Carbon cycle changes in the 21st century in response to temperature acclimation

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Alpine-Treeline Warming Experiment

Photo: J. DeCoste
CO$_2$ gain: Photosynthesis
CO₂ C gain: Photosynthesis

CO₂ C loss: Leaf Respiration
How does acclimation change carbon in the future?

1. CO₂
   C gain: Photosynthesis

2. CO₂
   C loss: Leaf Respiration
Photosynthetic response to temperature

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Assimilation (μmol m⁻² s⁻¹) vs. Leaf temperature (°C)

Adapted from Smith & Dukes 2013, GCB
Photosynthetic response to temperature

Assimilation (µmol m$^{-2}$ s$^{-1}$)

Leaf temperature (°C)

- $t_{growth} = 10$ °C
- $t_{growth} = 25$ °C
- $t_{growth} = 40$ °C

Smith & Dukes 2013, GCB; based on Kattge & Knorr 2007, PCE
Respiration response to temperature

Adapted from Atkins et al. 2008, *GCB*
Respiration response to temperature

Atkins et al. 2008, GCB
Hypotheses:
As future T increases, acclimation will...

Increase C gain

Warm ecosystems (T > 25):
Decrease C loss

Cool ecosystems (T < 25):
Increase C loss
No Temperature Acclimation
Photosynthetic Acclimation
Photosynthetic & Respiration Acclimation

RCP 8.5 Climate Scenario

Δ Total Ecosystem Carbon (Pg C)

Year

~ 20 Pg C
~ 10 Pg C
Δ = 2100 - 1850

No Temperature Acclimation
$\Delta = 2100 - 1850$

No Temperature Acclimation

Photosynthetic Acclimation
\( \Delta\Delta = (2100 - 1850 \text{ Acclimation}) - (2100 - 1850 \text{ No Acclimation}) \)

\( \Delta = 2100 - 1850 \)

No Temperature Acclimation
\[ \Delta \Delta = (2100 - 1850 \text{ Acclimation}) - (2100 - 1850 \text{ No Acclimation}) \]

No Temperature Acclimation

Photosynthetic Acclimation

\[ \Delta = 2100 - 1850 \]

\[ \Delta \Delta \text{ Ecosystem Carbon (g C m}^2) \]
\[ \Delta \Delta = (2100 - 1850 \text{ Acclimation}) - (2100 - 1850 \text{ No Acclimation}) \]

No Temperature Acclimation

Photosynthetic Acclimation

Photosynthetic & Respiration Acclimation

\[ \Delta = 2100 - 1850 \]

\[ \Delta \Delta \text{ Ecosystem Carbon (g C m}^2\text{)} \]
Amazon Carbon (Pg C)

- No Temperature Acclimation
- Photosynthetic Acclimation
- Photosynthetic & Respiration Acclimation

Amazon:
- No Temperature Acclimation: 0.30 Pg C
- Photosynthetic Acclimation: 0.32 Pg C
- Photosynthetic & Respiration Acclimation: 0.34 Pg C
Summary

*Including Temperature Acclimation...*

- increases global ecosystem C by 10-20 Pg
- increases ecosystem carbon in the Amazon, though rates are slower with acclimation
- changes initial stable states: acclimation simulations have more ecosystem carbon in 1850
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Throughout the 21st century, temperature acclimation can increase ecosystem carbon up to 20%, but there are large uncertainties associated with these changes.
Difference in Initial State Ecosystem Carbon (Pg C)

Photosynthetic Acclimation

Photosynthetic & Respiration Acclimation

(a) $t_{\text{growth}} = 10 ^\circ \text{C}$

Leaf temperature ($^\circ \text{C}$)

Respiration (arbitrary units)

$R_{\text{mT}}$
Nitrogen, Sun, or Water Limitation?

With Acclimation

No Acclimation

Δ Total Ecosystem Carbon

Year

1850 2100
Compared to simulations with no temperature acclimation:

\[ 2100 \Delta = (2100 \text{ Acclimation}) - (2100 \text{ No Acclimation}) \]
No Temperature Acclimation

Photosynthetic Acclimation

Photosynthetic + Respiration Acclimation

$\Delta =$ Change from No Acclimation