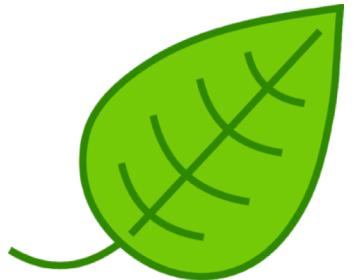


Scaling

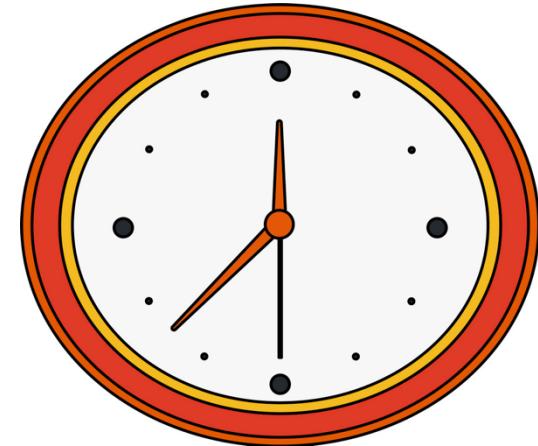


Scales in plant ecophysiology

Primary two dimensions of scaling are temporal and spatial

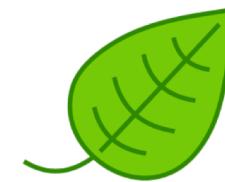
- Temporal

- The timeframe over which a driver or process of interest operates



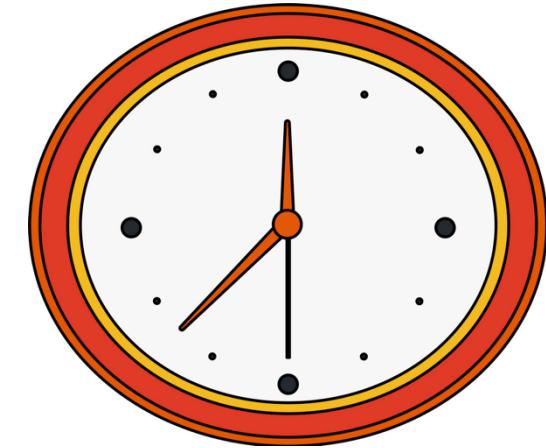
- Spatial

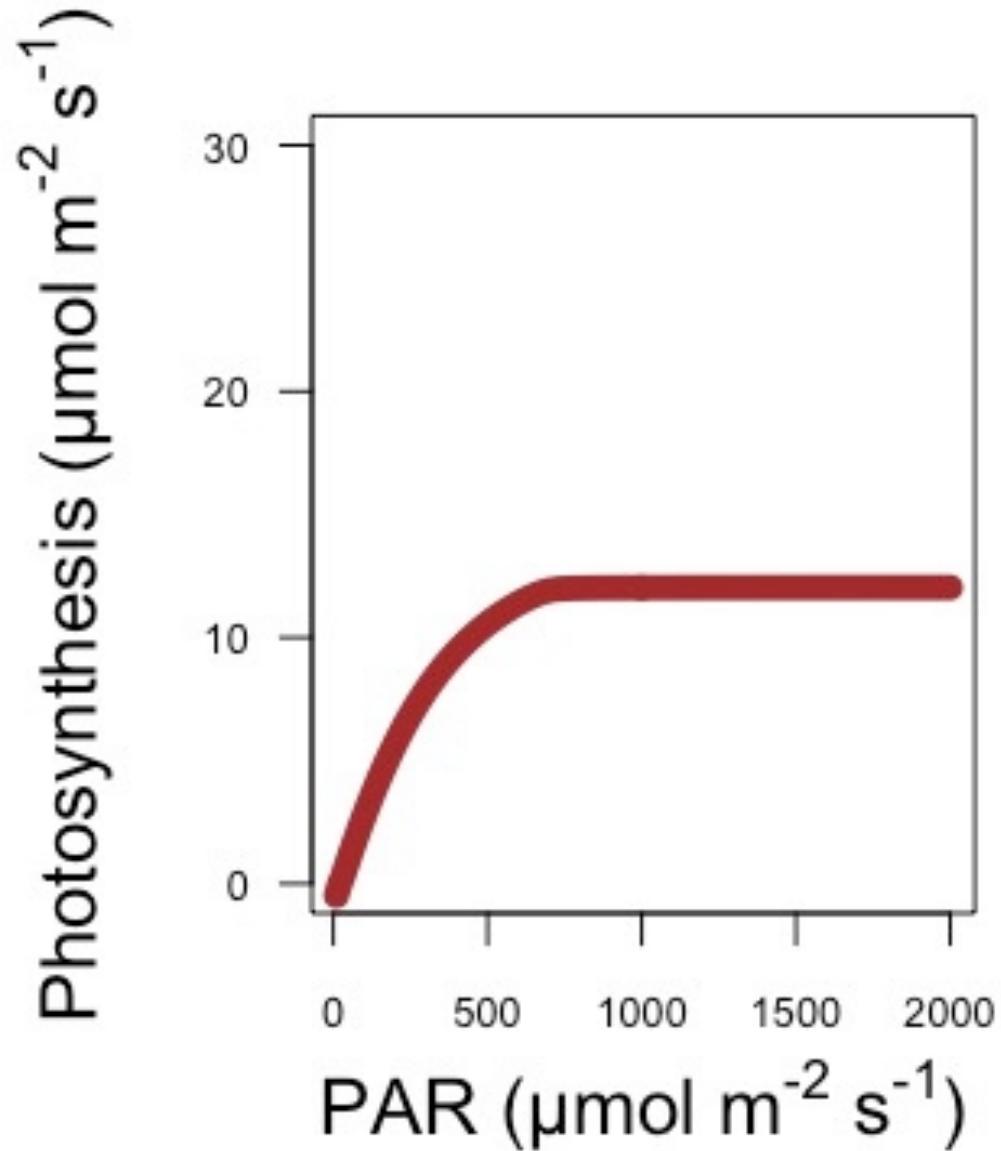
- The area over which a driver or processes of interest operates



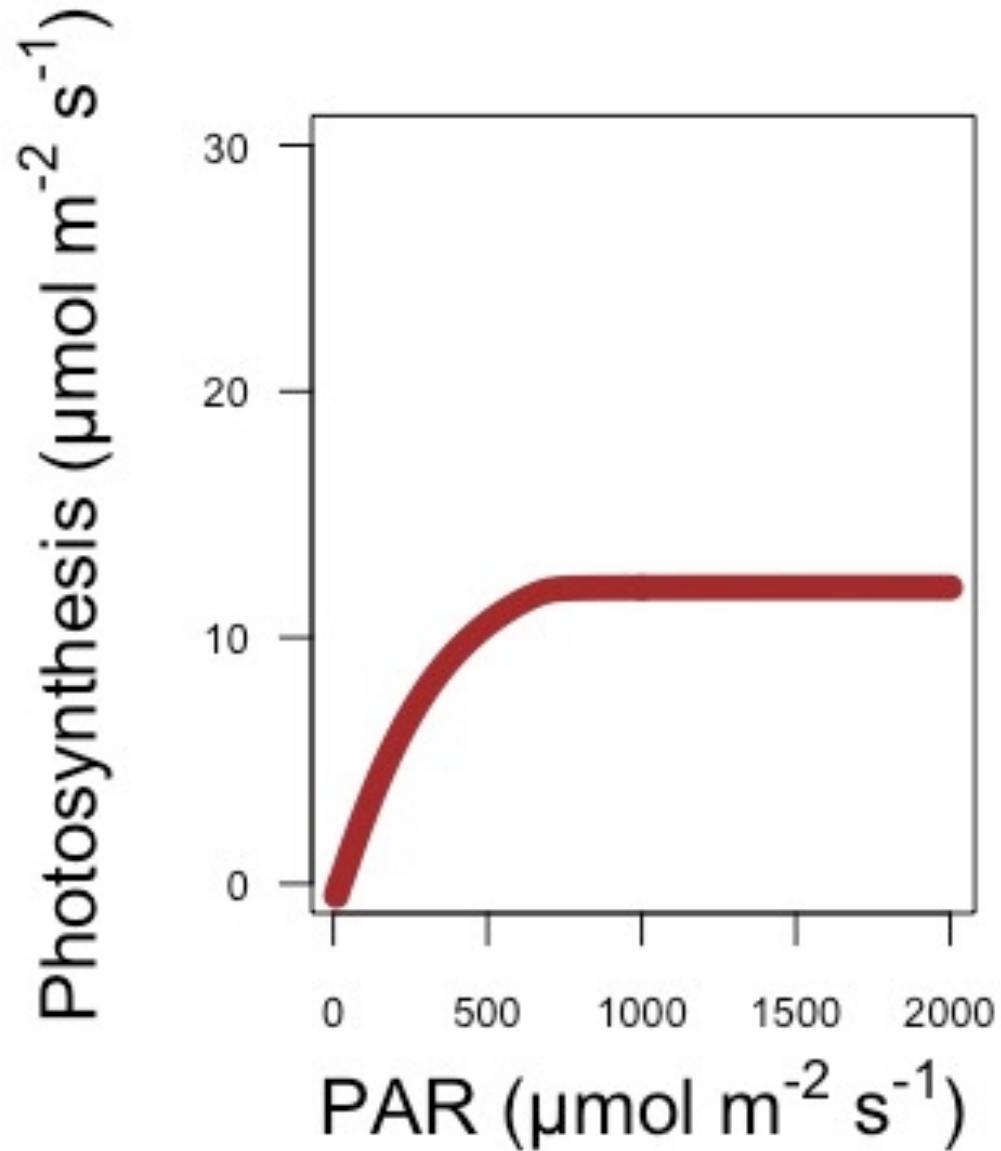
Primary two dimensions of scaling are temporal and spatial

- Temporal
 - The timeframe over which a driver or process of interest operates
- Spatial
 - The area over which a driver or processes of interest operates

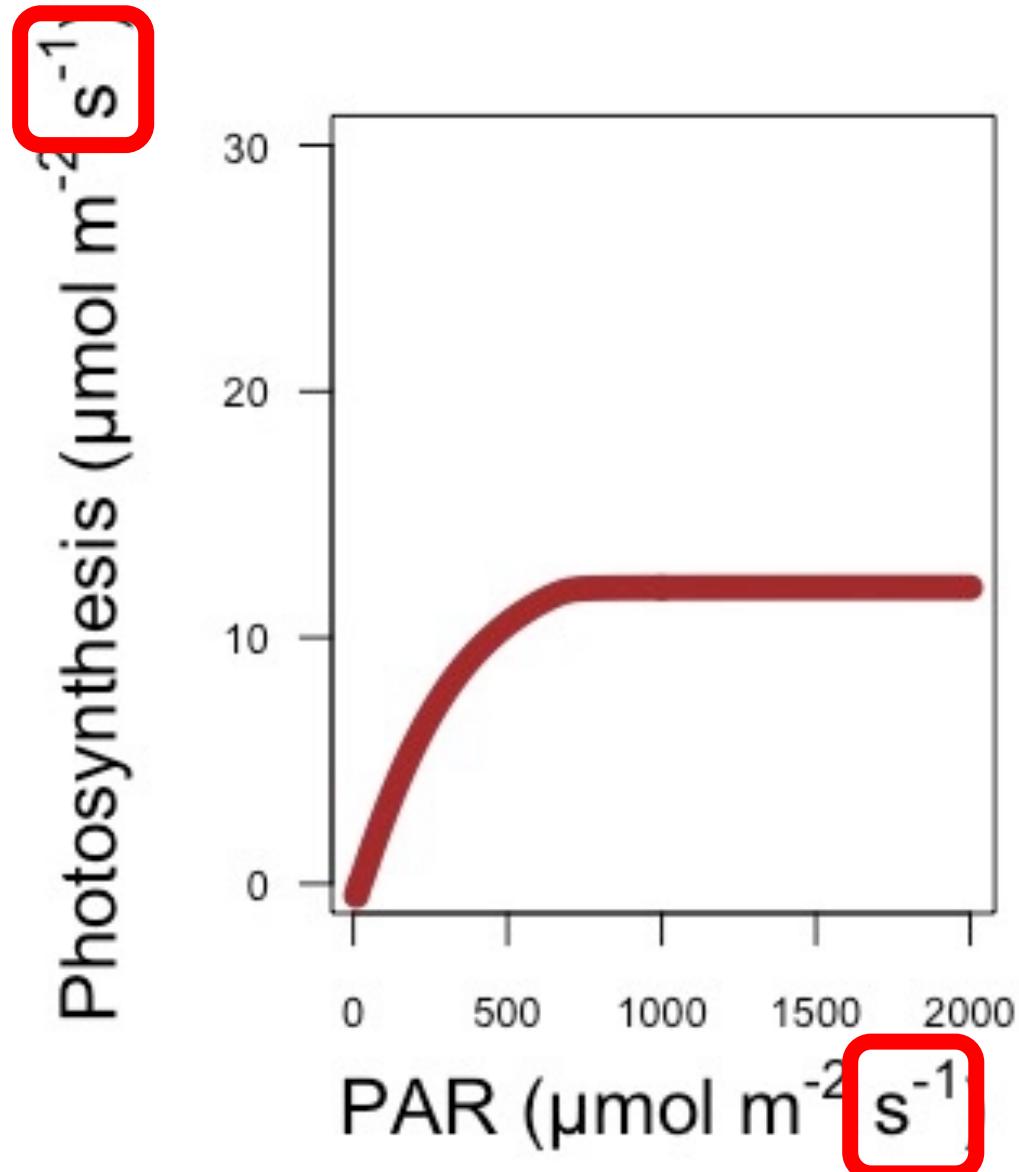




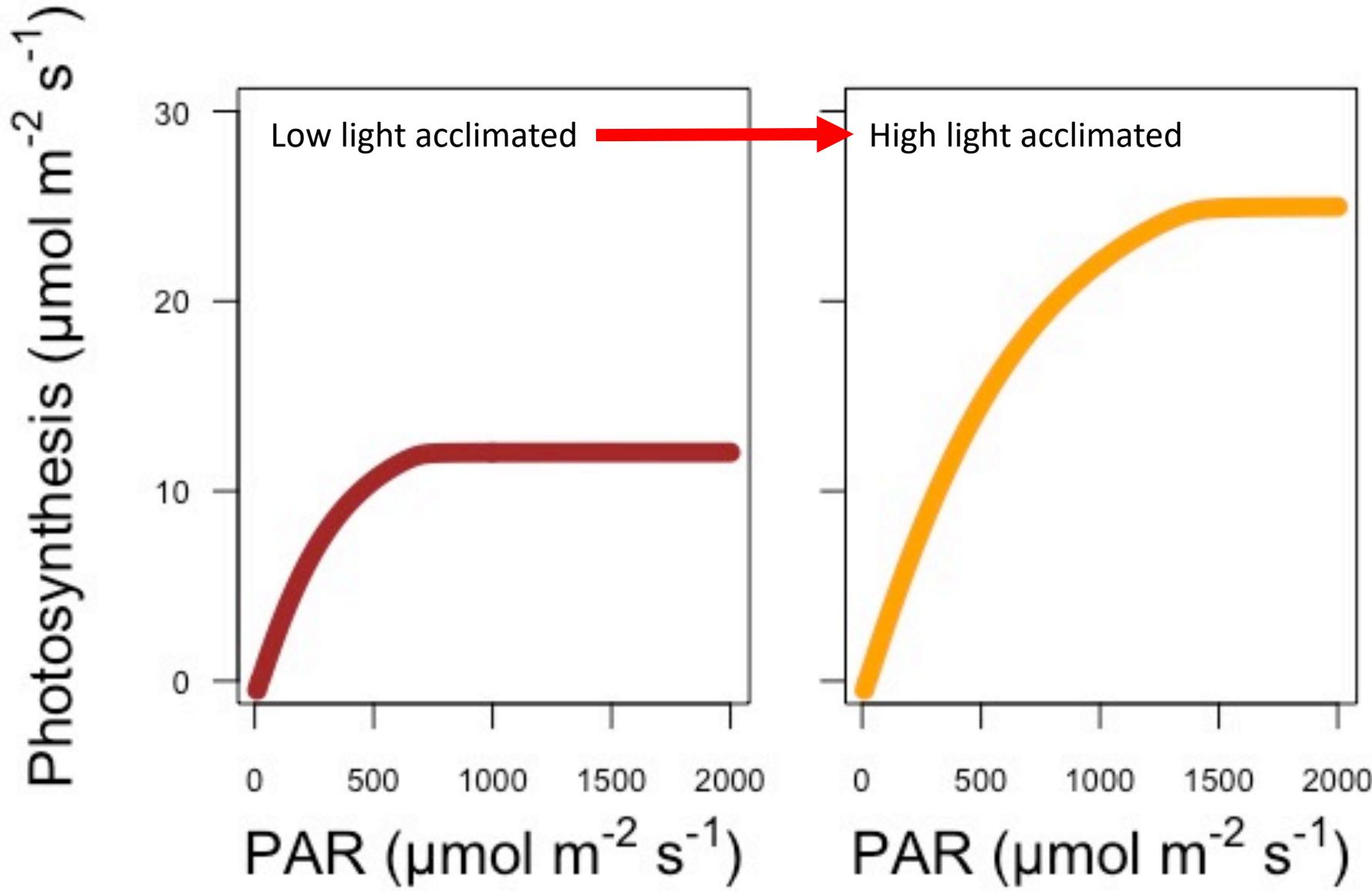
m = meters (single leaf), s = second



What is the timescale?



