Quantifying the Changes in Carbon Cycle Extremes Due to Land Use Change and Attribution to Climate Drivers Through Year 2300

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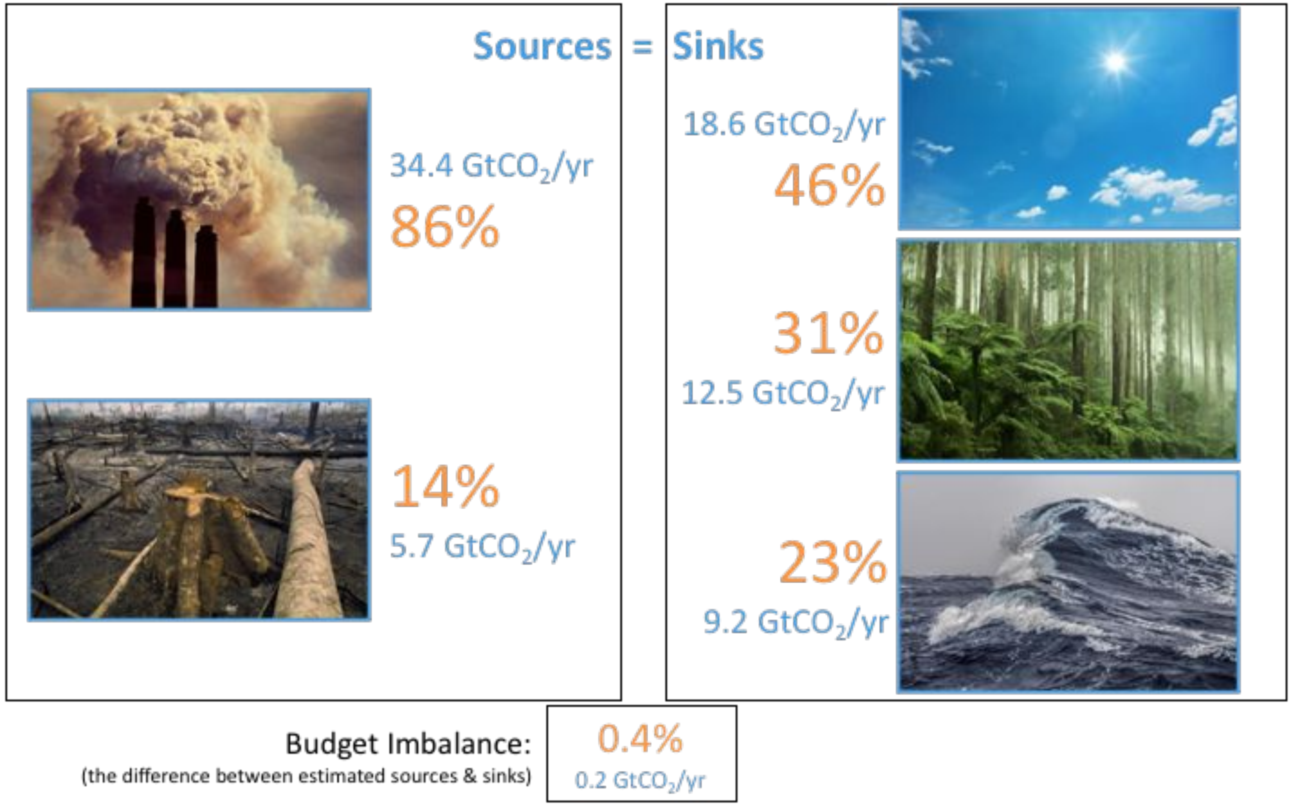
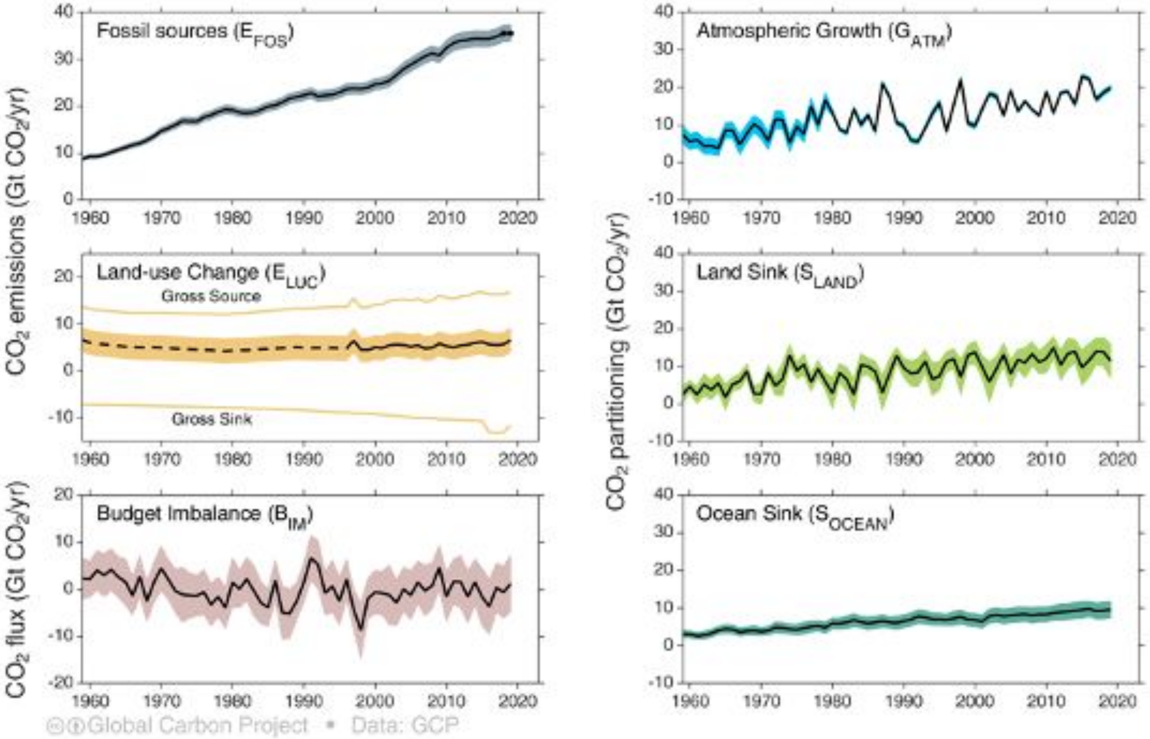
Terrestrial carbon uptake is 31%

Fate of anthropogenic CO_2 emissions (2010–2019)



Source: Friedlingstein et al 2020; Global Carbon Budget 2020

Changes in the budget over time



The budget imbalance is the total emissions minus the estimated growth in the atmosphere, land and ocean.It reflects the limits of our understanding of the carbon cycle.

Source : Global Carbon Budget 2020

What has already been done?

- The rising CO_2 emissions and LULCC have resulted in an increased occurrence of climate extremes such as droughts, heatwaves, fires, storms (Mazdiyasni and AghaKouchak, 2015; Turetsky et al., 2015; Doughty et al., 2015; Klotzbach et al., 2018), and such extremes are expected to further increase in the future.
- The rising CO_2 emissions are driving an increase in plant productivity and carbon uptake. 'But evidence is mounting that climate extremes such as droughts or storms can lead to a decrease in regional ecosystem carbon stocks and therefore have the potential to negate an expected increase in terrestrial carbon uptake' *(Reichstein et al., 2013)*.
- Most earth system models have climate change projections to the year 2100 and these projections may miss physical-biogeochemical feedbacks that arise later from the cumulative effects of climate warming *(Moore et al., 2018).*
- While the effects of increased warming due to greenhouse gases are spatially extensive, the LULCC effects are more regional *(Pitman et al., 2012)*.
- A large fraction of carbon extremes did not occur in concert with either temperature or precipitation extremes. Rather these carbon extremes are likely to be caused by the interactive effects of the concurrent temperature and precipitation anomalies (Pan et al. 2020).
- The impact of climate drivers on photosynthetic activity often has a lagged response because the terrestrial ecosystem has ingrained plasticity to buffer and push back effects of climate change (Zhang et al., 2014).

Research questions

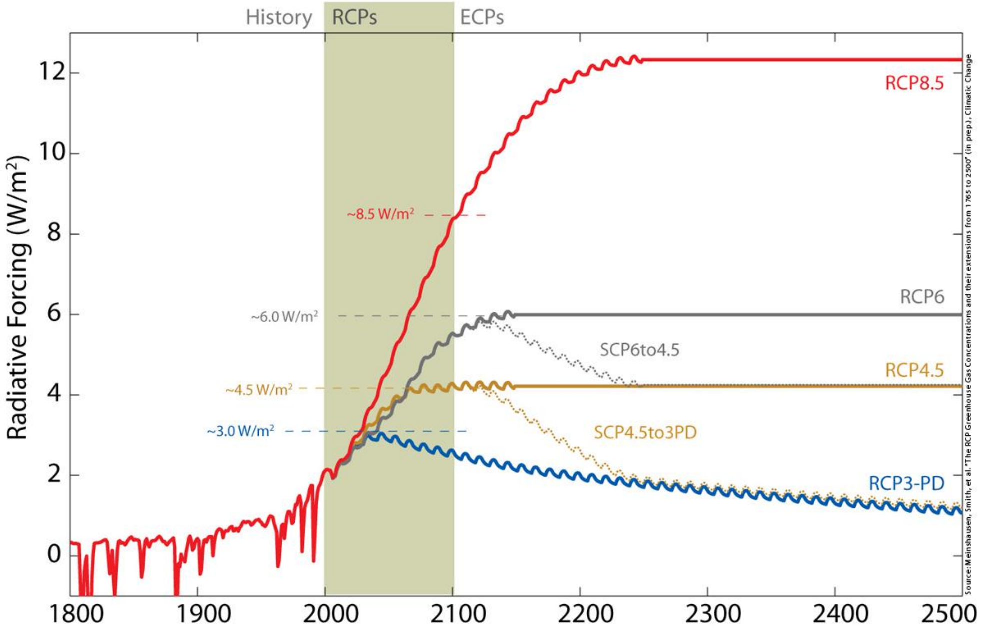
How is the severity of intensity, frequency, and extent of terrestrial carbon cycle extremes been modified by carbon emissions and land-use change?

1. Historic, RCP8.5, ECP8.5 CO_2 concentration from 1850-2300.
2. LULCC forcing + Scenario 1.
3. Attribution to individual and compound drivers.

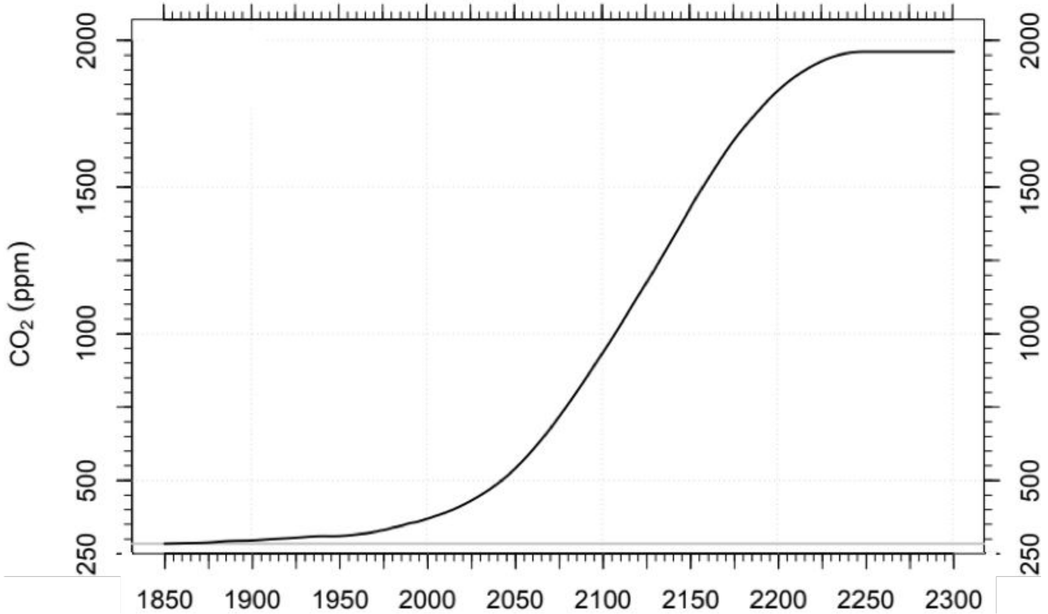
RCP: Representative Concentration Pathway; ECP: Extended Concentration Pathway; LULCC: Land-use and land-cover changes

