How close are we to the temperature tipping point of the biosphere?

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I. Background

All biological processes exhibit thermal optima; a temperature range within which processes accelerate most rapidly (T_{inf}), reach a maximum rate (T_{max}), and then decline. However different biological processes may not be synchronized in their response to increasing temperatures resulting in major dis-equilibria of ecosystem processes. Particularly, the linked processes of photosynthesis and respiration each form different arcs with curvature determined by their inherent sensitivity to temperature. Constraining the difference in temperature curves between photosynthesis and respiration allows us to quantify changes to global carbon metabolism and the land sink as a whole.

To date, the biosphere has largely acted as a sink of carbon from the atmosphere and mitigates atmospheric accumulation of CO_2. Here we ask the following questions:

- When temperature increases at what stage do photosynthesis and respiration responses become de-coupled?
- What is T_{max} for the land-sink, and where is current mean temperature range in regard to this important threshold?
- At what temperature do we expect the biosphere to become a source of carbon to the atmosphere, and when do we expect to experience those temperatures?

II. Data & Analysis

To address these questions we used the recently released FLUXNET2015 dataset comprised of 212 eddy covariance fluxtower sites which concurrently measure land-atmosphere carbon exchange along with micro-meteorological variables. We analyzed over 1500 site-years of daytime partitioned photosynthesis along with air temperature, sunlight and evaporative fraction (a metric for available water). As T_{max} for respiration is known to exceed temperatures observed by FLUXNET, we expanded our respiration dataset to include temperature gradient block data[3], and leaf-level respiration data[4]. We accounted for the effects of water and sunlight through partial correlation analysis and extracted the temperature signal of global carbon fluxes to fit MacroMolecular Rate Theory[2] and constrain the global temperature response of the land-sink..

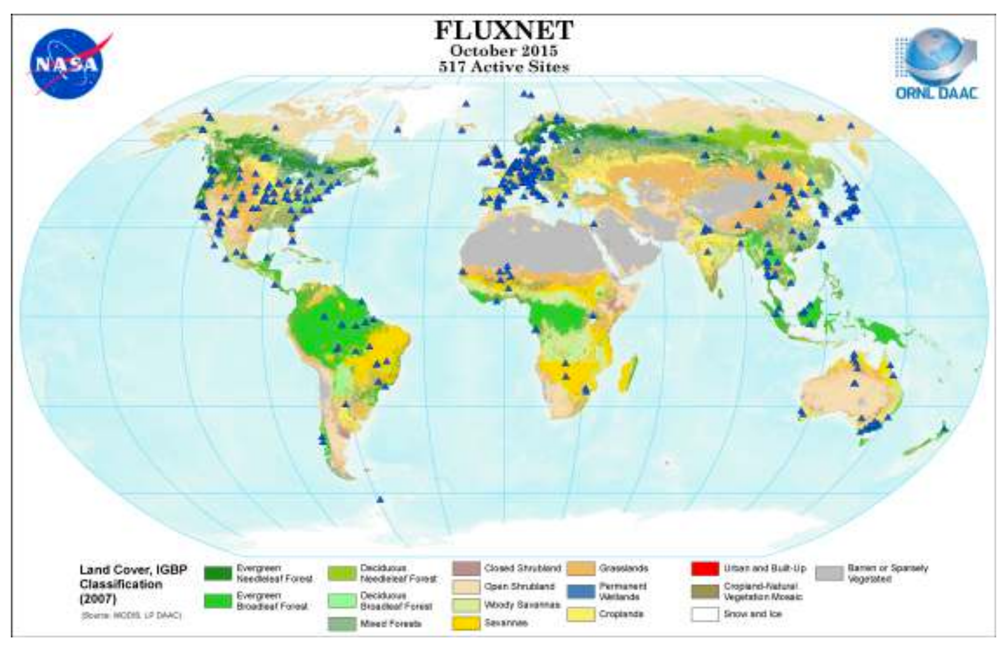


Figure 1. FLUXNET2015 tower locations along with Plant Functional Type (IGBP).

We then extracted future temperature projections from the WORLDCLIM dataset at the location of each FLUXNET tower site for all RCP scenarios and timesteps to project future biosphere metabolism.

