Ensemble-Based Soil Initialization for Seasonal-to-Decadal Predictions

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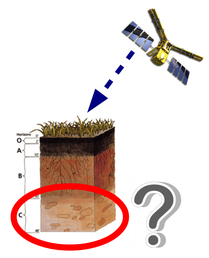
Motivation

As the ocean, the long-term memory of the (deep) soil exhibits potential seasonal-to-decadal predictability.[1]
→ Soil temperature & moisture should be initialized as realistic as possible.
Challenge: *There are **no** observations for the deep soil...*



Approach: Ensemble-based data assimilation

→ Use offline soil model (TERRA-ML from COSMO-CLM)
→ Assimilate atmospheric forcing data and satellite observations
→ TERRA-ML transports observational information downwards
→ Achieve optimized soil initial state for predictions

Observation Simulation System Experiments

TERRA-ML

- Multilayer land surface scheme, default in COSMO-CLM
- Prognoses soil temperature & moisture
- Offline model, driven by atmospheric forcing

Data assimilation experiment

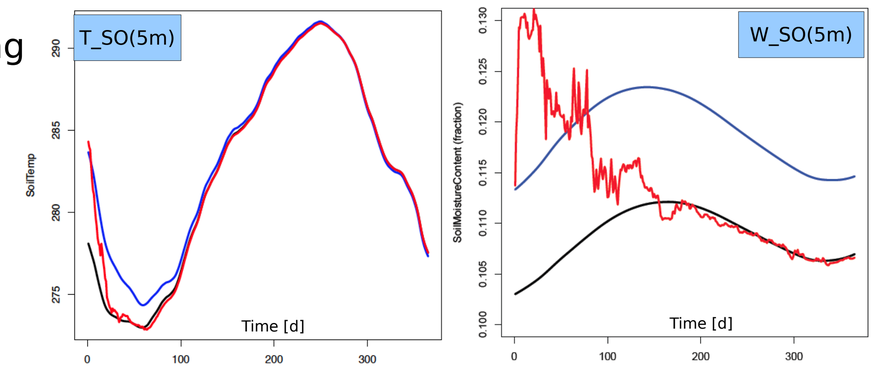
- One vertical soil column (Lindenberg)
- Use Ensemble Kalman Filter
- Generate truth run, but initialize filter with strong bias (initial uncertainty)

Observations

Soil temperature & moisture in first layer only

Results

Compare **filter analysis** with **spin-up** (forcing only) and **truth** over one year:



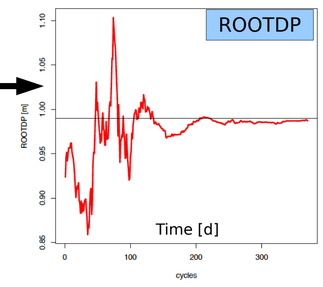
Evolution of **truth**, **analysis** and **spin-up** in 5m depth for soil temperature (T_SO) and moisture (W_SO) for one year.

State estimation

One observation per day already valuable:
→ Soil temperature & moisture are estimated more reliably and quicker than with spin-up

Parameter estimation

True *root depth* can be retrieved
→ Estimation of uncertain parameters works in principle



→ Deep soil estimation by ensemble data assimilation is feasible.

Regional Data Assimilation with Real Observations

Technical setup

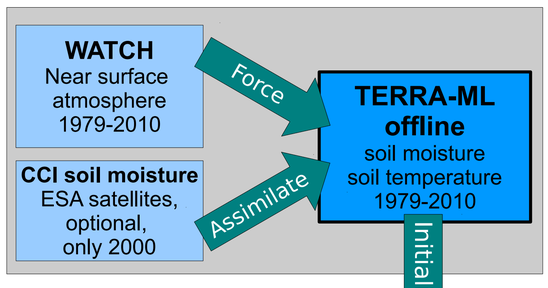
- Domain: Africa, decade 2001-2010, within the *MiKlip-DEPARTURE* project
- TERRA-ML coupled with Parallel Data Assimilation Framework (PDAF[2])
- Use Local Ensemble Transform Kalman filter (LETKF[3])

Methodology

- Create land surface re-analysis 1979-2010 using WATCH forcing data[4]
- Additionally assimilate satellite soil moisture in 2000

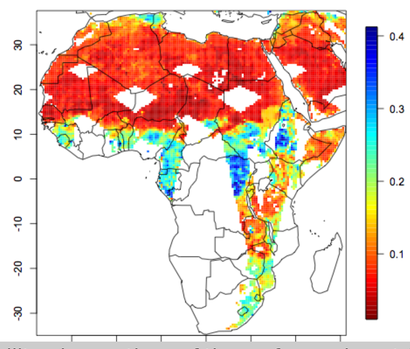
Data assimilation system

Generates soil initial conditions



Satellite observations

- Daily ESA CCI surface soil moisture[5] in year 2000
- Includes uncertainty information: used as observation error in DA system
- Soil temperature unobserved, but is updated through correlations with soil moisture *(e.g., heat capacity and transfer coefficient depend on soil moisture)*



