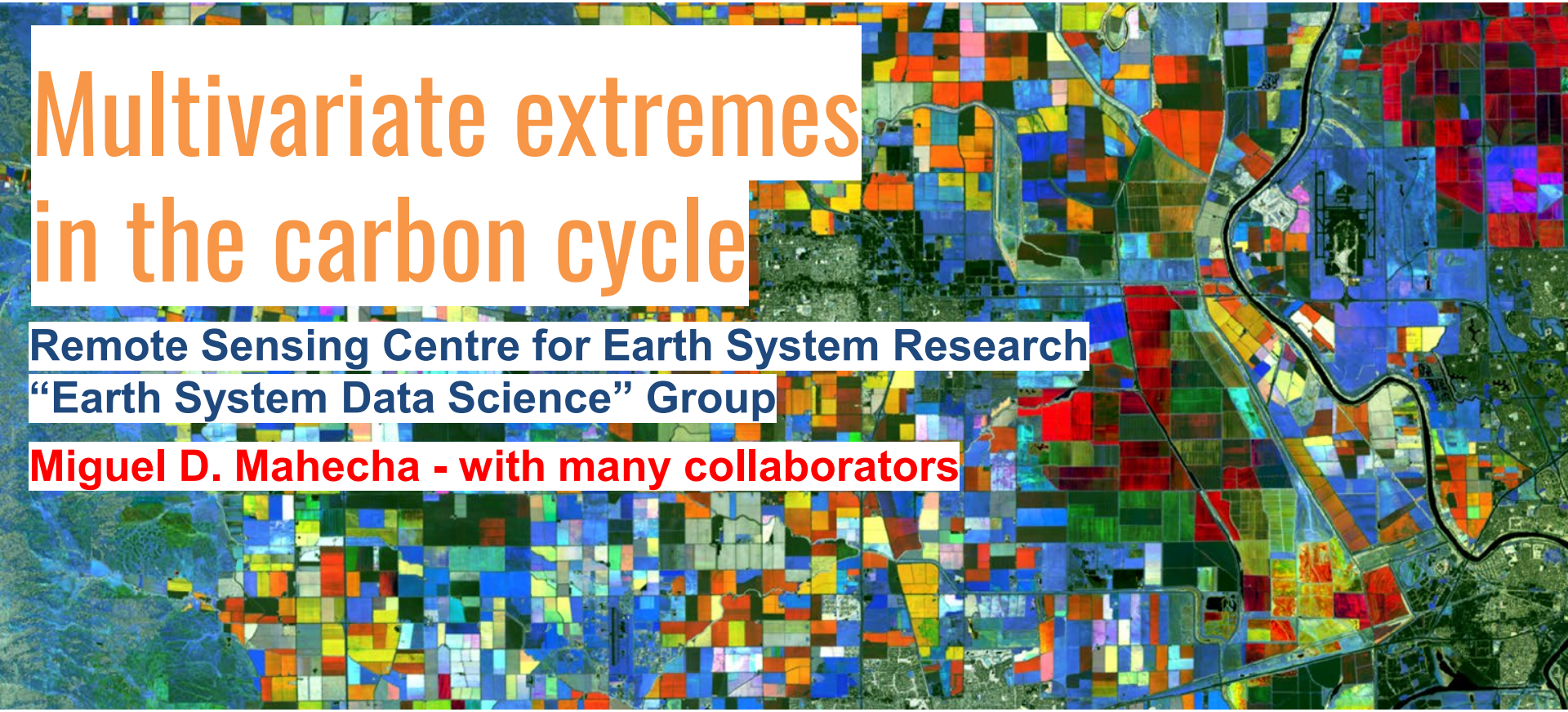
Multivariate extremes in the carbon cycle



Remote Sensing Centre for Earth System Research

“Earth System Data Science” Group

Miguel D. Mahecha - with many collaborators

UNIVERSITÄT LEIPZIG

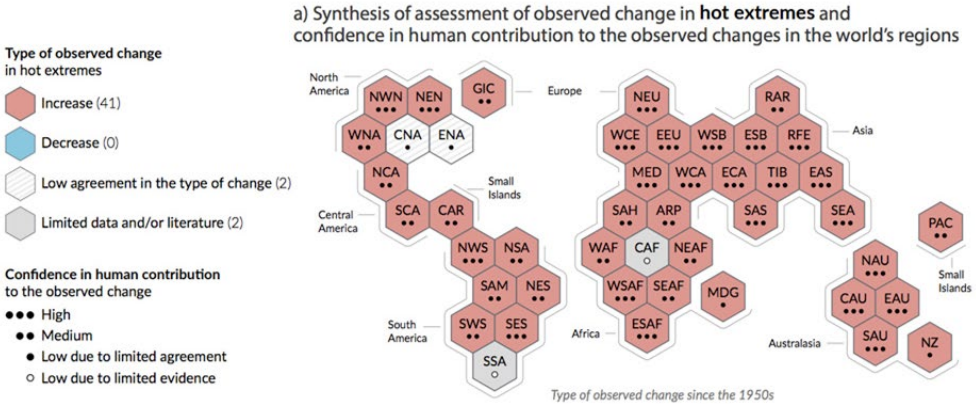
UFZ HELMHOLTZ Zentrum für Umweltforschung

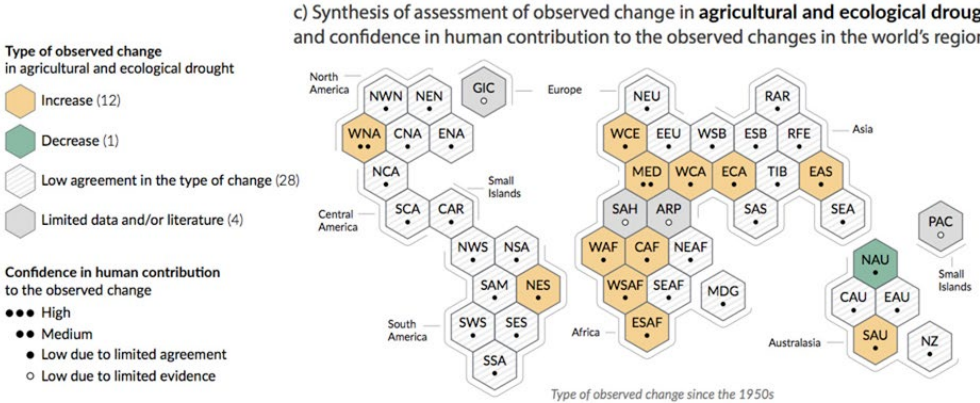
Personal twitter: @miguelmahechag1

Group web rsc4earth.de and @rsc4earth

Background: *Extremes and the biosphere*

Climate extremes are on the rise





IPCC AR6 WGI reference regions: North America: NWN (North-Western North America, NEN (North-Eastern North America), WNA (Western North America), CNA (Central North America), ENA (Eastern North America), Central America: NCA (Northern Central America), SCA (Southern Central America), CAR (Caribbean), South America: NWS (North-Western South America), NSA (Northern South America), NES (North-Eastern South America), SAM (South American Monsoon), SWS (South-Western South America), SES (South-Eastern South America), SSA (Southern South America), Europe: GIC (Greenland/Iceland), NEU (Northern Europe), WCE (Western and Central Europe), EEU (Eastern Europe), MED (Mediterranean), Africa: MED (Mediterranean), SAH (Sahara), WAF (Western Africa), CAF (Central Africa), NEAF (North Eastern Africa), SEAF (South Eastern Africa), WSAF (West Southern Africa), ESAF (East Southern Africa), MDG (Madagascar), Asia: RAR (Russian Arctic), WSB (West Siberia), ESB (East Siberia), RFE (Russian Far East), WCA (West Central Asia), ECA (East Central Asia), TIB (Tibetan Plateau), EAS (East Asia), ARP (Arabian Peninsula), SAS (South Asia), SEA (South East Asia), Australasia: NAU (Northern Australia), CAU (Central Australia), EAU (Eastern Australia), SAU (Southern Australia), NZ (New Zealand), Small Islands: CAR (Caribbean), PAC (Pacific Small Islands)Figure SPM.3a from AR6 WGI Summary of Policymakers, IPCC.

What are the effects on the carbon cycle?