IV. Results

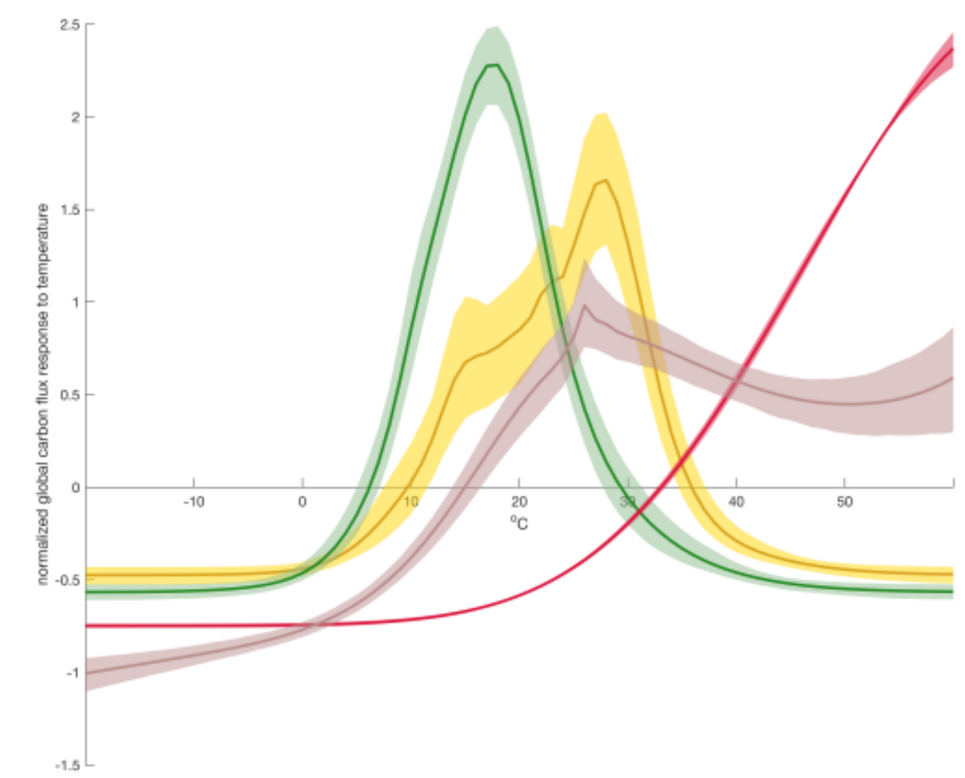


Figure 2. A 90% CI of the global temperature response of C3 photosynthesis (green), C4 photosynthesis (gold), ecosystem and leaf respiration (brown) and soil respiration (red).

Figure 2 shows the 90% CI temperature response of all major terrestrial carbon fluxes. We found that C3 and C4 photosynthesis had unique curvature, and that C3 photosynthesis had a much lower T_{max}, in line with our understanding of the physiology of these differing mechanisms. Leaf and ecosystem-level respiration also demonstrated a lower T_{max} than soil respiration, however observations used to constrain curvature failed to record theoretical T_{max}.

