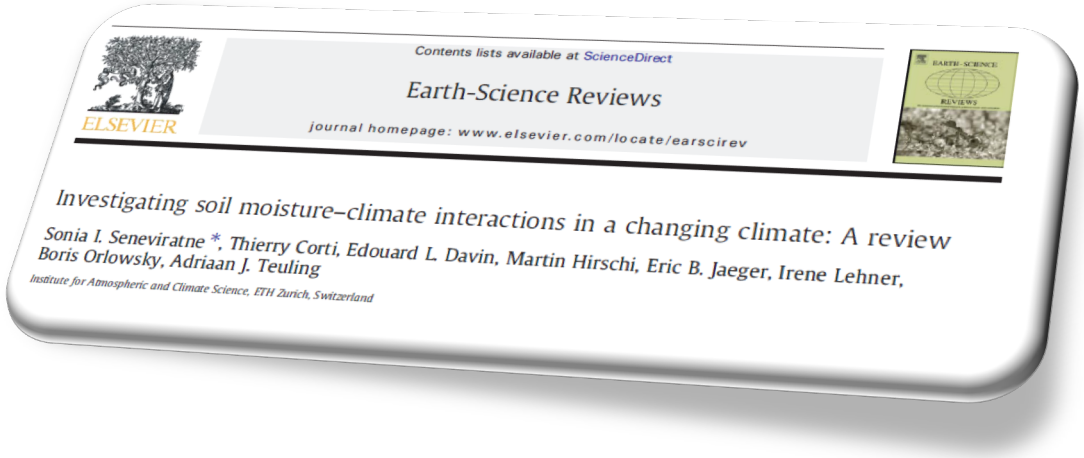
Introduction to soil moisture and analysis of satellite soil moisture time series and spatial patterns

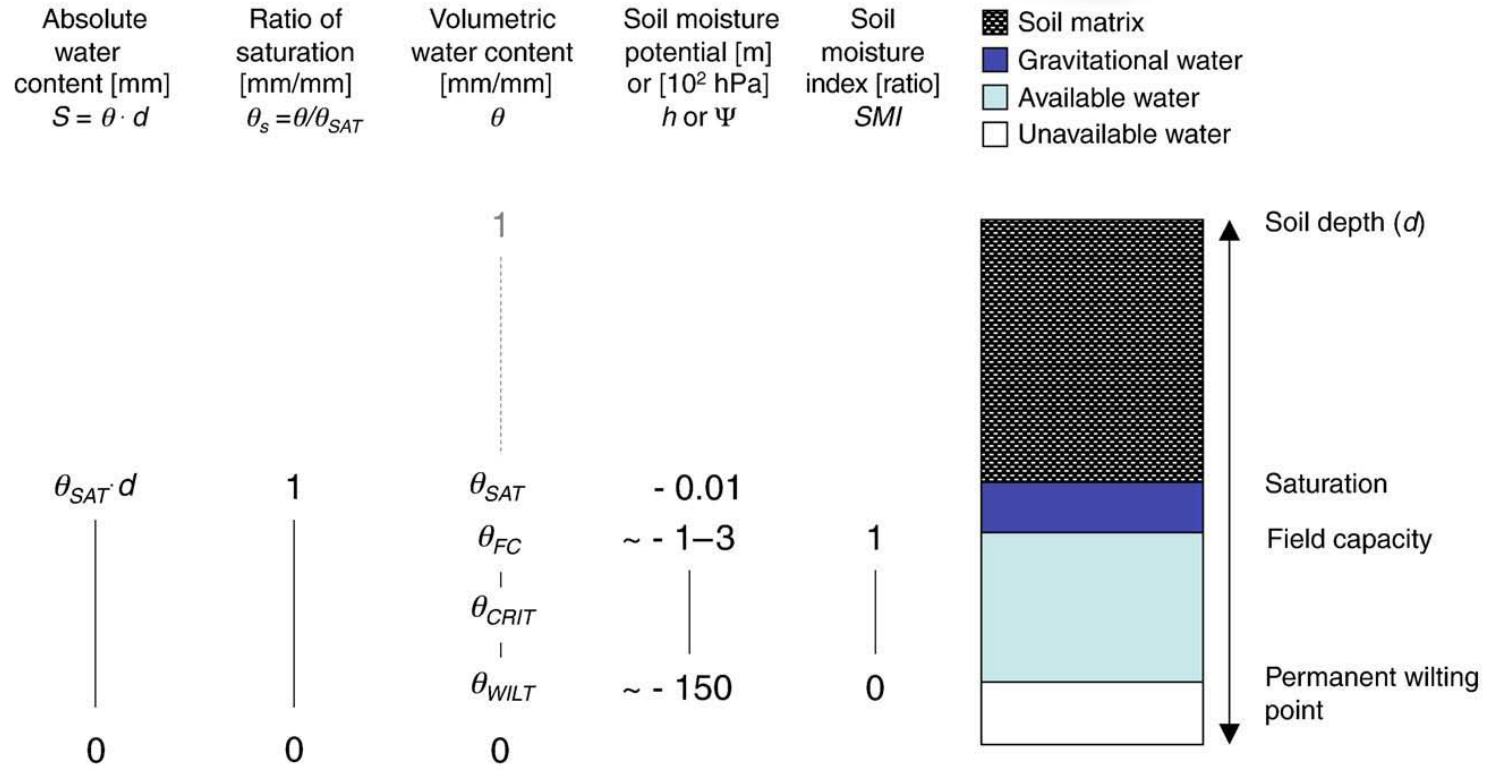
Simone Gabellani, Fabio Delogu
CIMA Foundation



In collaboration with L. Brocca, CNR - IRPI

What is soil moisture?



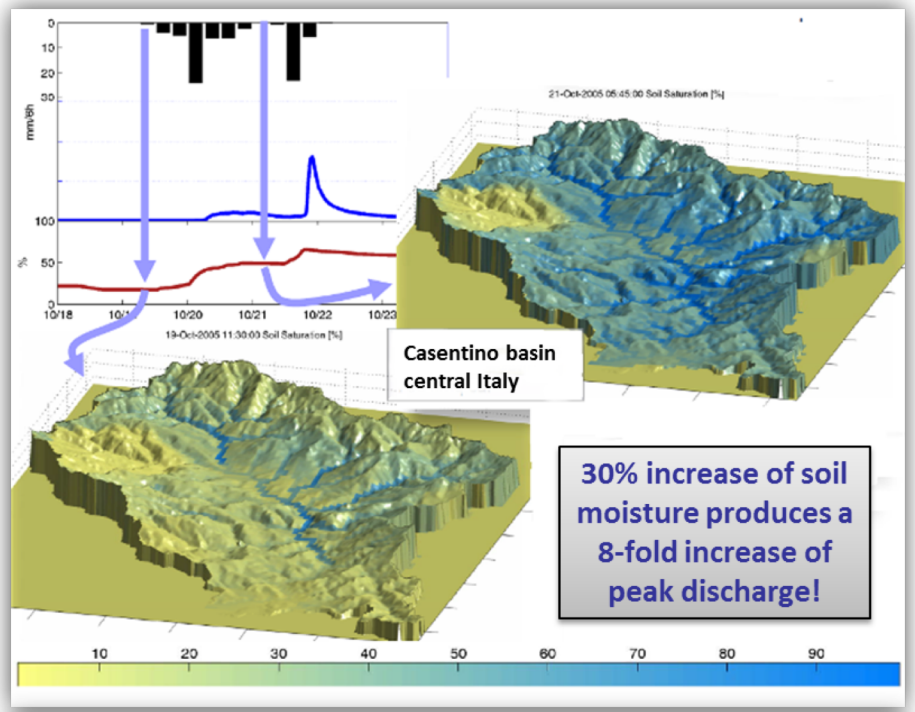


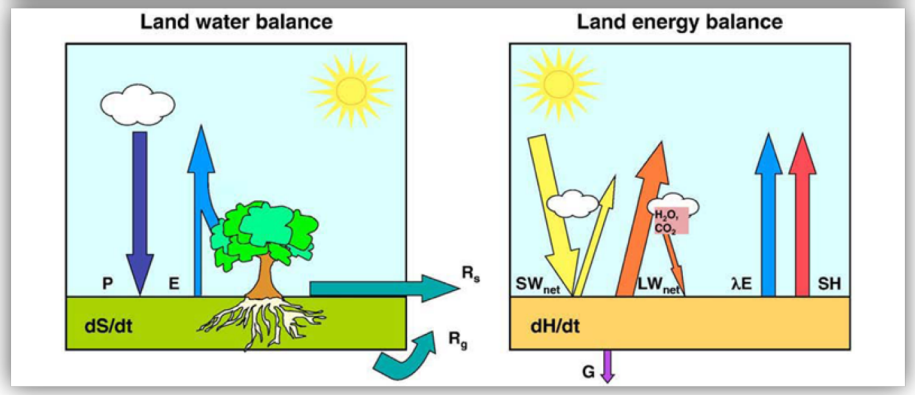
Soil moisture is a key variable of the climate system

Soil moisture generally refers to the amount of water stored in the unsaturated soil zone, although its exact definition can vary depending on the context, i.e. whether it is defined in relative, absolute or indirect terms, and depending on the reference storage.

2

Why soil moisture?





