The sensitivity of terrestrial carbon stocks to forest disturbance regimes

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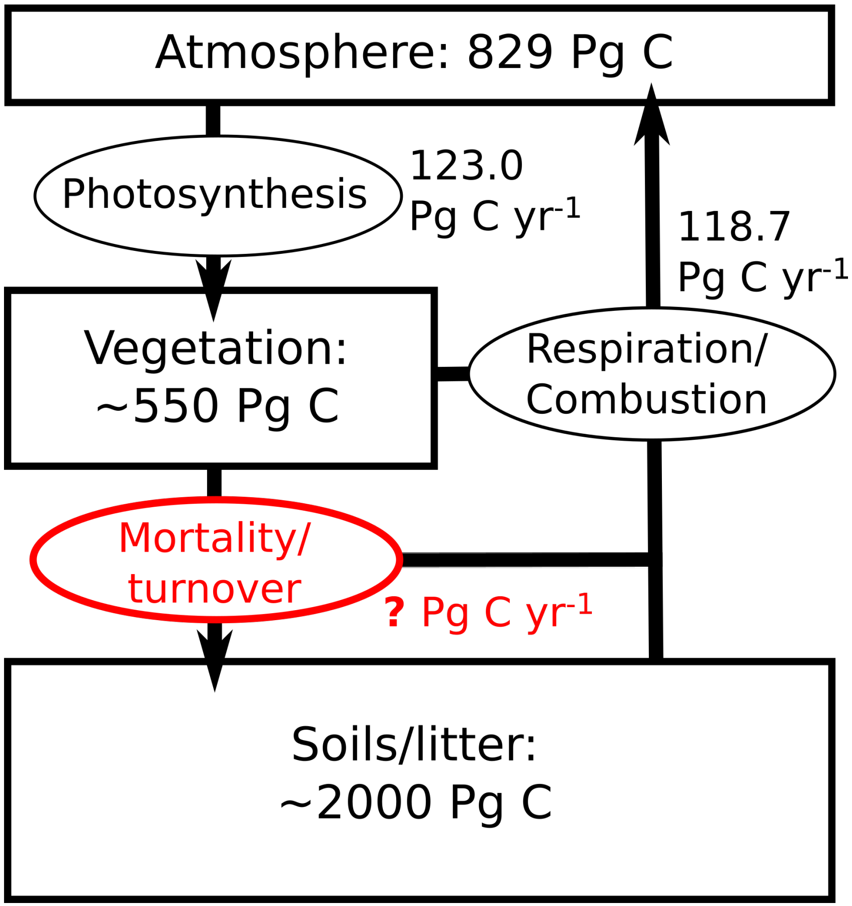
IMK-IFU: Atmospheric Environmental Research

KIT
Karlsruhe Institute of Technology

Dynamic global vegetation modelling: towards a third generation, Landskrona, May 2015

Introduction



Changes in mortality rate fundamentally change the carbon storage capacity of ecosystems

Numbers, Ciais et al. (2013)

Introduction: Mortality

Routes to tree mortality:

1) "Inability to acquire or mobilise sufficient resources to heal injuries or otherwise sustain life" (Waring, 1987)

- Shading
- Nutrient limitation
- Water stress
- Chronic herbivory
- Disease
- Age-related degradation

2) Exogenous, stand-destroying, disturbance events

- Fire
- Wind-throw
- Acute herbivory (e.g. insect outbreaks)
- Logging

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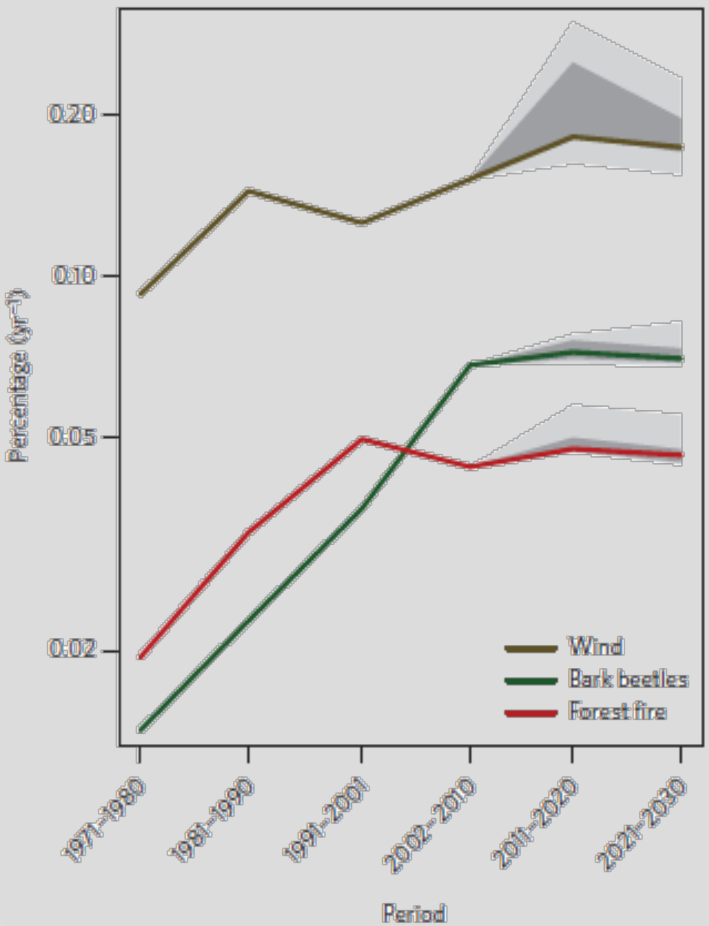
Focus here on disturbance mortality

Introduction: Disturbances

Disturbances are distinct processes with their own drivers

Disturbance damage in Europe (% timber stock) (Seidl et al., 2014)



We have reason to think that disturbance rates will increase in the future:

- Changing climate moves pests & diseases into new ranges
- Leaves become less nutritious under high [CO_2], requiring insects to eat more
- Increasing climatic extremes:
  - More hot/dry weather increasing fire incidence? (link not trivial)
  - Water stress makes trees more vulnerable to biotic attack
- Increases in storm severity?

Introduction: LPJ-GUESS

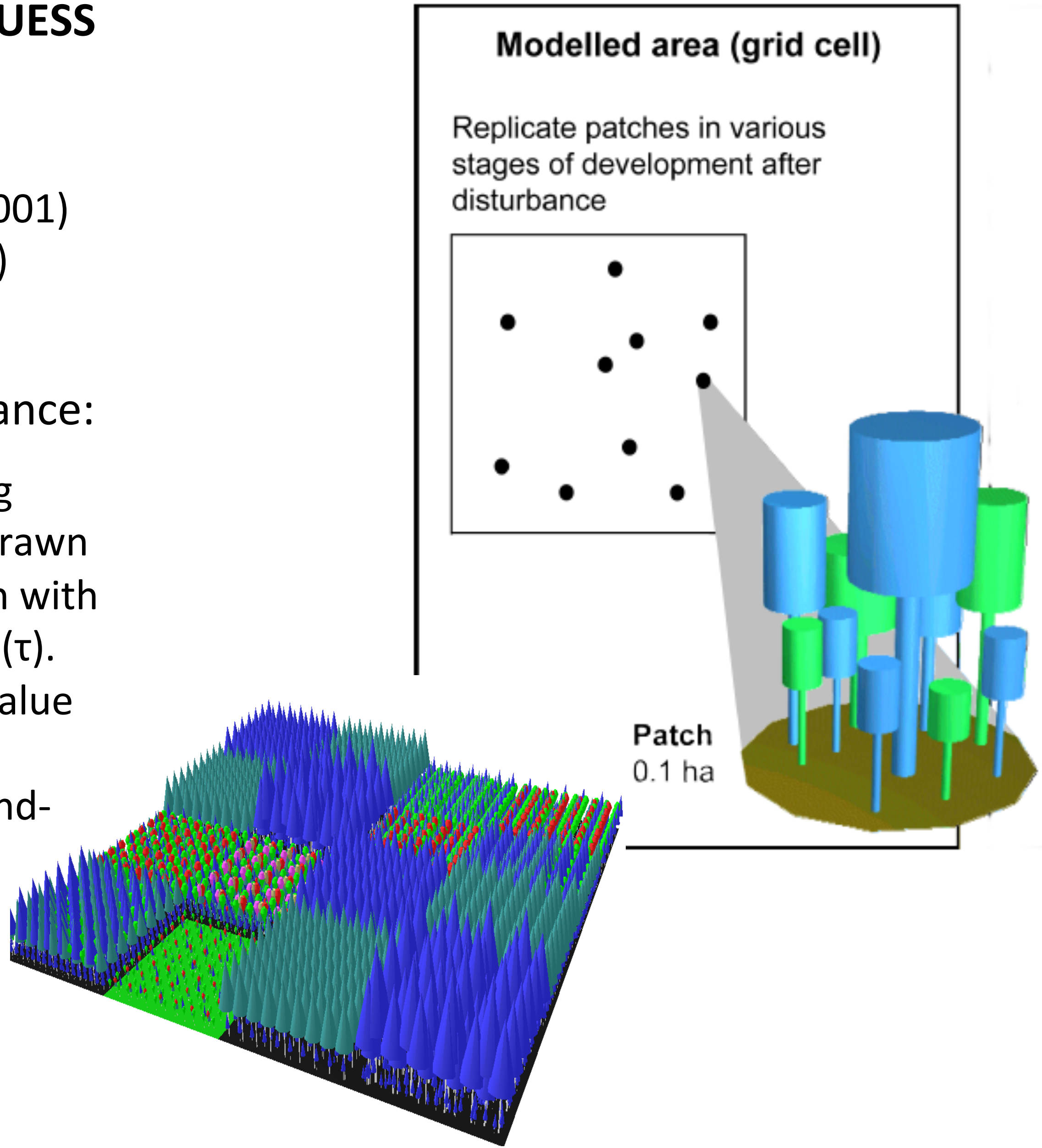
Disturbance mortality in LPJ-GUESS

Prognostic fire model:

- GLOBFIRM (Thonicke et al., 2001) or SIMFIRE (Knorr et al., 2014)
- PFT-specific fire resistance

Stochastic background disturbance:

- Likelihood of stand-destroying disturbance in any one year drawn from a probability distribution with a characteristic return period (τ).
- 100 years is standard global value for LPJ-GUESS.
- Intended to represent e.g. wind-throw, insect attack, logging.



