Water dynamics in the soil-plant-atmosphere continuum based on time-lagged correlations of satellite data

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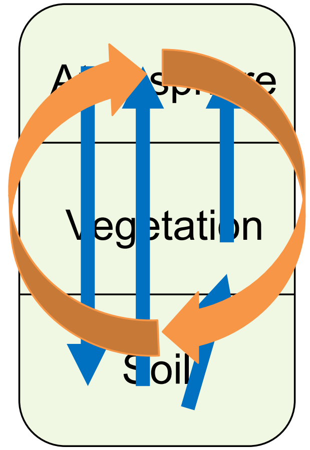
1. Introduction

What?

Study the **soil-plant-atmosphere continuum (SPAC)**

Water pools | Water fluxes | L-A interactions



Why?

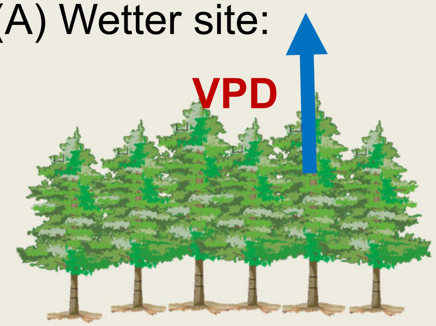
- Understand the link between water, carbon and energy cycles
- Soil moisture (SM) and vapor pressure deficit (VPD) condition evapotranspiration (ET) and productivity

Example 1 (Novick et al., 2016, Nature CC):

(A) VPD limitation on ET >> SM limitation on ET

(B) SM limitation on ET >> VPD limitation on ET

(A) Wetter site:

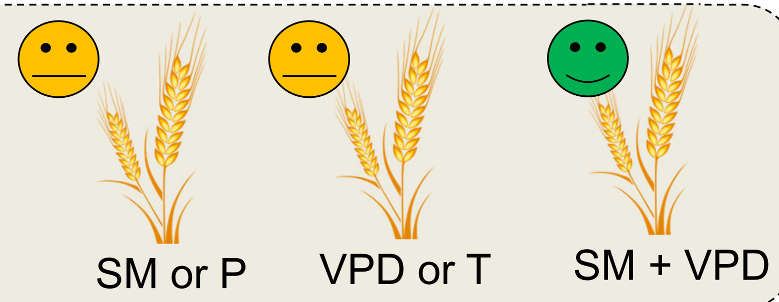


(B) Drier site:

DLR

Example 2 (Rigden et al., 2020, Nature Food):

Combining SM and VPD improves yield prediction…
… in comparison to using SM, P, T or VPD alone.



Example 3 (Feldman et al., 2020, GRL):

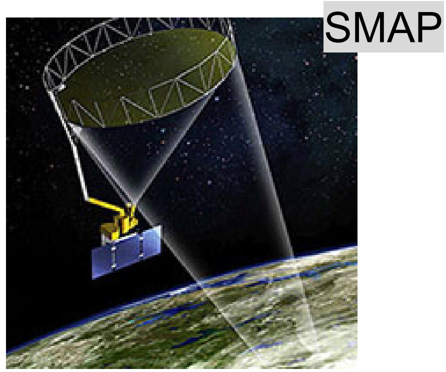
- African drylands
- VPD and daily temperature amplitude increase during soil drying
- SM-VPD interactions reinforce plant drying through evaporation

GOAL

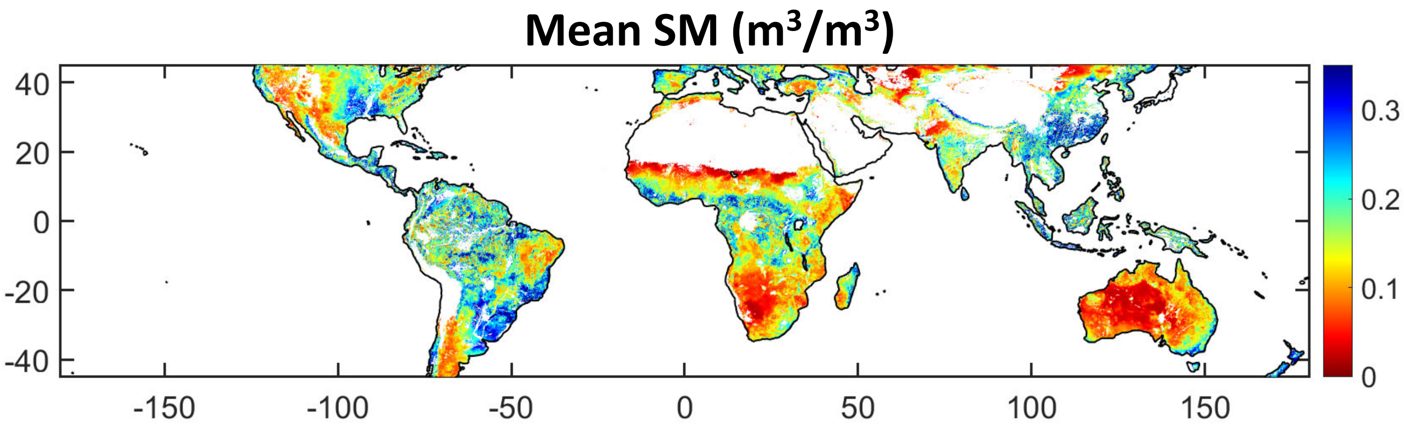
Analyze time-lagged correlations between SM, vegetation optical depth (VOD) and atmospheric VPD, all from satellites