FLOOD

DROUGHT

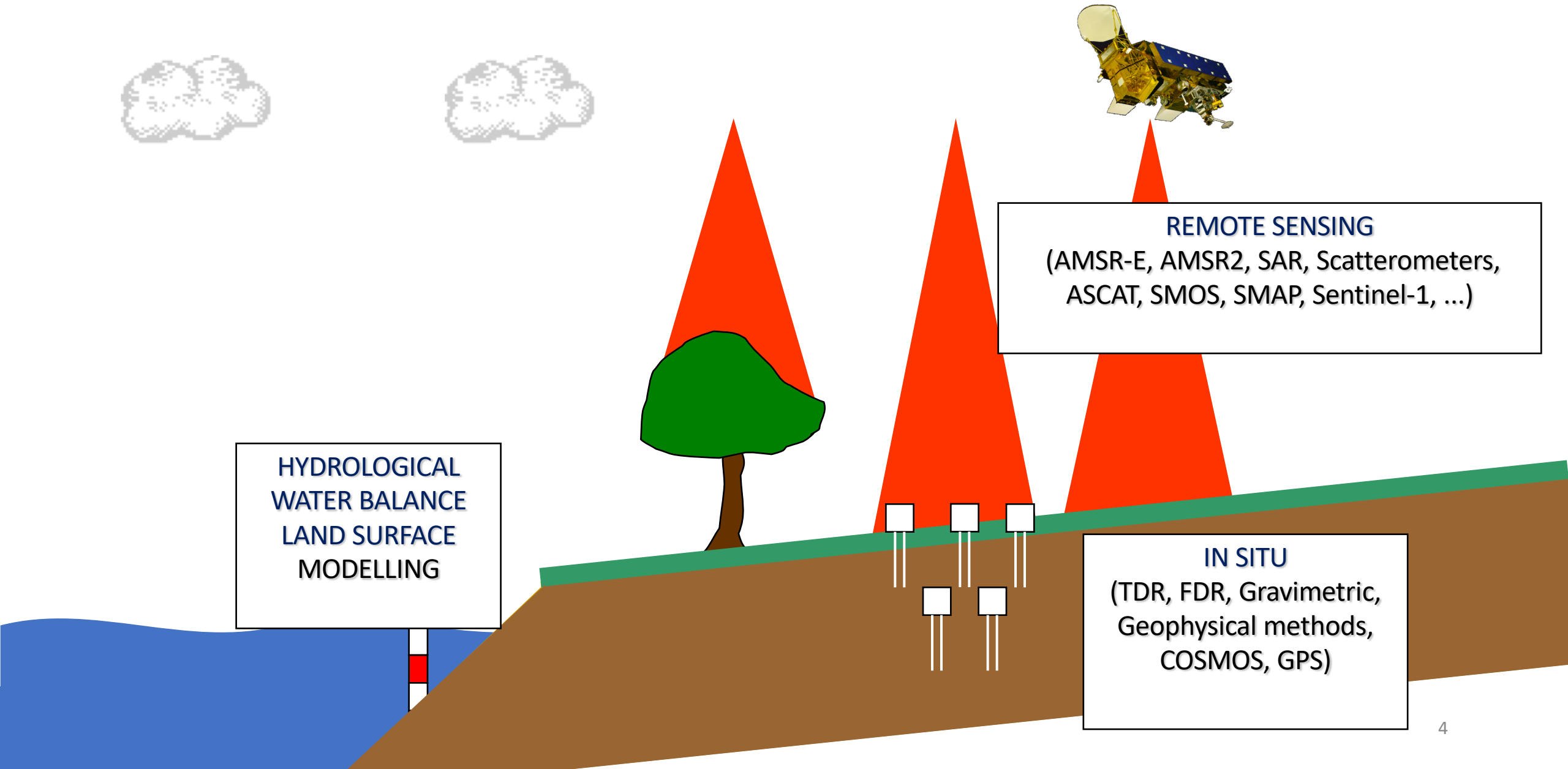
WEATHER PREDICTION

CLIMATE SYSTEM

LANDSLIDES

CROP PRODUCTION

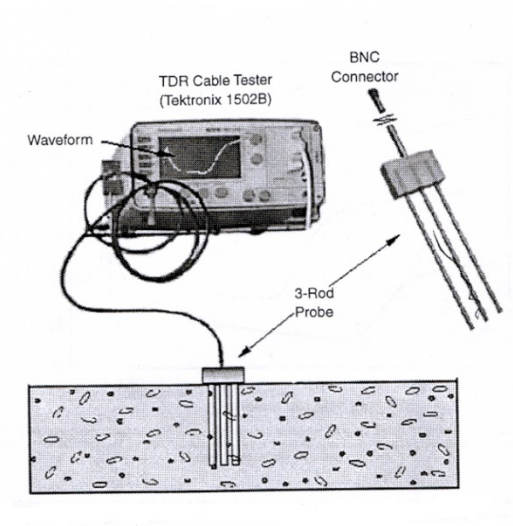
Soil moisture monitoring



In situ soil moisture monitoring

Point methods

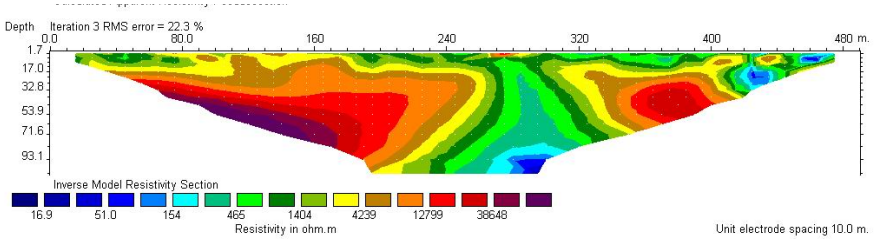
- Electromagnetic method: TDR



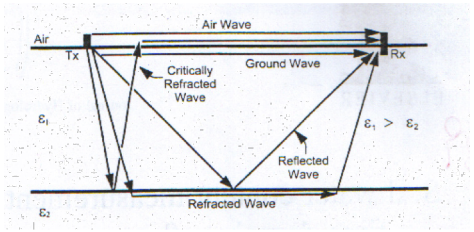
- Gravimetric method
- Neutron technique
- Optical method