Data source

Community Earth System Model Biogeochemistry Working Group, CESM1-BGC



Meinshausen et al. (2001) extended RCP forcing out to 2500



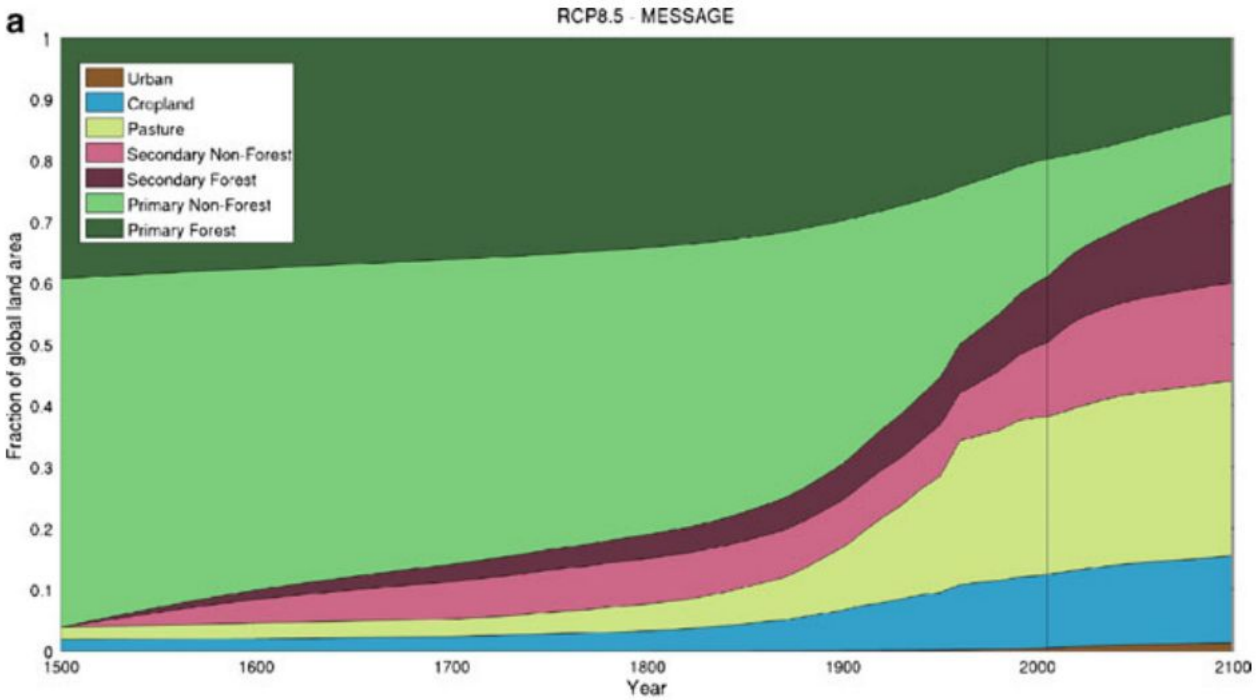
Source: Hoffman 2017 (AGU)

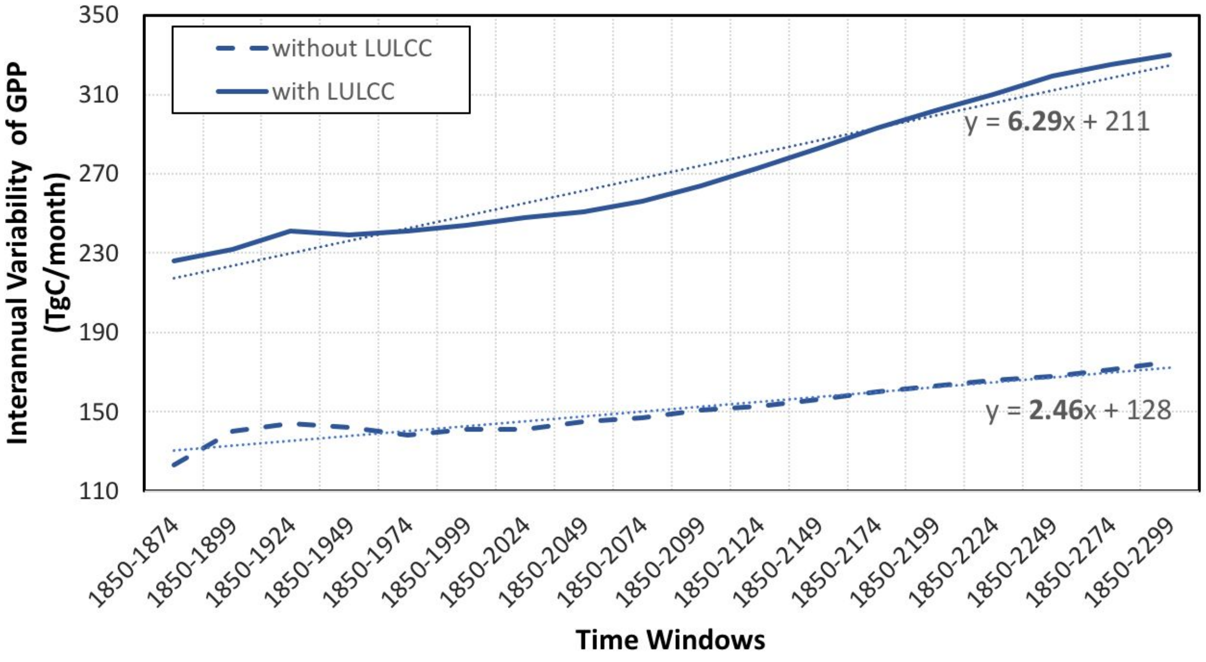
Prescribed atmospheric CO2 mole fraction was stabilized at 1962 ppm around 2250

- Resolution: 0.9375 x 1.25 (lat x lon)
- Monthly Mean Data
- Fully Coupled Simulations
- 1850-2300

- Simulations with and without land use & land cover change (LULCC) (*Hurtt et al. 2011*)
- Land use transition period 1850-2100 then kept constant at 2100 levels through the year 2300

LULCC increases the IAV of GPP



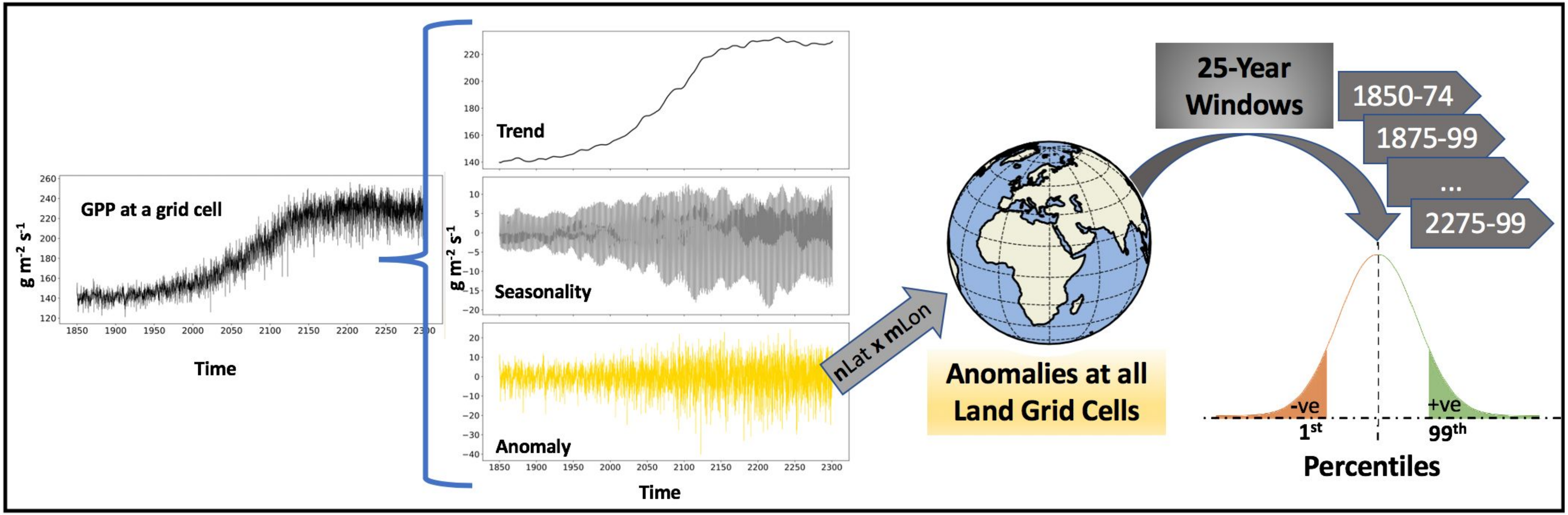


Global interannual variability (IAV) of GPP with and without LULCC. The IAV is calculated from 1850 as the base year to 25 year increments, as shown in x-axis.

- Simulations with and without land use & land cover change (LULCC) (*Hurtt et al. 2011*)
- Land use transition period 1850-2100 then kept constant at 2100 levels through the year 2300

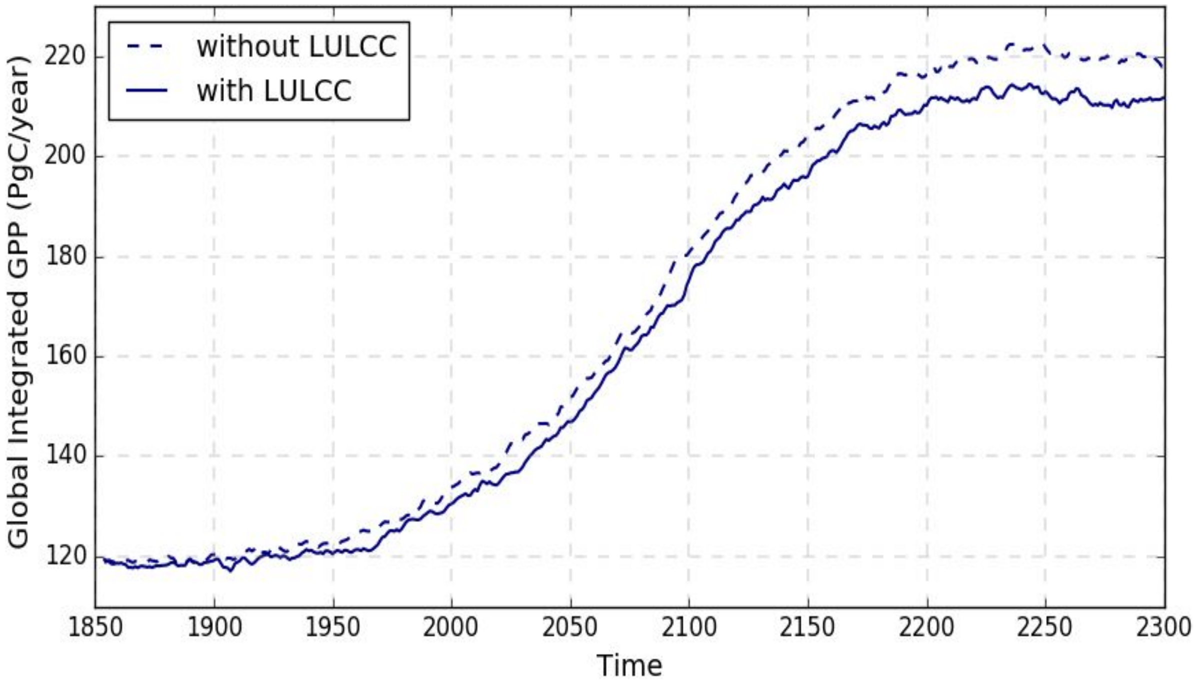
Source : Fig 9a from Hurtt et al., 2011; RCP 8.5

