B42H-1732: Quantifying Extremes in Net Biospheric Production and Attribution to Compound Climate Drivers

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Introduction

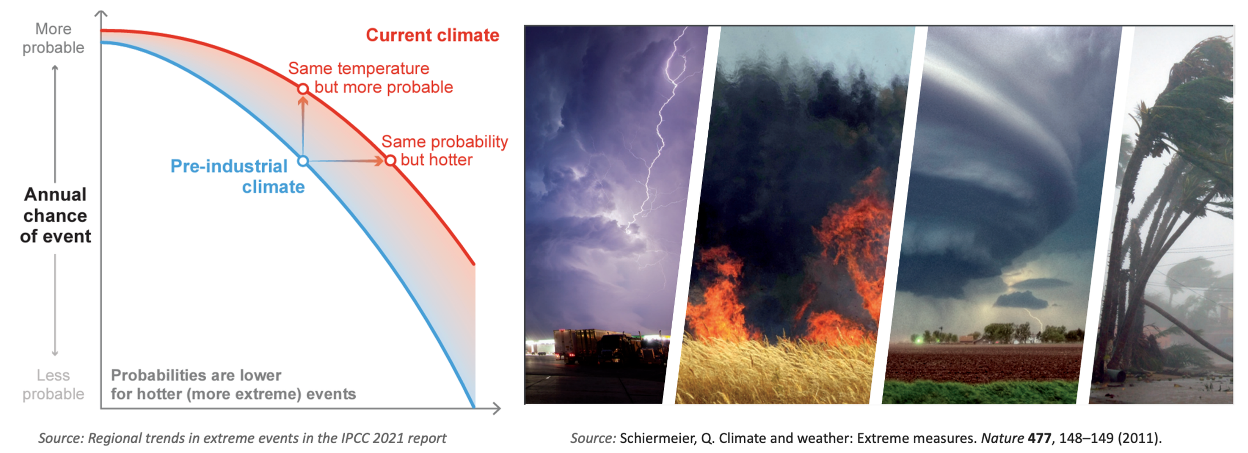

Figure 1: *Can increasing frequency and magnitude of climate extremes be associate with rising carbon emissions?*

- Net biospheric production (NBP), the total downward flux of carbon from the atmosphere to the land, represents the net carbon uptake after accounting for carbon losses from plant respiration, heterotrophic respiration, fire, and harvest and is a critical measure of land carbon storage.
- The growing terrestrial carbon sink provides negative feedback to climate change; however, exacerbating environmental changes and climate extremes, such as droughts, heatwaves, and fires, have the potential to reduce regional carbon stocks and moderate carbon uptake.

We investigated the extremes in NBP, also referred as carbon cycle extremes in this study, and their climate drivers from Earth system model simulations for the period 1850–2100 across several regions around the globe. The objectives of this research were to

1. quantify the magnitude, frequency, and spatial distribution of NBP extremes,
2. attribute individual and compound climate drivers of NBP extremes at multiple time lags, and
3. investigate the changes in climate-carbon cycle feedbacks at regional scales.

Data and Methods

Data

We used the Community Earth System Model (version 2) (CESM2) simulations at $1^\circ \times 1^\circ$ spatial and monthly temporal resolution. The CESM2 is a fully coupled global Earth system model composed of the atmosphere, ocean, land, sea ice, and land ice components. The simulations analyzed here were forced with atmospheric greenhouse gas concentrations, aerosols, and land use change for the historical (1850–2014) and Shared Socioeconomic Pathway 8.5 (SSP5-8.5; 2015–2100) scenario, wherein atmospheric CO_2 mole fraction rises from about 280 ppm in 1850 to 1150 ppm in 2100.

