Spatial emergent constraints: the example of soil carbon feedback, and the promise of remote-sensing

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4th Carbon from Space Workshop 2022

University *of* Exeter

Overview

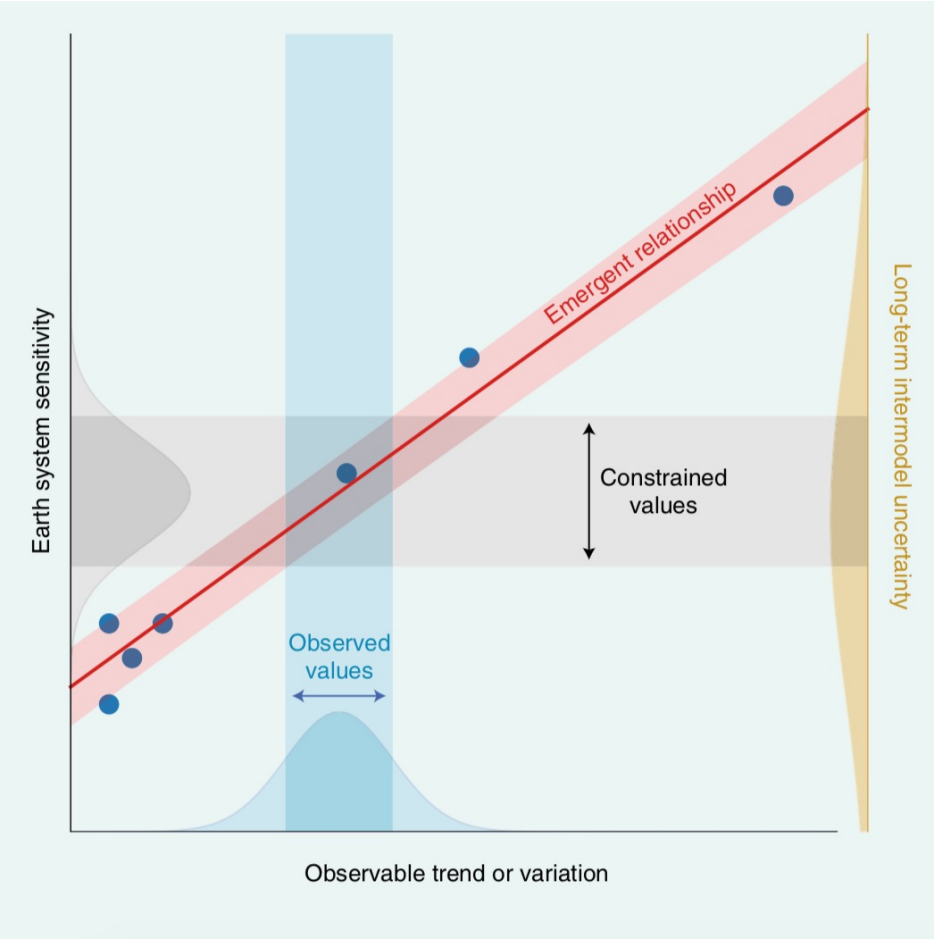
1. What are spatial Emergent Constraints?

2. An example spatial emergent constraint on soil carbon feedback to climate change.

3. The role of remote sensing in the promise of future spatial emergent constraints.

Emergent Constraints

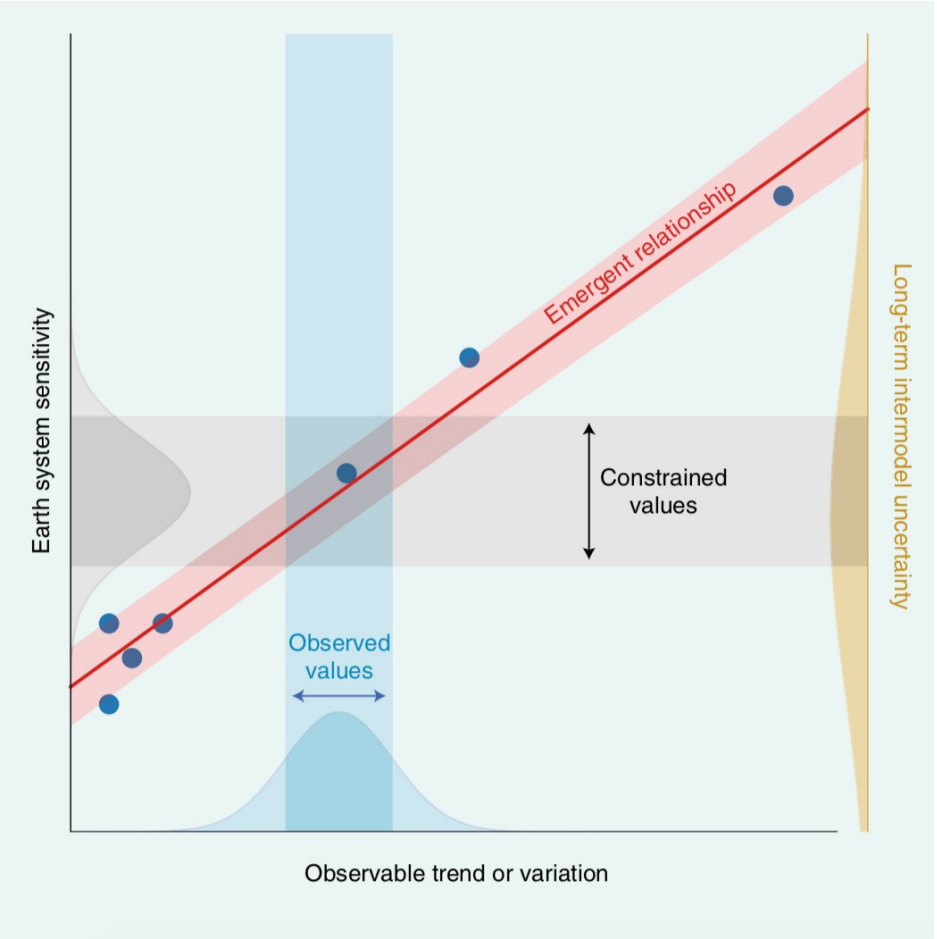
- Technique used to reduce uncertainty in climate change projections across an ensemble of models.
- Existing emergent constraints on the carbon cycle feedbacks.
- Should be based on a theoretical understanding of the Earth's climate system.