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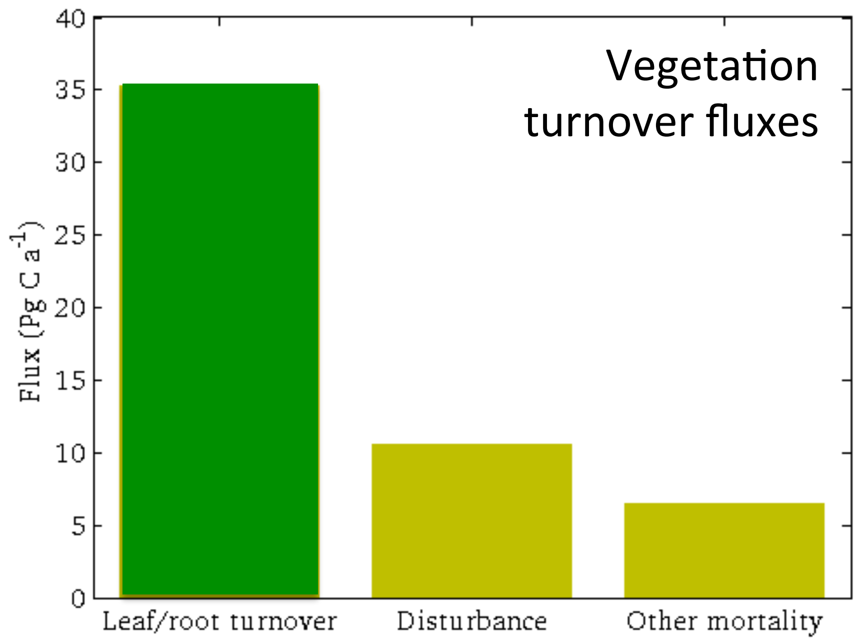
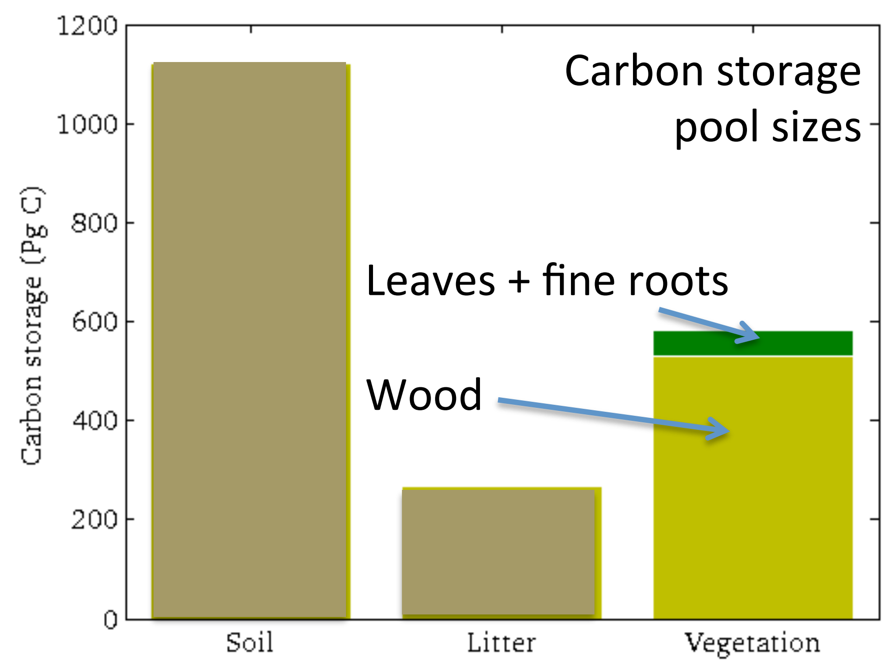


1996-2005 global means from LPJ-GUESS simulation with prognostic fire and 100 year disturbance return period (τ)



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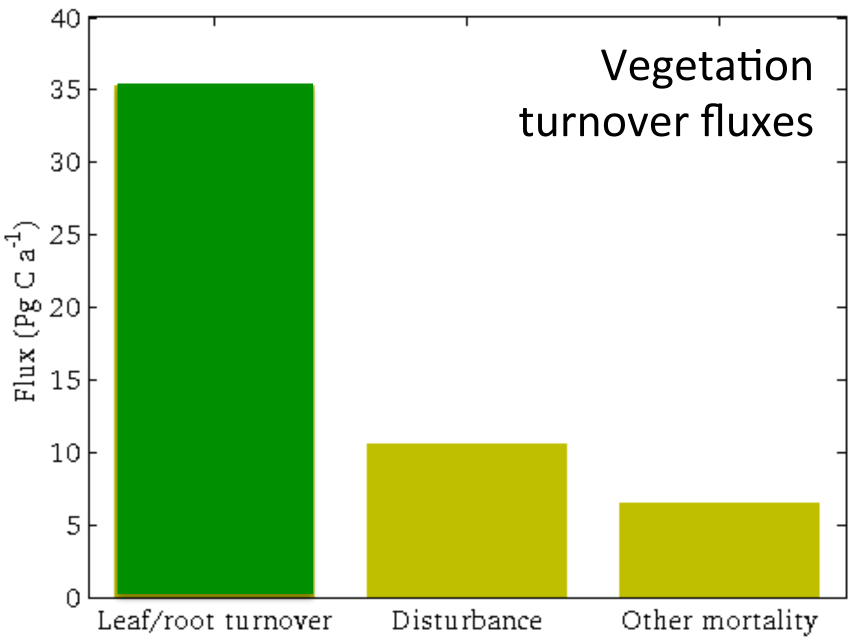
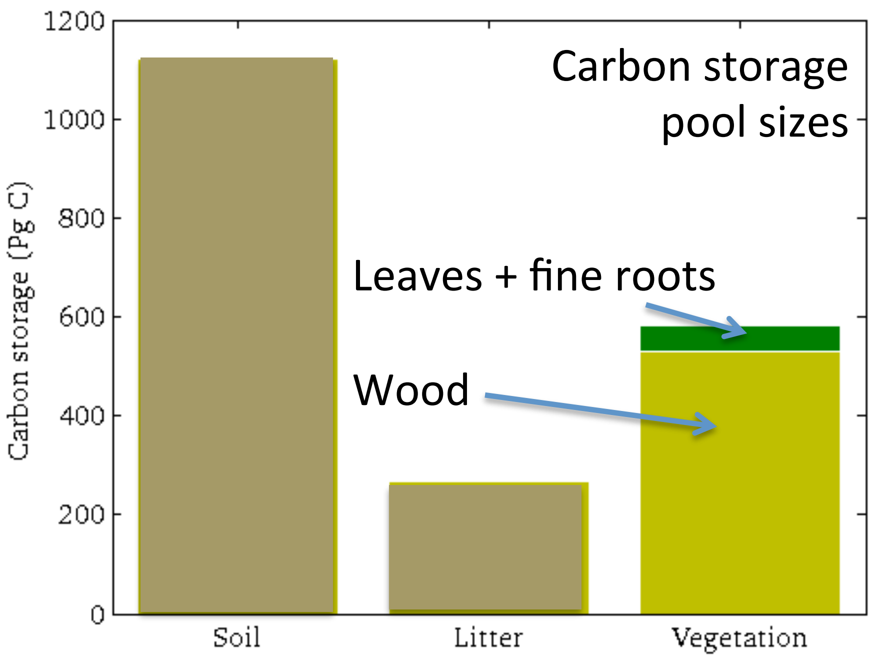


1996-2005 global means from LPJ-GUESS simulation with prognostic fire and 100 year disturbance return period (τ)

Disturbance dominates mortality fluxes in LPJ-GUESS

How sensitive is LPJ-GUESS to changing disturbance regimes?



Effect of changing disturbance rate: Methods

Basic set-up:
Historical simulations under CRU climate and [CO_2] 1850-2005
No prognostic fire