Distributed methods

- Geophysical techniques

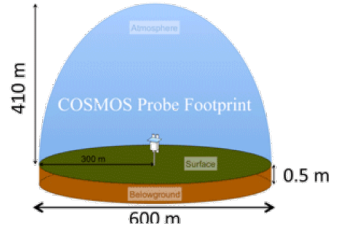


- Georadar



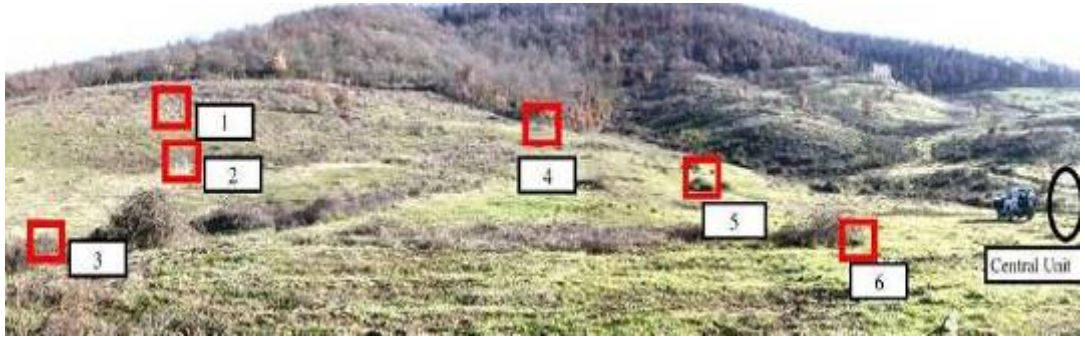
- GPS

- Cosmic Ray

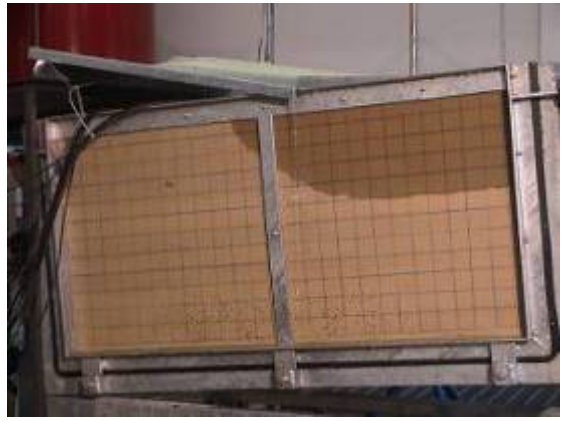


In situ soil moisture monitoring

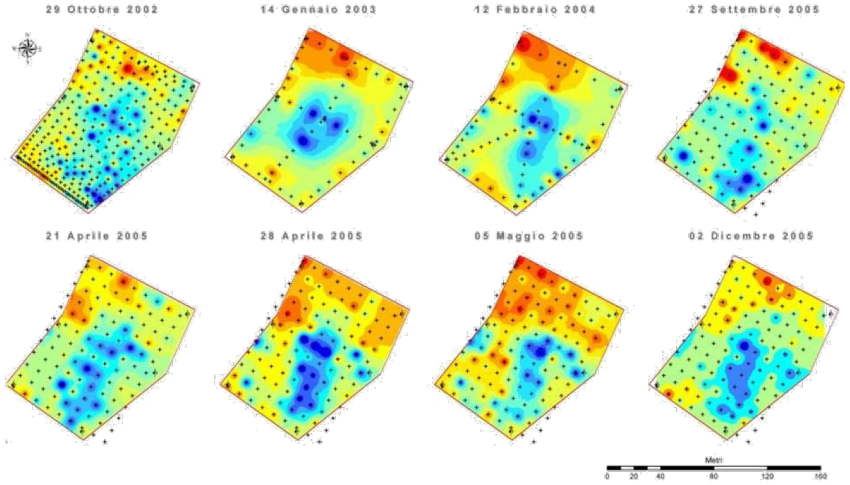
Experimental catchments



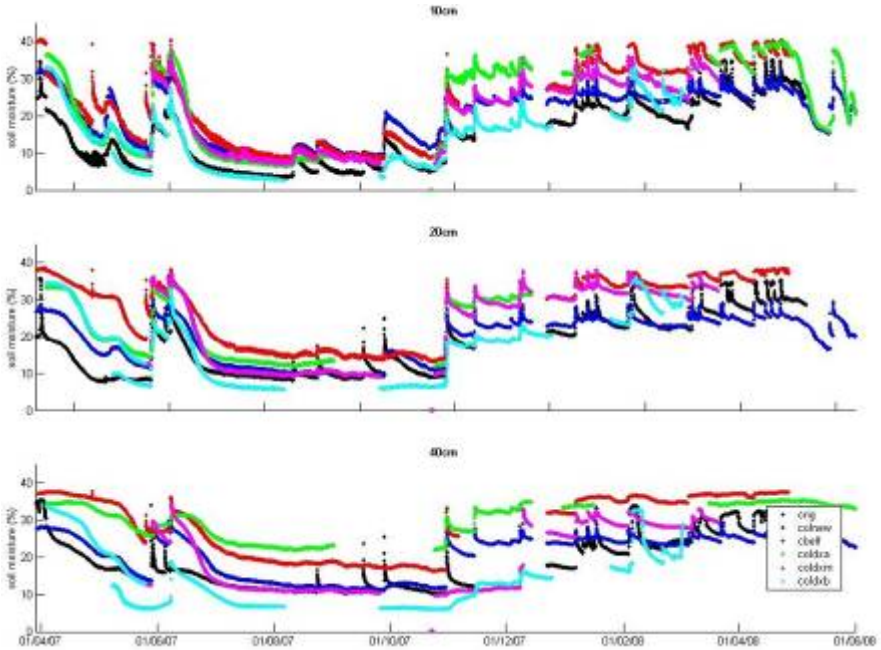
Laboratory



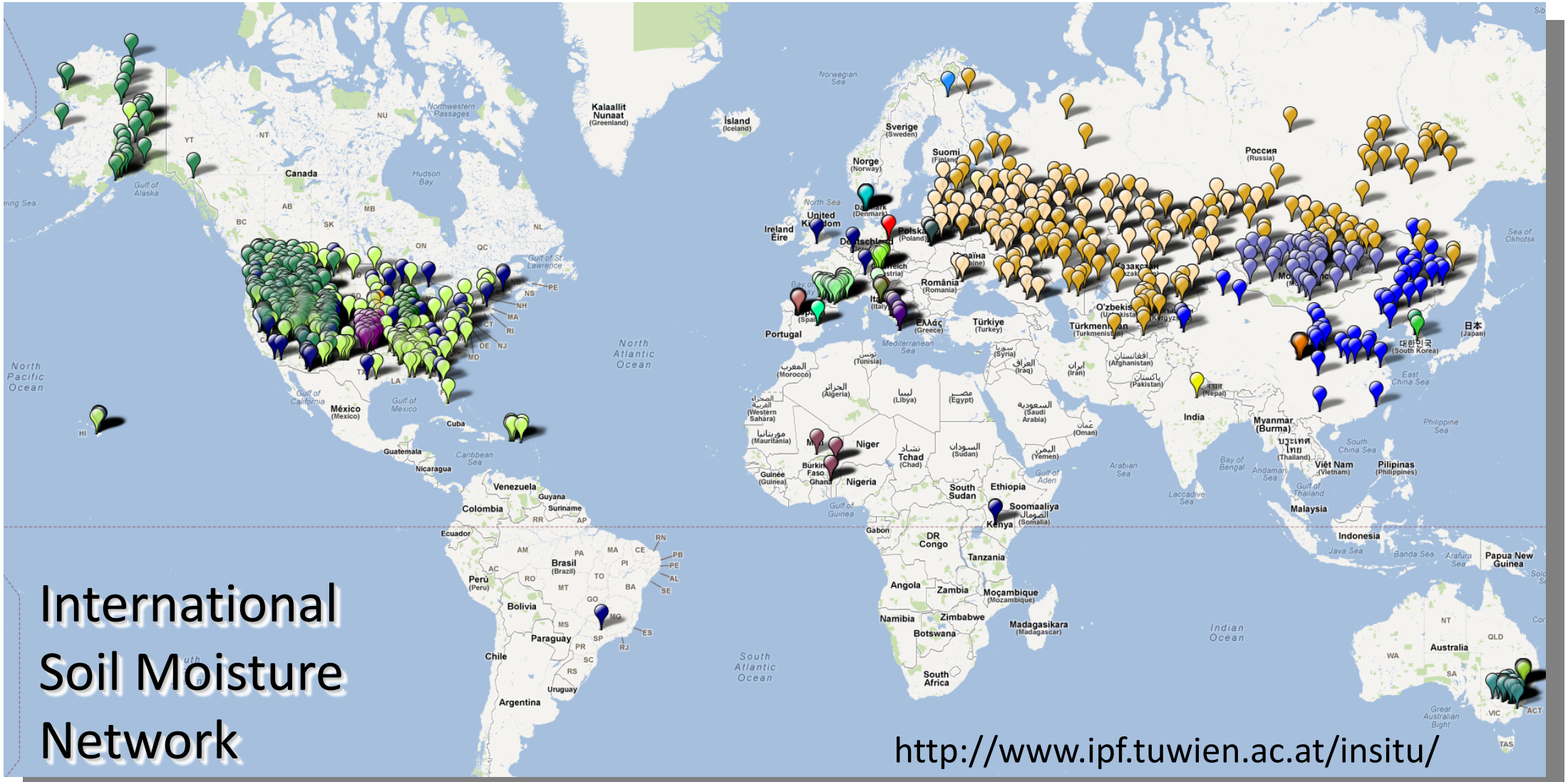
TDR spot measurements



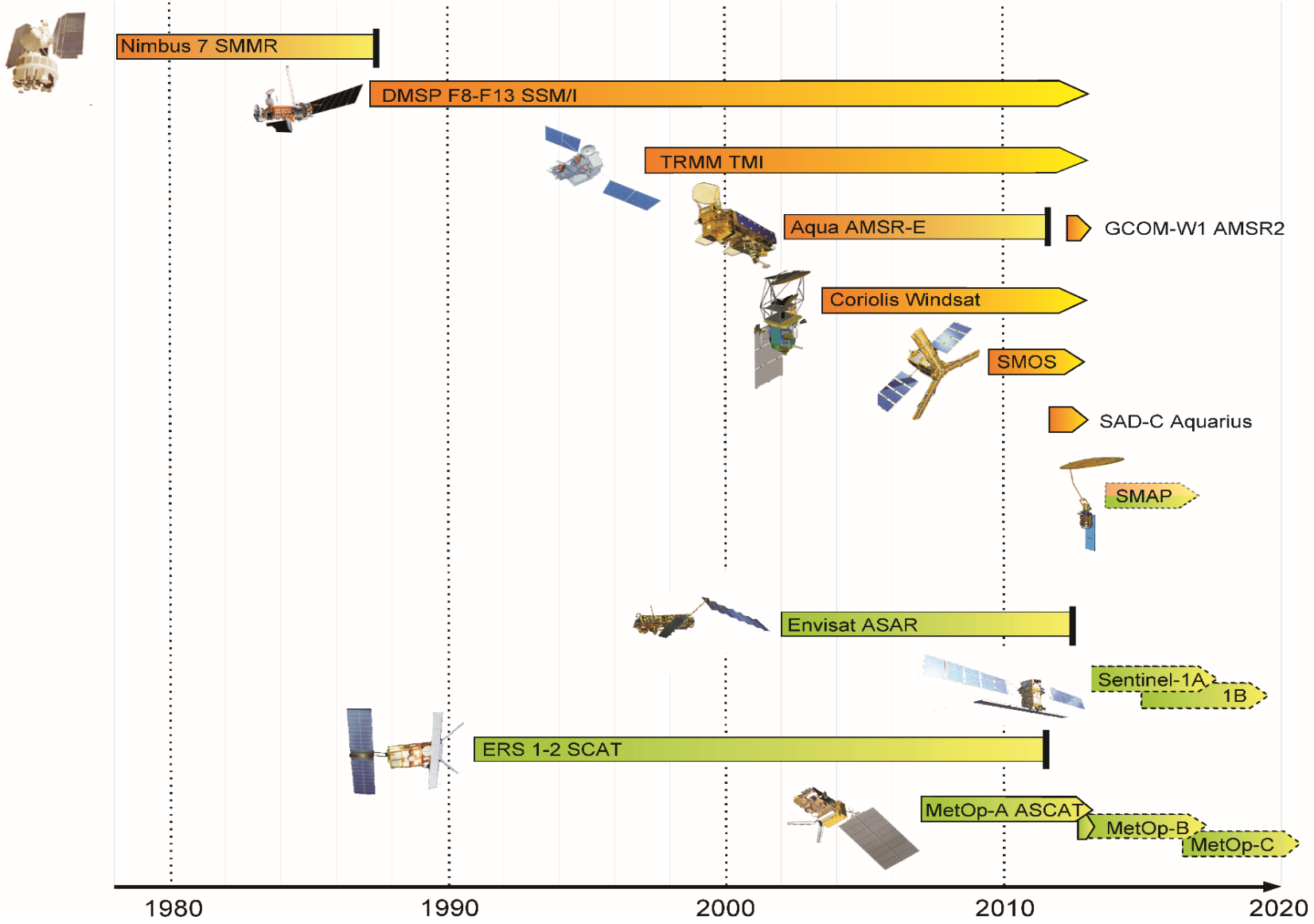
Continuous monitoring probes



In situ soil moisture monitoring



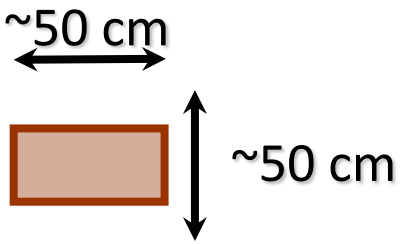
Remote sensing of soil moisture



The problem of spatial scale mismatch

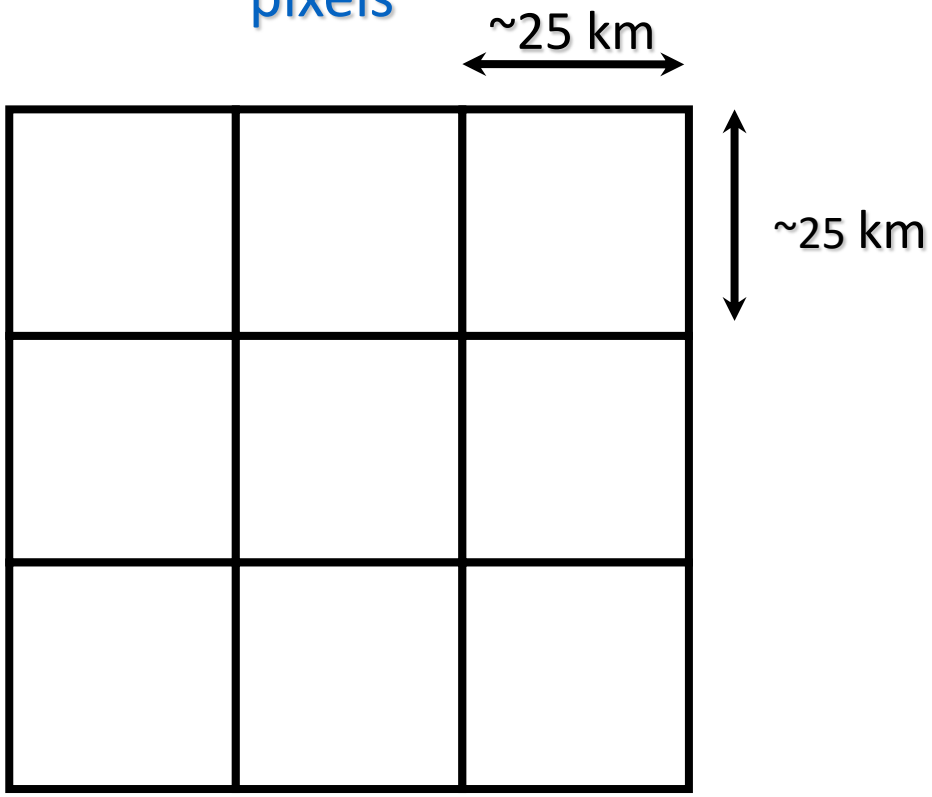
in-situ measurements

versus



A= ~10^{-1} m^2

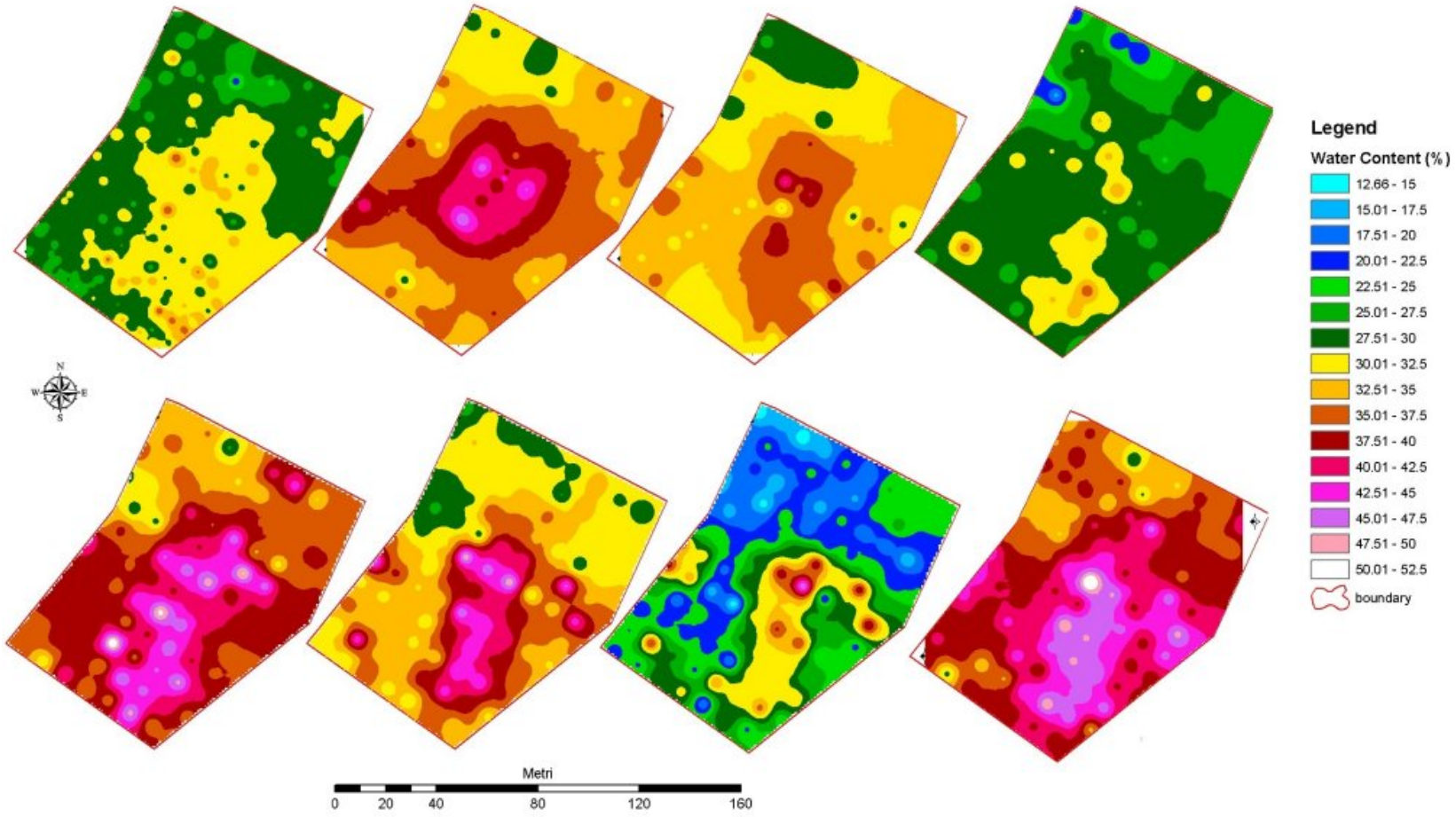
satellite pixels



A = ~10^{9} m^2

HOW IS IT POSSIBLE TO VALIDATE SATELLITE SOIL MOISTURE ESTIMATES WITH IN-SITU MEASUREMENTS?

The problem of spatial scale mismatch



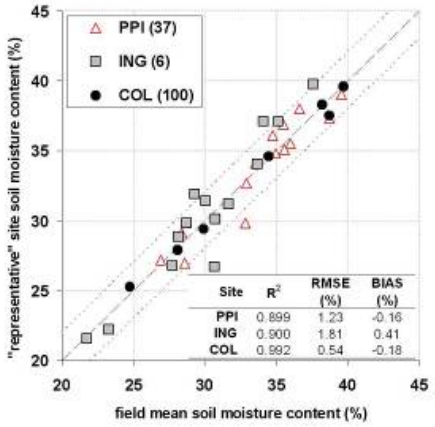
The **temporal stability analysis**, first proposed by Vachaud et al. [1985], helps to identify sampling points where the soil moisture can be considered representative of the monitored overall area with regard to average conditions. In practice, if the spatial distribution of soil moisture exhibits temporal stability, then its estimation over large areas will be possible through a limited number of measurements.

The problem of spatial support

What is the relation between point and area-averaged soil moisture measurements?

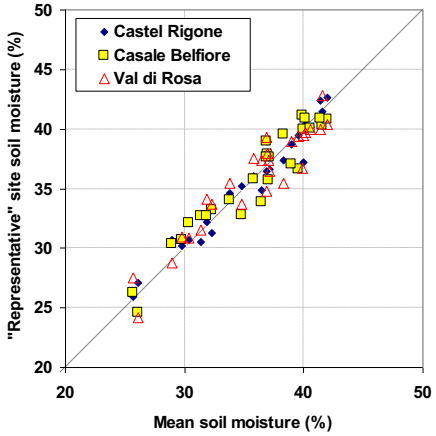
CENTRAL ITALY

PLOT SCALE
400-9000 m²



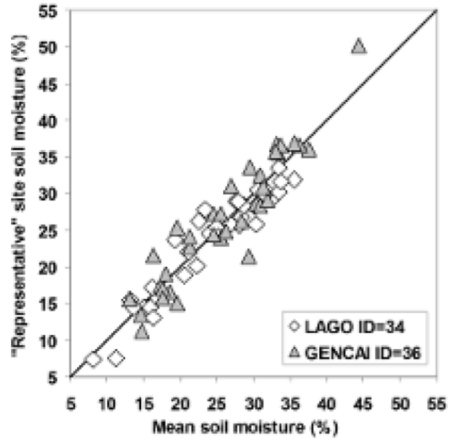
Brocca et al., 2009 (GEOD)

SMALL CATCHMENT
SCALE ~50 km²

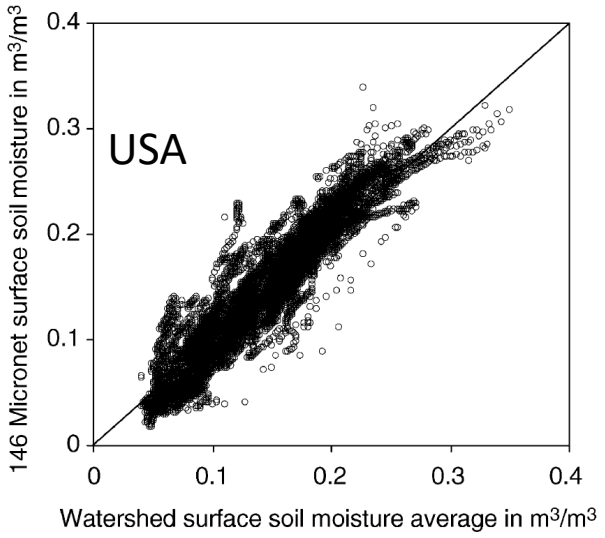


Brocca et al., 2010 (WRR)