Definition of GPP extreme events

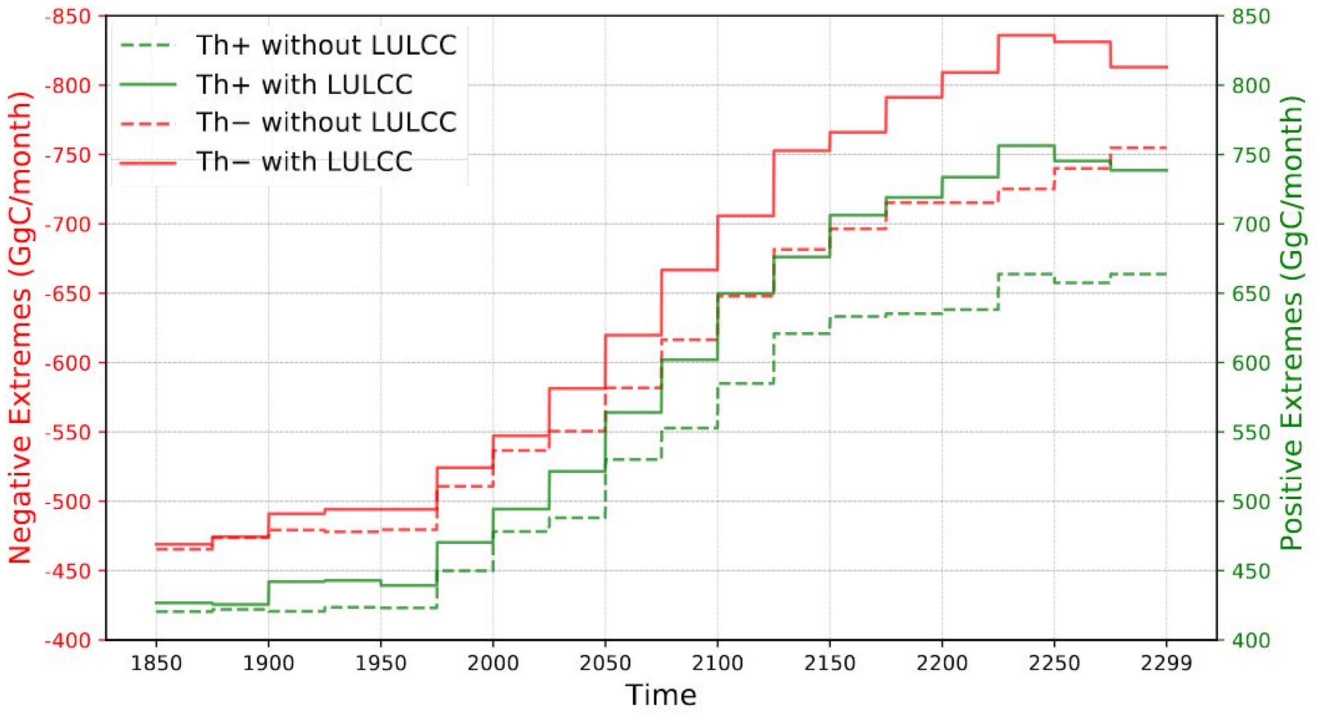


Non-linear trend is defined as the sum of frequencies greater than 10 years, using SSA.
Seasonality or modulated annual cycle is defined as frequencies of 12 months and its harmonics.
Hence, GPP anomalies comprised of the high-frequency signals (<12 months) and the interannual variability (>12 months and <10 years).
Thresholds are calculated at global scale for 25 year periods.

LULCC causes reduction in GPP and increase in threshold

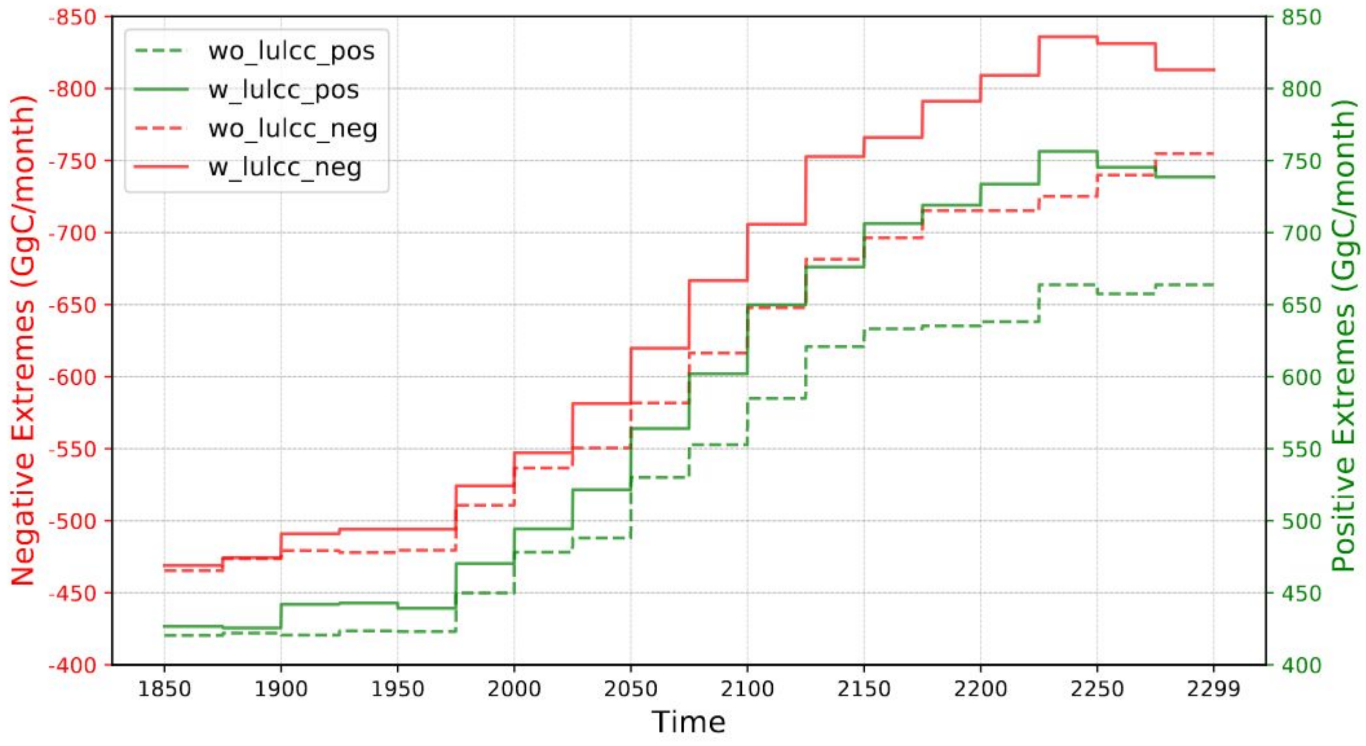


Global 5 year rolling of GPP for
without-LULCC and with-LULCC (1850-2300)



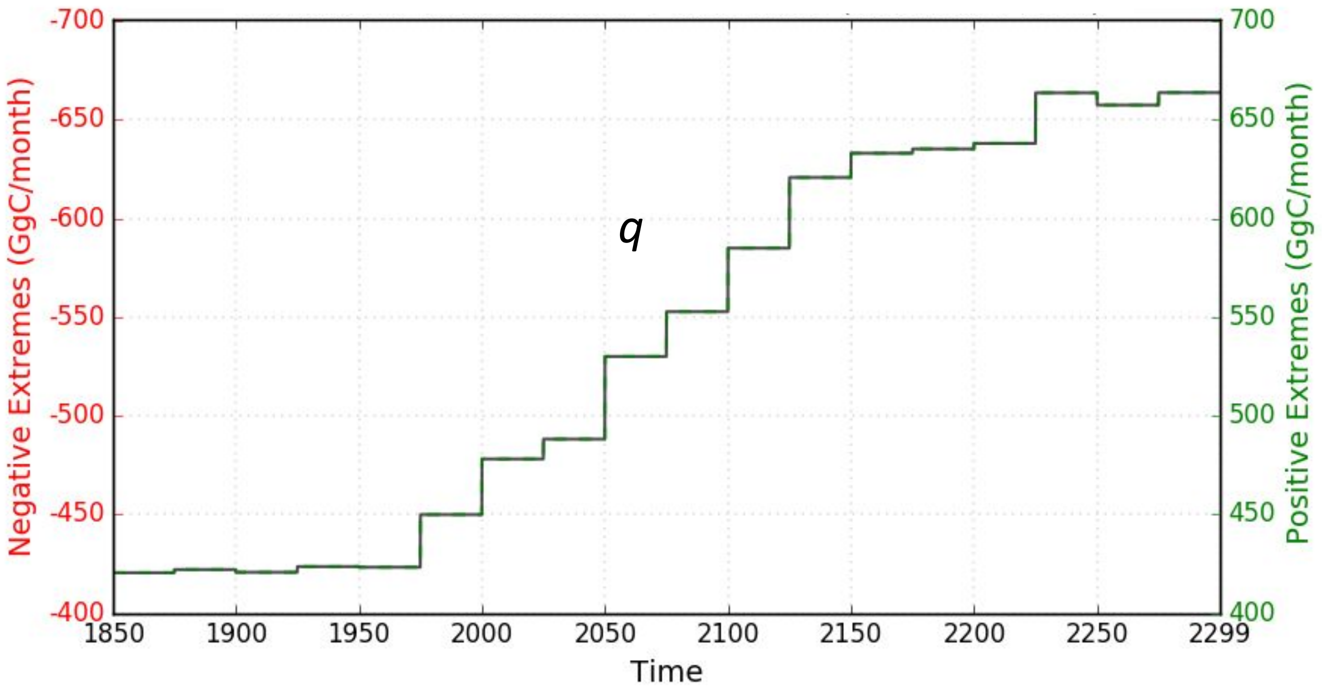
Thresholds of the GPP Extreme Events
(1850-2300)

Negative thresholds are higher than positive

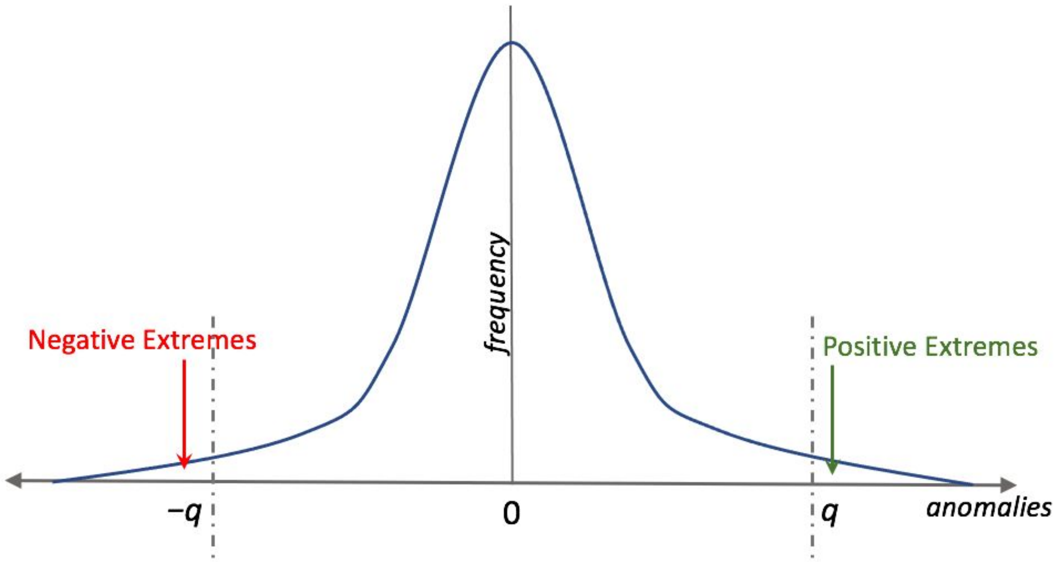


Thresholds of the GPP Extreme Events
(1850-2300)