Eyring et al.: Taking climate model evaluation to the next level, *Nature Climate Change*, 2019.

Spatial Emergent Constraints

- We define '*spatial emergent constraint*' – the use of a spatial sensitivity to constrain a temporal sensitivity.
- Remote sensing provides promise.
- A spatial temperature sensitivity to obtain a sensitivity to global warming.



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Spatial emergent constraint on soil carbon turnover to global warming

- Uncertainties in projected changes in soil carbon storage are key components of the uncertainties in the global carbon budgets for the Paris agreement targets.

- Motivated by Chadburn et al.: An observation-based constraint on permafrost loss as a function of global warming, Nature Climate Change, 2017.

- Varney et al.: A spatial emergent constraint on the sensitivity of soil carbon turnover to global warming, *Nature communications,* 2020.

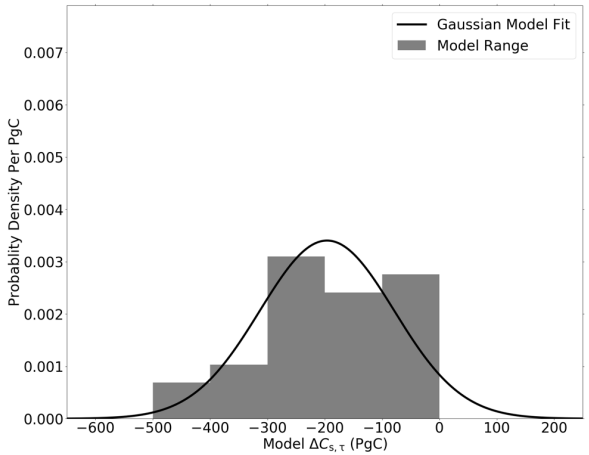
$$\tau_s = \frac{C_s}{R_h}$$

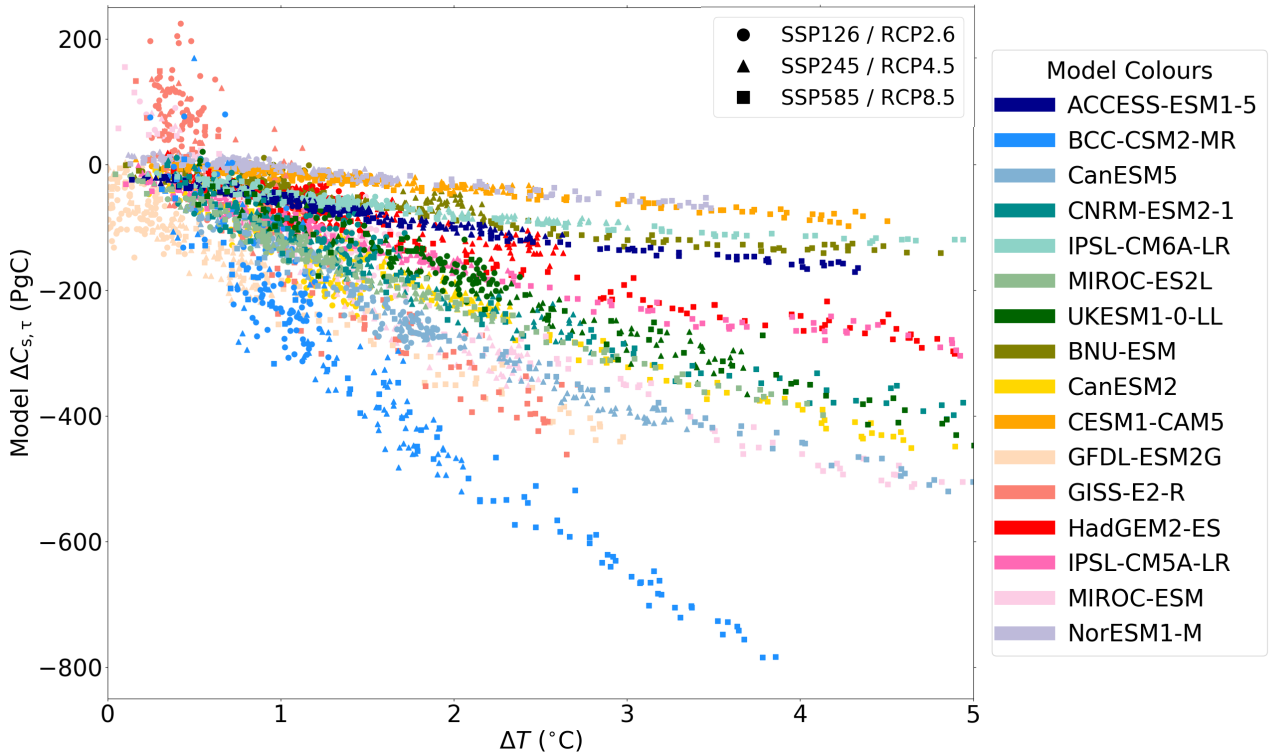
Soil carbon turnover time

(below-ground)

Spatial emergent constraint on soil carbon turnover to global warming

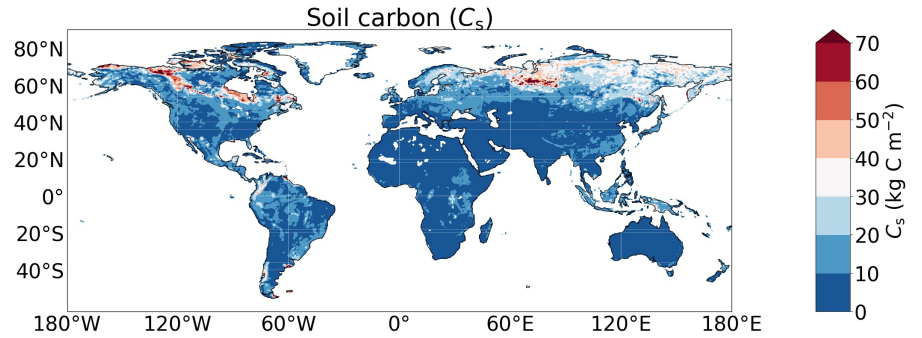
- Uncertainty in the projected change in soil carbon due to the response of soil carbon turnover time under climate change.
- Uncertainty has remained across CMIP generations.

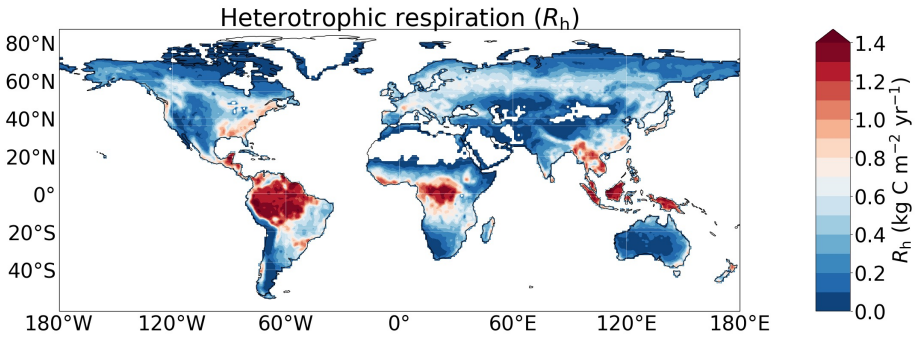


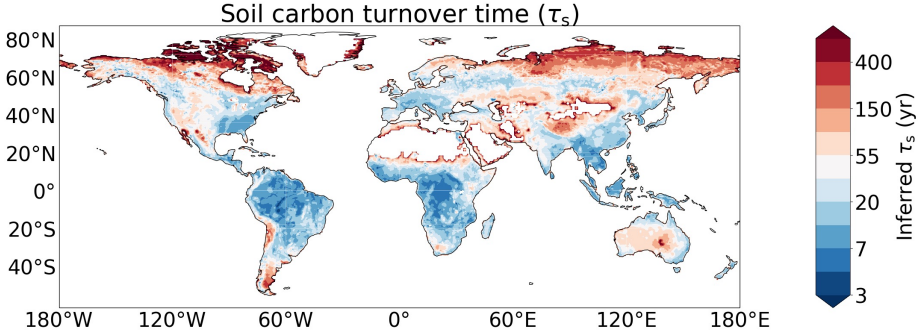


Varney et al.: A spatial emergent constraint on the sensitivity of soil carbon turnover to global warming, *Nature communications,* 2020.