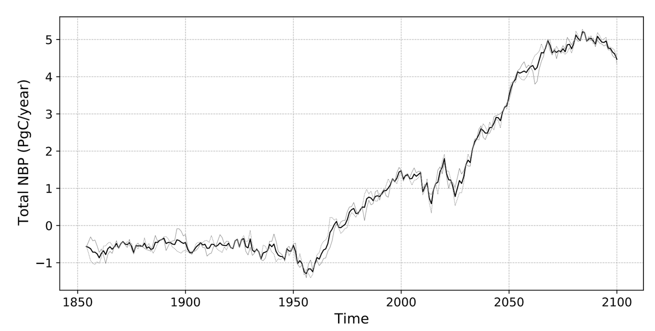

Figure 2: *The timeseries of globally integrated 5 year rolling mean of NBP from 1850–2100 for CESM2 ensemble members is shown in gray dashed lines. The timeseries of globally integrated 5 year rolling mean of multi-ensemble mean is shown in black solid line.*

Methods - Detection of NBP Extremes

We quantified the NBP extremes that were significant globally. We then compared the characteristics of global NBP extremes across SREX regions (defined in the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation).

- Anomalies$_{NBP}$ = Timeseries$_{NBP}$ − Nonlinear Trend$_{NBP}$ − Modulated Annual Cycle$_{NBP}$

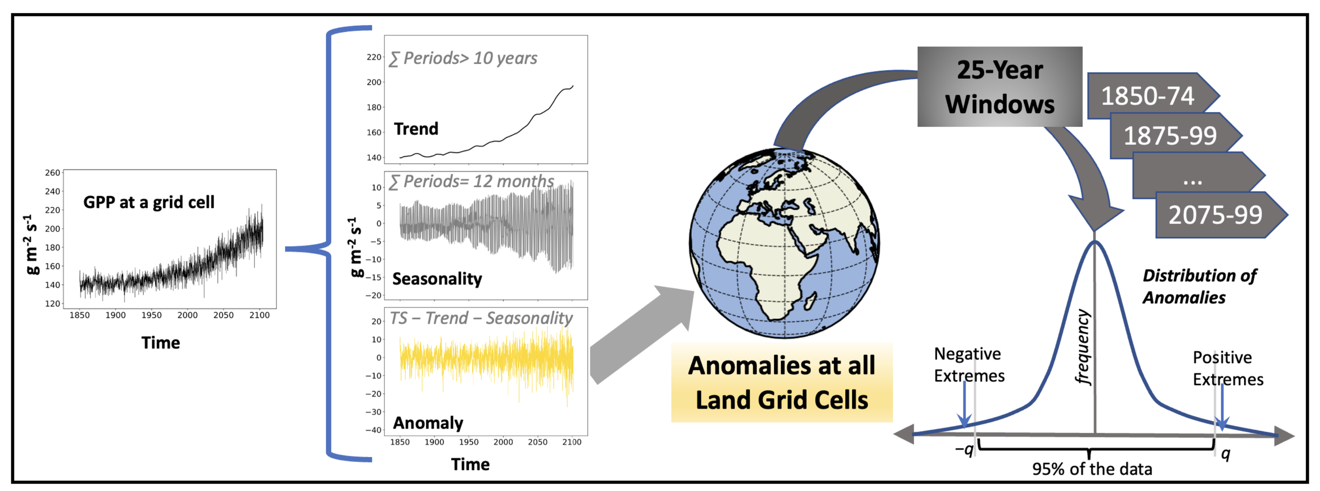

Figure 3: *The schematic diagram representing the NBP extremes. The threshold q is set at 5^{th} percentile in this study, such that 95% of the NBP anomalies lie within –q and q.*

Methods - Attribution of NBP Extremes to Climate Drivers

Using Pearson Correlation of time-continuous NBP extremes with anomalies of climate drivers, we quantified ($p < 0.05$):

- dominance (regression coefficient)
- response (sign of the regression coefficient)
- lagged response of climate on NBP extremes

Analysis of Carbon Cycle Extreme Events

- 5^{th} percentile NBP anomalies computed for every 25-year period from 1850 to 2100 rendered threshold trajectories that increased from 140 GgC/month to 220 GgC/month.
- The rate of increase of negative extremes in NBP (−834 MgC per month) was larger than positive extremes (804 MgC per month).

