Understanding the Impact of Multi-Year Droughts on Vegetation

An Observational and Model Approach (MODIS and LPJmL-5)

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Motivation

- Multi-year droughts (**MYDs**) have severe and lasting **impacts on vegetation.**
- Climate change is making MYDs **more frequent and intense**.
- **Understanding MYD impacts on vegetation** is crucial for mitigating climate risks.
- **Satellite records are limited**, restricting long-term analysis.
- Before extending the analysis back in time, we first **compare model simulations with satellite data** to ensure model reliability over the historical record.

Methods

This study combines **MODIS** satellite observations, **W5E5** meteorological reanalysis data, and the **LPJmL-5** dynamic vegetation model to assess vegetation sensitivity to droughts and **quantify the impact of MYDs on vegetation** across the 21st century. Drought conditions are measured using the Standardized Precipitation Evapotranspiration Index (**SPEI-12**), while vegetation response is captured through standardized Gross Primary Production (**GPP_{SA}**). MYDs are defined as periods when **SPEI-12 falls below −1 for at least 12 consecutive months**.

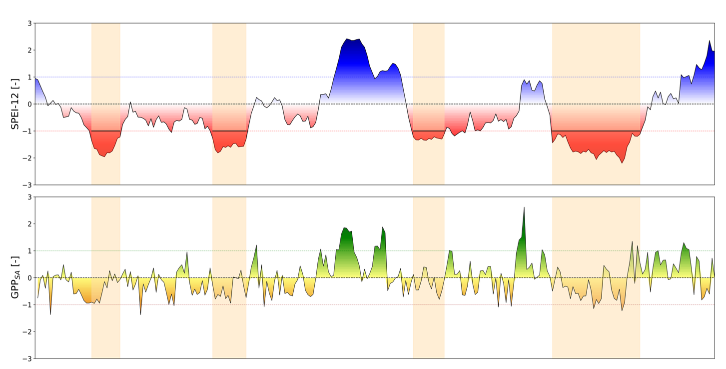
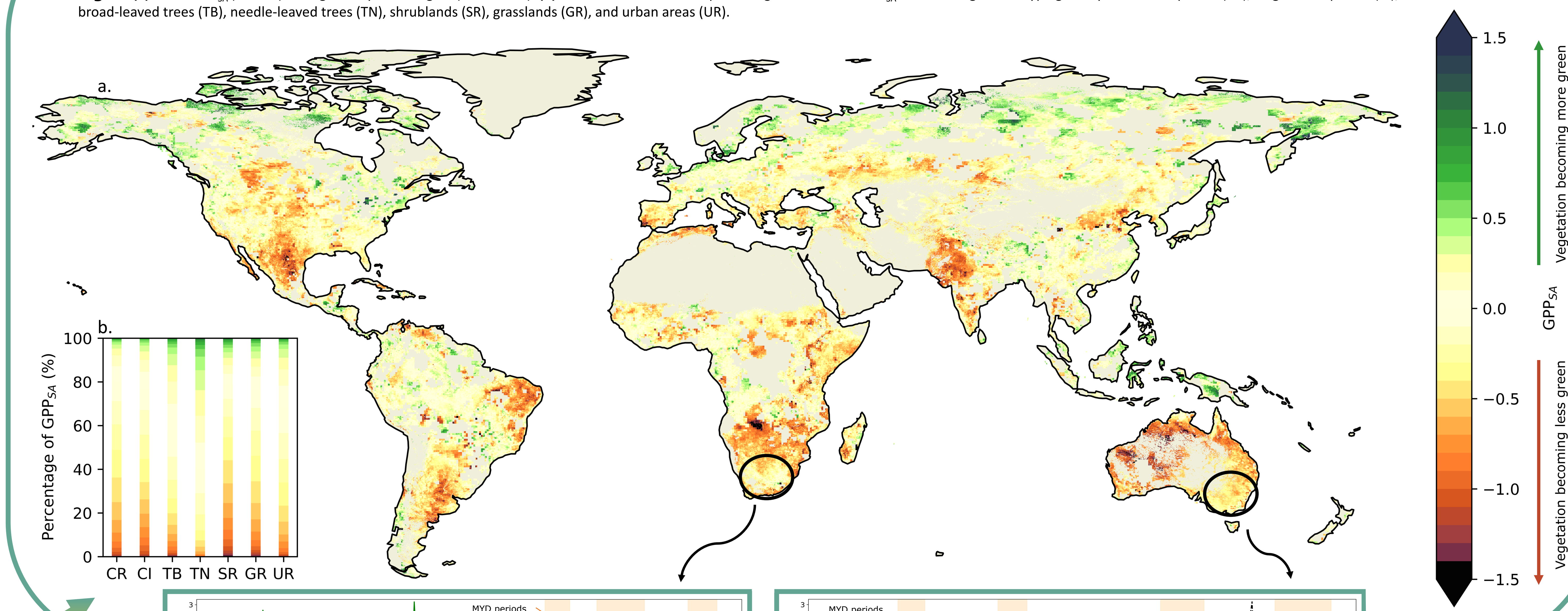
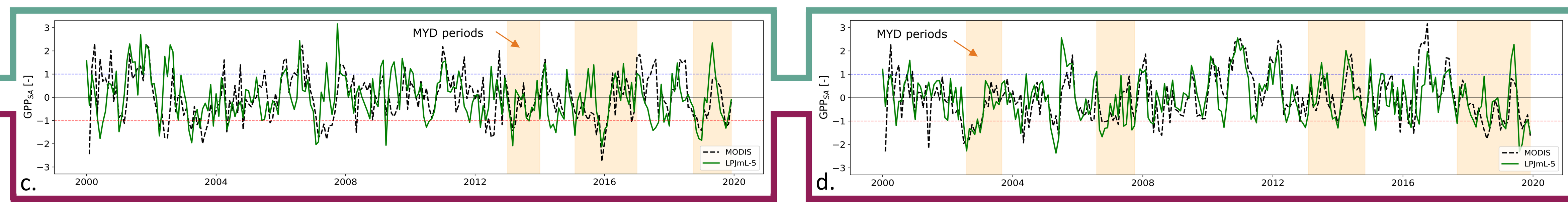