m = meters (single leaf), s = second



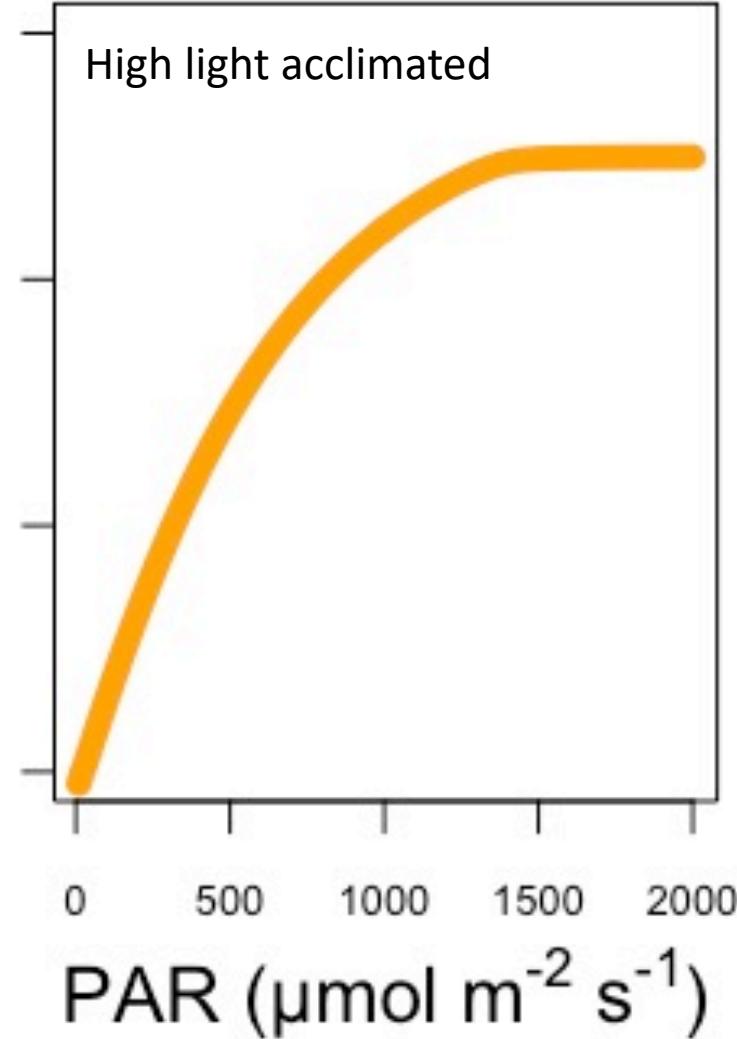
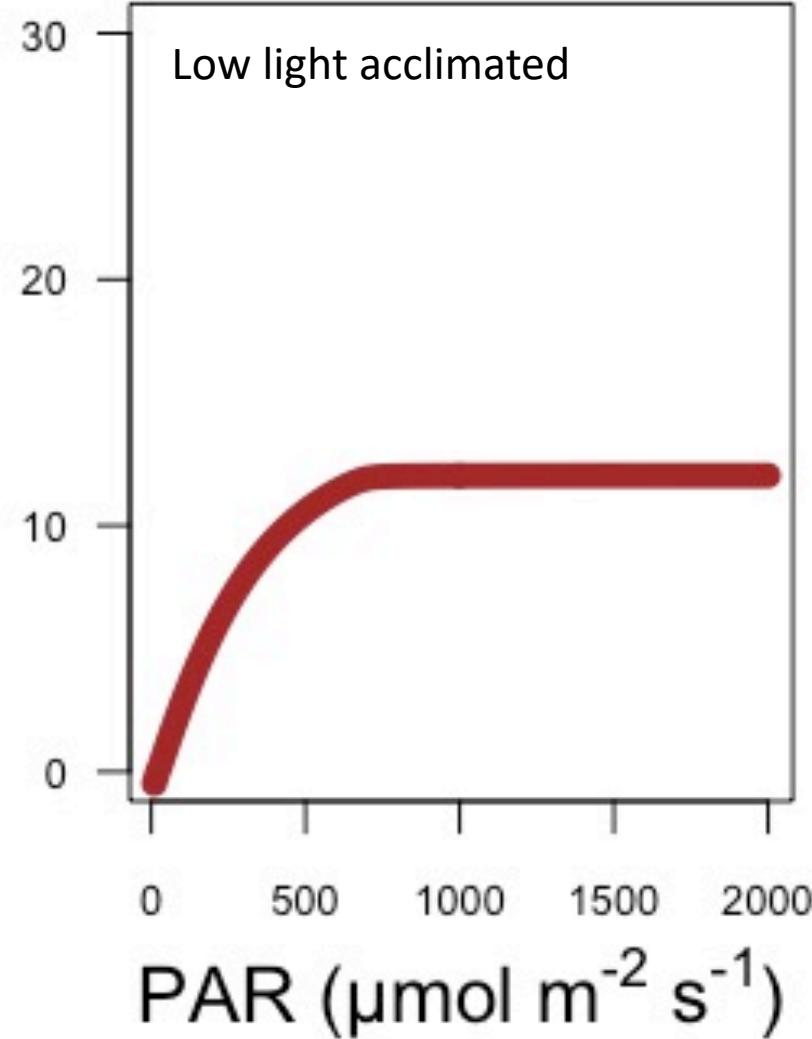
m = meters (single leaf), s = second

Primary two dimensions of scaling are temporal and spatial

- Temporal
 - The timescale over which a driver or process of interest operates
- Spatial
 - The area over which a driver or processes of interest operates



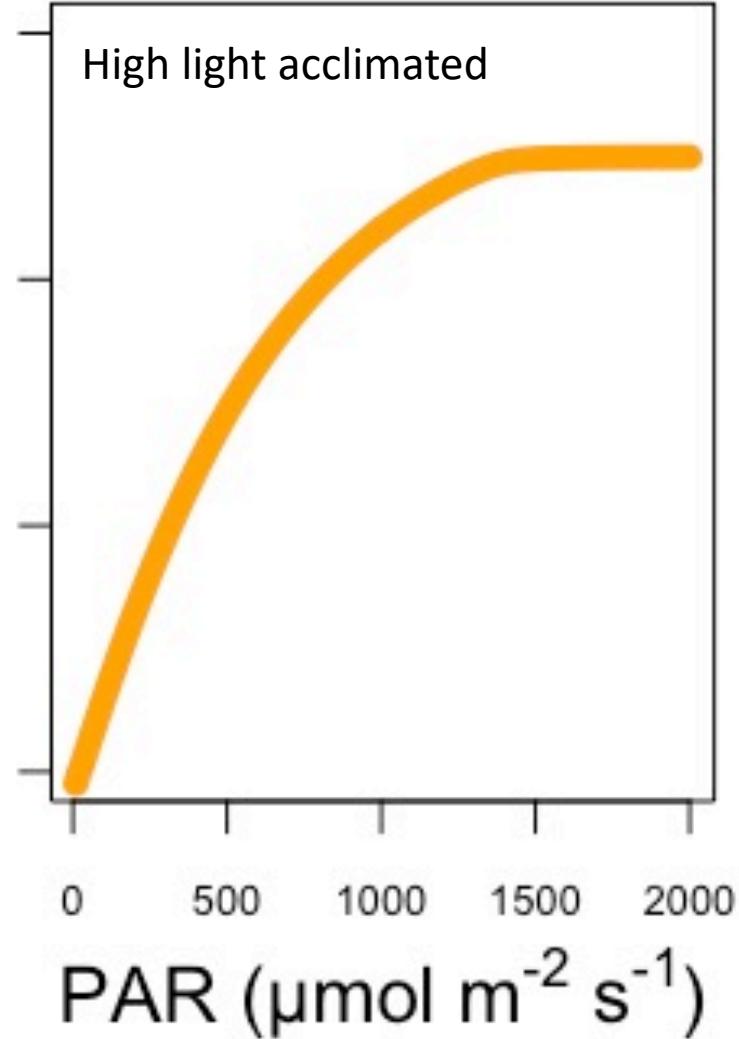
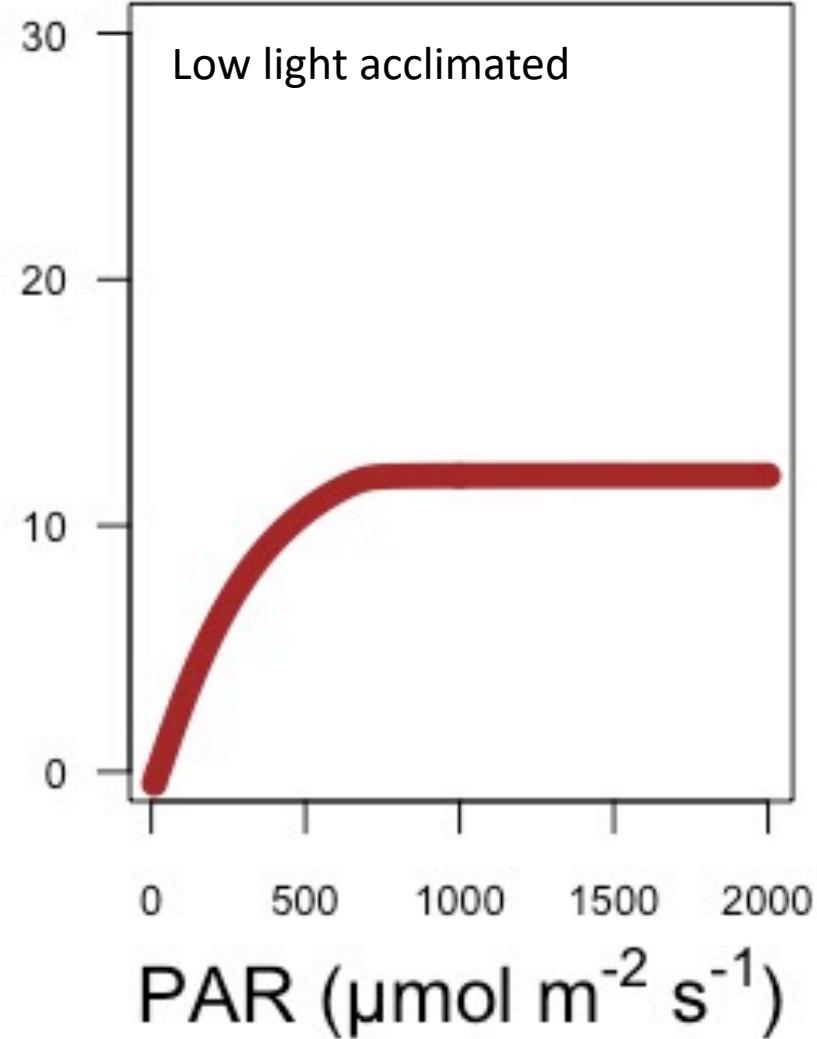
Photosynthesis ($\mu\text{mol m}^{-2} \text{s}^{-1}$)



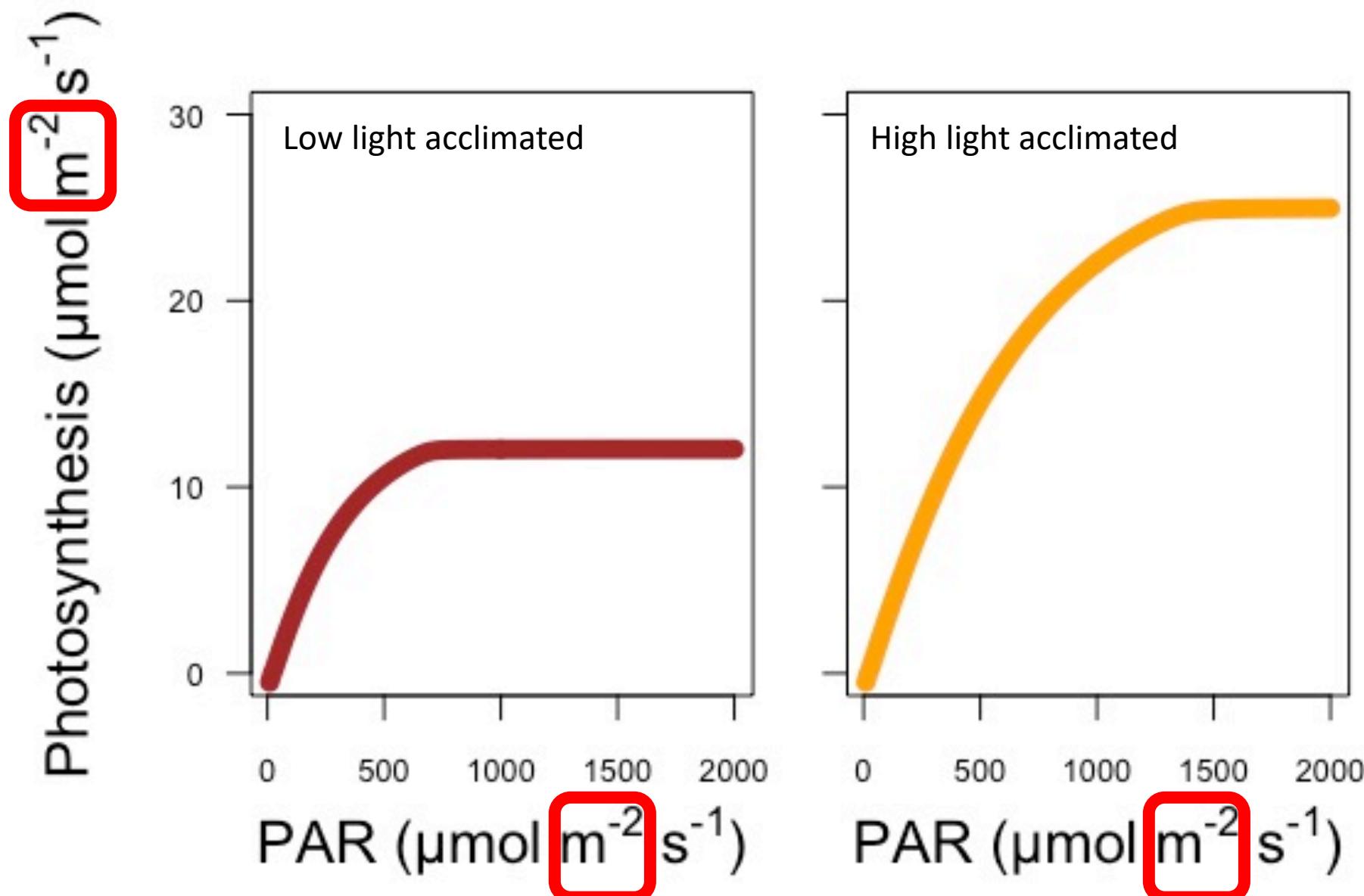
m = meters (single leaf), s = second

What is the spatial scale?
Is it different between panels?

Photosynthesis ($\mu\text{mol m}^{-2} \text{s}^{-1}$)

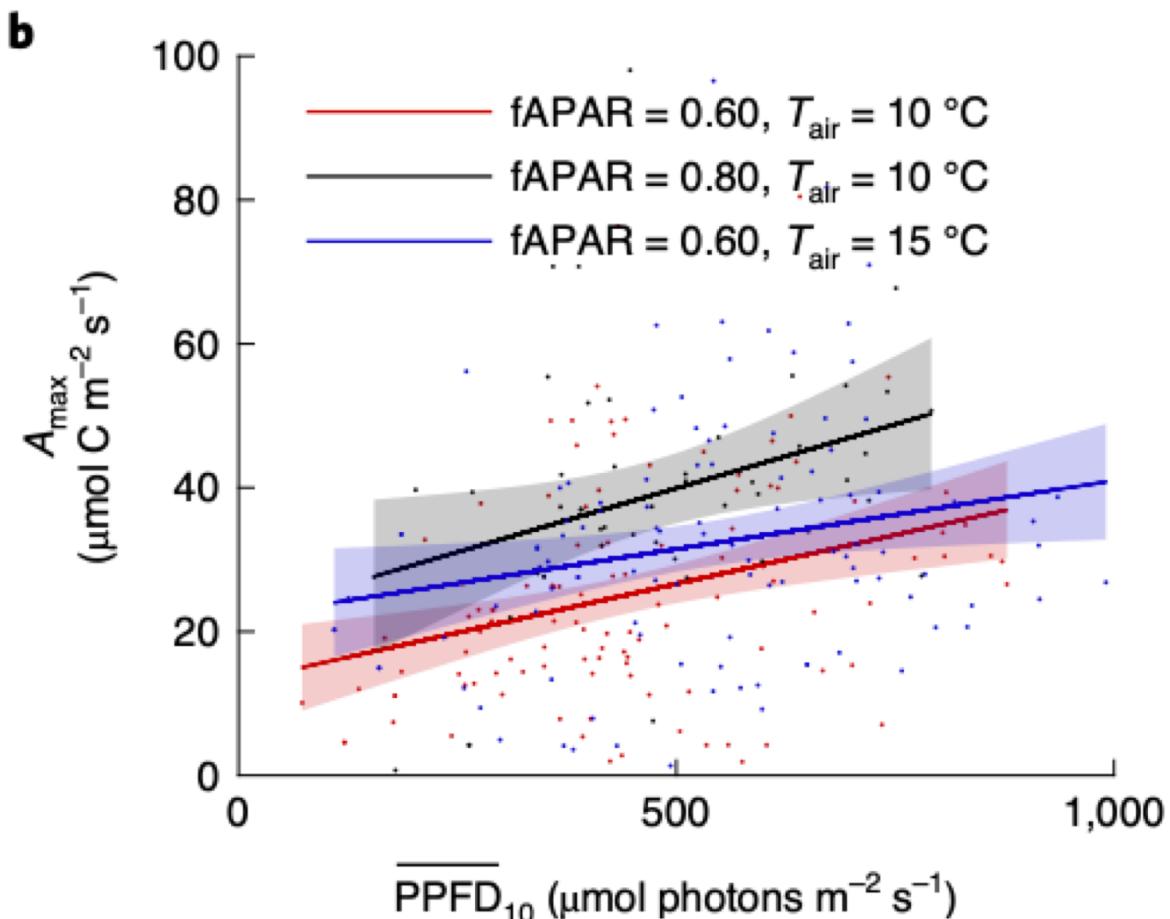


m = meters (single leaf), s = second



m = meters (single leaf), s = second

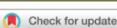
Example: testing similar processes at different scales