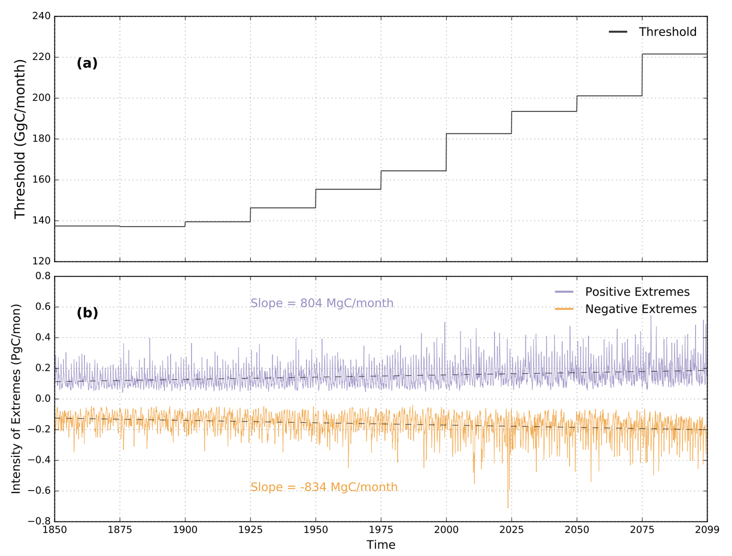

Figure 4: *(a) The 5^{th} percentile threshold, q, of NBP anomalies. The negative extremes in NBP are those NBP anomalies that are $< -q$ and positive extremes are $> q$. (b) The intensity of positive and negative extremes in NBP in CESM2 are represented by green and red color, respectively.*

- The distribution of the total magnitude and count of negative TCEs during 2075—99 across all the SREX regions followed a similar pattern, i.e., more frequent extremes were accompanied by larger carbon losses.
- The largest portion of carbon uptake loss was in the tropical SREX regions of the Amazon (AMZ), East Asia (EAS), and South Africa (SAF) for the period 2075—99.
- The magnitude and the total number of regions dominated by negative extremes in NBP are expected to gradually increase in the 21st century.

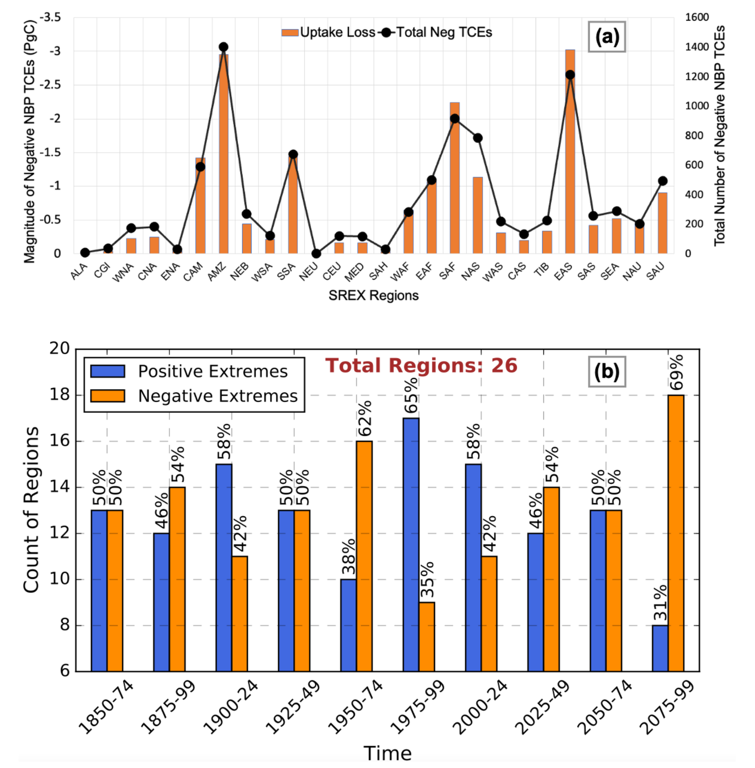

Figure 5: *(a) Total magnitude of negative carbon cycle extremes across SREX regions plotted as a bar graph (left y-axis). The total number of negative extremes (right y-axis) plotted as line graph. (b) Count (y-axis) of the regions dominated by either positive or negative NBP extremes.*

