Analysis of water dynamics in the soil-plant continuum using a multi-sensor approach

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1. Water in soil and vegetation from satellites

Objective: understanding the water pools and fluxes in the soil-plant continuum (SPC)

- Water content in soils: soil moisture from passive microwave remote sensing (L-band)
- Water content in vegetation:
  - Vegetation water content (VWC; kg/m²): water per unit area.
  - Gravimetric vegetation moisture (Mg; kg/kg): water per wet biomass ➔ Monitor water status: today’s presentation

**VWC** - Linked to biomass

Empirical approach: link VOD to VWC using the $b$-parameter (from land cover data)

\[
VOD = b \cdot VWC
\]

**Mg** - Linked to water status

Physically based approach\(^1\): link VOD and Mg

\[
VOD = 4\pi \left( \frac{VH}{\lambda} \right) \cdot Im[\sqrt{\varepsilon_{can}}]
\]

\[
\varepsilon_{can} = \varepsilon_{air} \left( 1 + 3\delta \frac{(\varepsilon_{veg} - \varepsilon_{air})}{(\varepsilon_{veg} + 2 \cdot \varepsilon_{air})} \right)
\]

\[
\varepsilon_{veg} = f(Mg) \quad \text{Ulaby & El Rayes, 1987}
\]

\(^1\)Fink et al., 2018
A multi-sensor approach (Fink et al., 2018) is applied to retrieve Mg and sense vegetation water status:

\[
\text{VOD} = 4\pi \left(\frac{VH}{\lambda}\right) \cdot \text{Im} \left[ \sqrt{\varepsilon_{\text{air}} \left( 1 + 3\delta \frac{(\varepsilon_{\text{veg}} - \varepsilon_{\text{air}})}{(\varepsilon_{\text{veg}} + 2 \cdot \varepsilon_{\text{air}})} \right)} \right]
\]

\[
\varepsilon_{\text{air}} = 1
\]
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\[
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\]

\[\varepsilon_{air} = 1\]

Step 2: compare modelled vs retrieved VODs.
A multi-sensor approach (Fink et al., 2018) is applied to retrieve Mg and sense vegetation water status:

\[ VOD = 4\pi \left( \frac{VH}{\lambda} \right) \cdot Im \left[ \sqrt{\varepsilon_{air} \left( 1 + 3\delta \frac{(\varepsilon_{veg} - \varepsilon_{air})}{(\varepsilon_{veg} + 2 \cdot \varepsilon_{air})} \right)} \right] \]

Where \( \varepsilon_{air} = 1 \)

\[ \min( |VOD_{Model} - VOD_{Radiometer}| ) \]

Indicating \( \varepsilon_{veg} \)

Ulaby and El-Rayes, 1987

Step 3: estimate Mg
2. Datasets used for Mg retrievals

Vegetation height (VH) – Maximum (TOC)

- ICESat-2 VH (October 2018 – September 2019) – New VH data
- VH from Simard et al. (2011; derived from ICESat-1 & auxiliary variables) – Reference data
Vegetation height (VH) – Maximum (TOC)

- ICESat-2 VH (October 2018 – September 2019) – New VH data
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VH max (ICESAT2) – Result of final VH product – VH max (ICESAT1 - Simard et al.)

Non-linear CDF-matching
Vegetation height (VH) – Maximum (TOC)

➢ ICESat-2 VH (October 2018 – September 2019) – New VH data
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Vegetation volume fraction ($\delta$)

- **Aquarius radar (2011-2014)** – A $\delta$ seasonality is built → dynamic variable
- $\delta$ derives from the Radar Vegetation Index (RVI):
  \[ RVI = \frac{8 \cdot \sigma_{HV}}{\sigma_{HH} + \sigma_{VV} + 2 \cdot \sigma_{HV}} \]
  \[ \delta = 0.01 \cdot RVI \]
- $\delta$ shows the vegetation structure:

Delta shows the vegetation volume fraction [m$^3$/m$^3$] recognized by an L-band radar. It is obtained by rescaling the radar vegetation index (RVI; Fink et al., 2018)

Examples of $\delta$ time-series for the Aquarius period. Colorbars show the number of pixels for each bin of the histogram.
Vegetation Optical Depth (VOD)

- SMAP VOD (2015-2019); retrieval algorithm: MT-DCA (Konings et al., 2016).
- Radiometer-derived VOD is compared to modelled VOD: then Mg is obtained.
3. Resulting Mg maps

➢ Mg maps for the period April 2015 – September 2019 have been obtained.

➢ Examples:

![Mean Mg (April to June 2015)]
➢ Mg maps for the period April 2015 – September 2019 have been obtained.

➢ Examples:

Mean Mg (July to September 2015)
➢ Mg maps for the period April 2015 – September 2019 have been obtained.

➢ Examples:

Differences (Mean Jul-Sep – Mean Apr-Jun)

Strongest dynamics in semi-arid regions
4. Study case: woody savanna in California

➢ Ongoing work: first time-series analyses in California.
➢ Pixels chosen (n=27) with (i) homogeneous IGBP “woody-savanna” & (ii) warm temperate, hot/dry summer climate (Csa category in Koppen-Geiger classification; Beck et al., 2018).

Complementary datasets
➢ Leaf Area Index (MODIS LAI; product MOD15A2H).
➢ Soil Moisture (SMAP SM; 9 km gridding; MT-DCA retrievals\(^2\)).
➢ Vegetation volume fraction (δ; Aquarius) climatology.
➢ All datasets aggregated at 9 km SMAP gridding.
➢ All datasets smoothed (91 d. mov. avg.) to study seasonality.

\(^2\) Konings et al., 2016
❖ Increasing SM precedes leaf growth (LAI) and structure changes (δ).
❖ Mg increases after LAI-δ peaks, suggesting water uptake after leaves growth.
❖ VOD high plateau during LAI & Mg maxima affirming double sensitivity of VOD (biomass & plant water)
Comparison of Mg with SM, LAI, VOD and δ time-series:

❖ Increasing SM precedes leaf growth (LAI) and structure changes (δ).
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Comparison of Mg with SM, LAI, VOD and δ time-series:

- Dry (wet) years could be linked to low (high) LAI values. Future work: study relationships of SM-LAI-Mg anomalies.

- Increasing SM precedes leaf growth (LAI) and structure changes (δ).

- Mg increases after LAI-δ peaks, suggesting water uptake after leaves growth.

- VOD high plateau during LAI & Mg maxima affirming double sensitivity of VOD (biomass & plant water)
5. Conclusions and future work

Developed datasets

➢ A new VH dataset from ICESat-2 has been presented.
➢ Dynamic vegetation volume fraction ($\delta$) to capture changes in the vegetation structure.

California study case: first comparisons of Mg with complementary datasets

➢ Greater Mg dynamics in semi-arid regions (e.g., Sahel).
➢ Comparison of Mg with soil and plant time-series are consistent with water fluxes in the SPC.

Future work

➢ Including the atmosphere layer (vapor pressure deficit; VPD) for a complete SPAC analysis.
➢ Studying lag-correlations among SM, Mg, VPD and LAI-VOD to study SPAC water fluxes and plant responses.
References


Thank you!

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