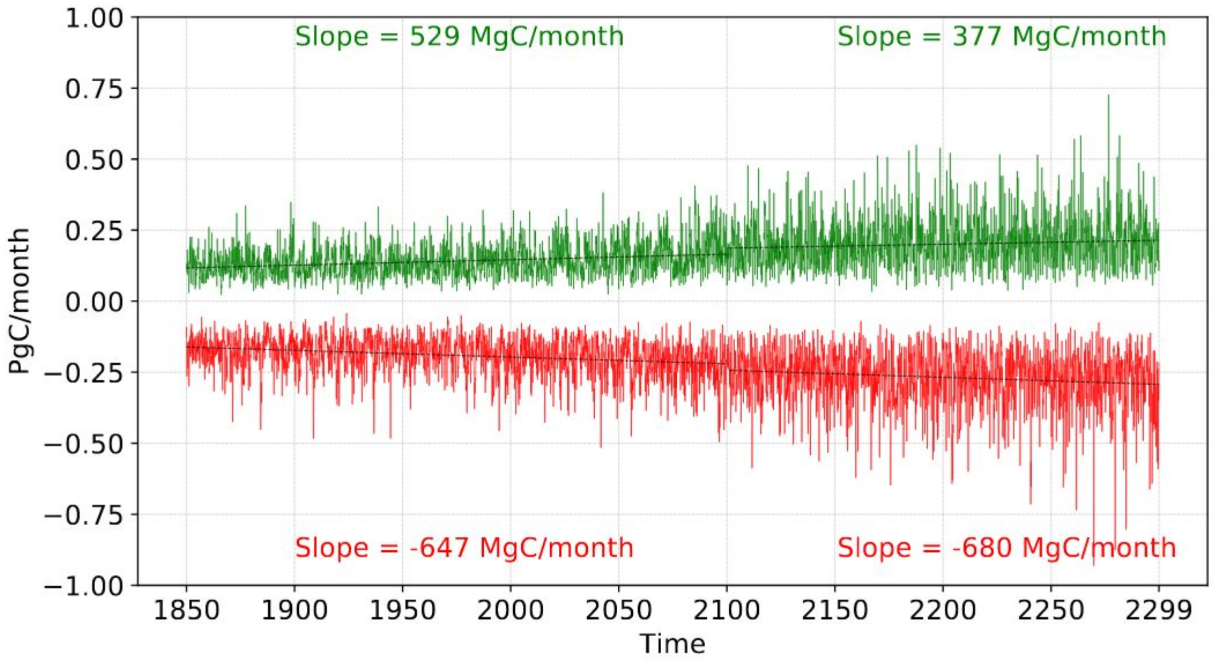
Selection of a common threshold



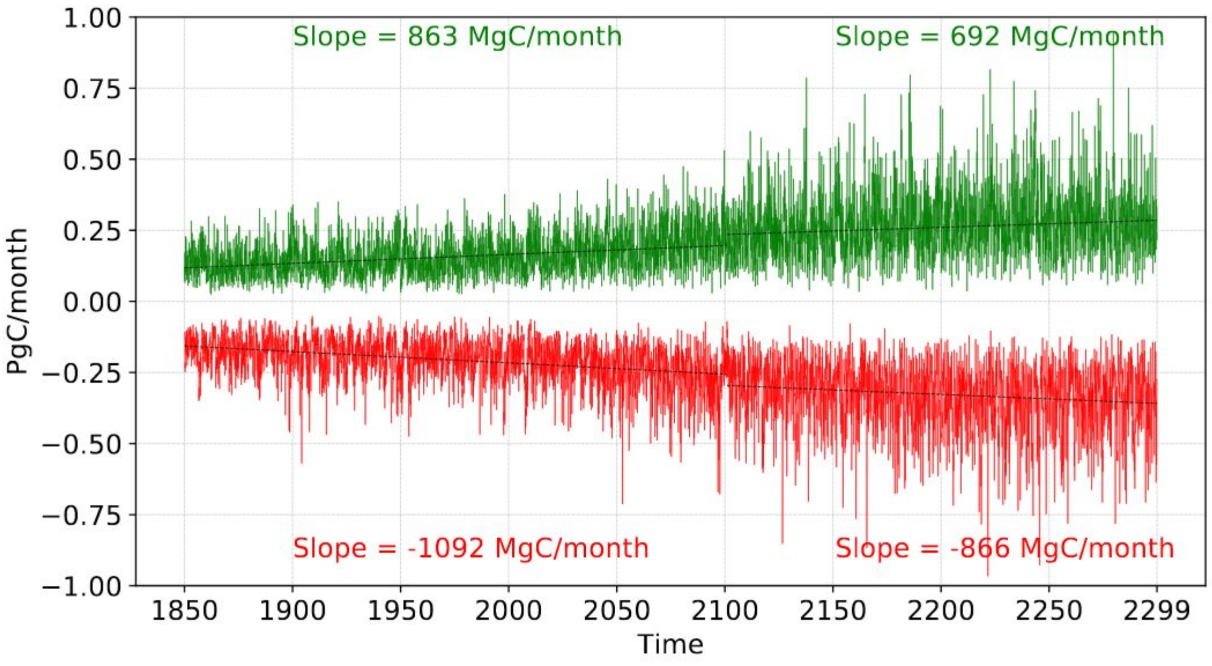
Common Threshold of the GPP Extreme Events
(1850-2300)



LULCC causes an increase in intensity of extremes



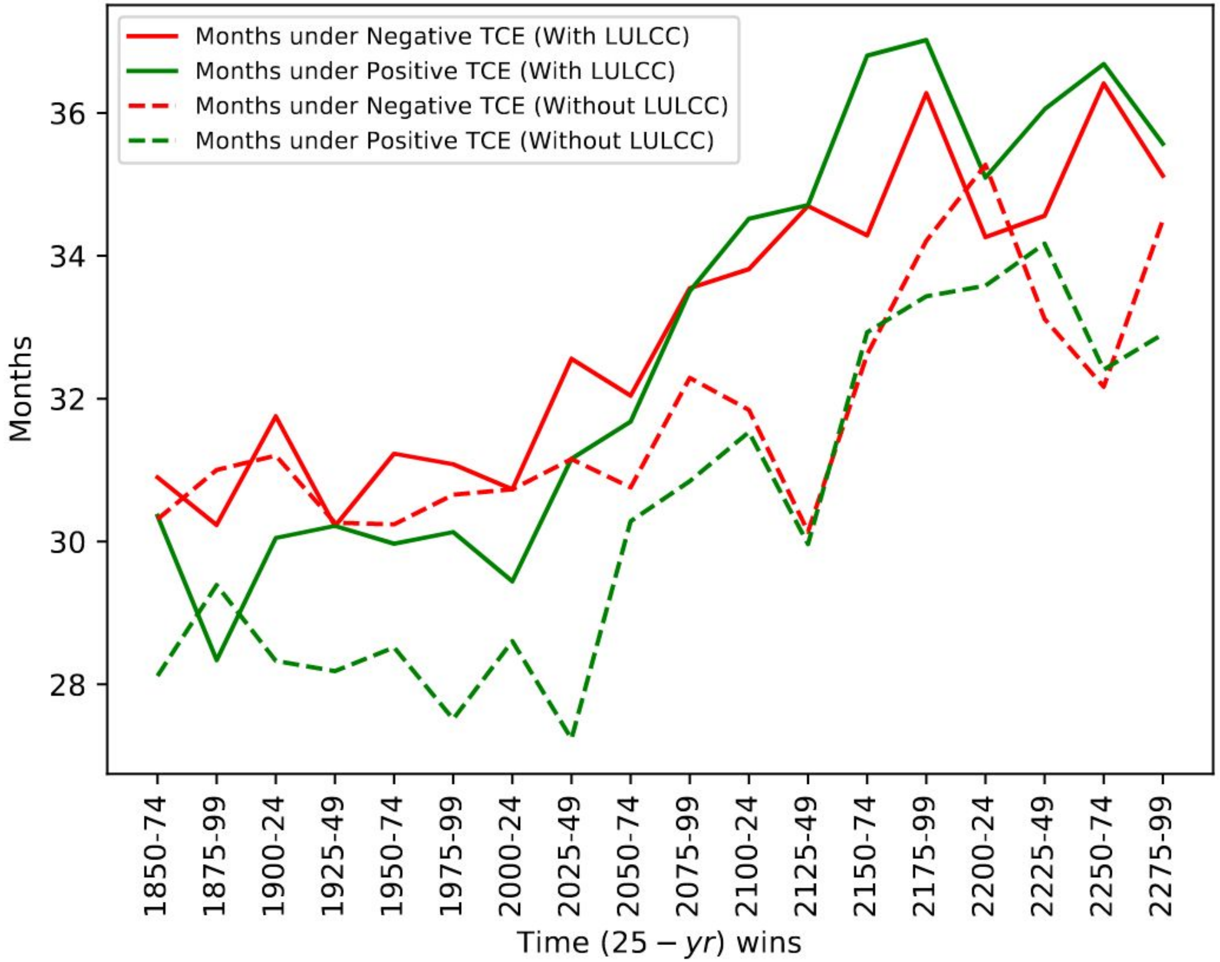
Intensity of the GPP Extreme Events without-LULCC (1850-2300)

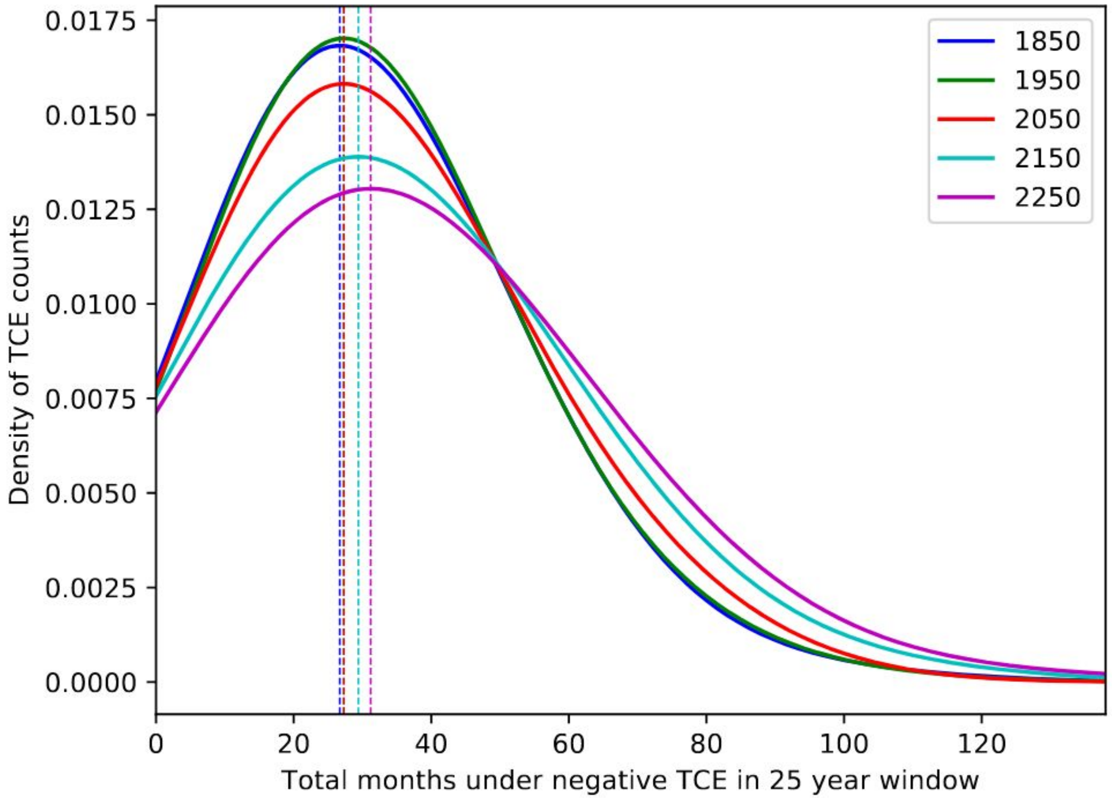


Intensity of the GPP Extreme Events with-LULCC (1850-2300)

w.r.t. to total global GPP, the additional losses in total carbon uptake due to LULCC increased from 6.9% (1850-2100) to 10% (2100-2300).

Increased duration of GPP TCEs





The dashed vertical lines shows the shifting of mean duration of negative TCEs to right, highlighting that the TCEs are getting longer over time.

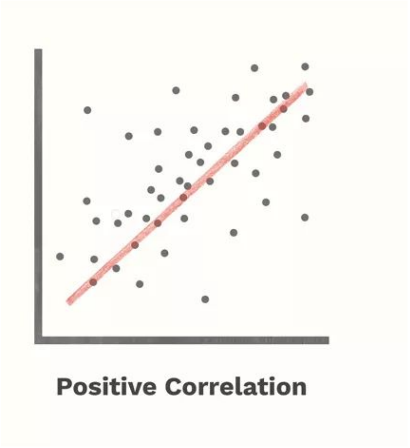
TCE: Time Continuous Extreme Events

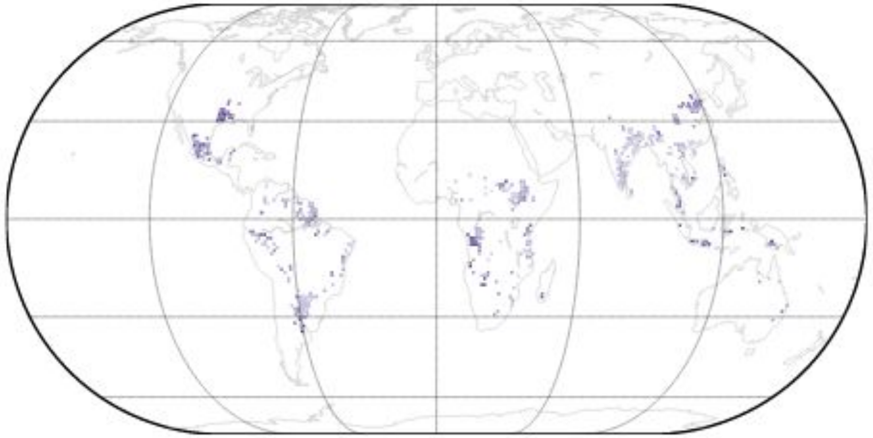
Attribution to individual and compound drivers