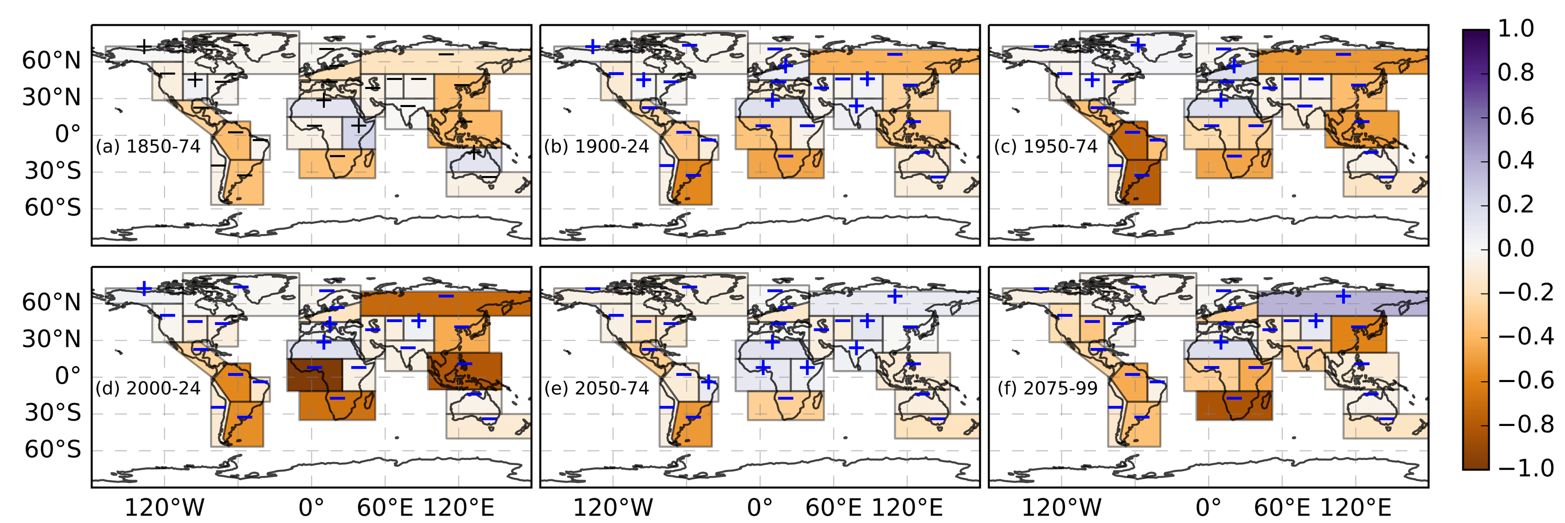

Figure 6: *The figure shows the sum of the magnitude of positive and negative NBP extremes during 25 year periods. The figure shows the total integrated net impact of carbon cycle extremes (PgC) across SREX regions for the following periods: (a) 1850–74, (b) 1900–24, (c) 1950–74, (d) 2000–24, (e) 2050–74, and (f) 2075–99. A net gain in carbon uptake during extremes is represented by a purple color and a '+' sign, and a net decrease is represented by an orange color and a '–' sign.*

- For most regions, the magnitude of negative NBP extremes in carbon uptake was higher than positive NBP extremes indicating that the impact of extremes results in a net loss of biomass productivity.
- The large magnitude of net carbon uptake changes during the period 2000–24 was likely due to the change in LULCC forcing from decadal to annual during 2000–2015.
- During 2075–99, 23 out of 26 SREX regions were dominated by negative NBP extreme events, especially in tropical regions.
- The losses in NBP during carbon cycle extremes were particularly large in the carbon-rich tropical region, followed by arid and semi-arid regions of the world.
- The globally integrated NBP in the CESM2 reached a peak around 2070, followed by a large decline toward the end of the 21st century.

