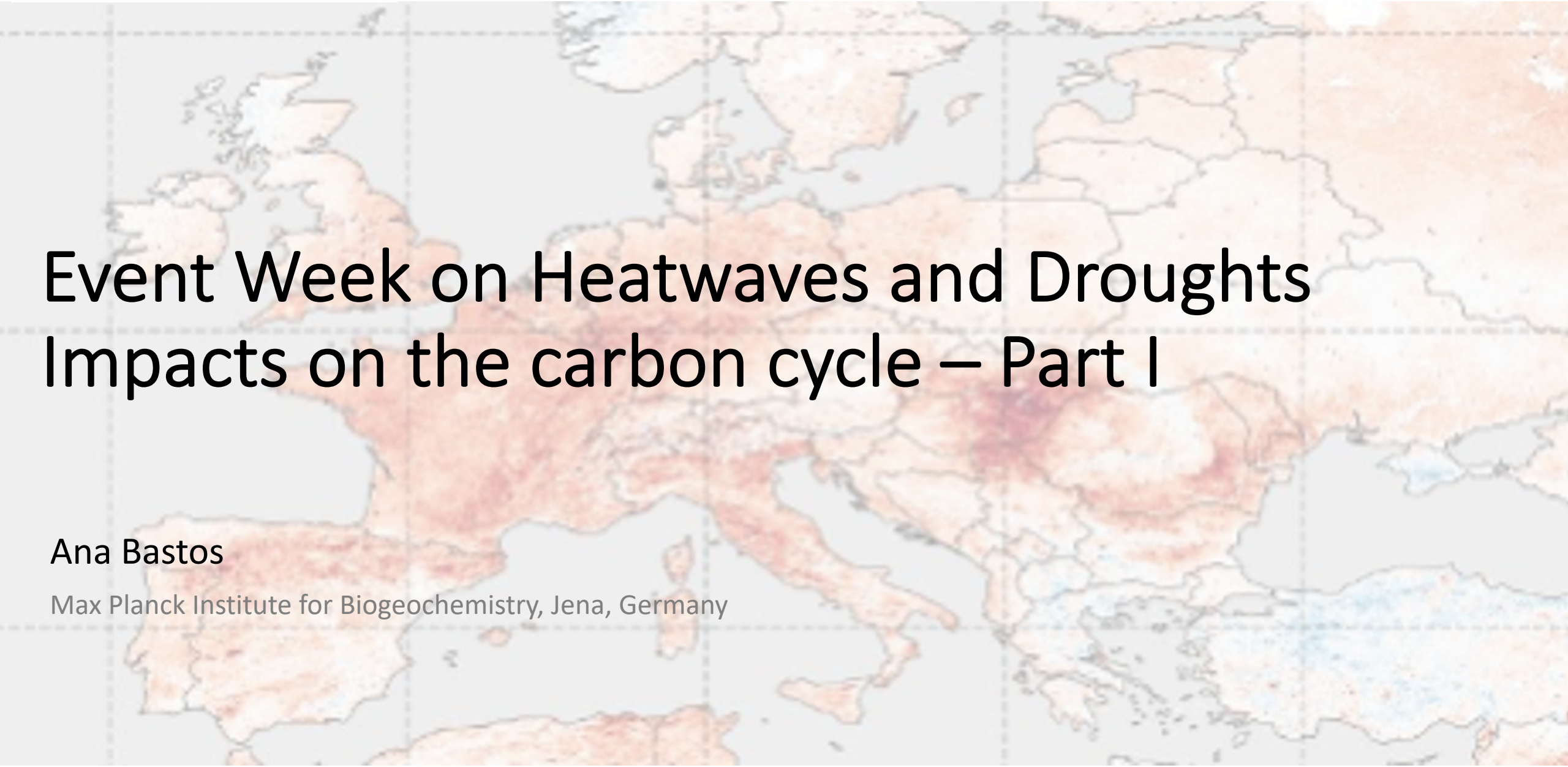
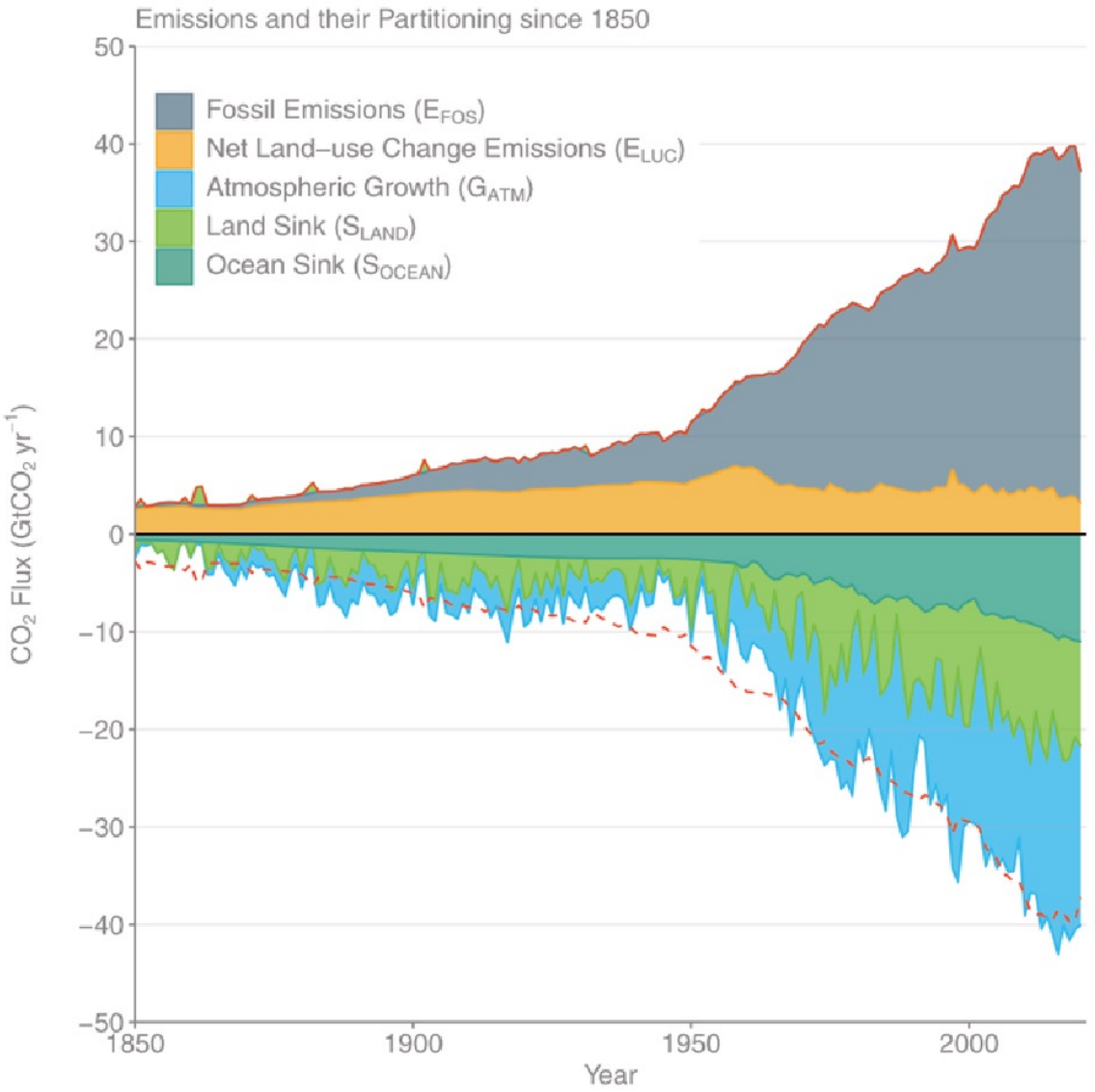


# Event Week on Heatwaves and Droughts
# Impacts on the carbon cycle – Part I

Ana Bastos

Max Planck Institute for Biogeochemistry, Jena, Germany

# Biosphere is a key component of the global carbon budget




Fossil carbon
89%

Land use change
11%

≈

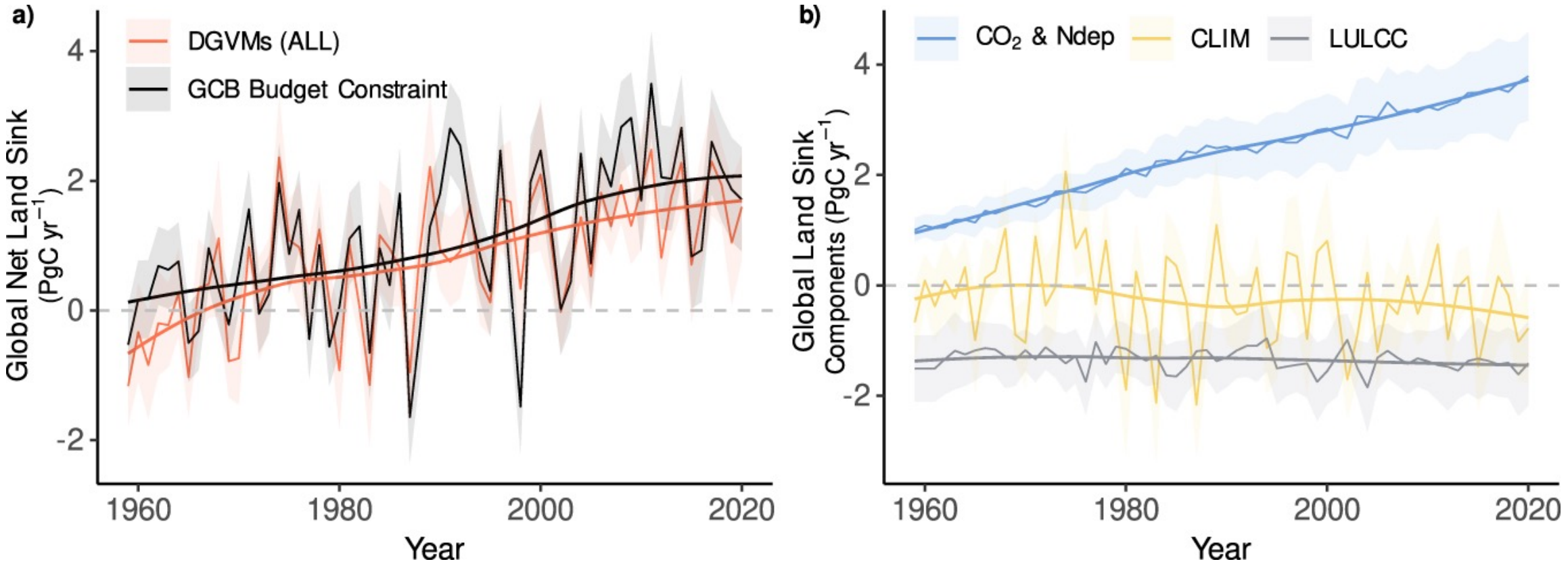
Ocean sink
26%

Land sink
29%

Atmosphere
48%

Friedlingstein et al. (2021); Global Carbon Project 2021

# Climate change driving slow-down of the land $CO_2$ sink?



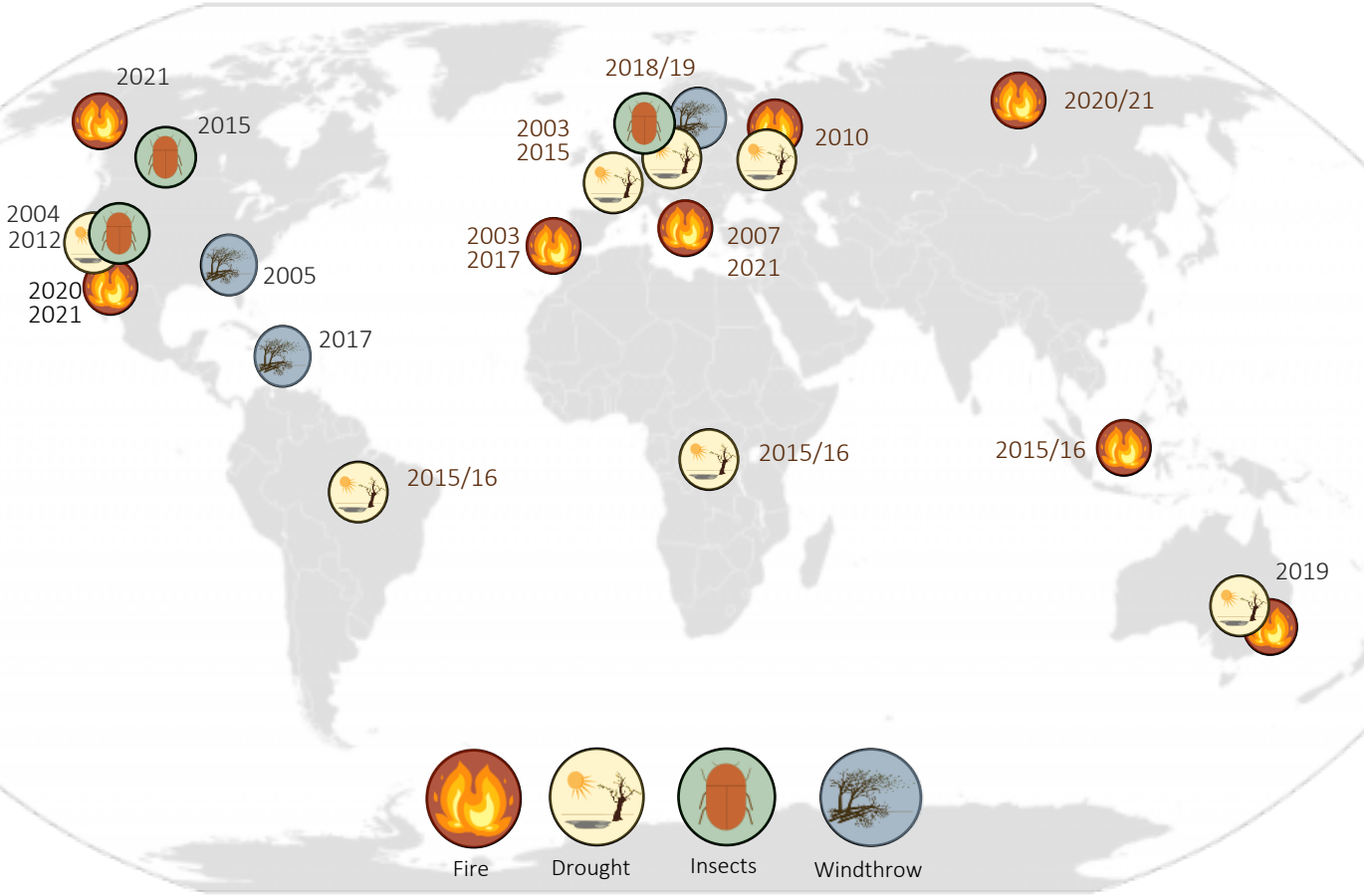

O'Sullivan et al. (2022)

