Future reversal of warming-enhanced vegetation productivity in the Northern Hemisphere

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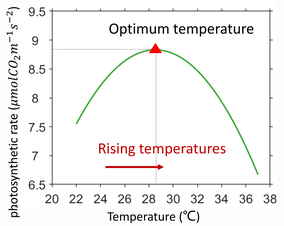
1. Introduction

The **extratropical Northern Hemisphere plants** play a critical role in mitigating global warming by fixing more C under warming and rising atmospheric CO_2 concentrations.

Fig. 1 Schematic representation of photosynthesis response to temperature



Weakened temperate control on productivity

- Recent studies indicate a **weakening** or even **negative** temperature control on northern ecosystem productivity with warming.

Summer, the flourish but hottest season

- Summer is the peak season for plant growth but also with temperatures **most possible to exceed optimal threshold** for growth.

Question: Would vegetation productivity respond negatively to future summer warming?

2. Data & Method

Model data:

- 9 Earth system models participating in **CMIP6** from **2001-2100**.
- Model outputs of GPP, air temperature, precipitation, solar radiation.

Observation data:

- FluxCOM GPP, solar-induced chlorophyll fluorescence and CRU climate datasets for **model validation** and **bias correction**
- Optimum temperature for vegetation productivity.

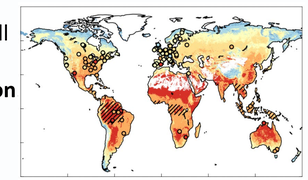


Fig. 2 ecosystem-scale optimum temperature for vegetation productivity (Huang et al., 2019)

Analysis:

Modelled reversal time

- Time at which partial correlation coefficient between **modelled** GPP and temperature shifts from positive to significant negative.

v.s.

Theoretical reversal time

- Time when model-projected summer temperature (bias corrected) exceeds **observation-based** optimum temperature for vegetation productivity.

3. Results

Future changes in relationship between GPP and temperature

- GPP-temperature correlations remain positive for regions >60°N but become **negative at lower latitudes** by the **end of this century**.
- GPP-temperature correlations generally tend to **decrease widely** in **temperate** and **boral** regions in this century.

Northern plants will suffer from increasing photosynthetic inhabitation induced by warming.

when?

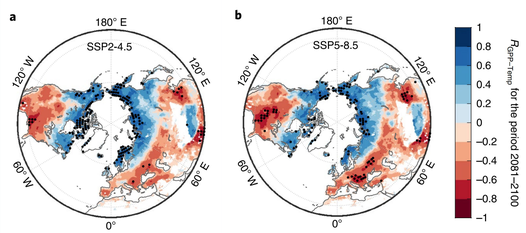


Fig. 3 Spatial pattern of partial correlation coefficient between summer GPP and temperature by the end of this century

Reversal *time* of warming-enhanced vegetation productivity

- The reversal time is **progressively delayed** from the mid-low latitudes (~2030-2040) to the high latitudes (>2090).
- By **2060**, about **48%** of the northern vegetated land will experience a reversal, this ratio will rise to **78%** by **2100**.
- Only productivity in the Arctic and the Tibetan Plateau continues to be warming enhanced by 2100.

Modelled reversal time ⟷ Differences ⟷ **Theoretical reversal time**

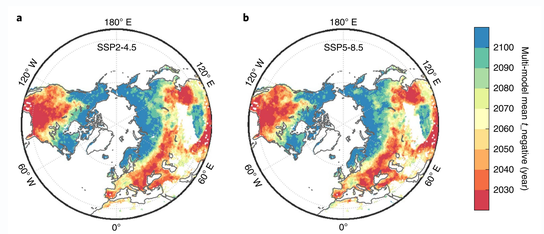


Fig. 4 Emergent time of significantly negative temperature-productivity correlation

Timing of temperature over optimal-productivity requirement

- The reversal time is only projected to be later than 2080 in a few sporadic areas of northern North America and eastern Eurasia.
- The 'safety line' of vegetation productivity under the current level of warming is limited, and the **entire extratropical NH may exceed its optimal temperature for productivity** in the 21st century.

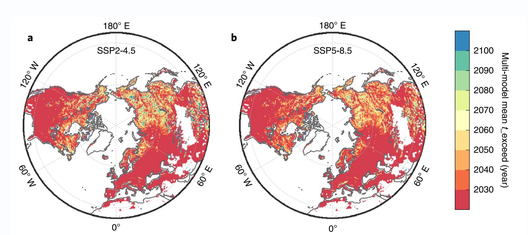


Fig. 5 Timing when summer temperature exceeds the optimal temperature for vegetation productivity

4. Discussions

Reasons for later modelled than theoretical reversal time

(1) Plant thermal acclimation

- **Thermal acclimation** of plants has been increasingly **adopted in Earth System Models**, whereas **observation-based optimum temperature** was assumed to be **constant** over time.
- Thermal acclimation may allow plants to operate at higher temperatures without reducing productivity.

(2) Enhanced water use efficiency

- All models **simulate** the **CO_2 effect on stomatal conductance**, which can suppress transpiration by partial stomatal closure and result in enhanced water use efficiency under elevated CO_2 concentrations.

(3) Vegetation dynamics

- The models with dynamic vegetation generally predicted a later reversal time than those without.
- **Woody encroachment** toward higher latitudes may transform biomes into warm-adapted ones.

(4) Biases in structure and parameterization of models

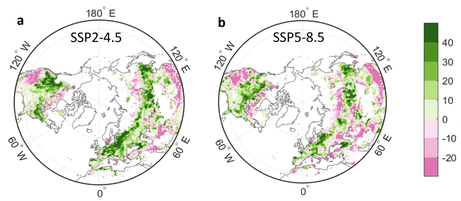


Fig. 6 Delay of reversal time when taking dynamic vegetation into consideration

5. Conclusions

- **Reversal** of **positive productivity-temperature correlation** generally occurs **before 2070** in regions <60°N, though Arctic productivity continues to increase with further summer warming.
- The modelled correlation reversal time is generally later than the timing of temperature over optimal productivity requirement, suggesting partial **mitigation** from plant **photosynthetic thermal acclimation**.
- Vegetation productivity could be impaired by climate change in the 21st century, which could negatively impact the global land carbon sink.

References

1. Huang M.T. et al. Air temperature optima of vegetation productivity across global biomes. Nature Ecology & Evolution 3, 772-779 (2019)