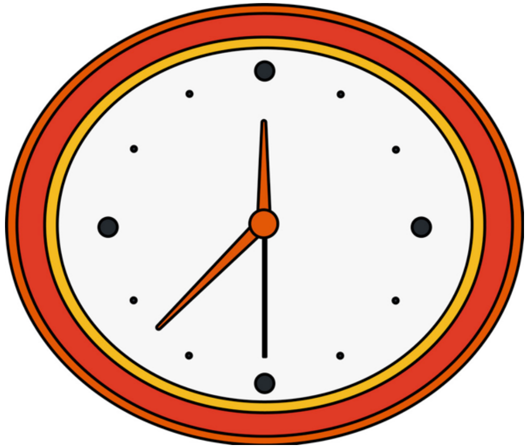
Scaling

Scales in plant ecophysiology

Primary two dimensions of scaling are temporal and spatial

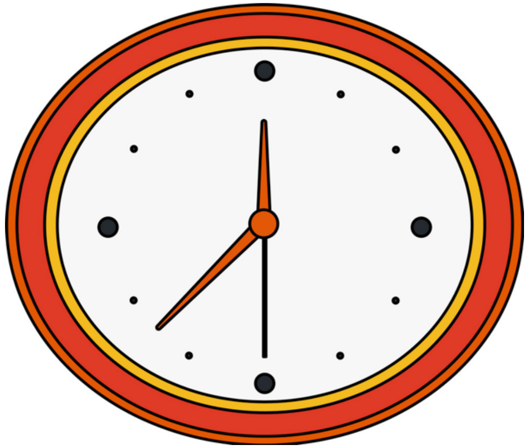
- Temporal
  - The timeframe over which a driver or process of interest operates