# Extreme weather and high impact events

2012-2015 multi-year drought

Hurricane Maria 2017


2015/16 El-Niño

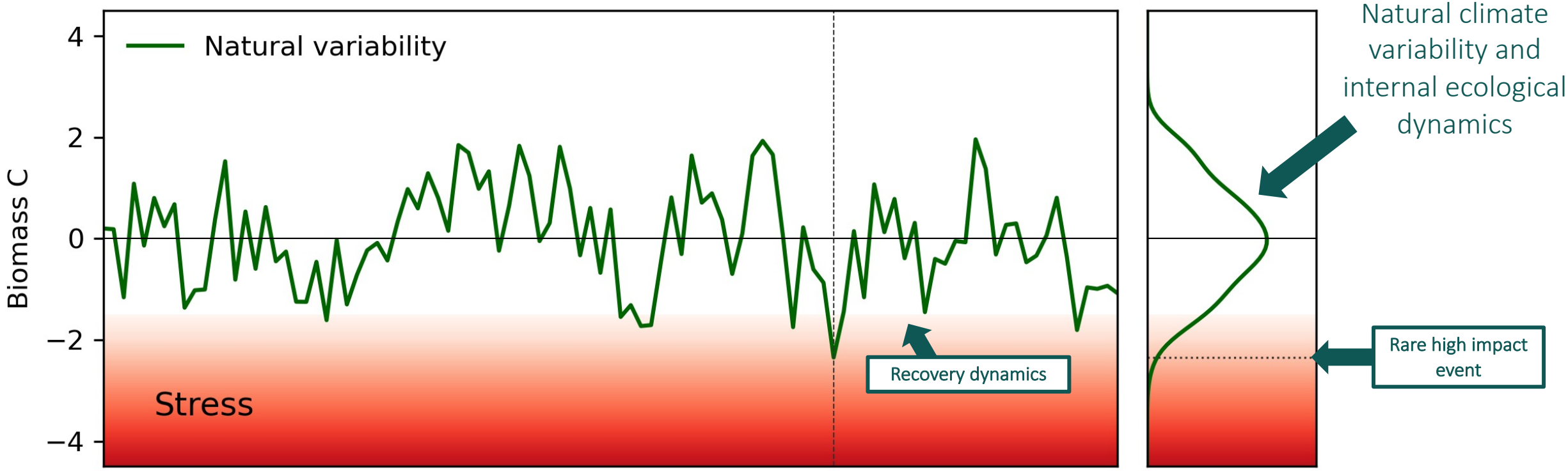




Siberian Heatwaves 2020/21

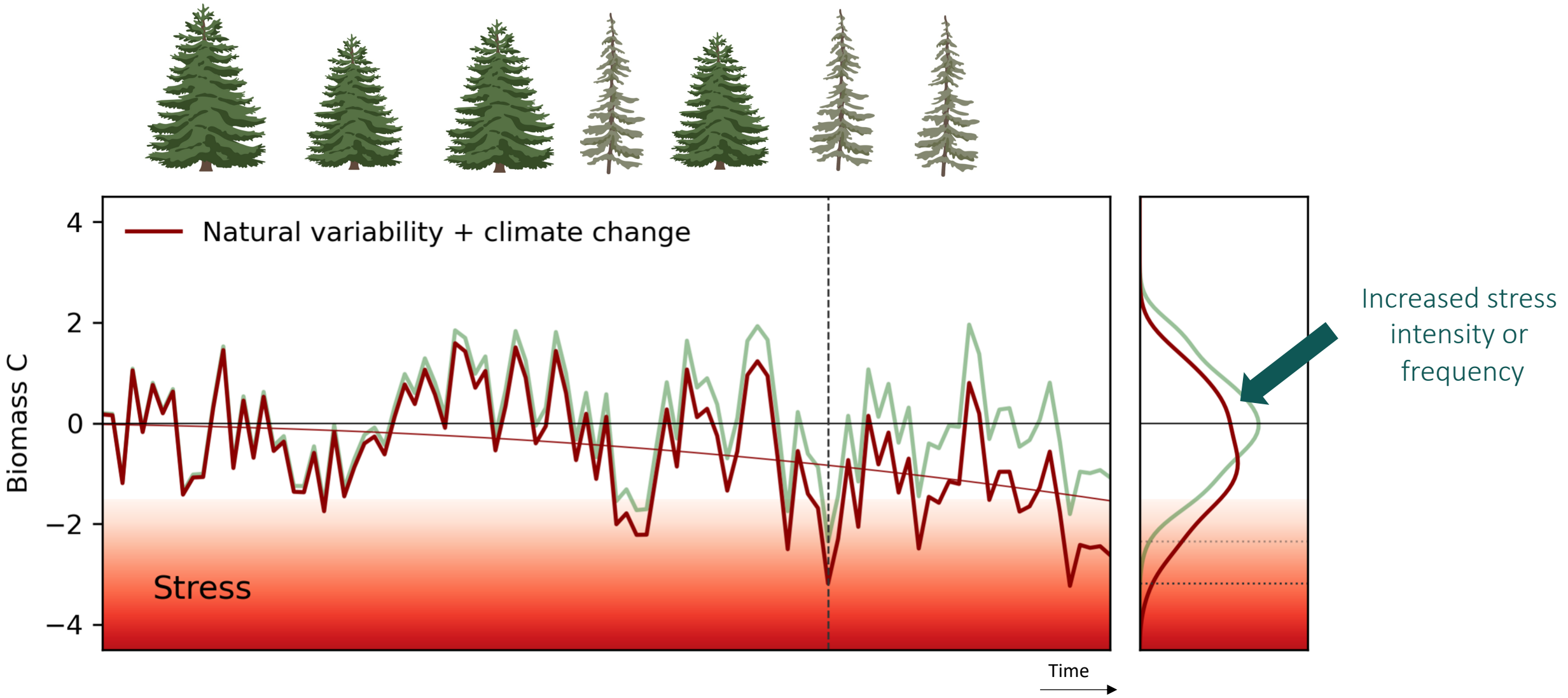
2003/ 2010 / 2018 heat & drought


2017-2019 multi-year drought
2019 heatwave

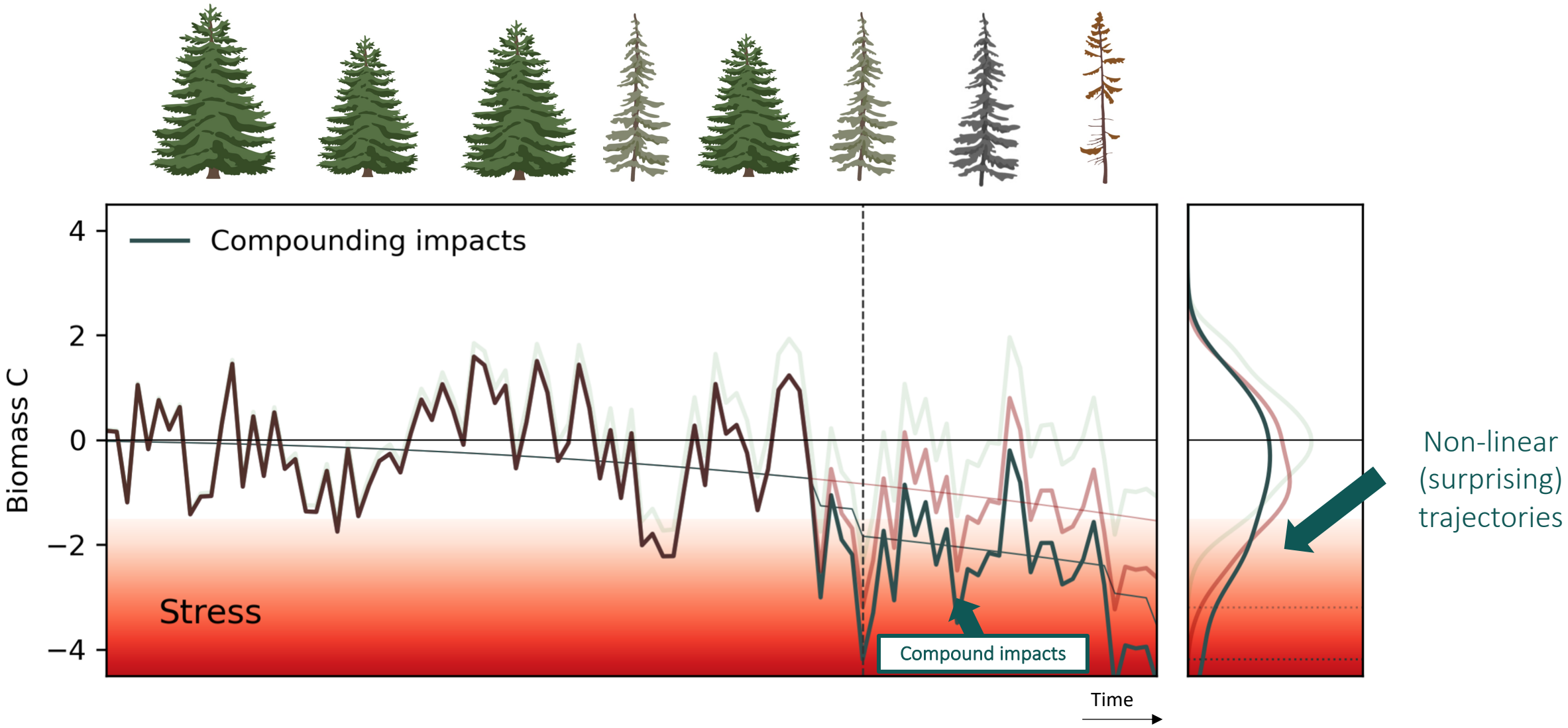
# Climate change risks to the global carbon cycle



# Climate change risks to the global carbon cycle



# Climate change risks to the global carbon cycle

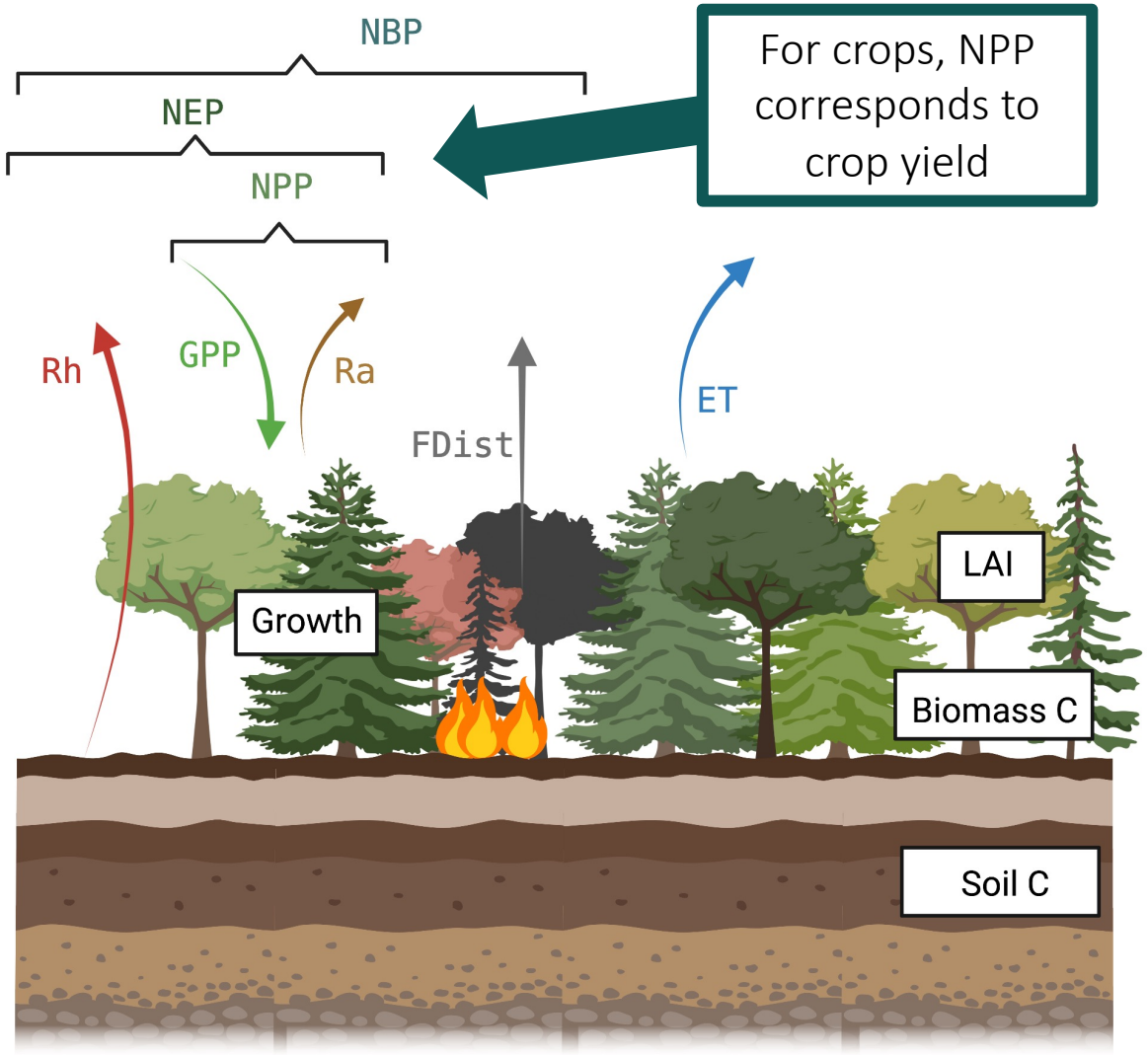


# Key C-cycle variables for impact assessment

NPP = GPP – Ra

NEP = NPP – Rh

NBP = NEP - Fdisturbance




Gross Primary Productivity (photosynthesis)

Autotrophic Respiration

Heterotrophic Respiration

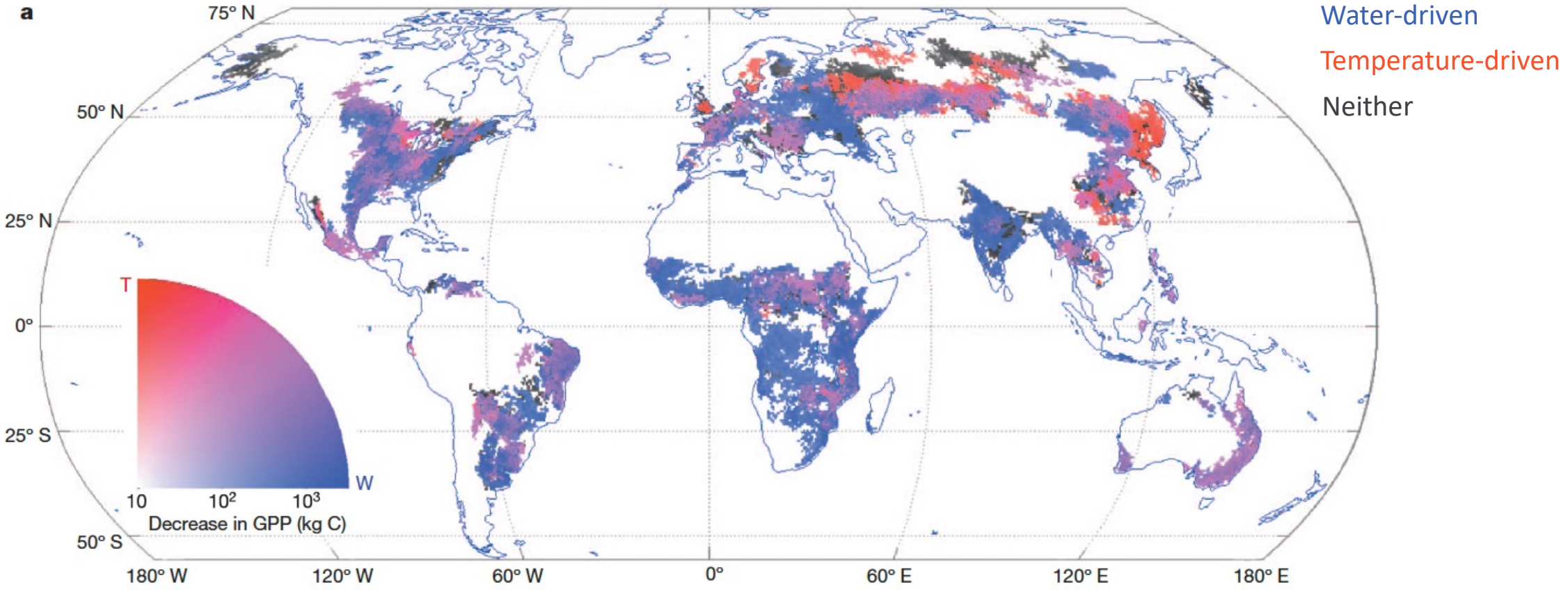
Disturbance fluxes

Evapotranspiration

+ Phenology
+ Composition
+ Diversity
+ Structure (e.g. height, age)

# Extreme events and the carbon cycle

Water and temperature extremes drive losses in regional Gross Primary Productivity




Water-driven

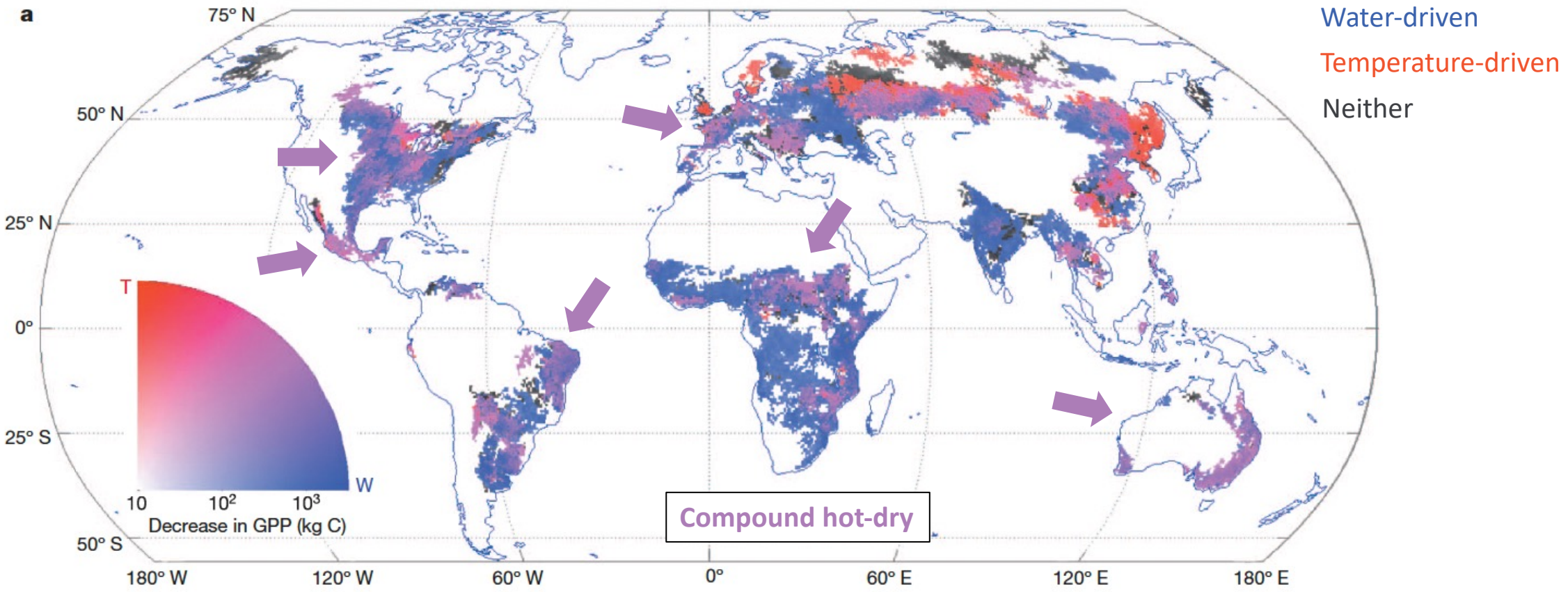
Temperature-driven

Neither

Reichstein et al. (2013)