nature
ecology & evolution

ARTICLES

<https://doi.org/10.1038/s41559-020-1258-7>

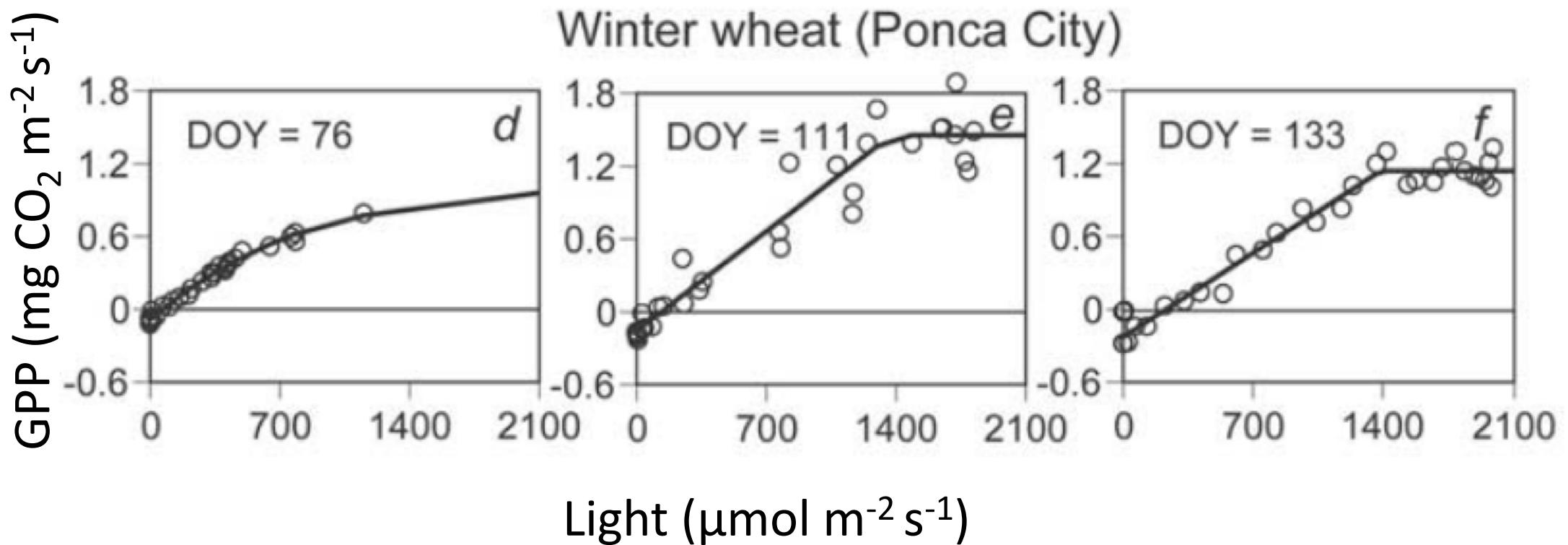


Global evidence for the acclimation of ecosystem photosynthesis to light

Xiangzhong Luo ^{1,2} and Trevor F. Keenan ^{1,2}

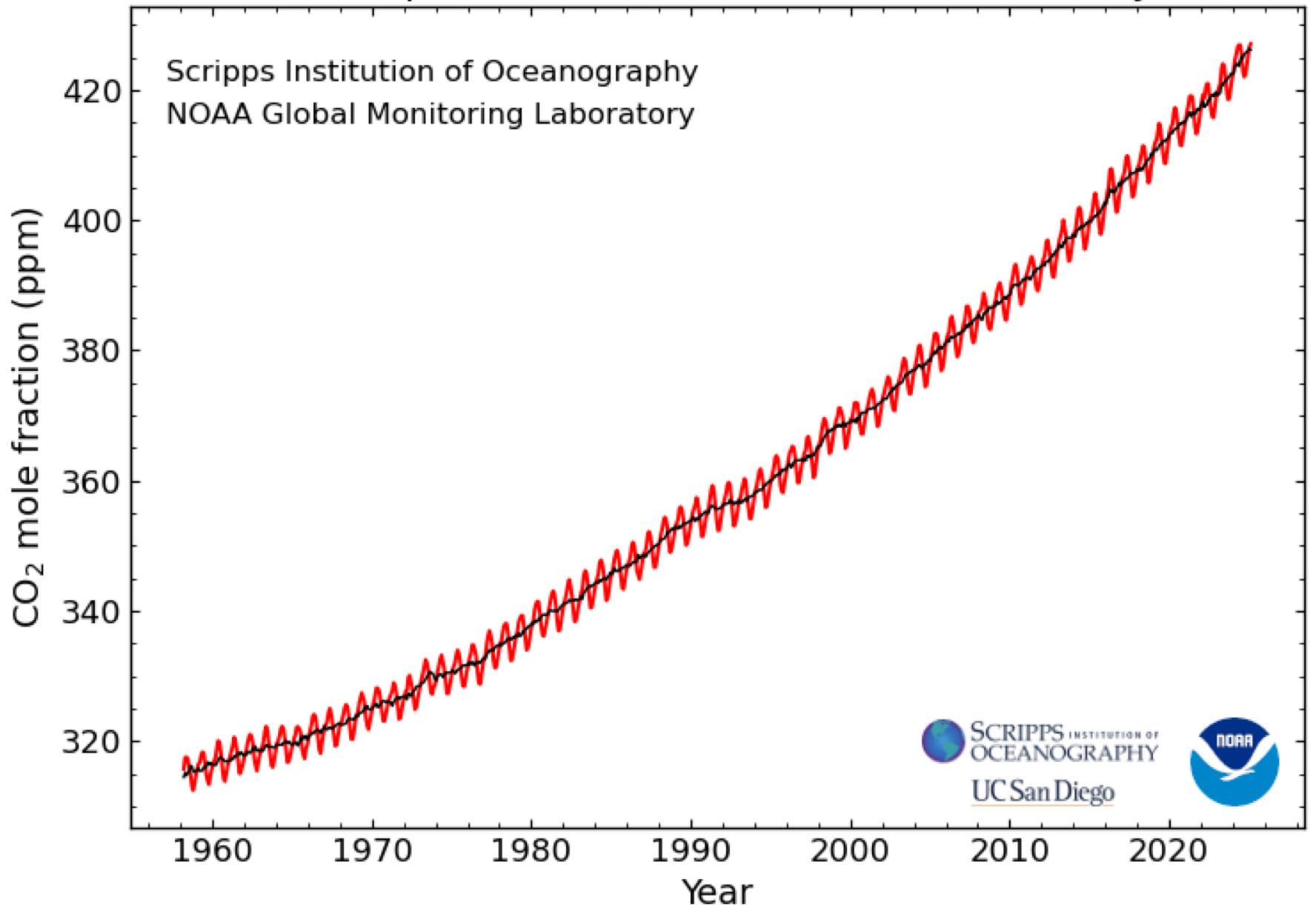
m = meters (single leaf), s = second, $\overline{\text{PPFD}}_{10}$ = light over the past 10 days

Example: testing similar processes at different scales



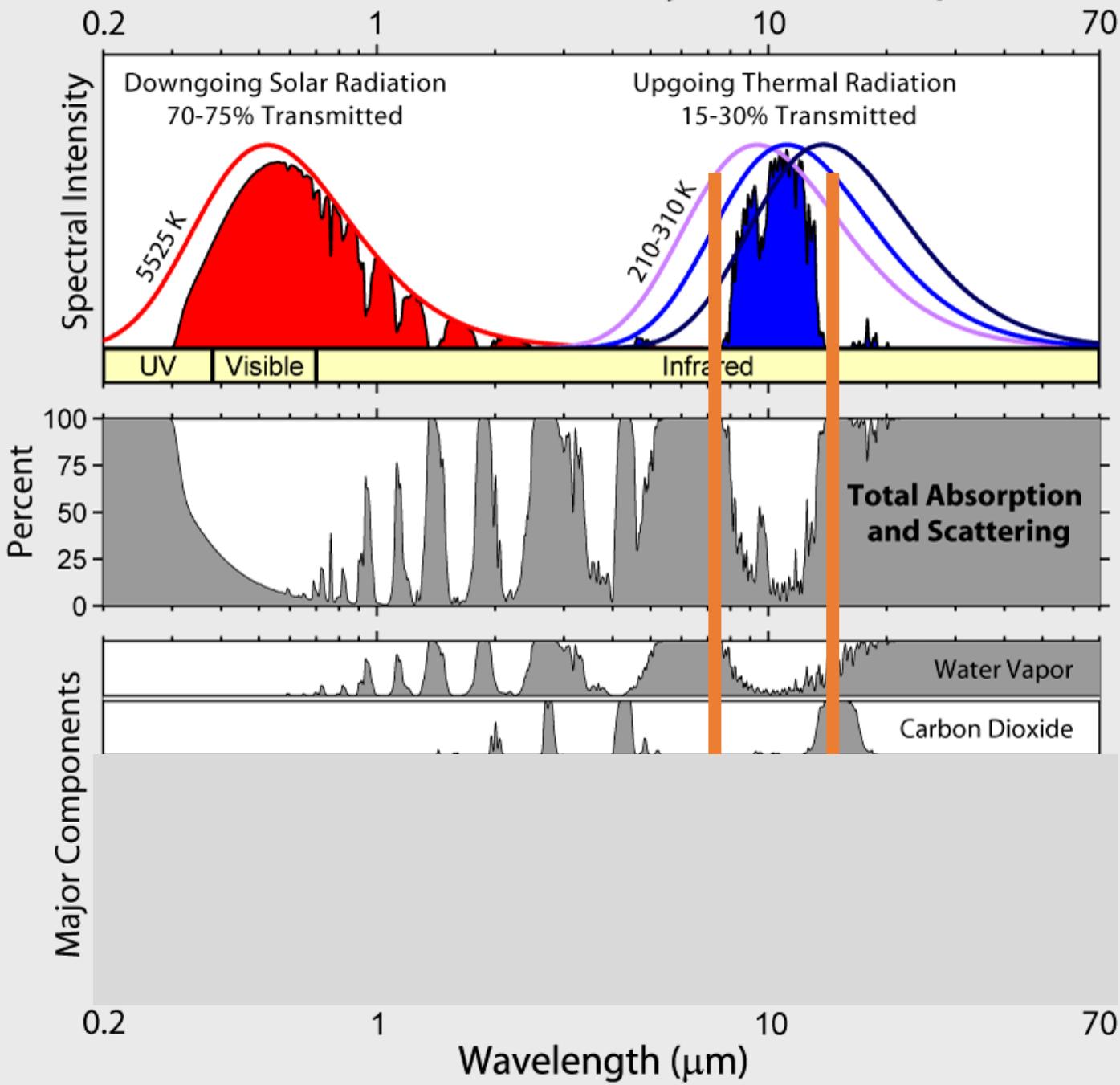
The importance of scaling: an example exercise

Atmospheric CO₂ at Mauna Loa Observatory



Going up 1.5
ppm / year

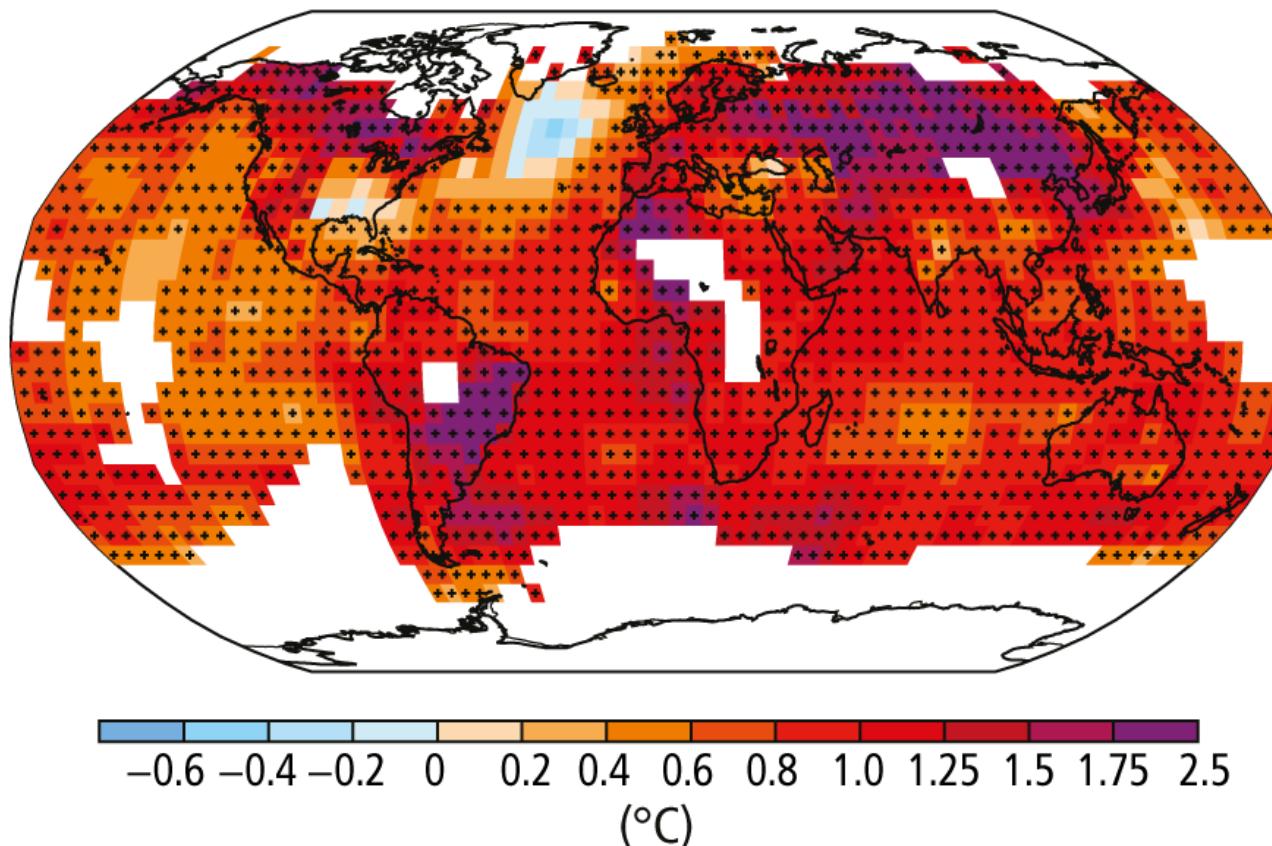
Radiation Transmitted by the Atmosphere



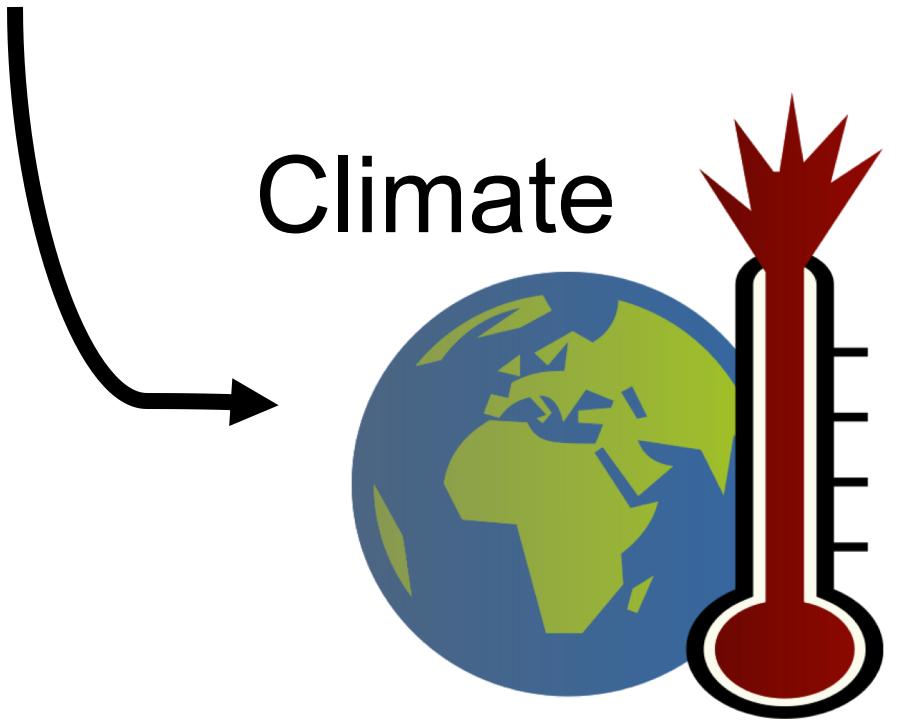
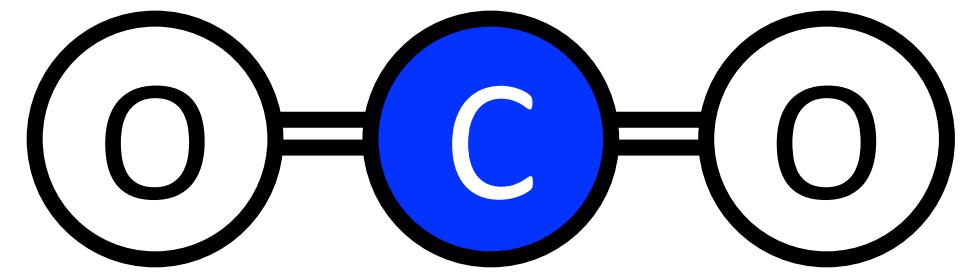
The climate is warming