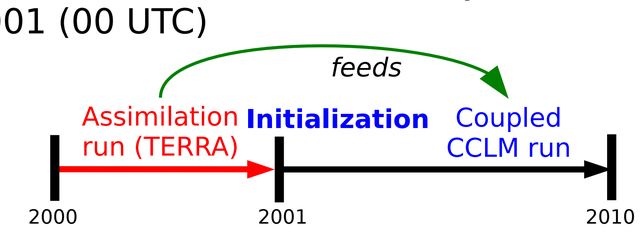
Satellite observations of the surface volumetric soil moisture content on 16.06.2000.

→ Regional, ensemble-based land surface data assimilation system fully working.

Impact on Decadal Predictions

Setup

- Decadal COSMO-CLM hindcast (2001-2010) for Africa, downscales global MPI-ESM
- Initialize with soil fields from DA system at 01.01.2001 (00 UTC)

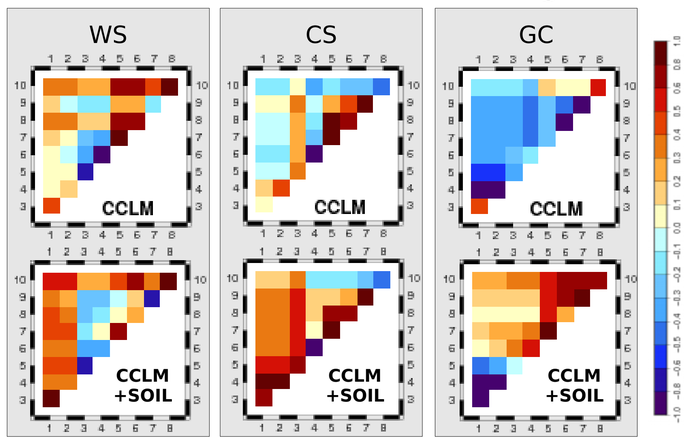


Evaluation

- West African Monsoon (WAM) precipitation in three regions: *Guinea Coast* (GC), *Western* & *Central Sahel* (WS, CS)
- Compare new soil initialization (**CCLM-SOIL**) with standard initialization (= soil taken from ERA-driven historical COSMO-CLM run)

Results

Correlations with observations for all sub-periods of the decade in the 3 regions:



Correlations between observed & simulated JJAS precipitation for all sub-periods in 2001-2010. The upper panel shows the results for the standard CCLM hindcasts, while the lower panel uses **new soil initial conditions**. *X-axis = start year ; Y-axis = end year*

→ Soil initialization consistently improves the predictability of sub-periods in all regions:

- WS/CS: particularly for longer periods
- GC: particularly at end of decade

Comparison with other boundary conditions

***MPI-ESM**: global model*
CCLM: standard COSMO-CLM
CCLM-VEG: with VEG3D instead of TERRA_ML
CCLM-LUC: with new land use data to generate the BC
CCLM-SOIL: with new soil initial fields

- RCMs outperform the GCM and land surface BCs influence the decadal predictability
- Improved soil initialization increases skill in both regions

Conclusions and Outlook

Conclusions

→ Soil initialization is relevant for medium-range climate
→ Predictive skill can be enhanced by soil initialization with ensemble data assimilation due to long-term memory
→ Limited by model & observations errors, but high potential due to improved satellite observations within past years

WEATHER Initial Value Problem — **SEASONAL/ DECADAL** ← Both → — **CLIMATE** Boundary Value Problem

Outlook

- Further evaluation
- Use new satellite products
- Application to other predictions/models
- Exploration of parameter estimation

References
[1] Bellucci et al. (2015): Advancements in decadal climate predictability: the role of non-oceanic drivers. Reviews of Geophysics, 53, 165-202.
[2] Nerger and Hiller (2013). Software for Ensemble-based Data Assimilation Systems - Implementation Strategies and Scalability. Comp. & Geosc, 55, 110-118.
[3] Hunt et al. (2007): Efficient data assimilation for spatiotemporal chaos: A local ensemble transform Kalman filter. Physica D, 230, 112–126.
[4] Weedon et al. (2014): The WFDEI meteorological forcing data set: WATCH Forcing Data methodology applied to ERA-Interim reanalysis data. Water Res. Res., 50, 7505-7514.
[5] Dorigo et al. (2014): Evaluation of the ESA CCI soil moisture product using ground-based observations. Remote Sensing of Environment, 162, 380-395

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