Climate drivers considered for the attribution

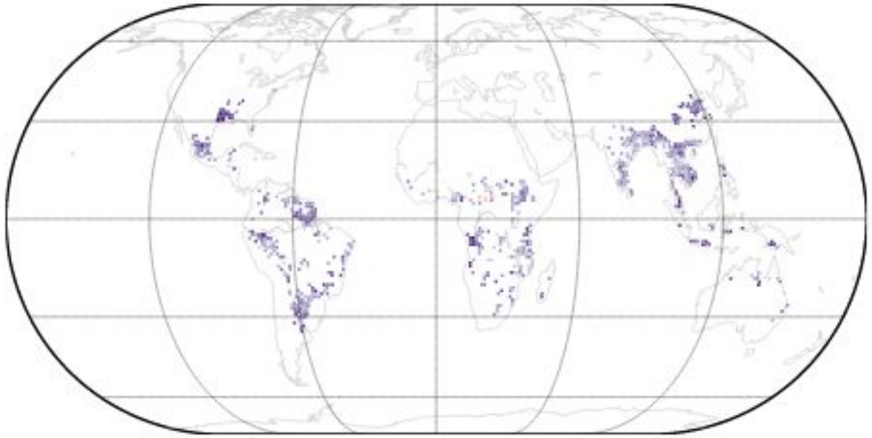
Water	Prcp	Atmospheric rain + snow
	P–ET	Precipitation minus Evapotranspiration
	Soilmoist	Soil moisture to 1-m depth
Temperature	T_{max}	Monthly maximum daily temperature
	T_{sa}	Monthly mean daily temperature
	T_{min}	Monthly minimum daily temperature
Fire	Fire	Total column level carbon loss due to fire