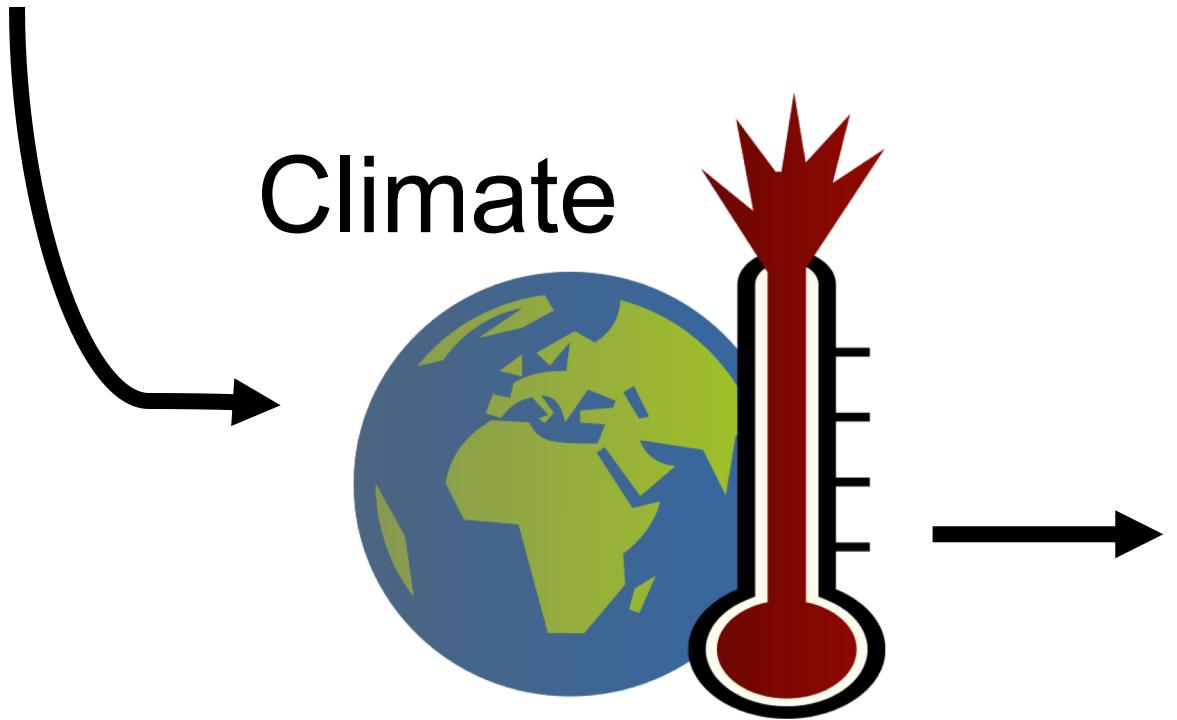
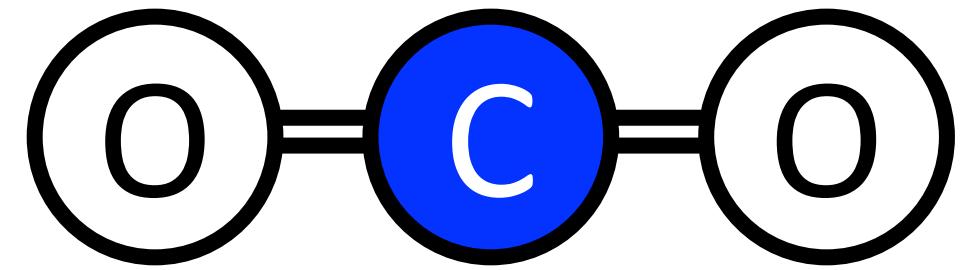
(b)