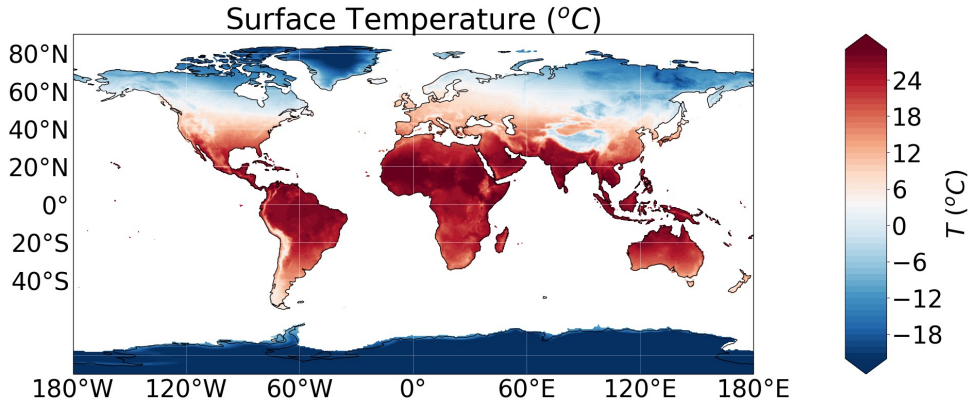
Spatial emergent constraint on soil carbon turnover to global warming







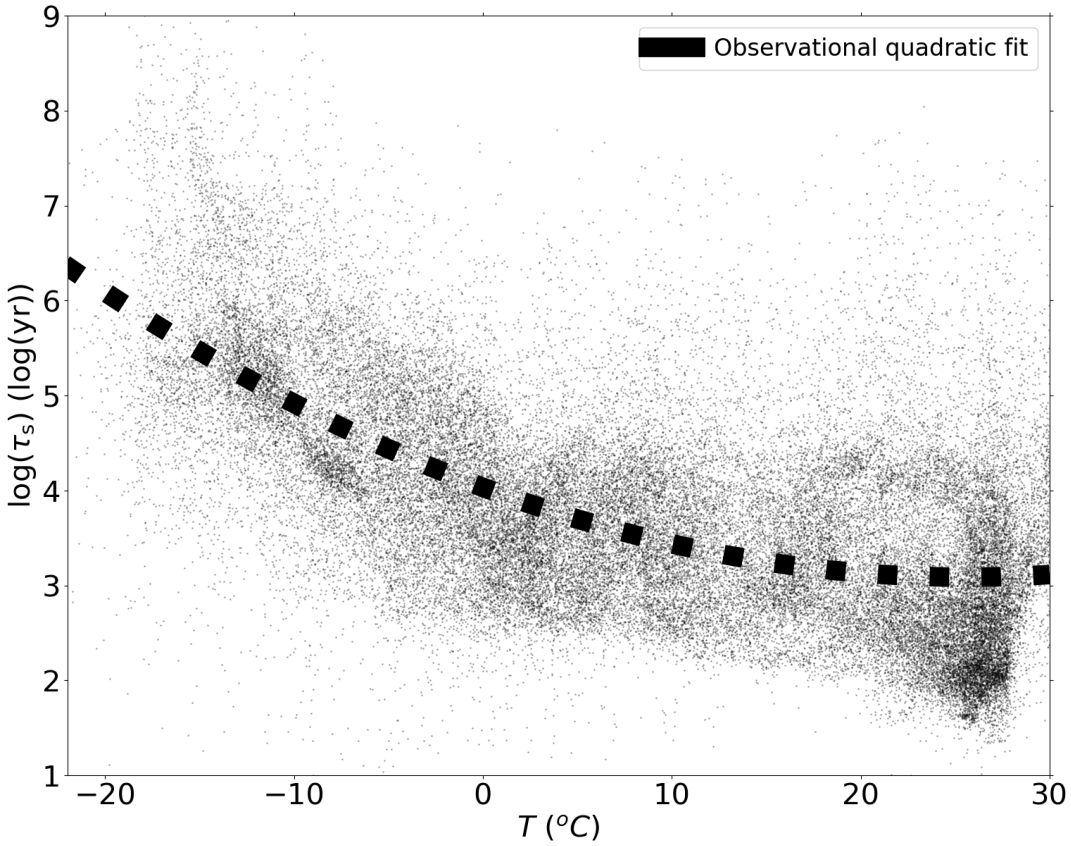
$$\tau_s = \frac{C_s}{R_h}$$



- Harmonized world soil database (2012).
- The northern circumpolar soil carbon database: spatially distributed datasets of soil coverage and soil carbon storage in the northern permafrost regions (2013).
- CARDAMOM 2001-2010 global carbon Model-Data Fusion (MDF) analysis, (2015).
- The WFDEI meteorological forcing data set: WATCH Forcing Data methodology applied to ERA-Interim reanalysis data (2014).