Spatial distribution of extremes and driver correlations

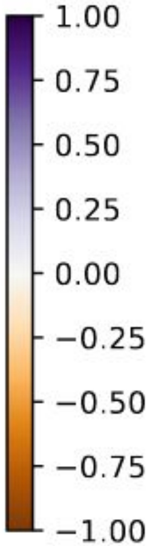




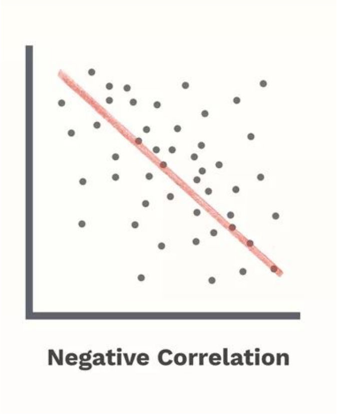
(a) Precipitation

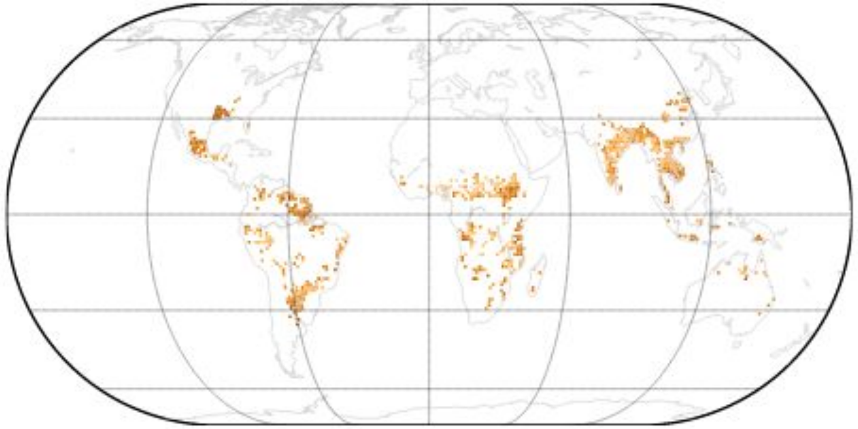


(b) Soil Moisture

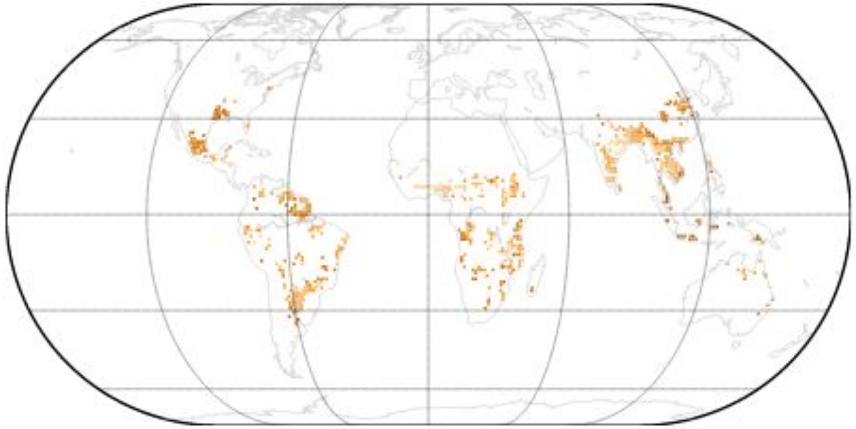


Correlations for With LULCC; 2000-24; Lag: 1 month





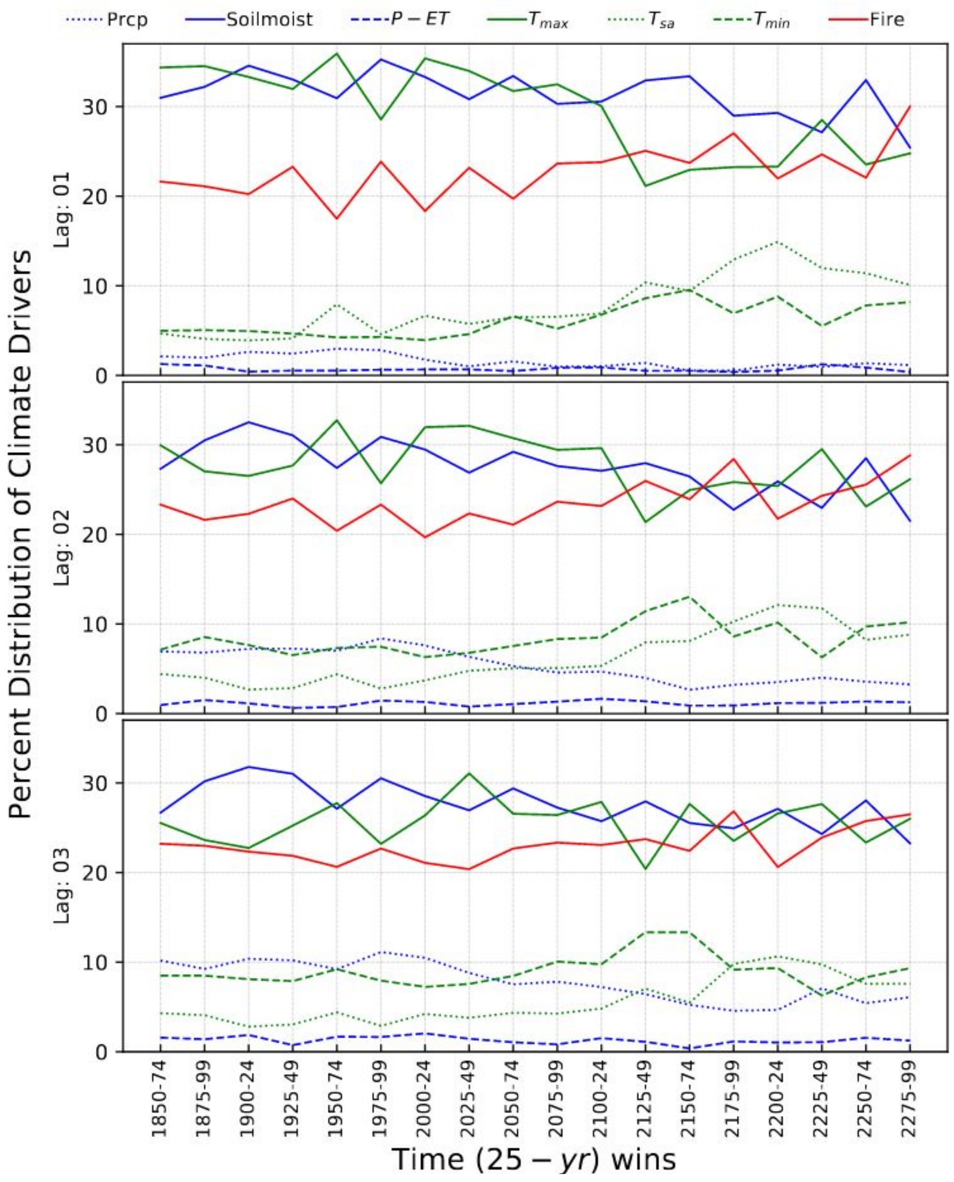
(d) Monthly Max Temperature



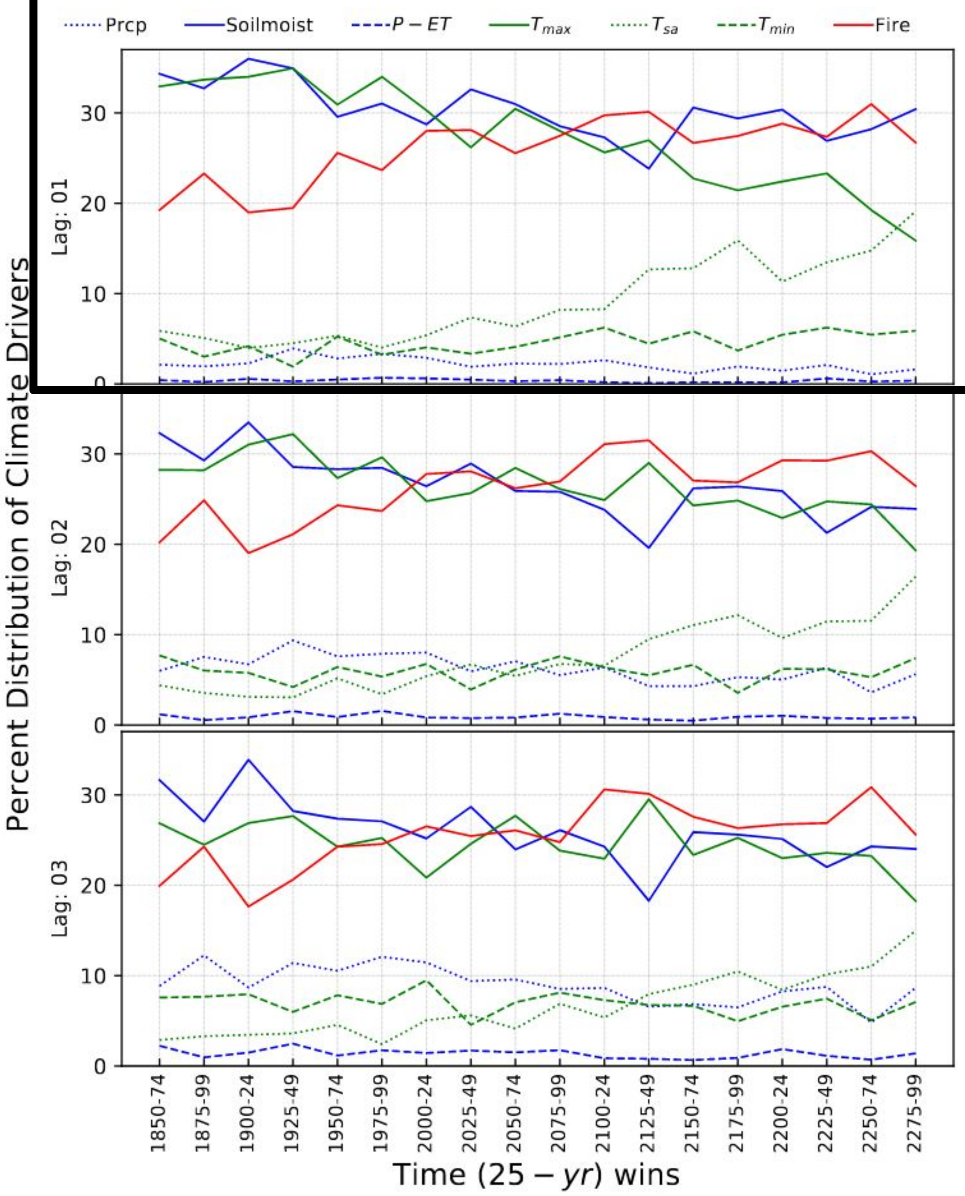
(e) Fire

Dominant driver distribution at multiple lags

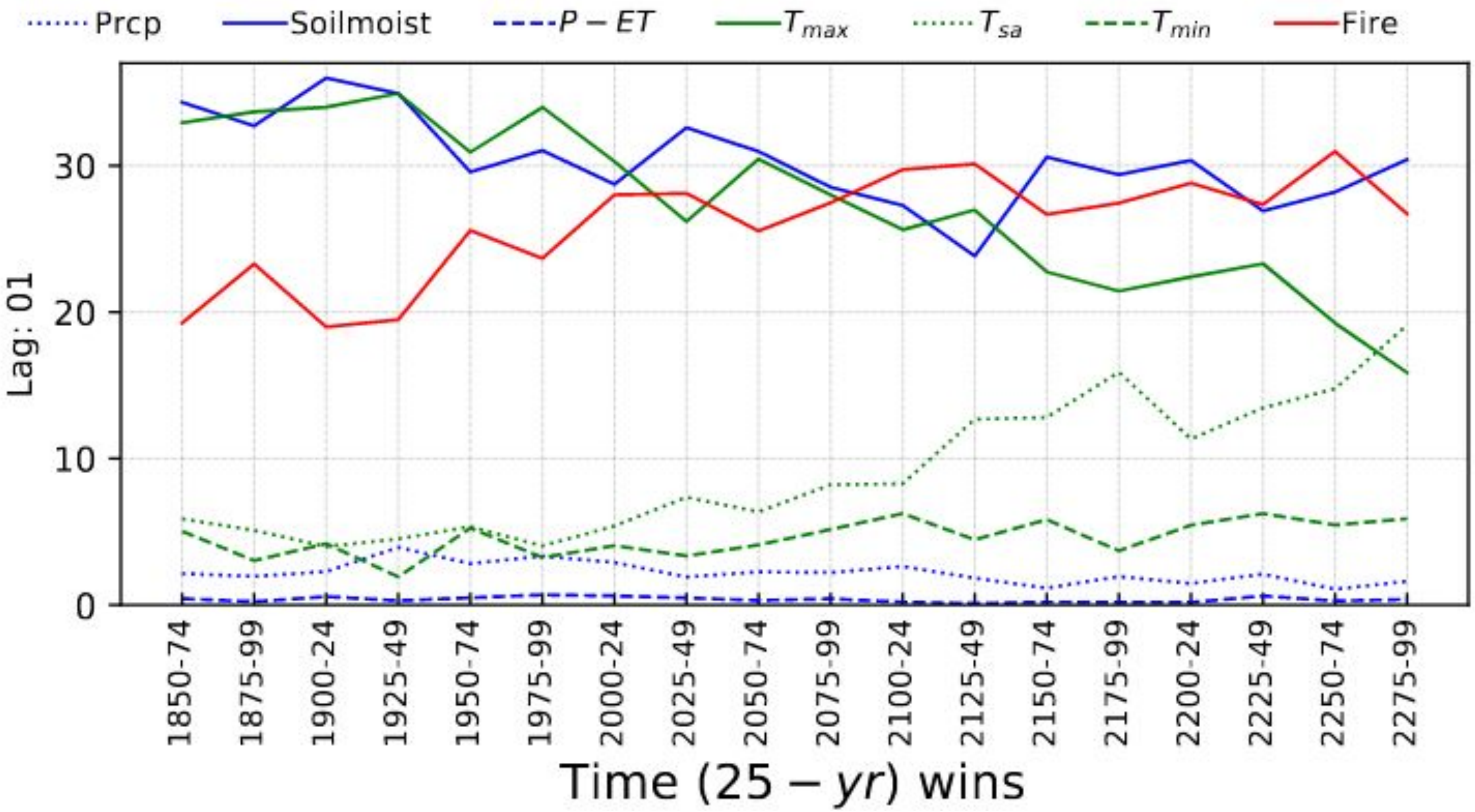
without-LULCC



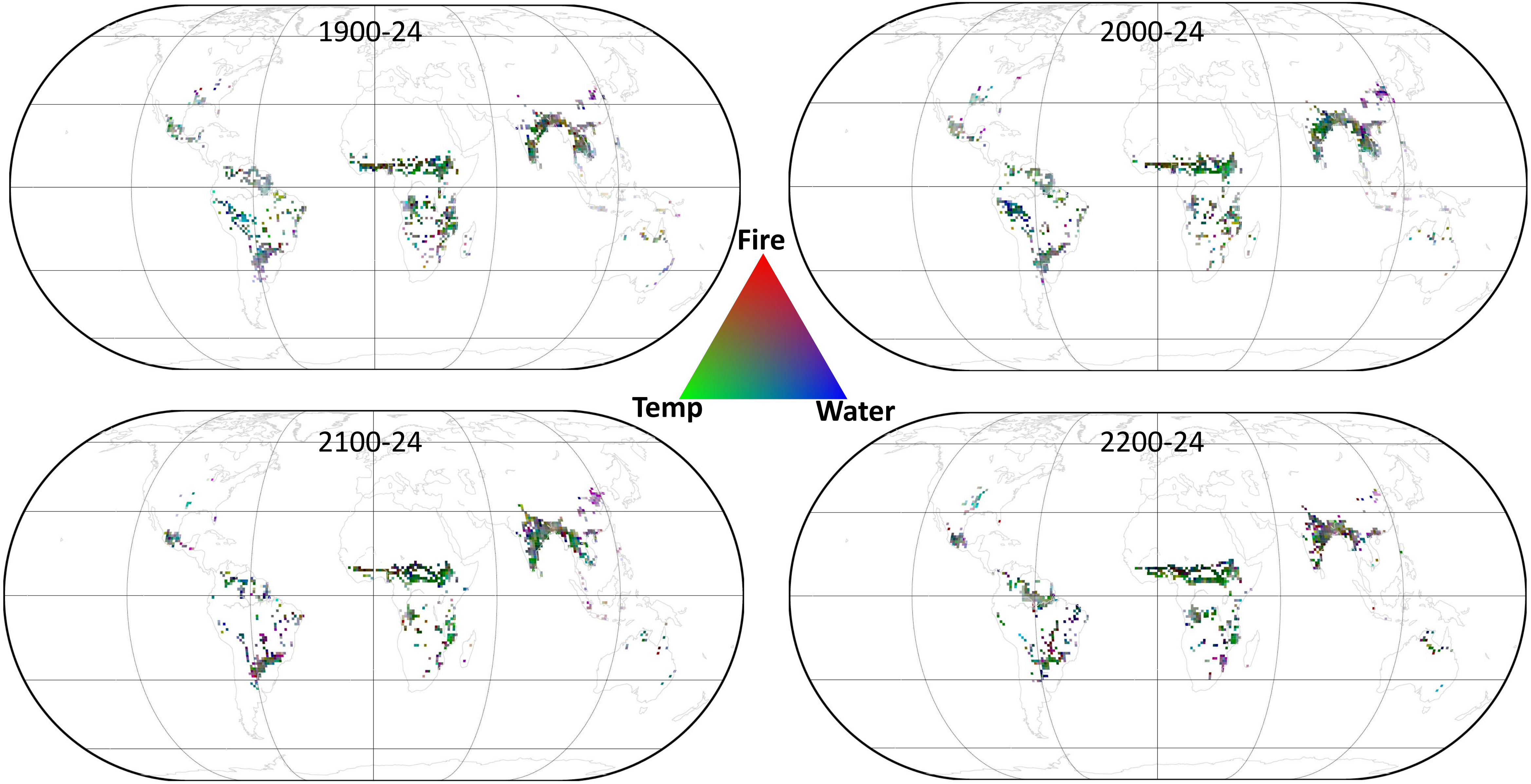
with-LULCC



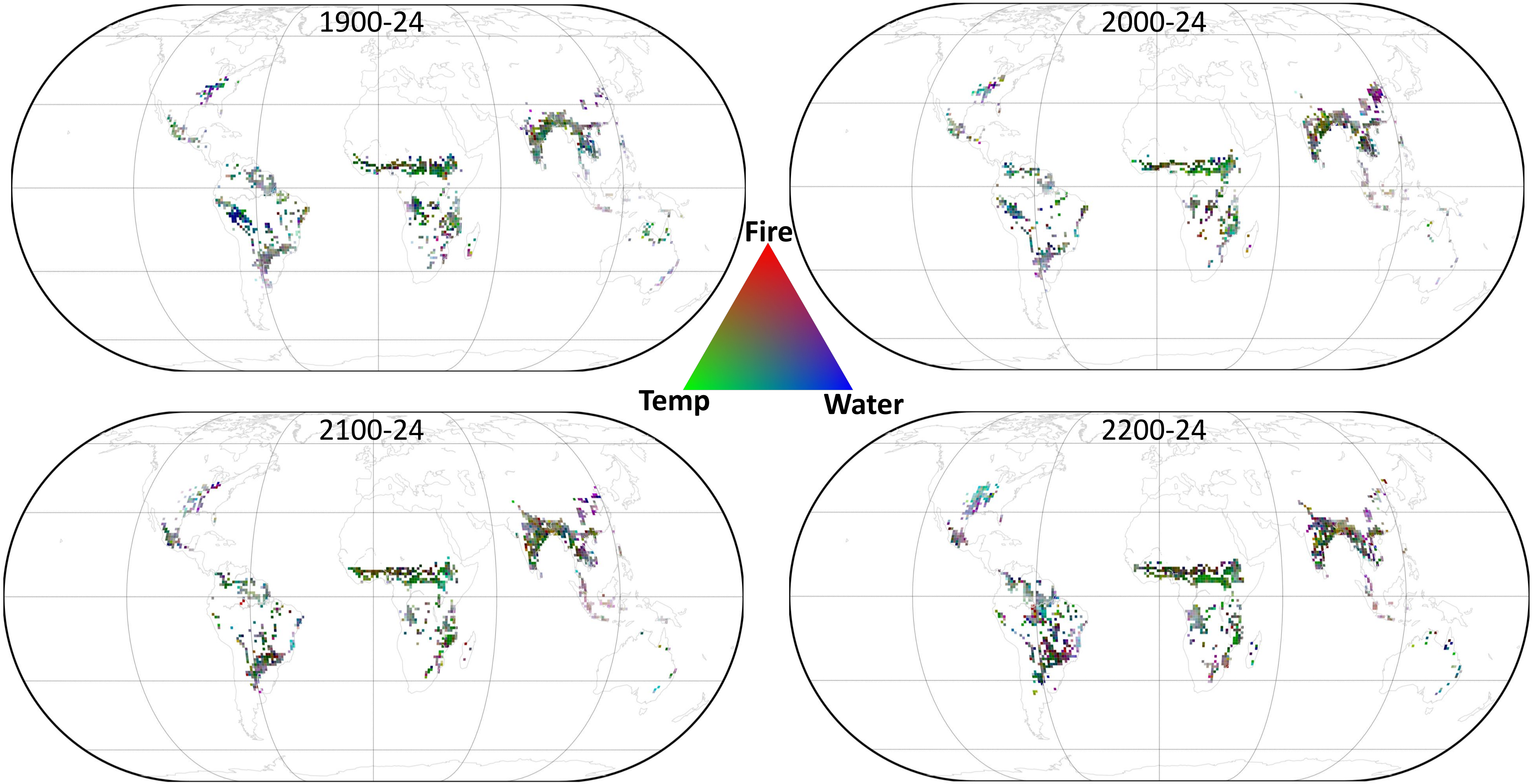
Dominant drivers at lag 1 month for w-LULCC



Compound climate drivers (wo-LULCC)

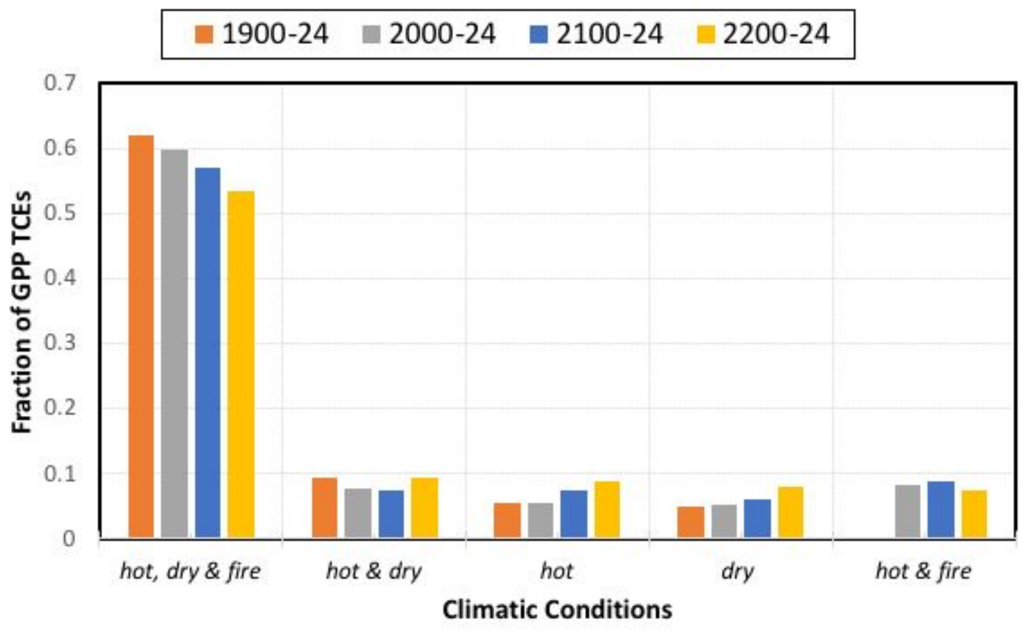


Compound climate drivers (w-LULCC)