τ = 1000, 400, 200, 100, 50, 25 years

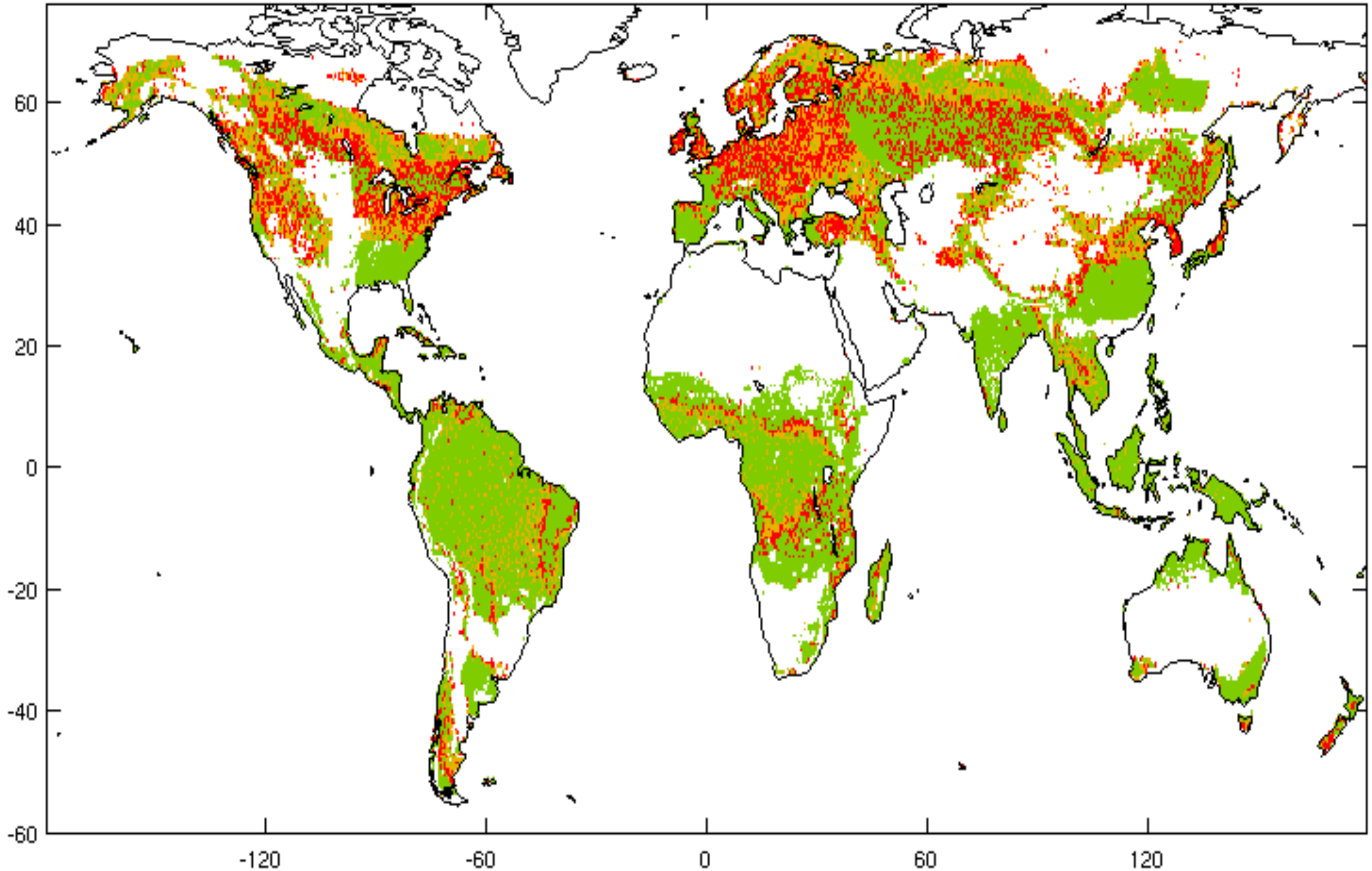
Treatment of disturbance in 3 different ways

1. All trees killed, all biomass to litter (e.g. intense insect outbreak)
2. All trees killed, 70% of wood biomass removed (e.g. logging)
3. Fire, trees killed according to PFT likelihoods

Results are for forested land only
(masked by HYDE 3.1 current land-use)

Effect of changing disturbance rate: Forest composition

Disturbance-induced changes in dominant PFT

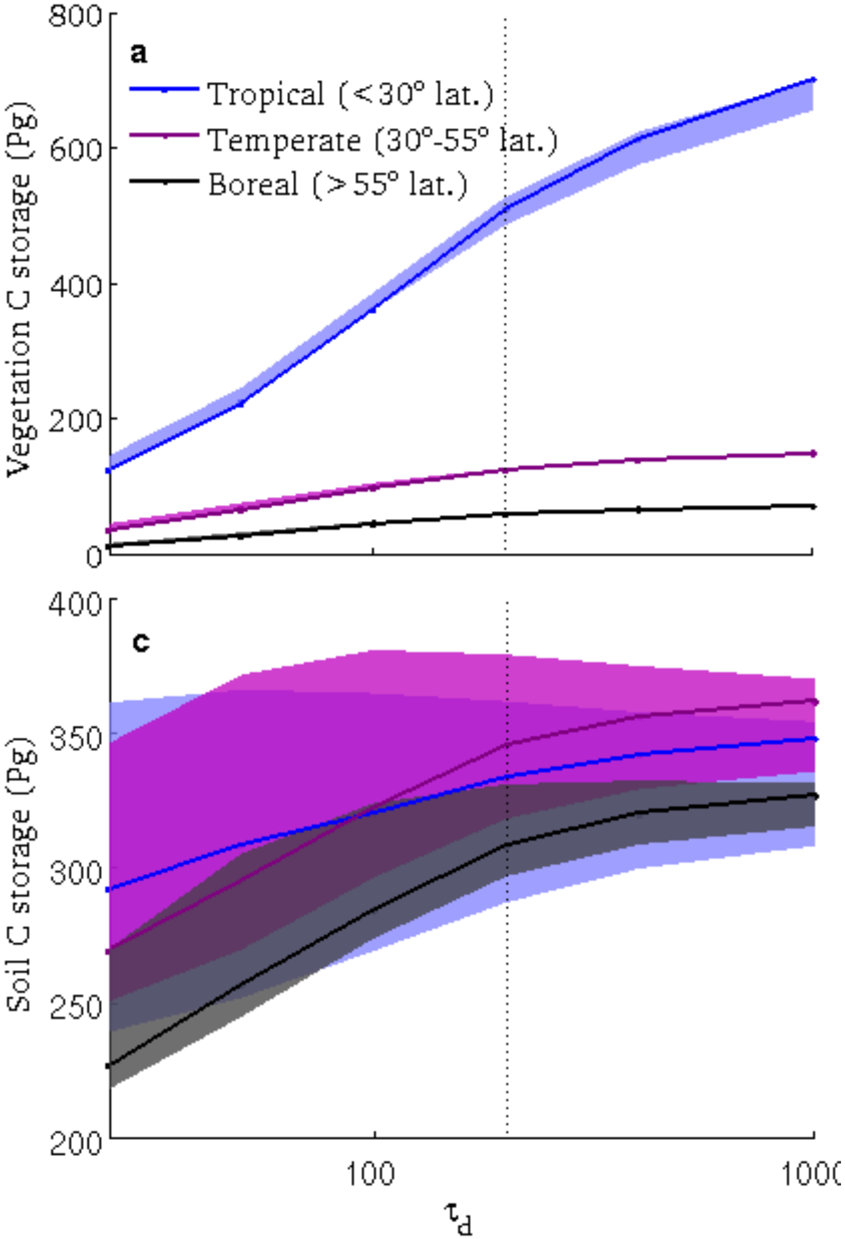


= Grid-cells containing forest (τ=200)

= Dominant PFT changes when τ=100, relative to τ=200

= Dominant PFT changes when τ=50, relative to τ=200

Effect of changing disturbance rate: Carbon storage



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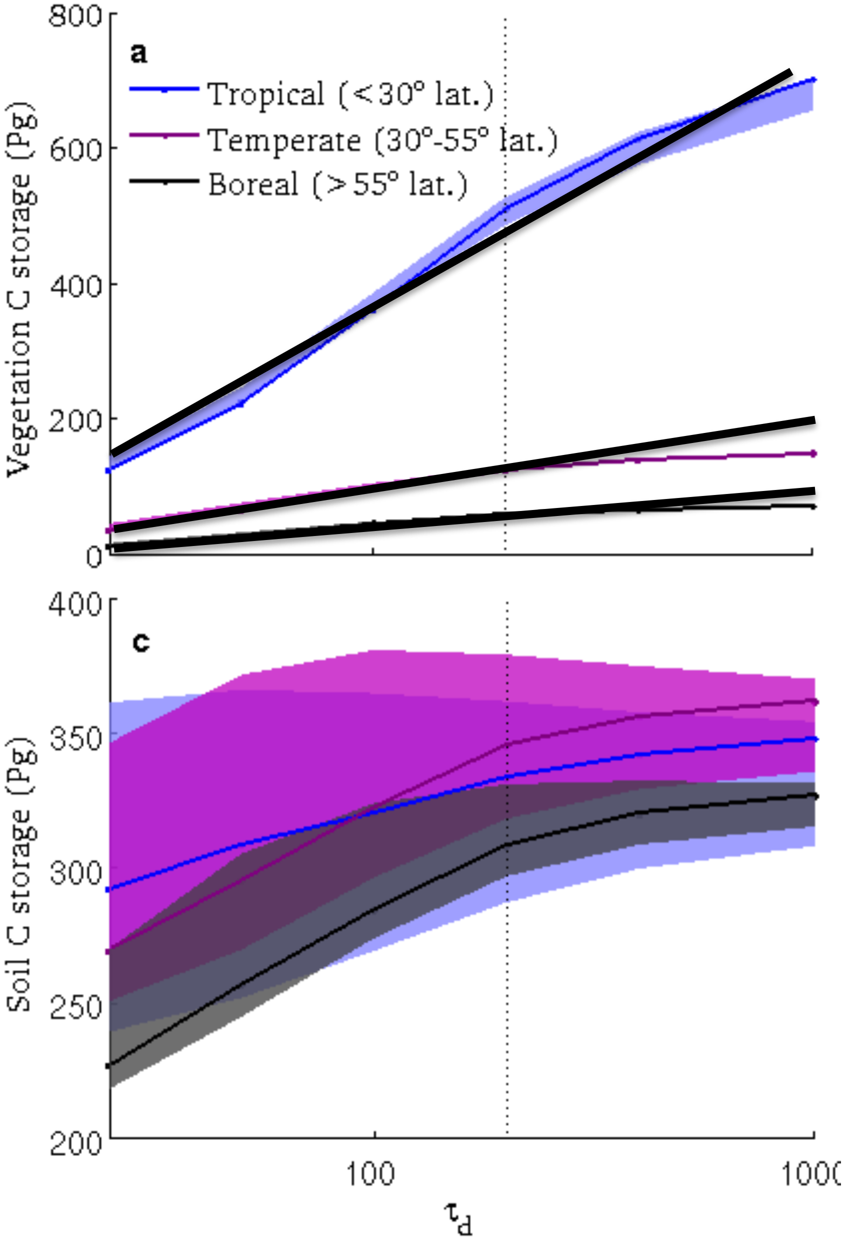
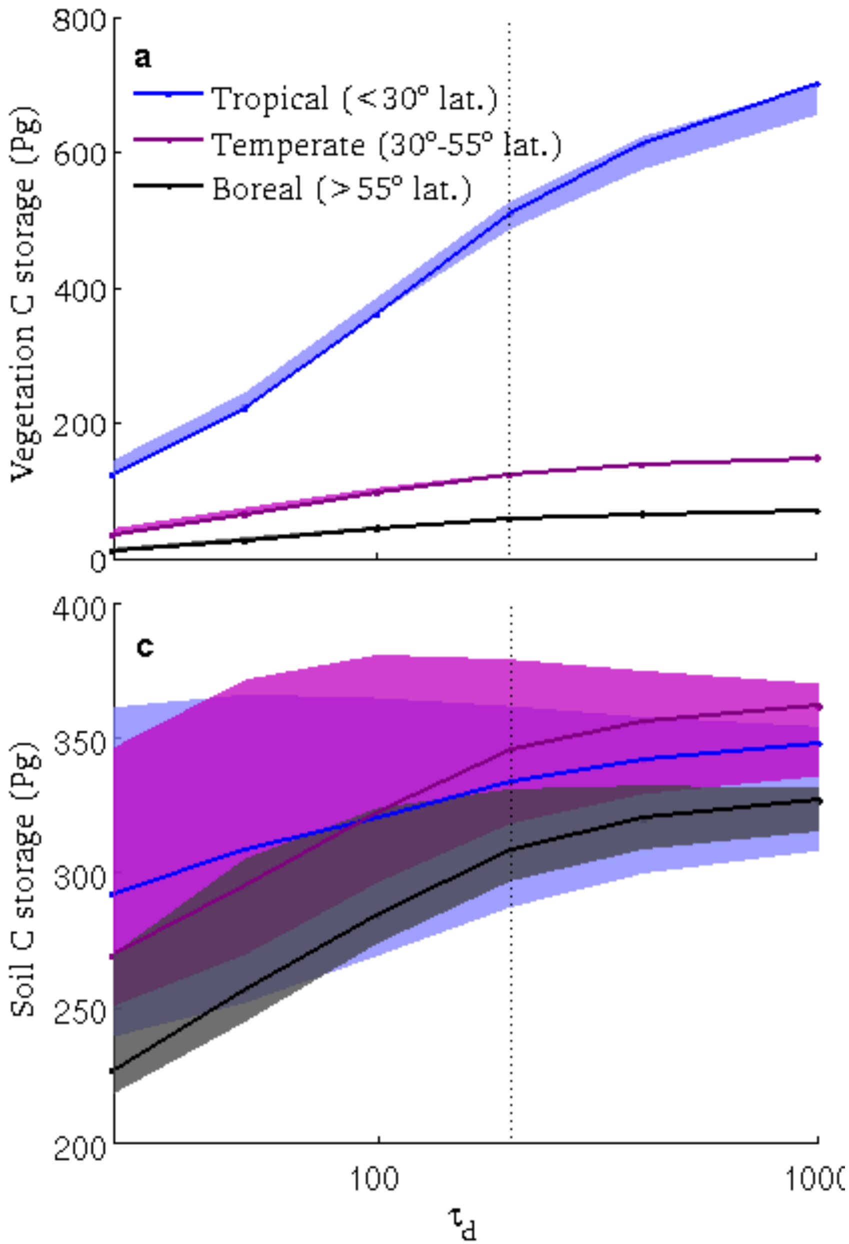