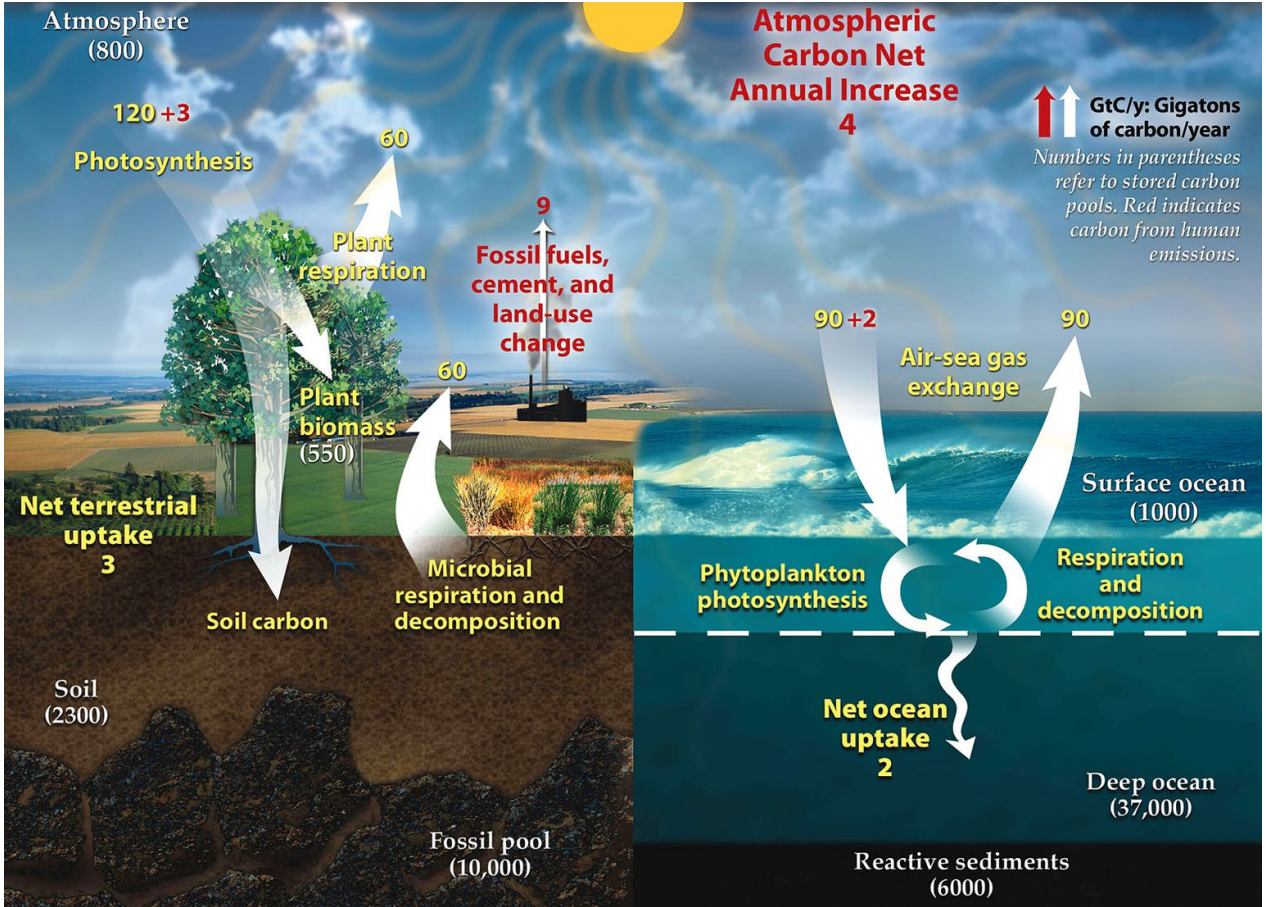
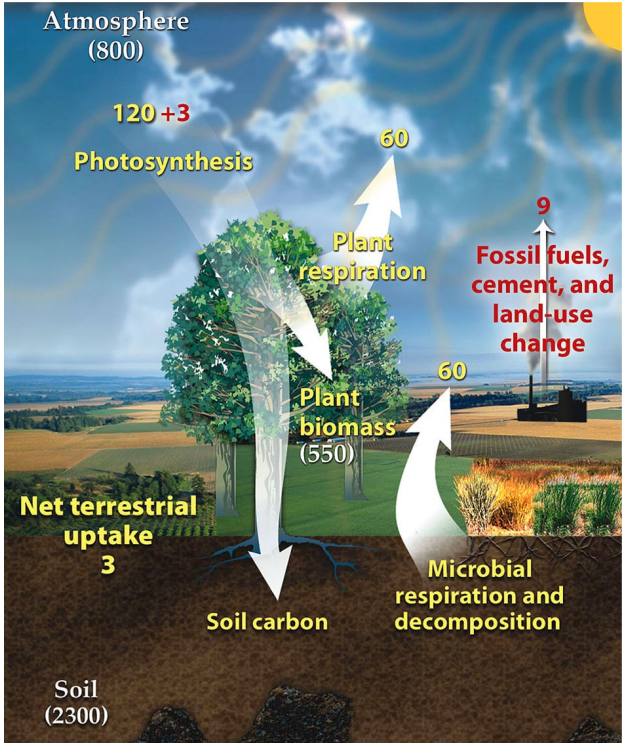
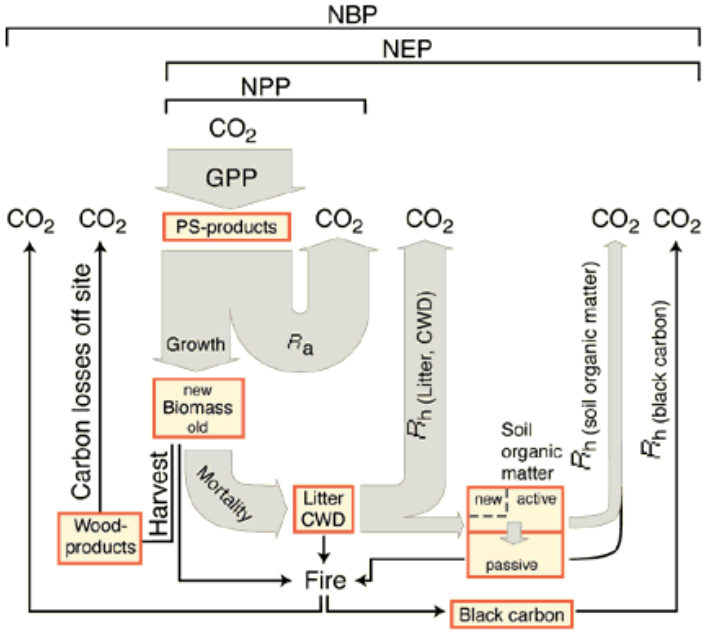


Diagram adapted from U.S. DOE, Biological and Environmental Research Information System. - http://earthobservatory.nasa.gov/Features/CarbonCycle/

What are the effects on the carbon cycle?