Spatial emergent constraint on soil carbon turnover to global warming

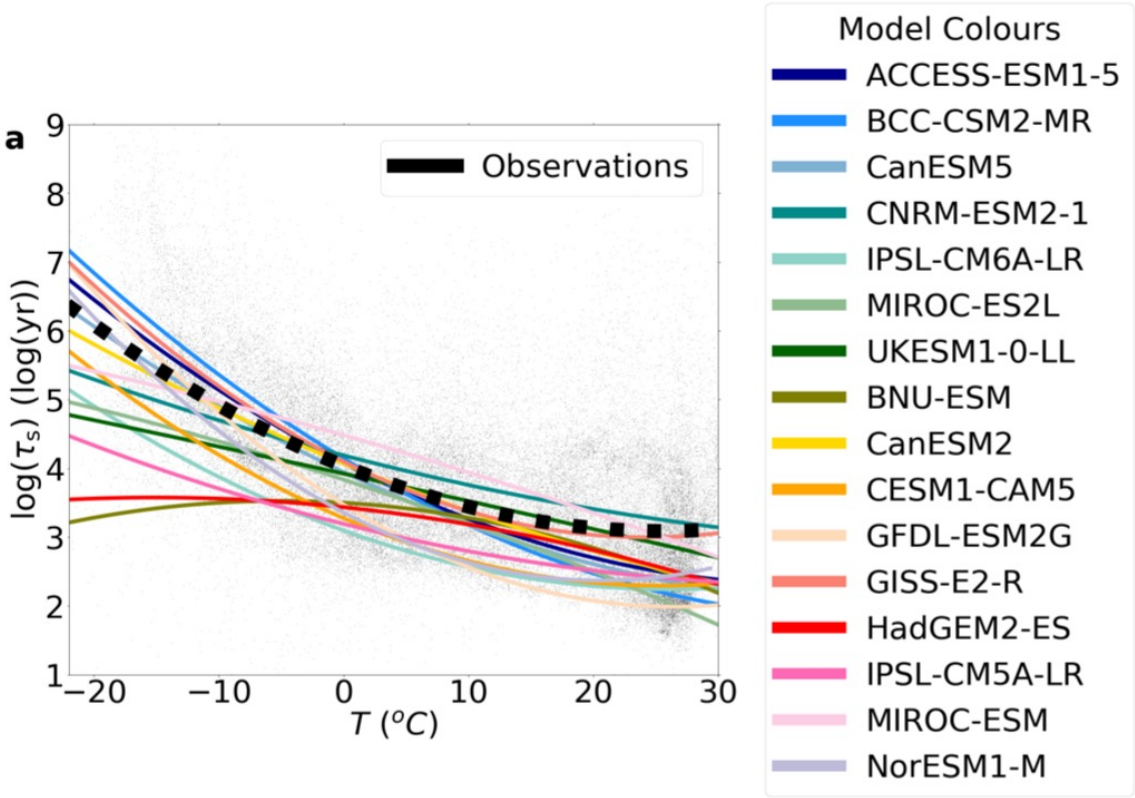
- We use the relationship between spatial τ_s and spatial temperature to estimate the sensitivity of τ_s to temperature.



Varney et al.: A spatial emergent constraint on the sensitivity of soil carbon turnover to global warming, *Nature communications,* 2020.