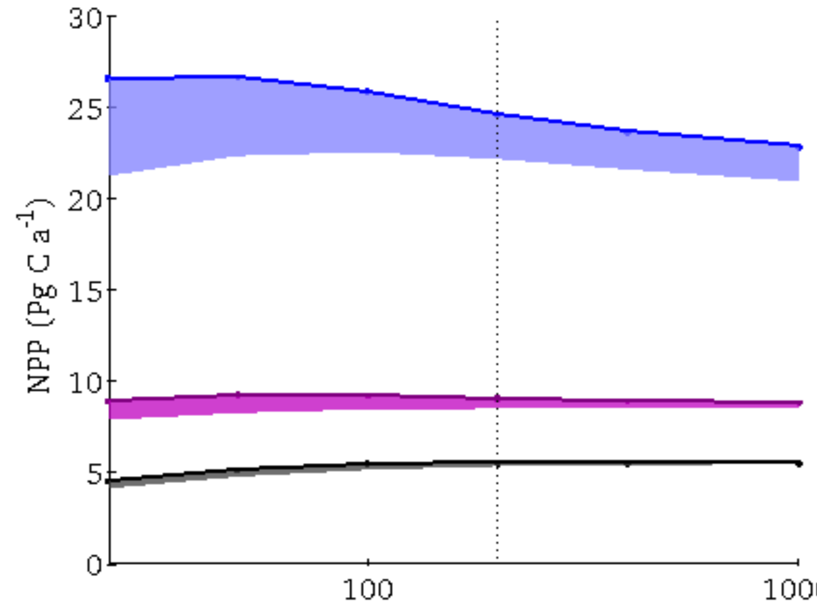
Effect on vegetation carbon is quasi log-linear

Whatever the actual disturbance rate, changes in τ have large effects on C storage

Not strongly sensitive to N feedbacks from soil

Effect of changing disturbance rate: Carbon storage



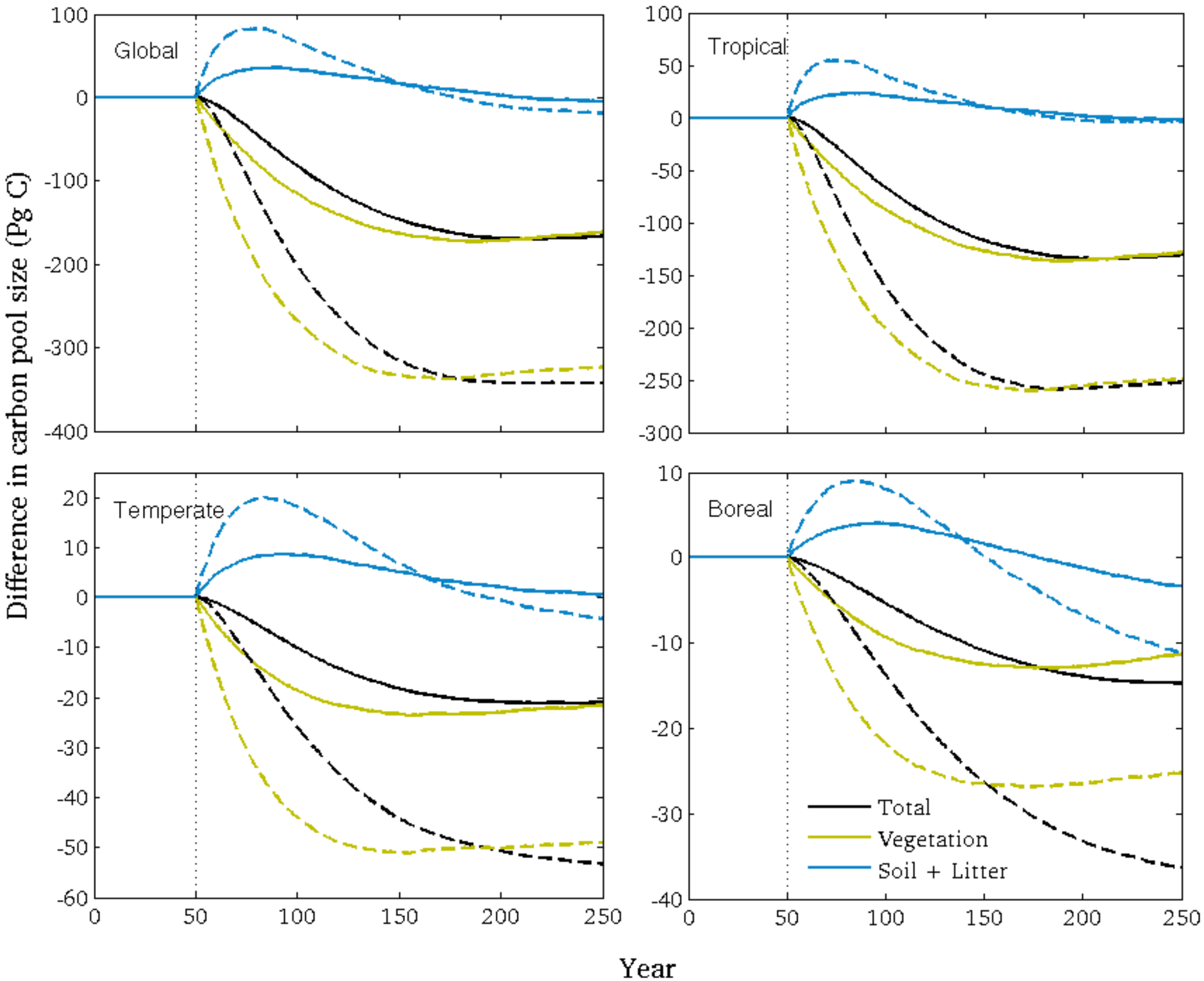


Soil response in high latitudes is driven by NPP

NPP is reduced at short disturbance return periods, due to lack of canopy closure