2. Data

- Study period: April 2015 – March 2020
- Study area: global between 45°N and 45°S
- Soil Moisture Active-Passive (SMAP) L3 SM data (9 km grid)



smap.jpl.nasa.gov



Data screening

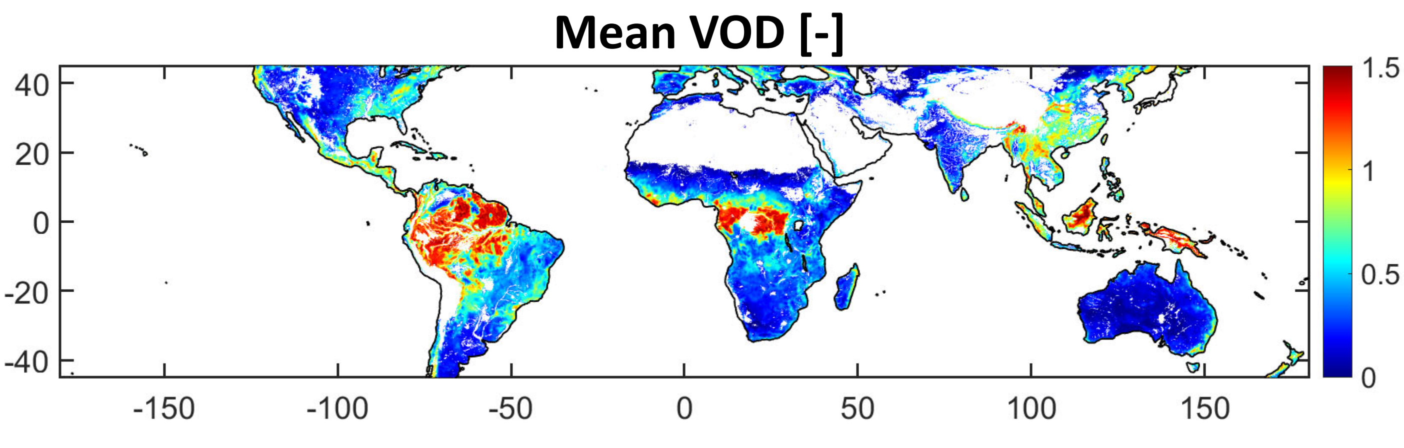
- Snow & frozen ground:
  - ✓ SMAP L3 data
- Water and no vegetation:
  - ✓ ESA-CCI land cover

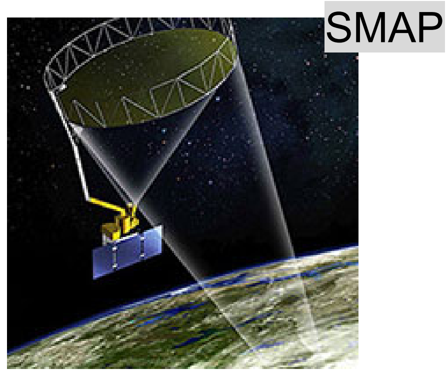
Deseasoning time-series

1. Overlap study years
2. Apply a 61-day moving mean
3. Substract 3-day averaged time-series to the seasonality

2. Data

- Study period: April 2015 – March 2020
- Study area: global between 45°N and 45°S
- SMAP vegetation optical depth (VOD; 9 km grid)
- VOD reflects changes in vegetation moisture and biomass





