# Impact of Large-Scale Climate Extremes on Biospheric Carbon Fluxes: An Intercomparison Based on MsTMIP Data

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# A Multi-scale Synthesis and Terrestrial Model Intercomparison Project

- common experimental protocol for running $>$ 20 Terrestrial Biosphere Models (TBMs)

[Huntzinger et al., GMDD 2013; Wei et al., GMDD, 2013]

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# A Multi-scale Synthesis and Terrestrial Model Intercomparison Project

- common experimental protocol for running $> 20$ Terrestrial Biosphere Models (TBMs)
- same set of driver data
- evaluate how structural differences in model design impact estimates of carbon uptake and release

[Huntzinger et al., GMDD 2013; Wei et al., GMDD, 2013]

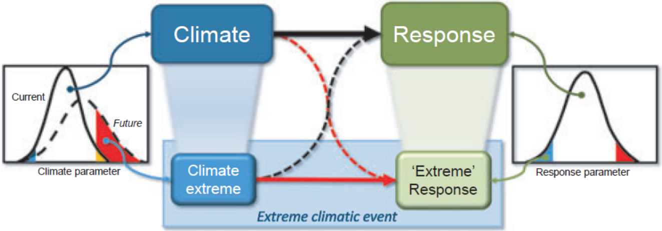
# Models, variables and resolution

- version: Global MsTMIP v1.0
- models used in this study (PI)
  - biome-bgc (Weile Wang, [Thornton et al., 2002])
  - clm (Dan Hayes, [Mao et al., 2011, 2012])
  - clm4vic (Maoyi Huang, [Li et al., 2011])
  - dlem (Hanqin Tian, [Tian et al., 2011, 2012])
  - gtec (Daniel Riccuito)
  - isam (Atul Jain)
  - lpj (Benjamin Poulter, [Sitch et al., 2003])
  - orchidee-lsce (Shushi Peng, [Krinner et al., 2005])
  - vegas (Ning Zeng, [Zeng et al., 2005])
  - visit (Akihiko Ito, [Ito, 2010])
- Gross Primary Production (GPP), Total Respiration (TR), Net Ecosystem Exchange (NEE)
- 0.5 degree spatial resolution, monthly temporal resolution, 1981-2010

# Two perspectives: drivers and responses

**“Forward assessment”:**
identify climate extremes and analyze their impacts

**“Backward assessment”:**
identify extreme changes in carbon fluxes and analyze their causes



# Definition of extreme events in climate drivers

- compute standardized precipitation index (SPI) at each pixel (time scale 3 months)
- compute standardized temperature index (STI, in the spirit of SPI) at each pixel (time scale 1 month)
- define a value as *extreme* if it exceeds $\pm 2$

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$\rightsquigarrow$ 4 categories of climate extremes:

1. *drought*: SPI $< -2$ (-P),
2. *extremely wet period*: SPI $> 2$ (+P),
3. *cold spell*: STI $< -2$ (-T), and
4. *heat extreme*: STI $> 2$ (+T).

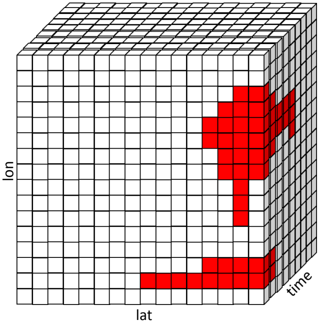
# Definition of extreme events in carbon fluxes

Let $x$ denote the carbon flux of a certain month. Then define $x$ as *extreme* if

$$|x - \bar{x}| > 2\sigma(x)$$

# Search for large spatiotemporally contiguous extremes

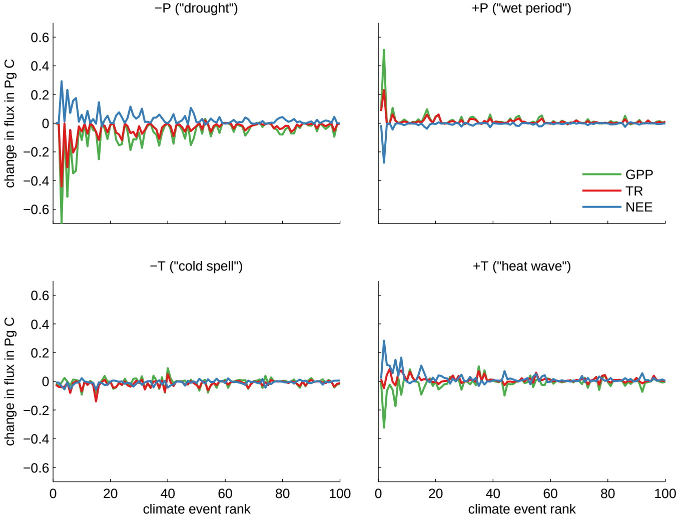
For each variable, combine extremes that are contiguous in time or space to *extreme events*.