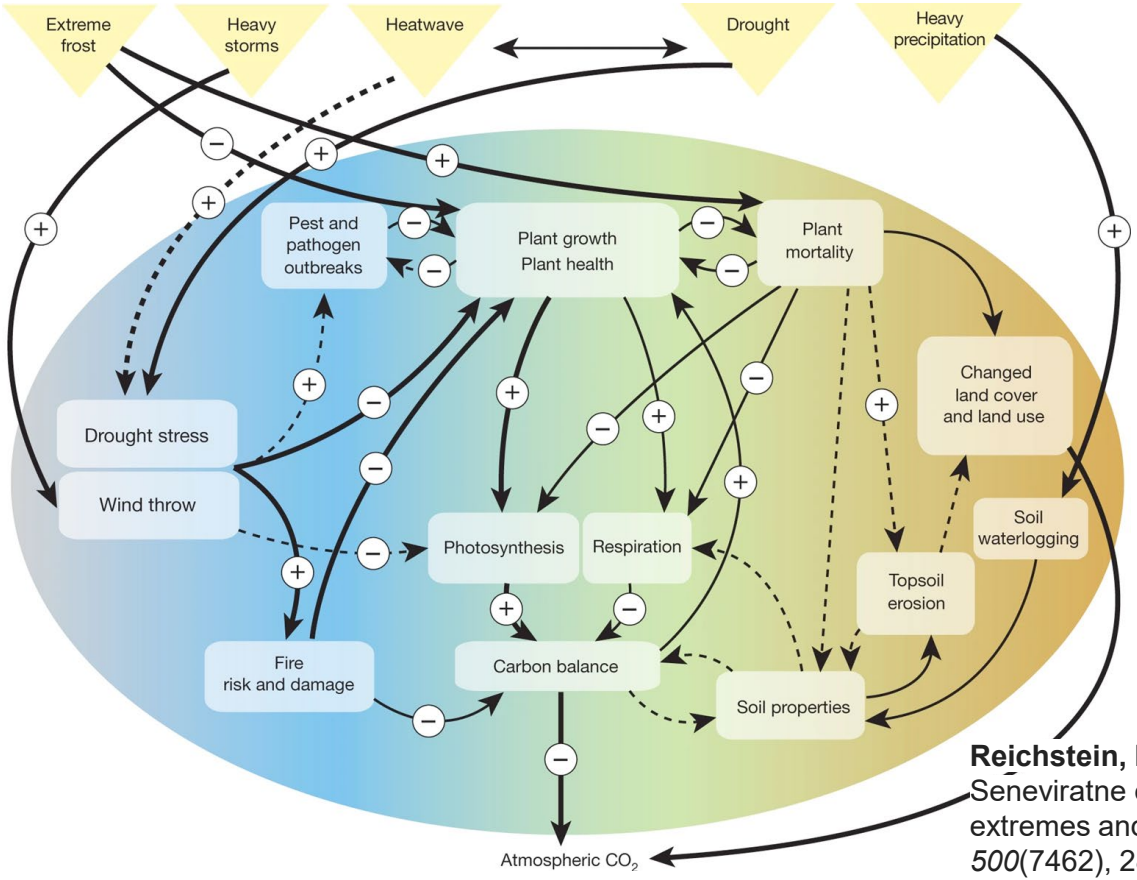




Schulze (2006) Biogeosciences, 3, 147–166,

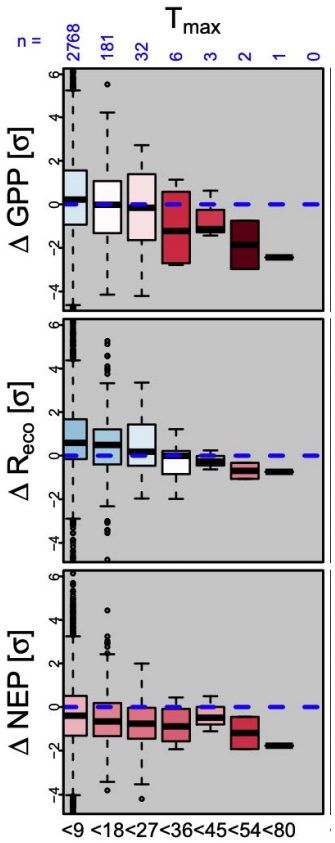
GPP = Gross Primary Productivity: Total uptake of CO_2
NPP = Net Primary Productivity: GPP - Autotrophic Resp
NEP = Net Ecosystem Productivity
NEP = GPP - Respiration

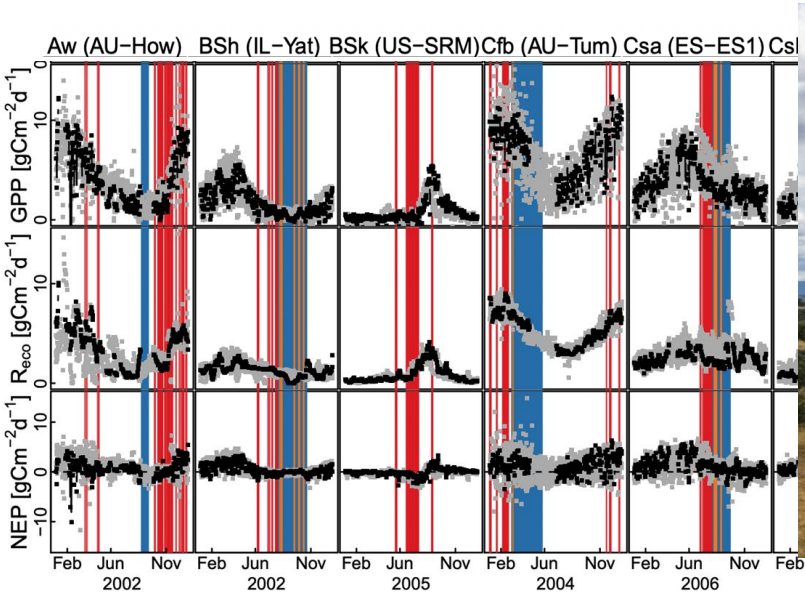
Multiple pathways possible

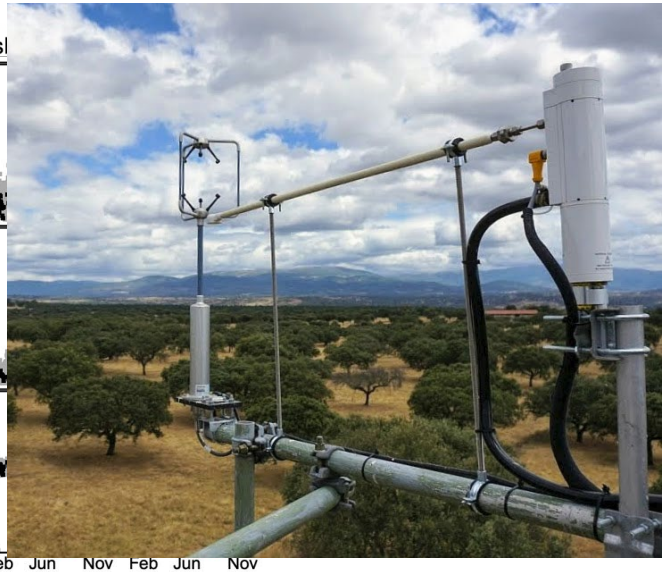


Reichstein, Bahn, Ciais, Frank, Mahecha, Seneviratne et al. (2013). Climate extremes and the carbon cycle. *Nature*, *500*(7462), 287-295.

Can we see that in in-situ measurements?

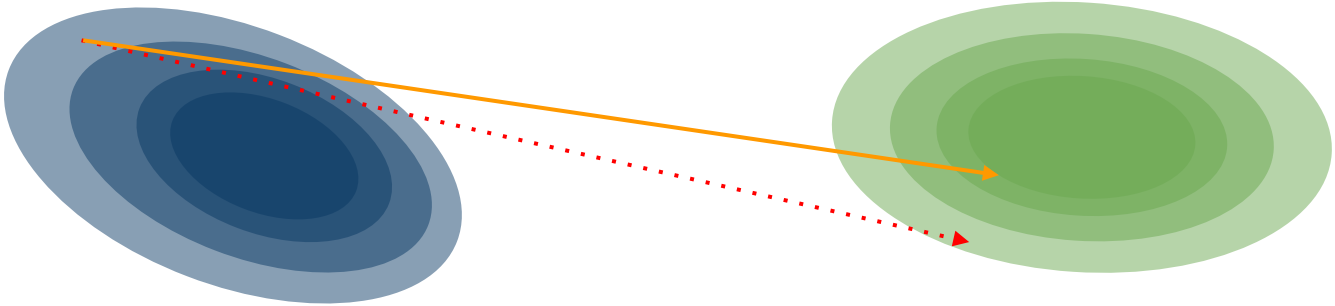






von Buttlar, J., Zscheischler, J.,... & Mahecha, M. D. (2018). Impacts of droughts and extreme-temperature events on gross primary production and ecosystem respiration: a systematic assessment across ecosystems and climate zones. *Biogeosciences*, *15*(5), 1293-1318.