Spatial emergent constraint on soil carbon turnover to global warming

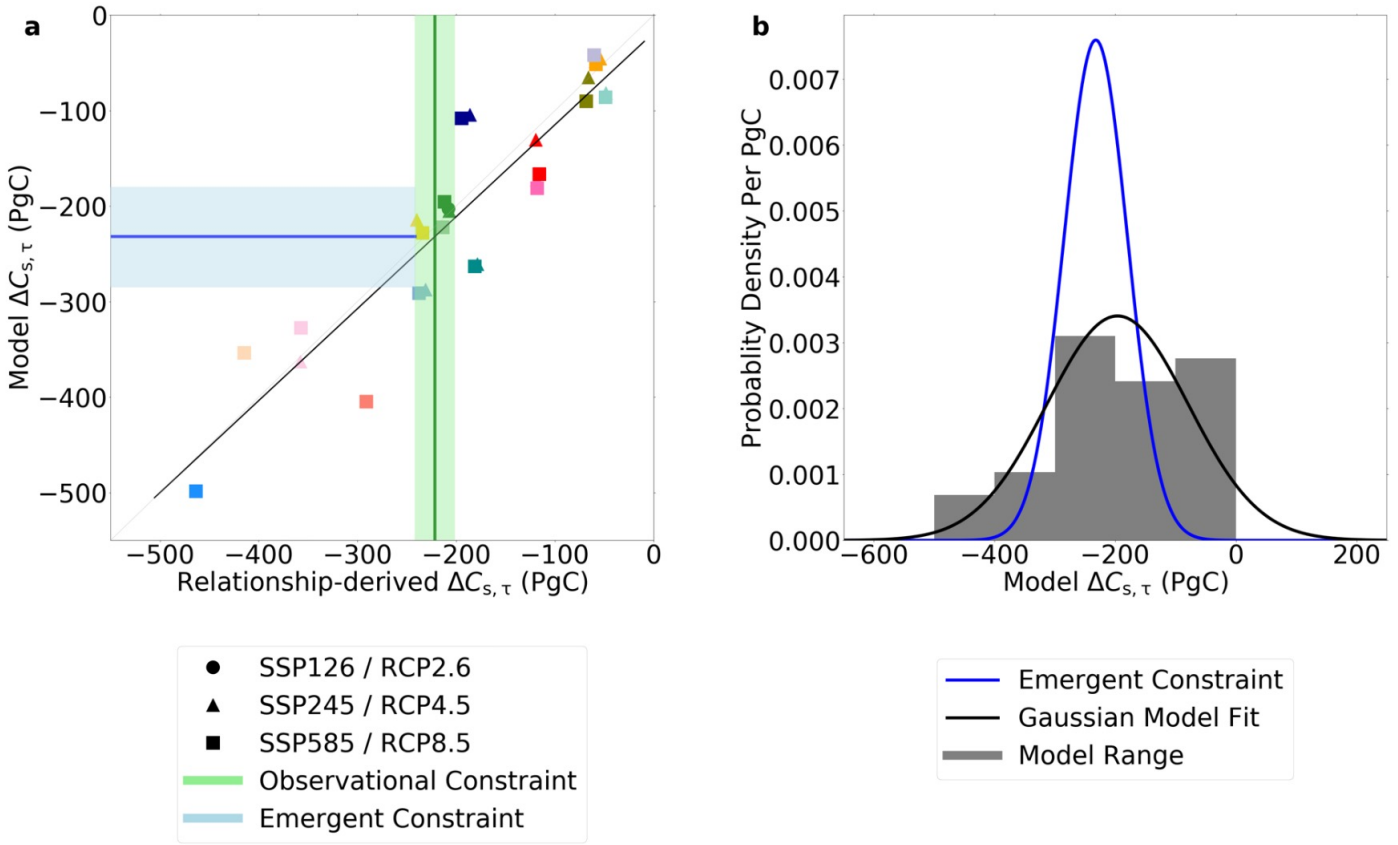
- Variation in the sensitivities between the models, and between models and observations.
- *Can this spatial temperature sensitivity be used to infer a temporal sensitivity to global warming?*



Varney et al.: A spatial emergent constraint on the sensitivity of soil carbon turnover to global warming, *Nature communications,* 2020.

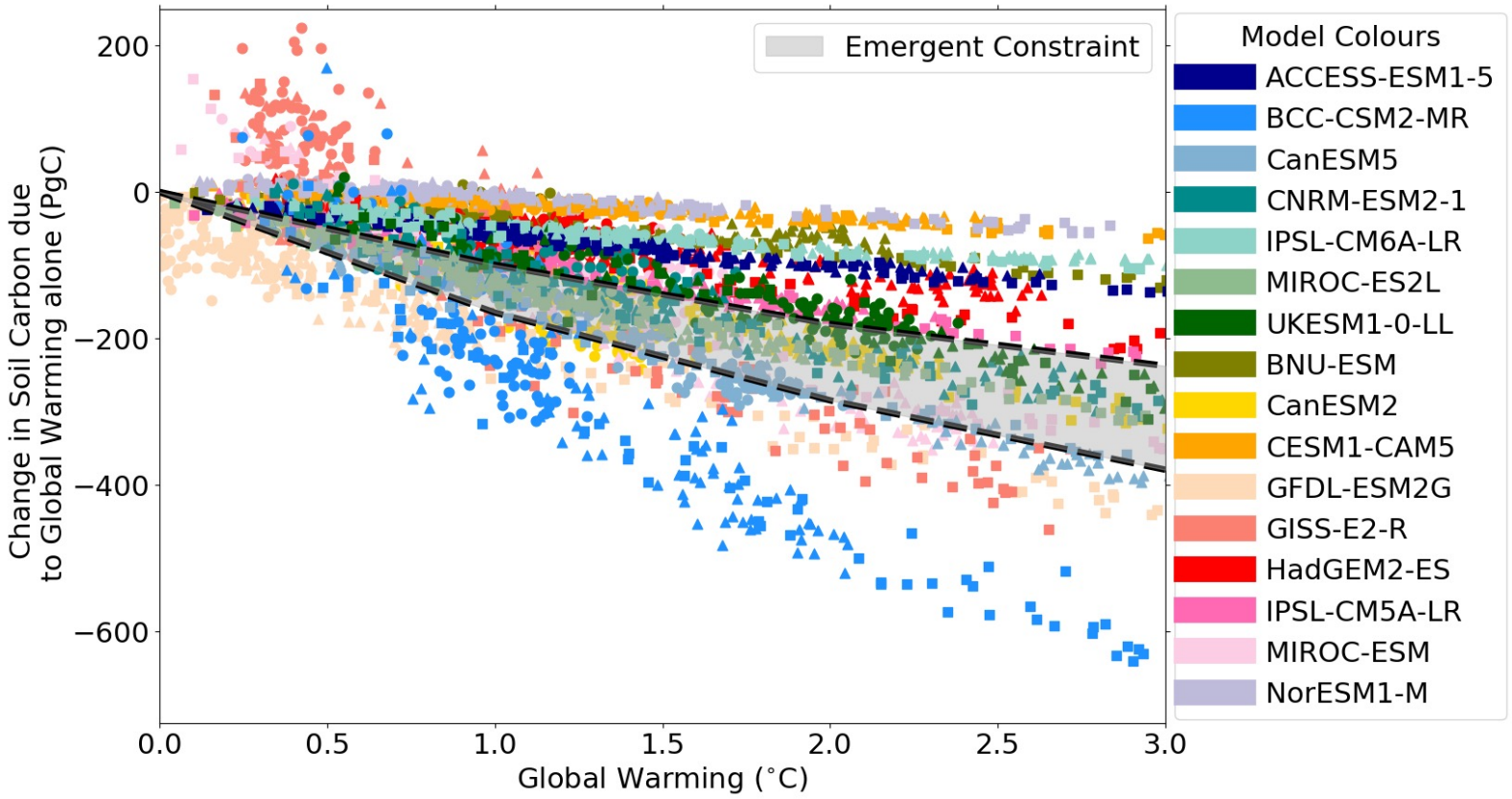
Spatial emergent constraint on soil carbon turnover to global warming