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Data screening

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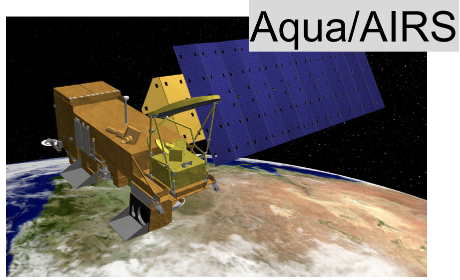
Deseasoning time-series

1. Overlap study years
2. Apply a 61-day moving mean
3. Substract 3-day averaged time-series to the seasonality

2. Data

- Study period: April 2015 – March 2020
- Study area: global between 45°N and 45°S
- VPD from the Atmospheric Infrared Sounder (AIRS; 1° resolution)
- Resampled to the SMAP 9-km grid (nearest neighbour)



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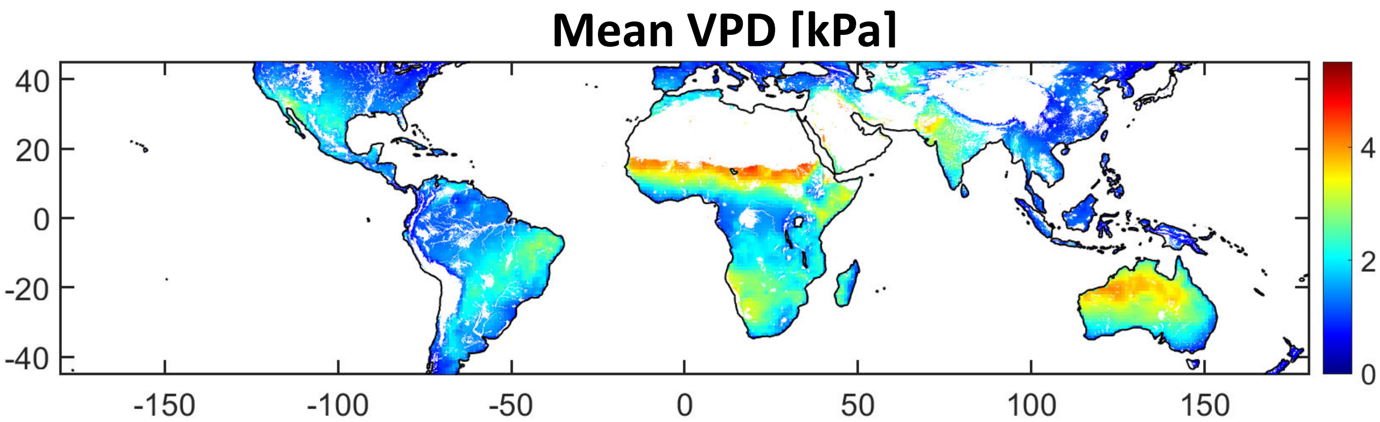


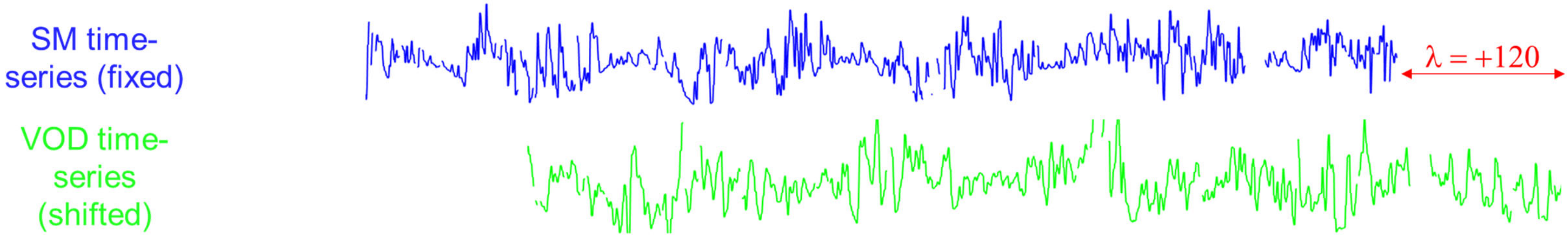
Deseasoning time-series

1. Overlap study years
2. Apply a 61-day moving mean
3. Substract 3-day averaged time-series to the seasonality

3. Methods

① Find, for each pixel, the maximum time-lagged Pearson’s correlation coefficient (r) for each pair: SM-VOD, SM-VPD and VOD-VPD