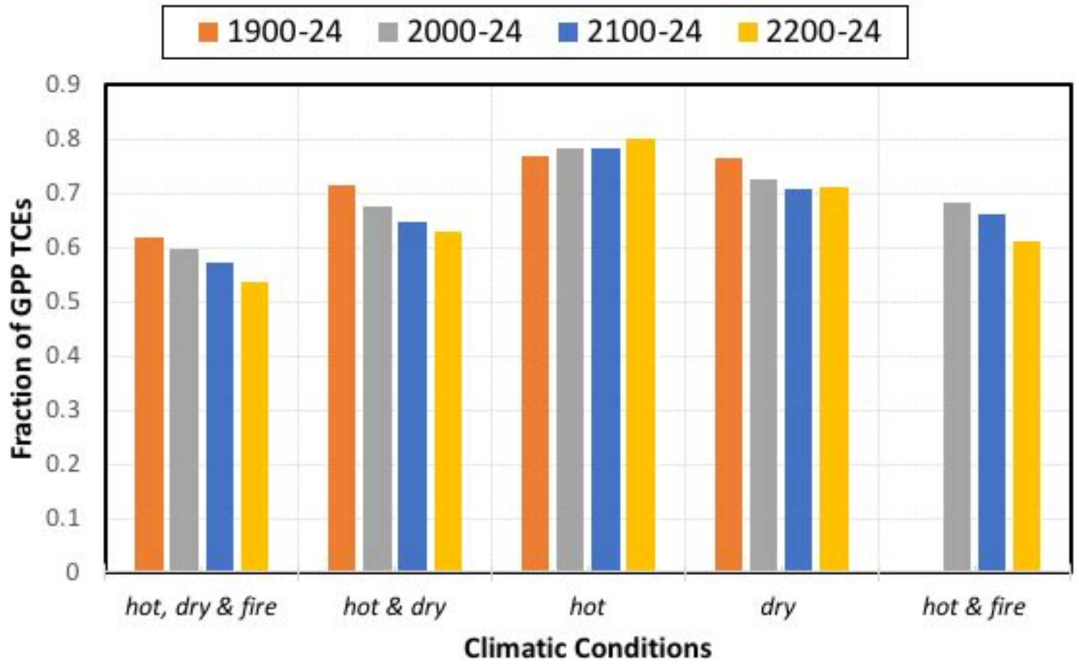


Compound effect of climate drivers is larger

Mutually Exclusive Compound Drivers



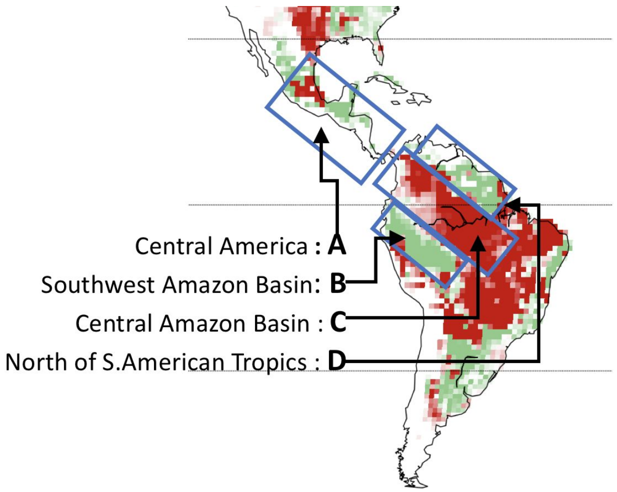
Mutually Inclusive Compound Drivers

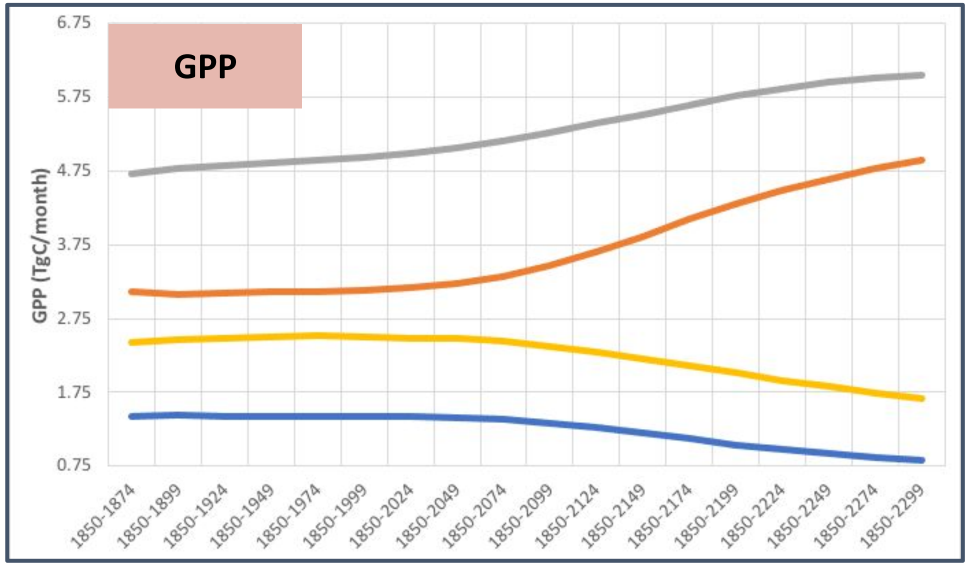


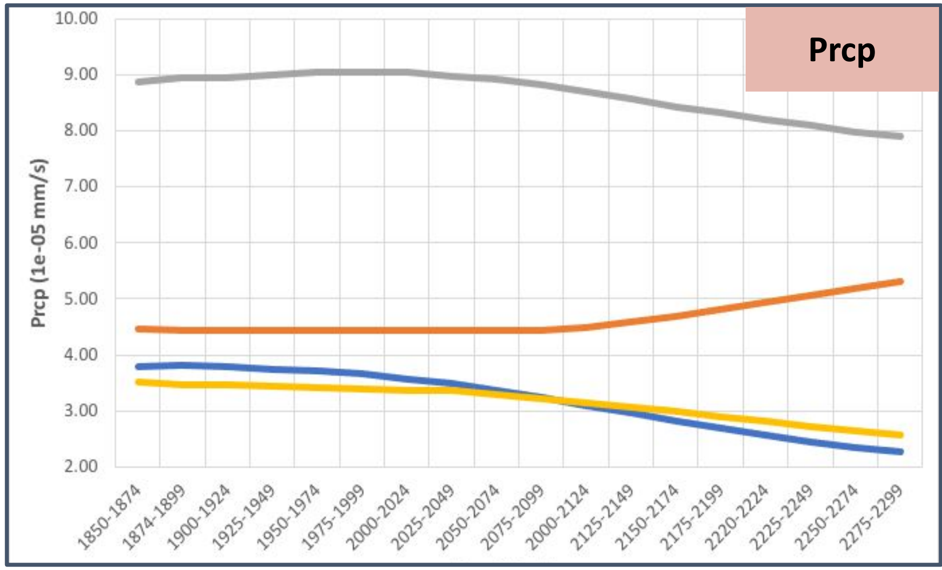
Attribution of time continuous extreme events in GPP to compound effect of climate drivers for the simulation with LULCC at lag of 1 month.

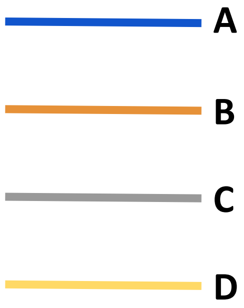
The results are shown for only those compound conditions that contributed more than 5% of the carbon cycle TCE events.

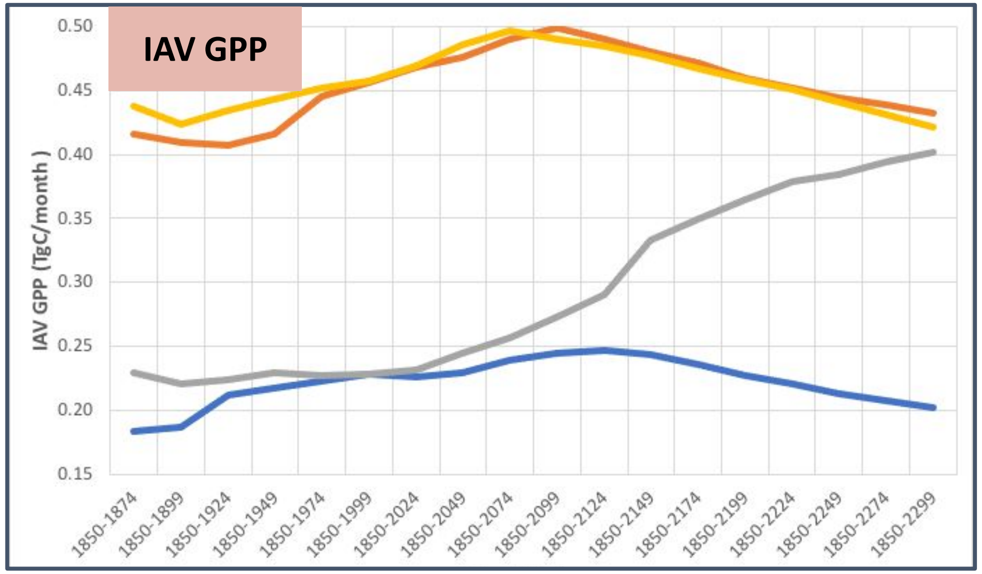
Investigating regional variations in carbon extremes