Effect of changing disturbance rate: Timescales

Fixed climate and [CO_2], sudden change in disturbance rate

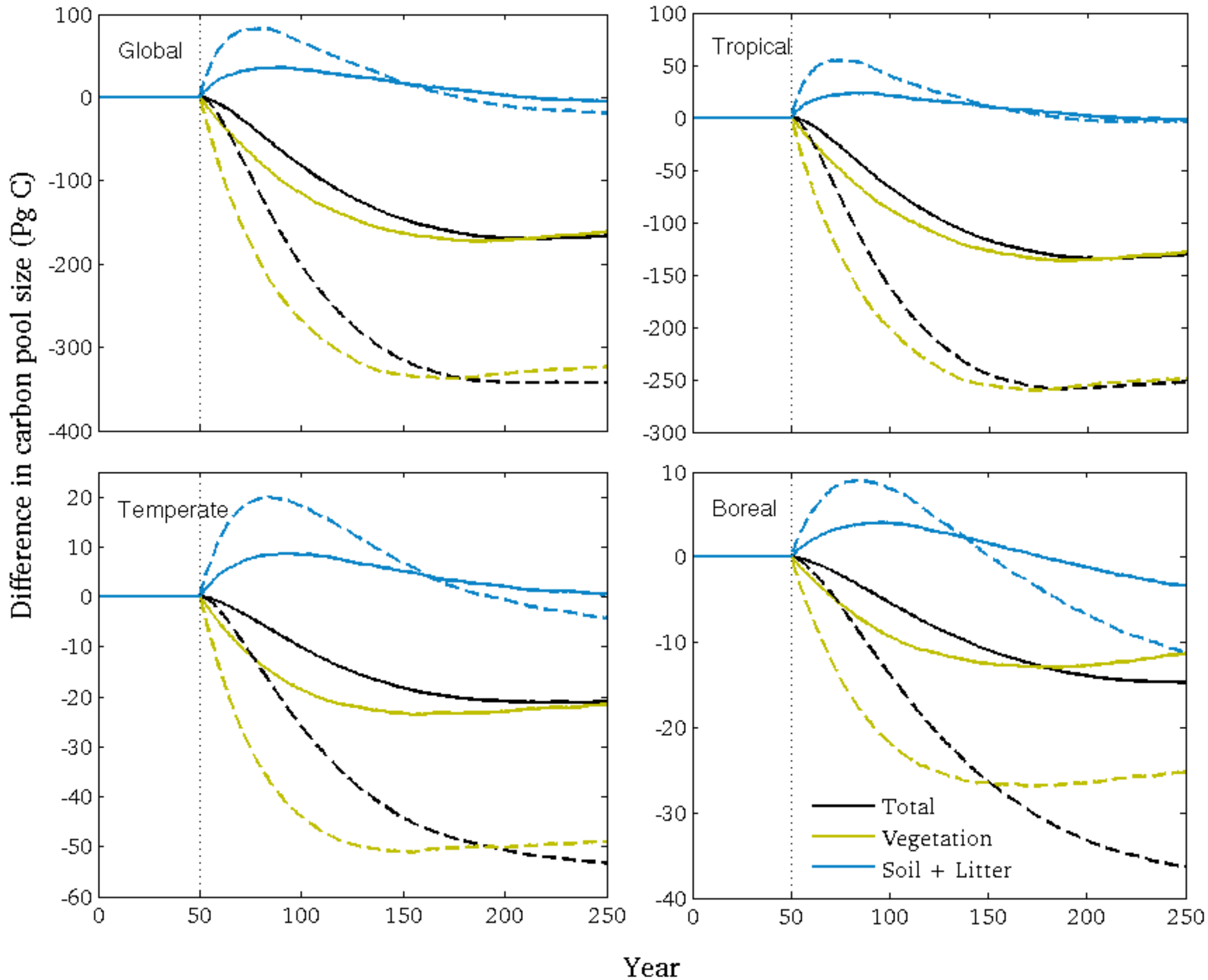


Solid lines:
τ=200 to τ=100
Dashed lines:
T=200 to τ=50

Vegetation C
Soil + Litter C
Total C

Effect of changing disturbance rate: Timescales

Fixed climate and [CO_2], sudden change in disturbance rate



Solid lines:
τ=200 to τ=100
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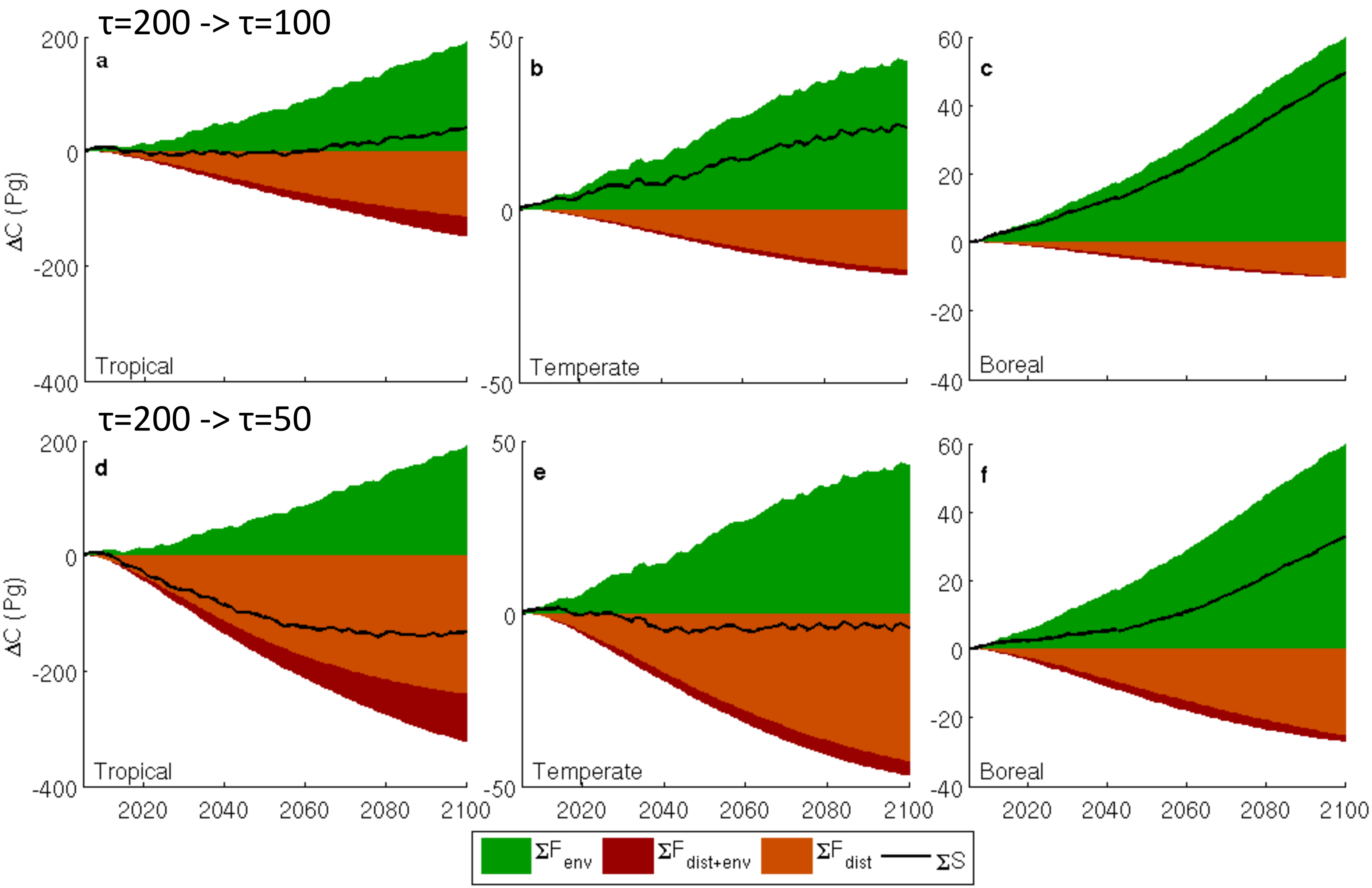
Vegetation C
Soil + Litter C
Total C