- ✓ Time-lags (λ) between -120 and +120 days, at daily time steps



↳ Build correlation time-series ➡ Choose maximum r and λ

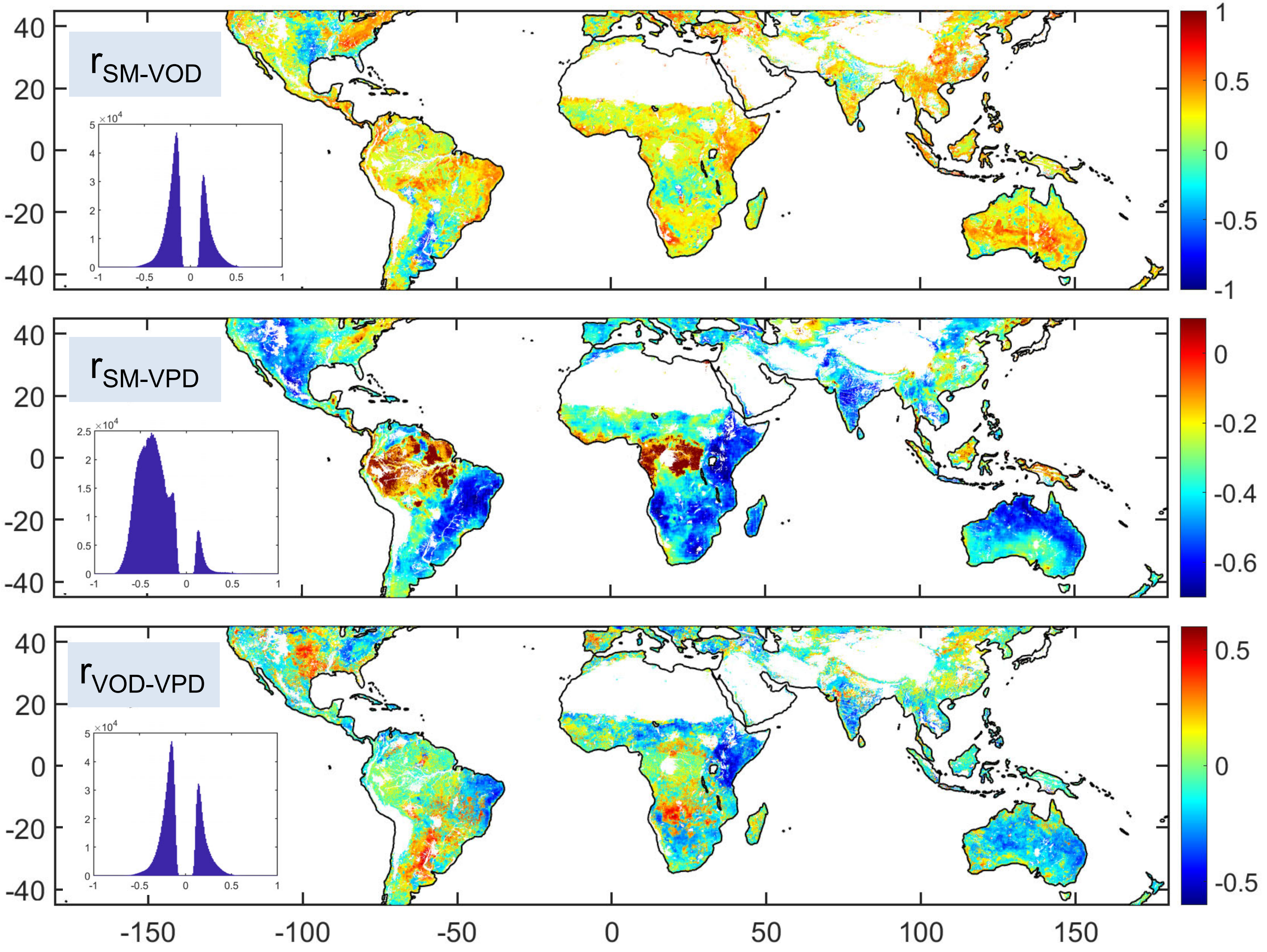
② Look for all possible combinations of:

- ✓ Variable pairs
- ✓ Time-lags (λ<0, λ=0, λ>0)
- ✓ Correlations (r<0, r=0, r>0)

➡ Look for common patterns and study their spatial distribution

4. Results

Correlation coefficients (r)