- Successfully constrain changes in soil carbon due to reductions in turnover.
- Uncertainty in projections of $\Delta C_{s,\tau}$ reduced from -196 ± 117 PgC to -232 ± 52 PgC for 2°C global warming.



Varney et al.: A spatial emergent constraint on the sensitivity of soil carbon turnover to global warming, *Nature communications,* 2020.

Spatial emergent constraint on soil carbon turnover to global warming



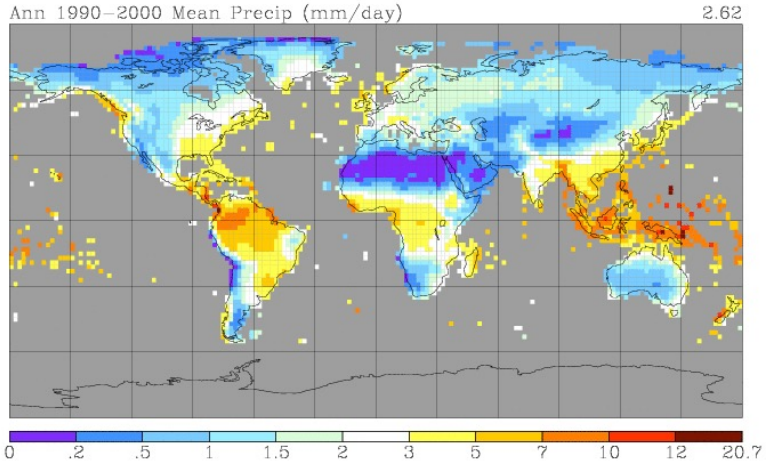
Varney et al.: A spatial emergent constraint on the sensitivity of soil carbon turnover to global warming, *Nature communications,* 2020.

Future possible spatial emergent constraints?

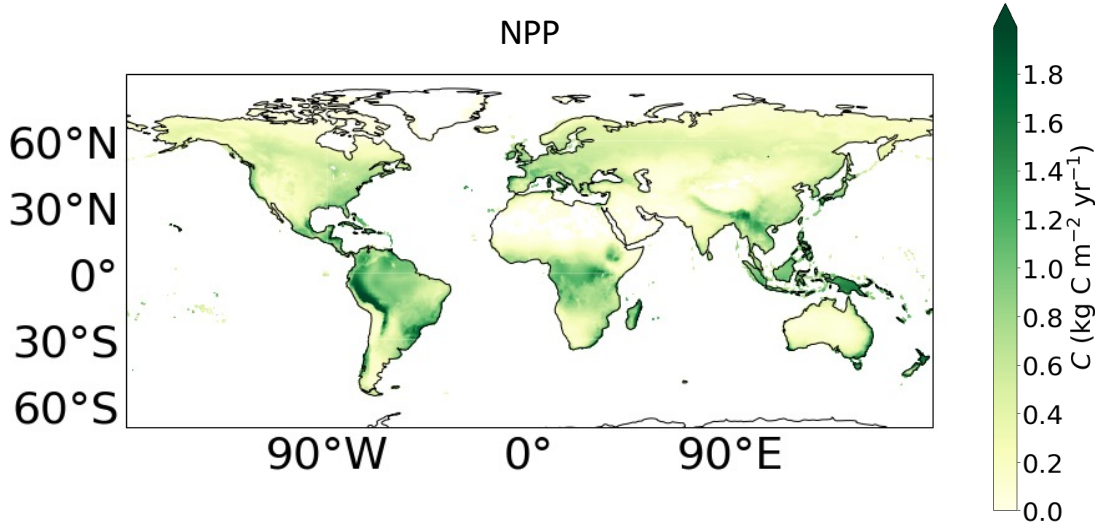
- Promise of new spatial emergent constraints on other Earth system processes.
- Requires datasets with high spatial resolution – such as remote sensing data.
- Using remote sensing data to infer spatial variability, which can be used to inform future change.