Some overarching question:



n-Dim Climate System

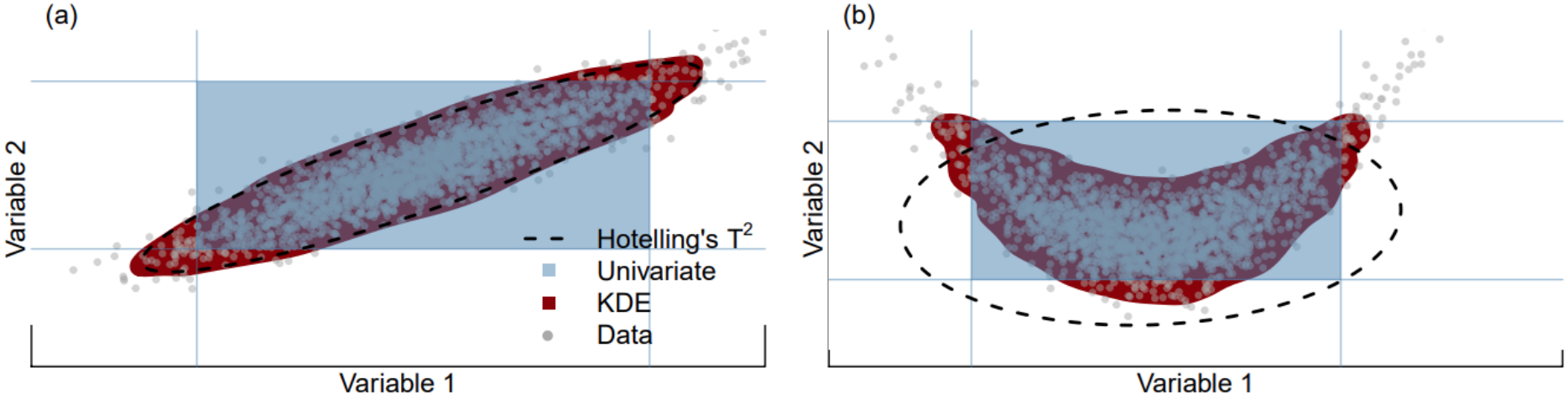
n-Dim Terrestrial Biosphere

- *How to consider that events originate from multivariate/compound events?*
- *Why do we see sometimes extreme responses, why sometimes not?*
- *Can similar climate extremes lead to the different responses? If so, what is controlling that?*

Multidimensional extremes:

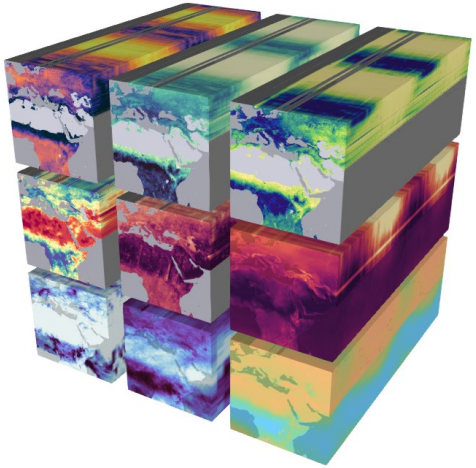
Based on analysis ready data cubes

What are multivariate extremes then?

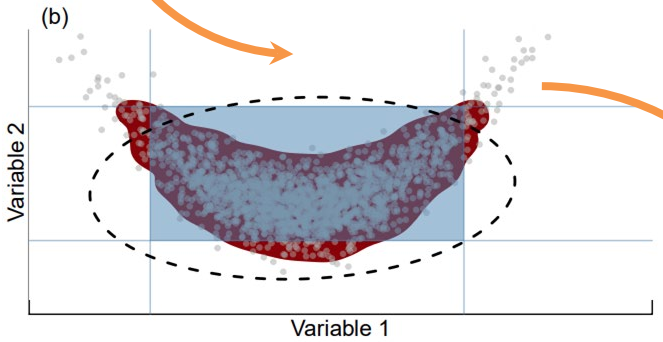


Flach, M., Sippel, S., … & Mahecha, M. D. (2018). Contrasting biosphere responses to hydrometeorological extremes: revisiting the 2010 western Russian heatwave. *Biogeosciences*, *15*(20), 6067-6085.

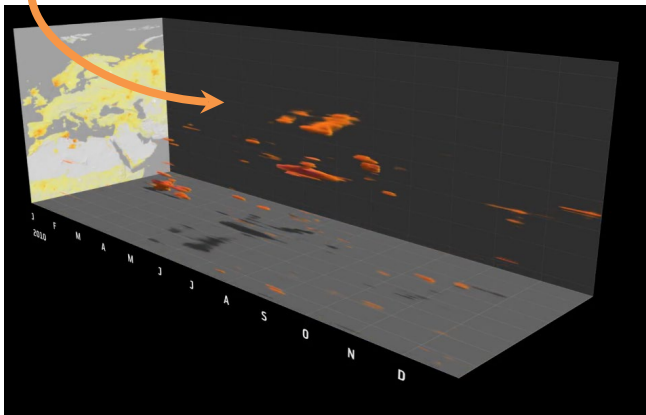
What are multivariate extremes then?



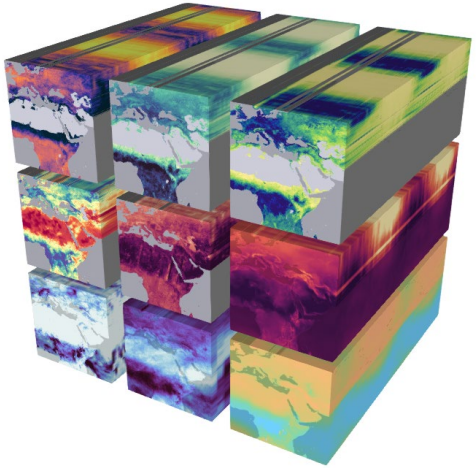
Mahecha., Gans., … & Reichstein (2022). *Earth System Dynamics, 11, 201.234*

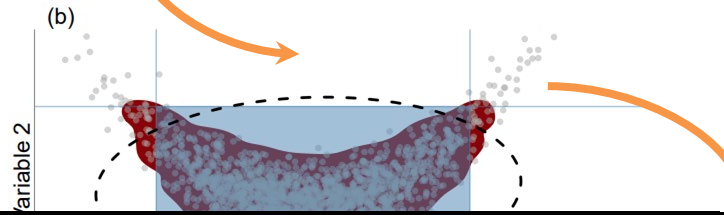


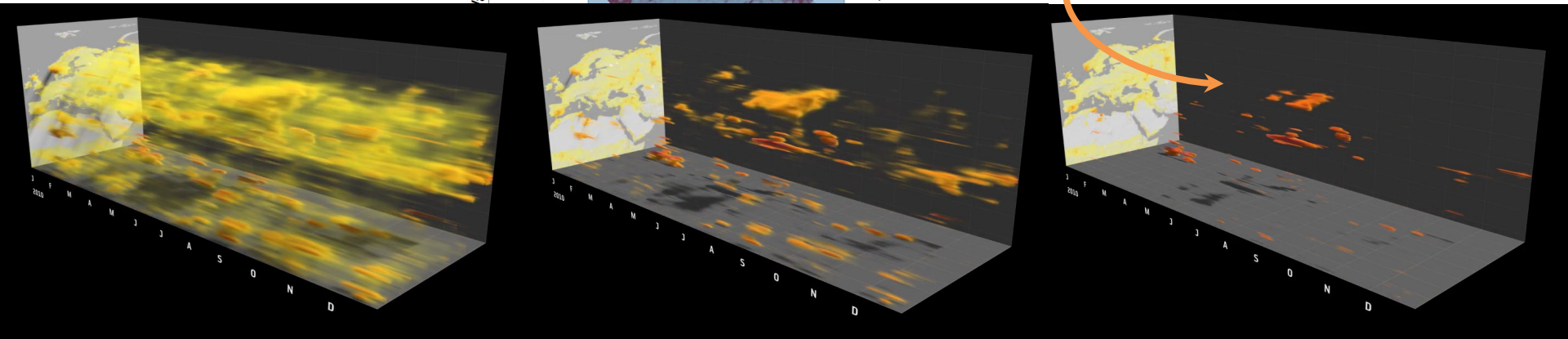
Flach., … & Mahecha, M. D. (2018). *Biogeosciences*, *15*(20), 6067-6085.