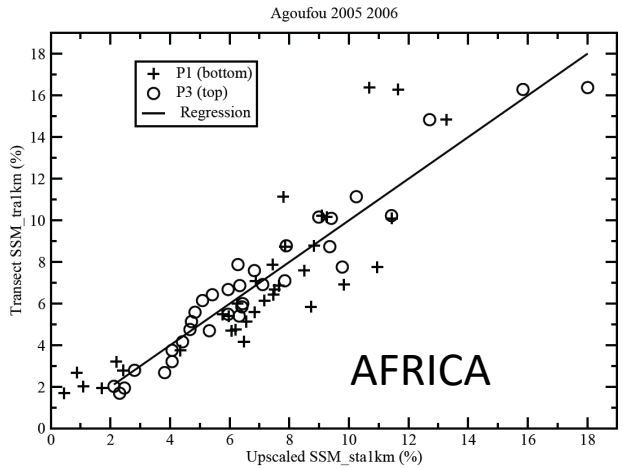
CATCHMENT SCALE
~250 km²



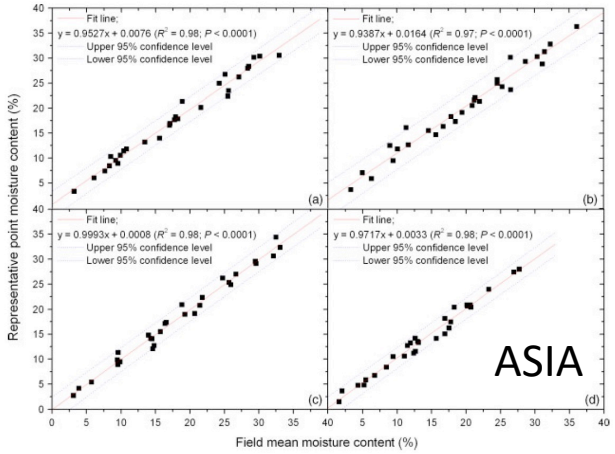
Brocca et al., 2012 (JoH)



Cosh et al., 2006 (JoH)

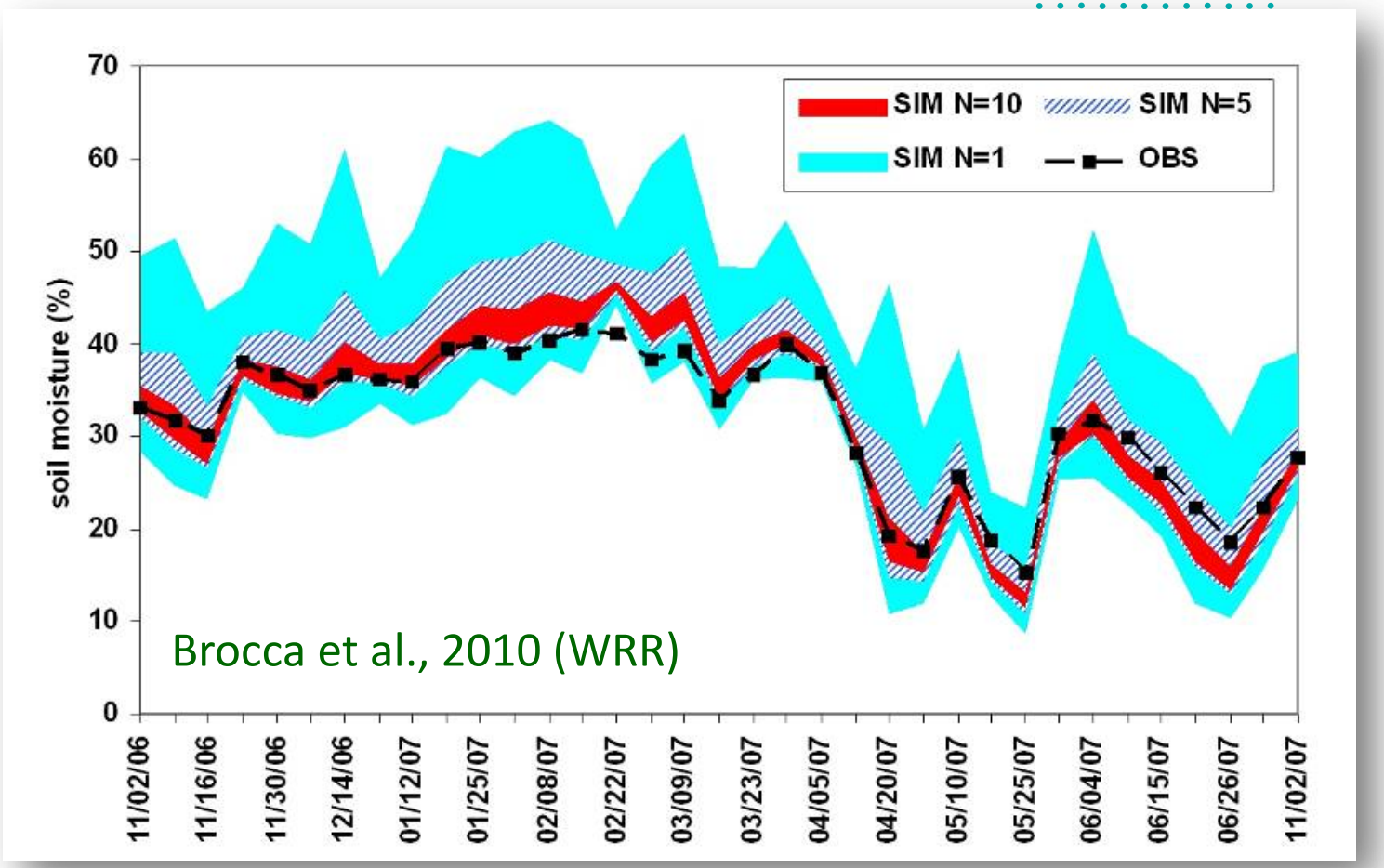


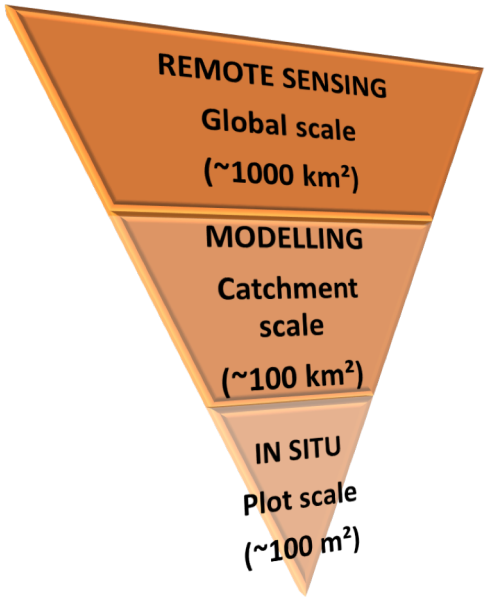
de Rosnay et al., 2009 (JoH)



Zhao et al., 2010 (HYP)

The problem of spatial support

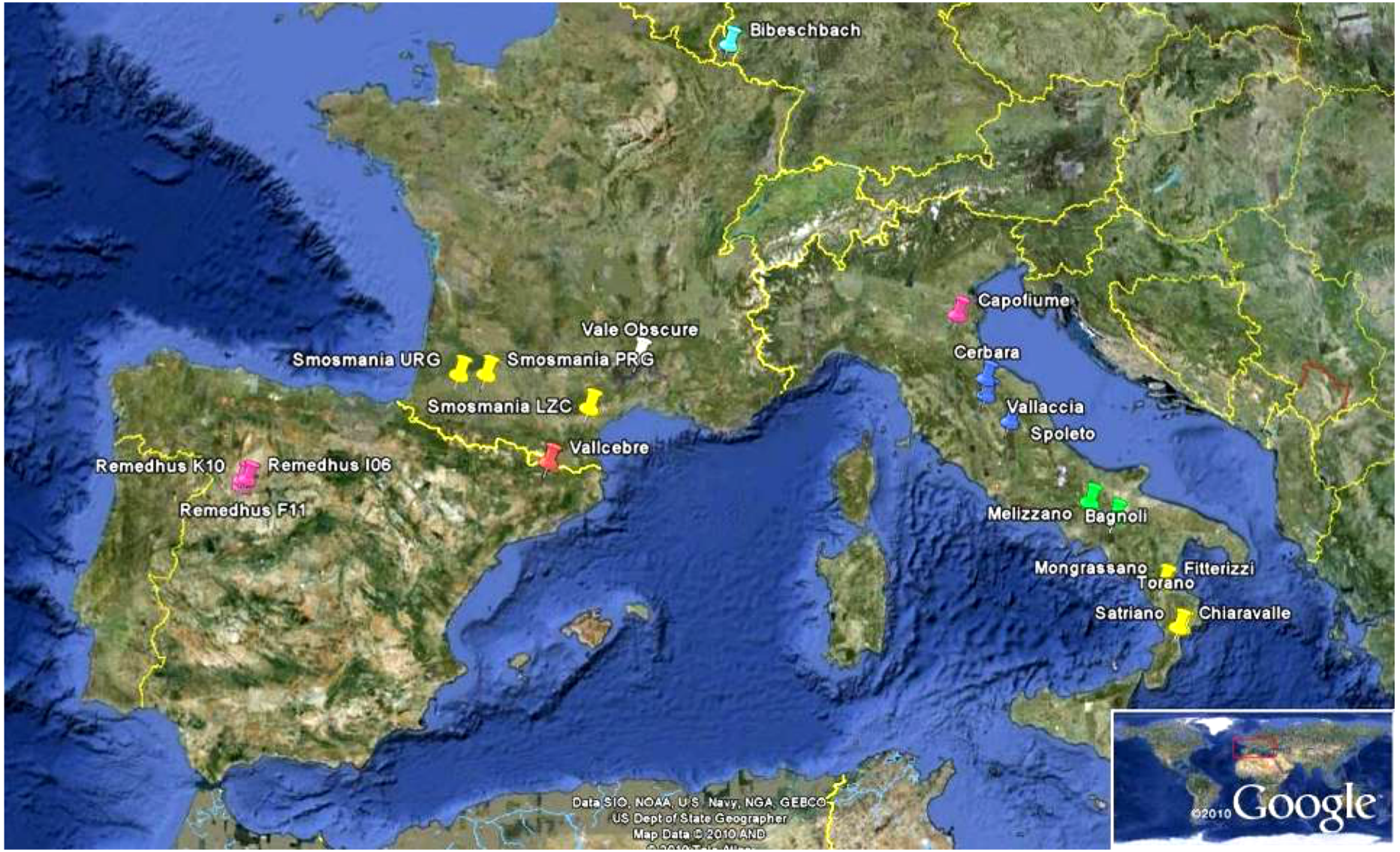




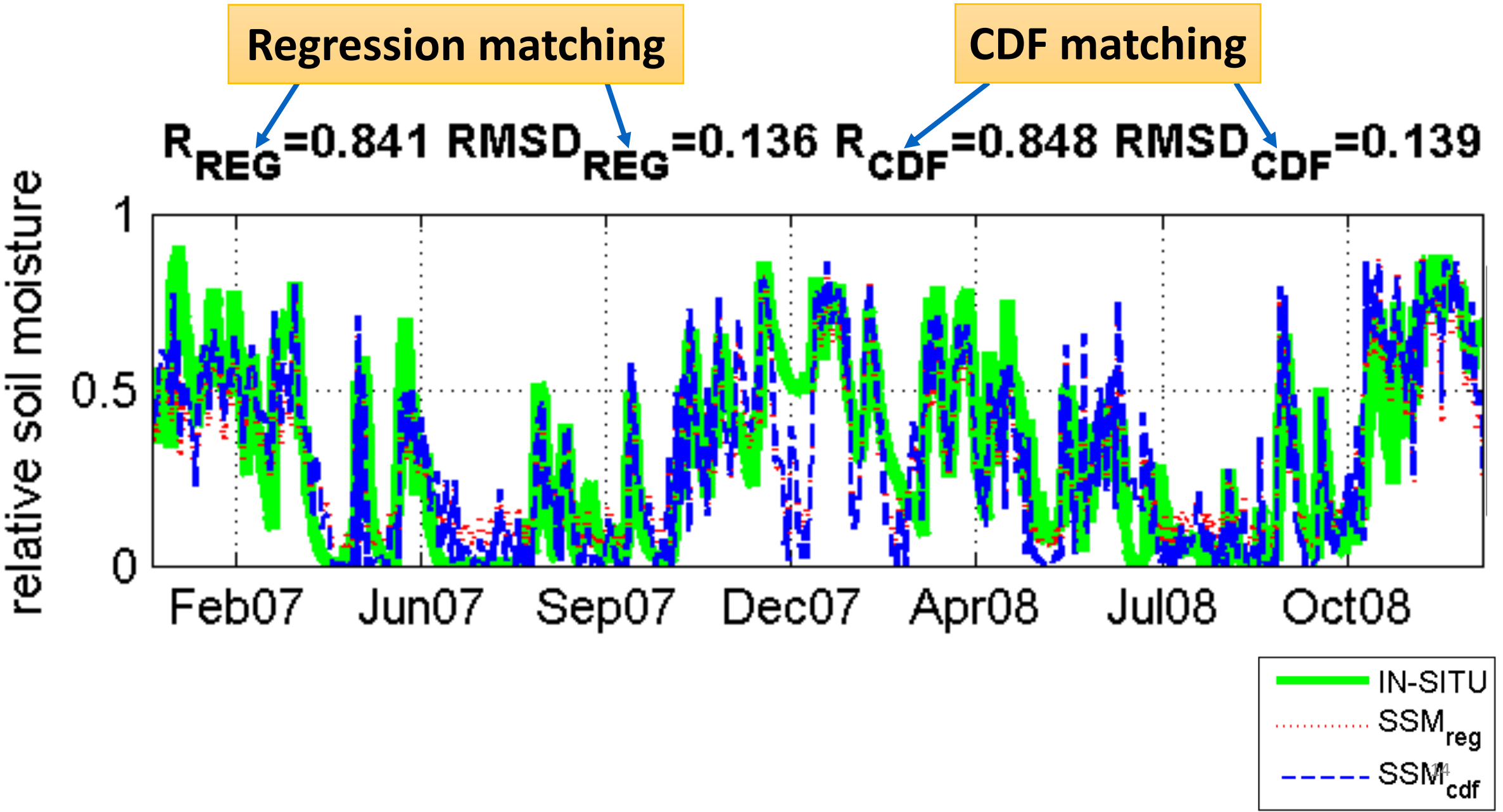
In relative terms, soil moisture temporal variability is more significant than the spatial variability with implications for soil moisture monitoring. In fact, instead of a fine spatial resolution, a high temporal resolution could be more effective for hydrological modeling

An important consequence of this insight in term of remote sensing is that coarse spatial resolution satellite sensor with daily revisit time can be more useful than high resolution sensors with monthly revisit time.