Observed change in surface temperature
1901–2012

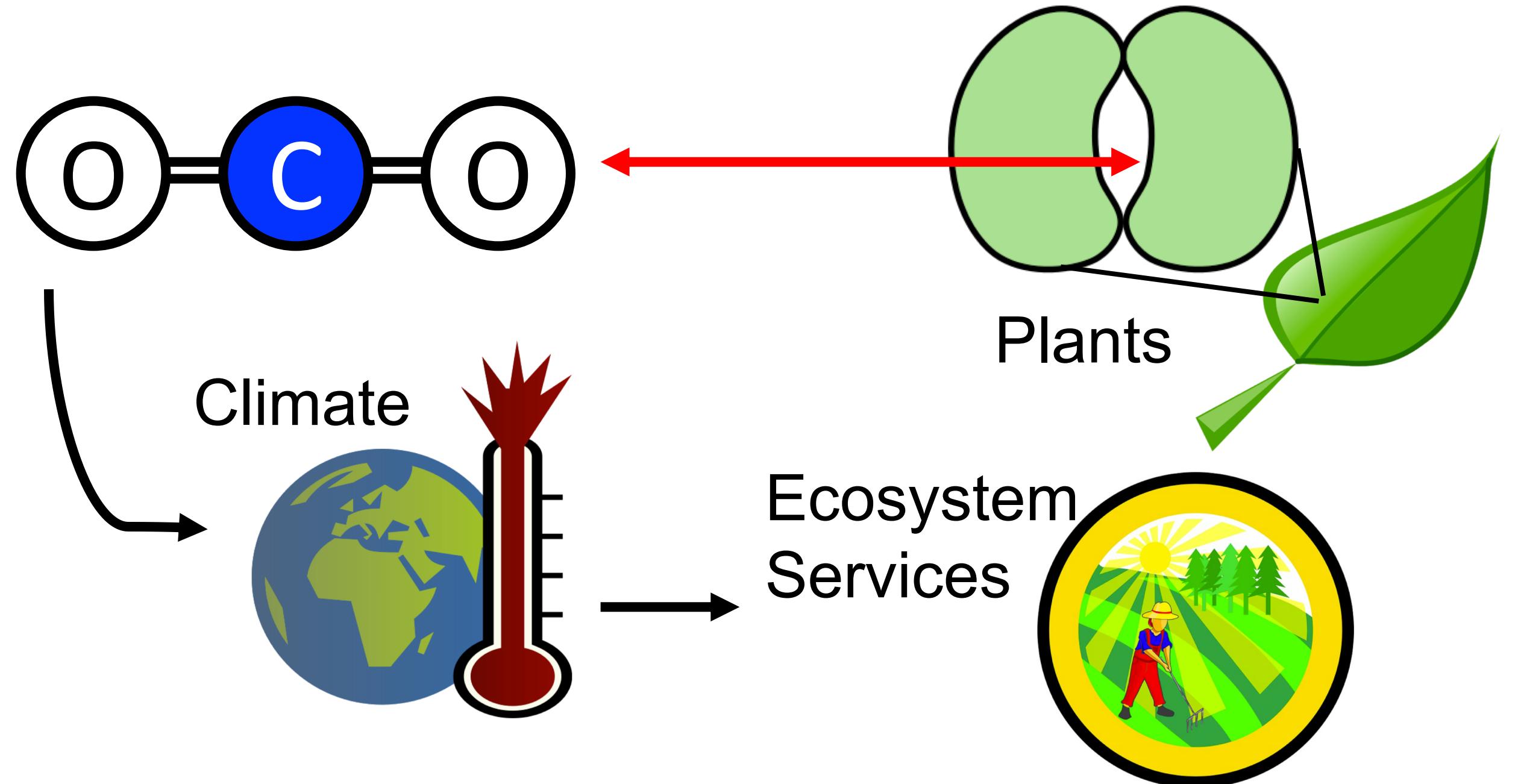


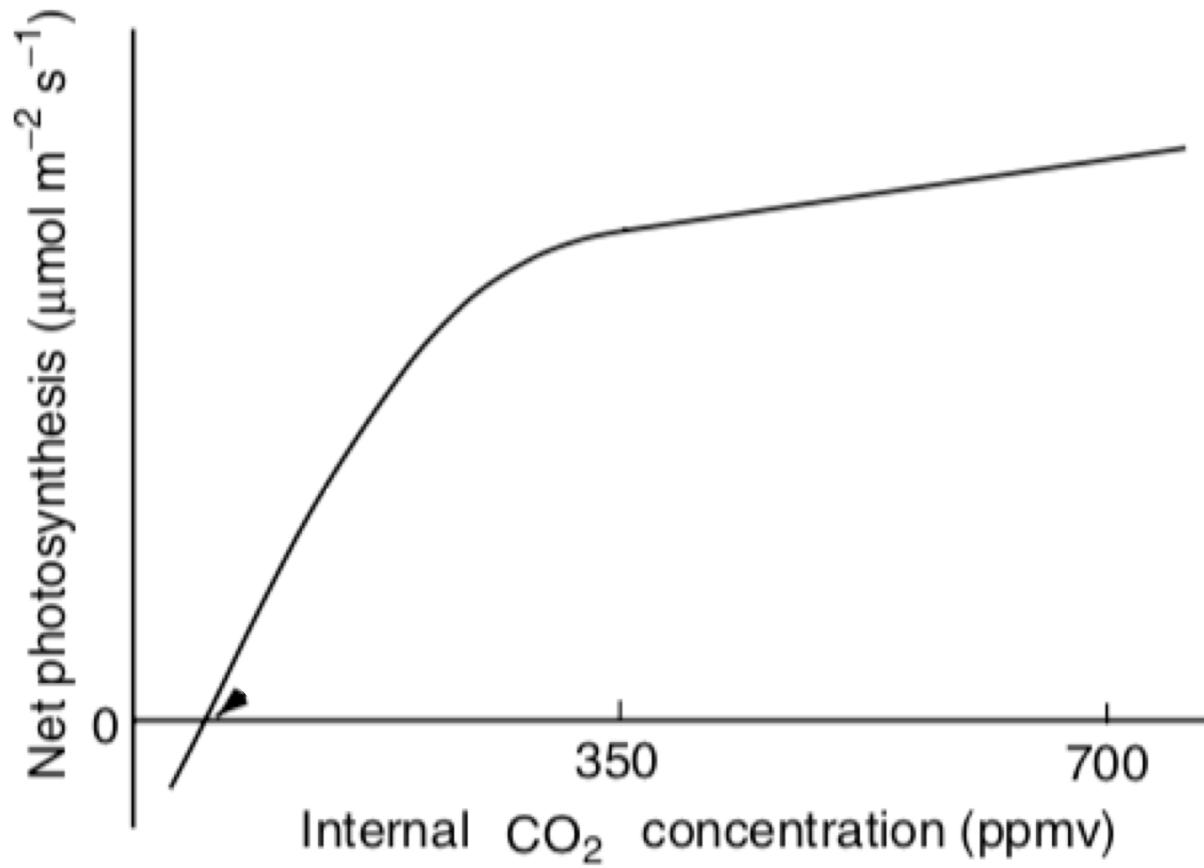
Poles and land
are warming
the fastest

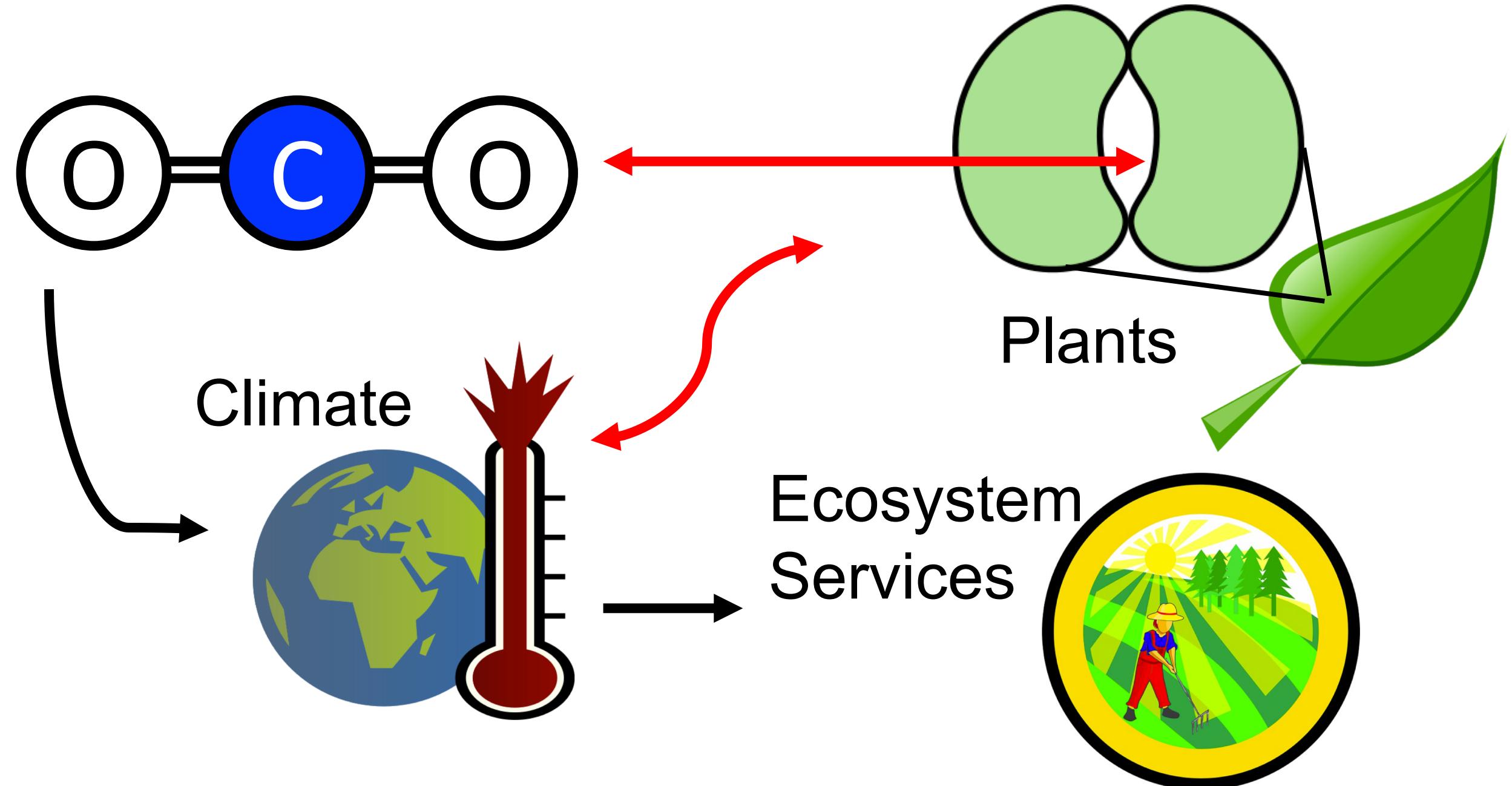


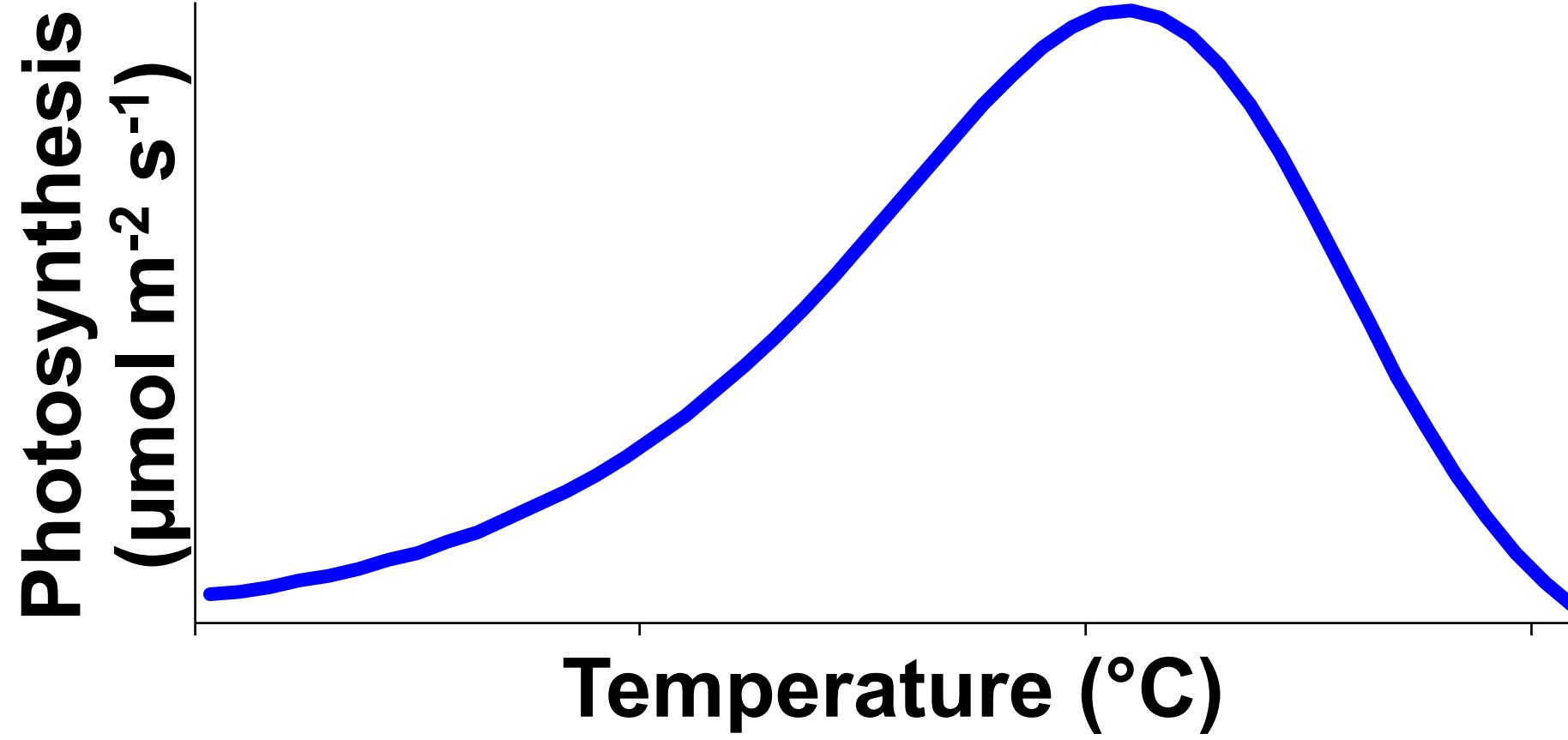


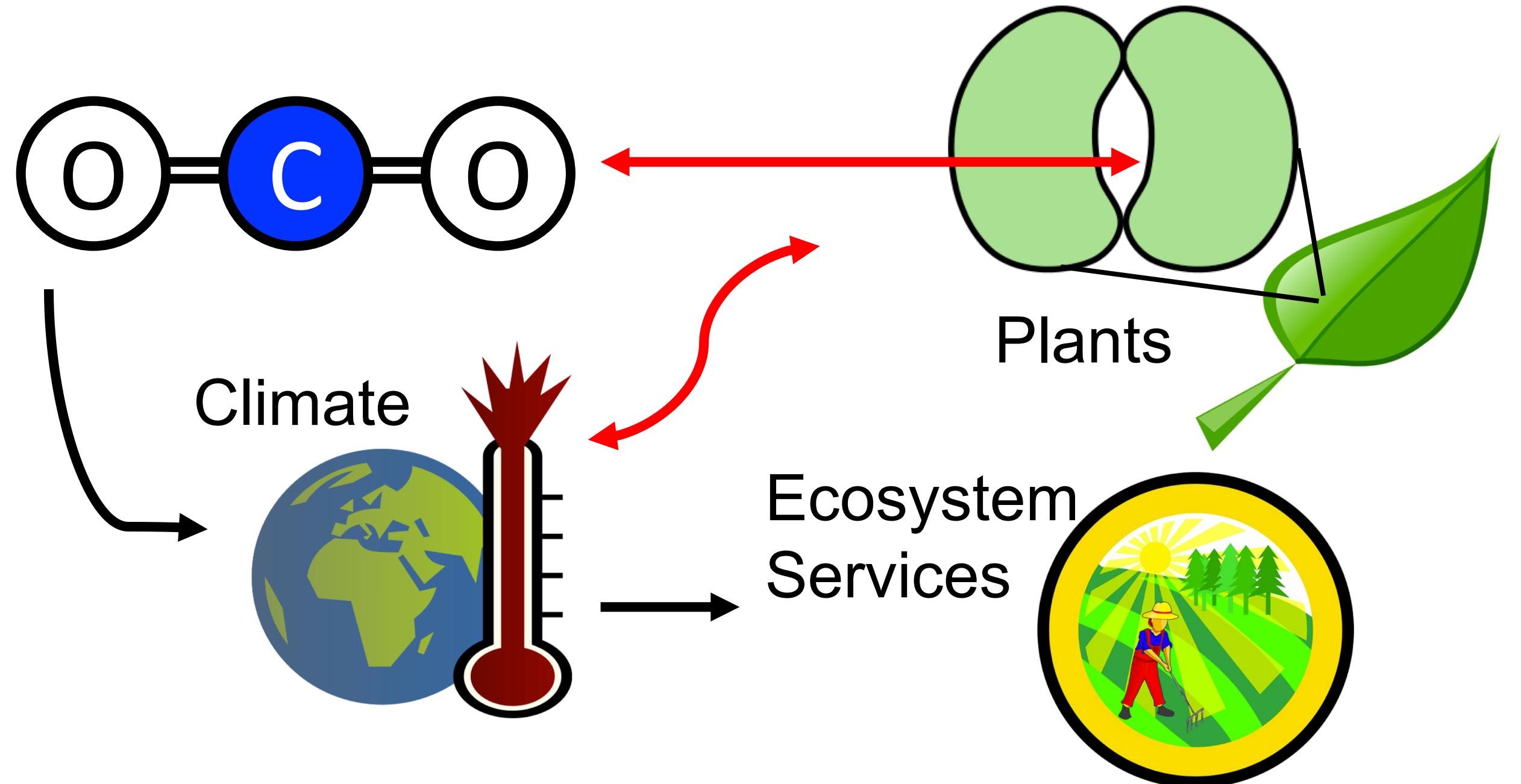
Ecosystem
Services

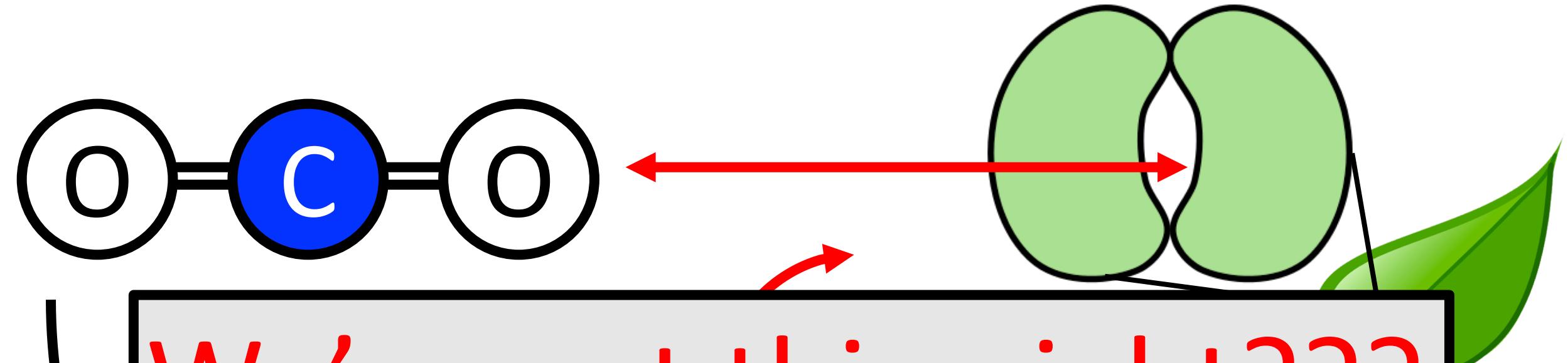




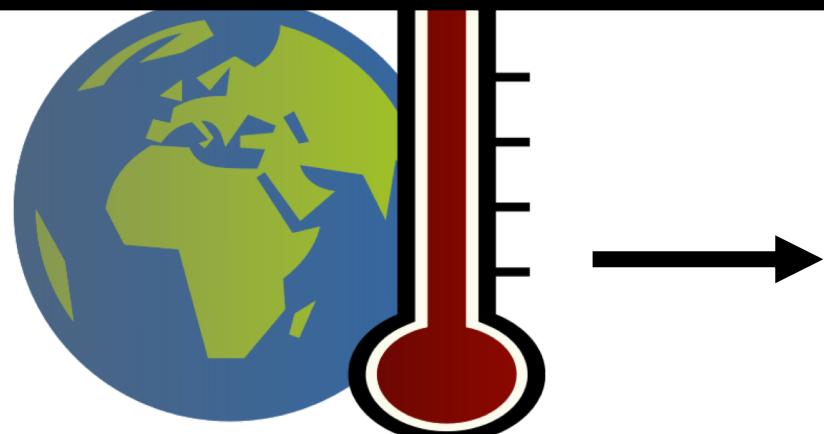








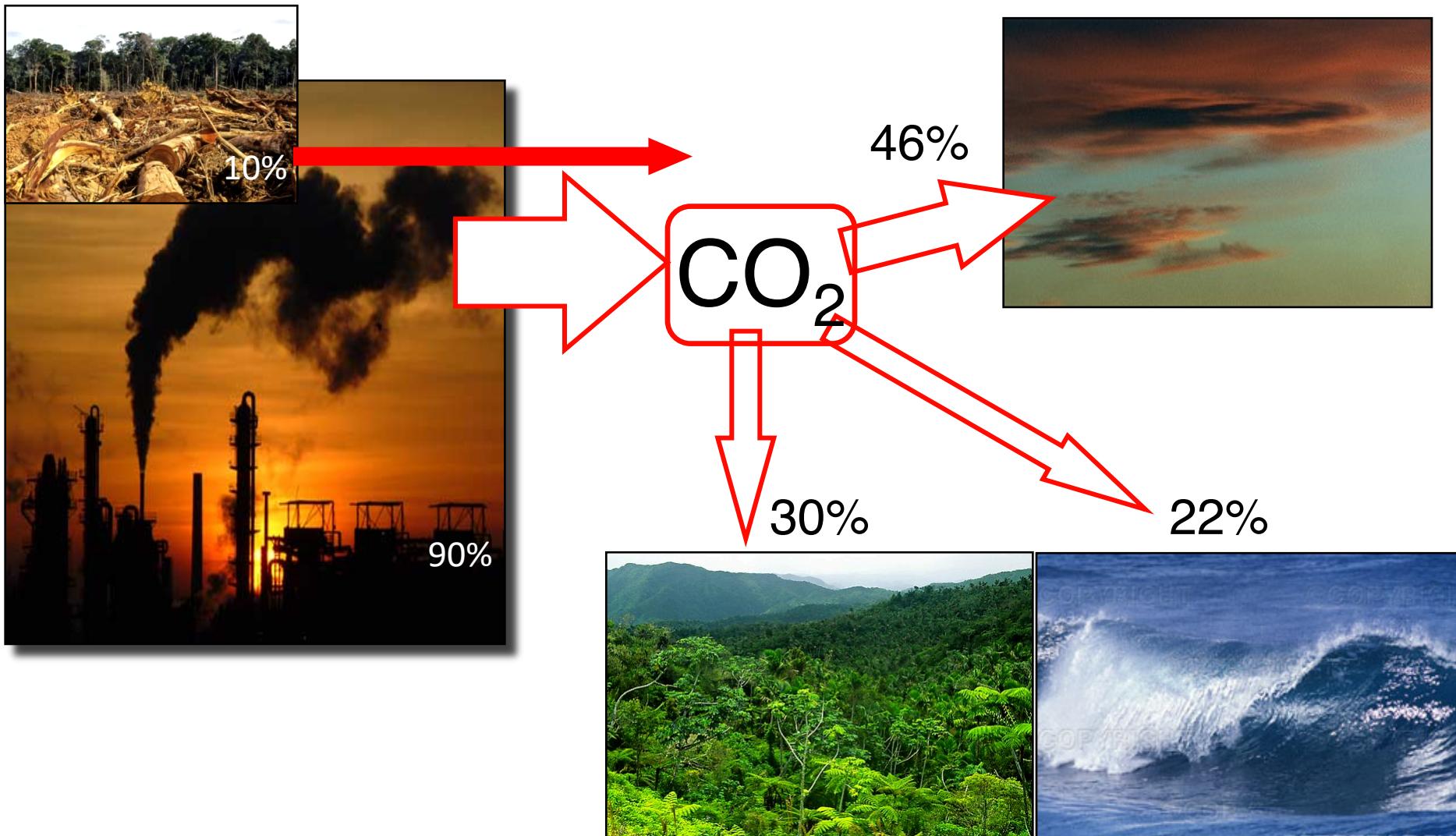
We've got this, right???

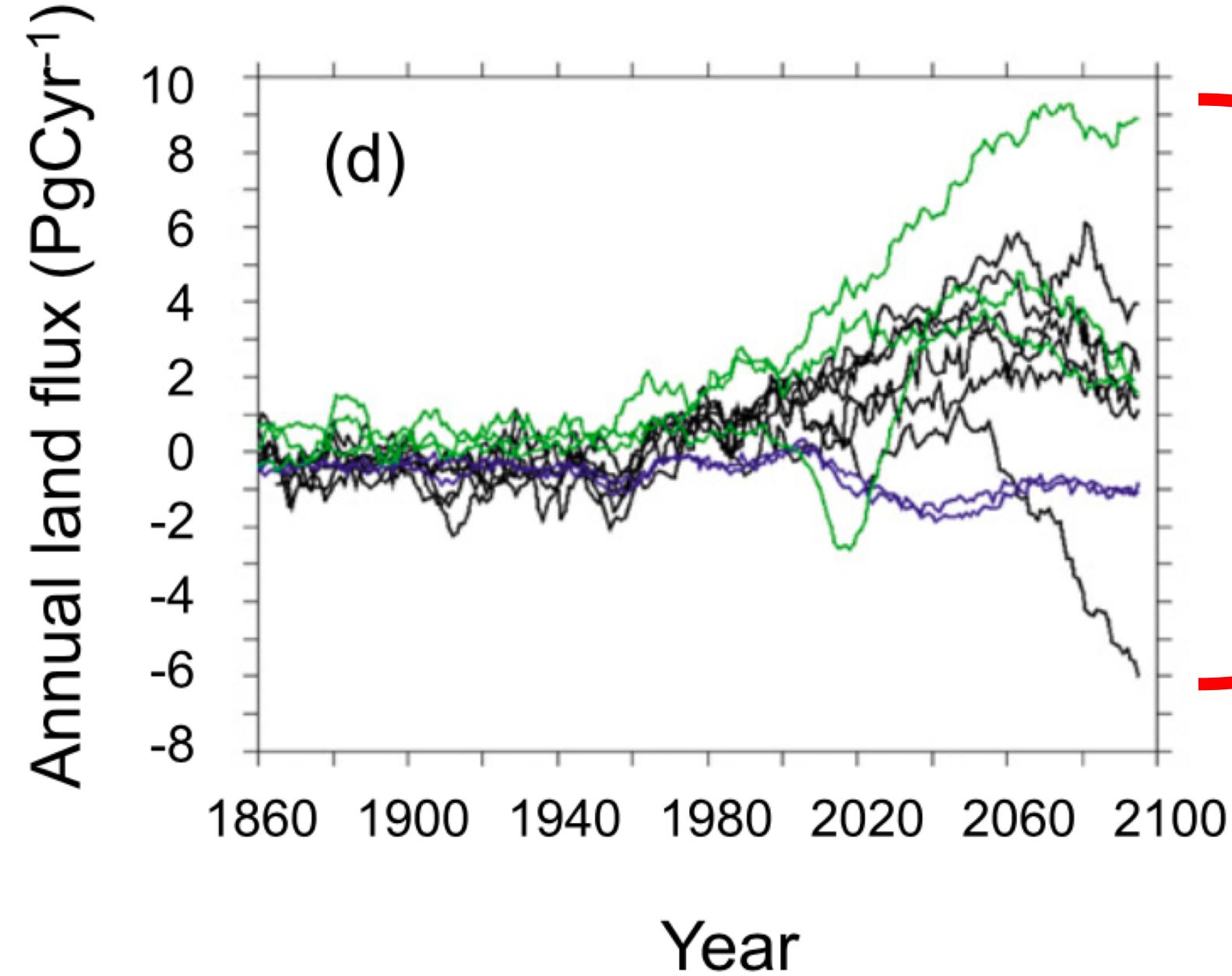


Ecosystem
Services



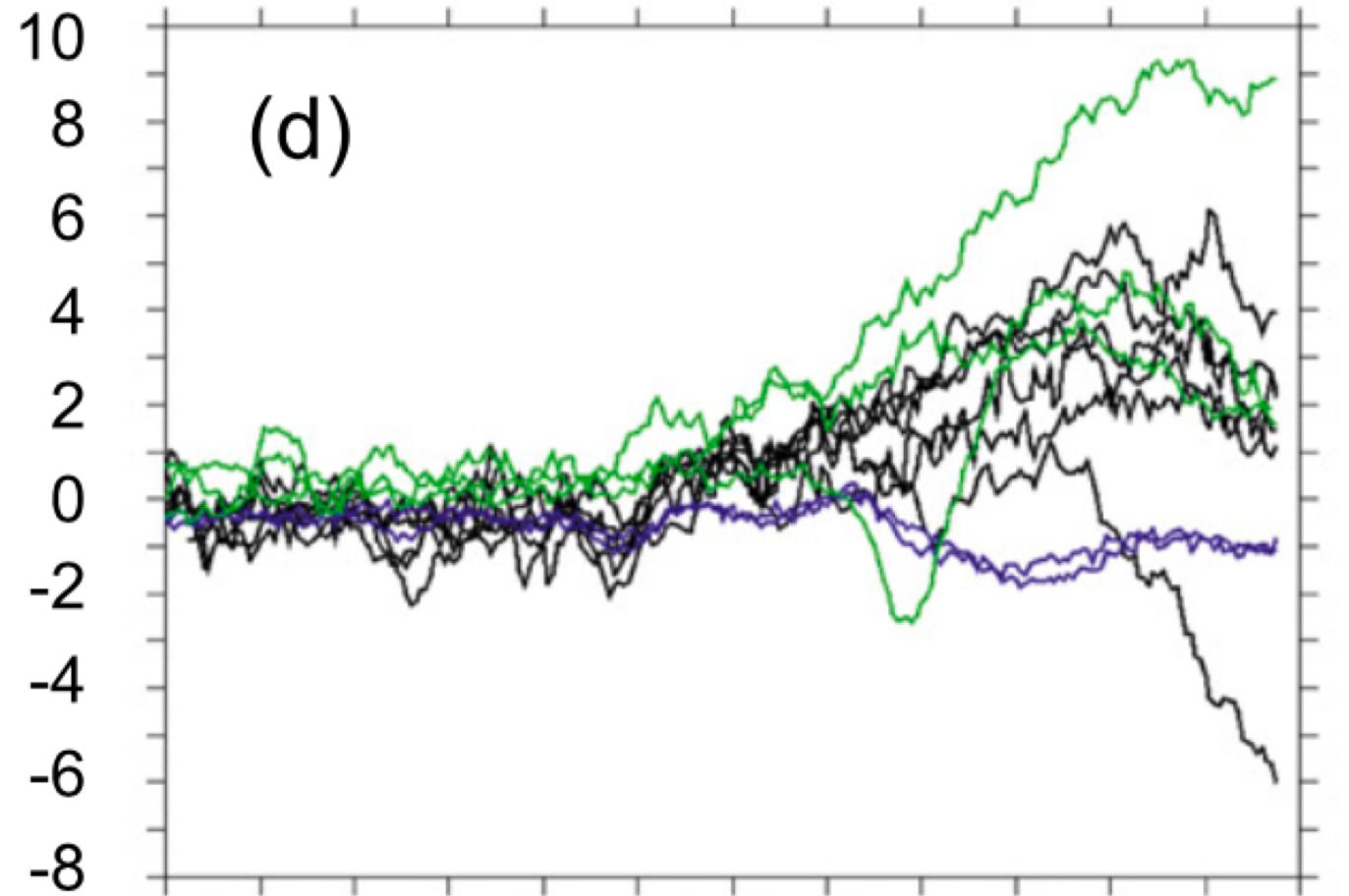
We've got a good handle on present-day land carbon uptake and storage (~30% of fossil fuel emissions)





The direction and
magnitude of the
future land carbon sink
is not known

Annual land flux (PgCyr^{-1})