# Extreme events and the carbon cycle

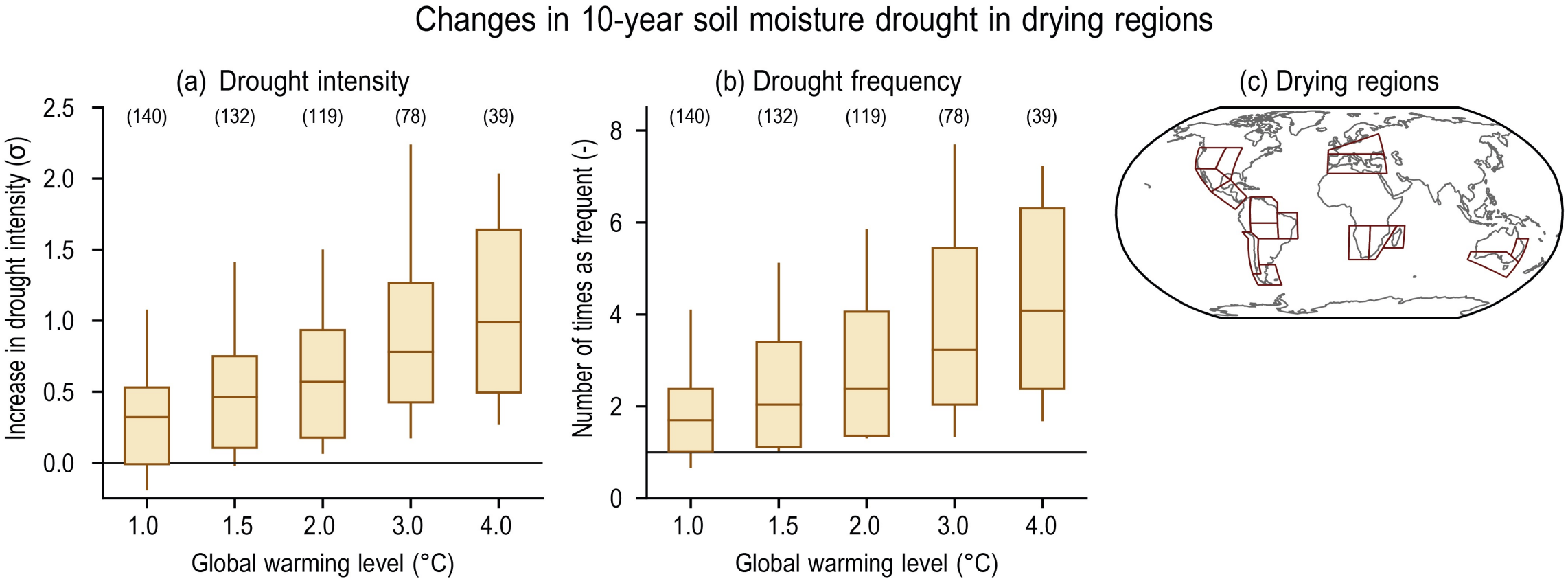
Water and temperature extremes drive losses in regional Gross Primary Productivity




Reichstein et al. (2013)

# Extreme events and the carbon cycle

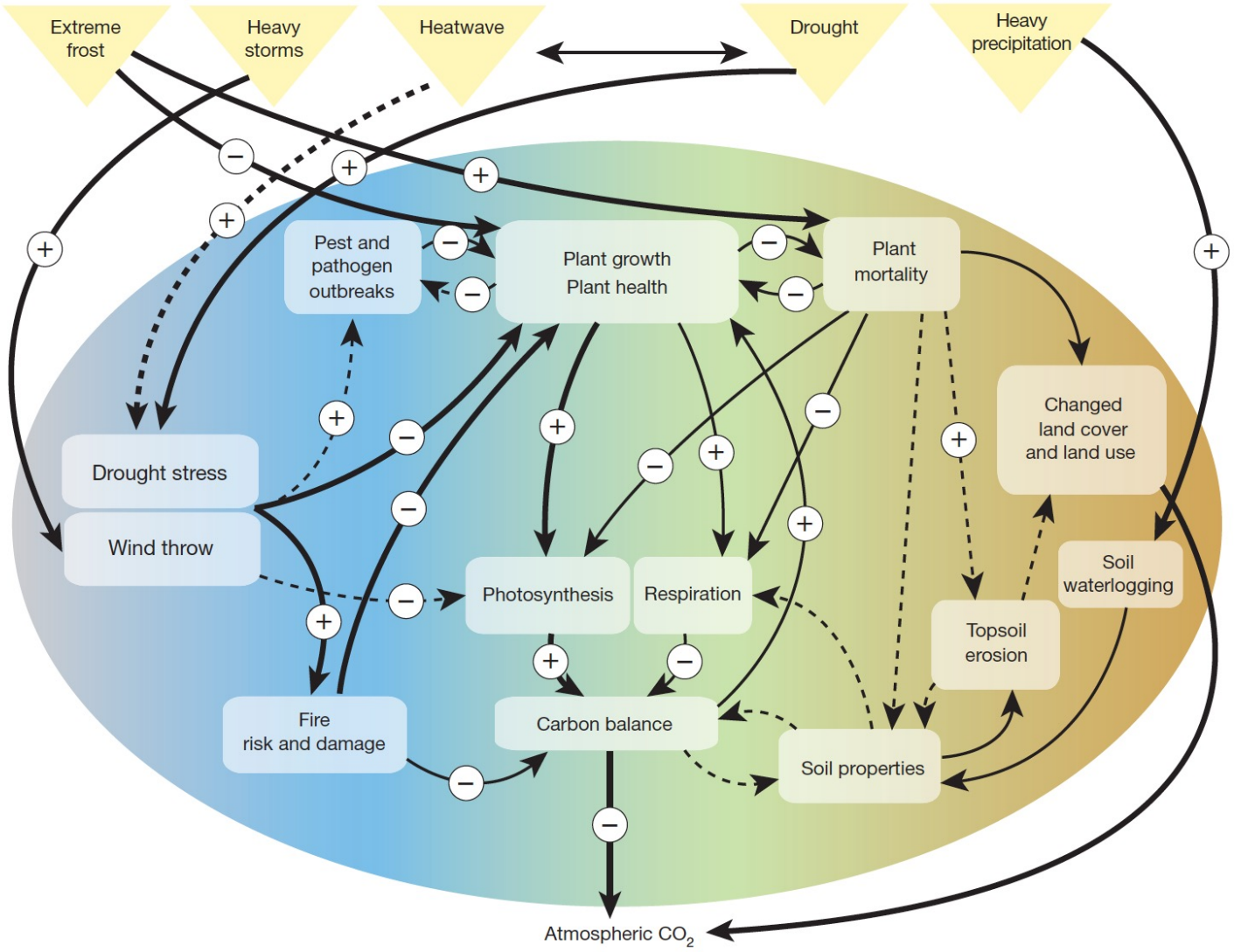
Hot and dry extremes projected to become more intense and frequent in many of these regions



# Challenges in impact assessment: ecological feedbacks

Extreme events affect multiple ecological processes which interact directly and indirectly, leading to complex dynamics and impacts on the carbon cycle

These might also be state dependent (e.g. phenological stage)



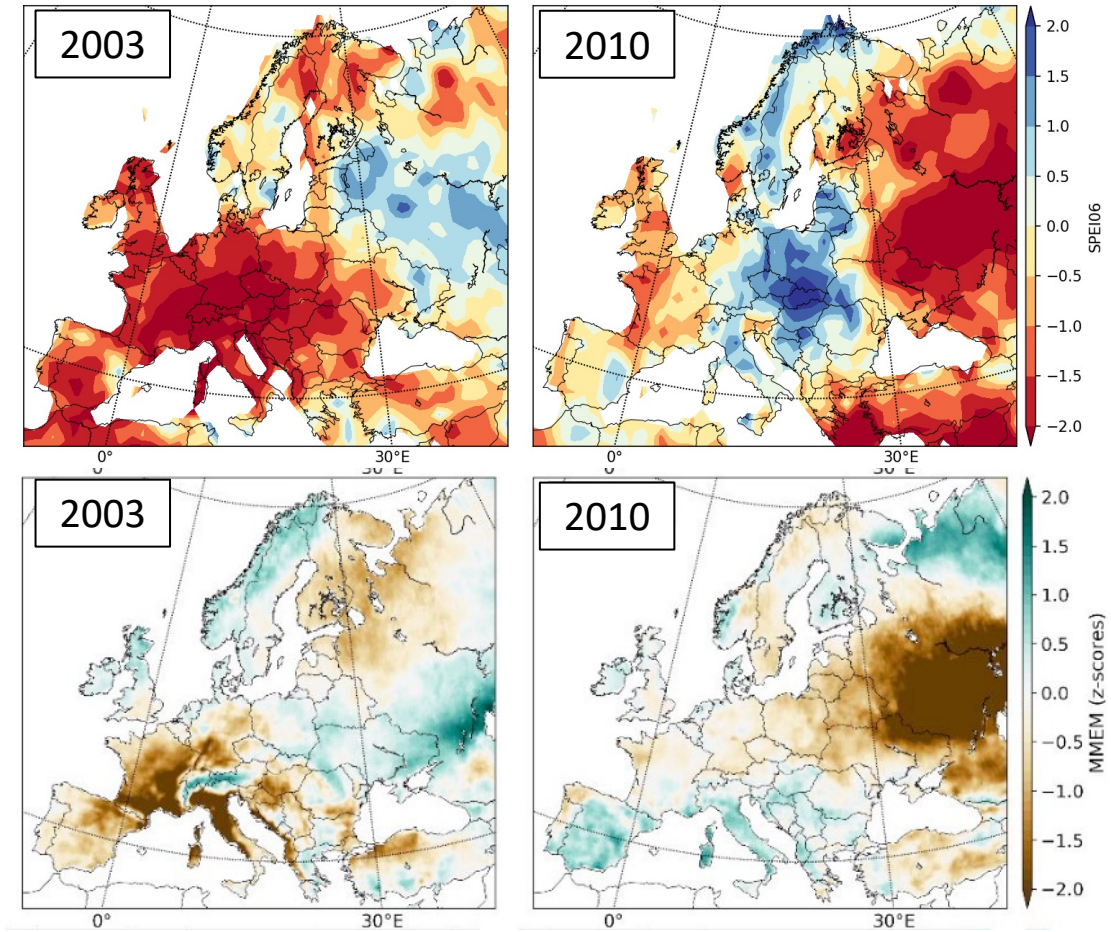

Reichstein et al. (2013)

# Not all events are the same: the 2003, 2010 and 2018 drought-heat events in Europe

# Impacts of recent extreme summers in Europe

Summer drought conditions (SPEI)

Net $CO_2$ uptake anomaly (DGVMs)



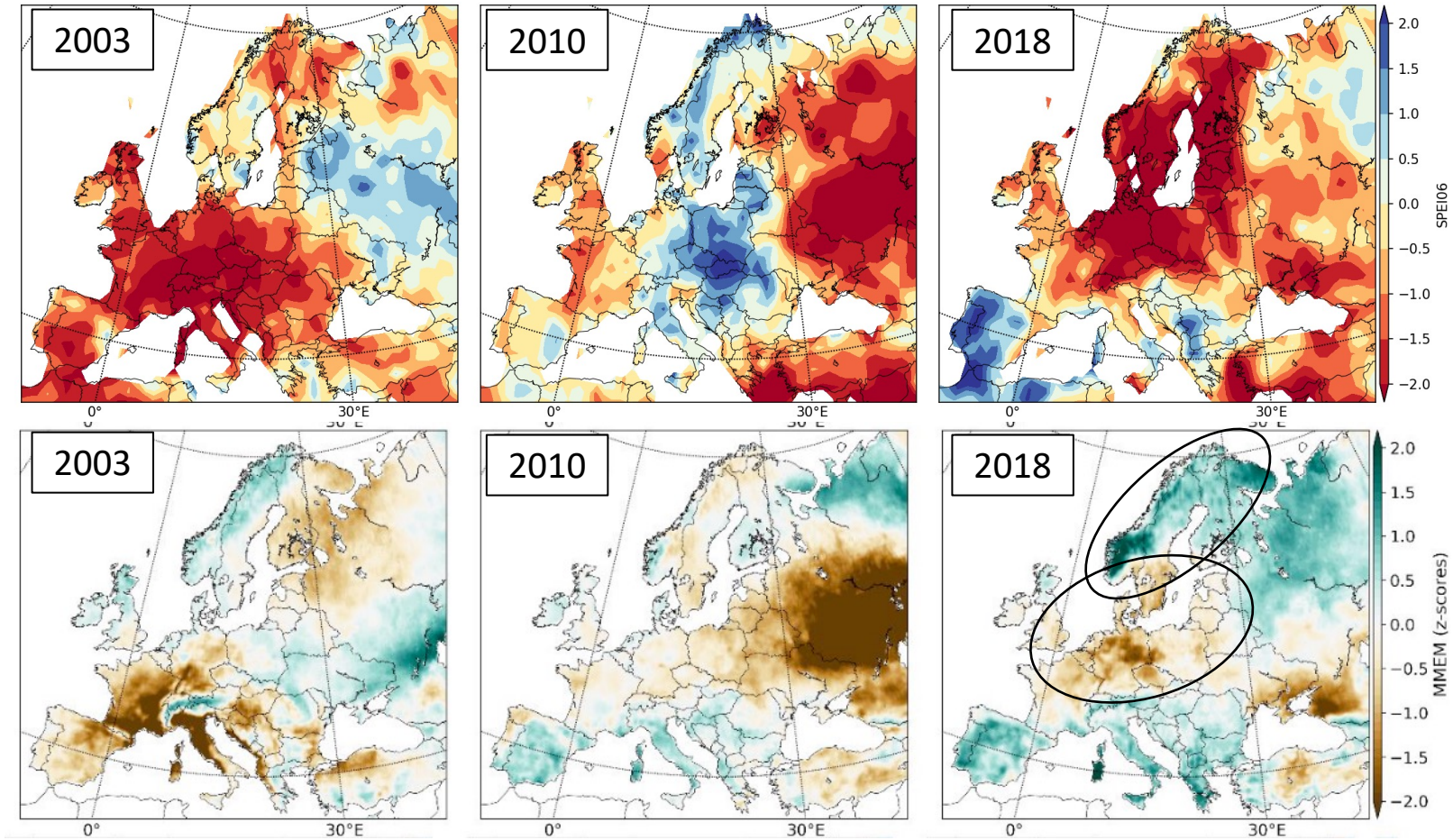

2003 and 2010: less $CO_2$ uptake than average during drought

Bastos et al. (2020, PTRS-B)

# Impacts of recent extreme summers in Europe

Summer drought conditions (SPEI)

Net $CO_2$ uptake anomaly (DGVMs)



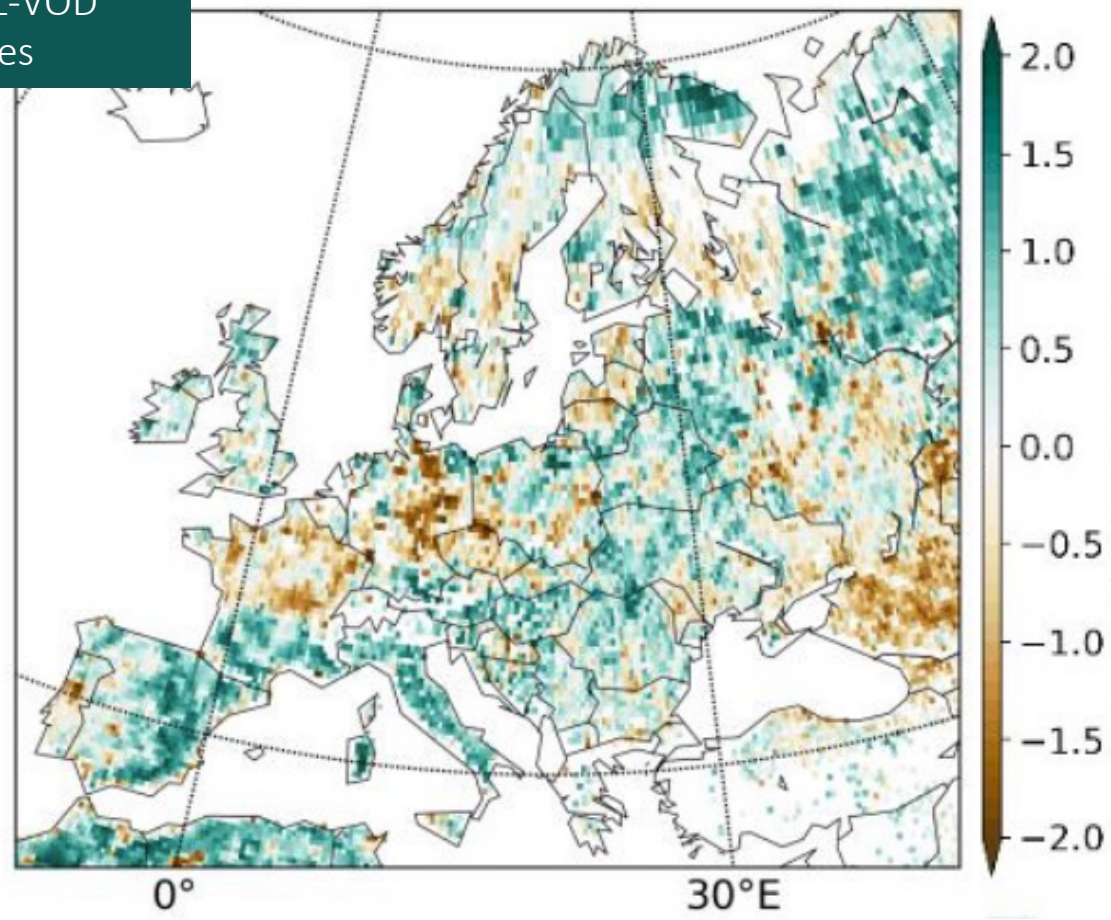

2003 and 2010: less $CO_2$ uptake than average during drought

But contrasting impacts in 2018: why?