Attribution to Climate Drivers

- The percent of the total number of grid cells that show soil moisture as a dominant driver of NBP TCEs was about 40 to 50% from 1850 to 2100 across multiple lags.
- The total number of grid cells dominated by precipitation doubled (10 to 20%) when the lag was increased from 1 to 3 months. This implies that antecedent declines in precipitation limit carbon uptake more than a recent decline in precipitation and possibly cause a decline in soil moisture.
- By the end of the 21st century, the model indicates that 70% of the total number of NBP extremes will be water-driven, i.e., due to soil moisture and precipitation.

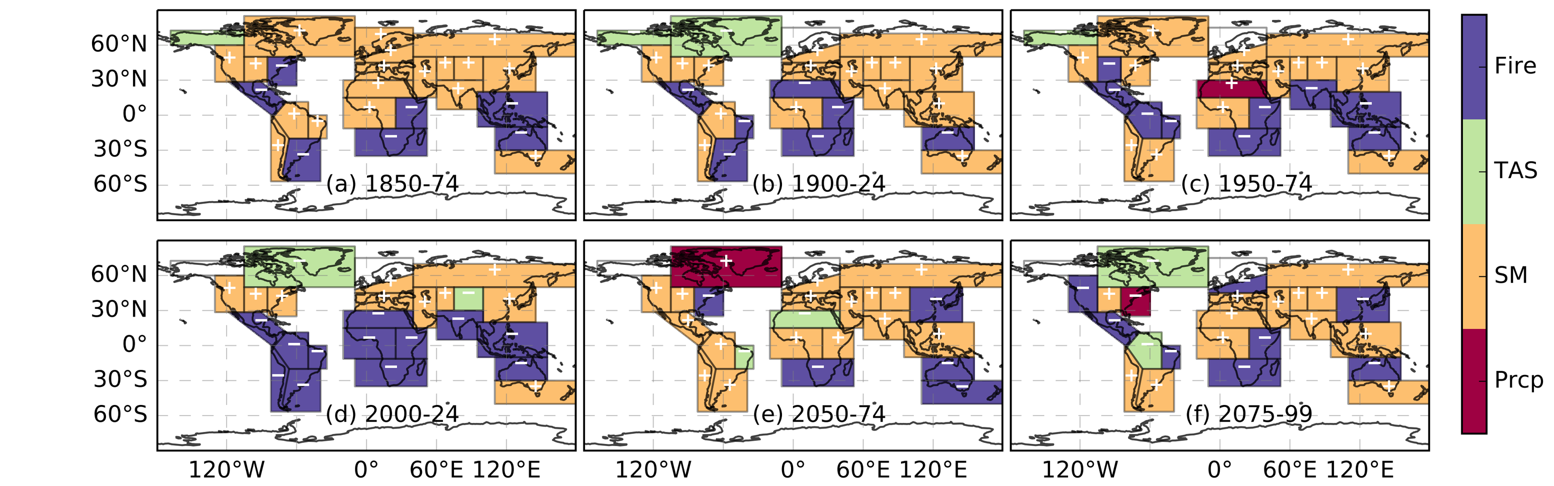

Figure 7: *Spatial distribution of dominant climate drivers across SREX regions. The color in every SREX region represents the most dominant climate driver causing carbon cycle extremes at 1 month lag for following periods: (a) 1850–74, (b) 1900–24, (c) 1950–74, (d) 2000–24, (e) 2050–74, and (f) 2075–99. The positive ('+') and negative ('–') sign within a region represents the correlation relationship of NBP extremes with every dominant climate drivers.*

- Every other extreme event associated with anomalous loss in biospheric productivity was driven by the interactive effect of water limitation, and hot days (heat waves), both of which together could trigger fire and rapid loss of carbon.
- Although the negative impact of water limitation (dry) on NBP extremes was the highest (driving inclusively about 90% of all NBP extremes), rising atmospheric CO_2 concentration and climate change led to an increasing number, 54% during 1900–24 to 62% during 2050–74, of NBP extremes driven inclusively by hot climatic conditions. For the same periods, extremes driven inclusively by hot & dry rose by 8%.