Satellite soil moisture products assessment



Satellite soil moisture products assessment



The Soil Water Index (exponential filter)

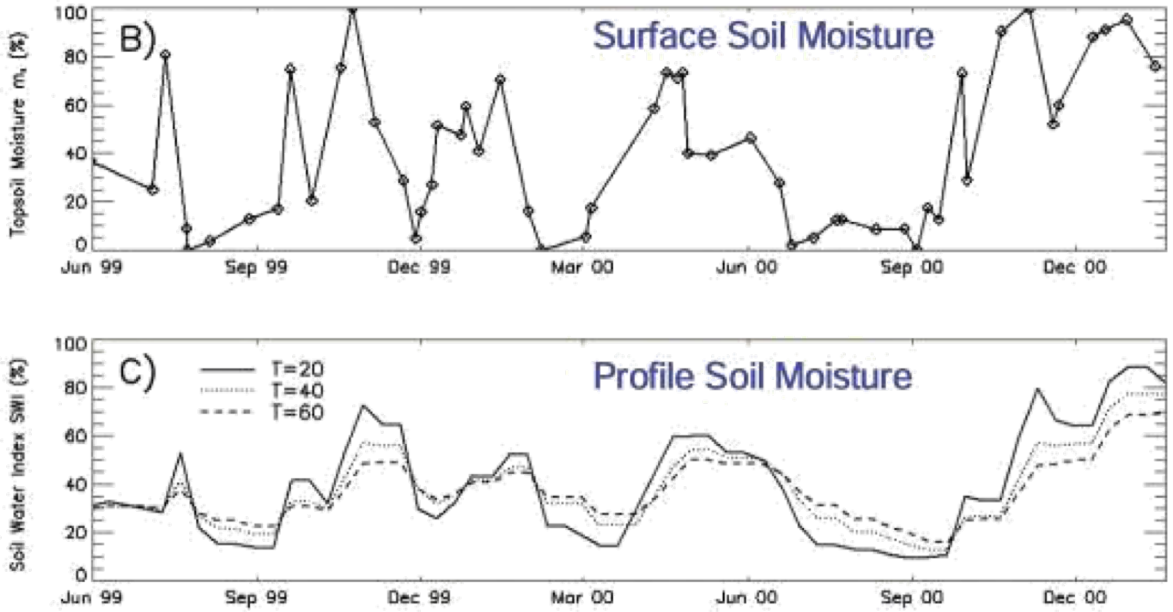
DISCRETE FORMULATION

$$SWI(t) = \frac{\sum_i m_{s,t_i} \, exp\left(-\frac{t - t_i}{T}\right)}{\sum_i exp\left(-\frac{t - t_i}{T}\right)}$$

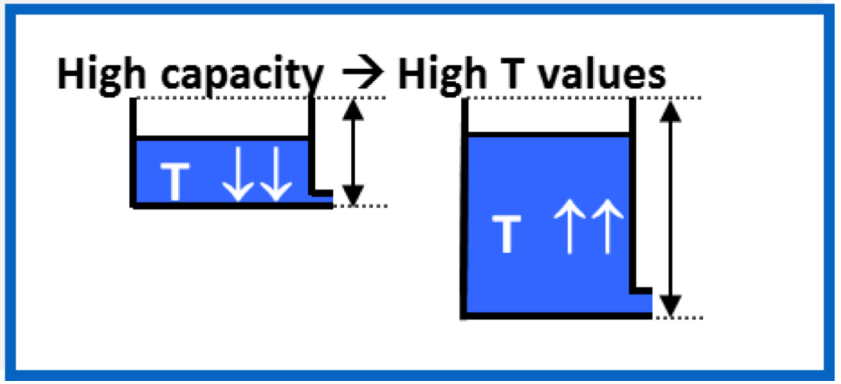
RECURSIVE FORMULATION; easier to implement!

$$\mathrm{SWI}_{(n)} = \mathrm{SWI}_{(n-1)} + K_n(\mathrm{ms}(t_n) - \mathrm{SWI}_{(n-1)})$$

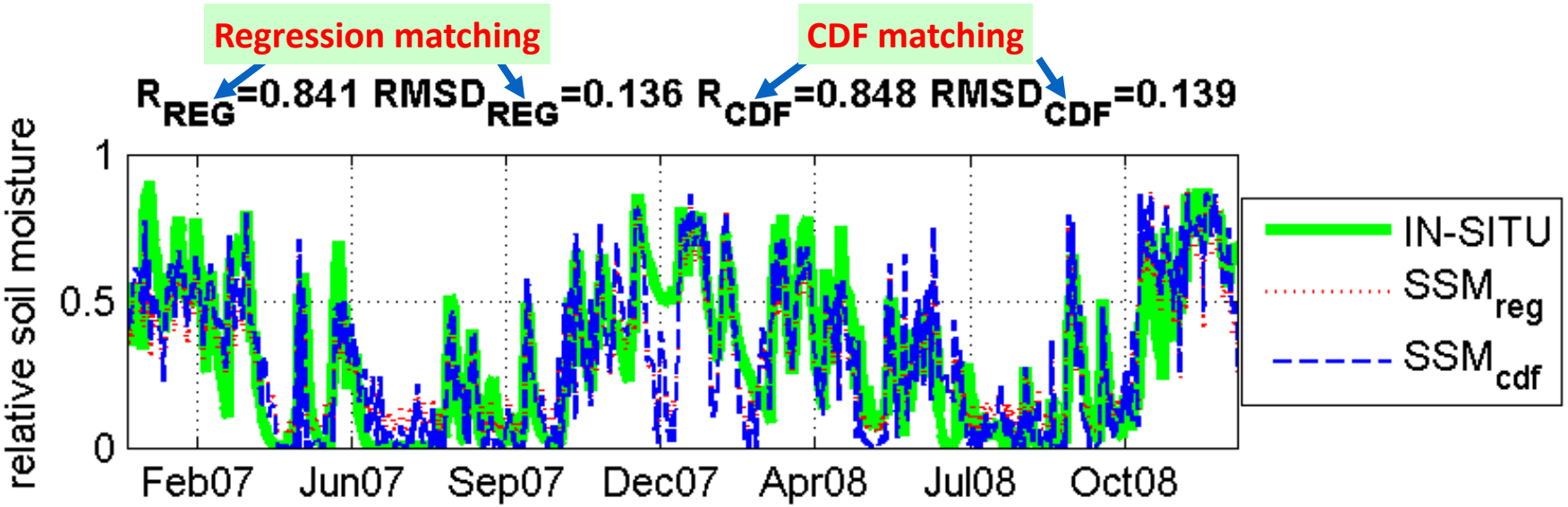
$$K_n = \frac{K_{n-1}}{K_{n-1} + e^{-\frac{(t_n - t_{n-1})}{T}}}$$