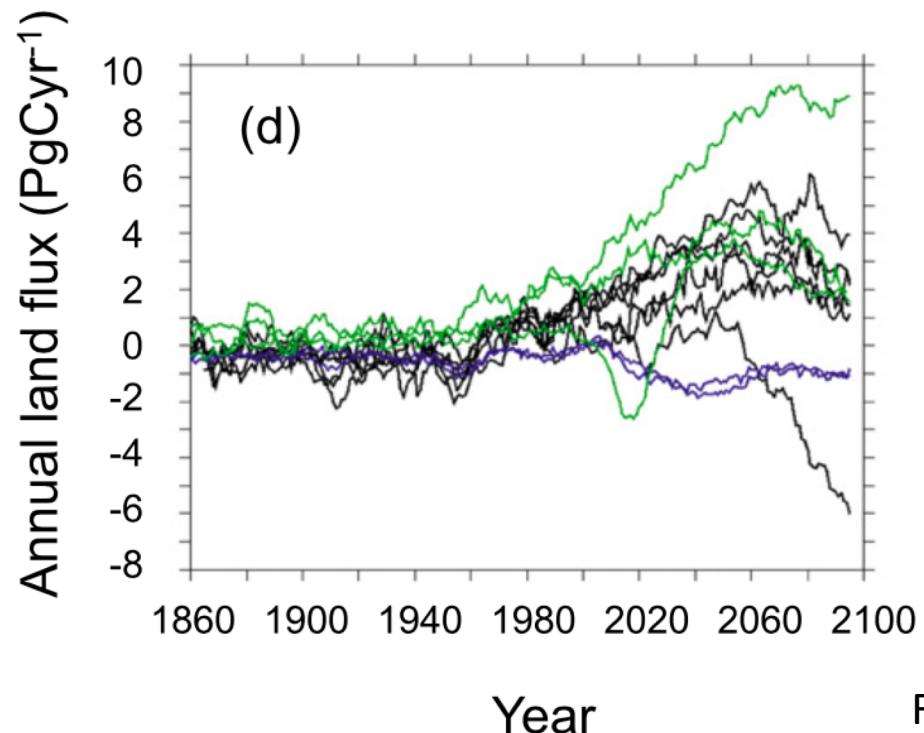


Land carbon sink
correlates well with
photosynthesis on land
($r^2 > 0.9$)

Year

Class activity

- In teams of 3-4, answer the following question: If photosynthesis drives the land carbon sink strength and temperature and CO₂ responses of photosynthesis are well characterized, why is the future carbon sink so uncertain?
- Hint: this is a scaling issue



Working across scales:
measurements

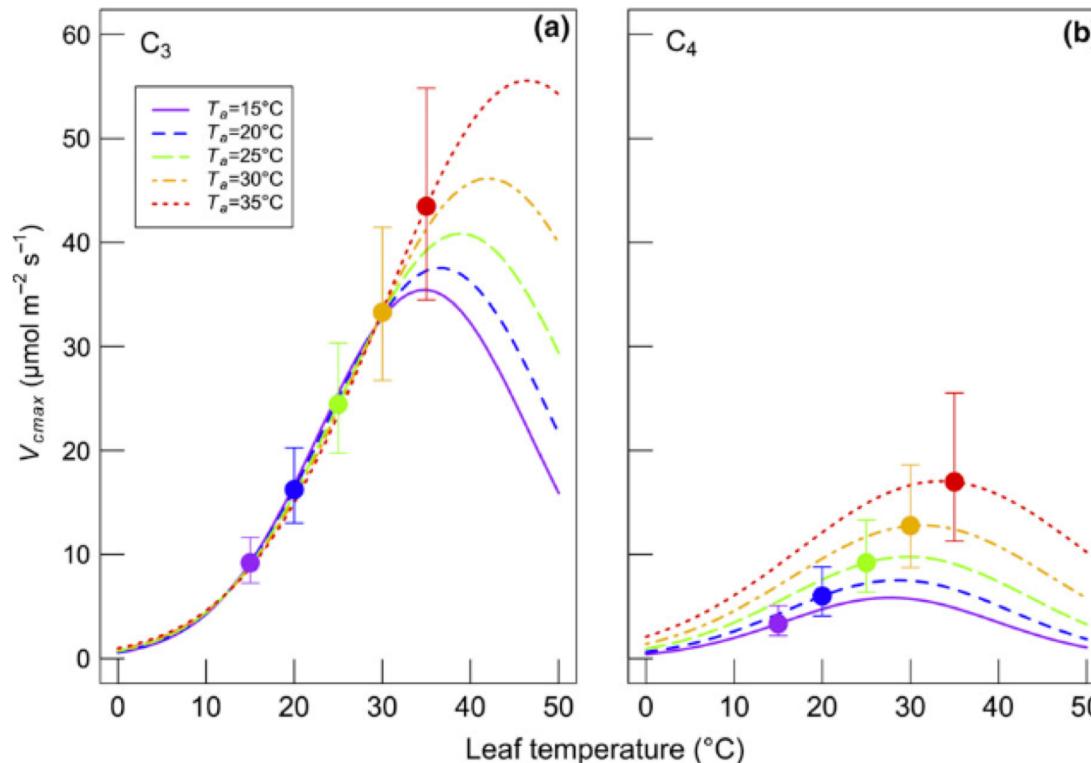
Scale tradeoff

- Mechanisms are easier to characterize at smaller scales
 - As you increase scale, the details become less clear
- Outcomes are easier to characterize at larger scales
 - As you reduce scale, it is difficult to understand all the interactions that might influence a process

Ecophysiological scale consideration 1: controlled versus uncontrolled conditions

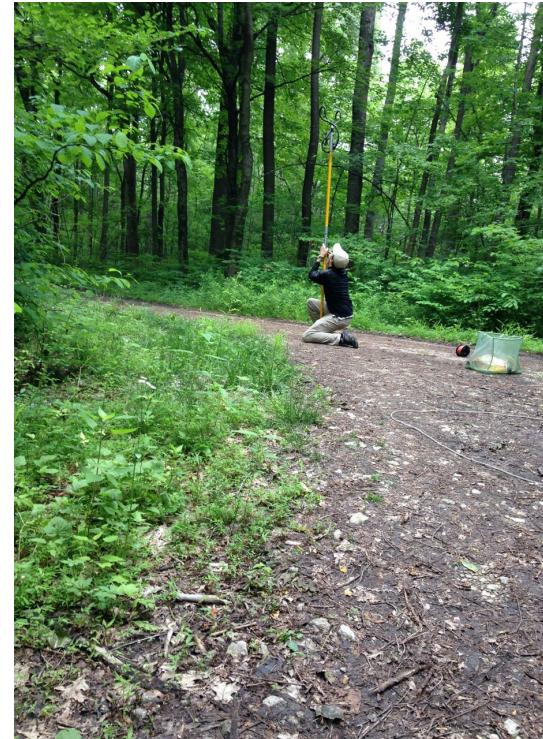
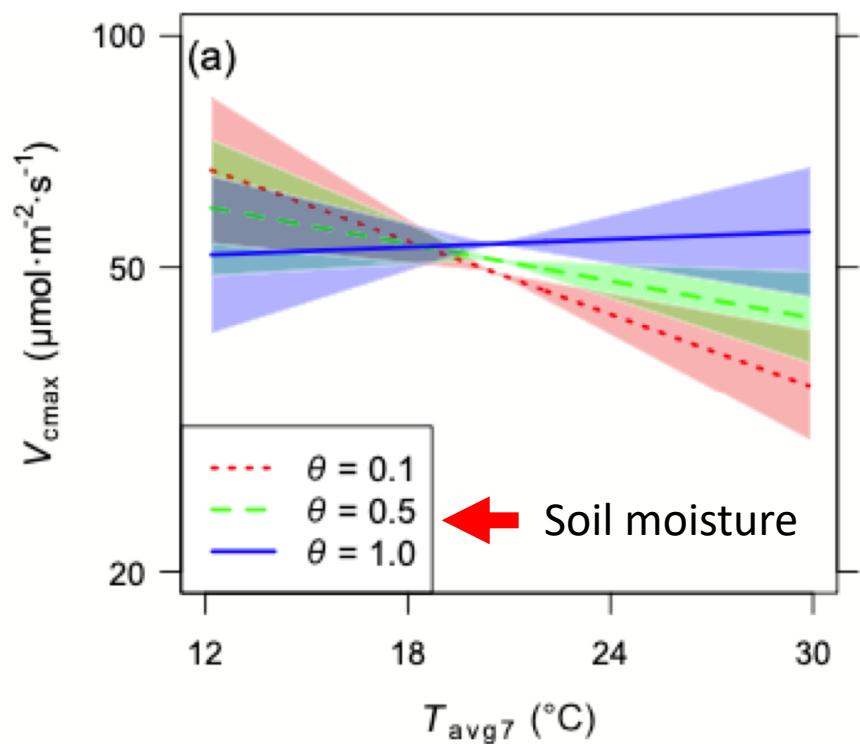
Ecophysiological scale consideration 1: controlled versus uncontrolled conditions

- Controlled environment
 - **Pro:** can measure ecophysiological process response while holding all conditions constant



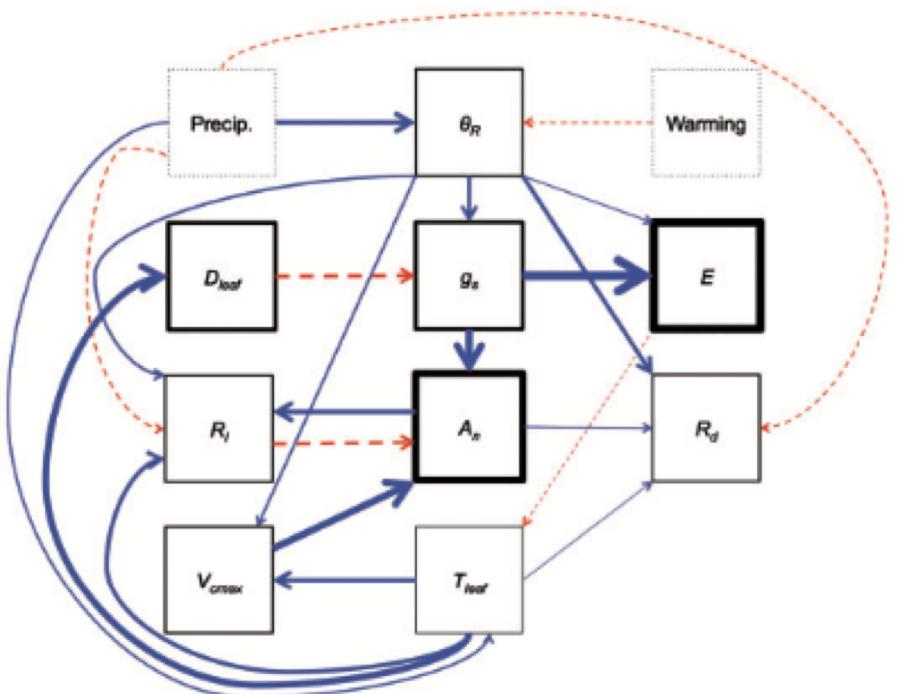
Ecophysiological scale consideration 1: controlled versus uncontrolled conditions

- Controlled environment
 - **Con:** might miss important interactions, environment not in-tact



Ecophysiological scale consideration 1: controlled versus uncontrolled conditions

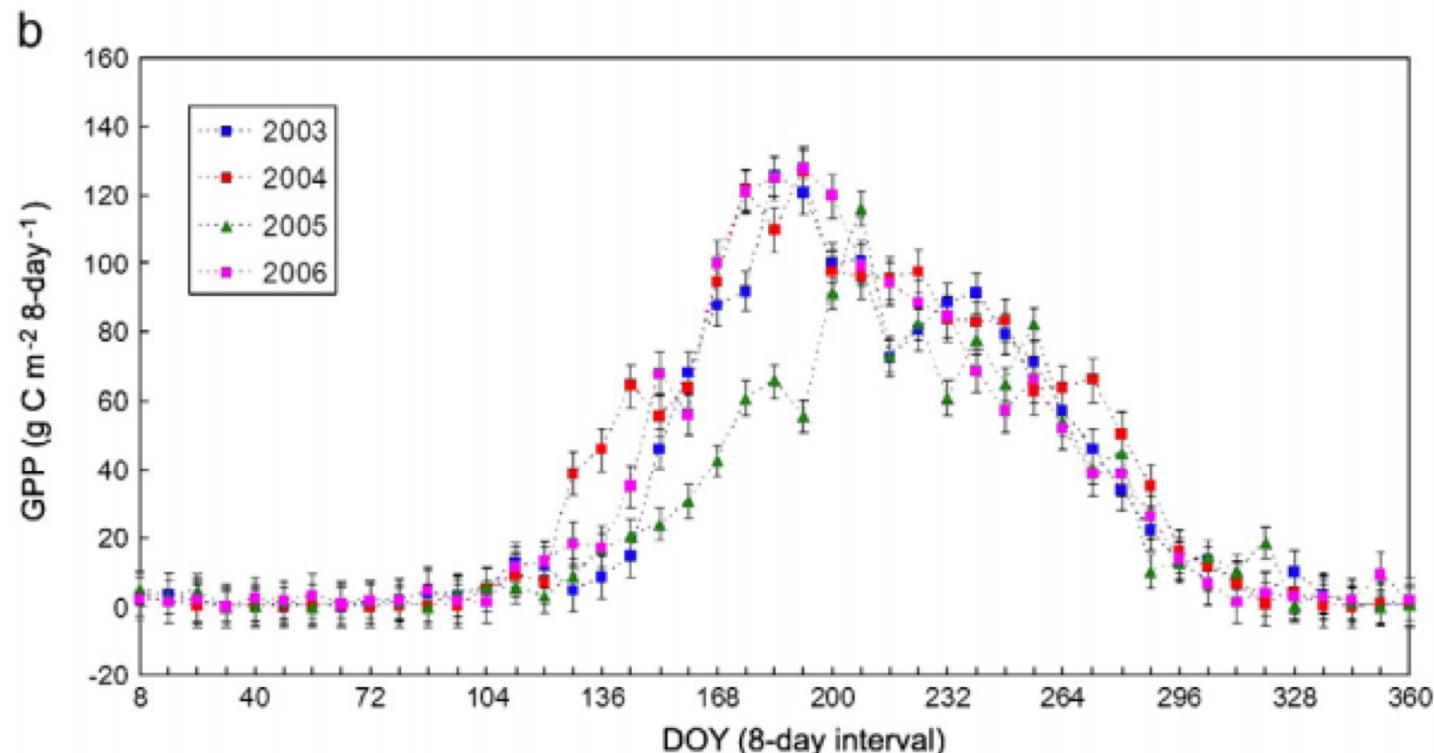
- Middle ground: field manipulations
 - **Pro:** can manipulate in-tact environment
 - **Con:** still not truly “natural”; expensive; complex



Ecophysiological scale consideration 2: organ versus ecosystem

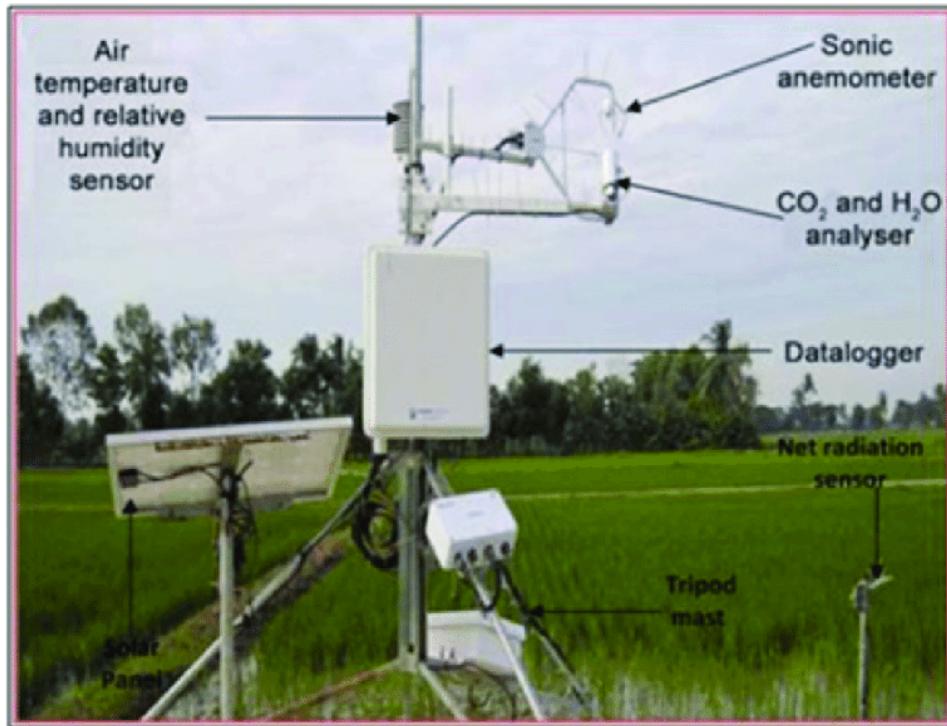
Ecophysiological scale consideration 2: organ versus ecosystem

- Ecosystem-scale measurements
 - **Pro:** measure the impact on more important scale



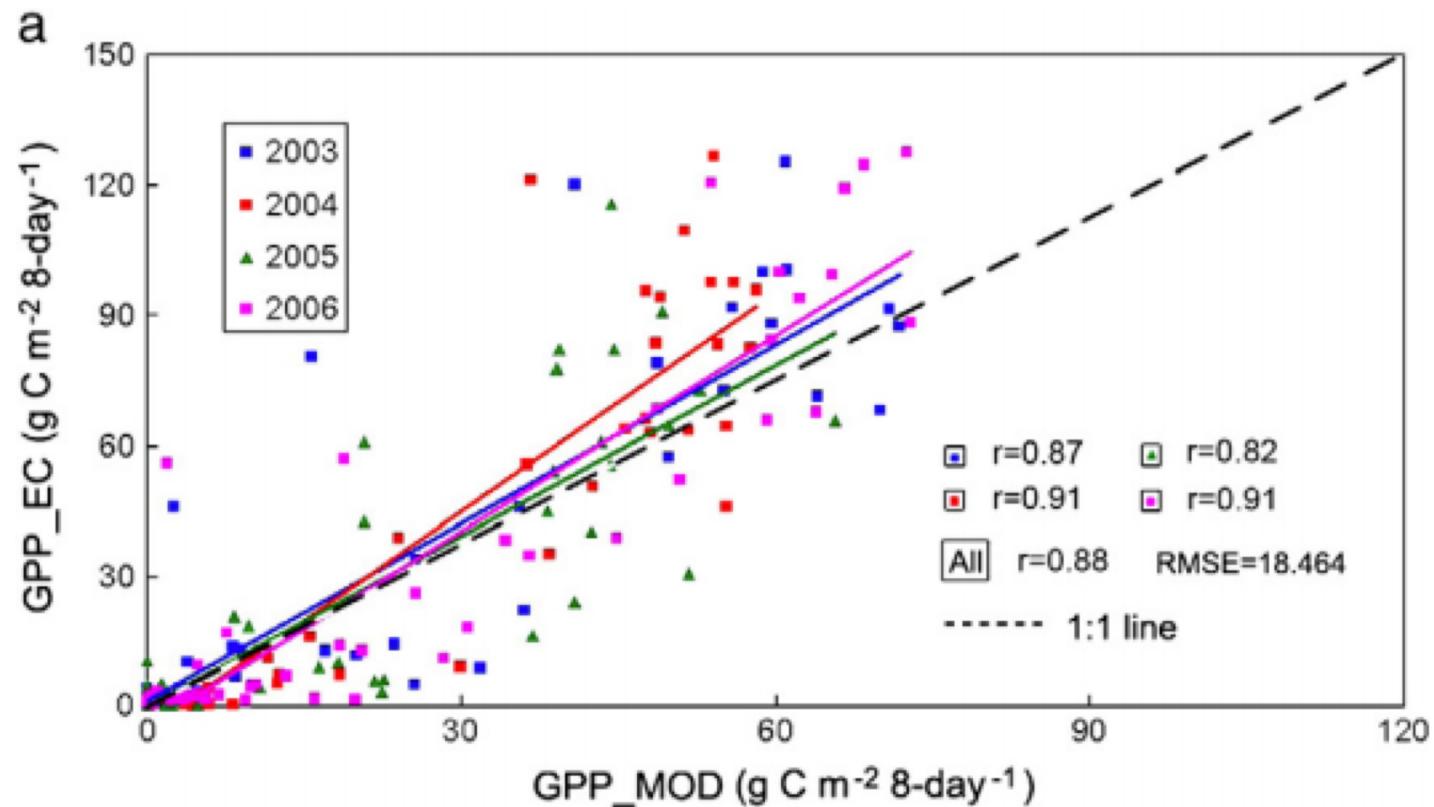
Ecophysiological scale consideration 2: organ versus ecosystem