Fig 1: Example timeseries of SPEI-12 and GPP_{SA}. MYD periods are shaded in orange.

Observations (MODIS)

Fig. 2: **(a)** Mean GPP_{SA} (MODIS) during multi-year droughts (2000-2019). **(b)** shows the accumulated percentage of the mean GPP_{SA} for each vegetation type globally: rainfed croplands (CR), irrigated croplands (CI), broad-leaved trees (TB), needle-leaved trees (TN), shrublands (SR), grasslands (GR), and urban areas (UR).





Model (LPJmL-5)

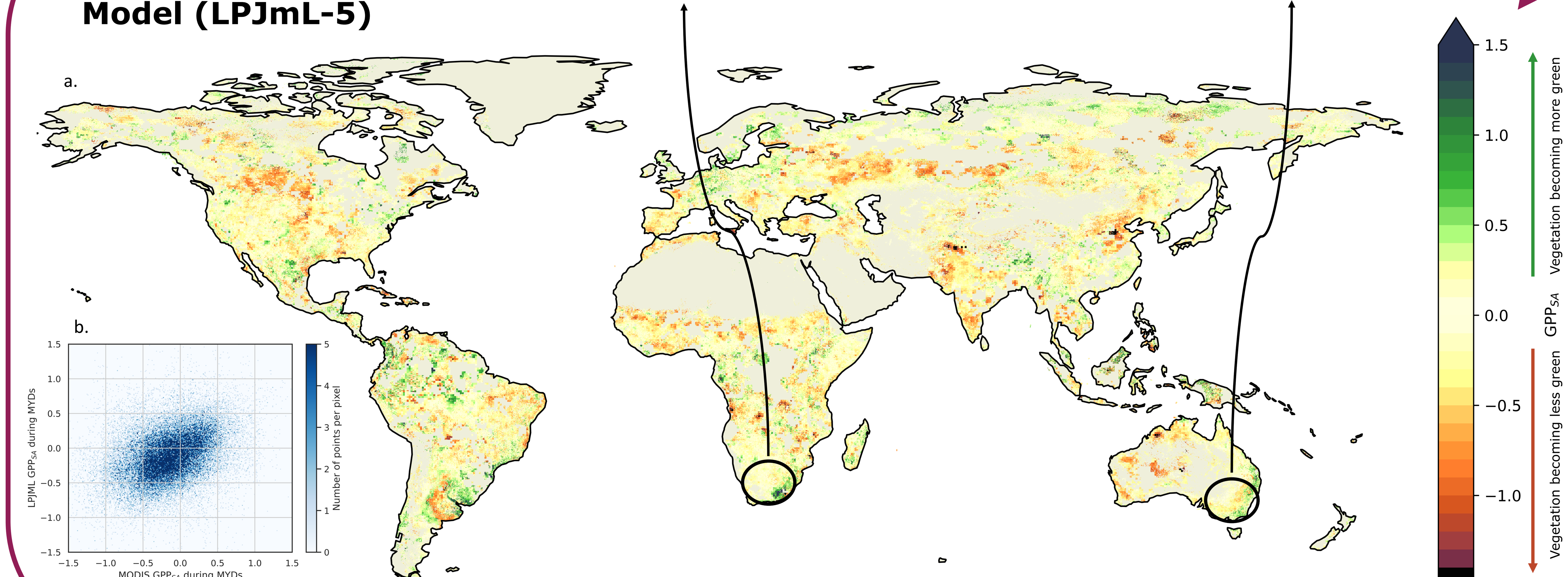


Fig. 4: **(a)** Mean GPP_{SA} (LPJML-5) during multi-year droughts (2000-2019). **(b)** provides a scatter plot comparing the GPP_{SA} during multi-year droughts between observations (MODIS) and the model (LPJmL-5). **(c)** and **(d)** show time series of the GPP_{SA} (2000-2019) for observations (black dashed line) and the model (green line) for two of the focus regions. MYD periods are shaded in orange.

Model input

Variable	Dataset	Variable	Dataset
Temperature	W5E5	Soil type	USDA
Longwave downward radiation	W5E5	Nitrogen deposition	ISIMIP 3a
Shortwave downward radiation	W5E5	Soil pH	ISIMIP 3a
Precipitation	W5E5	Landuse	MAPSMAP
Wind speed	W5E5	Countrycode	COW
Landcover	ESA	CO_2	ISIMIP 3a

Table 1: Data inputs for LPJmL-5

Model validation

Model performance (KGE) shows strong agreement with satellite GPP data across temperate and boreal regions, while performance is generally lower in tropical regions.