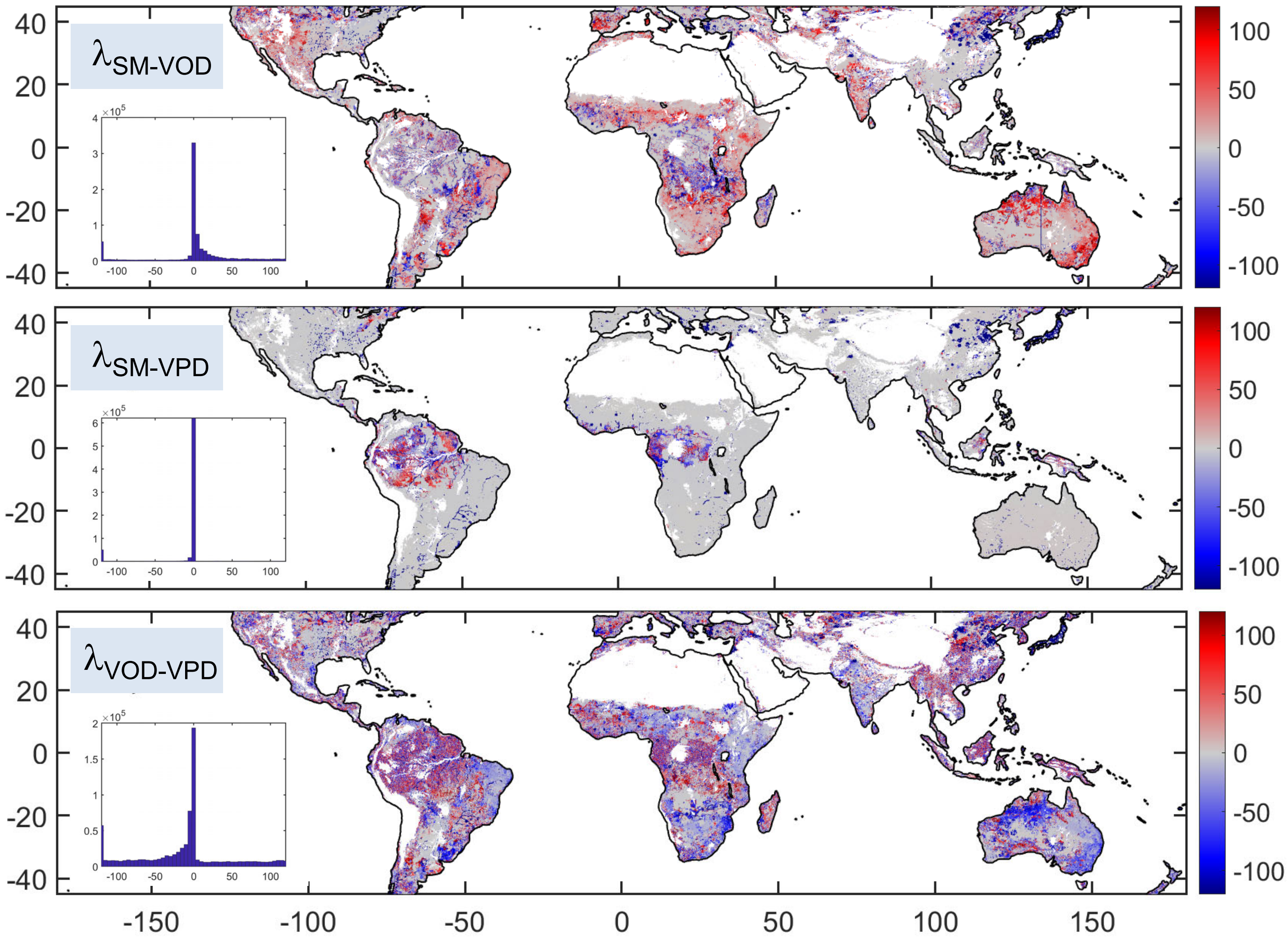


- **+r:** in semiarid areas (but not only!)
- **-r:** Argentina, Southern US and subtropical Africa.

- **+r:** only in tropical regions (low SM retrievability)
- **-r** dominates in most regions

- **+r:** in subtropical Africa, southern US and Argentina.
- **-r:** mostly in semiarid areas