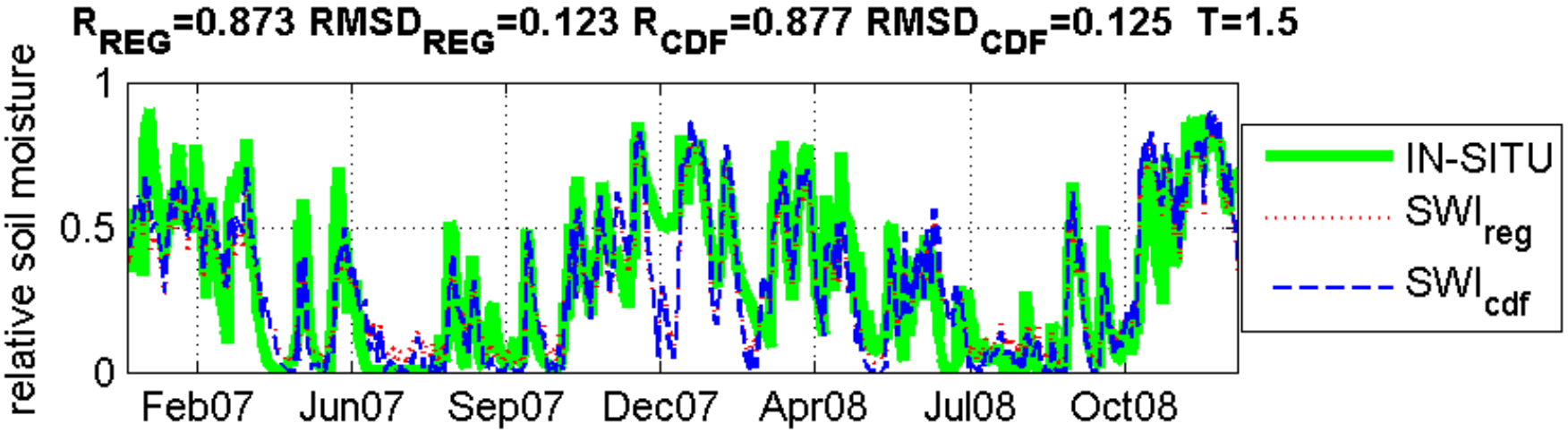
Filtering



Satellite soil moisture products assessment



Surface Soil Moisture

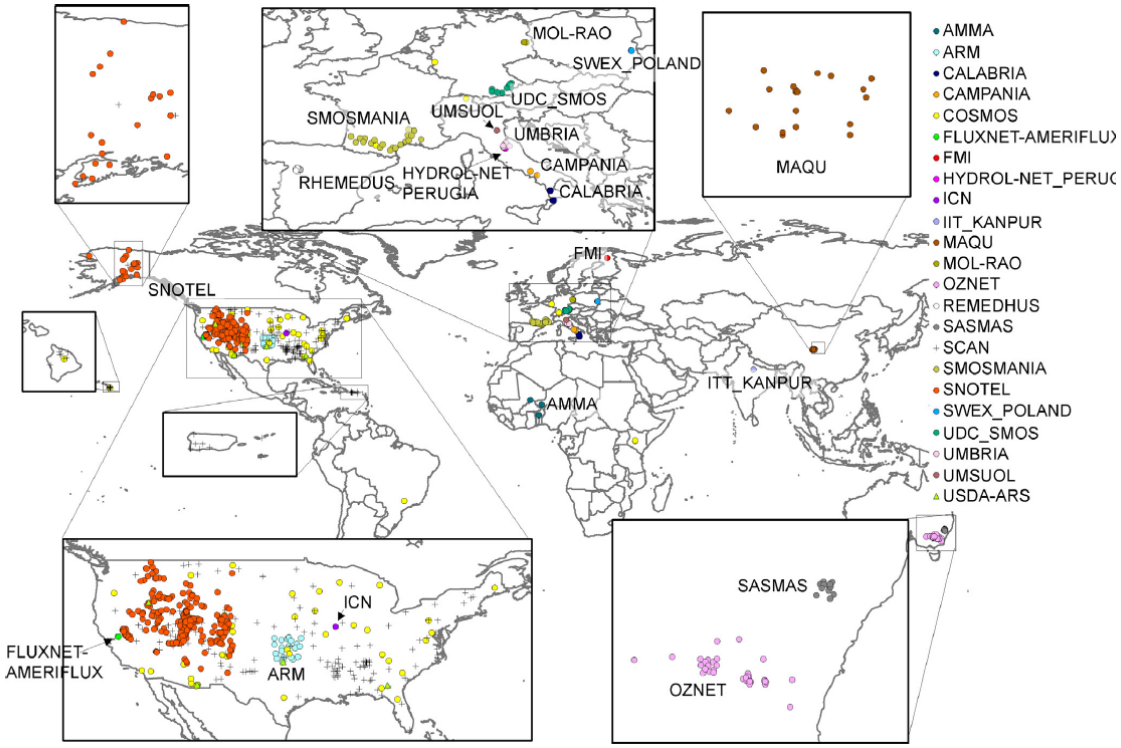


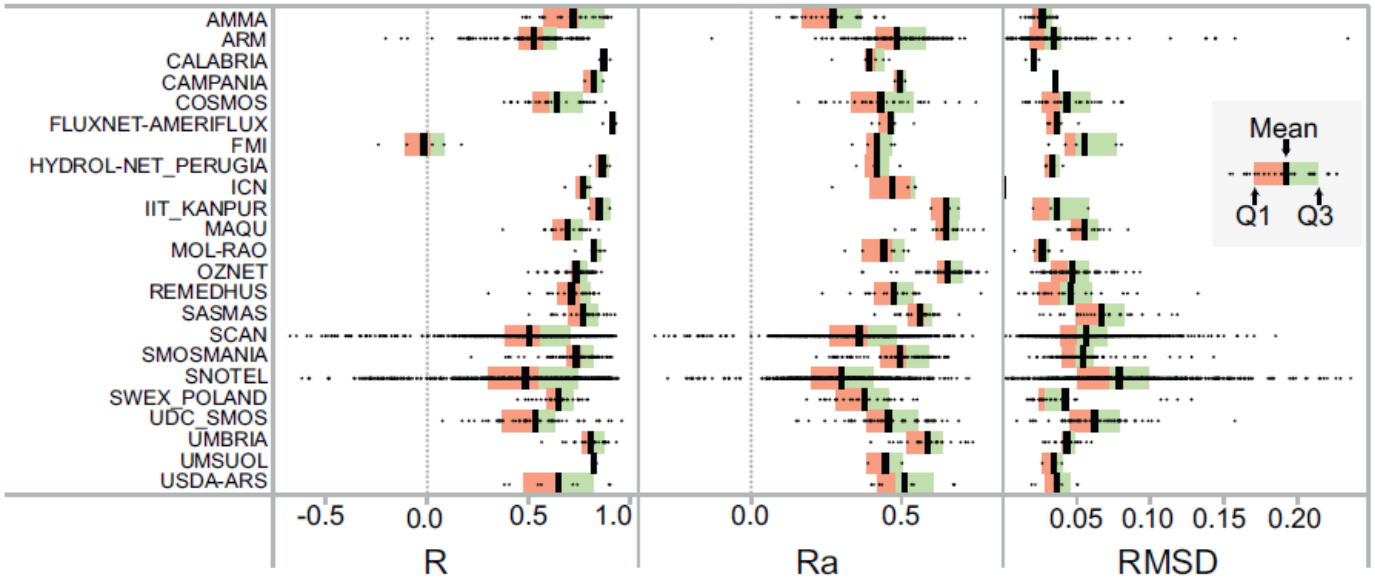
Soil Water Index

Satellite soil moisture products assessment

Validation of the ASCAT Soil Water Index using in situ data from the International Soil Moisture Network

Christoph Paulik, Wouter Dorigo, Wolgang Wagner, Richard Kidd*

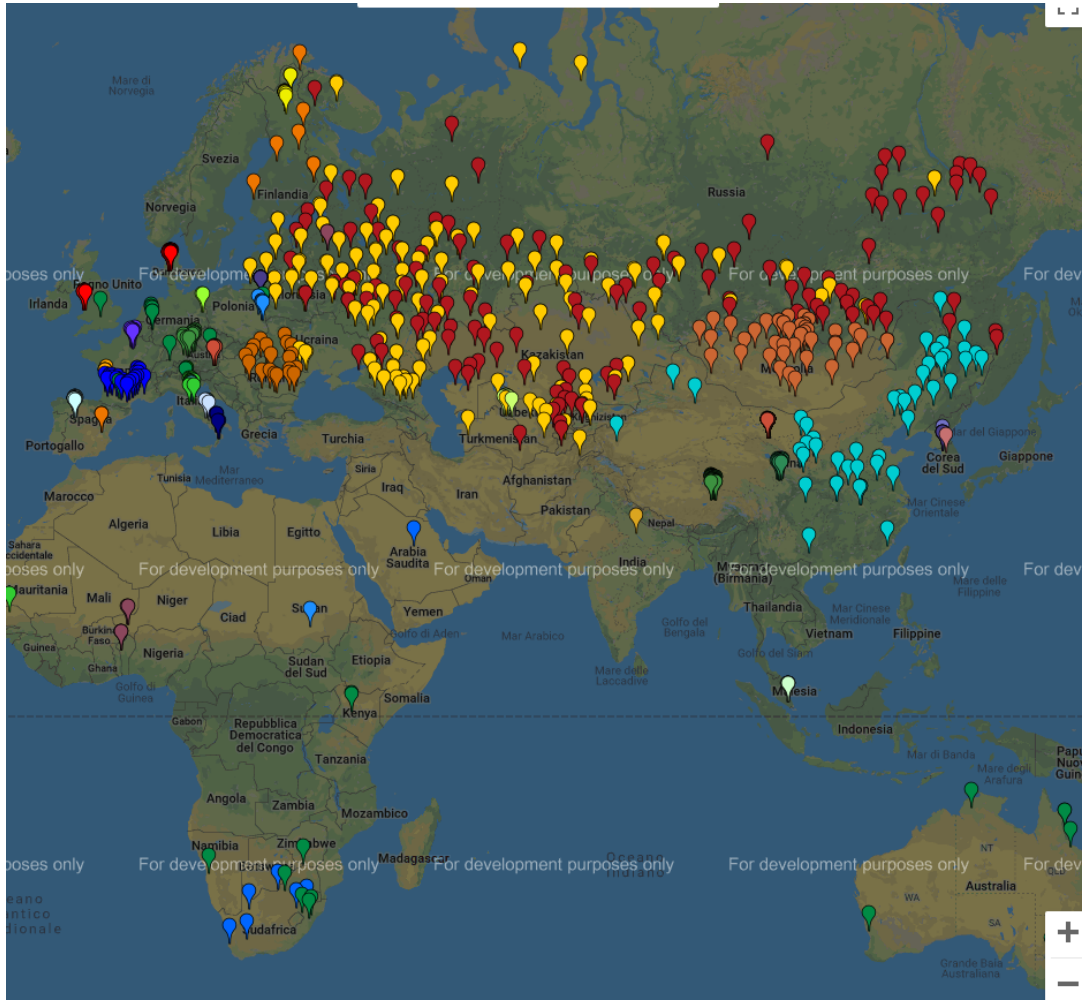




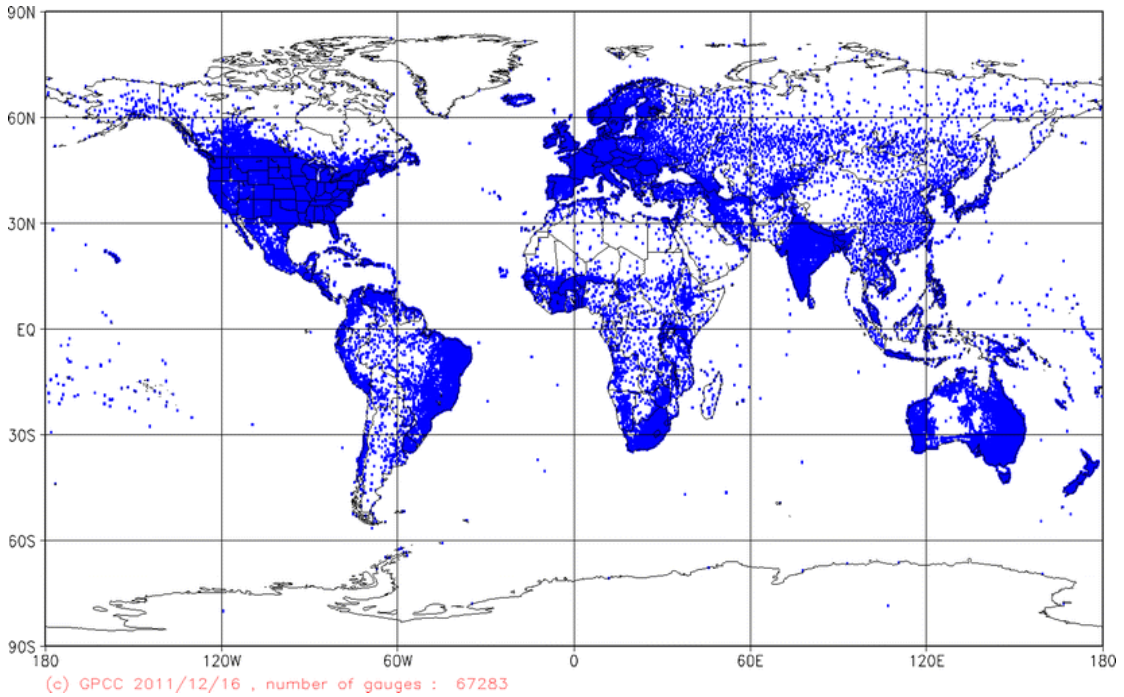
1’800’000 measurements !!!

Soil moisture spatial assessment

International Soil Moisture Network (ISMN, Dorigo et al. 2015) stations from 1980 to 2018 having data (no full coverage is guaranteed)



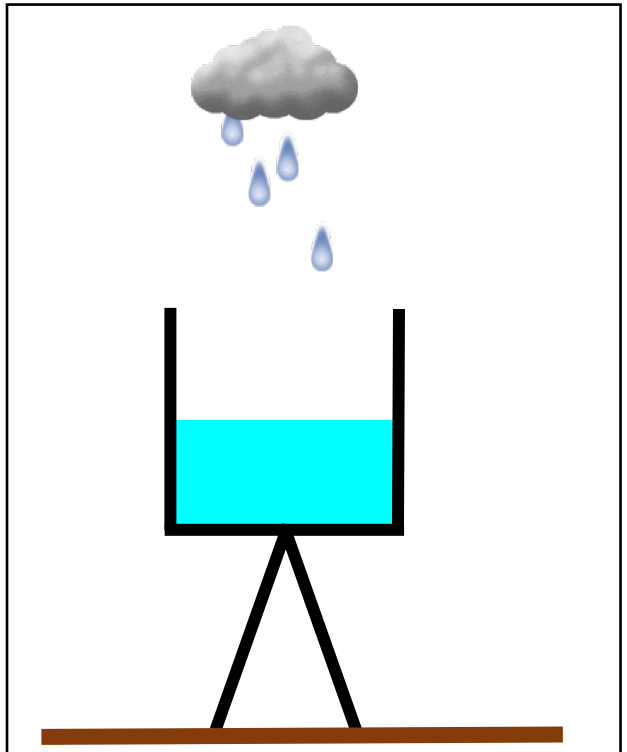
Rain gauge coverage of the Global Precipitation Climatology Center (GPCC)



The scarcity (and the short available time series) of ground-based soil moisture measurements limits their use for spatial assessment of satellite products

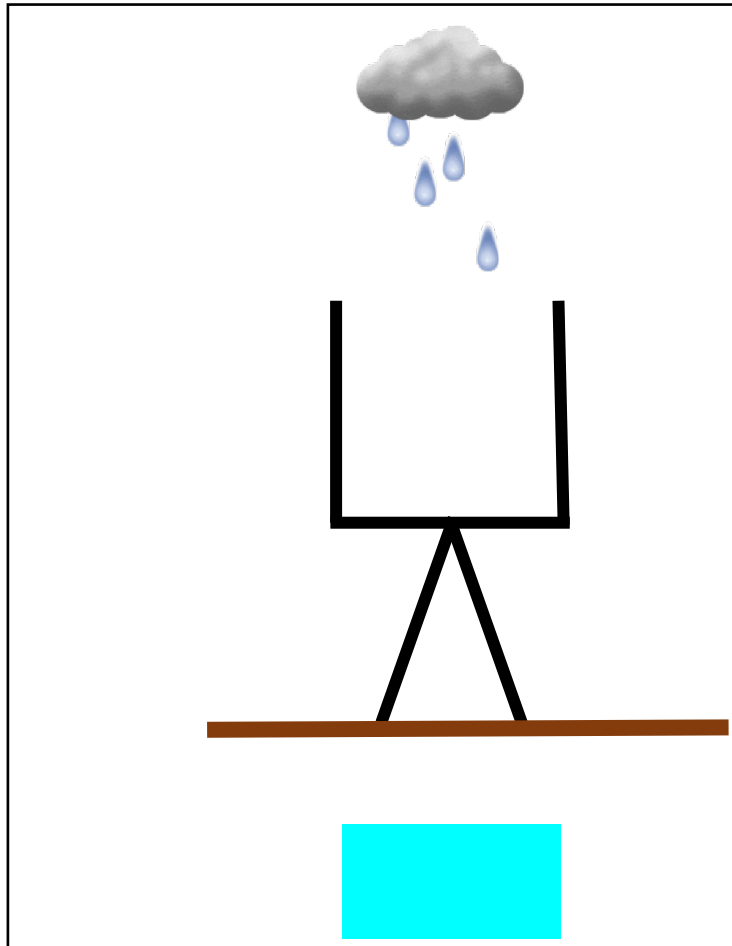
Soil moisture (indirect) spatial assessment

HOW DO WE MEASURE RAINFALL?