Extreme events are sorted according to their size
= integral of STI/SPI/C flux anomalies over spatiotemporal domain of the event. [Zscheischler et al., Ecol. Inf., 2013; Zscheischler et al., ERL., 2013]

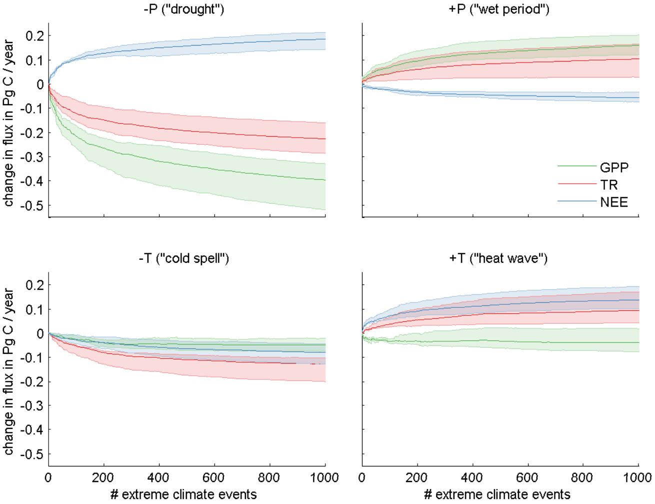
# Forward analysis

Impact of climate extremes on carbon fluxes averaged across models.



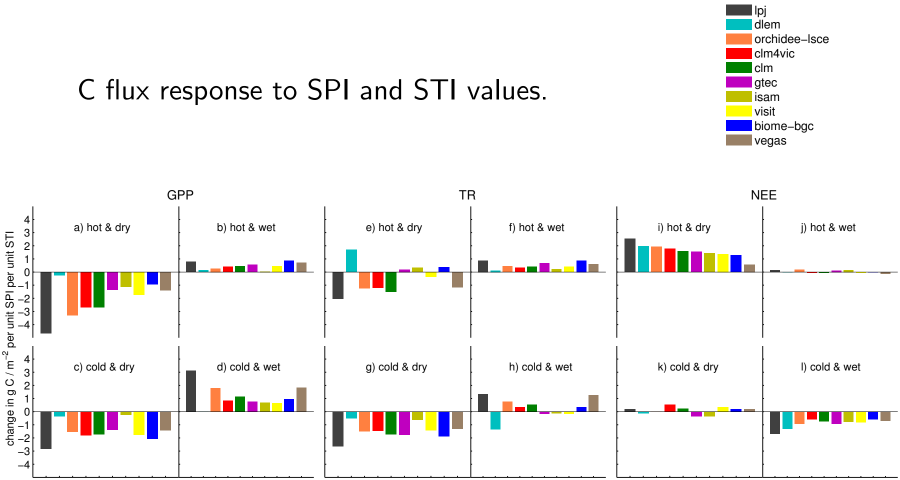
# Forward analysis

Cumulative impact of 1000 largest climate extremes.

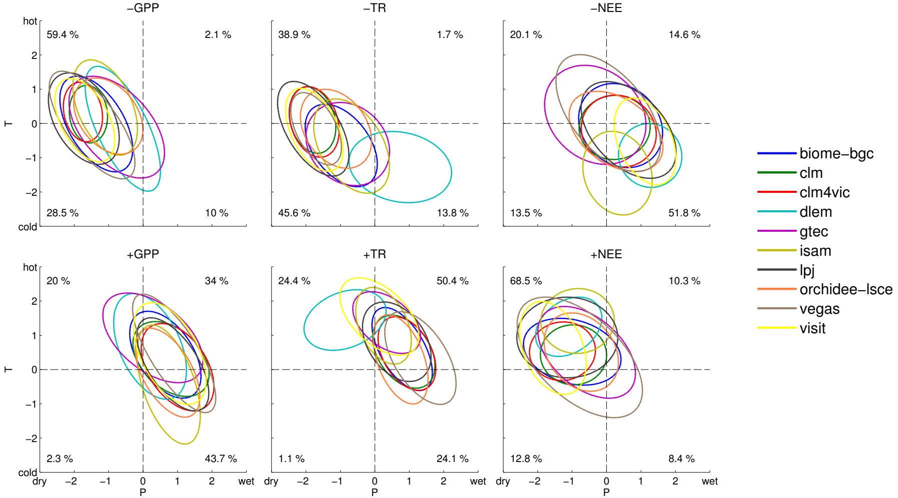


# C flux sensitivity to extreme events

C flux response to SPI and STI values.



# Backward analysis – all models – globe




Range of mean SPI and STI values during the 100 largest C flux extremes.

