Groundwater dynamics retrievals in Africa using SMOS soil moisture measurements

T. Pellarin, L. Oxarango, J.M. Cohard, A. Depeyre, B. Hector, Y. Kerr, J.P. Vandervaere
Groundwater dynamics retrievals in Africa using SMOS soil moisture measurements

T. Pellarin¹, L. Oxarango, J.M. Cohard, A. Depeyre, B. Hector, Y. Kerr, J.P. Vandervaere

Assumption

Soil moisture dynamics at 5 cm is a signature of water dynamics in deeper soil layers.

Methodology

1- Get accurate surface soil moisture estimates (PrISM product)
2- Force the Richards model (1D) with surface soil moisture
3- Select relevant hydraulic parameters using GRACE measurements
Soil moisture estimates
The PrISM* methodology
*Precipitation Inferred from Soil Moisture

Concept of PrISM:
Exploit the differences between satellite soil moisture measurements (SMOS/SMAP/ASCAT) and simulated soil moisture based on an existing satellite precipitation product

\[
\theta_t = (\theta_{t-1} - \theta_{res})e^{\frac{\Delta t}{\tau}} + (\theta_{sat} - (\theta_{t-1} - \theta_{res})) \left(1 - e^{-\frac{P(t)}{d_{soil}}}\right) + \theta_{res}
\]

Simple adaptation to the Antecedent Precipitation Index (API):

\[
\theta_t : \text{soil moisture (m}^3\text{/m}^3\text{)}
\]

\[
\theta_{res} : \text{residual soil moisture (m}^3\text{/m}^3\text{)}
\]

\[
\theta_{sat} : \text{saturated soil moisture (m}^3\text{/m}^3\text{)}
\]

\[
\Delta t : \text{time step (h)}
\]

\[
\tau : \text{soil moisture drying -- out velocity (h)}
\]

\[
d_{soil} : \text{soil thickness (mm)}
\]
The PrISM* methodology

*Precipitation Inferred from Soil Moisture


Concept of PrISM:
Exploit the differences between satellite soil moisture measurements (SMOS/SMAP/ASCAT) and simulated soil moisture based on an existing satellite product

STEP 1

Satellite rainfall product

STEP 2

Rainfall perturbation

STEP 3

Most probable SM trajectories

\[ P_{\text{event}} = p_{\text{event}} \times \text{Random}[0 \text{ to } 2] \]

Derived PrISM rainfall product

= Particle Filter Assimilation Scheme
Evaluation of the PrISM-SM product over 4 pixels in Africa

PrISM-SM product is available on every 0.25°pixel of Africa, 3-hour temporal resolution.
Water propagation using 1D Richards equation
Methodology: use the Richards equation (1931) to propagate moisture from the surface to the depths.

\[
\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[ K(\theta) \left( \frac{\partial h}{\partial z} + 1 \right) \right] \quad K(\theta) = f(\text{Van Genuchten coefficients } \alpha, m, K_{\text{sat}})
\]

3 examples of hydraulic parameters

<table>
<thead>
<tr>
<th>Soil depth (0-14m)</th>
<th>Soil moisture</th>
<th>Richards model and hydraulic parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benin</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Methodology: use the Richards equation (1931) to propagate moisture from the surface to the depths.

\[
\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[ K(\theta) \left( \frac{\partial h}{\partial z} + 1 \right) \right]
\]

\[K(\theta) = f(\text{Van Genuchten coefficients } \alpha, m, K_{\text{sat}})\]

3 examples of hydraulic parameters

\[\alpha = 0.5, m = 0.4, K_{\text{sat}} = 10^{-6} \text{ m/s}\]

\[\alpha = 0.2, m = 0.8, K_{\text{sat}} = 10^{-6} \text{ m/s}\]

\[\alpha = 0.2, m = 0.8, K_{\text{sat}} = 10^{-5} \text{ m/s}\]
Methodology: use the Richards equation (1931) to propagate moisture from the surface to the depths. 

\[ \frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[ K(\theta) \left( \frac{\partial h}{\partial z} + 1 \right) \right] \]

\[ K(\theta) = f(\text{Van Genuchten coefficients } \alpha, m, K_{\text{sat}}) \]

Checking with in situ water table depth

3 examples of hydraulic parameters

\begin{align*}
\alpha &= 0.2, m = 0.8 \\
K_{\text{sat}} &= 10^{-5} \text{ m/s} \\
\alpha &= 0.2, m = 0.8 \\
K_{\text{sat}} &= 10^{-6} \text{ m/s} \\
\alpha &= 0.5, m = 0.4 \\
K_{\text{sat}} &= 10^{-6} \text{ m/s}
\end{align*}
Illustration of equivalent water height variations over 6 pixels in Africa (simulation in blue, GRACE in black)
Conclusions & Perspectives

- Run automatic detection of hydraulic parameters over all Africa
- Assess the PrISM groundwater product using insitu aquifer measurements
- Evaluate the product on root moisture (0-2m) using field measurements.
- Inserting the algorithm into the PrISM operational processing chain

Cuthbert et al., Nature, 2019 [https://doi.org/10.1038/s41586-019-1441-7](https://doi.org/10.1038/s41586-019-1441-7)