Future possible spatial emergent constraints?

- Can we constrain future changes in NPP using the sensitivity to precipitation changes?
- Possibility to use the variation in ‘greenness’ (LAI etc.) from satellites in response to observed variations in rainfall?



NASA GISS, Annual mean precipitation data (CRU TS 2.0).

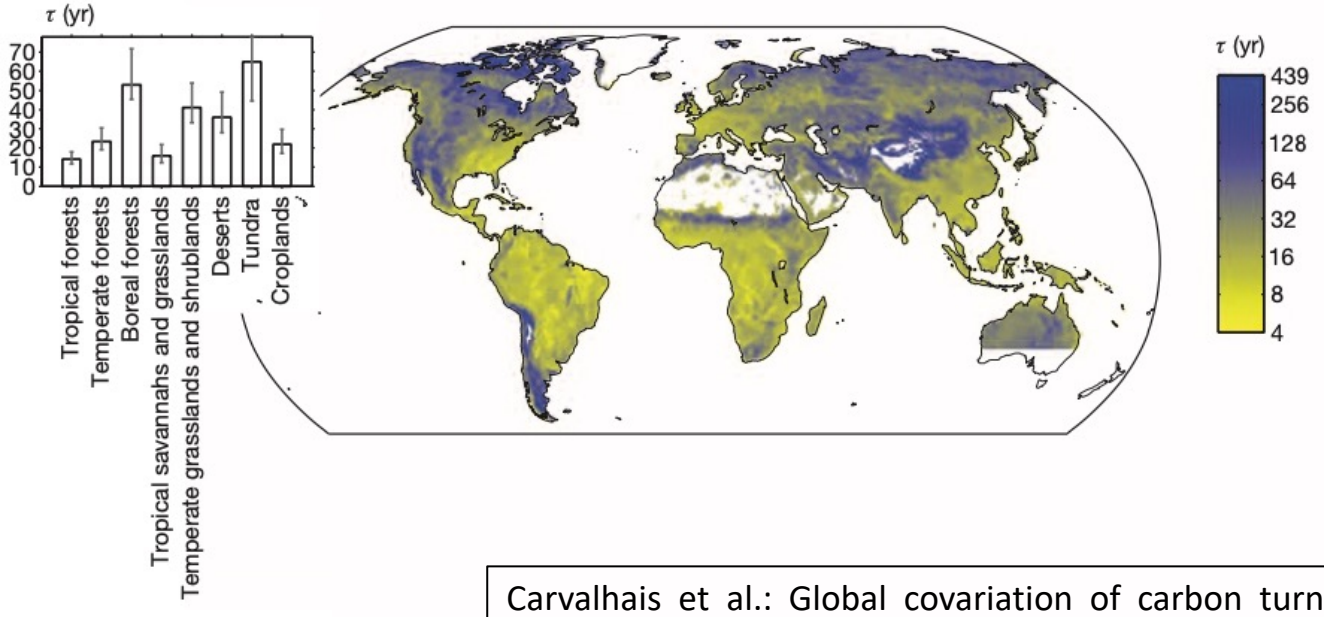


Varney, R. M., et al.: Evaluation of soil carbon simulation in CMIP6 Earth system models, *Biogeosciences*, 2022.

Future possible spatial emergent constraints?

- A spatial emergent constraint on the sensitivity of ecosystem carbon turnover to global warming?

Ecosystem carbon turnover time



Carvalhais et al.: Global covariation of carbon turnover times with climate in terrestrial ecosystems, *Nature*, 2014.

Conclusions

- Emergent constraints constrain future model uncertainties.
- Spatial emergent constraint – use of a spatial variation to constrain future changes.
- We used the ‘real world’ spatial temperature sensitivity to constrain a future response to warming - halved the uncertainty in the soil carbon turnover response to 2°C global warming.
- Remote sensing data provides new possibilities for spatial emergent constraints on Earth system sensitivities.

Thank you for listening.

Any questions?

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Varney, R. M., Chadburn, S. E., Friedlingstein, P., Burke, E. J., Koven, C. D., Hugelius, G., and Cox, P. M. A spatial emergent constraint on the sensitivity of soil carbon turnover to global warming. Nature communications, 11(1):1–8 (2020).

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Climate-Carbon Interactions in the Current Century

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Carvalhais, N., Forkel, M., Khomik, M. et al. Global covariation of carbon turnover times with climate in terrestrial ecosystems. Nature 514, 213–217 (2014).

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