We need a spatiotemporal event detector

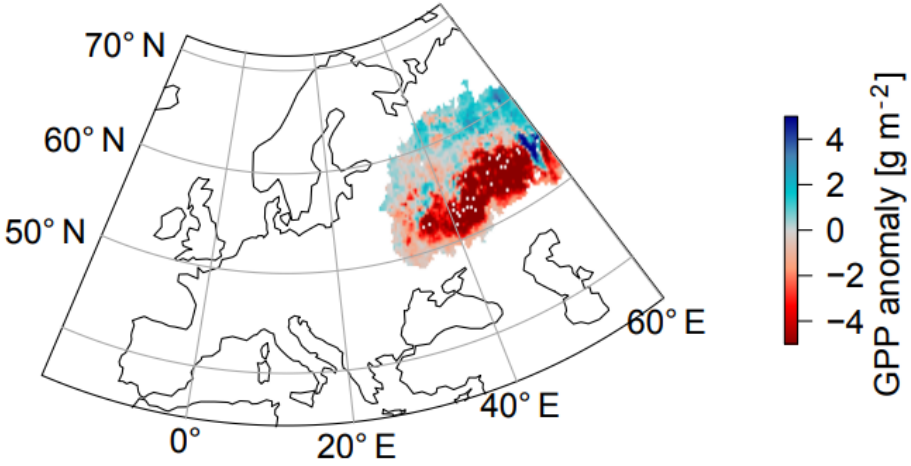




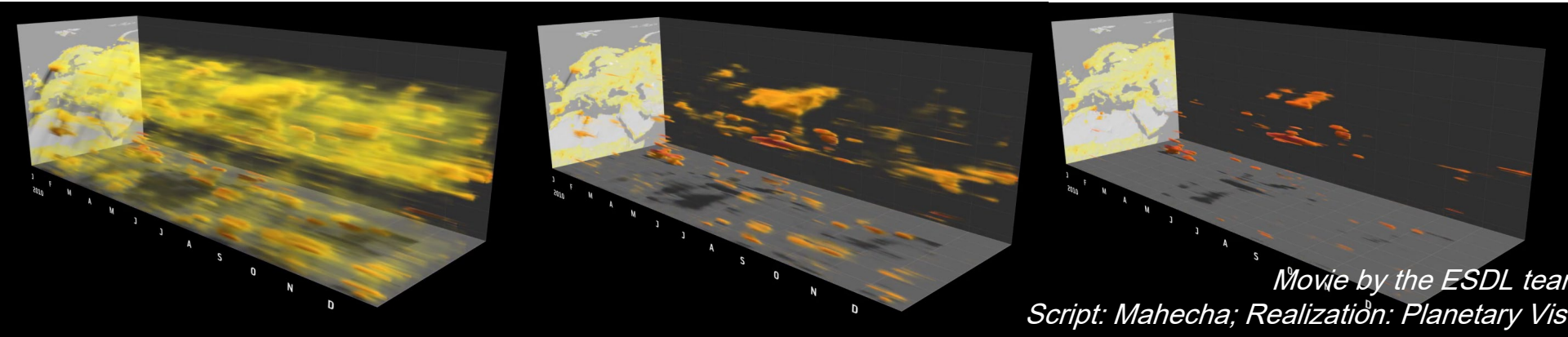


Multivariate extreme event detection:
Impacts on the carbon cycle

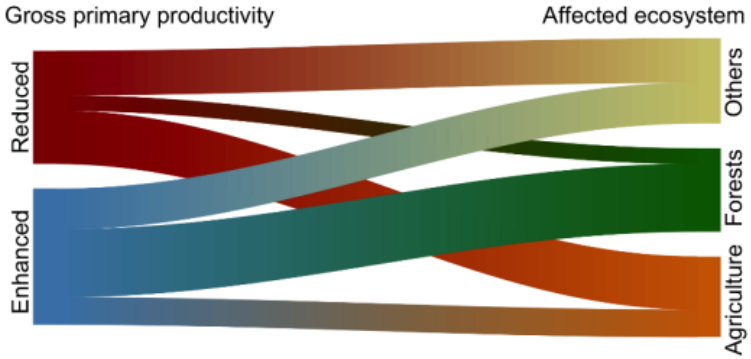
What are the responses of the biosphere?



Flach, M., et al. (2021). *Biogeosciences*, *18*(1), 39-53.



GPP anomalies are positive and negative



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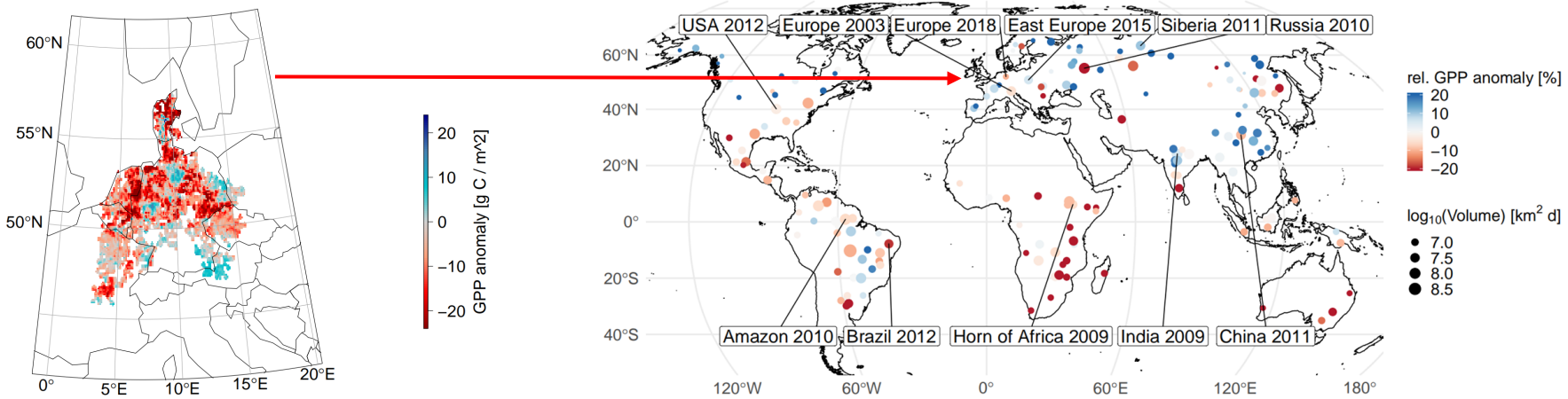
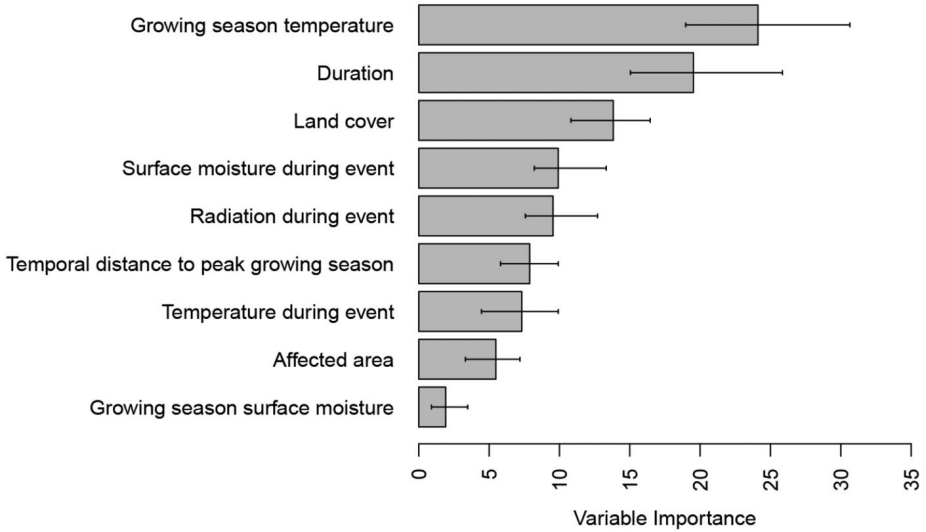
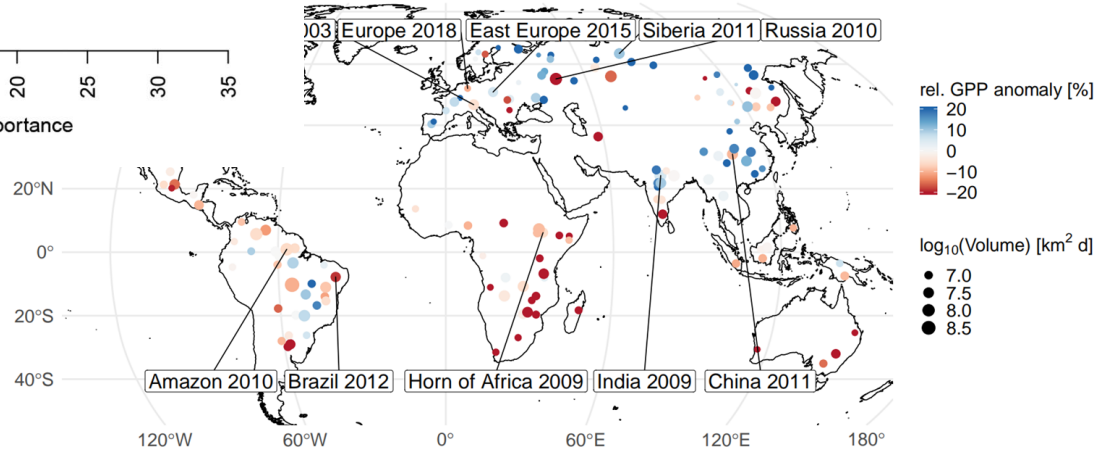