e-folding time (veg):
τ=100, 40-48 years
τ=50, 28-34 years

Rapid, and consistent across regions

Effect of changing disturbance rate: Future carbon sink

RCP 8.5 climate and $[CO_2]$, sudden change in disturbance rate at 2005



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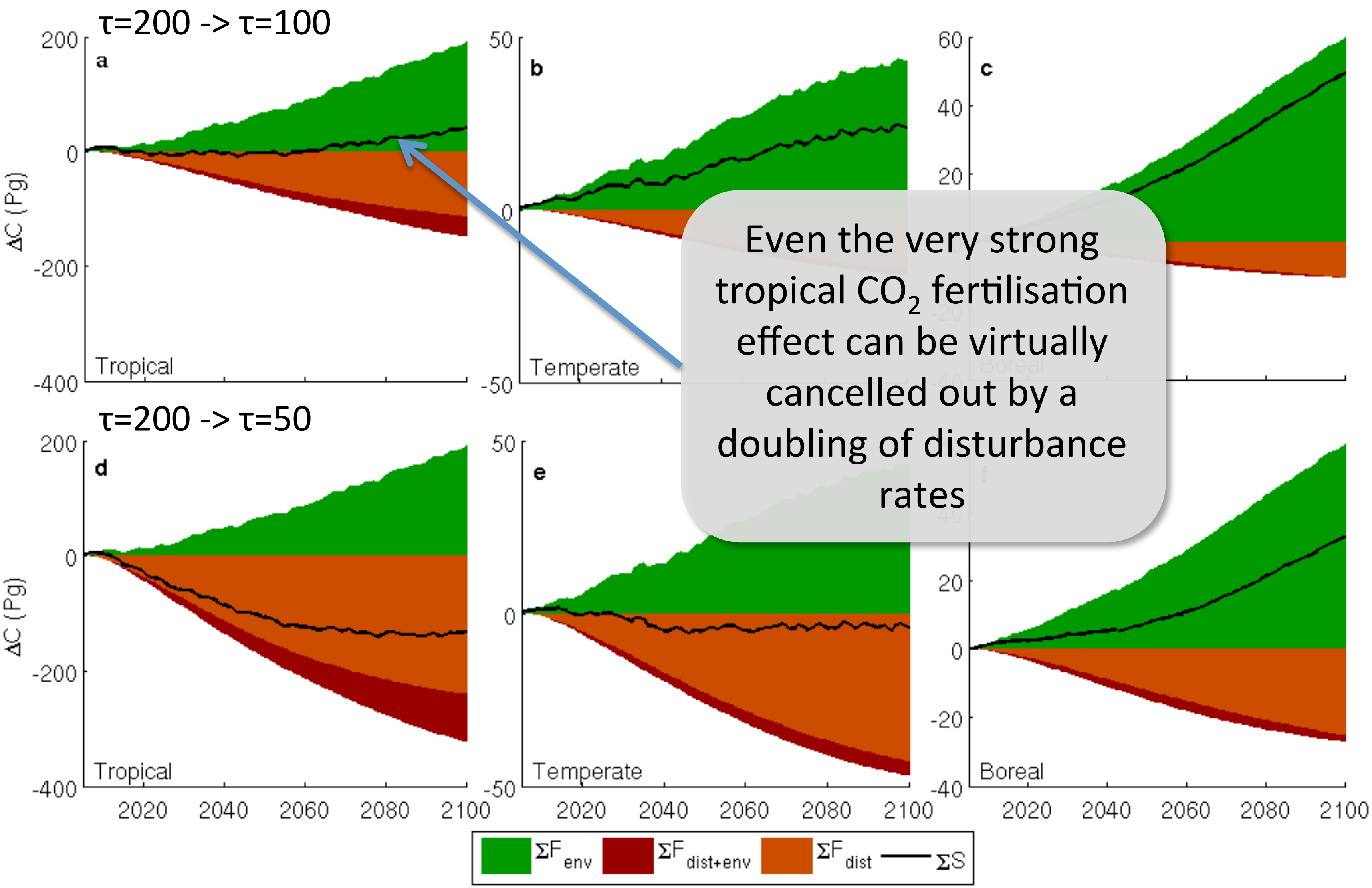
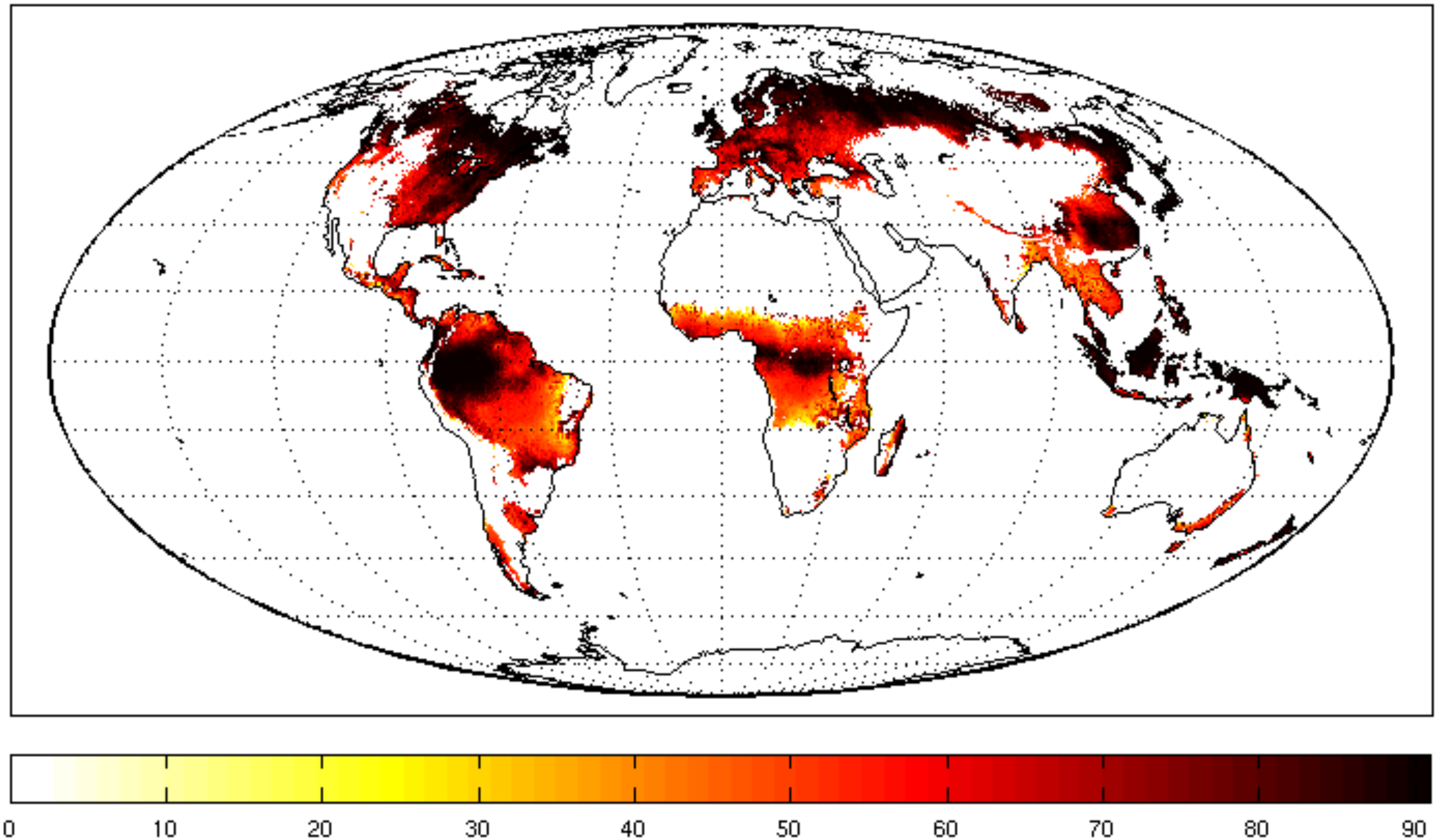


Actual disturbance rates

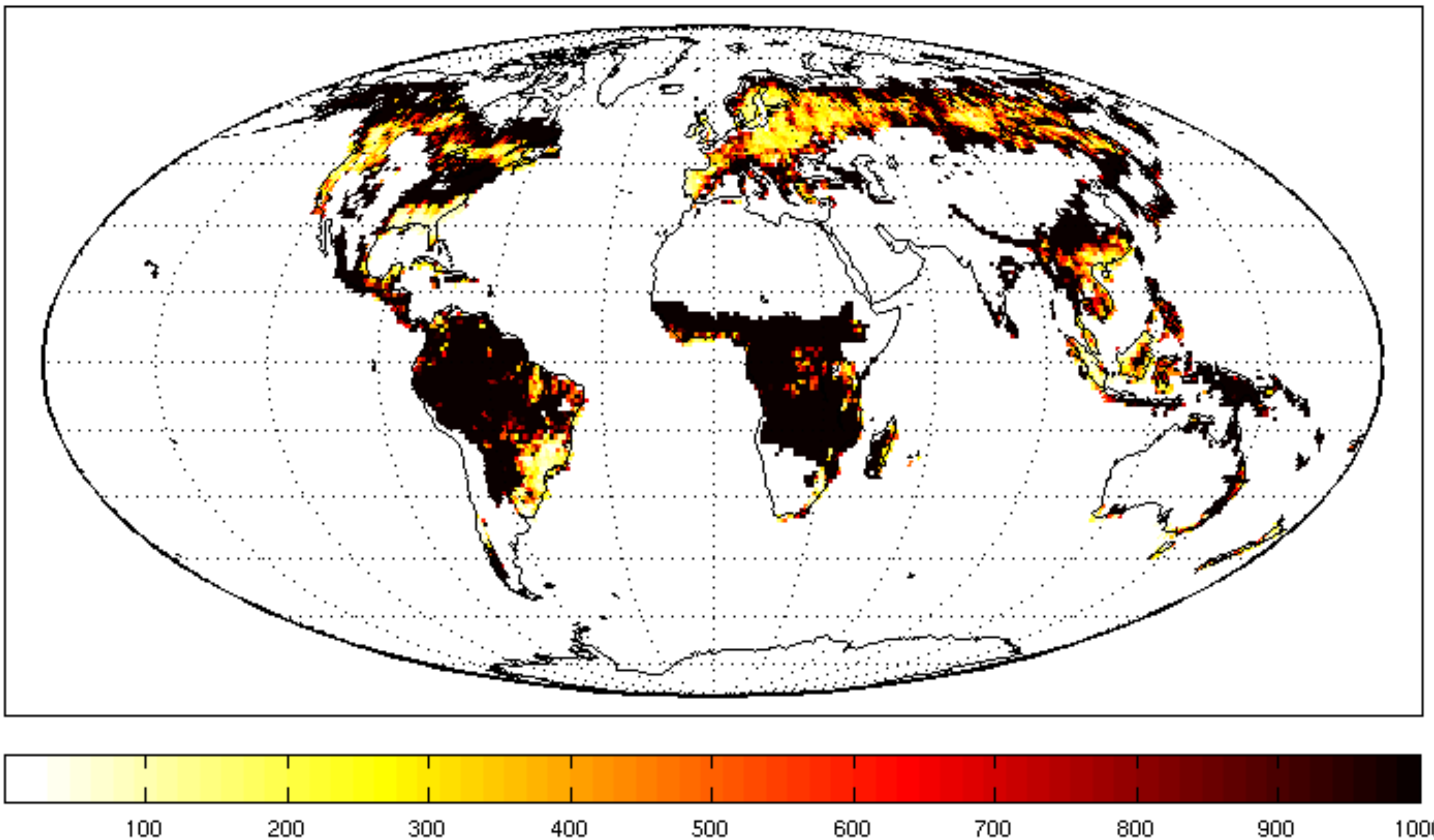
Standard LPJ-GUESS disturbance return period for forested areas (combined fire and background)



Actual disturbance rates

Hansen et al. (2013) calculate forest loss over 2001-2012 from satellite measurements at 30 m resolution

Here recalculated to give τ at 1° x 1° resolution (land-use change corrected)