# Compound versus additive impact – NEE

$$\begin{aligned} I &= \text{Impact} \\ \textit{heatwave} &\Rightarrow I_H \\ \textit{drought} &\Rightarrow I_D \\ \textit{heatw.\&dr.} &\Rightarrow I_{HD} \\ I_{HD} &= I_H + I_D? \end{aligned}$$

# Compound versus additive impact – NEE

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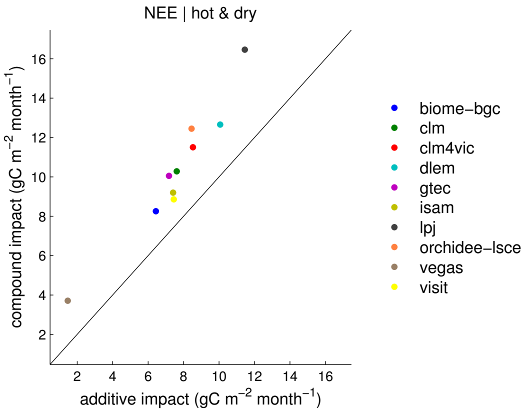


The compound impact of heat waves and droughts is larger than their added impact.

# Compound versus additive impact – TR

$$I = \text{Impact}$$
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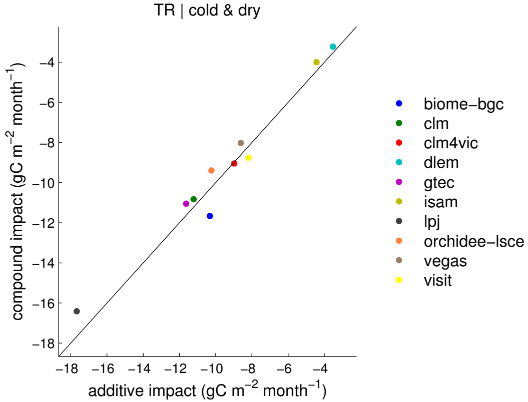
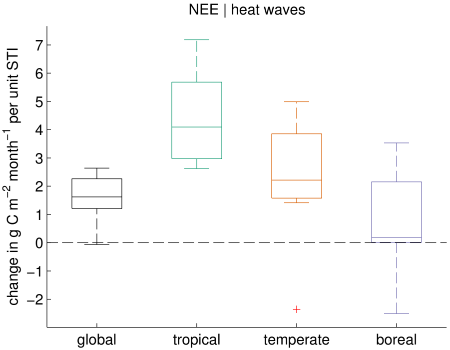
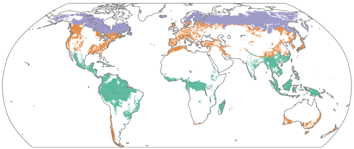



The compound impact of cold spells and droughts is equal to their added impact.

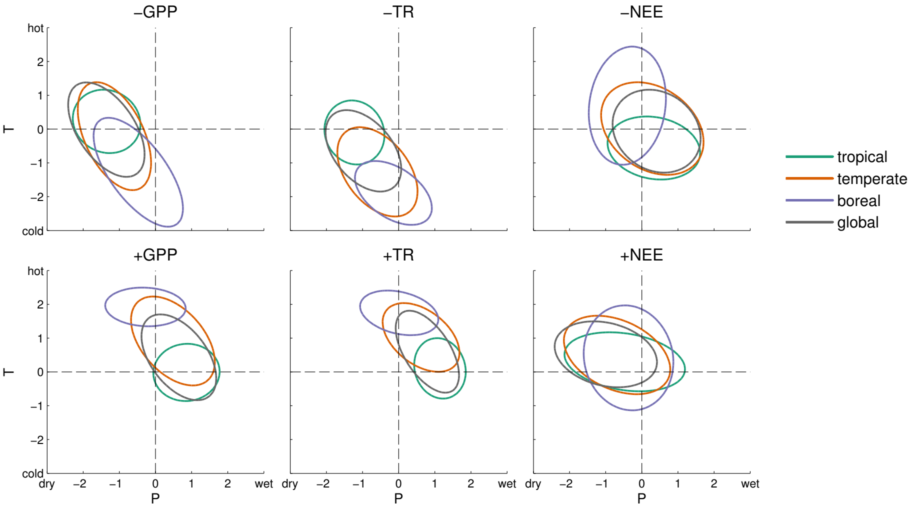
# Forward: NEE response to heat waves in regions



Large uncertainties in the response to heat waves in boreal forests.

# Backward analysis – biome dependent




Extremes in GPP and TR are P driven in tropical forests but T driven in boreal forests.

# Conclusions

1. at global scale droughts and heat waves lead to large net carbon release or decrease in carbon C sink
2. models agree on direction of response but magnitude of impact largely differs across models
3. hot and dry conditions compound each other
4. disagreement between models for NEE response to climate extremes in boreal forests