Global responses of GPP to extremes



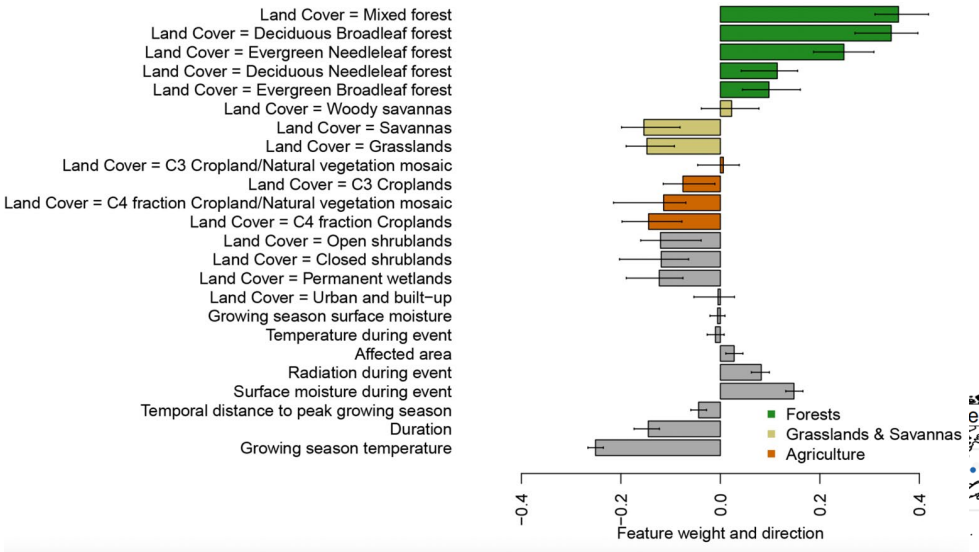
Explaining with ML what determines the direction of impacts

Flach, M., et al. (2021). *Biogeosciences*, *18*(1), 39-53.



Global responses of GPP to extremes

No lag effects …



Explaining with ML what determines the direction of impacts

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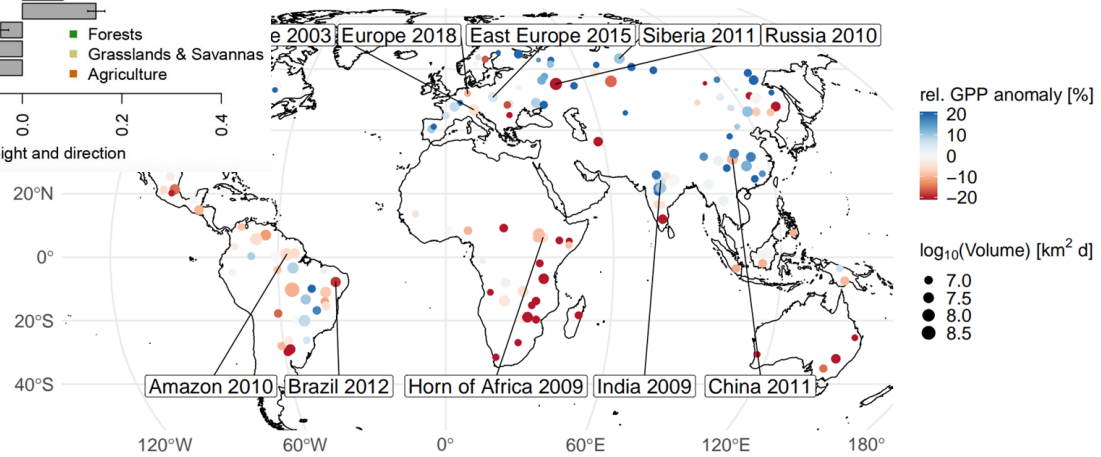
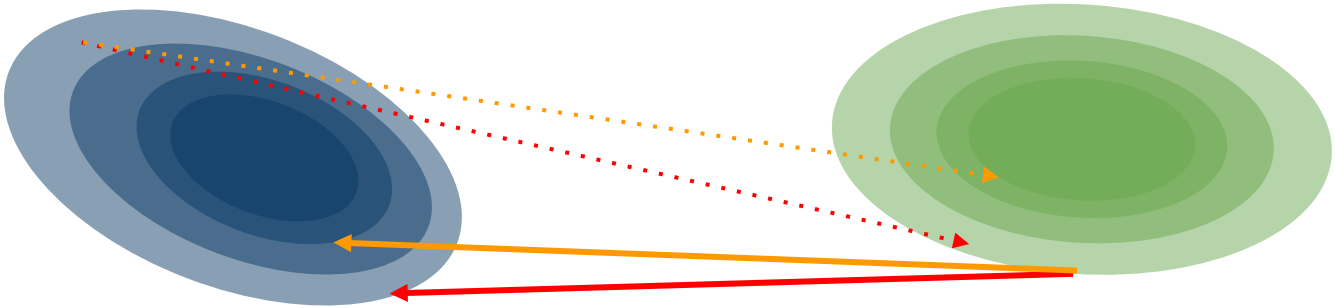


Multivariate anomalies in the responses:

The inverse approach

The backward idea to event detection



n-Dim Climate System

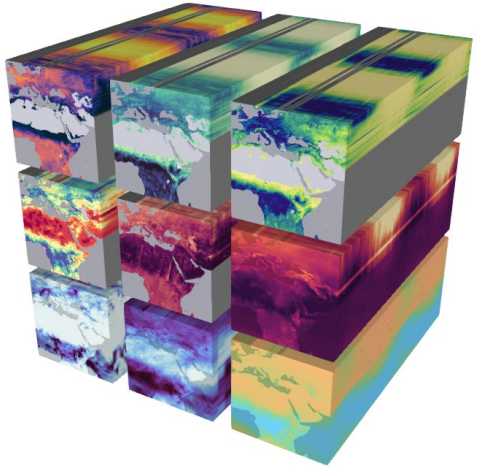
n-Dim Terrestrial Biosphere

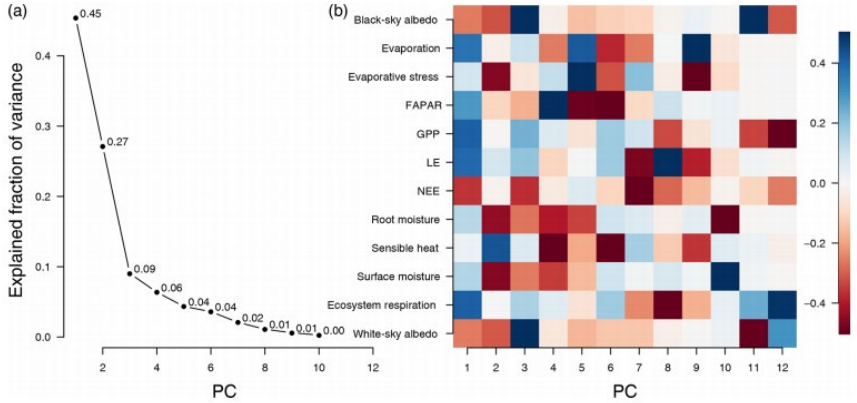
Forward: Detect extremes in the climate system → understand anomalous vegetation responses

Backward: Detect extremes in the biosphere → understand driving climate anomalies