Time lags (λ): -120 to +120 days

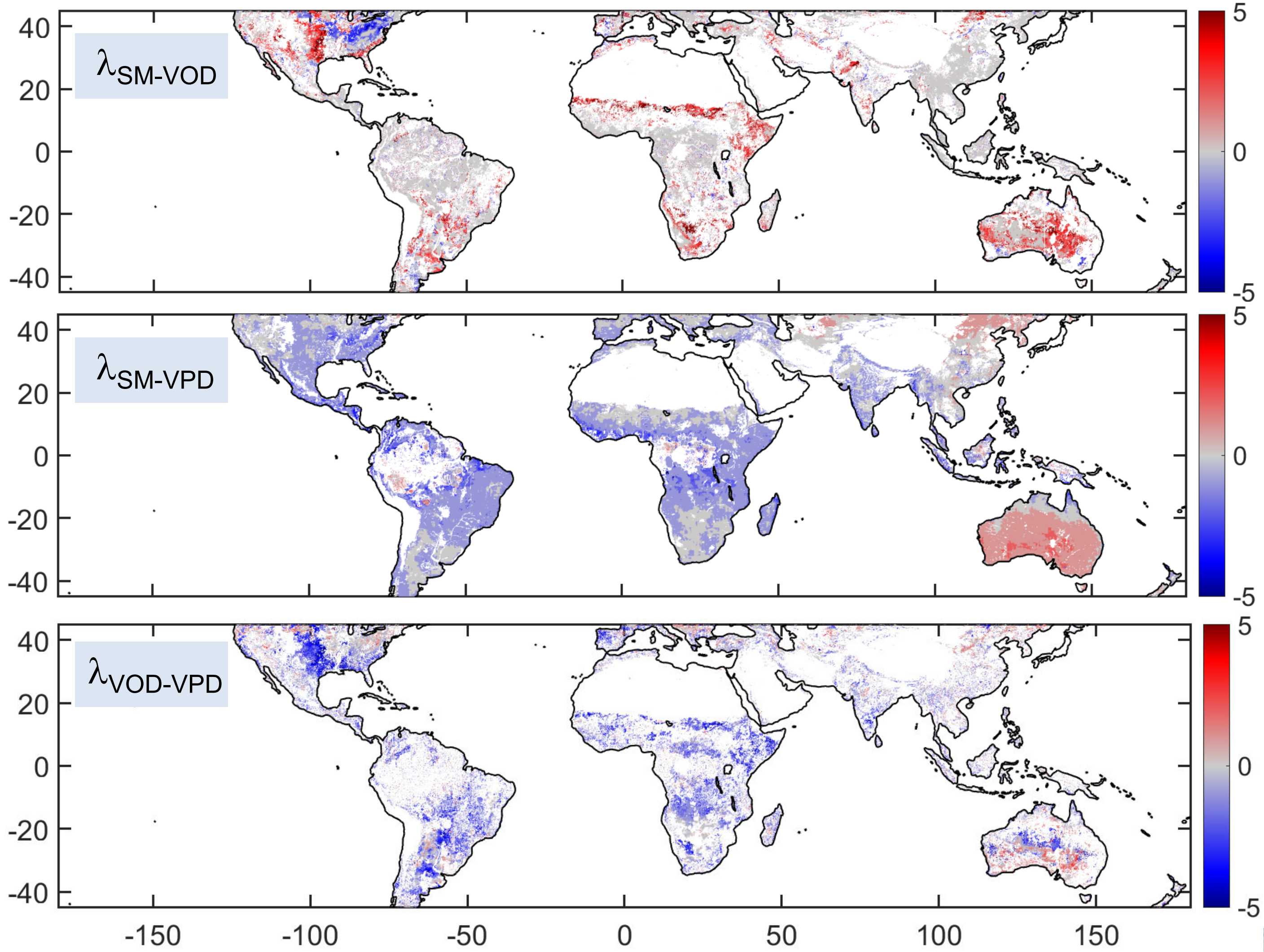


- SM precedes VOD (λ>0), with long lags, in semiarid areas and parts of Australia
- VOD precedes SM (λ<0), with long lags, in subtropical Africa.

- Time-lags close to zero dominate
- Long time-lags: low SM retrievability

- VPD precedes VOD (λ<0), with long time-lags, in most regions.

