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Resilience of Terrestrial Ecosystems: Photosynthetic Response to Hydroclimatic Disturbance Across Pan-tropics

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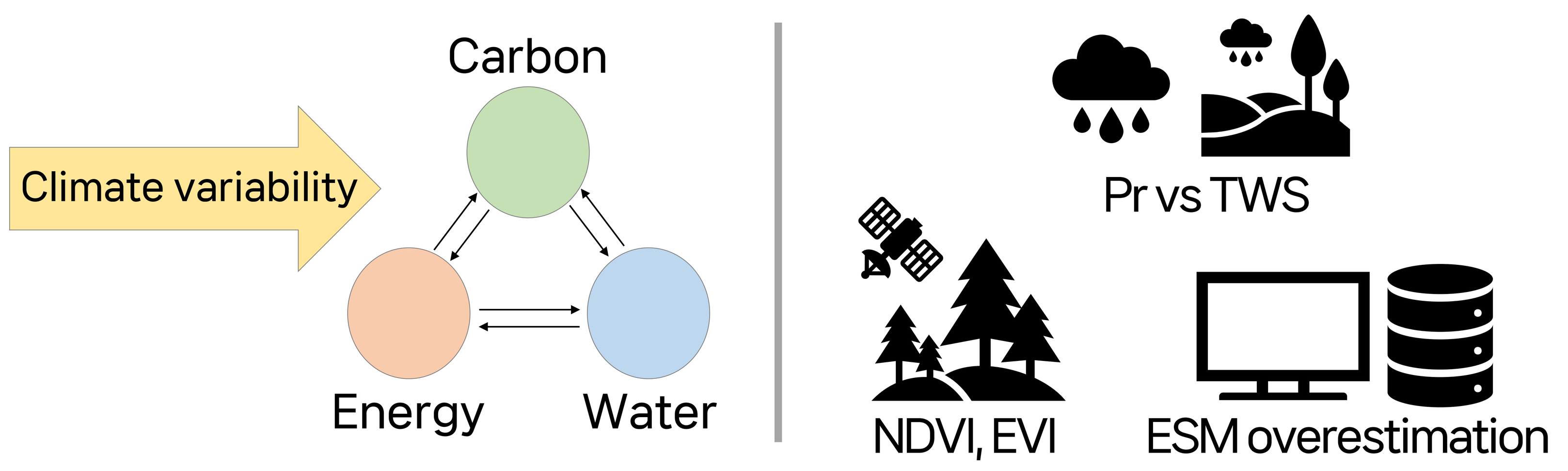
Introduction

- **Photosynthetic activity** in terrestrial ecosystems tightly link between the **global energy, water and carbon cycles**.
- **Ongoing changes** in the energy and hydrological cycles can **alter** the structure of terrestrial ecosystems over time.
- Therefore, it is necessary to identify the **vegetation response** to **climate variability**, which is a key component of ecosystem **resilience**.

- **Vegetation indicies** (e.g. NDVI, EVI) do not accurately represent the pan-tropical terrestrial ecosystem productivity.
- Previous studies use **precipitation** as the **water availability**, but terrestrial ecosystems can also utilize the water in the **root-zone**.
- Current **Earth system models** (ESMs) **overestimate** the relationship between soil moisture and vegetation productivity, especially in **tropical rainforests**.

- There are rising concerns about **resilience of tropical rainforests**, where Amazon rainforest is classified as one of the **Climate Tipping Points** (CTPs).
- **Theoretical resilience indicators** have been proposed to detect the **early warning signals** of climate tipping points, including the biosphere, but these indicators lack of **physical or biogeochemical meanings**.