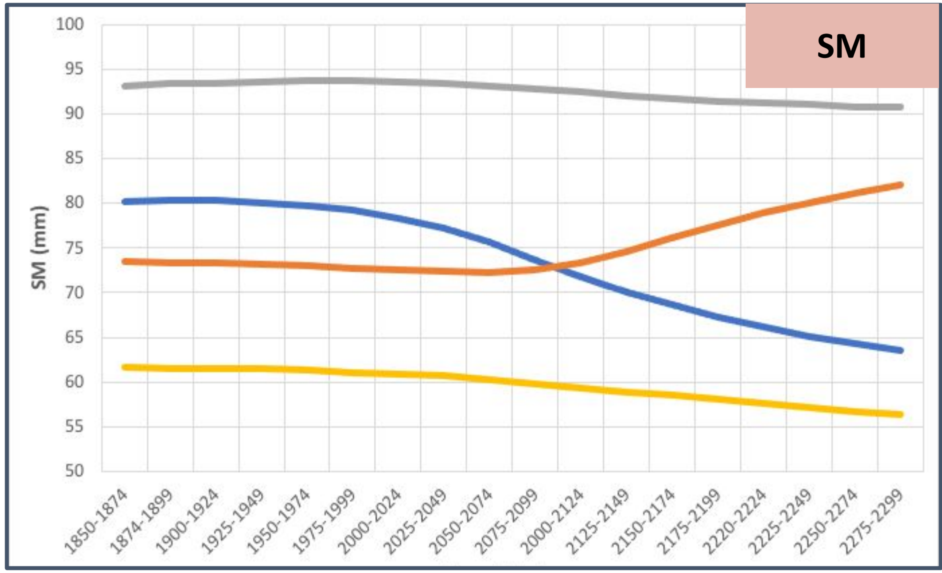




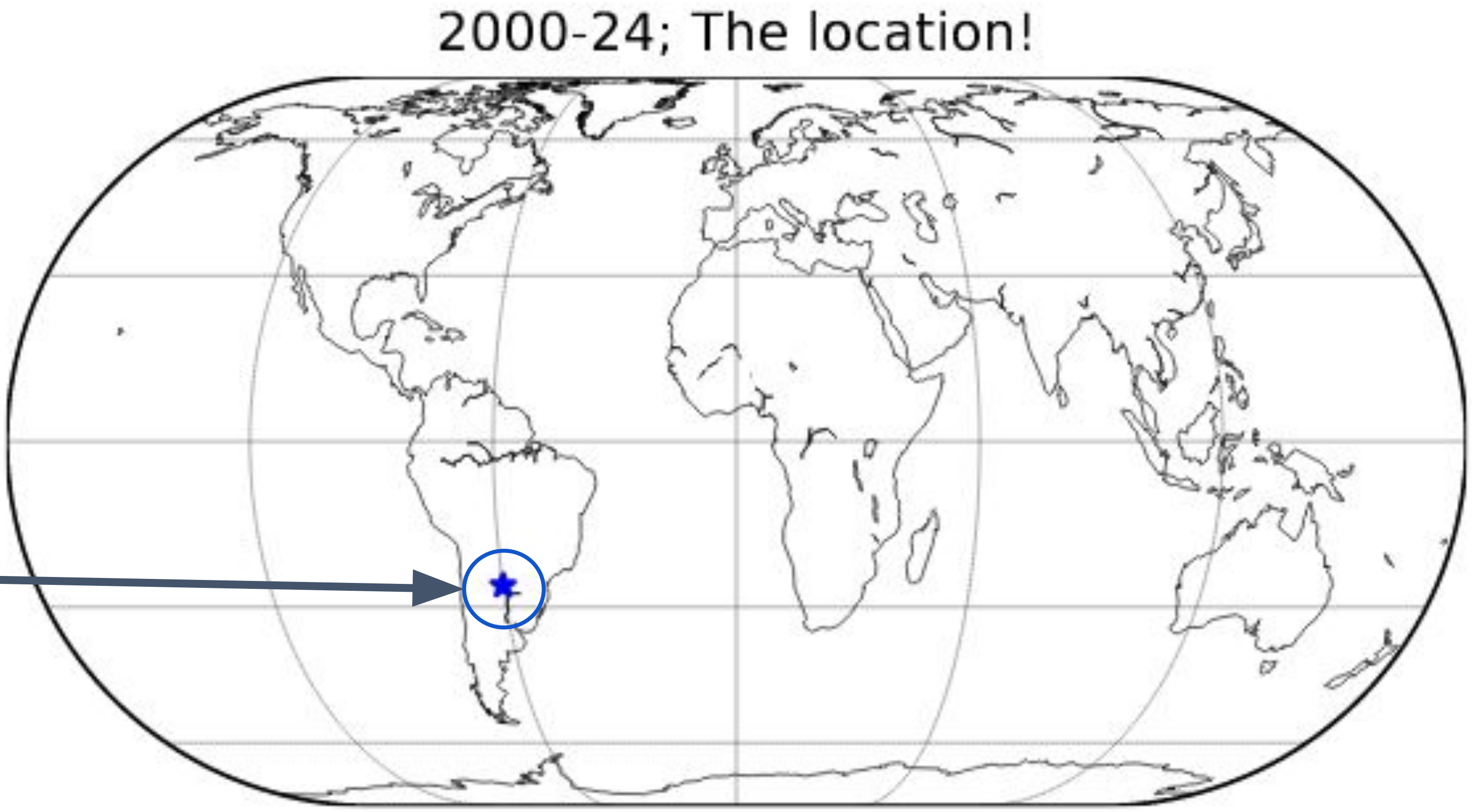








Investigating the effect of LULCC at a location

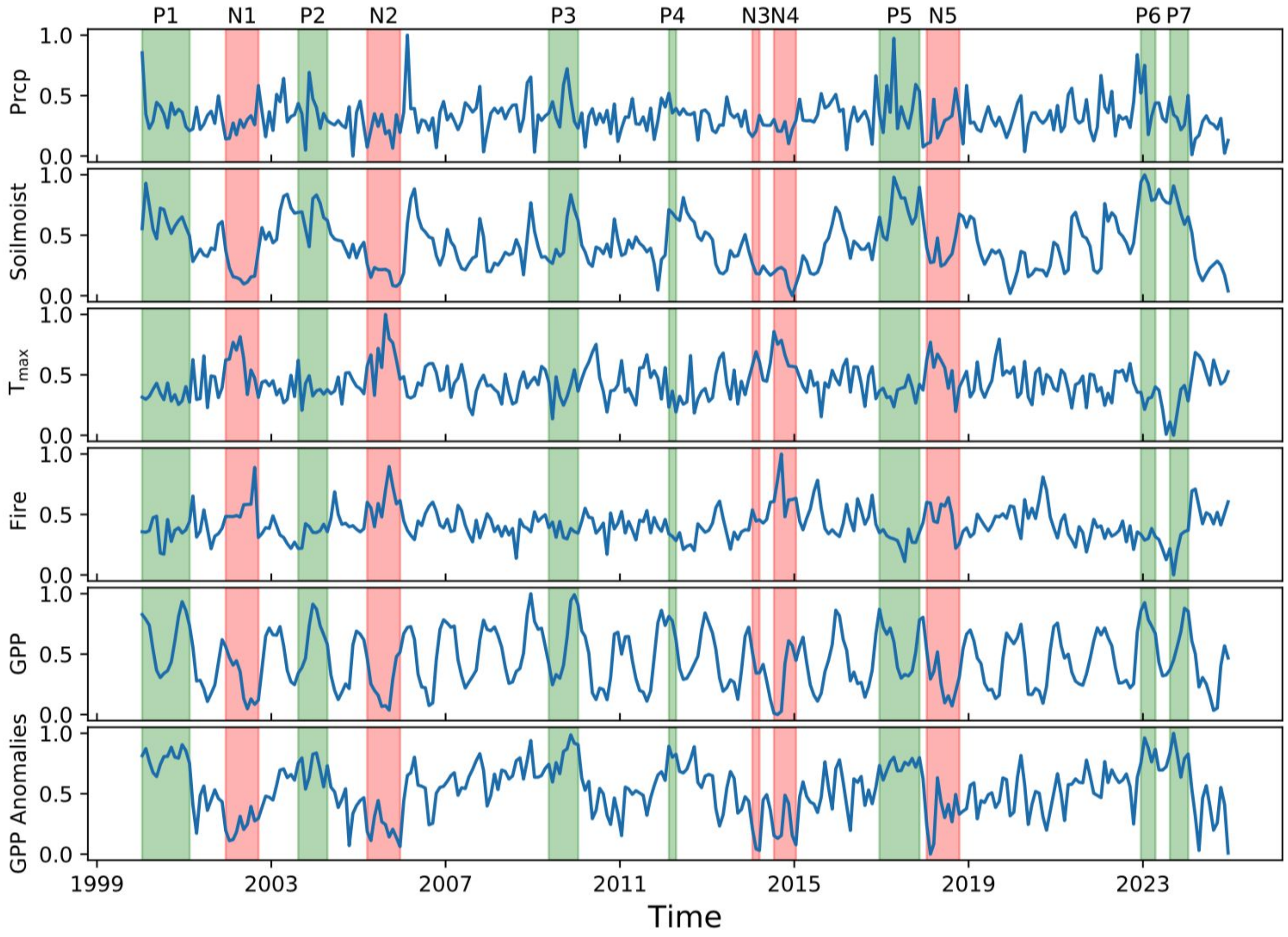


Pampa del Indio,
Chaco Province, Argentina

PFT (I)	PFT(II)	PFT(III)
BDT Temperate (43.2%)	BET Temperate (17.91%)	C3 grass (17.48%)

Difference in drivers of positive and negative TCEs

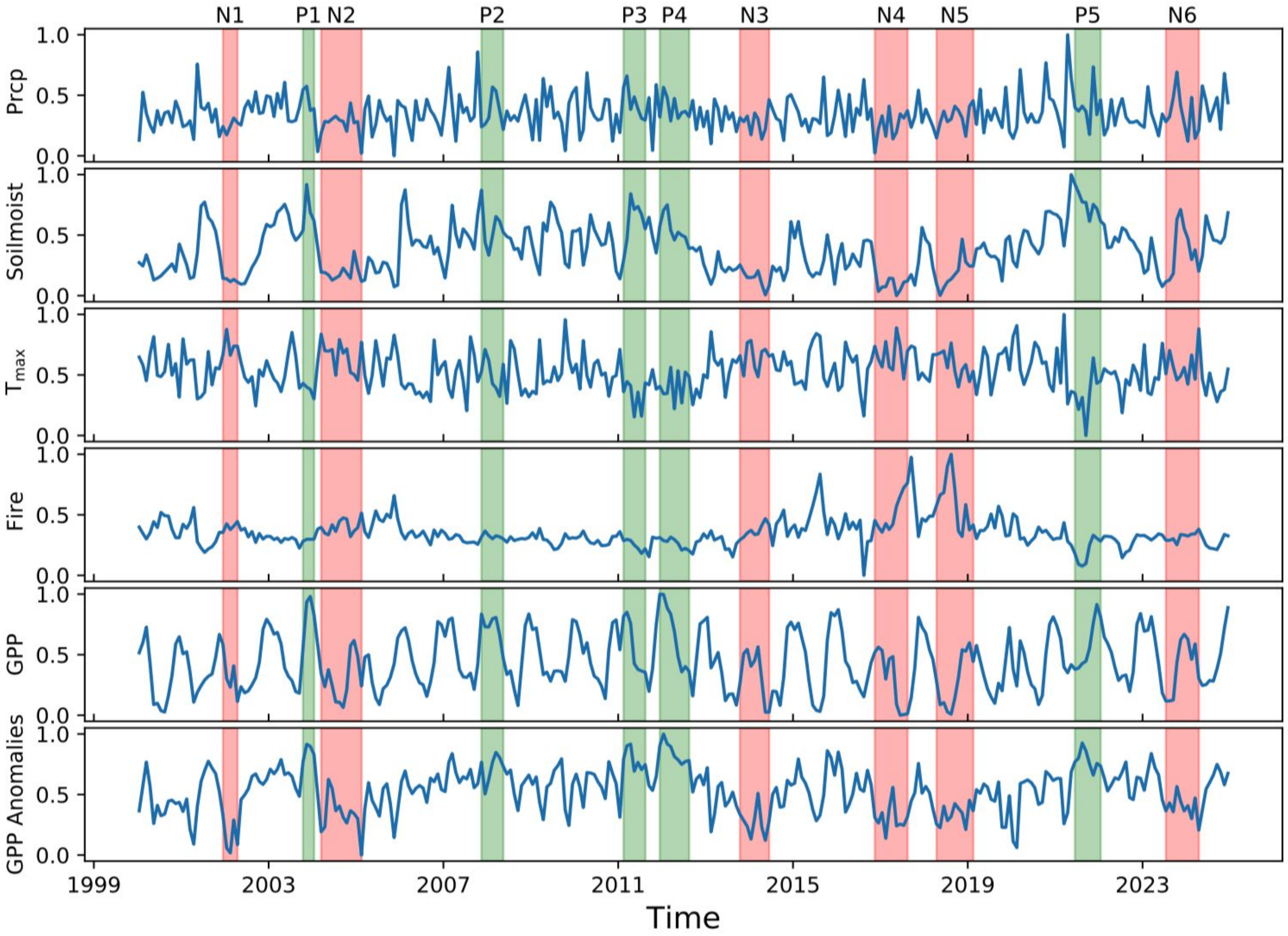
Without LULCC	
Positive TCEs	7 TCEs or 53 months
Negative TCEs	5 TCEs or 40 months
Uptake gain	35.17 TgC
Uptake loss	-28.15 TgC
Net Change	**7.02 TgC**



Anomalies of Climate Drivers and GPP during 2000-24 for the simulation wo-LULCC

From net positive to negative carbon uptake with LULCC

With LULCC	
Positive TCEs	5 TCEs or 35 months
Negative TCEs	6 TCEs or 57 months
Uptake gain	23.87 TgC
Uptake loss	-35.86 TgC
Net Change	**-11.99 TgC**



Anomalies of Climate Drivers and GPP during 2000-24 for the simulation w-LULCC

Key Points

- We analyzed extreme anomalies in GPP under high CO_2 climate change simulations from 1850 through 2300, with and without LULCC forcing.
- Human activities, through land-use change, will increase the intensity, duration, and frequency of anomalous losses during GPP extremes.
- The soil moisture is the dominant climate driver for persisting extremes in GPP and precipitation is the dominant trigger.
- The number of extremes driven by interactive effect of multiple climate drivers are larger than individual drivers.

Limitations and future work

- Only looking at very large extremes in GPP i.e. 1 percentile. The areas with large vegetation will witness highest percent share.

- The results are based only on one model simulations. More model simulations are needed that are run beyond 2100.

- We considered the average cumulative effects of lagged climate drivers, one could also study the attribution by giving more weight to the climate drivers at shorter lags.

A few references

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Acknowledgement

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Thank you!

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