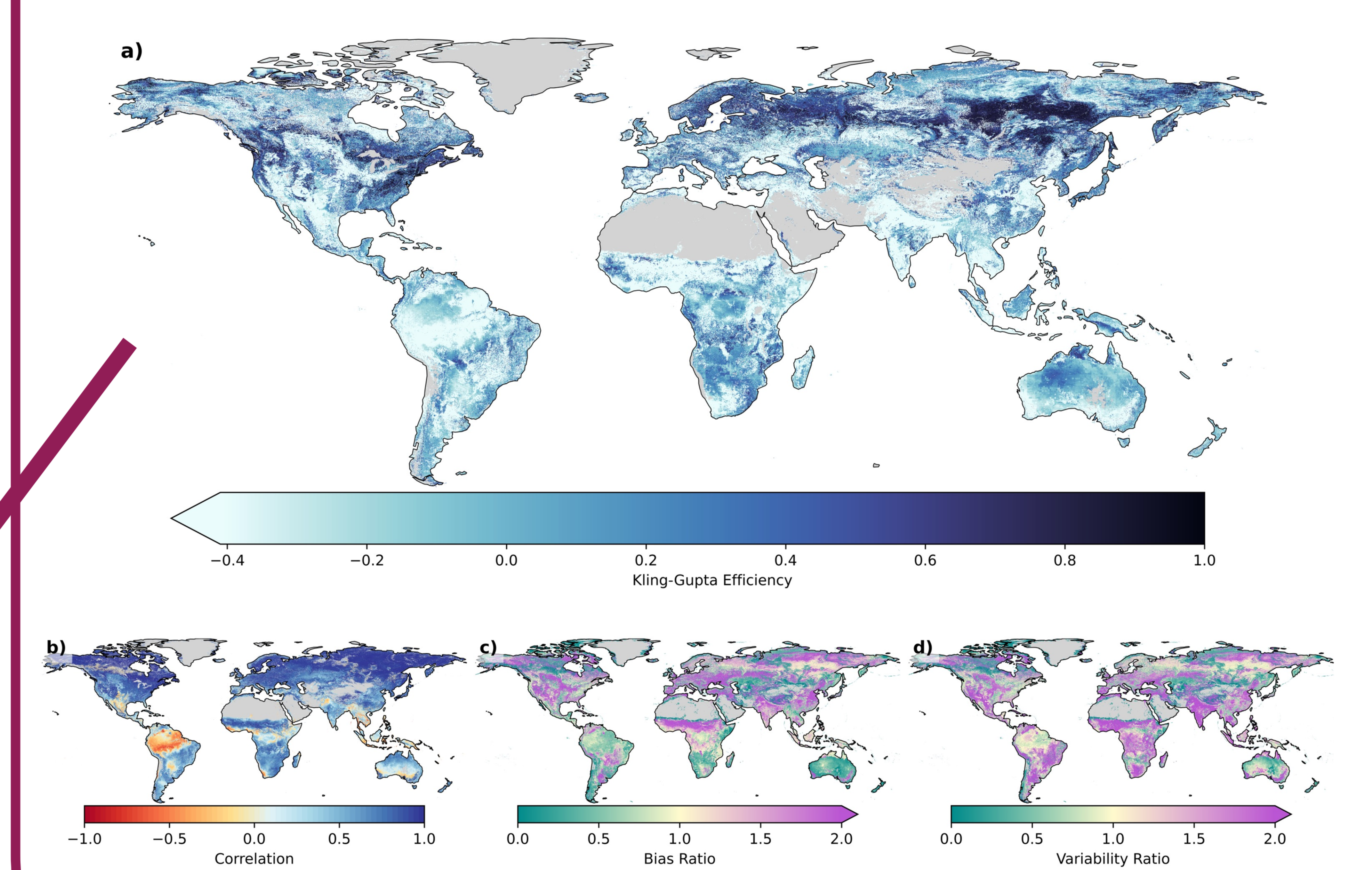


Fig 3: **(a)** KGE decomposition between LPJML-5 GPP with W5E5 daily climate input and MODIS GPP. KGE consists of: **(b)** Correlation, **(c)** bias ratio and **(d)** variability ratio.

Conclusions

- **Vegetation response to MYDs varies by region and vegetation type** (Fig. 2).
- Shrublands are most negatively affected, while needle-leaved trees sometimes show greening (Fig. 2).
- Model performance (KGE) shows reasonable agreement with satellite GPP data (Fig. 3).
- The **LPJmL-5 model shows weaker drought responses** compared to MODIS observations (Fig. 4).
- **Next steps:** extend the analysis back in time.

References

Ruijsch, D., van Mourik, J., Biemans, H., Hauswirth, S.M., Wanders, N (in review). Thrive or Wither: Exploring the Impacts of Multi-Year Droughts on Vegetation. *Biogeosciences*.

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