Methods

Satellite data used in this study:

Product	Variable	Resolution		Period
SIF005 (bias-corrected)	Solar-Induced Fluorescence	0.05°	Monthly	2002-2018
GRACE TWSA	Terrestrial Water Storage Anomaly	1°	Monthly	2002-2016
CERES EBAF	Downward Shortwave Radiation	1°	Monthly	2000-
TRMM 3B43	Precipitation	0.25°	3 hourly	1998-
MCD12C1	Land cover	0.05°	Yearly	2001-

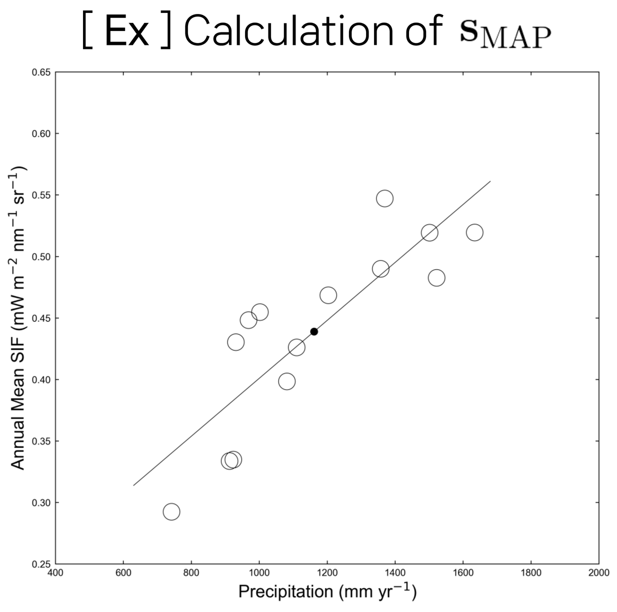
- **Harmonized long-term SIF** (Wen, J., 2020) is used and we did additional **bias correction** with **TROPOMI SIF** observations using **quantile mapping**.

  MAP < 200 mm, Mean SIF < 0.05 mW/m^2/nm/sr are excluded.

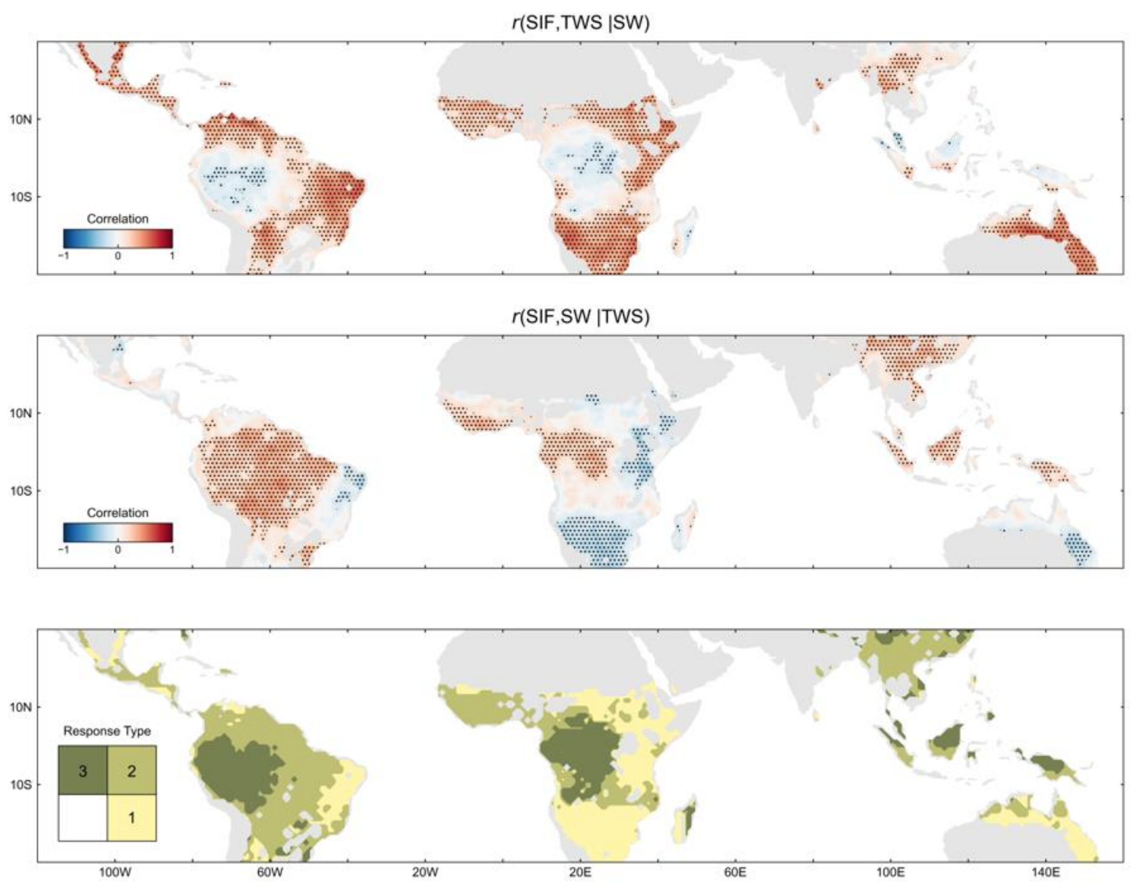
- Monthly **z-score anomalies** are calculated by removing long-term trend and seasonality, then **partial correlations** between anomalies are calculated.
- Here, **terrestrial ecosystem sensitivity** (TES) is calculated as the inter-annual linear sensitivity of SIF to MAP, then transformed into normalized scale.