The backward idea to event detection

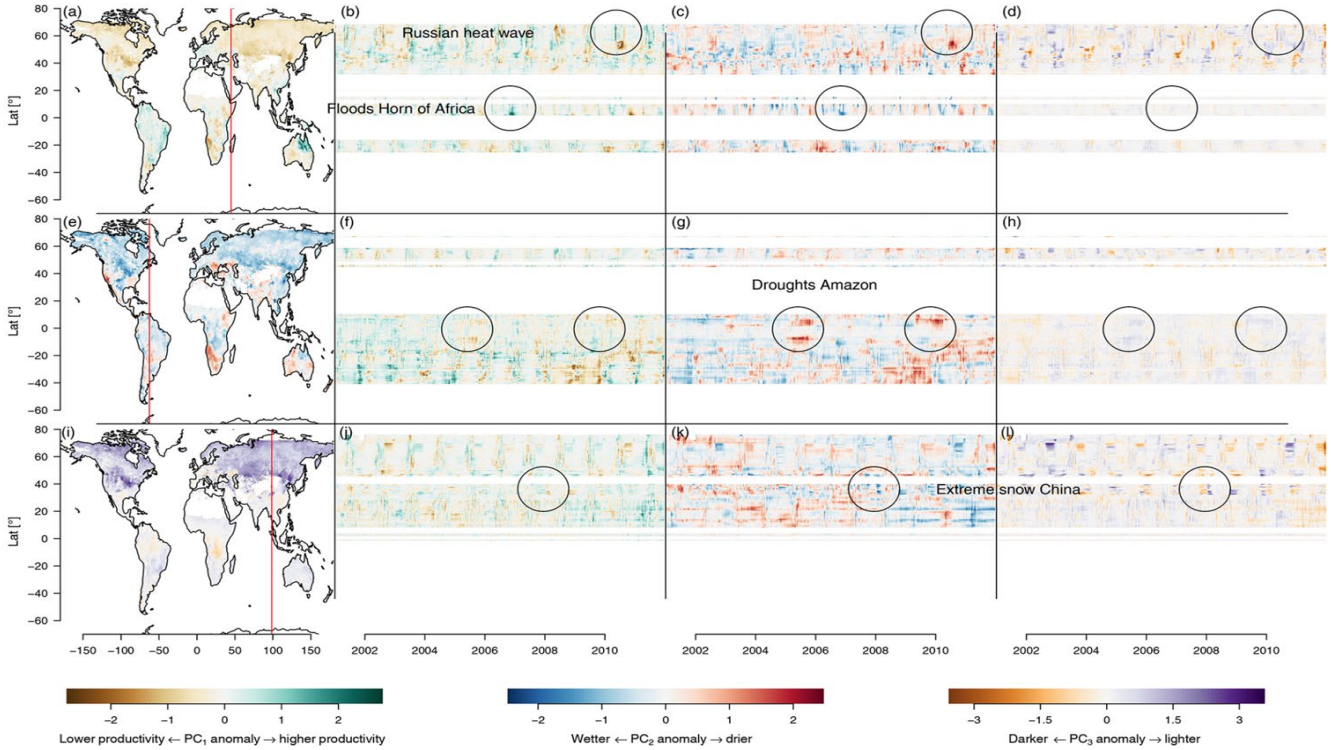
- Dimensionality reduction of relevant land surface data
- Interpretation of the impacts and dynamics





Kraemer, G., Camps-Valls, G., Reichstein, M., & Mahecha, M. D. (2020). Summarizing the state of the terrestrial biosphere in few dimensions. *Biogeosciences*, *17*(9), 2397-2424.

Low-dimensional land surface anomalies

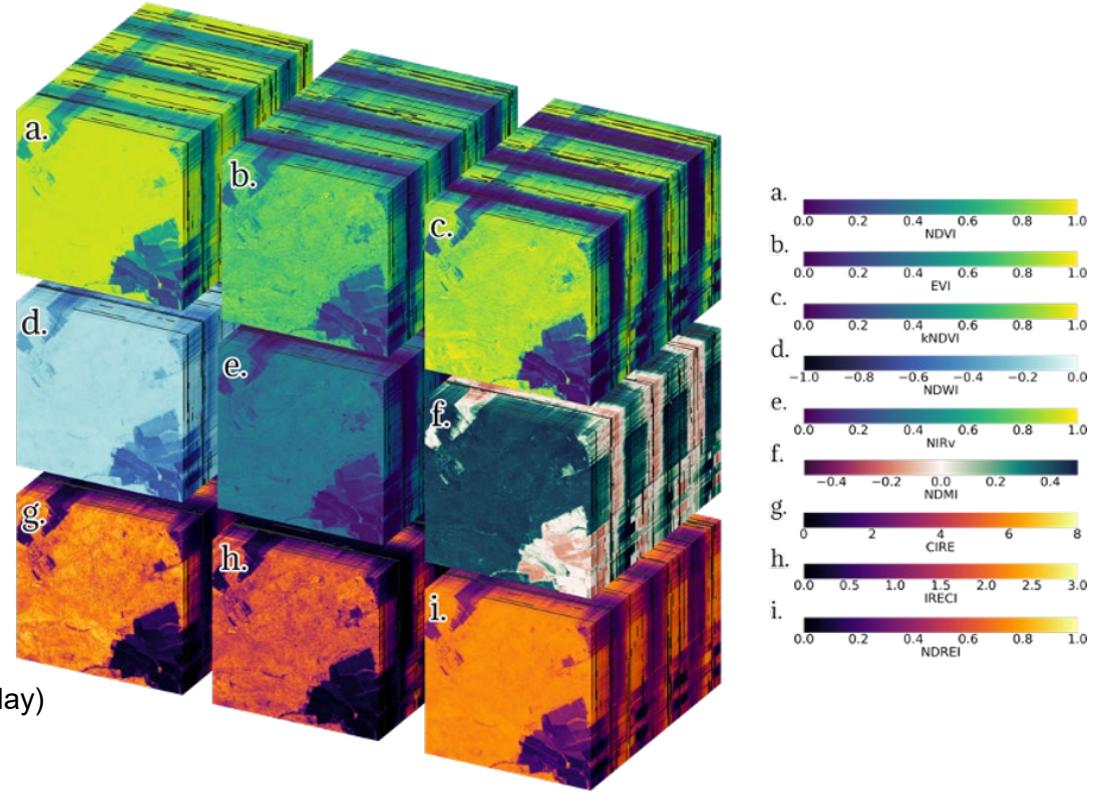


Kraemer, G., Camps-Valls, G., Reichstein, M., & Mahecha, M. D. (2020). Summarizing the state of the terrestrial biosphere in few dimensions. *Biogeosciences*, *17*(9), 2397-2424.

Challenges ahead:

Potential and limitations of remote sensing

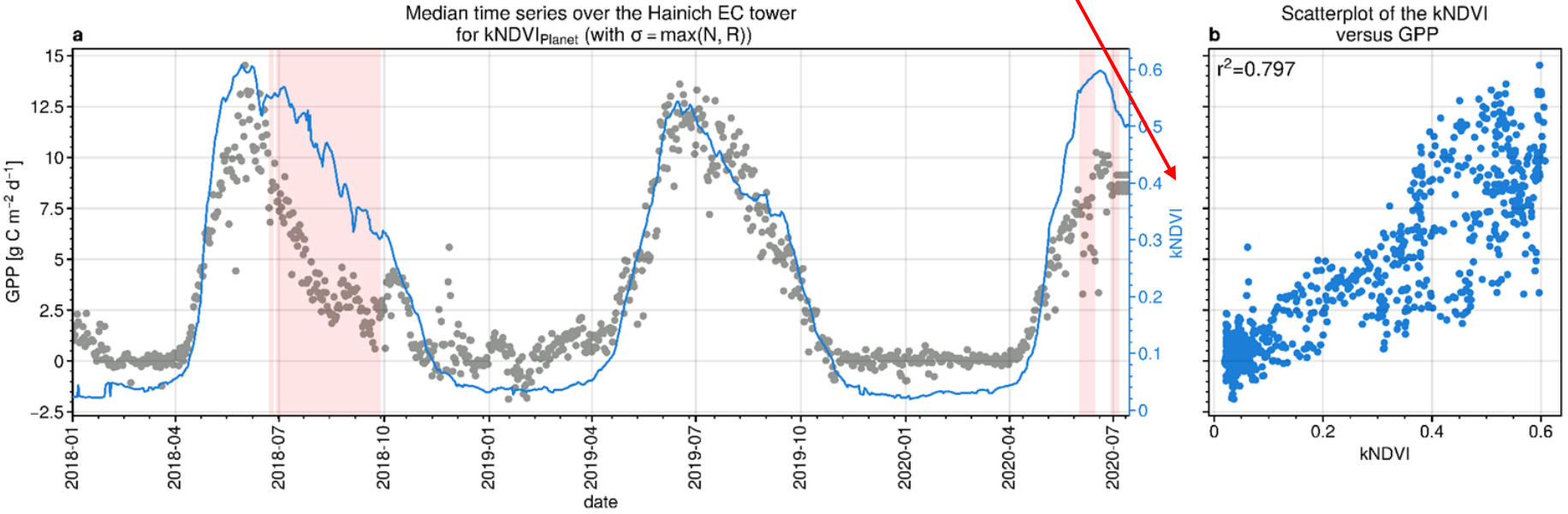
Relevant to address regional issues



David Montero (in prep), Poster C1.07 ML4Earth (Thursday)
visualization **Maximilian Söchting** via **lexcube.org**