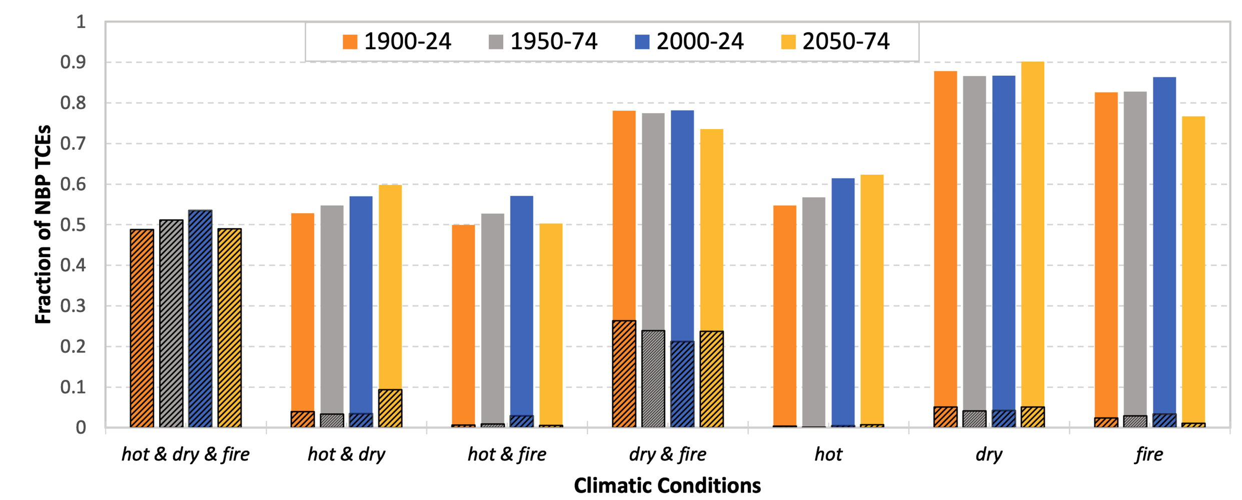

Figure 8: *Fractional distribution of carbon cycle time-continuous extremes (TCEs) driven by compound climate drivers at a lag of 1 month. The unhatched and hatched bars represent the mutually inclusive and exclusive compound and individual climate drivers, respectively. The exclusive climate drivers are always less than or equal to mutually inclusive drivers. The different colored bar represents the following periods: 1900–24, 1950–74, 2000–24, and 2050–74 (from left to right bar).*

Conclusions

Our analysis of carbon cycle extremes suggest:

- Increasing frequency and magnitude of negative carbon cycle extremes accelerate the weakening of carbon sink towards the end of the 21st century.
- Tropical regions with the largest standing biomass are expected to experience large and frequent carbon cycle extremes.
- The soil moisture anomalies are the largest driver of carbon cycle extremes. With increasing temperatures, the dominance of fire and hot drivers is expected to further increase.
- The compound effect of all three climate drivers (hot, dry, and fire) causes the largest fraction of NBP TCEs.

Read full paper at:

Sharma, B., Kumar, J., Ganguly, A. R., & Hoffman, F. M. (2022). "Carbon Cycle Extremes Accelerate Weakening of the Land Carbon Sink in the Late 21st Century". Biogeosciences Discuss. [preprint], https://doi.org/10.5194/bg-2022-178, in review, 2022.

Acknowledgement

This research was supported by the Reducing Uncertainties in Biogeochemical Interactions through Synthesis and Computation (RUBISCO) Science Focus Area, which is sponsored by the Regional and Global Model Analysis (RGMA) activity of the Earth & Environmental Systems Modeling (EESM) Program in the Earth and Environmental Systems Sciences Division (EESSD) of the Office of Biological and Environmental Research (BER) in the US Department of Energy (DOE) of Science. ORNL is managed by UT-Battelle, LLC, for the DOE under contract DE-AC05-00OR22725.