- $$r(X,Y|Z) = \frac{r(X,Y) - r(X,Z)\,r(Z,Y)}{\sqrt{1-r(X,Z)^2}\sqrt{1-r(Z,Y)^2}}$$
- $$\mathbf{TES} = \frac{\tan^{-1}(\mathbf{s}_{\mathrm{MAP}}) + \pi/2}{\pi},\quad 0 < \mathbf{TES} < 1$$

[Ex] Calculation of $\mathbf{s}_{\mathrm{MAP}}$



Results

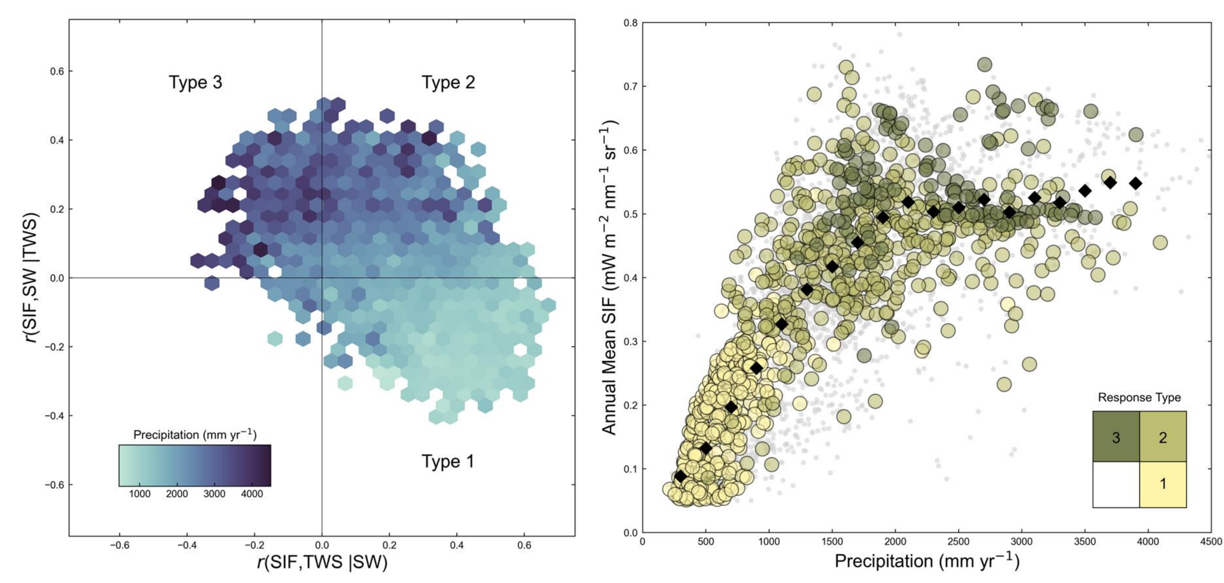


r(SIF, TWS | SW) = **Water-limitation**
- negative coupling in **tropical rainforests** = cloud cover effect