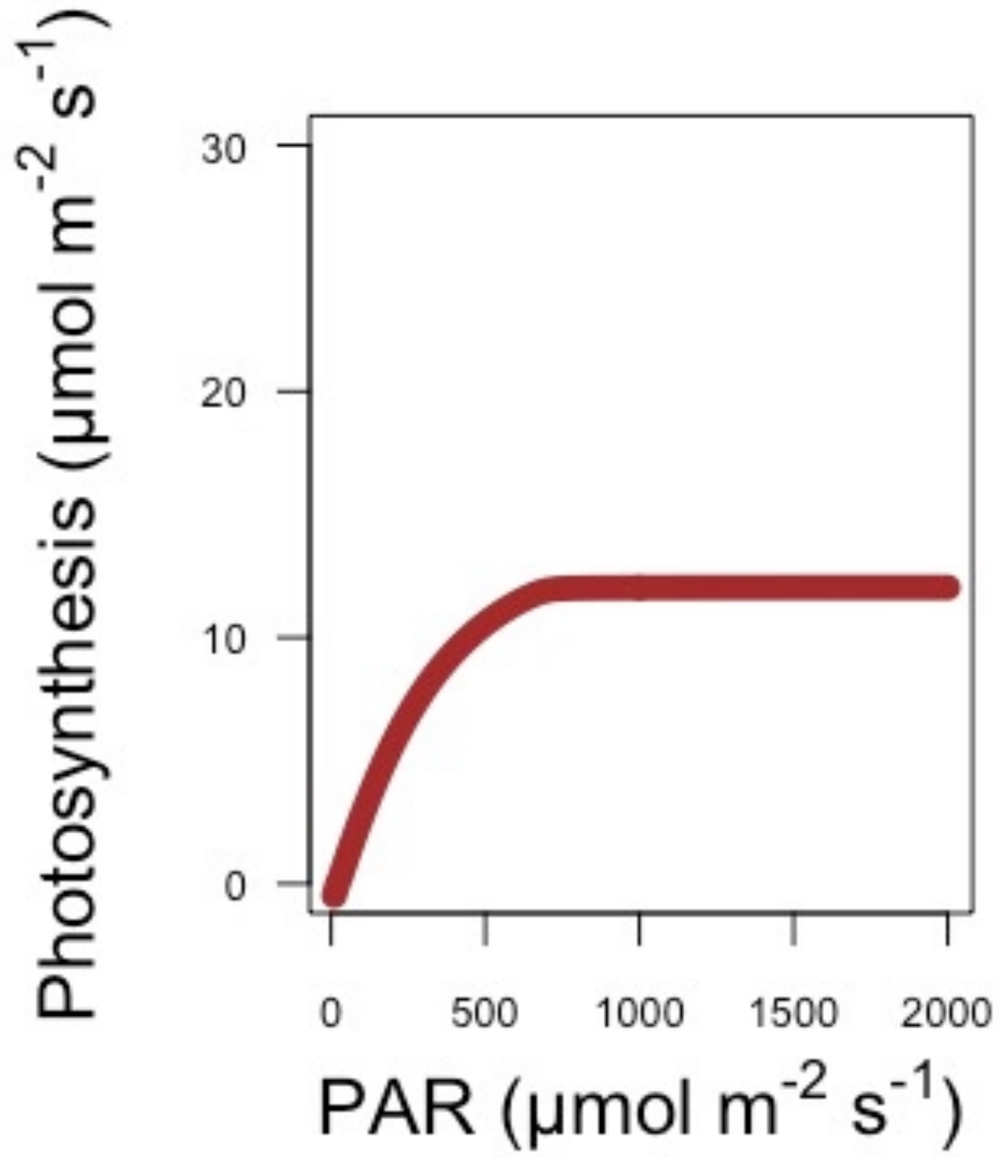


- Spatial
  - The area over which a driver or processes of interest operates

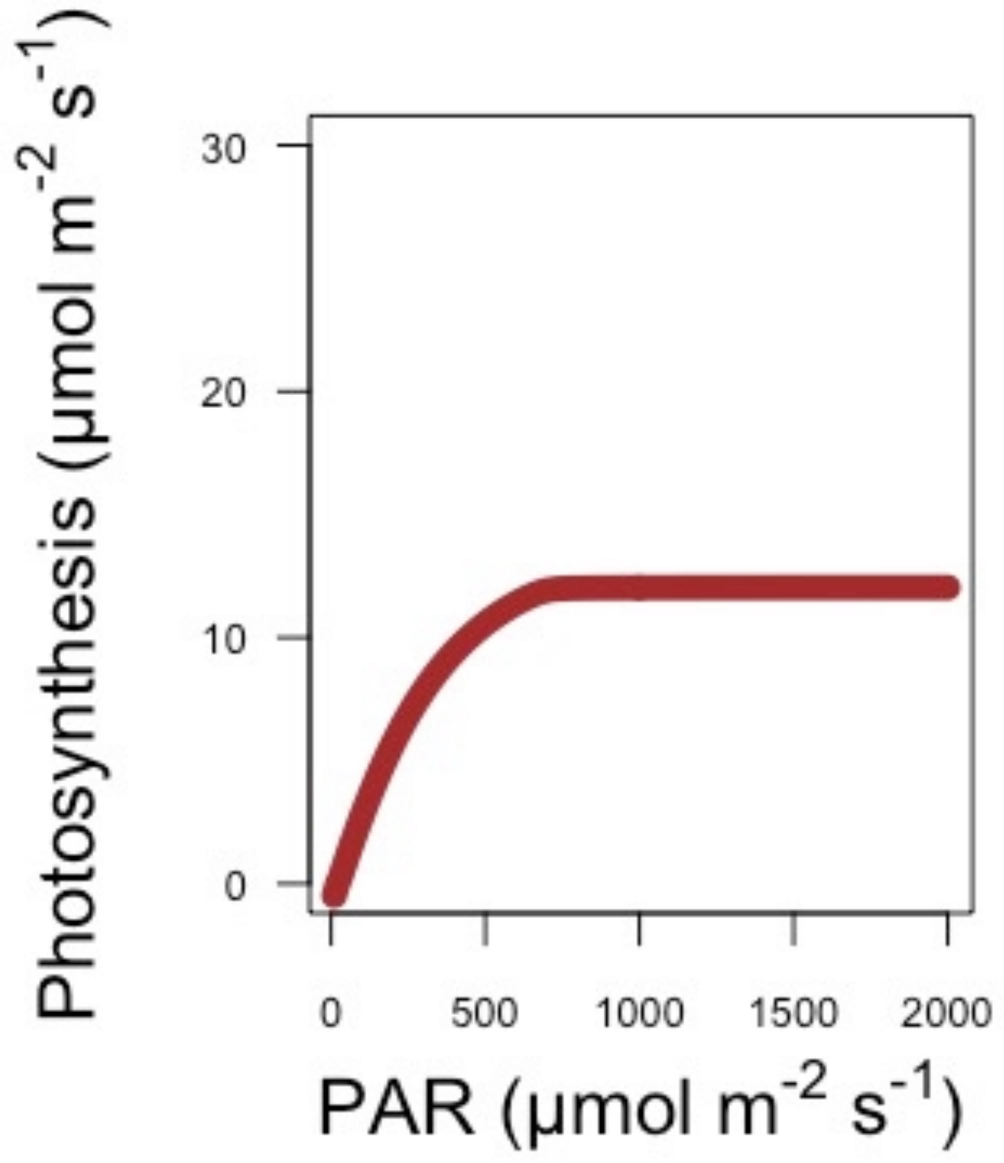
Primary two dimensions of scaling are temporal and spatial