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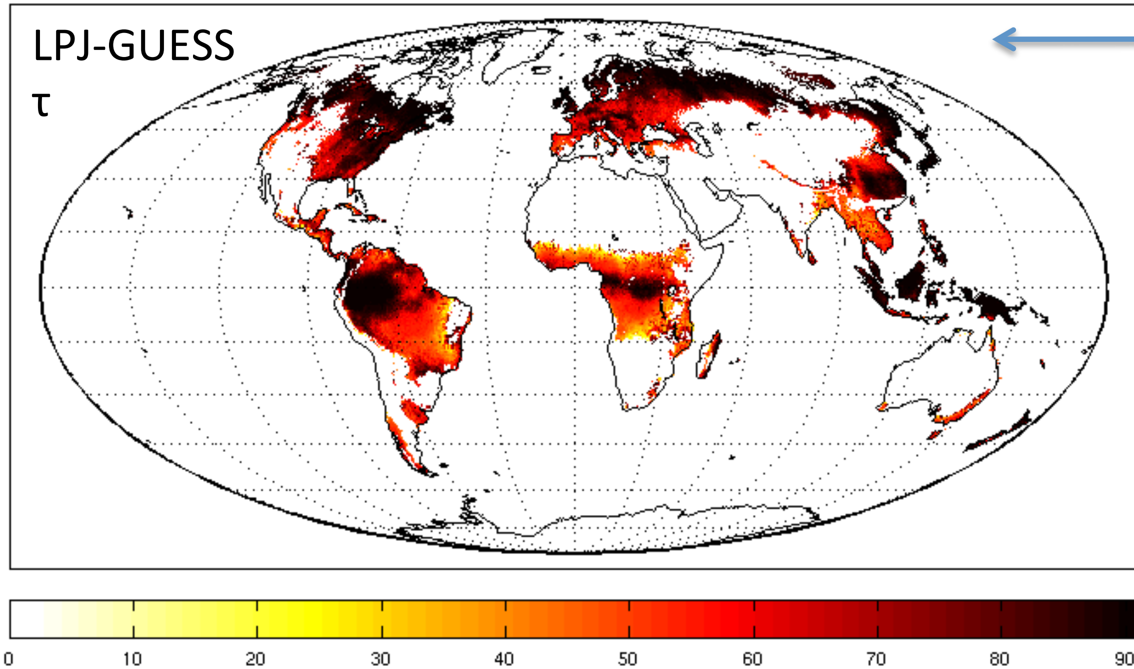
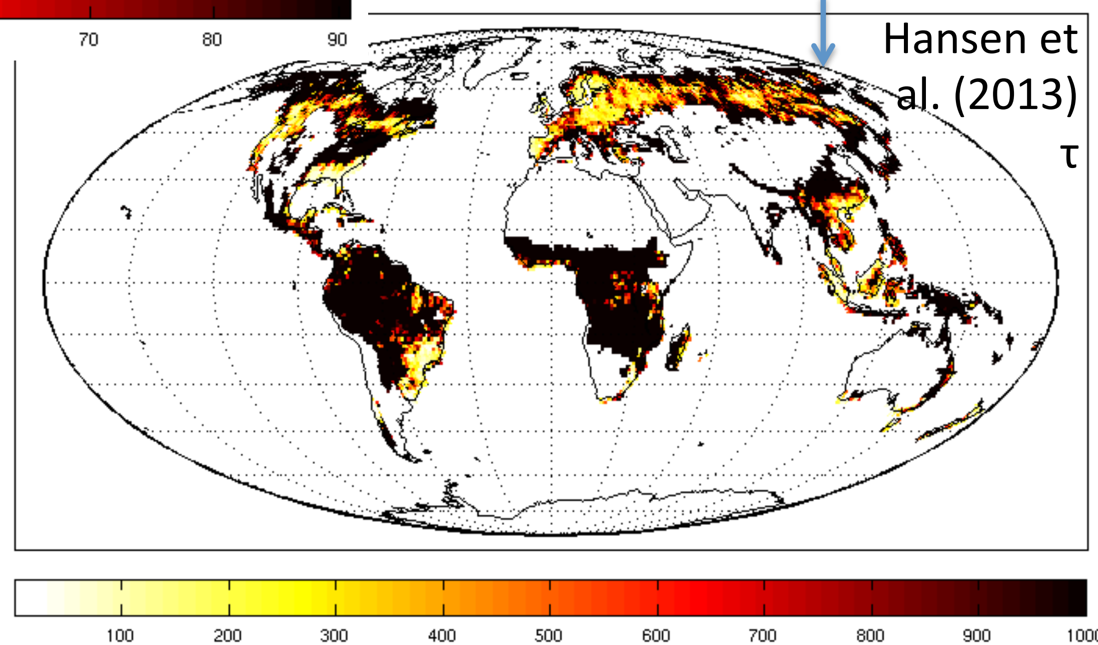


Global mean is τ = 72 years

Note difference in scales!

Global mean is τ = 260 years



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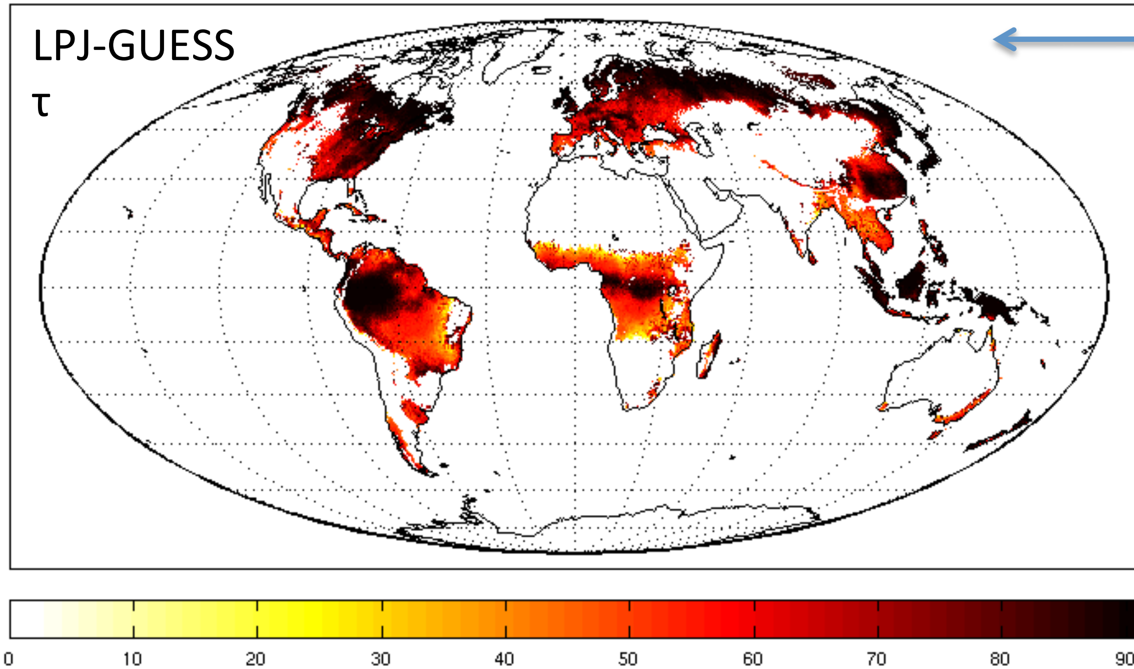

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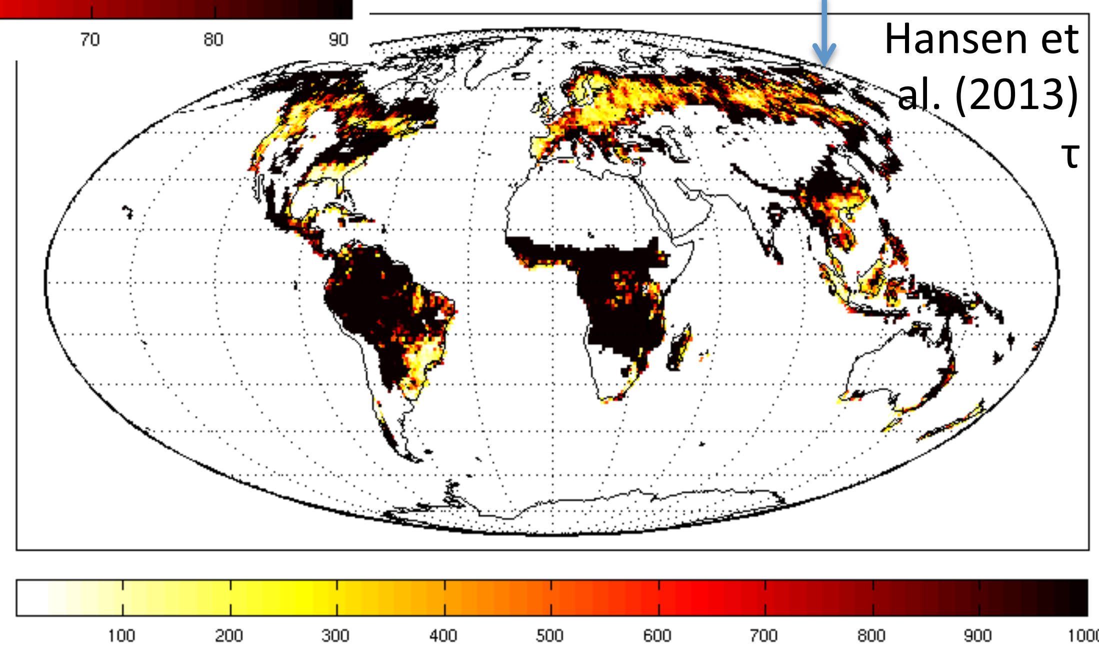
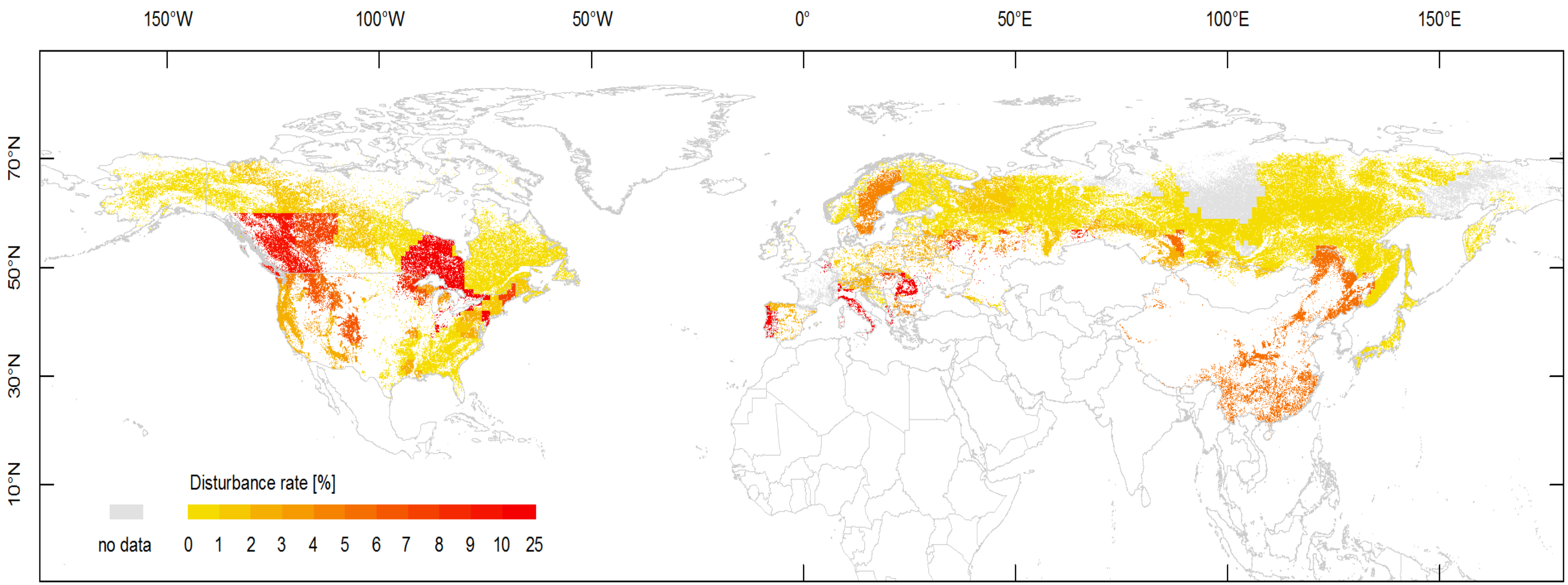