Bastos et al. (2020, PTRS-B)

# Was 2018 special?

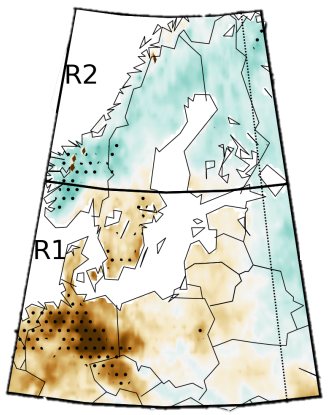
Annual L-VOD anomalies

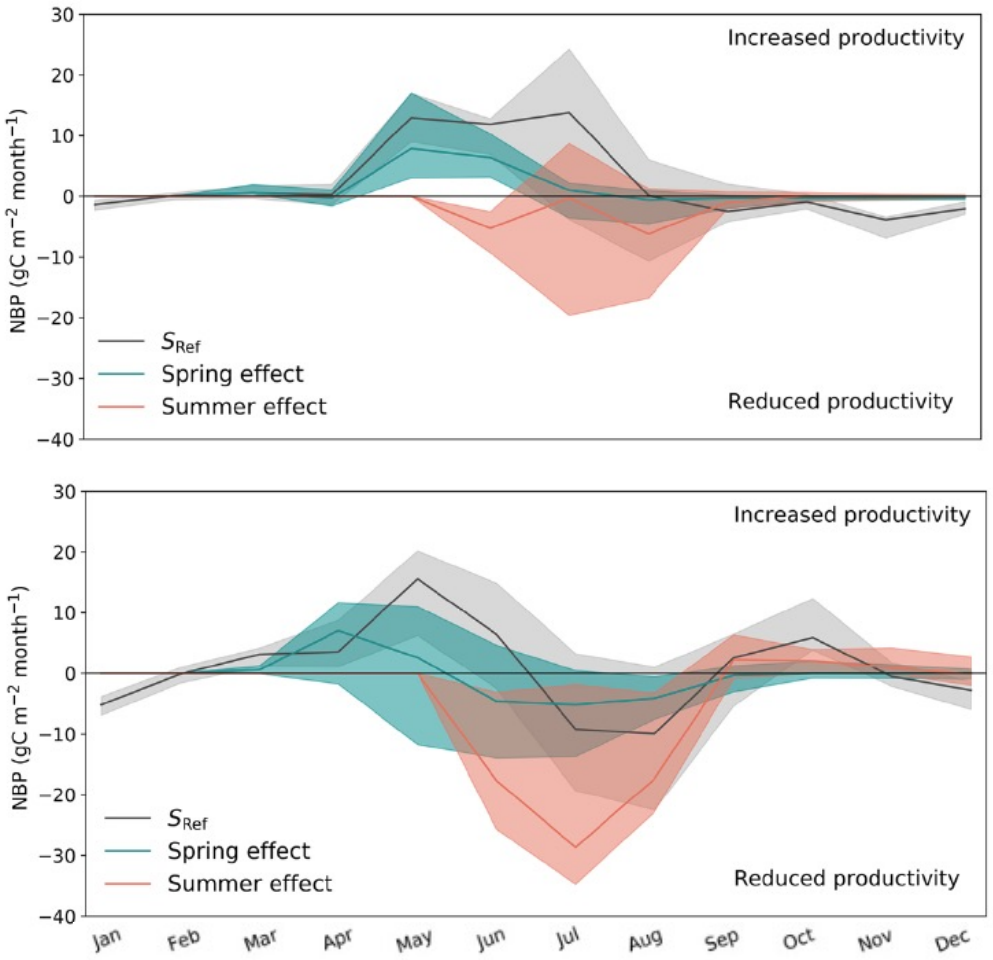



Models in agreement with observations
→ we can use them to understand impacts

Bastos et al. (2020, Sci. Adv.)

# Was 2018 special?

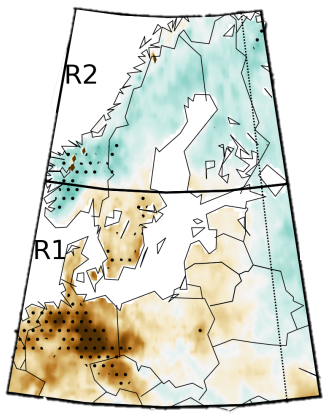


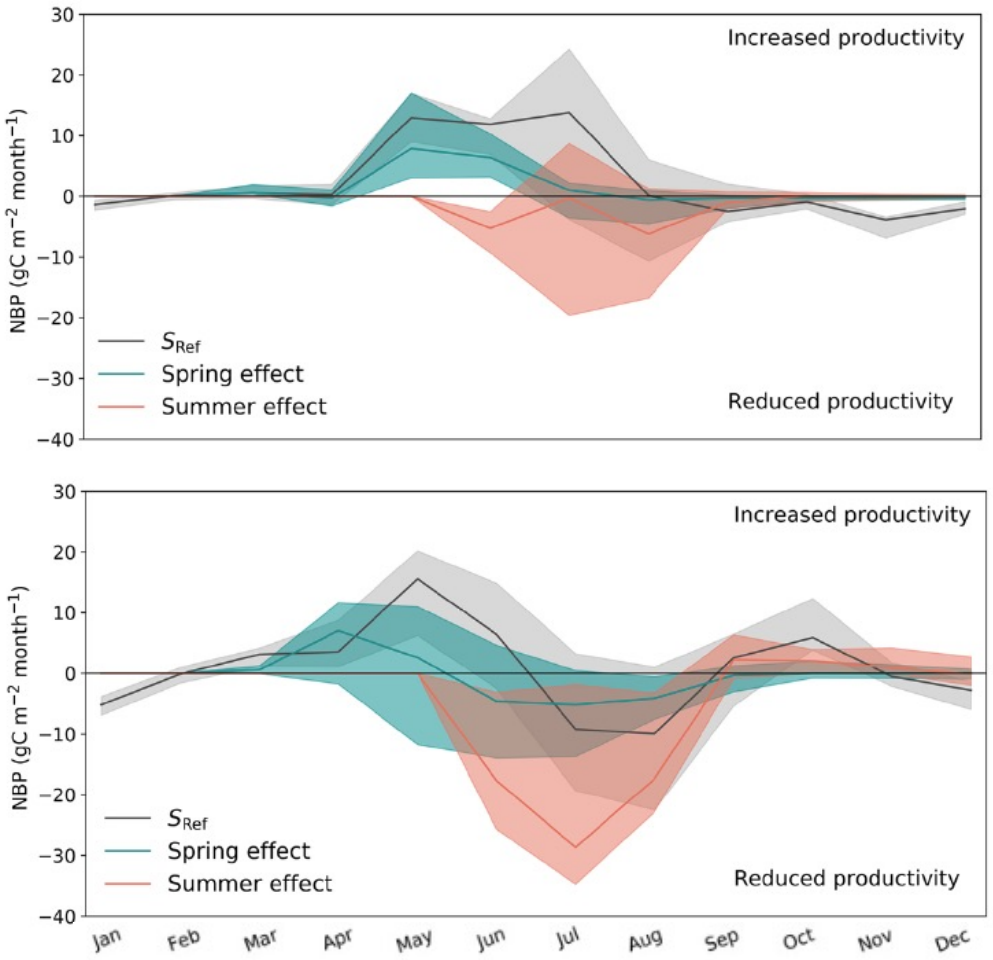




Reference simulation

Bastos et al. (2020, Sci. Adv.)

# Was 2018 special?



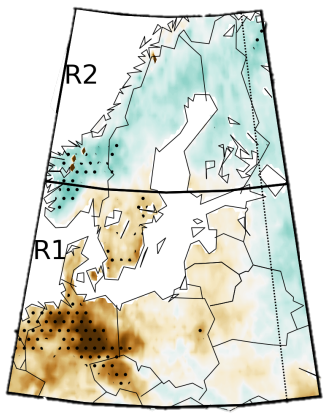

Reference simulation

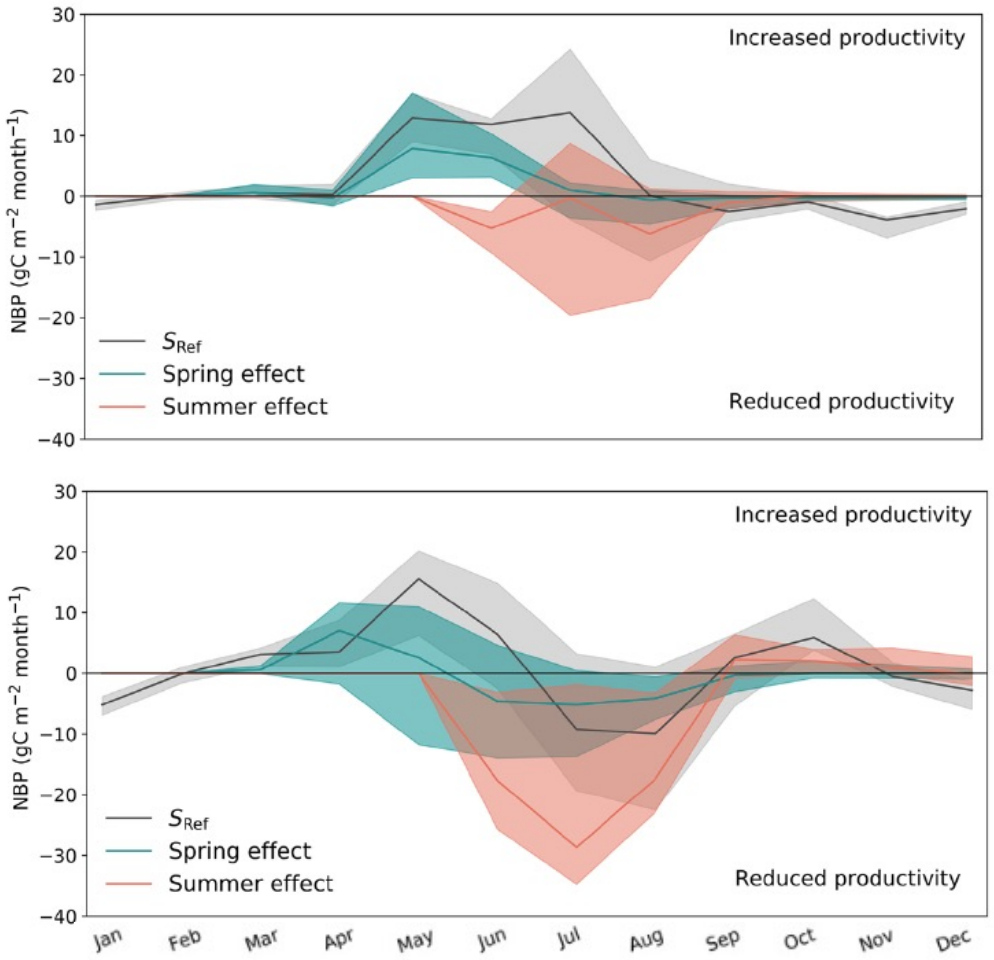
"What if spring would have been normal?"

"What if summer would have been normal?"

Bastos et al. (2020, Sci. Adv.)

# Was 2018 special?



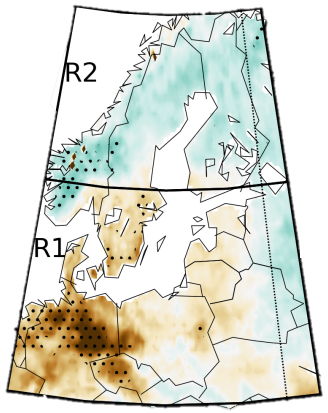

Reference simulation
"What if spring would have been normal?"
"What if summer would have been normal?"

⚠ Summer heat and drought still associated with decreased productivity, but not "seen" by observations because of legacy effects from spring

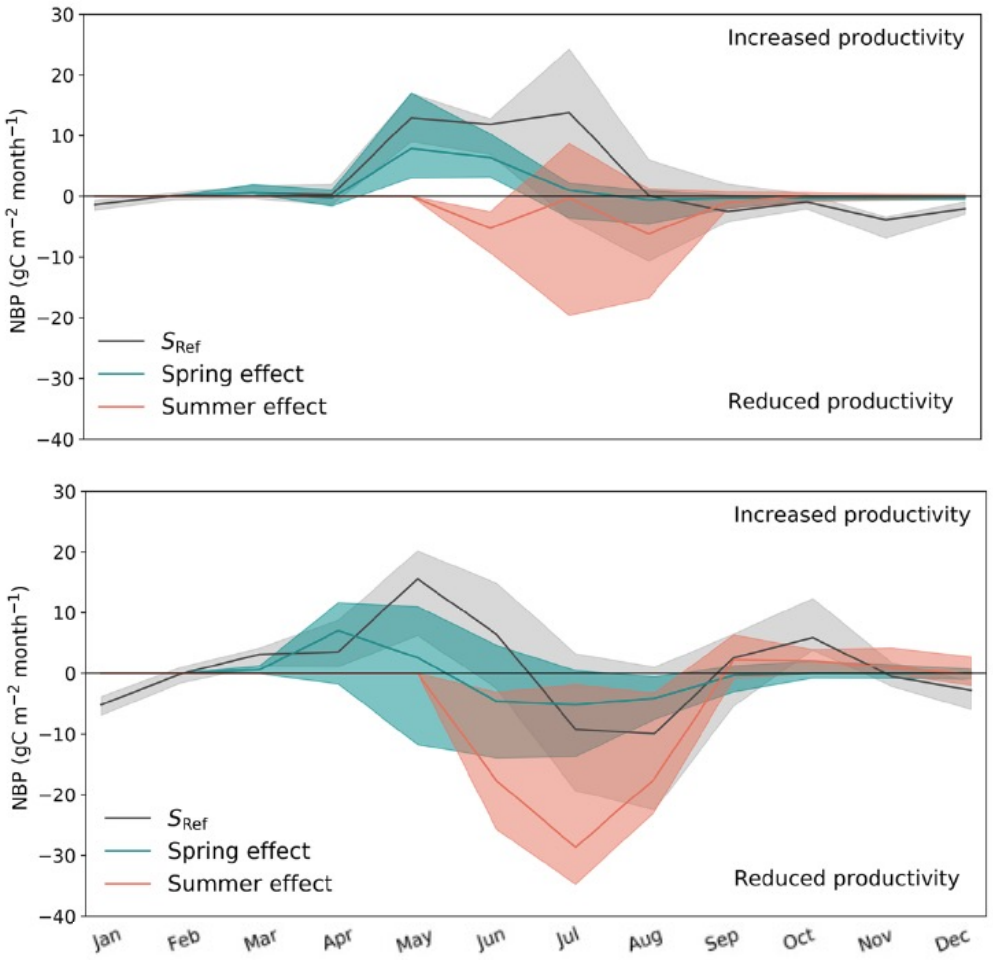
Bastos et al. (2020, Sci. Adv.)

# Was 2018 special?

Spring productivity enhancement → offsetting effect




Spring productivity enhancement → amplified impacts




Reference simulation
"What if spring would have been normal?"
"What if summer would have been normal?"

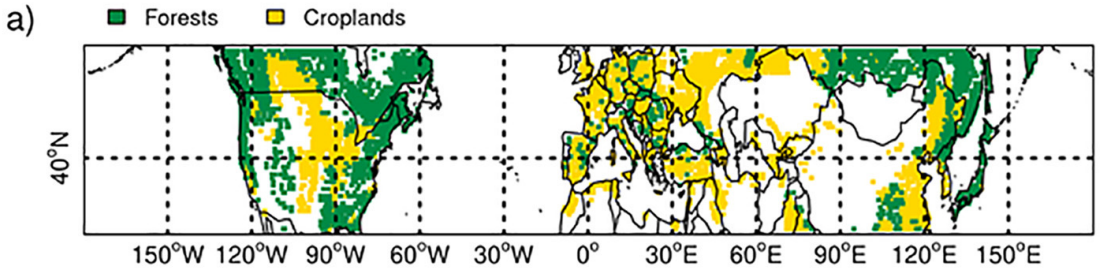
⚠ Summer heat and drought still associated with decreased productivity, but not "seen" by observations because of legacy effects from spring

Differences in impacts and seasonal legacy effects likely explained by differences in dominant land cover (**crops vs forests**)

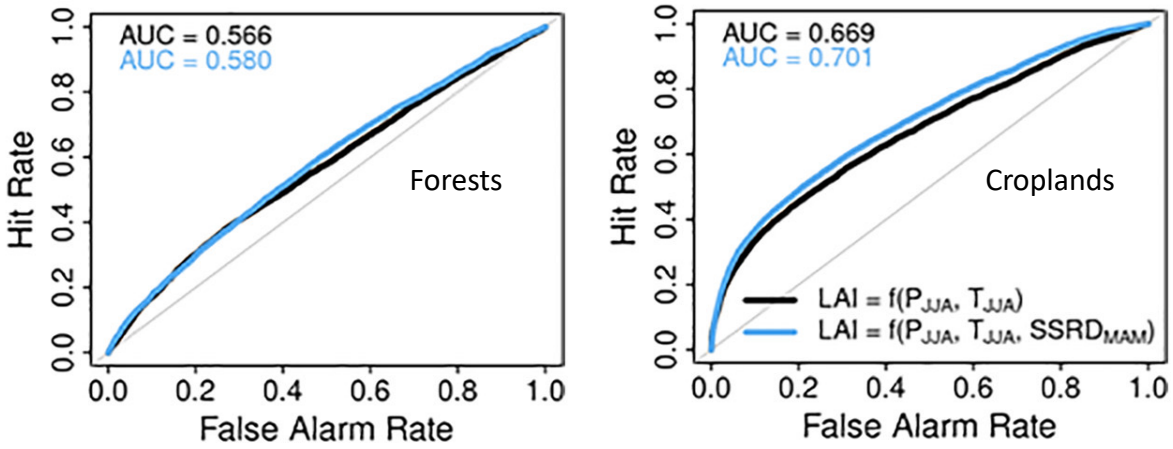
Bastos et al. (2020, Sci. Adv.)