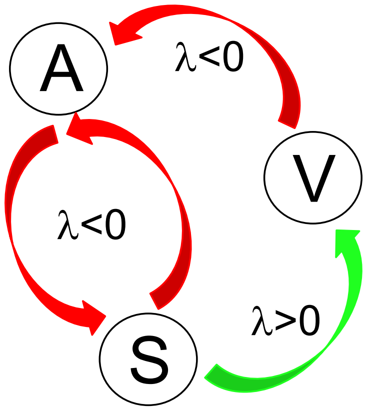
Time lags (λ): zoom at -5 to +5 days

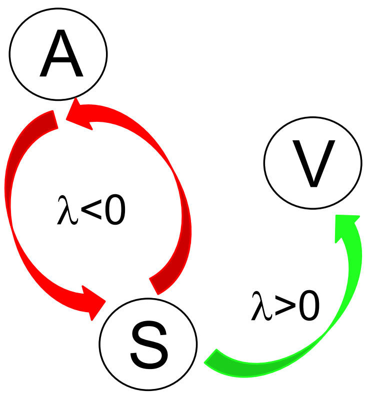


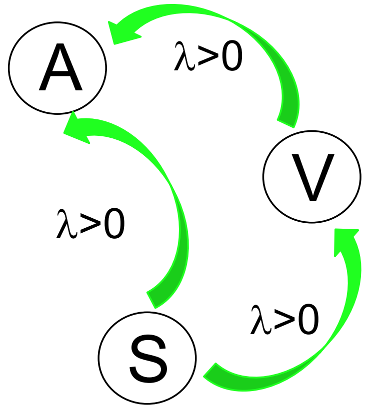
- SM precedes VOD (λ>0) in African drylands, Australia and southern US.
- VOD precedes SM (λ<0), with short lags, in the Apalaches (US).
- SM precedes VPD (λ>0) in Australia.
- VPD precedes SM (λ<0), with short lags, in almost all other areas.
- VPD precedes VOD (λ<0) in many regions in Africa and America.

- Combining 3 variables, 3 time-lags ($\lambda>0$, $\lambda=0$, $\lambda<0$), and 2 correlations ($r>0$, $r<0$) → 729 possible combinations.
- 65% of these combinations can be grouped in 3 similar patterns