- Ecosystem-scale measurements
 - **Pro:** measure the impact on more important scale; lots of options



Ecophysiological scale consideration 2: organ versus ecosystem

- Ecosystem-scale measurements
 - **Con:** not a direct measurement; some disagreement



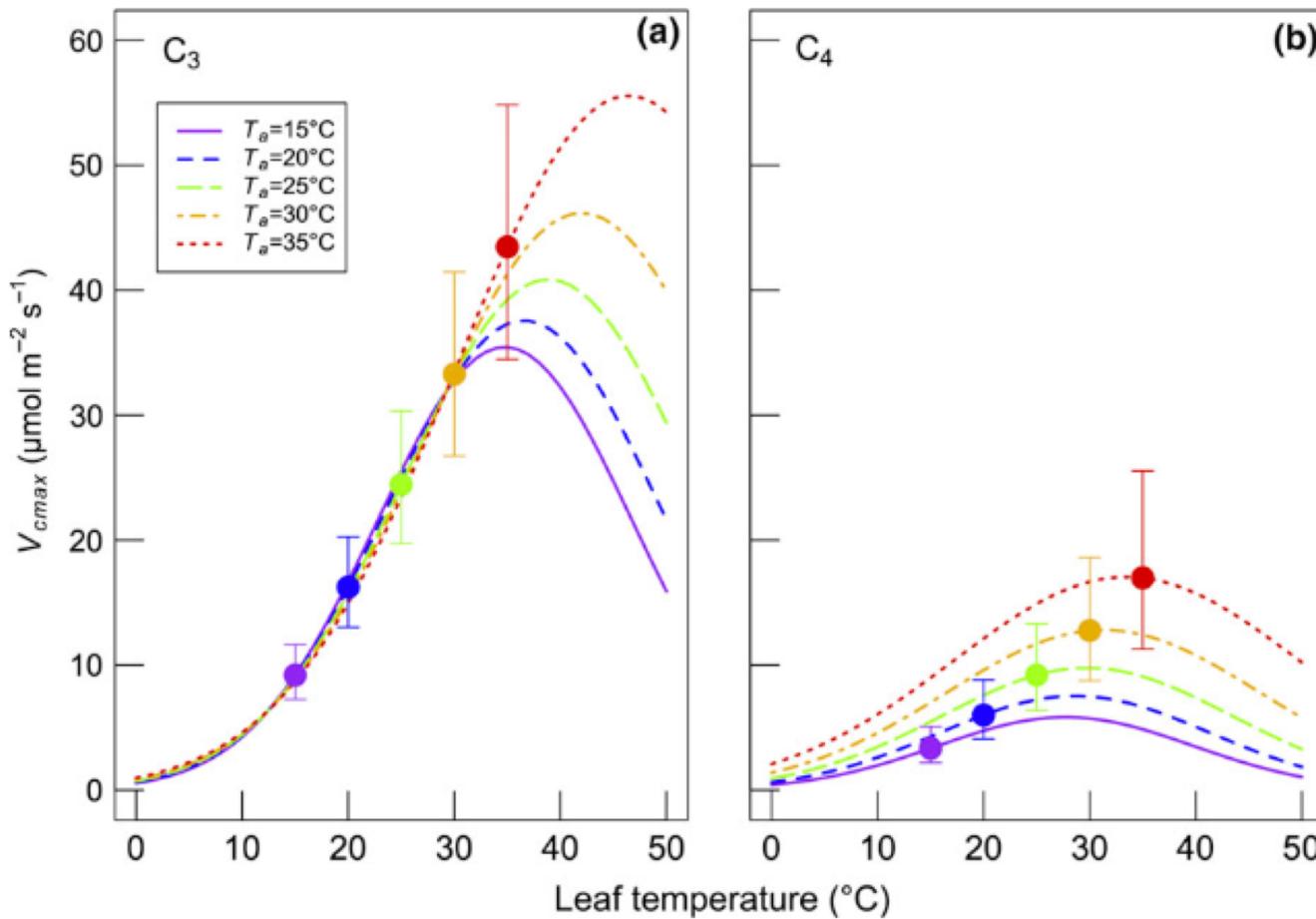
Working across scales: modeling

Models provide a way to assess the scalability of mechanisms (example with photosynthetic acclimation)

Models provide a way to assess the scalability of mechanisms

Steps involved

1. Evaluate process mechanisms under highly controlled conditions (small scale)



Models provide a way to assess the scalability of mechanisms

Steps involved

1. Evaluate process mechanisms under highly controlled conditions (small scale)
2. Develop a theory for process and it's environmental response

A Biochemical Model of Photosynthetic CO₂ Assimilation in Leaves of C₃ Species

G.D. Farquhar¹, S. von Caemmerer¹, and J.A. Berry²

¹ Department of Environmental Biology, Research School of Biological Sciences, Australian National University, P.O. Box 475, Canberra City ACT 2601, Australia and

² Carnegie Institution of Washington, Department of Plant Biology, Stanford, Cal. 94305, USA

VOL. 161, NO. 1 THE AMERICAN NATURALIST JANUARY 2003

Least-Cost Input Mixtures of Water and Nitrogen for Photosynthesis

Ian J. Wright,^{1,*} Peter B. Reich,^{2,†} and Mark Westoby^{1,‡}

Models provide a way to assess the scalability of mechanisms

Steps involved

1. Evaluate process mechanisms under highly controlled conditions (small scale)
2. Develop a theory for process and it's environmental response
3. Quantify the theory and build a model

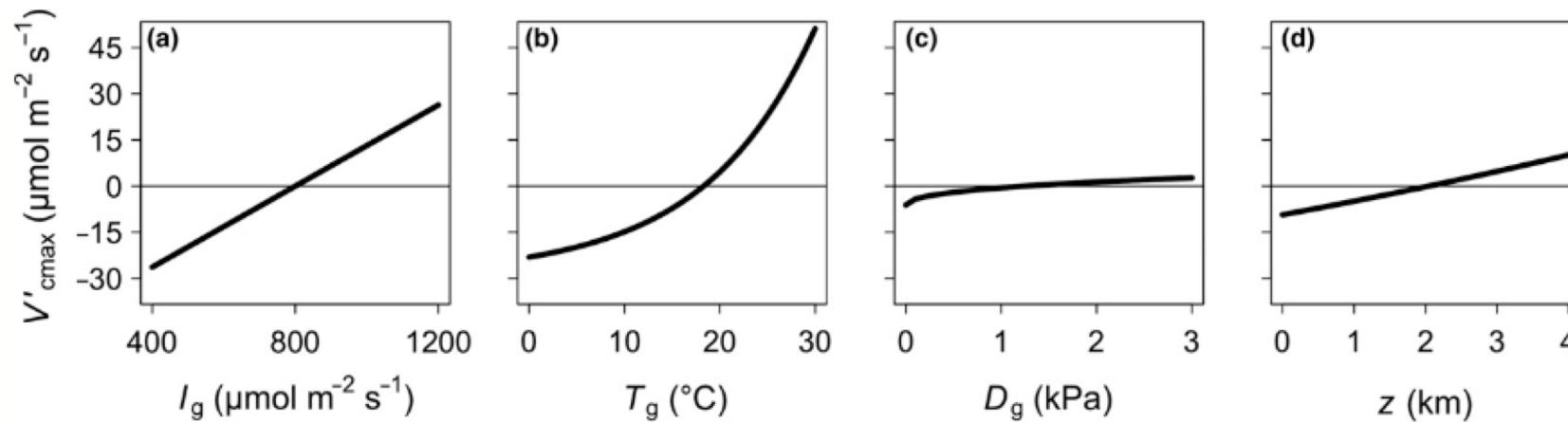
LETTER

Global photosynthetic capacity is optimized to the environment

Abstract

Nicholas G. Smith,^{1,2*} 

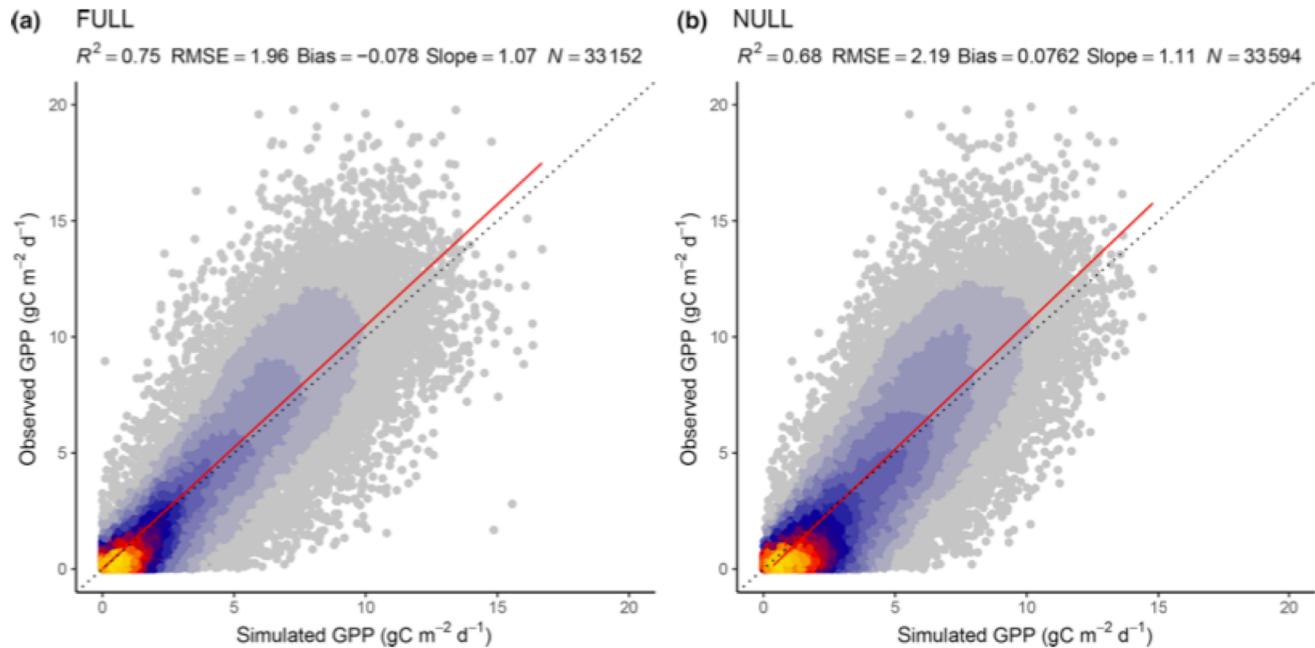
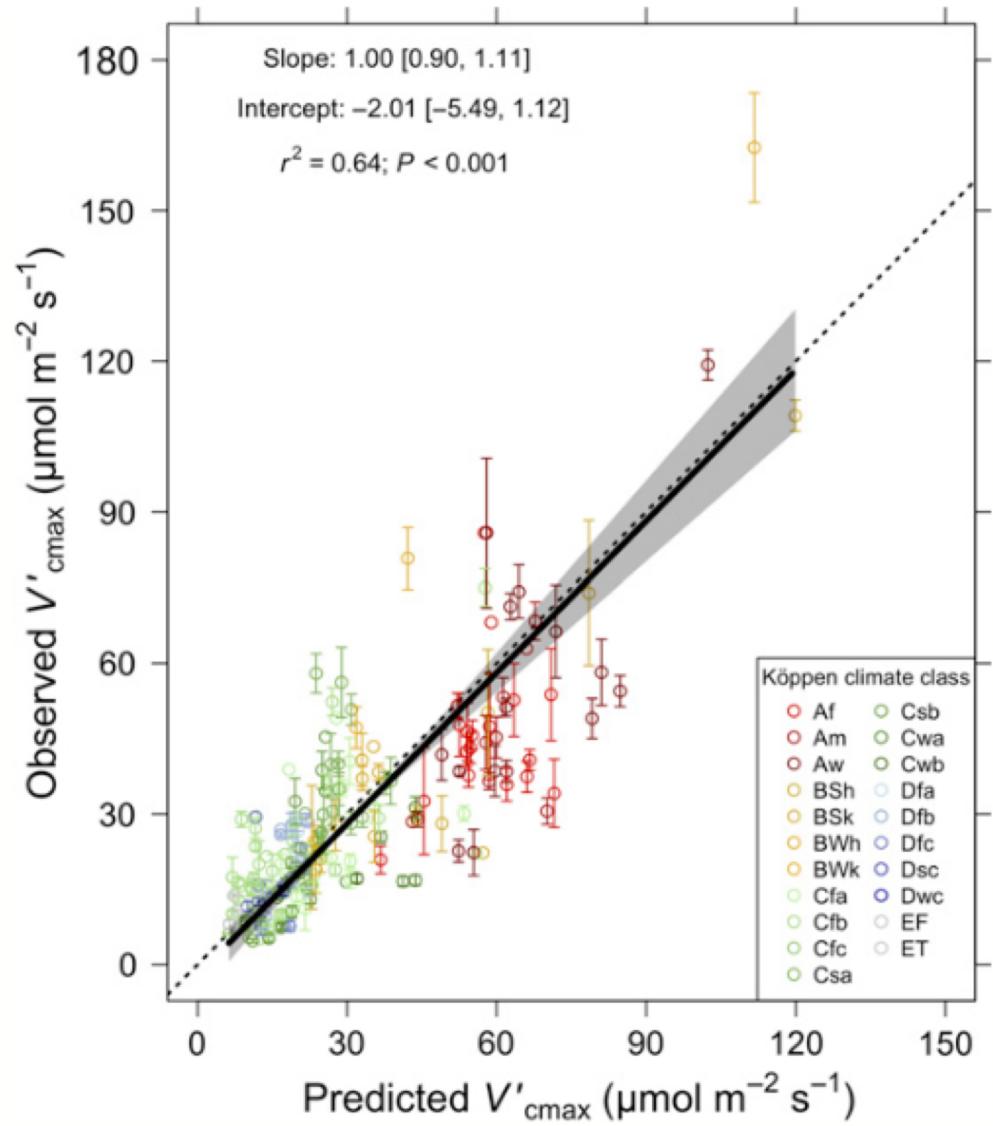
Earth system models (ESMs) use photosynthetic capacity, indexed by the maximum Rubisco car-



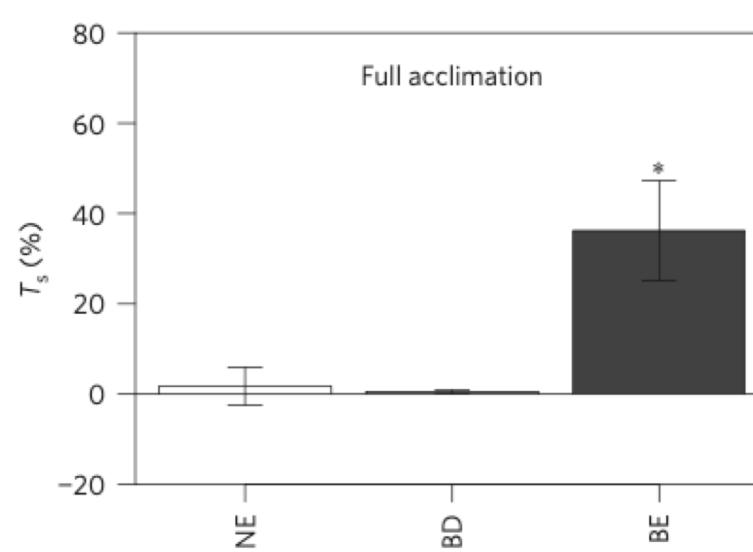
Models provide a way to assess the scalability of mechanisms

Steps involved

1. Evaluate process mechanisms under highly controlled conditions (small scale)
2. Develop a theory for process and it's environmental response
3. Quantify the theory and build a model
4. Simulate similar or connected processes that can be measured at larger scales



Stocker et al. (2020)