# Spring pre-conditioning of summer extremes

We evaluated how spring weather influenced the probability of low summer LAI extremes (logistic regression model)




## Effect of spring weather vs. summer only




Forests show no significant spring preconditioning effect



Bevacqua et al. (2021, Earth's Future)

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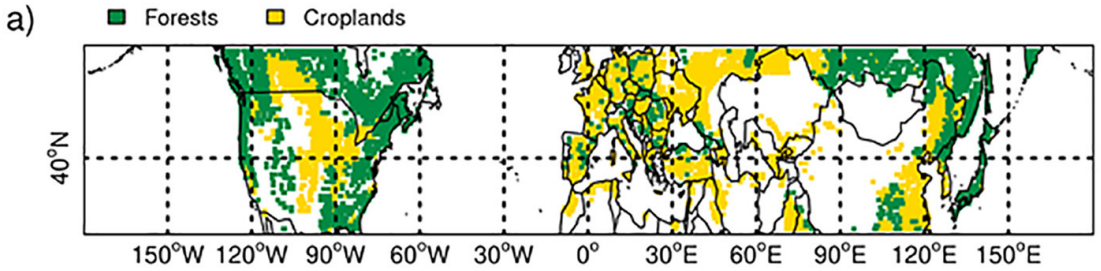


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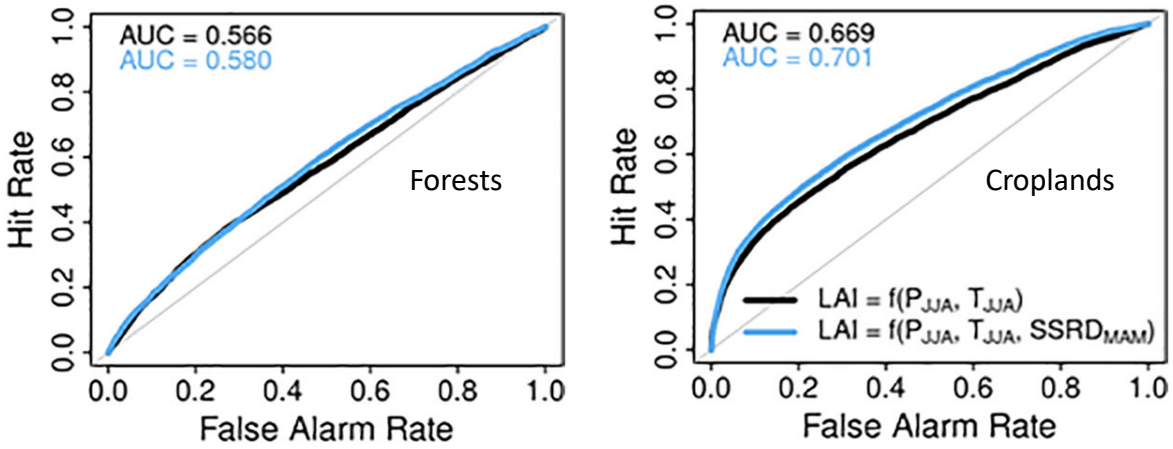
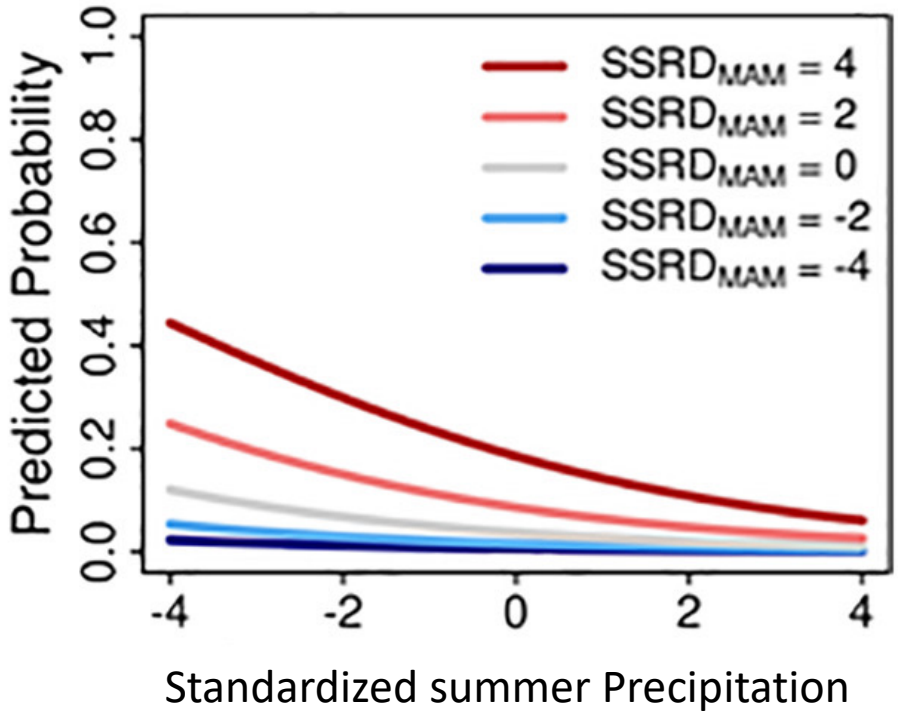



Forests show no significant spring preconditioning effect

## Probability of low LAI vs. JJA drought and MAM radiation




For crops, strong non-linear dependence on spring radiation and temperature

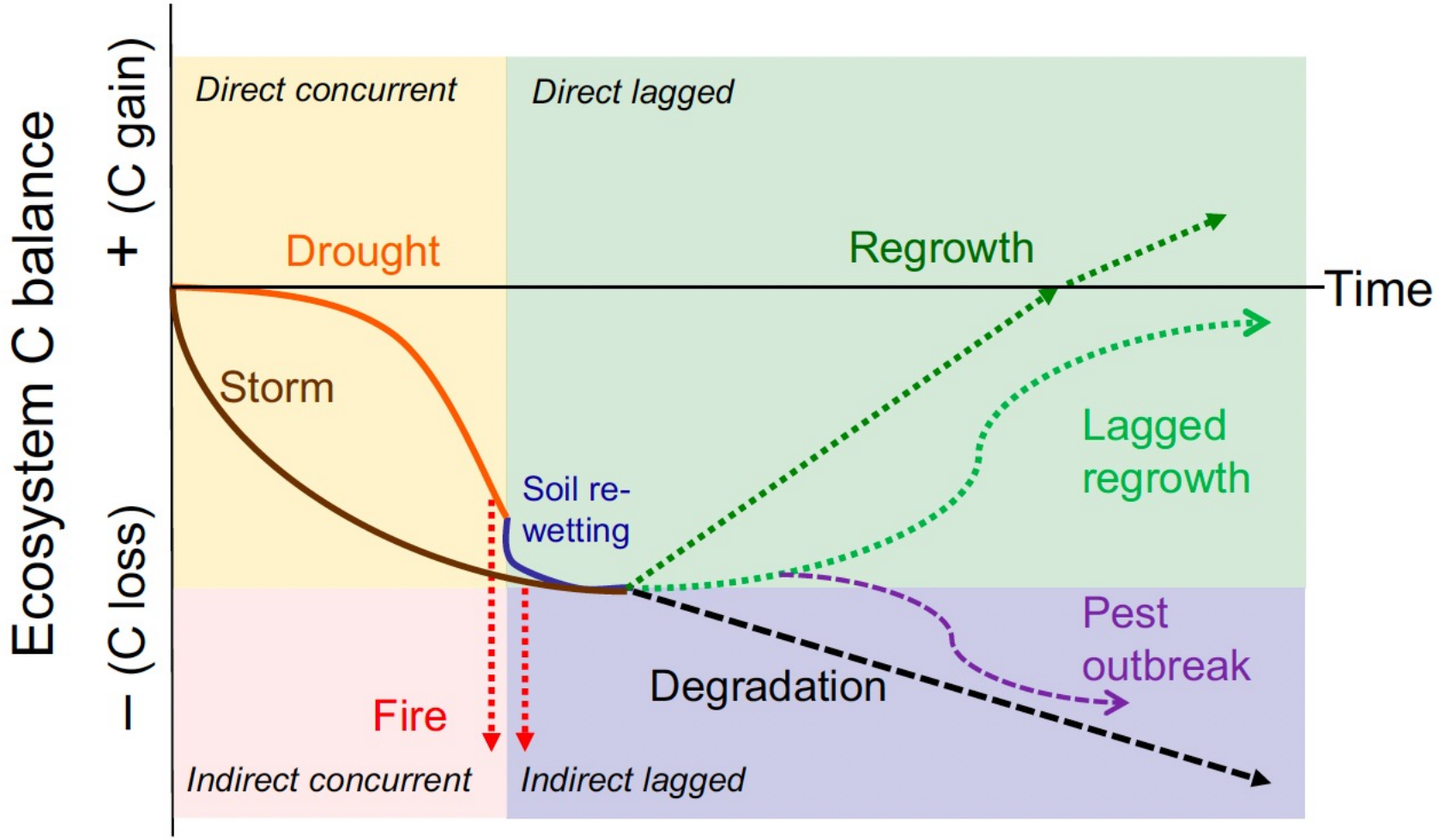


Bevacqua et al. (2021, Earth's Future)

# Challenges in impact assessment: cascading impacts

Extreme events affect multiple ecological processes which interact directly and indirectly, leading to complex resulting impacts

They can also have indirect effects, through lagged effects or influence on additional disturbances

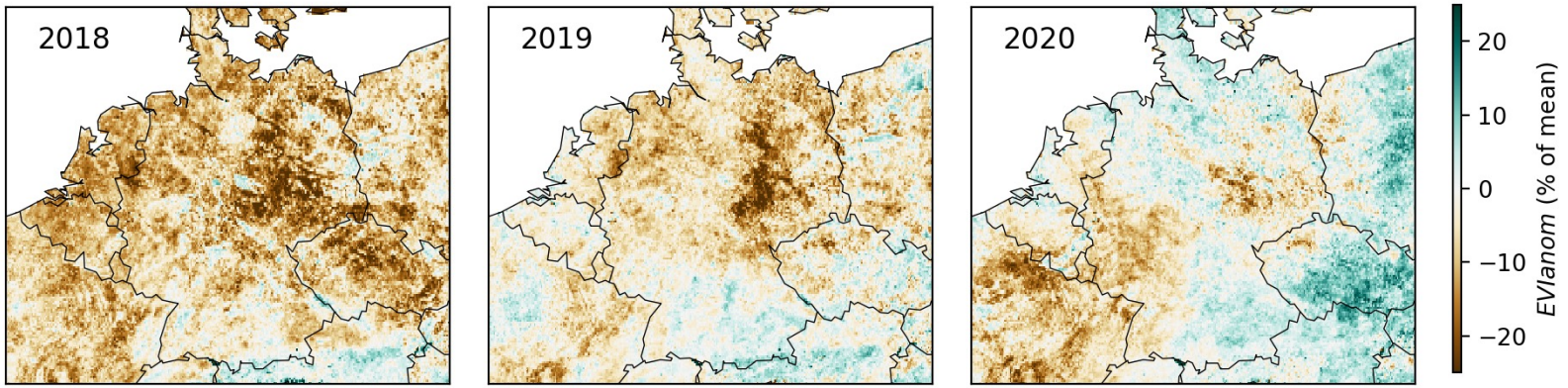



Frank et al. (2015) *GCB*

# Did ecosystems recover after 2018?

# The aftermath of heat-drought 2018

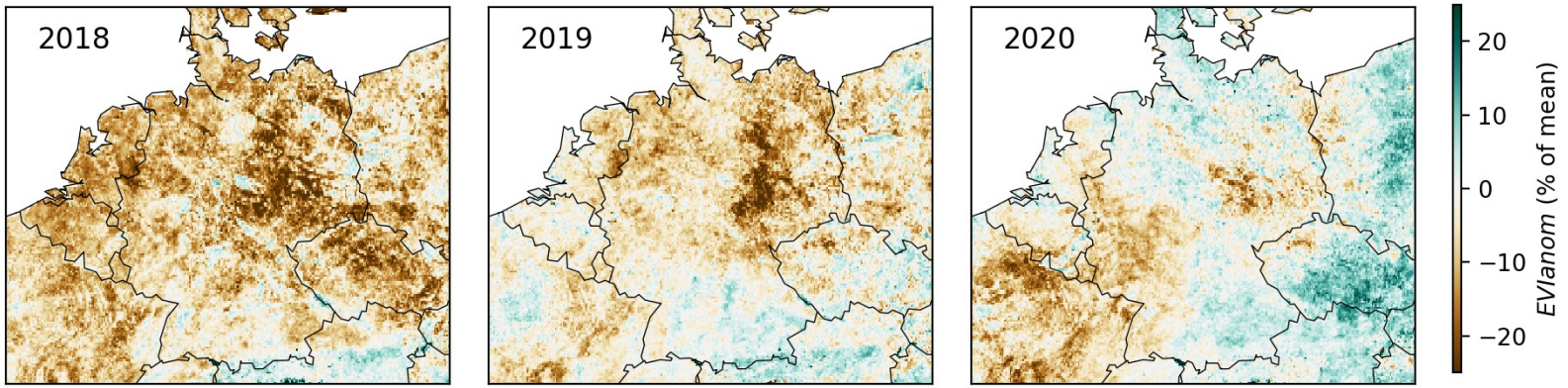
## Anomalies in surface greenness relative to 2000-2020



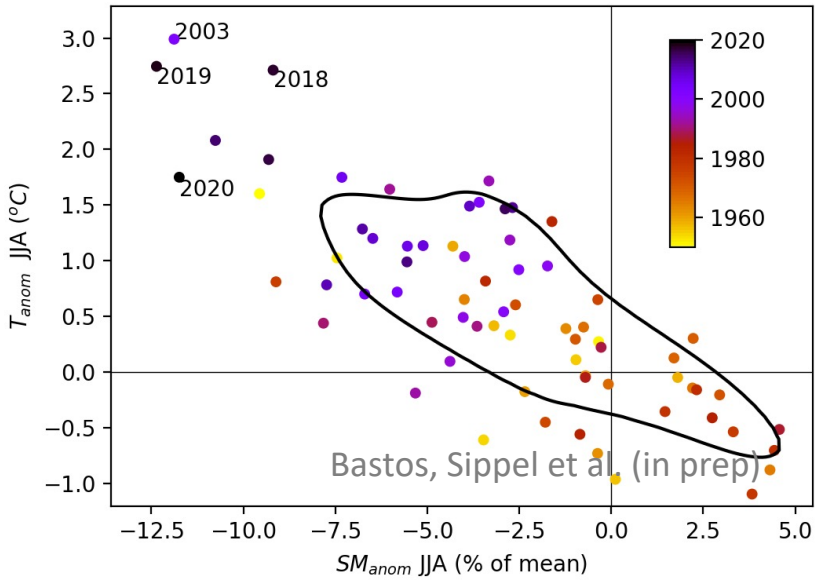

Many regions show persisting browning in 2019 and 2020 in the aftermath of 2018

# The aftermath of heat-drought 2018

## Anomalies in surface greenness relative to 2000-2020




## Climate anomalies (JJA) in Central Europe

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# The aftermath of heat-drought 2018

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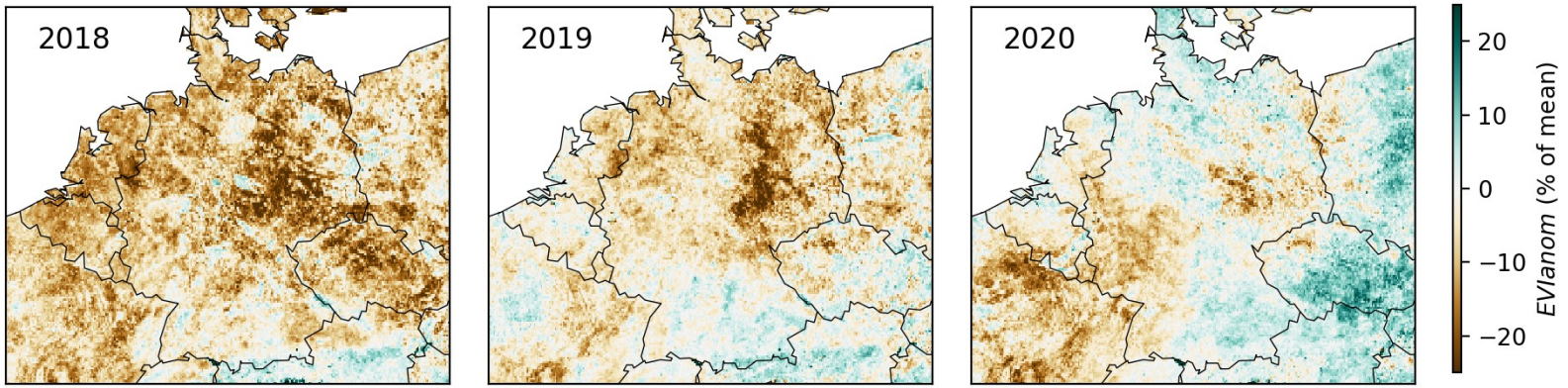


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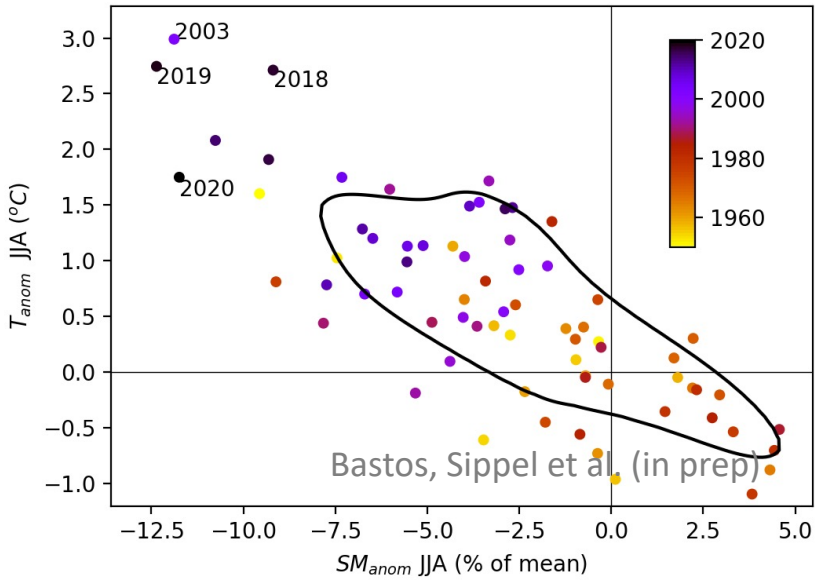



Many regions show persisting browning in 2019 and 2020 in the aftermath of 2018

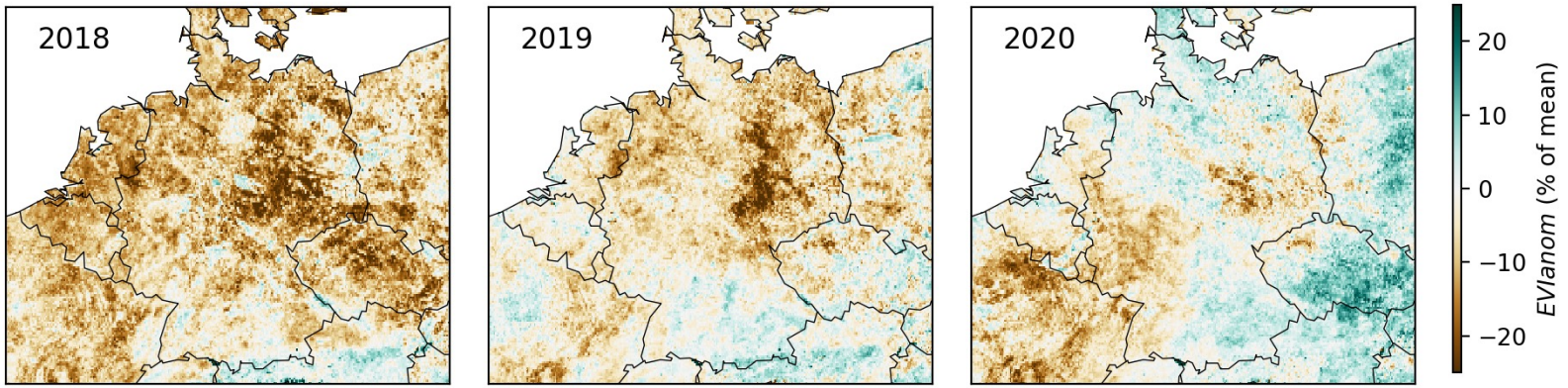
"Normal" impacts of repeated extremes?