VPD-driven (with V→A)	VPD-driven (w/o V→A)	SM-VOD-driven

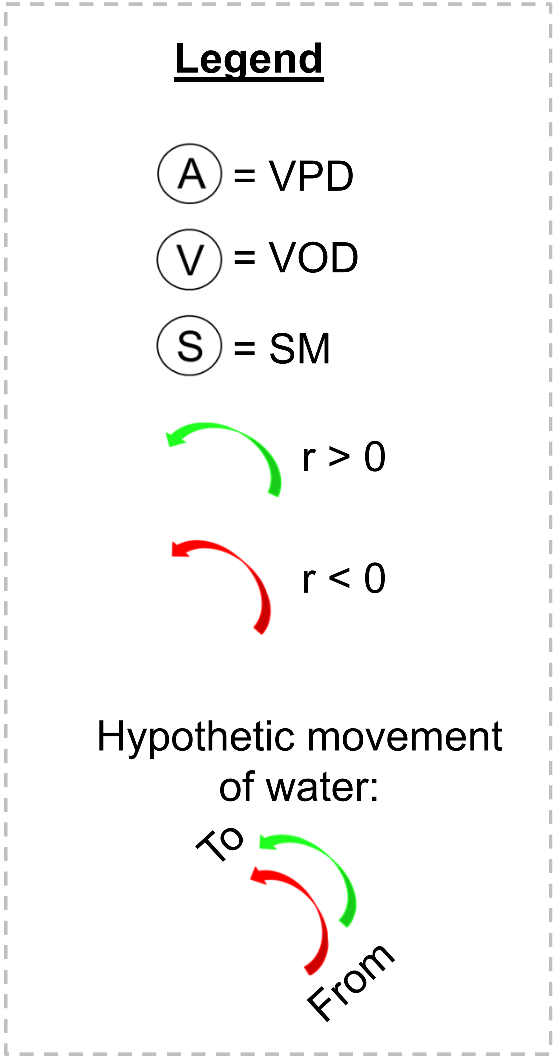




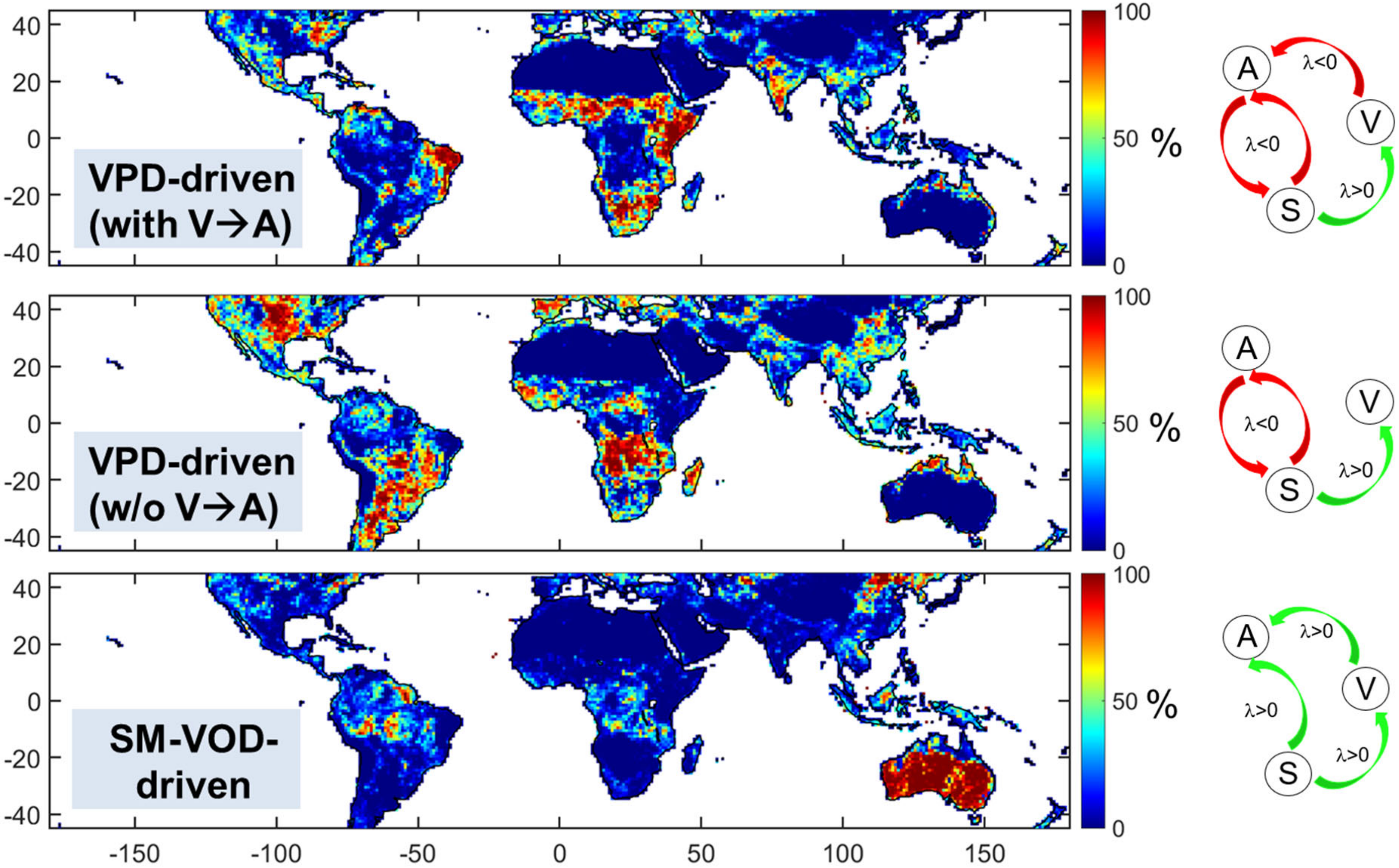


22% 26% 17%

65%



For each 1°-cell, which percentage of each pattern do we find?



VPD anticipates both soil and vegetation conditions in most semi-arid areas (except Australia).

VPD anticipates only soil conditions in most sub-tropical regions.

SM and/or VOD anticipate the atmospheric dryness in Australia.

5. Discussion and conclusions

- Increasing **SM leads to short-term responses in VOD** mostly in semi-arid areas
  - ✓ Likely shows plant water uptake
  - ✓ Previous research has shown this pattern after rain events (Feldman et al., 2018; Nat. Plants)
- Longer SM-VOD time-lags in subtropical Africa:
  - ✓ Consistent with **decoupling** of soil and plant water storages in the region (Tian et al., 2018; Nat. Ecol. Evol.)

- SM rapidly responds to changes in atmospheric dryness (VPD):
  - ✓ Lagged correlations may capture **evaporation and precipitation** effects.

- VOD responds to variations in atmospheric dryness (VPD): we are likely observing transpiration
- Longer time-lags in the VOD-VPD relationship (if compared to the SM-VPD one):
  - ✓ Delayed plant response due to stomata regulation?

- Most pixels (65%) are classified in **three hypothetic patterns**:
  - ✓ Driest regions (except Australia): VPD impacts both SM and VOD, suggesting regulation of soil and plant water content from ET.
  - ✓ Subtropical areas: impact of VPD on SM suggest that evaporation/precipitation are observed
  - ✓ Australia: SM-VOD driving VPD suggest that soil and plant moisture reinforce dryness…

    …but this pattern does not predominate in other dry regions

- Time-lagged correlations: appropriate for **preliminar analysis of quasi-global SPAC** water fluxes

- Still, **attribution of causes and effects requires future work** on:
  - ✓ Including more variables: NDVI, isohydricity, temperature, precipitation...
  - ✓ Using causality análisis (e.g., Granger)

Thanks for your attention!!!