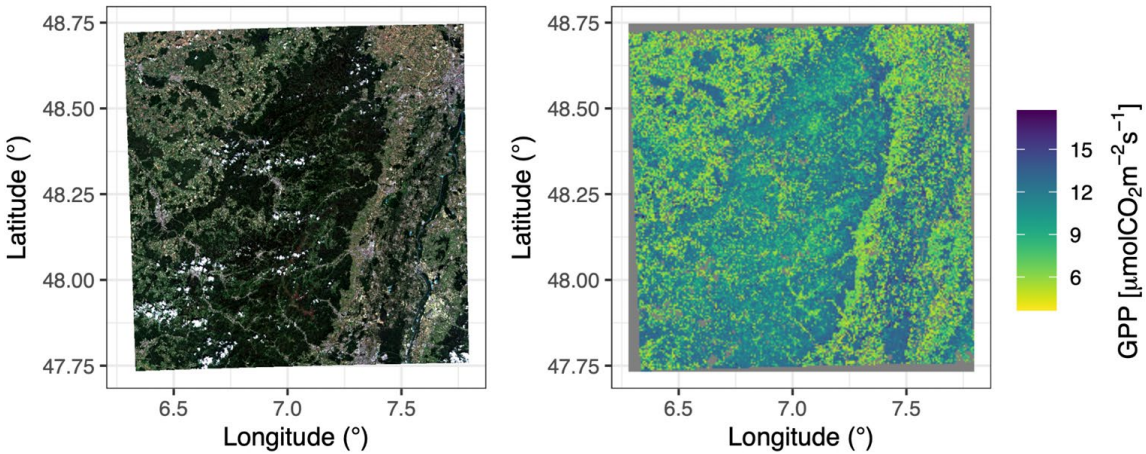
Limits of remote sensing

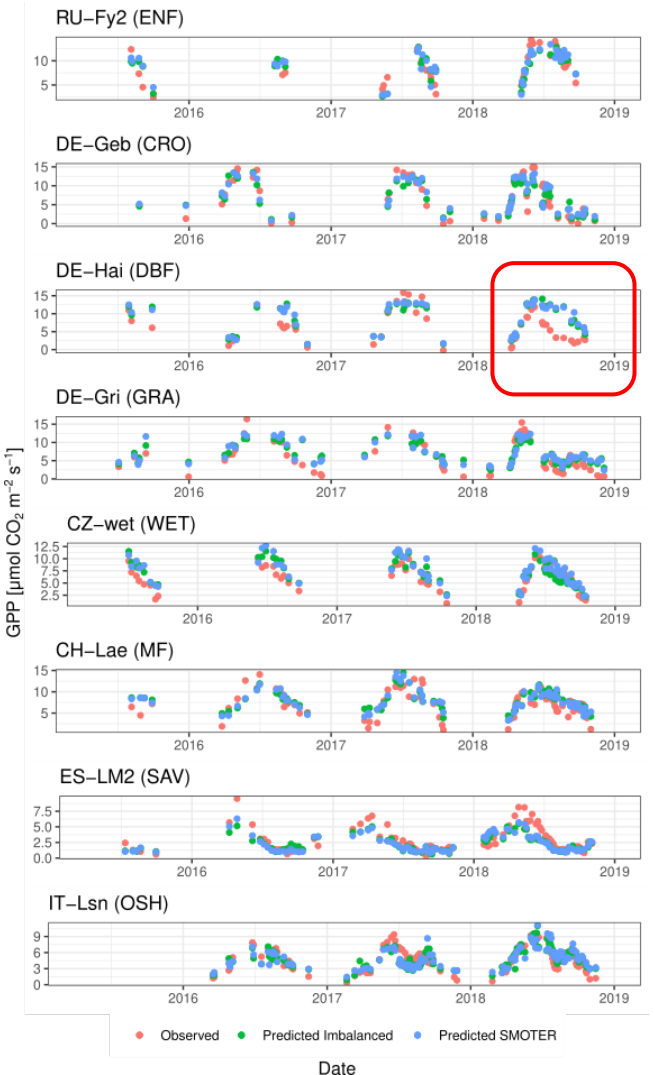
Camps-Valls, G., Campos-Taberner, M., Moreno-Martínez, Á., Walther, S., Duveiller, G., Cescatti, A. Mahecha, M.D., ... & Running, S. W. (2021). A unified vegetation index for quantifying the terrestrial biosphere. *Science Advances*, *7*(9), eabc7447.



Montero, D., … & Wieneke, S. (in prep)

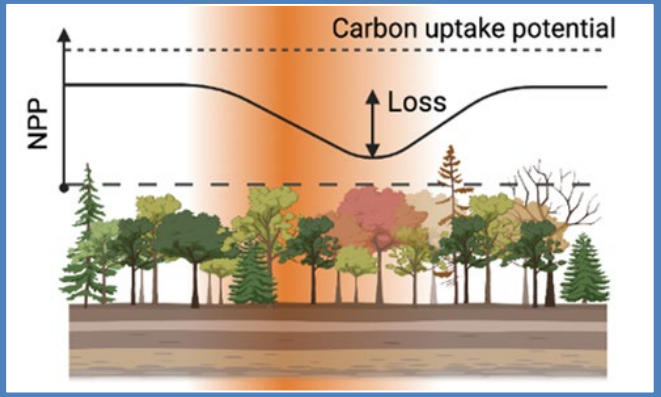
Limits of remote sensing





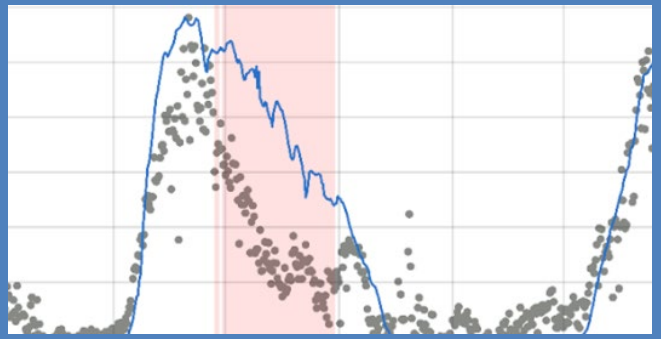
Pabon, D., et al. (2022). *IEEE Transactions on Geoscience and Remote Sensing.* 10.1109/TGRS.2022.3152272

Take home message and challenges ahead

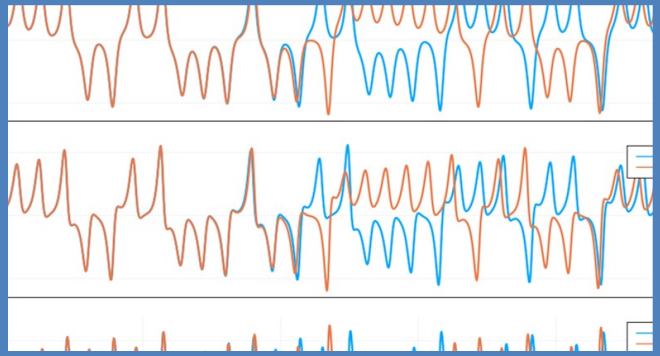


Impacts of extremes depend on ecosystem structure and diversity

Biggest challenge is probably disentangling temporal sequences



Higher spatial and spectral resolutions will not solve all challenges



Machine learning will help, once it is able to disentangle complex dynamics