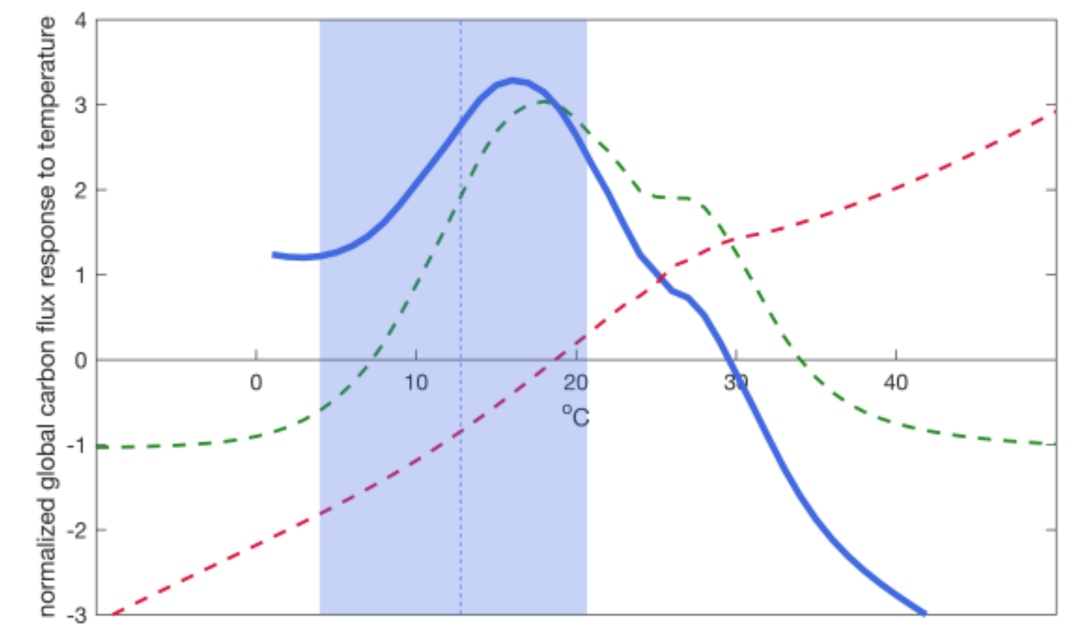
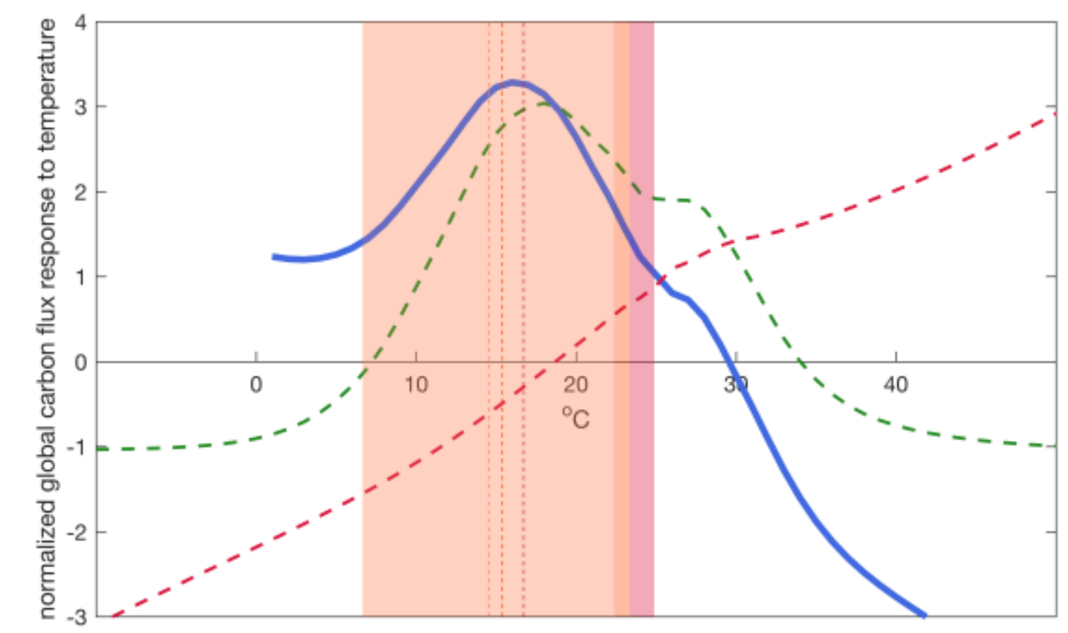
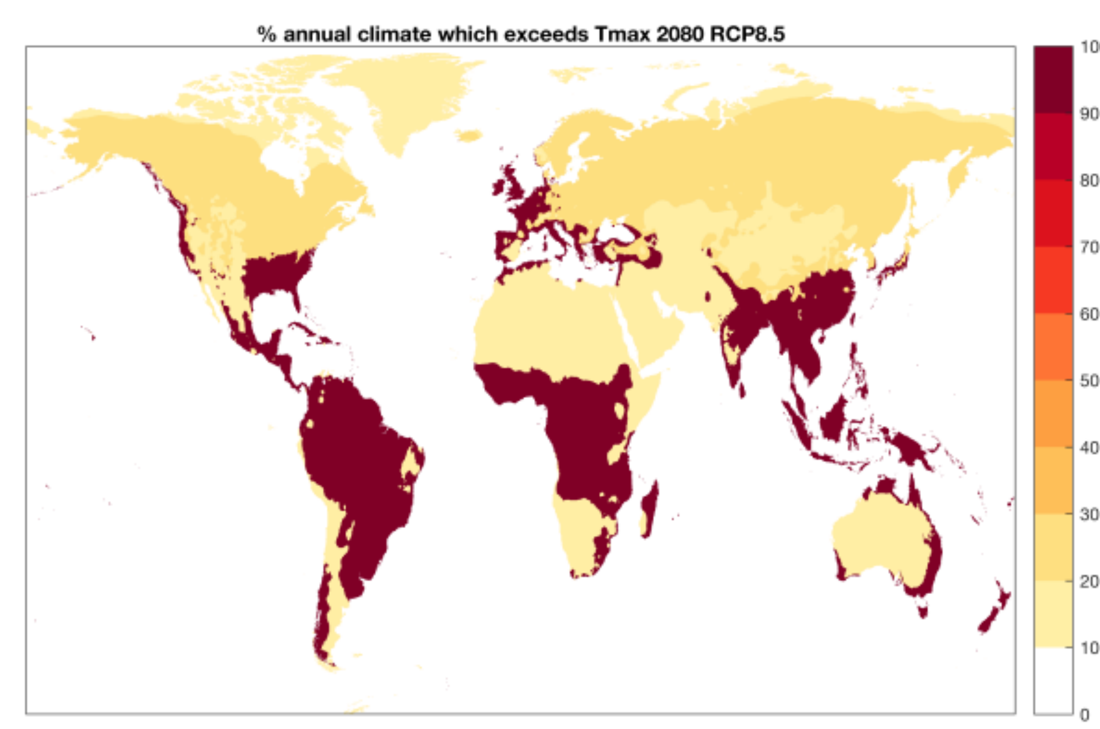