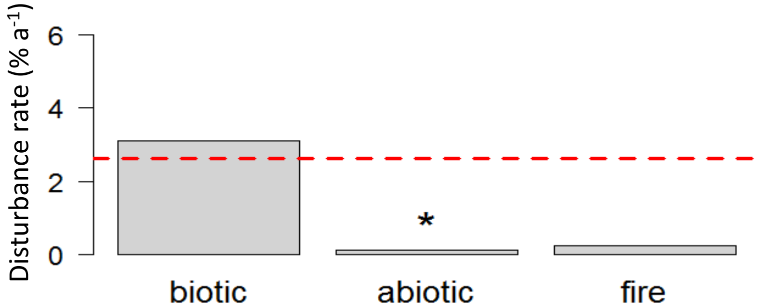
Perhaps we disturb too much in LPJ-GUESS?

Compensating for other mortality mechanisms?

Actual disturbance rates: Biotic attack

Synthesis of biotic disturbance rates (M. Kautz)





Disturbance rate by cause
(based on area affected)

Kautz et al. in prep.

Actual disturbance rates: Biotic attack

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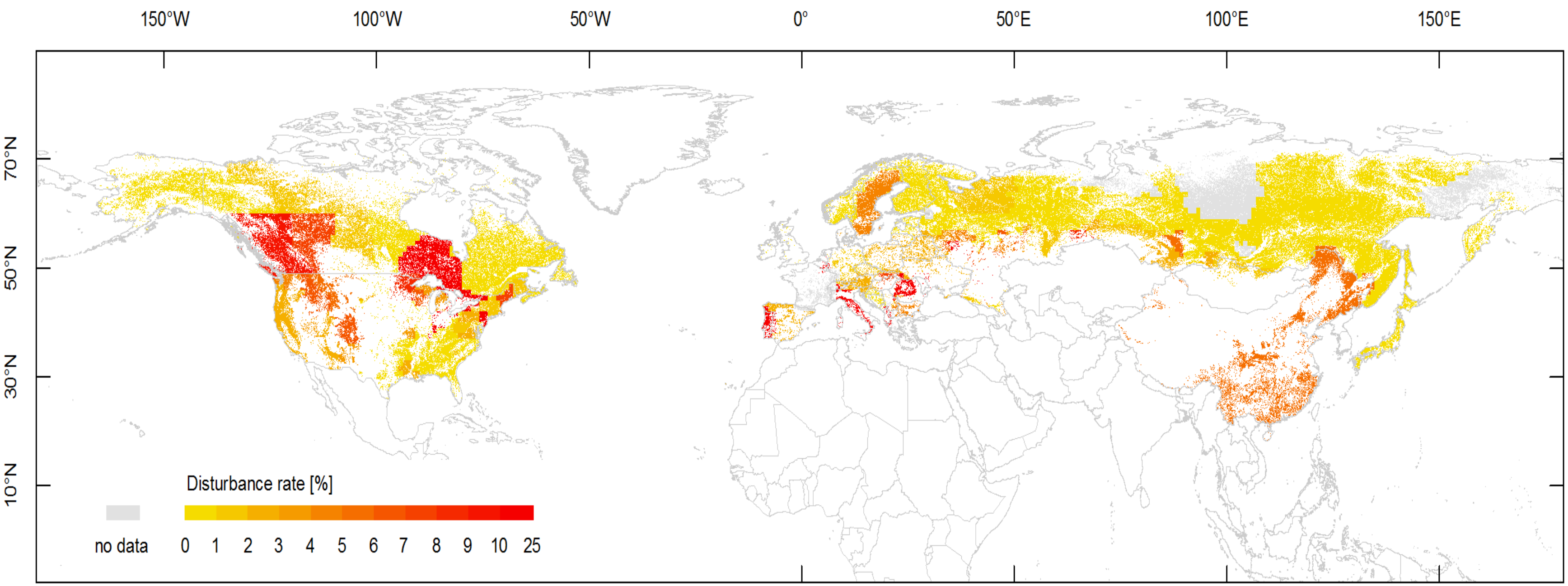

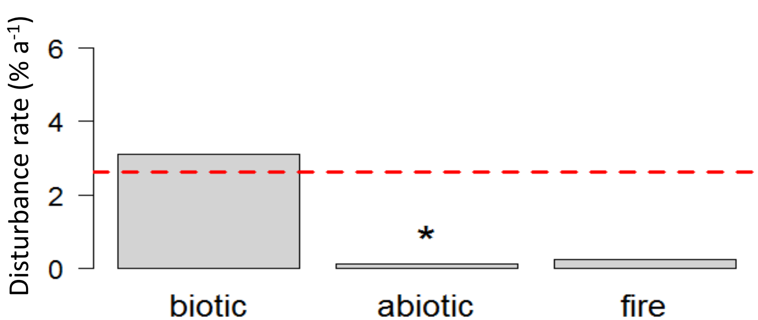

Disturbance rate by cause
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Challenge:

Return period

Kind of disturbance

Mortality rates

Conclusions

Total carbon storage and ecosystem composition is very sensitive to disturbance. It could define terrestrial biosphere carbon fluxes over the next century.

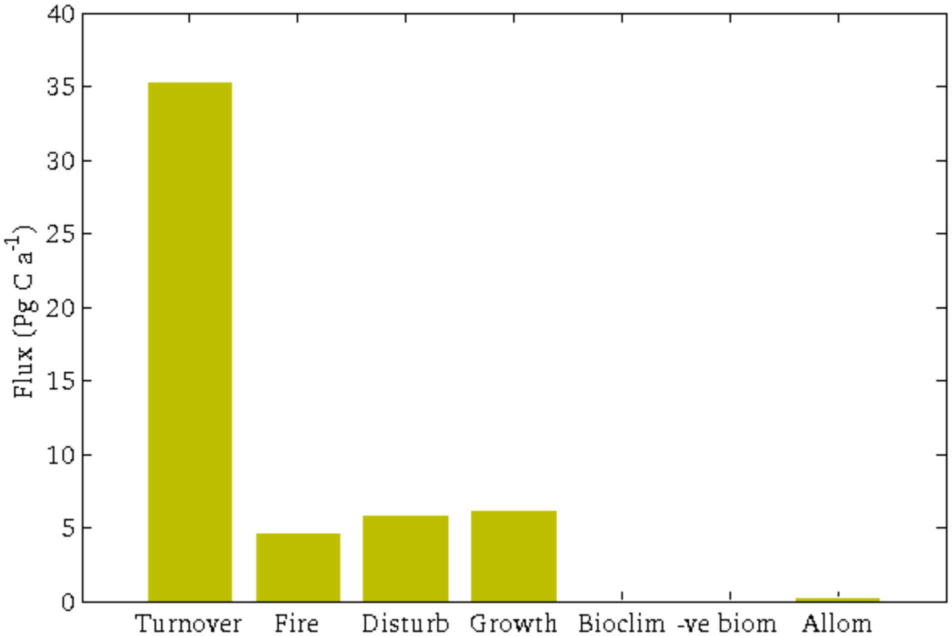
Although the focus here was on "disturbance", the character of these results holds for mortality more generally (effect in the DGVM is basically the same), e.g. drought mortality.

We currently have a very poor understanding of the importance of different tree mortality mechanisms globally.

Effective prognostic modelling of disturbances and other mortality mechanisms is crucial to understand forest dynamics under environmental change, and for reliable projections of future carbon storage.

What processes drive mortality in current DGVMs?

How do you kill your trees?



- What processes are driving differences in turnover rates (esp. mortality) between the DGVMs?
- Realism - are known mortality events captured? By which mechanisms? (Allen et al., 2010, drought; Kautz et al., in prep; FAO)
- Do 2nd generation DGVMs do better? Do they have fundamentally different responses under climate change?

Possibilities:

a) Addition of mortality flux outputs to ongoing activities (e.g. GCP)
b) PLUME emulator offer possibility to compare the effects of mortality mechanisms in a framework where everything else is standardised. Clear attribution. Possibility to swap mechanisms between models. Requires only a few extra outputs to simulations.