Increased vulnerability due to legacy effects?

- Damage to crown
- Loss of hydraulic conductivity
- Depletion of carbon reserves
- Lower resistance to pests

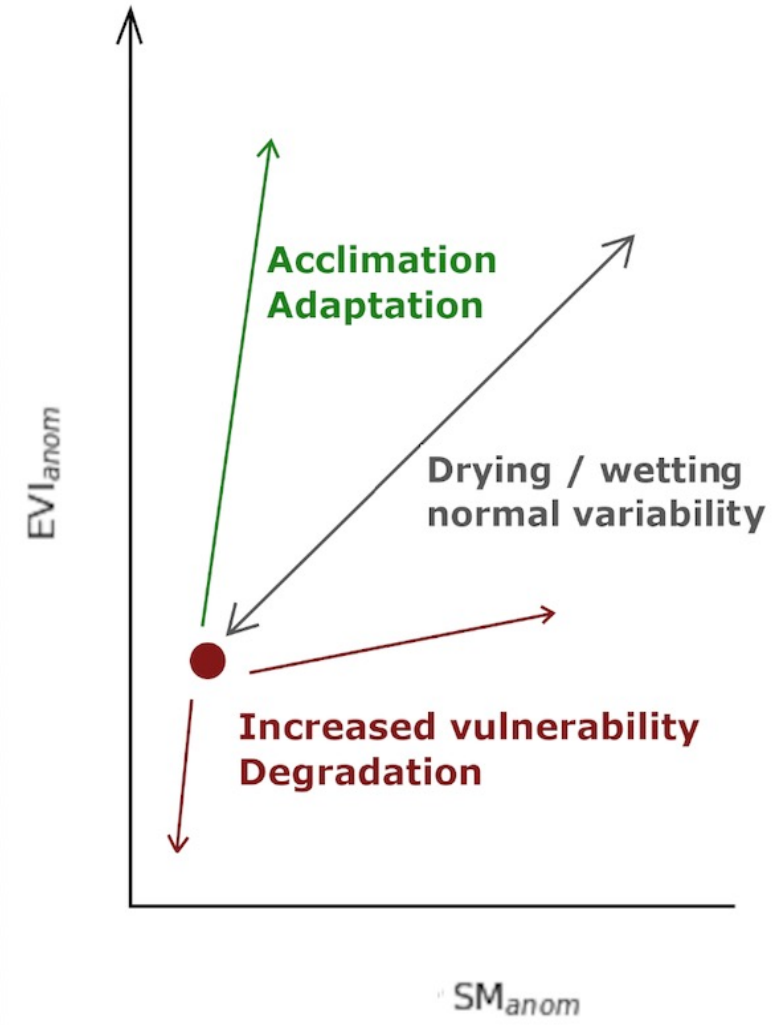
# The aftermath of heat-drought 2018

## Anomalies in surface greenness relative to 2000-2020




Many regions show persisting browning in 2019 and 2020 in the aftermath of 2018

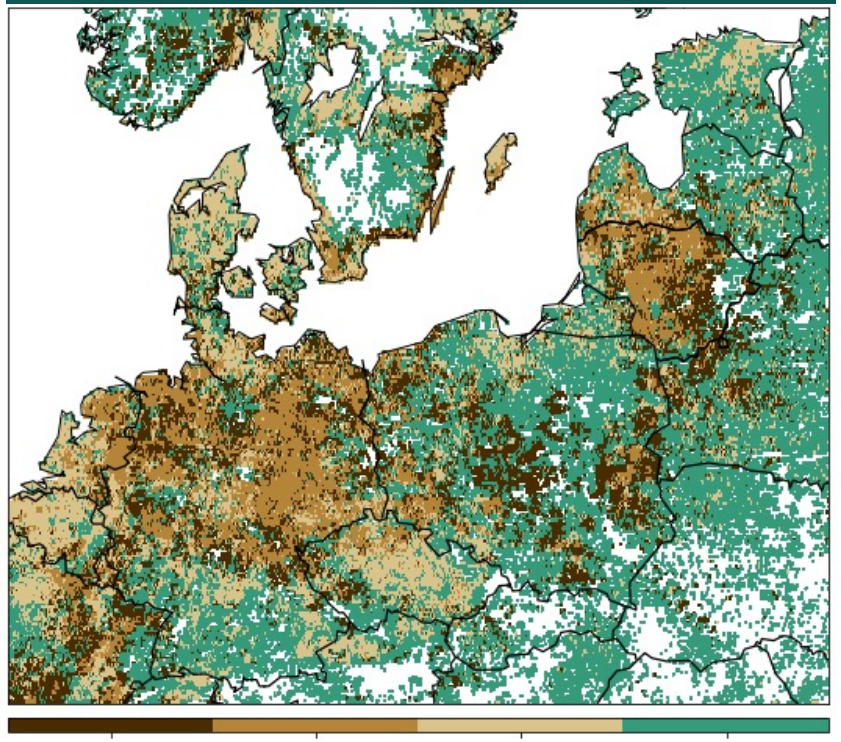
- "Normal" impacts of repeated extremes?
- Increased vulnerability due to legacy effects?




Bastos et al. (2021) ESD

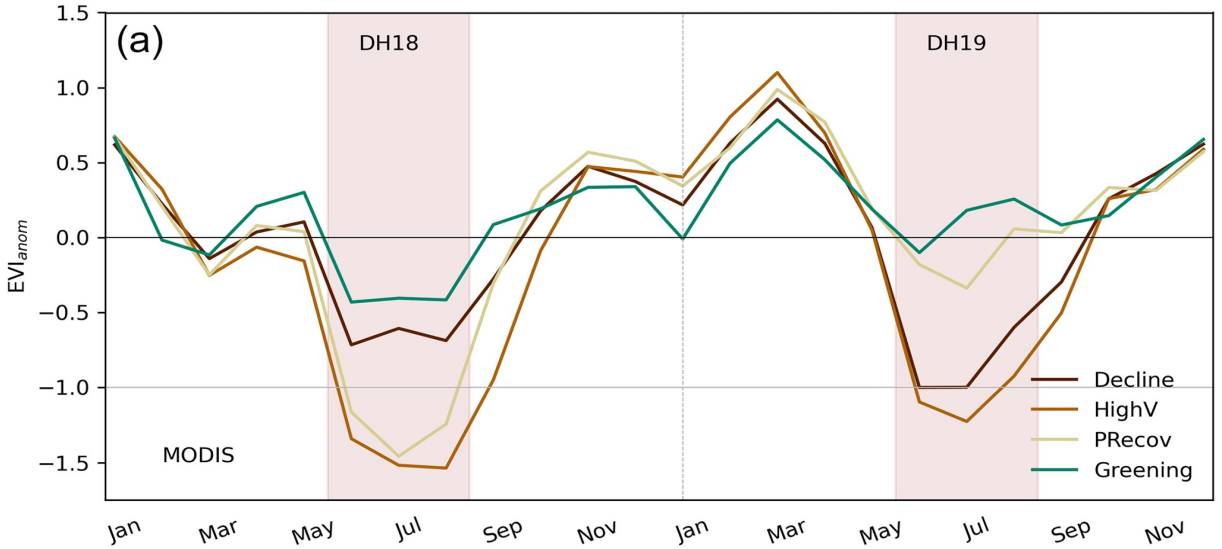
# Vulnerability to the 2018/19 compound ecoclimatic event

Clusters of similar EVI anomalies(2018, 2019)



Decline High vul. Part. rec. Greening

We group pixels according to their standardized EVI anomalies in both summers using unsupervised clustering:

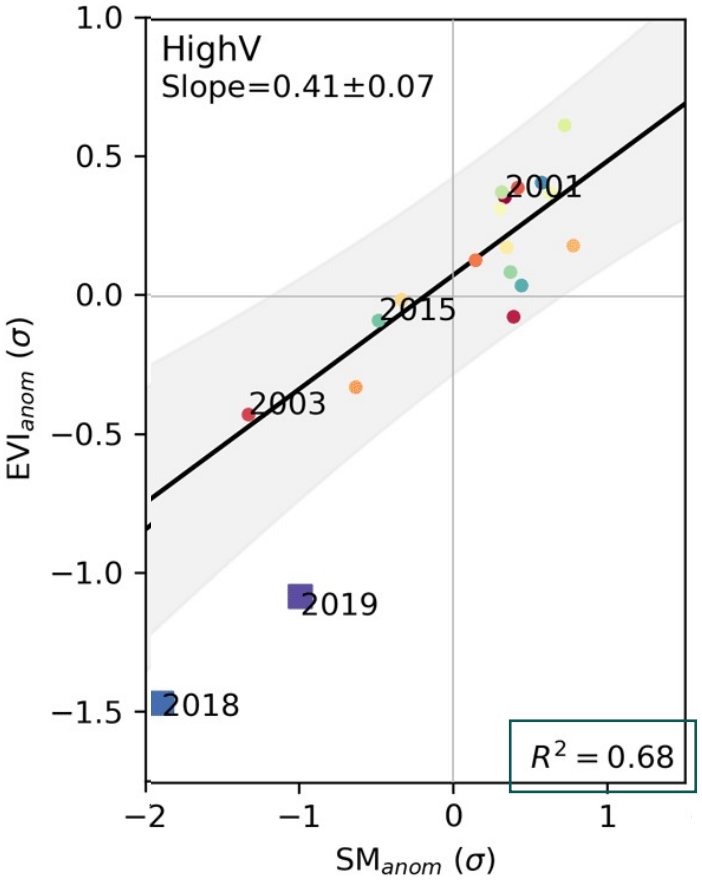




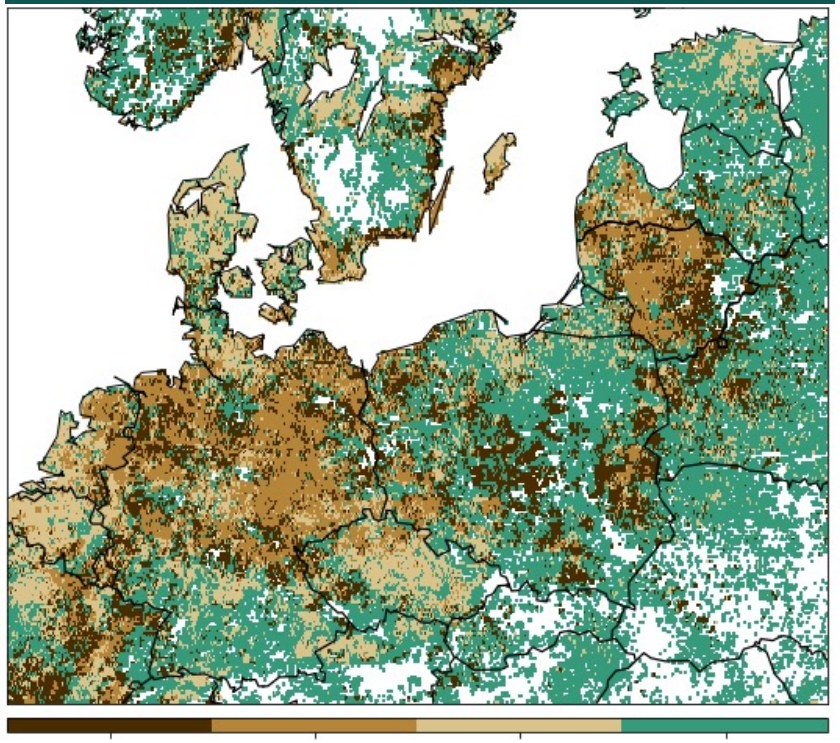

Bastos et al. (2021) ESD

# Vulnerability to the 2018/19 compound ecoclimatic event

High vulnerability cluster (15%)

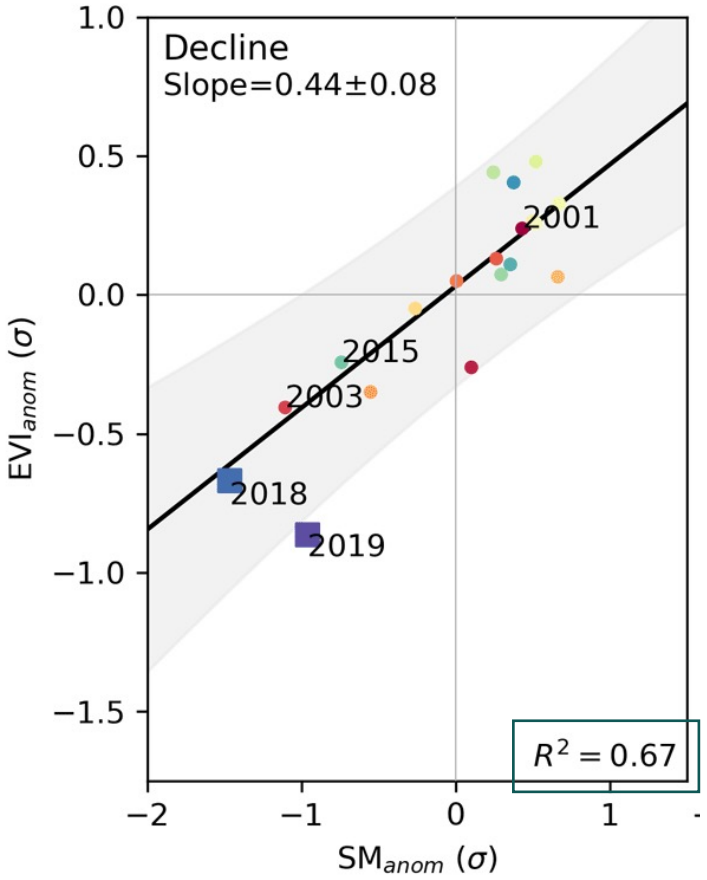



Clusters of similar EVI anomalies 2018-2019



Decline High vul. Part. rec. Greening

Decline cluster (20%)






Bastos et al. (2021) ESD

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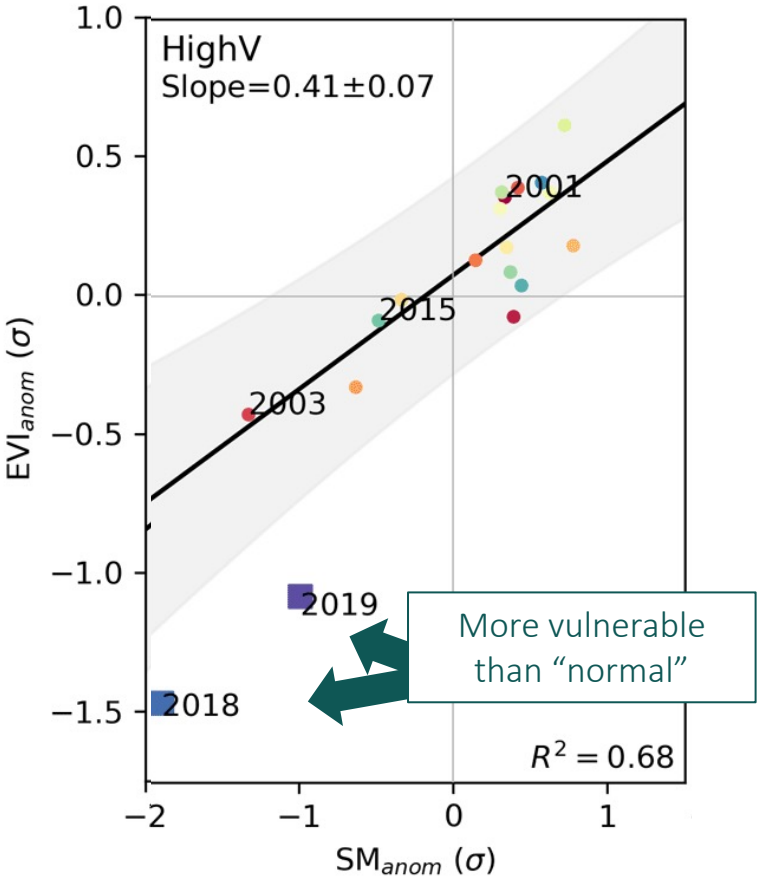
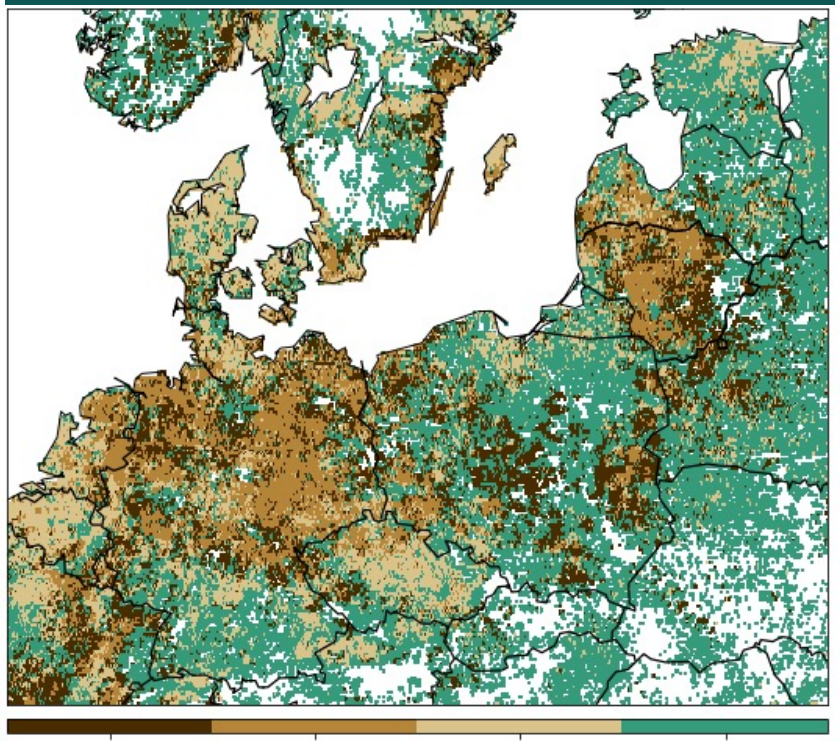
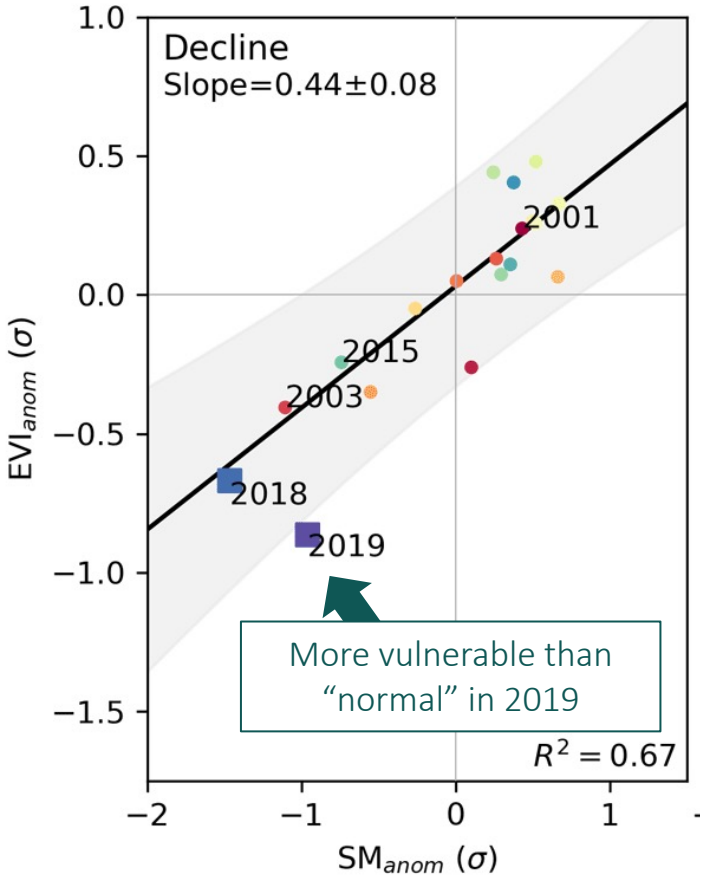