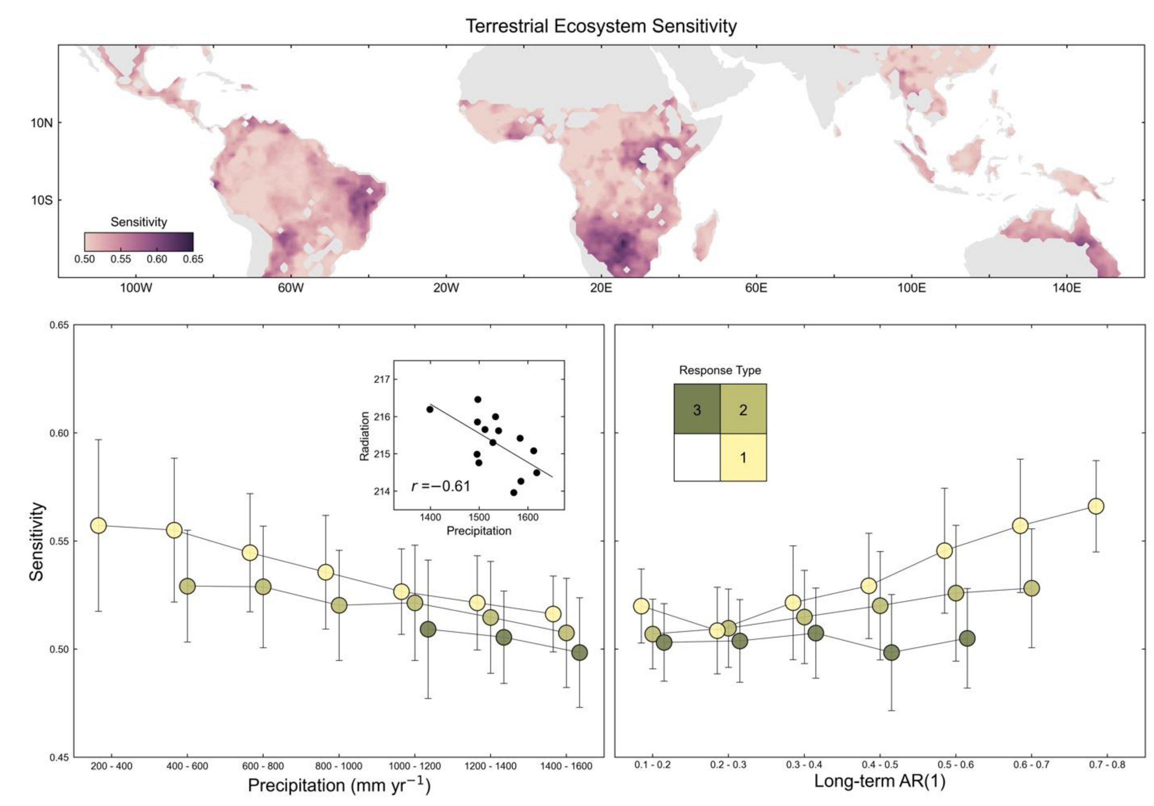
r(SIF, SW | TWS) = **Energy-limitation**
- negative coupling in **semi-arid regions** = temperature, VPD effect

- Based on the **coupling strength**, we divide terrestrial ecosystems into **three response types**:

Type 1 : r(SIF, TWS | SW) > 0, r(SIF, SW | TWS) < 0 = wet tropical rainforests
Type 2 : r(SIF, TWS | SW) > 0, r(SIF, SW | TWS) > 0 = temperate vegetations
Type 3 : r(SIF, TWS | SW) < 0, r(SIF, SW | TWS) > 0 = semi-arid regions



- We observe that **MAP** controls the **vegetation response type**.
- From the **functional relationship** between MAP and SIF, our proposed **vegetation response types** are well-separated with **MAP** levels.



- We can observe the **different patterns** in **sensitivity** for each **response types**.
- **Water-limited ecosystems** tend to be more sensitive and **Energy-limited ecosystems** tend to be less sensitive, which can be explained with their different **coupling strengths**.
- **AR(1) coefficient** have **positive** correlation with our proposed **TES**.
- **Temporal changes** in **vegetation-climate coupling strength** can alter these ecosystems to respond **more abrubtly** with the **hydroclimatic disturbances**.

Conclusion

- We identified the **vegetation response** to **hydroclimatic disturbance**, then classified into **three types** based on the **coupling strength**.
- We observed the **disparate** change pattern of **terrestrial ecosystem sensitivity** for each types, which is controlled by the **vegetation-climate coupling strength**.
- We suggest new **opportunities** that **climate tipping points** in biosphere can be further interpreted with the insights from **coupled carbon-water-energy cycle**.