Figure 3. Integrated global temperature response curves for photosynthesis (green), respiration (red) and the land-sink (blue).



The top panel of figure 3 shows the integrated global temperature response of photosynthesis (green) and respiration (red), as well as the sign of the carbon land-sink (blue). Annual mean temperature (dashed line) between 1991-2014 resided close to the inflection point of global photosynthesis, while mean annual temperature range (blue bar) extended just past T_{max}, supporting the land-sink of carbon to the biosphere.

The bottom panel of figure 3 demonstrates 2060-2080 annual mean temperature projections (dashed line) and annual mean temperature range (shaded bars) for RCP 2.6, 4.5 and 8.5 respectively. Annual mean temperature across all three scenarios resided close to the temperature peak of the land-sink, however, increasingly large portions of annual climate exceeded T_{max}. A warming of annual temperature range is likely to push many biomes past maximum photosynthesis and into periods of rapid decline, indicating a decrease in the land-sink, and a transition to a source of carbon from the biosphere to the atmosphere as respiration continues to increase.



With un-mitigated warming, by 2080 many of the world's most productive biomes are likely to spend the majority of their year at temperatures where photosynthesis is slowing (past T_{inf}) or rapidly declining (past T_{max}) (figure 4). The increase in temperature observed by FLUXNET from 1991-2015 already places part of annual climate past the tipping point of the land-sink (figure 3, top panel). Our analysis suggests that *any* additional warming increases the proportion of time past T_{max} potentially altering both the sign and magnitude of carbon assimilation on a global scale.

Figure 4. The percent of annual climate which exceeds T_{inf} or T_{max} by biome, indicating a slowing and then cessation of the land-sink.

V. Citations

[1]Schipper, Louis A., et al. "Thermodynamic theory explains the temperature optima of soil microbial processes and high Q10 values at low temperatures." *Global change biology* 20.11 (2014): 3578-3586.
[2]Arcus, Vickery L., et al. "On the temperature dependence of enzyme-catalyzed rates." *Biochemistry* 55.12 (2016): 1681-1688.
[3]Robinson, Jasmine. M., et al. "Rapid laboratory measurement of the temperature dependence of soil respiration and application to changes in three diverse soils through the year." Biogeochemistry 133.1 (2017): 101-112.
4 Liang, Liyin et al., in prep.

VI. Datasource

www.fluxdata.org www.worldclim.org

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