We “measure” the water level in the gauge for getting rainfall

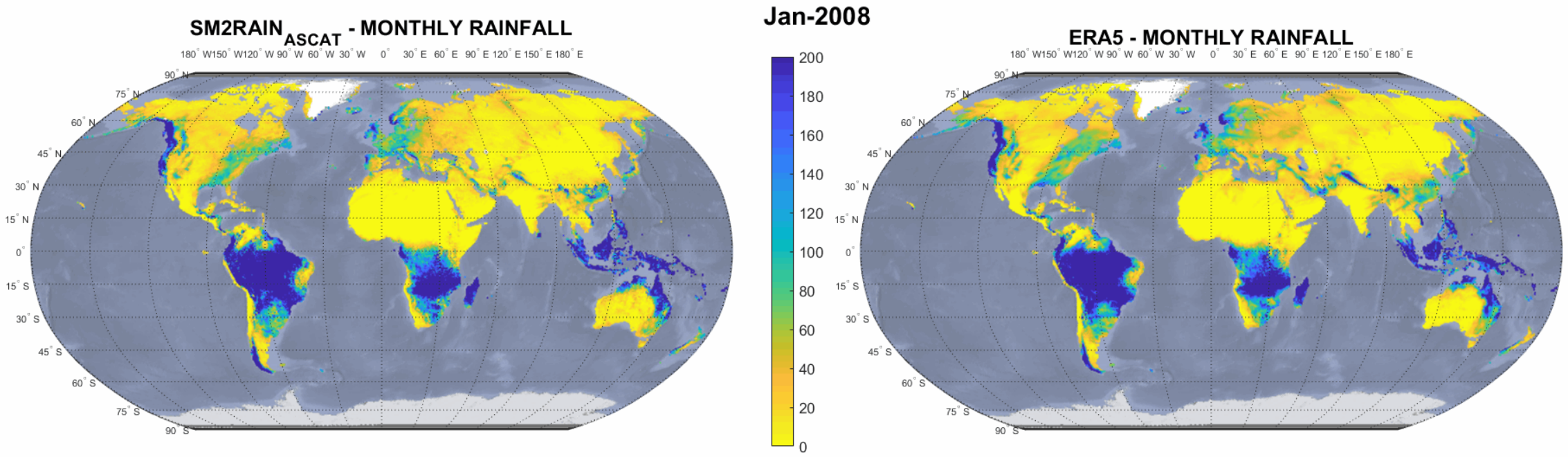
RAIN GAUGE

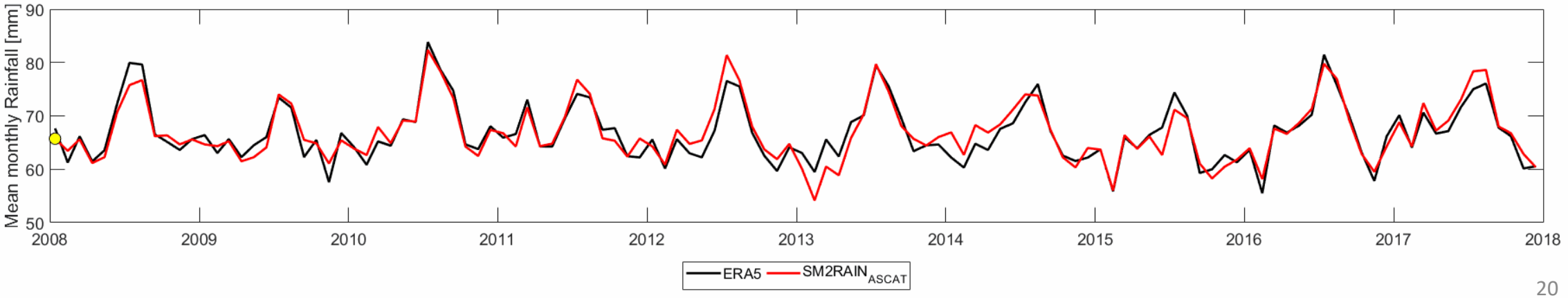


We “measure” the water level in the soil (**SOIL MOISTURE**) for getting rainfall