## Clusters of similar EVI anomalies 2018-2019



Decline High vul. Part. rec. Greening

## Decline cluster (20%)





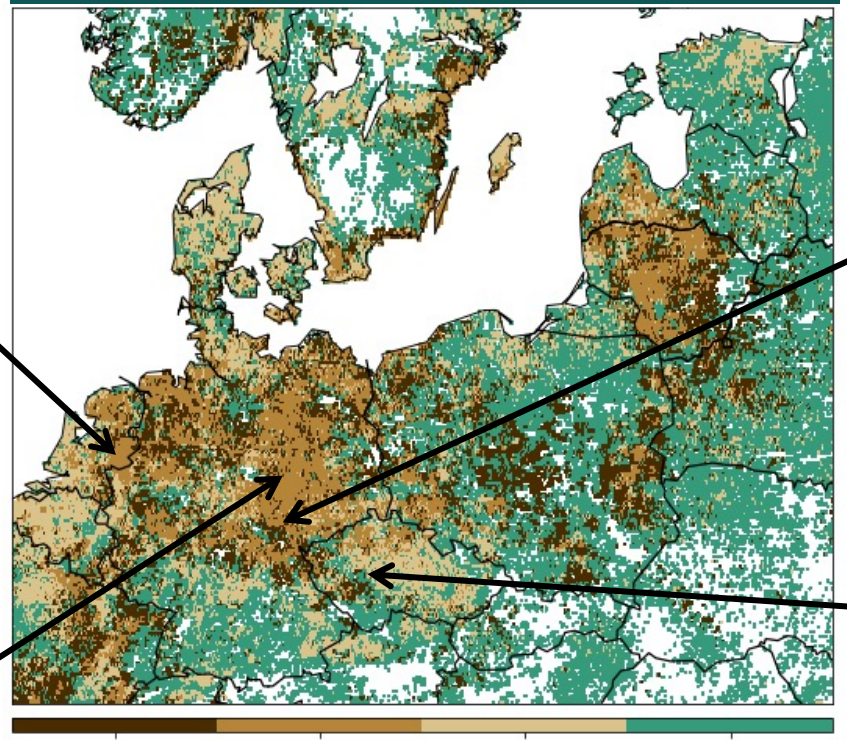

Bastos et al. (2021) ESD

# Vulnerability to the 2018/19 compound ecoclimatic event

## High vulnerability cluster (15%)

Crops + grasslands

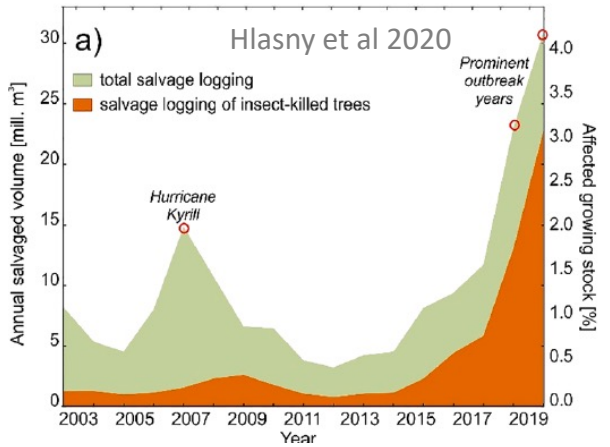

## Clusters of similar EVI anomalies 2018-2019



Decline High vul. Part. rec. Greening

## Decline cluster (20%)

Forests + grasslands



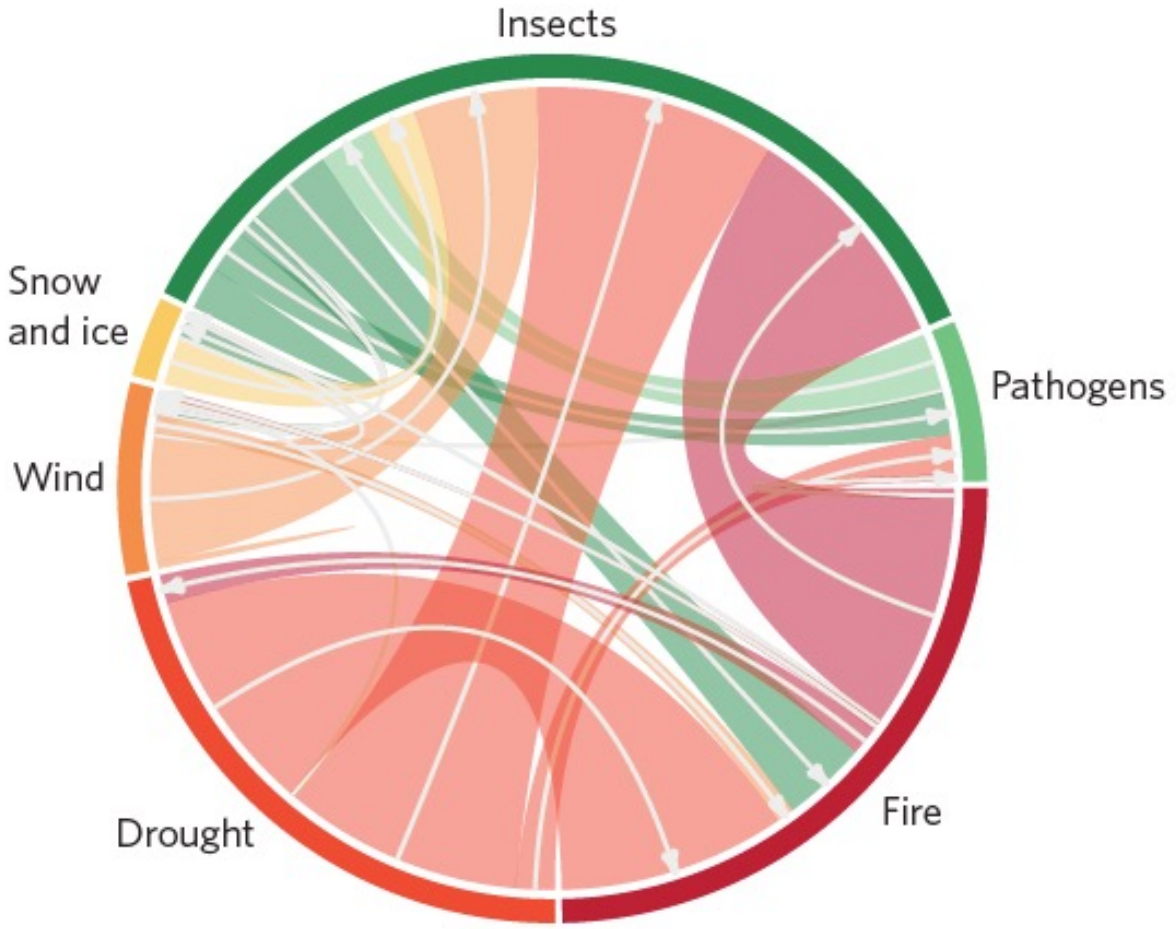

Bastos et al. (2021) ESD

# Challenges in impact assessment: disturbance interactions

Forest disturbances are driven by climate anomalies and extremes

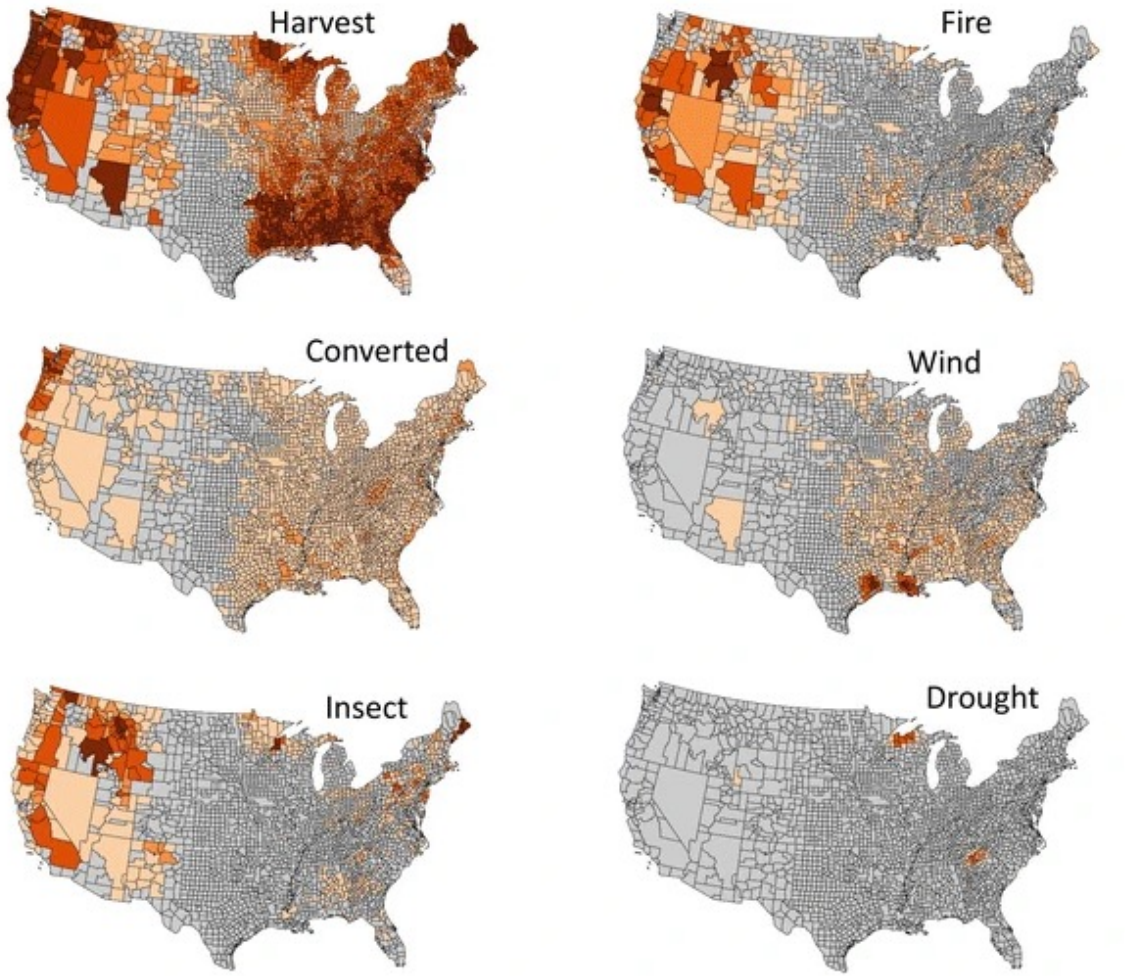
In turn, disturbance agents can interact (most are amplifying interactions)

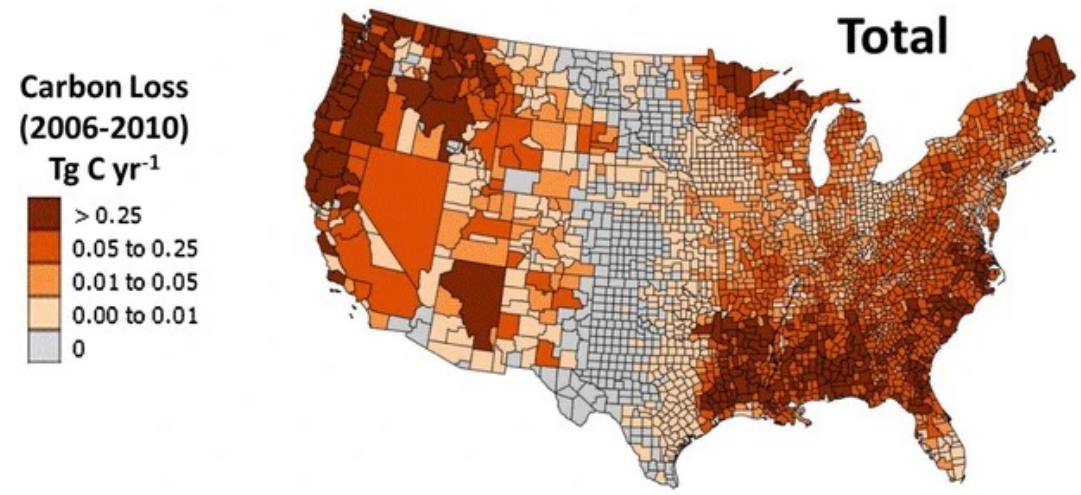
More frequent and intense extremes can lead to complex feedbacks and cascading effects




Seidel et al. (2017)

# Challenges in impact assessment: disturbance interactions



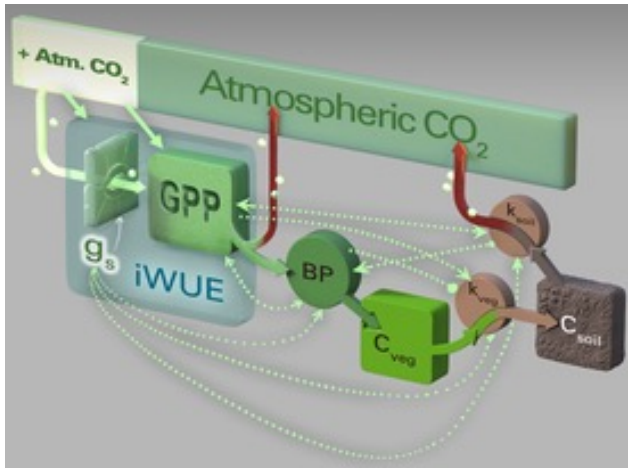

While droughts lead to small carbon losses generally, disturbances associated with drought lead to large losses: fires and insects

Harris et al. (2016) CBM

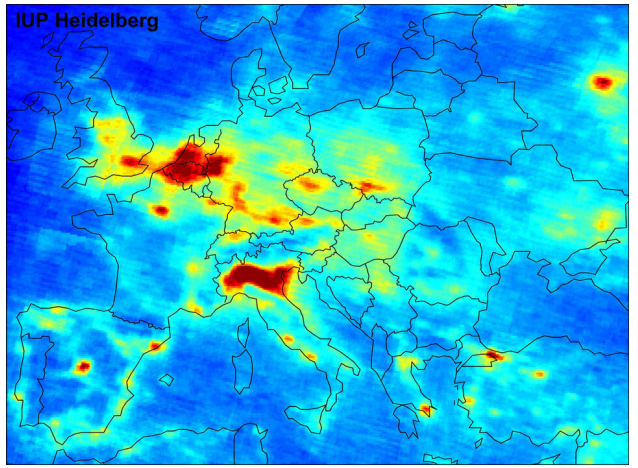
# Challenges in impact assessment: human activities

Humans influence impacts of extreme and compound events through many other processes beyond climate change