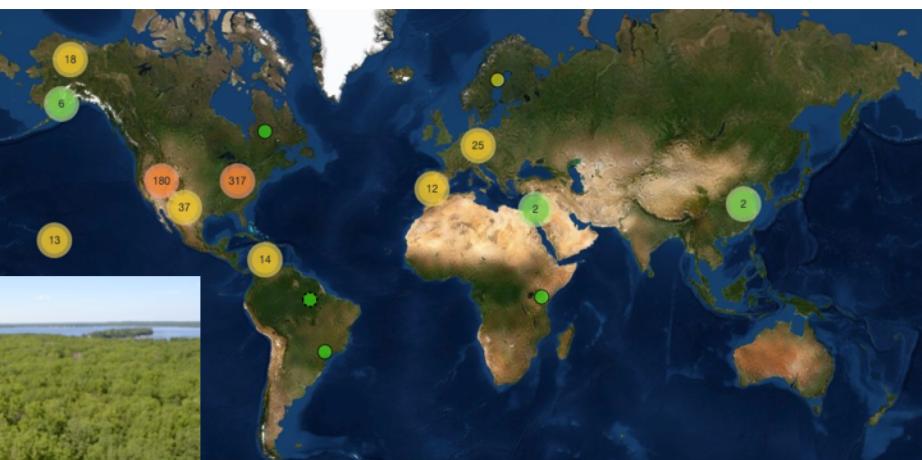
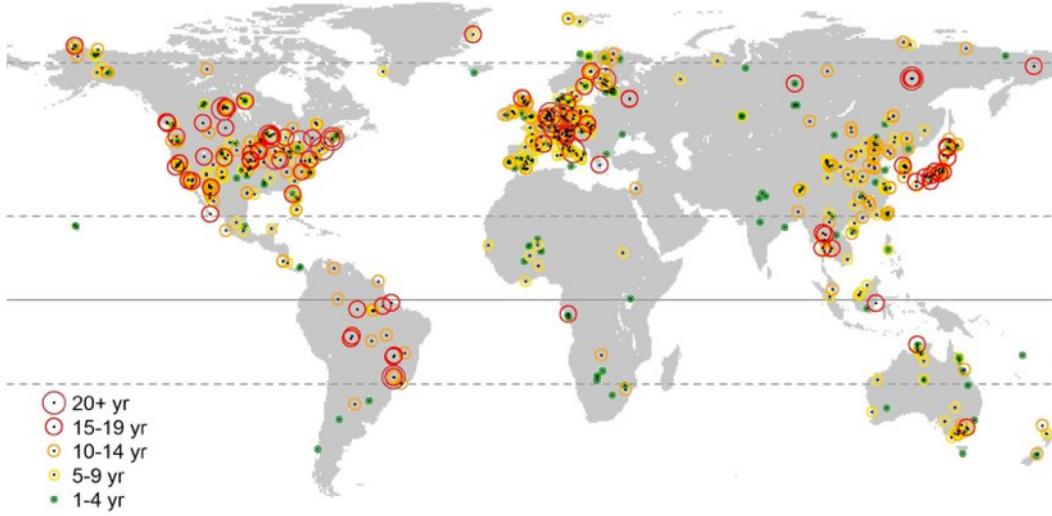


Improved scaling: coordinated
research networks

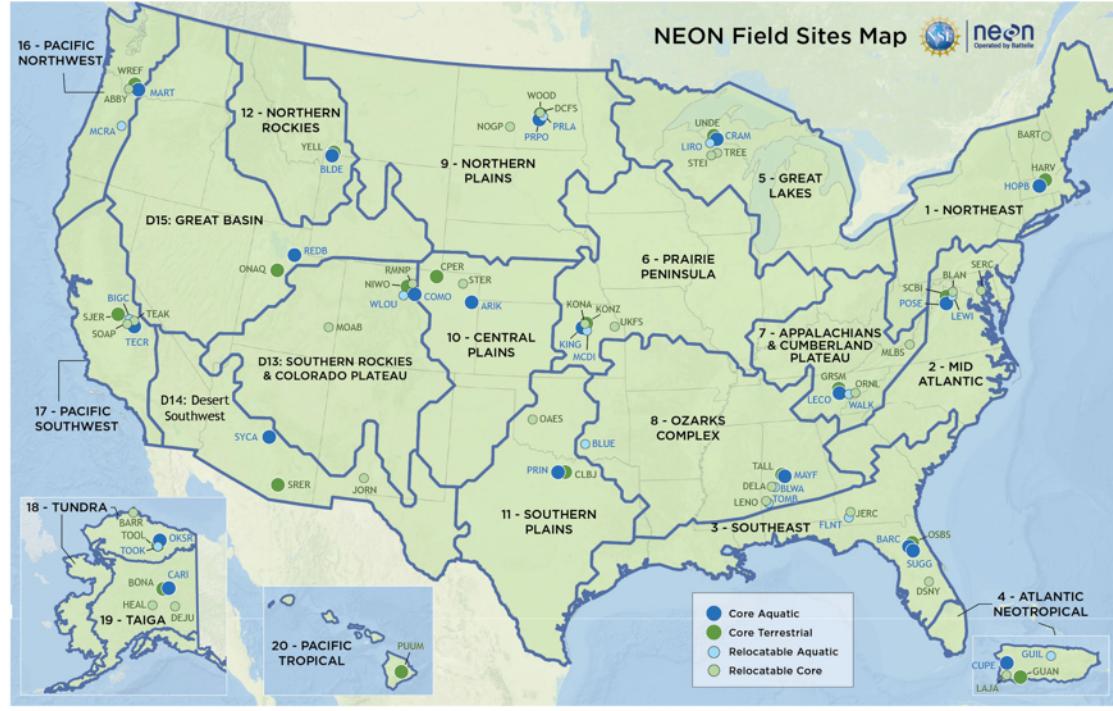
	Consistent methodology	Causal inference	Realistic complexity	Environmental gradients	Site-specific design
Single-site experiments	✓	✓	?	?	✓
Observational networks	✓		✓	✓	
Process-based models	✓	✓		✓	✓
Empirical/statistical models	✓		?	✓	✓
Meta-analyses		?	✓	✓	
Distributed experiments	✓	✓	✓	✓	



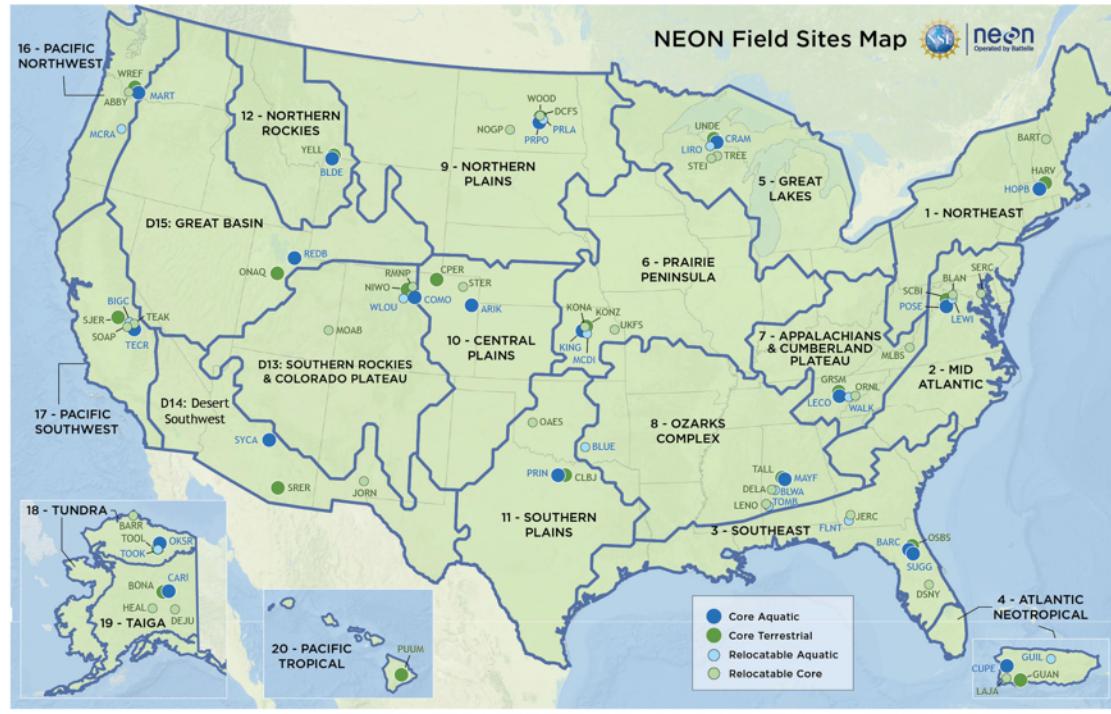
PhenoCam Network



The National Ecological Observatory Network (NEON)



The National Ecological Observatory Network (NEON)



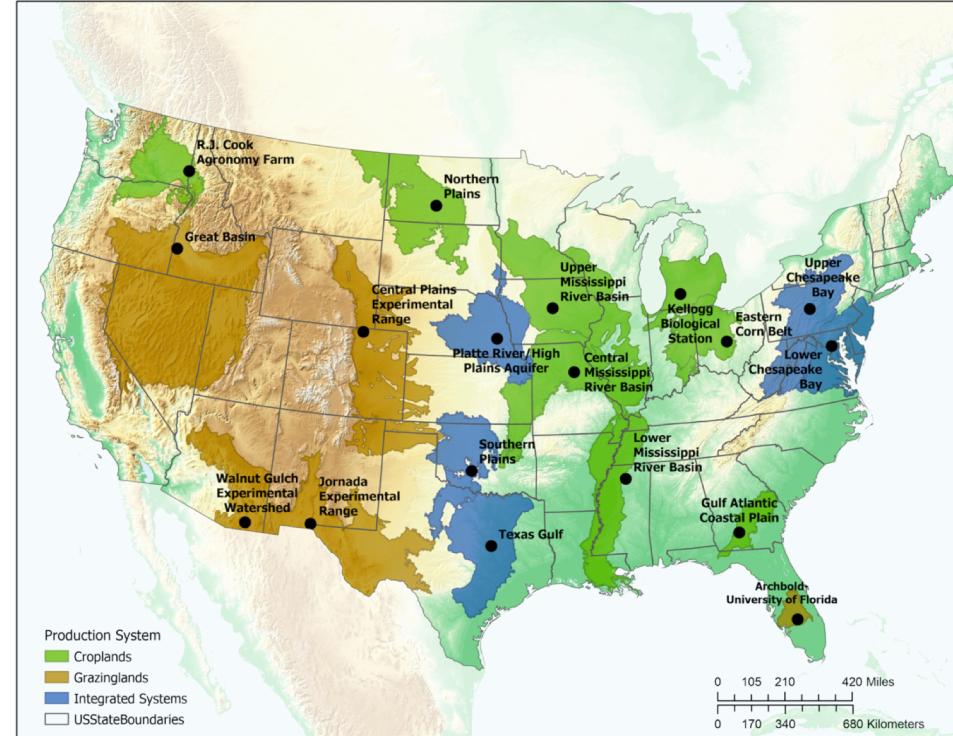
Viewpoint

Reimagining NEON Operations: We Can Do Better

ALAN K. KNAPP AND SCOTT L. COLLINS

BioScience (October 2019)

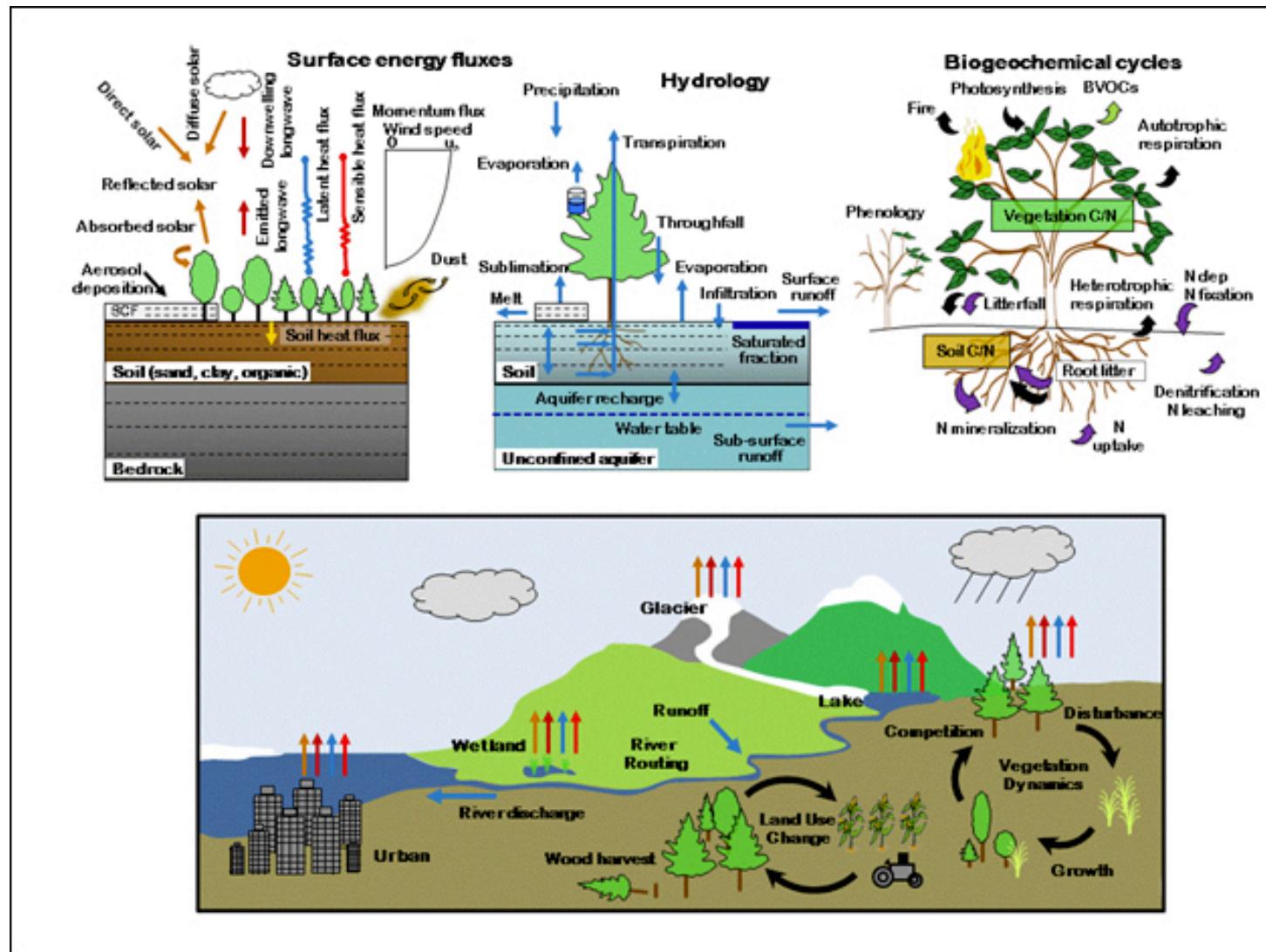
Long-term ecological and agricultural research sites (LTER and LTAR)



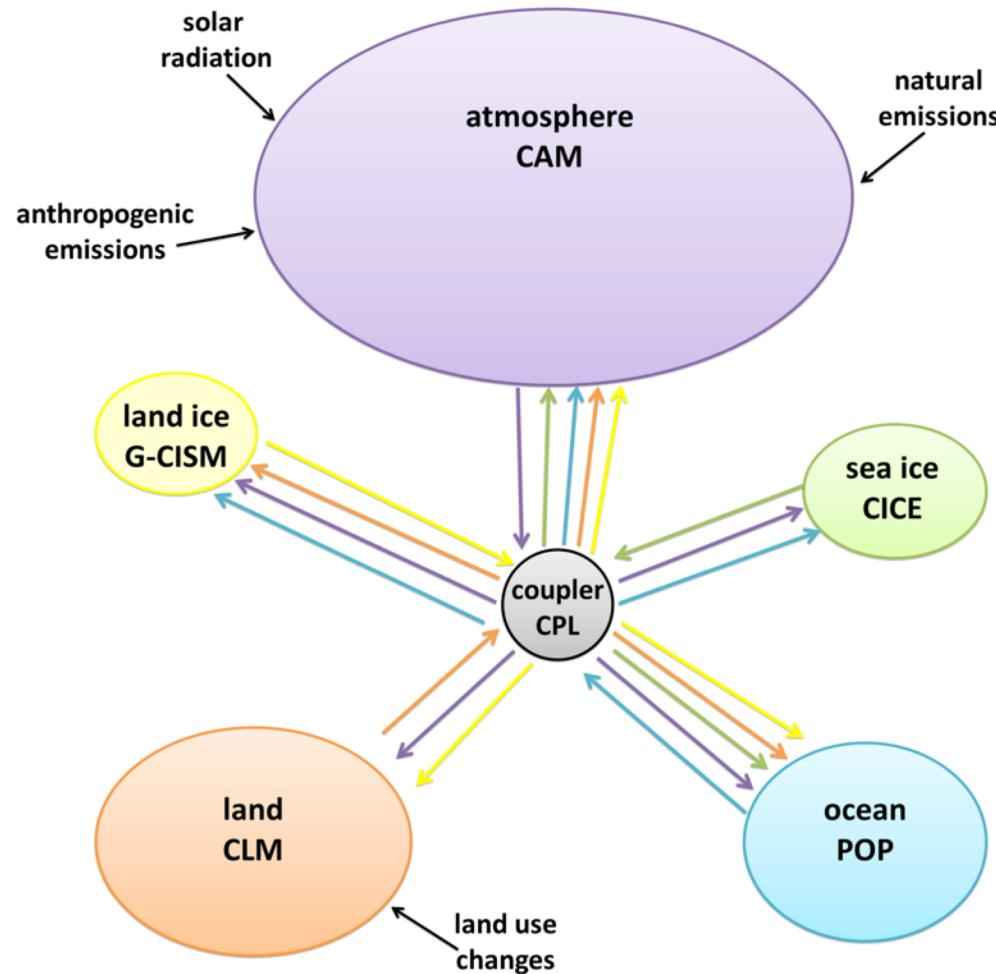
**Measurements not
coordinated**

Future predictions: large-scale
models

Land surface models



Earth System Models



Future predictions: realism versus reliability



Reliable, robust and realistic: the three R's of next-generation land-surface modelling

I. C. Prentice^{1,2}, X. Liang³, B. E. Medlyn^{2,4}, and Y.-P. Wang⁵

Adding processes to models may improve their realism...



Reliable, robust and realistic: the three R's of next-generation land-surface modelling

I. C. Prentice^{1,2}, X. Liang³, B. E. Medlyn^{2,4}, and Y.-P. Wang⁵

...but may also make them more unreliable and uncertain

Literature review consideration:
What scale(s) are you evaluating?