Remotely sensed multi-decadal soil moisture for studying climate and vegetation dynamics

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Role of soil moisture in the climate system

- Soil moisture availability plays an important role in:
  - Water cycle: (sub)surface Runoff, Precipitation, Evapotranspiration
  - Energy cycle: Latent/Sensible heat flux
  - Carbon cycle: Carbon uptake and release

Seneviratne et al., 2010, ESR
Microwaves

- Microwaves (1 mm – 1 m wavelength)
  - Very sensitive to soil water content below relaxation frequency of water (< 10 GHz)
  - All-weather, day-round measurement capability
  - Penetrate vegetation and soil to some extent
    - Penetration depth increases with wavelength

The dipole moment of water molecules causes “orientational polarisation”, i.e. a high dielectric constant

Dielectric constant of water
Passive and Active Microwave Sensors

- **Passive**
  - Passive remote sensing systems record electromagnetic energy that is emitted from the Earth surface ("brightness temperatures" in °K)
  - Sensors
    - Microwave radiometers

- **Active**
  - Active remote sensors create their own electromagnetic energy ("Backscatter" in dB)
  - Sensors
    - Scatterometer (SCAT)
    - Synthetic Aperture Radar (SAR)
    - Altimeters
Backscatter from vegetation surfaces comes from surface-, volume- and multiple scattering.

\[
\sigma^0_{\text{total}} = \sigma^0_{\text{volume}} + \sigma^0_{\text{surface}} + \sigma^0_{\text{interaction}}
\]
Products considered in CCI

- Radiometer products:
  - Different frequencies (C-, X-, Ku-band; 4.3, 2.8, 1.6 cm)
  - VUA Land surface Parameter Retrieval Model (LPRM)
  - Radiative transfer based
  - Volumetric soil moisture \([m^3m^{-3}]\)

- Scatterometer products
  - C-band
  - TU Wien algorithm
  - Change detection
  - Soil moisture as percentage saturation (0-100%)

- Merged product
  - Volumetric soil moisture \([m^3m^{-3}]\)
  - 0.25° resolution
  - Daily
  - 1978-2010
How do we merge them?

SM rescaled between min and max
Methodology in a nut shell

1. Individual radiometer products

2. Individual scatterometer products

3. Scaling and merging passive products to climatology AMSR-E

4. Scaling and merging active products to climatology ASCAT

5. Rescale active and passive to GLDAS-Noah SSM reference

6. Test sensitivity to vegetation density

7. Blend rescaled active and passive datasets
Rescaling by CDF-matching

Cumulative Frequency Distribution

Soil Moisture (m³ m⁻³)

0 0.1 0.2 0.3 0.4 0.5

AMSRE

Rescaled

TRMM

Monthly Average Soil Moisture (m³ m⁻³)


AMSRE

TRMM

TRMM Rescaled
Merging active and passive observations

Regions where rescaled Passive and Active Microwave products are highly correlated ($R\geq 0.65$) during the period 2007 - 2008

Merging active and passive observations

- For the other areas, vegetation optical depth is used to decide whether the merged active or the merged passive dataset is used.


Areas where, according to triple collocation, ASCAT (blue) or AMSR-E (red) shows lowest error (Dorigo et al., 2010, HESS)
Properties and accuracy of ECV soil moisture data set varies over time and in space.

Notice, that SCAT data is only available over limited regions after 2001 instead of global coverage due to instrument issues.
Merging active and passive observations

- For areas with moderate to dense vegetation we use active.
- For (semi-)arid areas we use passive.
- In transition zones we use both by averaging.
- Ranking maps are dynamic over time, depending on available sensors.
Anomalies related to climate modes


La Nina 2010/2011
Understanding land-atmosphere interactions

Probability of convective precipitation over drier soils

Trends 1988-2010

SM-ECV

SM ERA Interim

GPCP

SM-GLDAS-Noah

Trends 1988-2010


ECV_SM

NDVI GIMMS 3g
Surface vs Rootzone SM

Albergel, Dorigo et al. (in review), JHM
Lag in vegetation response

Cross-correlation between ECV_SM and NDVI using a lag of 5 (a) to 0 (f) months.

Chen et al (in review), RSE
Can MW soil moisture be used for crop prediction?

- MW Soil moisture anomaly versus cereal yield anomaly
  - Australia

Source yield data: The World Bank
Trends 1988-2010

Trends in NDVI

Challenges (a few)

- Multi-satellite soil moisture has a large potential for studying interaction soil moisture – climate - vegetation
- Relationship between soil moisture and vegetation is not straightforward:
  - Response time + vegetation type should be considered
  - Precipitation is main driver, but other meteorological and human factors also play a role: temperature forcing, deforestation, LULC change
  - Distribution of soil moisture availability over vegetation period may be more important than total amounts
- Trends are often driven by climate modes and therefore trends may not be monotonic.
- Artifacts in the SM dataset related to sensor characteristics may lead to spurious trends