Modelled and observed surface soil moisture spatio-temporal dynamics in a land-atmosphere hotspot

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- Motivation for studying Southeastern South America
- Surface Soil Moisture (SSM) observations and models used to quantify drydowns.
- Comparing SMOS and ORCHIDEE drydown characteristic times.
- Further lessons to be gained from e-folding times for SSM
Southeastern South America (SESA)

SESA (19.75\(^\circ\)-42.5\(^\circ\)S and 70.5\(^\circ\)-48.75\(^\circ\)W) is an area of approximately 4.2 million Km\(^2\), and includes the southern part of La Plata Basin, the second largest basin of South America.

It has the largest population density of the continent and is the most productive region in terms of agriculture, livestock and industry.

It is a transition zone between wet and dry climates, in a gradient from the northeast (annual mean precipitation: 1200mm) to the southwest (annual mean precipitation: 300mm) of SESA.

It has been considered a land surface-atmosphere hotspot due to the coupling of SM and evapotranspiration and temperature.
Motivation

SESA includes the low and flat Pampas plains where the most severe subtropical storms (mesoscale convective systems) of the globe are developed during DJF (austral summer).

RELAMPAGO (*Remote sensing of Electrification Lightning and Meso-micro scale Processes with Adaptive Ground Observations*) International Project (CONICET, National Weather Service, CIMA, UBA, NSF-USA) wants to answer why and how these storms are established over SESA (start in 2018).

The impact on such extreme events is related partially with SM state over SESA.

In this context, our objective is to study the surface soil moisture spatio-temporal dynamics through drydowns in SESA as seen by SMOS and modeled by ORCHIDEE, for the austral summers (DJF) of the years 2010-2014 (4 summers).
Model and satellite data

Land Surface Model: ORCHIDEE (Organizing Carbon and Hydrology in Dynamic Ecosystems, http://orchidee.ipsl.fr/), developed by IPSL
  Forcing data: Earth2Observe
  Spatial resolution: 25 km.
  Soil vertical resolution: 11 levels over 2m, top 4.5cm described by 5 layers.

Experiments:
  ★ Change in soil classification: Zobler vs. FAO
  ★ Vegetation distribution: Olson vs. ESA-CCI
  ★ Reduced drizzle in the MSWEP rainfall forcing

Satellite surface soil moisture (SSM) data: SMOS Soil Moisture Level 3 products distributed by BEC (Barcelona Expert Centre)
  ★ Products binned in 3hourly windows.
  ★ Soil moisture maps are on the EASE-ML 25km grid
  ★ Ascending and Descending treated separately.

Satellite Rainfall data: TRMM Multisatellite Precipitation Analysis 3B42
  ★ 3hourly data
  ★ 25km resolution grid
Definition and detection of drydowns

\[ \theta_v = Ae^{\left(-\frac{t}{\tau}\right)} + \theta_{eq} \]

**ORCHIDEE**

Drydowns start: day with accumulated rainfall of at least 20 mm and with at least 5 subsequent days without rainfall (P<1 mm)

Drydowns end: when a rainfall of more than 1 mm occurs

**SMOS+TRMM**

- **Drydowns start:**
  1) Starts detection when SSM increases at least 0.1 m³/m³ (2.5 times product accuracy, SMOS)
  2) exclude drydowns of length shorter than 5 days.
  3) exclude drydowns with less than 20mm accumulated rainfall in the previous 24 hours (TRMM)
- **Drydowns end:**
  1) Filter-1: when there is a SM value increase, no matter the amount (SMOS).
  2) Filter-2: when there are two consecutive SM increases, no matter the amount, or when there is a single increase of 0.1 m³/m³.

*No fitting is attempted for SMOS or ORCHIDEE when less than 4 SSM values are available.*

The presentation will focus on the drydown time constant: \( \tau \)
Time constant for SMOS

Increase of SSM (m³/m³) which triggers the detection of drydown.

TRMM rainfall (mm) in the previous 24h needed.

Median quality of fit (\(R^2\))
Time constant for ORCHIDEE

Median quality of fit ($R^2$)

<table>
<thead>
<tr>
<th>Sampling</th>
<th>Soil depth</th>
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<tr>
<td>4.5cm</td>
<td>2.1cm</td>
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Box plots showing SMupper - Tao (days) with various sampling methods and soil depths.
Comparing SMOS & ORCHIDEE

When ORCHIDEE is sampled as SMOS, the two diagnosed $\tau$ are very close. Different studies concluded that $\tau$ from satellite derived SSM is smaller than *in-situ* measurements?
On the importance of $\tau$

A simple model of SSM:

- We use a Markov chain to generate an annual cycle of rainfall on the basis of time between rain events.
- After each rain event (of constant amplitude) we draw based on a normal distribution the time of the next rain.

- In space the rain sequences are independent.
- The time step is daily.
Simple surface soil moisture model

- Soil moisture is given by a simply decay law.

\[
SSM^t = SSM^{t-1} \left(1 - e^{-\frac{1}{\tau}}\right) + P^t
\]

- This produces times series like those observed or modelled for SSM with a single parameter: \(\tau\)

- These time series can serve to test statistical measures.

- The reference time series is for \(\tau = 2\)
Sensitivity of correlations to variations of $\tau$

- The reference is $\tau = 2d$
- Variations from $\tau = 2$ to $10d$
- The temporal Pearson correlation is relatively insensitive
- Spatial correlation is more sensitive to $\tau$ than temporal Corr..
- Largest sensitivity during the high rainfall frequency periods.

$\tau$ differences could explain the poor spatial correlations found between SMOS and ORCHIDEE over Spain (Polcher et al. 2016).
Conclusion

- Exponential decay of surface soil moisture (SSM) is a useful model.
- It is difficult to fit when precipitation is unknown, i.e. remote sensed SSM.
- The proximity of the sampling period and decay time seem to affect results for remote sensed SSM.
- Differences in decay times could be an explanation of poor spatial correlations (but good temporal corr. !) between observed SSM and models.
- The drydown periods offer good perspectives for land surface model validation but methodological difficulties still need to be addressed