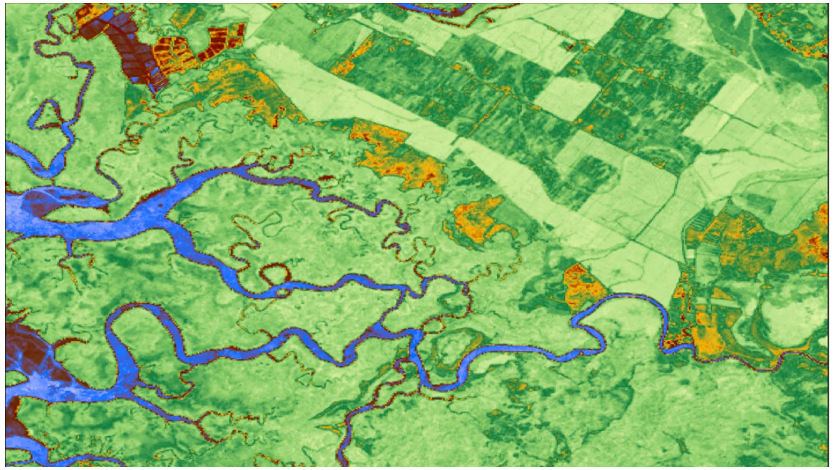
## Elevated $CO_2$




## Pollution




## Land / water use & lanscape changes



## Biodiversity

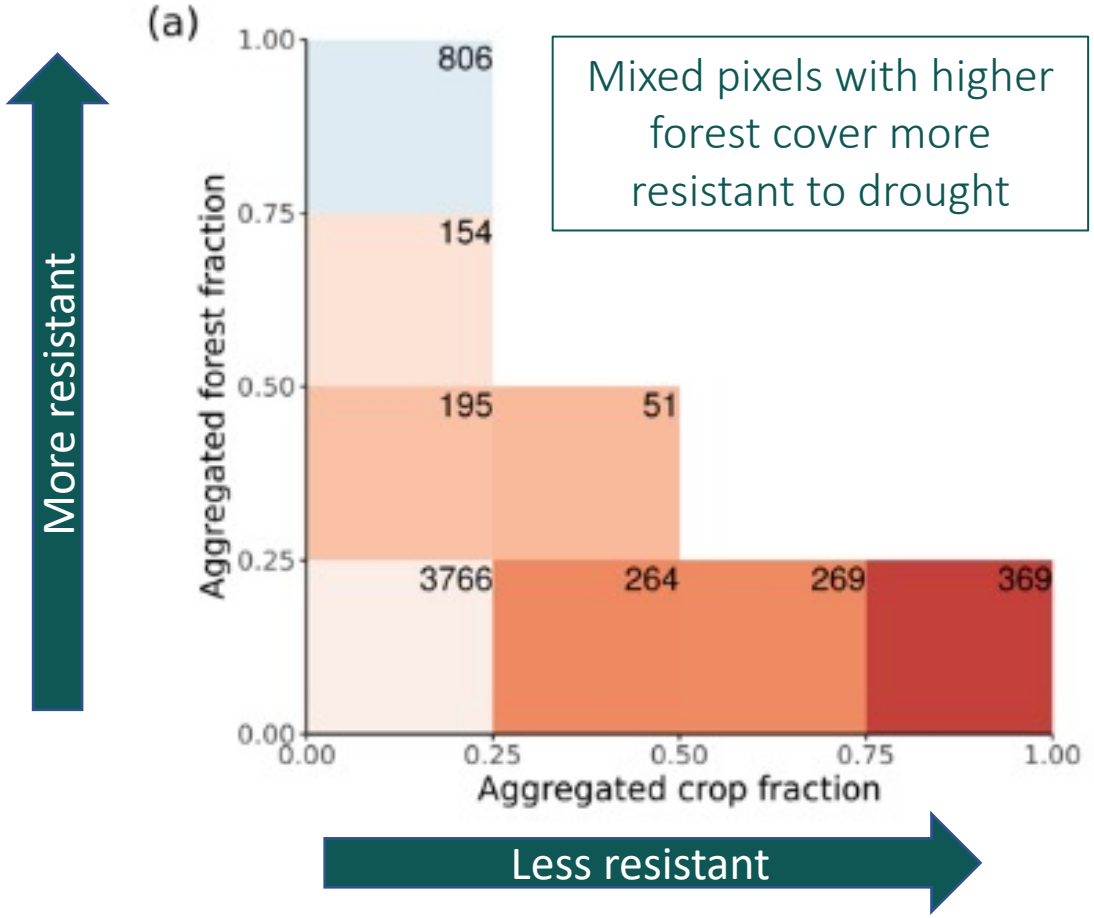
## Nutrients

Seidel et al. (2017)

# Global vegetation vulnerability to heat-drought

Chenwei Xiao

How do land cover and management affect vulnerability to drought?




Mixed pixels with higher forest cover more resistant to drought



Xiao, …, & Bastos (in discussion for ESD)

# Global vegetation vulnerability to heat-drought

Chenwei Xiao

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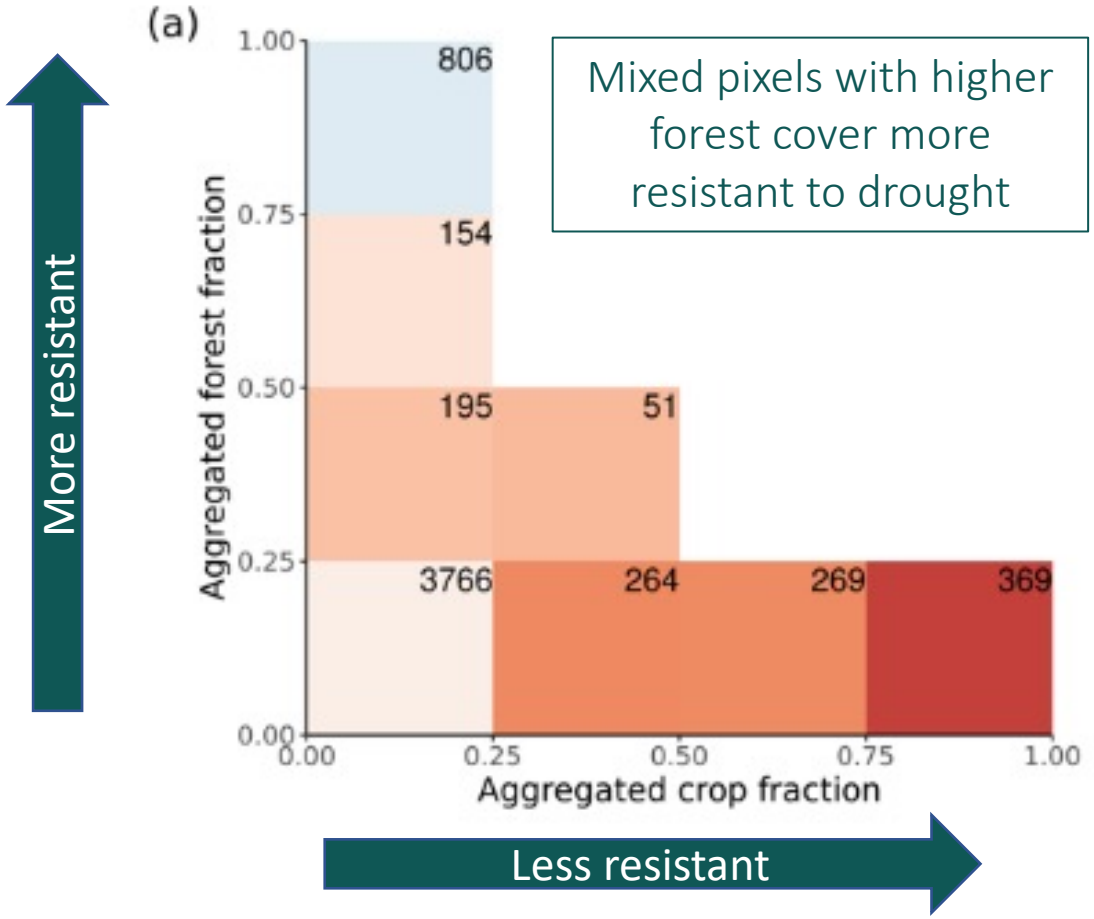


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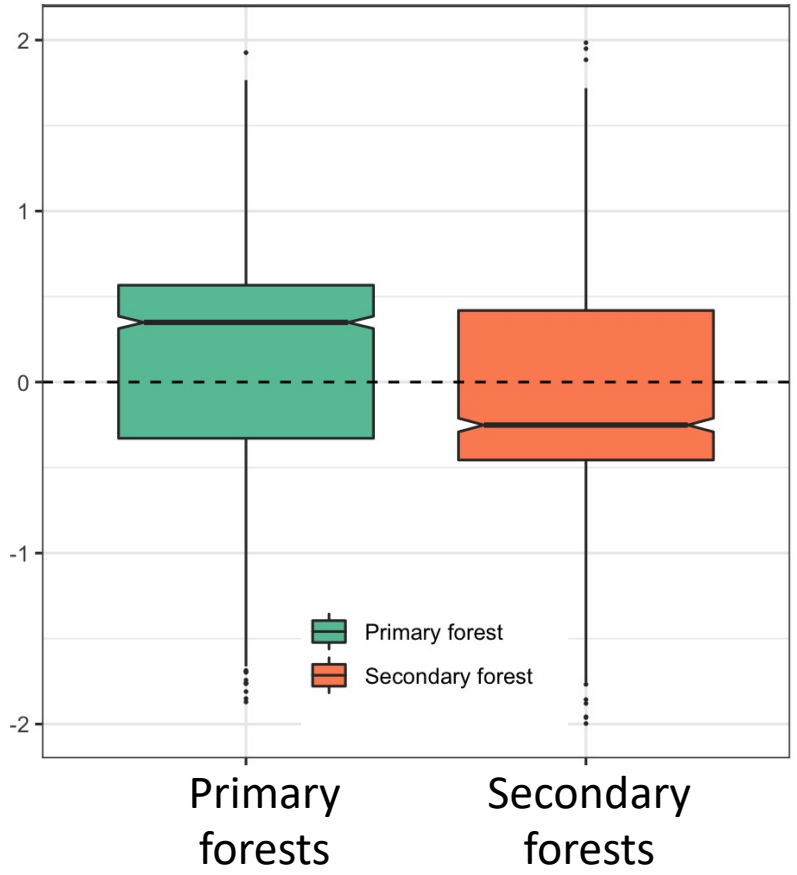



Less vulnerable

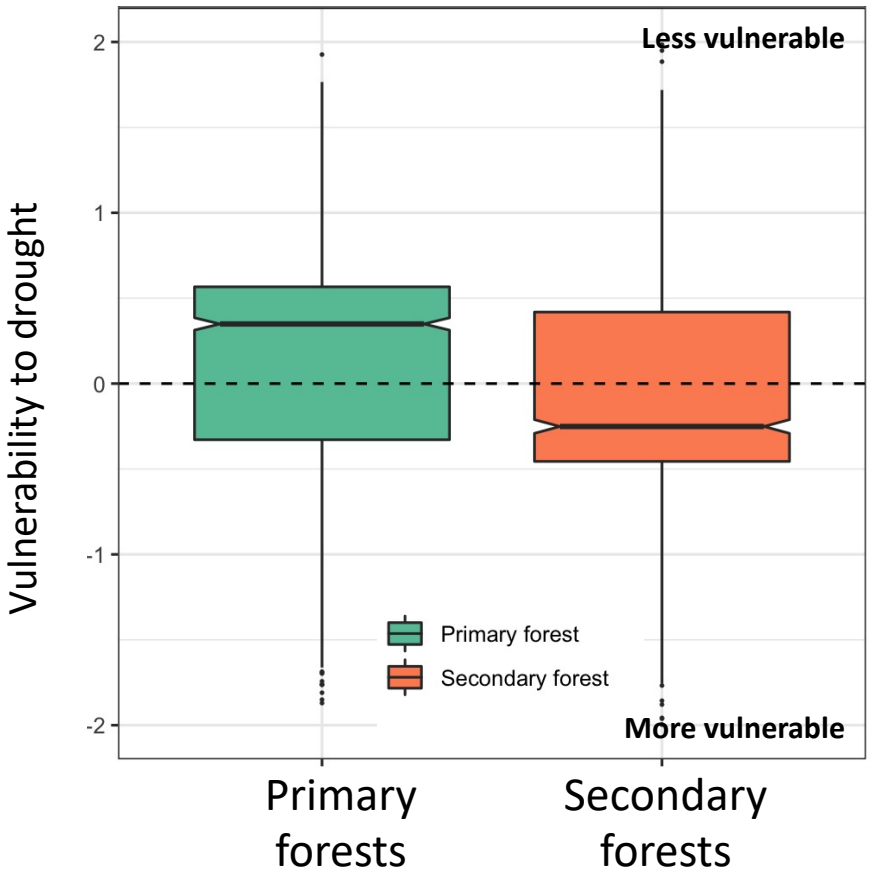
More vulnerable

Secondary forests more vulnerable to drought



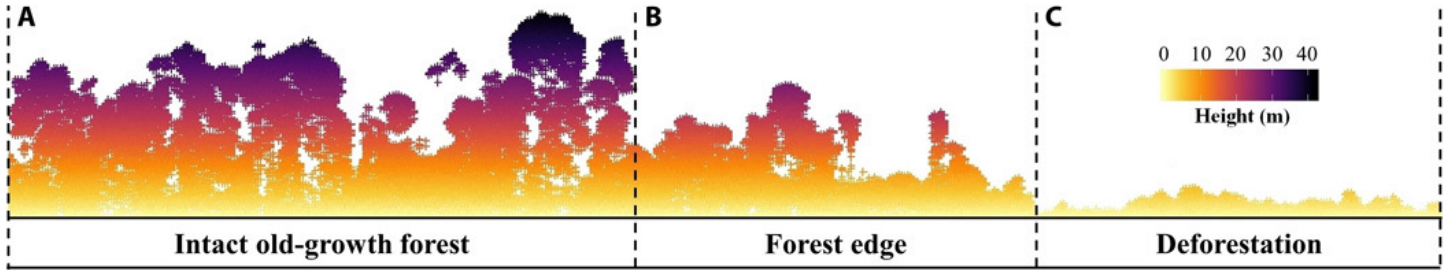
Xiao, …, & Bastos (in discussion for ESD)

# Vegetation vulnerability to heat-drought



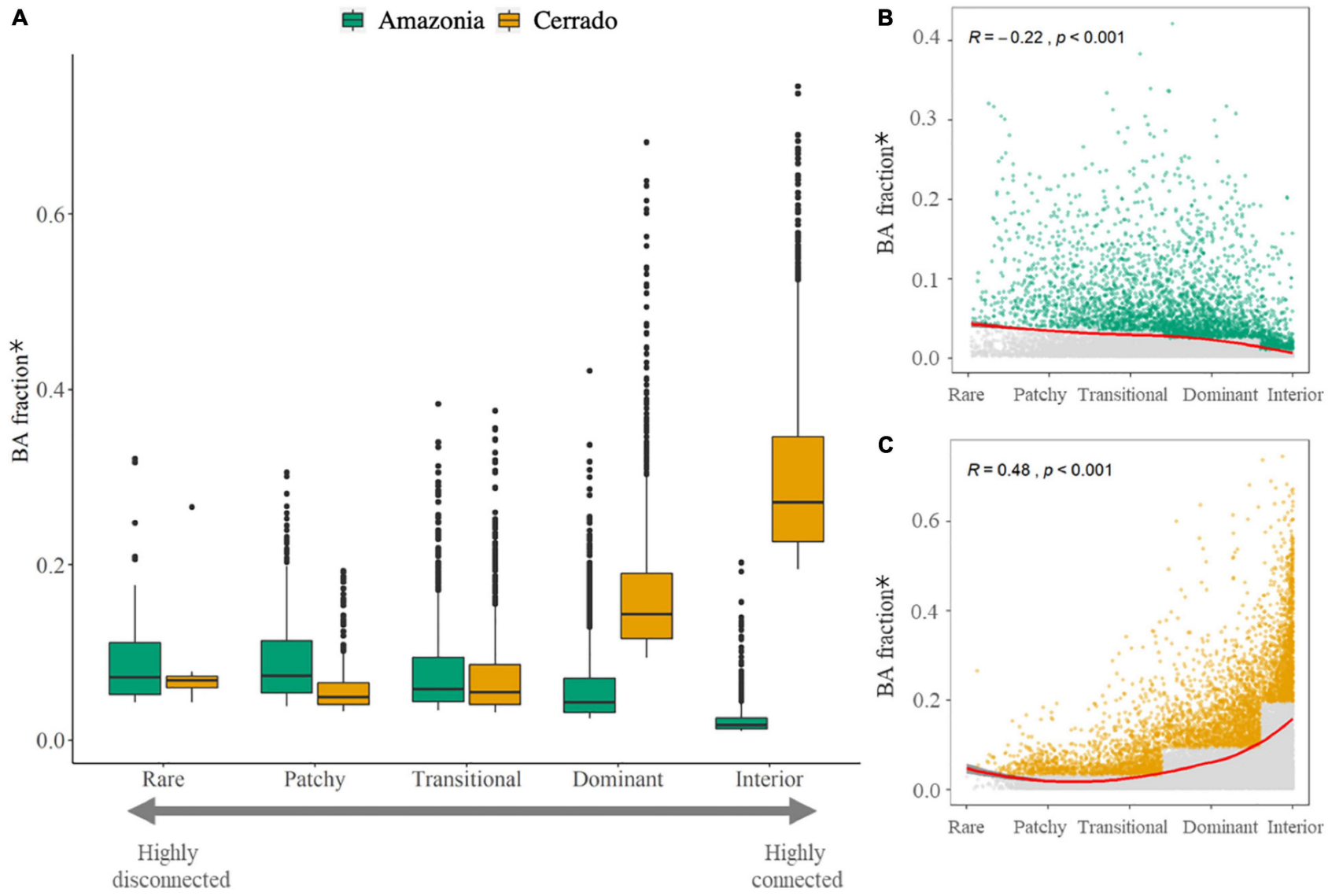

We need to consider human impacts on ecological factors that influence vulnerability to extremes


For example, vulnerability to drought is higher for primary forests versus secondary (disturbed by humans ) forests




Silva-Junior et al. (2020) *Science*

# Landscape fragmentation and burned area




Rosan et al. (2022) *Front. Forests and Glob. Change*

# Summary

- Quantifying concurrent and cascading effects from extreme events is important to evaluate **resilience to changing climate& extremes**

- Land Surface Models simulate **direct impacts reasonably well** in many regions,

- but **cannot yet simulate legacy** effects (hydraulic failure, compounding disturbances, …)

- Understanding how **human activities beyond climate change** influence ecosystem resilience to extremes is key

- **Increasing availablity of long-term EO data** (remote-sensing, in-situ) allow quantifying impacts and legacy effects and improve classification of different disturbance types…

  … helping to **develop theory needed for Earth System Models**

Want to know more about ecological impacts of extremes?