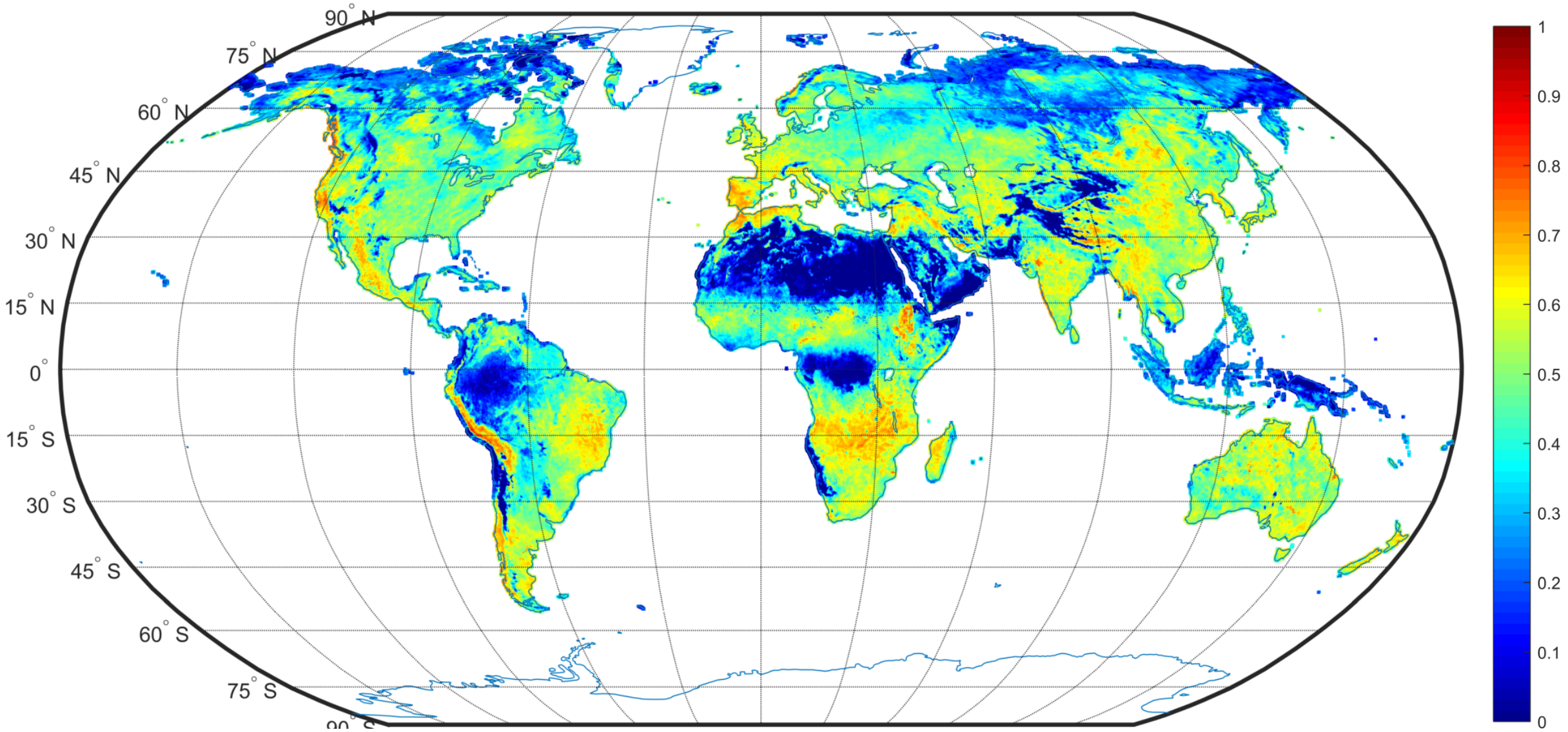
SM2RAIN

Soil moisture (indirect) spatial assessment

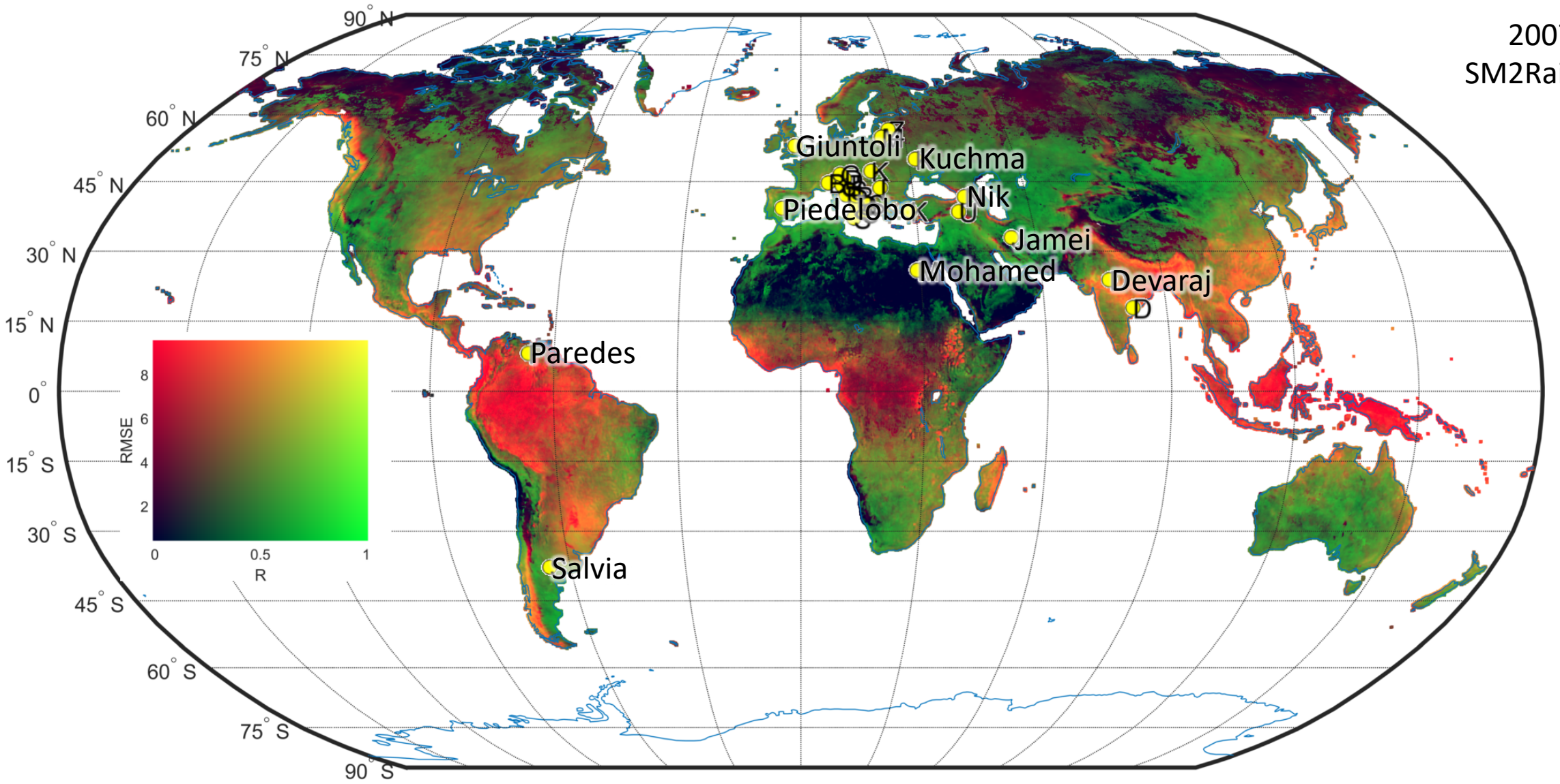




Soil moisture (indirect) spatial assessment

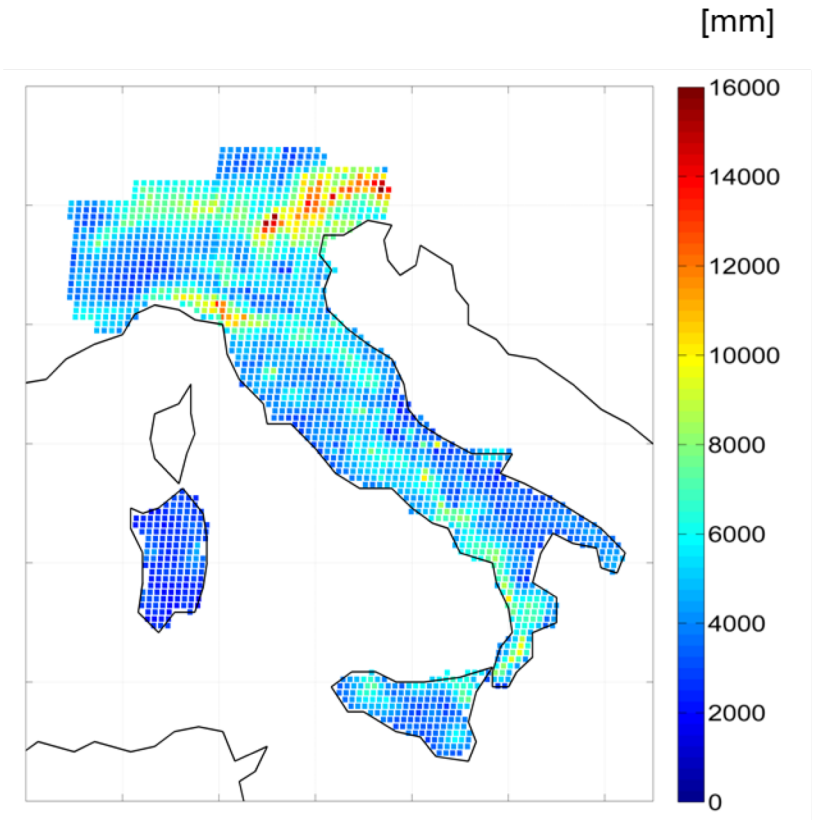


Soil moisture (indirect) spatial assessment



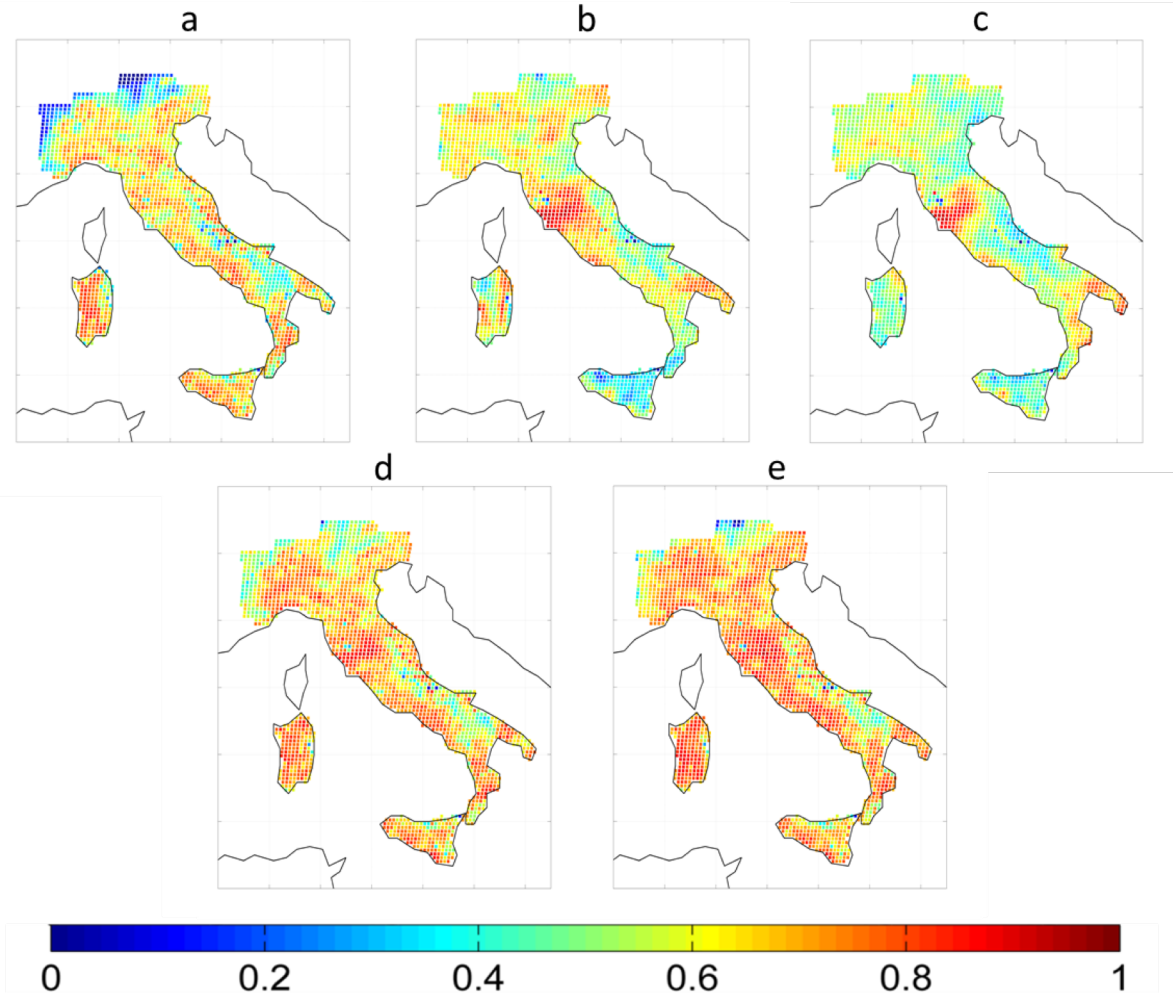
2007-2018
SM2Rain vs ERA5

Soil moisture (indirect) spatial assessment



Cumulated observed rainfall (in mm) over the whole analysis period (2010-2013), more than **3000 rain gauges**

Ciabatta et al, 2015, JHM



Correlation (R) maps for 5 days of accumulated rainfall for SM2RASC (a, median R= 0.62), 3B42-RT (b, median R= 0.6), H05 (c, median R= 0.53), SM2RASC+H05 (d, median R= 0.68) and SM2RASC+3B42-RT (e, median R= 0.71) during the validation period (2012-2013).

Soil moisture spatial assessment

We assume we have three data sets, Θ_1, Θ_2 and Θ_3, each containing N observations of the same geophysical process. The observations can be derived from models, *in-situ* or satellite data. They are spatially and temporarily collocated and have mutually independent error structures and no systematic biases. Each observation i in these data sets differs from the hypothetical truth Θ by a residual r_i (we omit index i).

$$\Theta_1 = \Theta + r_1$$
$$\Theta_2 = \Theta + r_2$$
$$\Theta_3 = \Theta + r_3$$

TRIPLE COLLOCATION

To quantify the quality of each set of observations we need to estimate the variance σ_{12}, σ_2, σ_{32}, of the residuals.

Assuming that the residuals are uncorrelated between the datasets we get an expression for the variance in which all variables are known

$$\sigma_1^2 = \langle (\Theta_1 - \Theta_2)(\Theta_1 - \Theta_3) \rangle$$
$$\sigma_2^2 = \langle (\Theta_1 - \Theta_2)(\Theta_2 - \Theta_3) \rangle$$
$$\sigma_3^2 = \langle (\Theta_1 - \Theta_3)(\Theta_2 - \Theta_3) \rangle$$

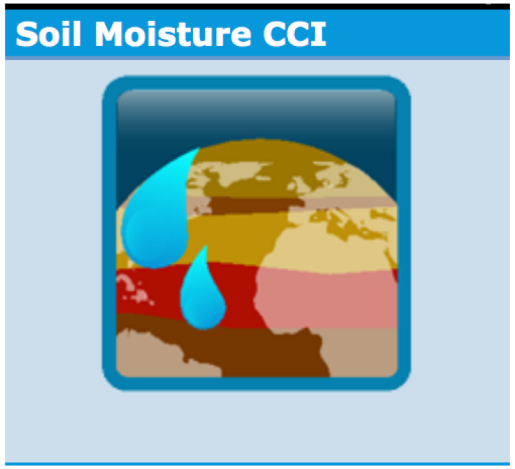
Hypothesis: (i) Linearity between the true soil moisture signal and the observations, (ii) signal and error stationarity, (iii) independency between the errors and the soil moisture signal (error orthogonality), and (iv) independency between the errors of X, Y and Z (zero error cross-correlation).

Soil moisture spatial assessment

Noah GLDAS
Land Surface Model L4 3 hourly 0.25 x 0.25 degree V2.1
Data Availability: 2005-01-01

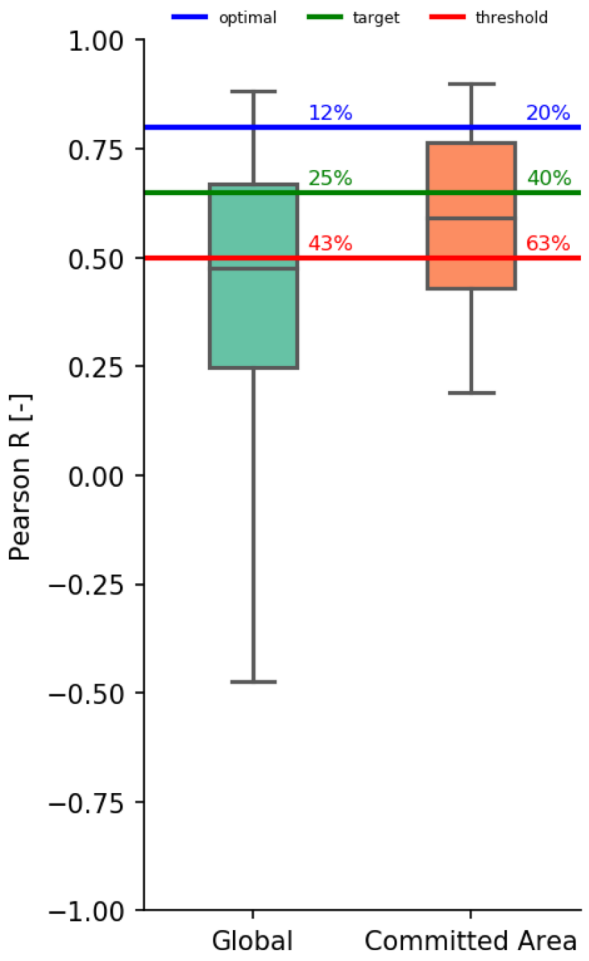
TRIPLE COLLOCATION
- **Noah GLDAS**
- **Passive ESA-CCI v04.4 SM product**
- **ASCAT SM (e.g. SSM_ASCAT_DR2019_TS12.5 / H115)**

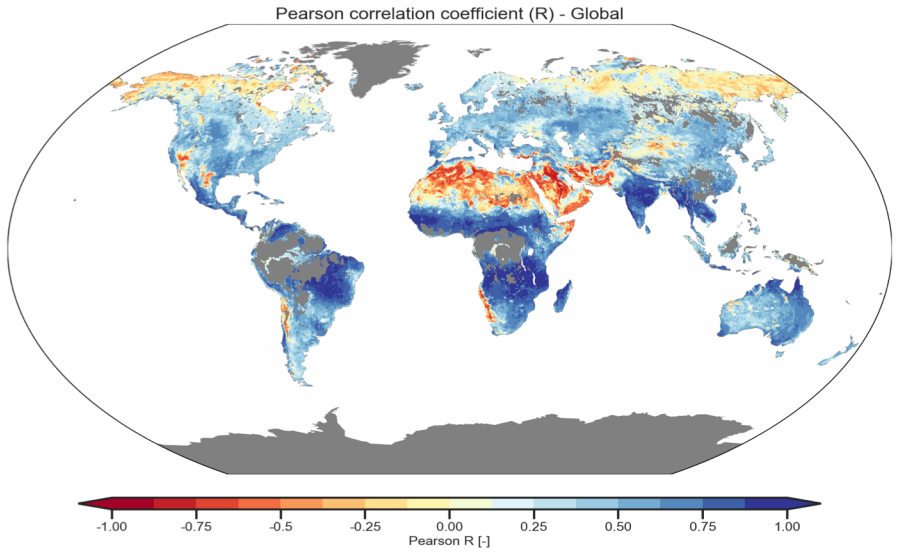
Passive ESA-CCI v04.4 soil moisture product
Data Availability: since 2007-01-01
Soil Moisture L3S SSMV Passive V04.3 product based on passive microwave observations from Nimbus 7 SMMR, DMSP SSM/I, TRMM TMI, Aqua AMSR-E, Coriolis WindSat, and GCOM-W1 AMSR2.
25 × 25 km for top of the soil

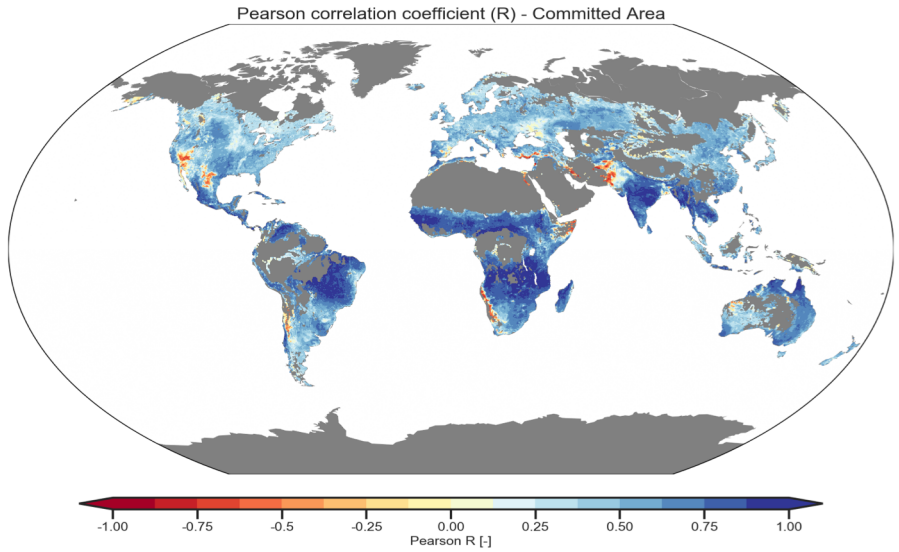


Soil moisture spatial assessment

Pearson Correlation Coefficient







Validation Period
2007-01-01
2018-12-31

The committed area represents a restricted geographical region with high confidence in the successful retrieval of surface soil moisture information from Metop ASCAT. The area is limited to low and moderate vegetation regimes, unfrozen and no snow cover, low to moderate topographic variations, as well as no wetlands and coastal areas

TRIPLE COLLOCATION

Soil Moisture Week

Thank you