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



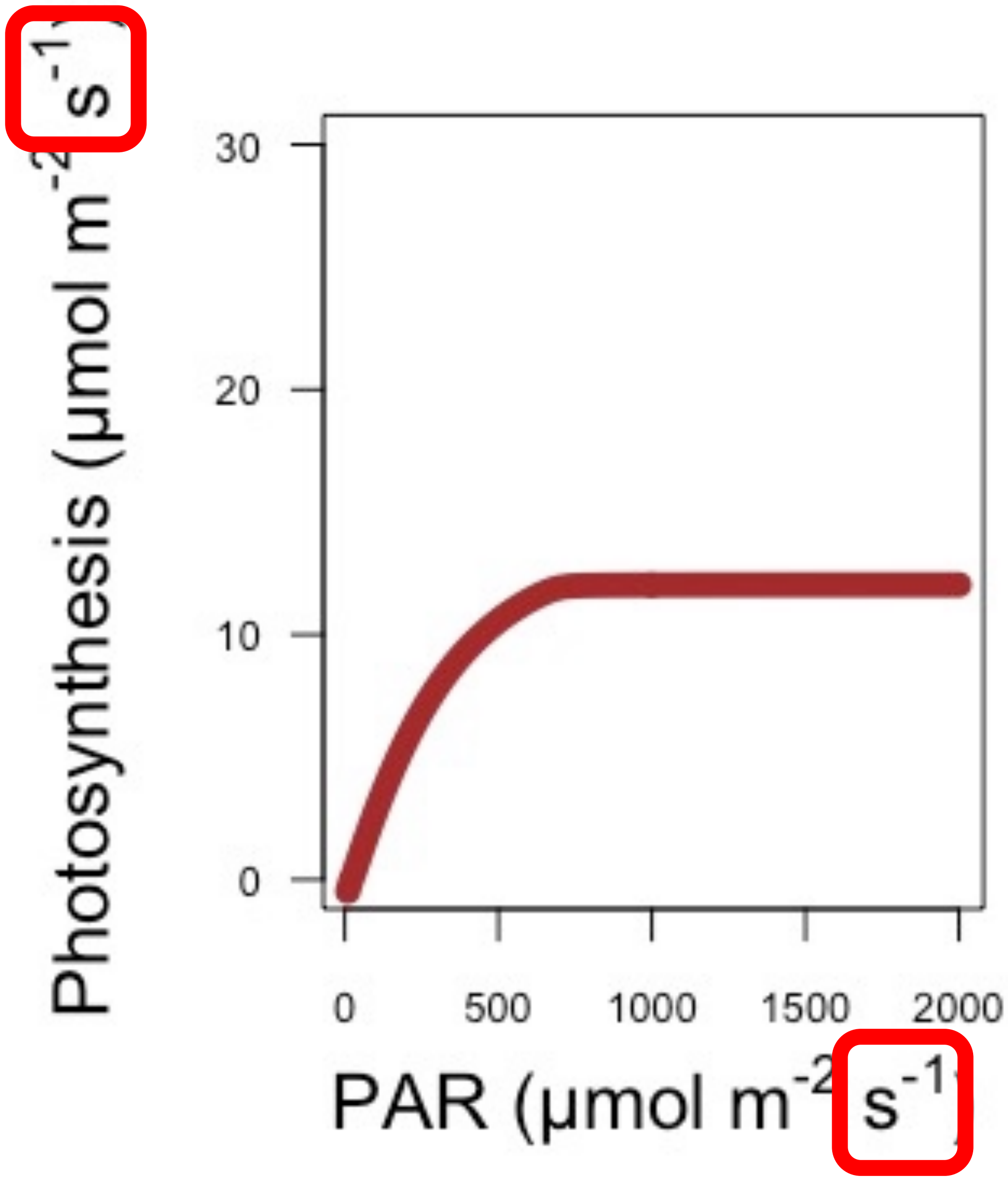


m = meters (single leaf), s = second

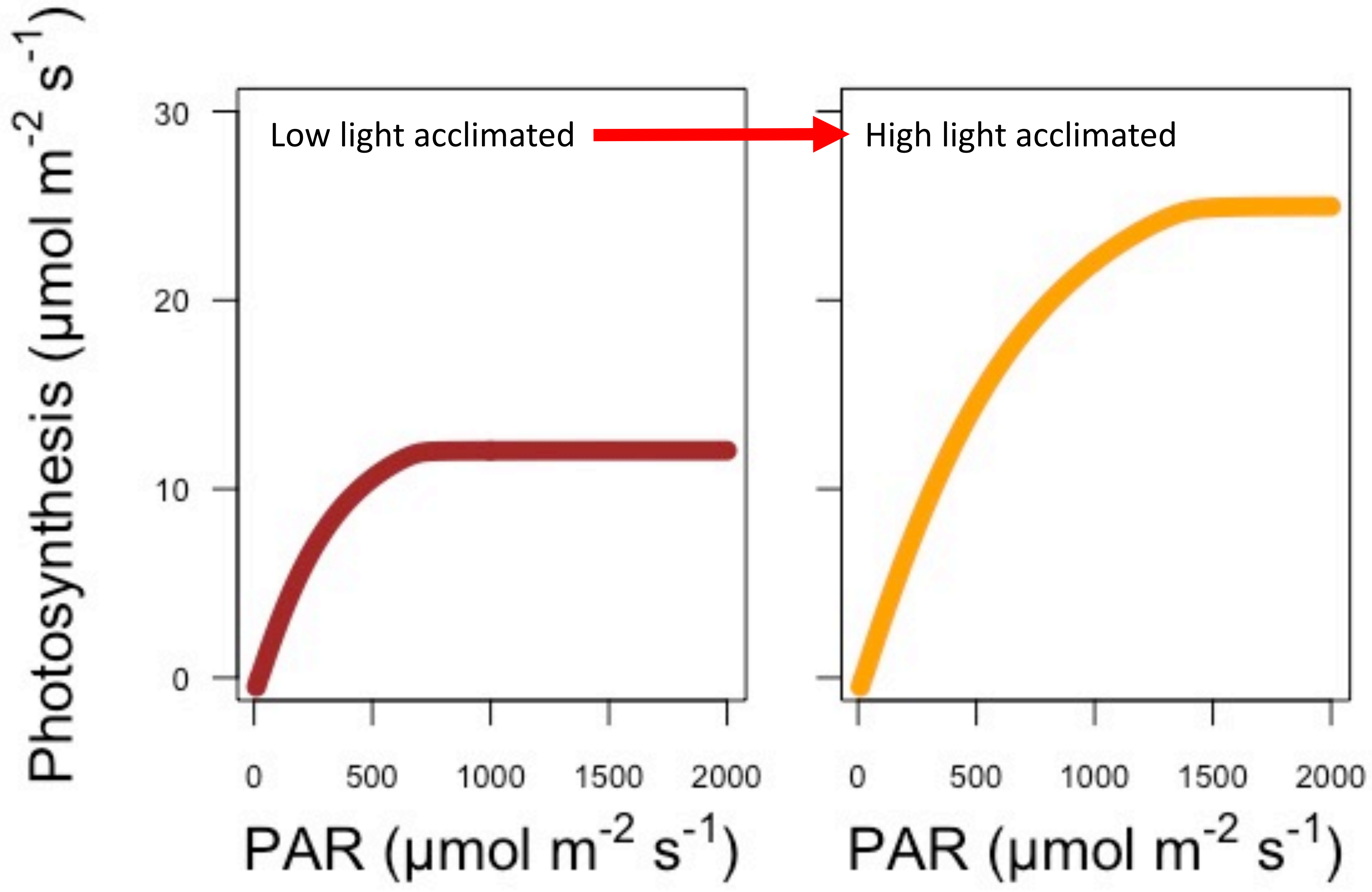


What is the timescale?

m = meters (single leaf), s = second



m = meters (single leaf), s = second



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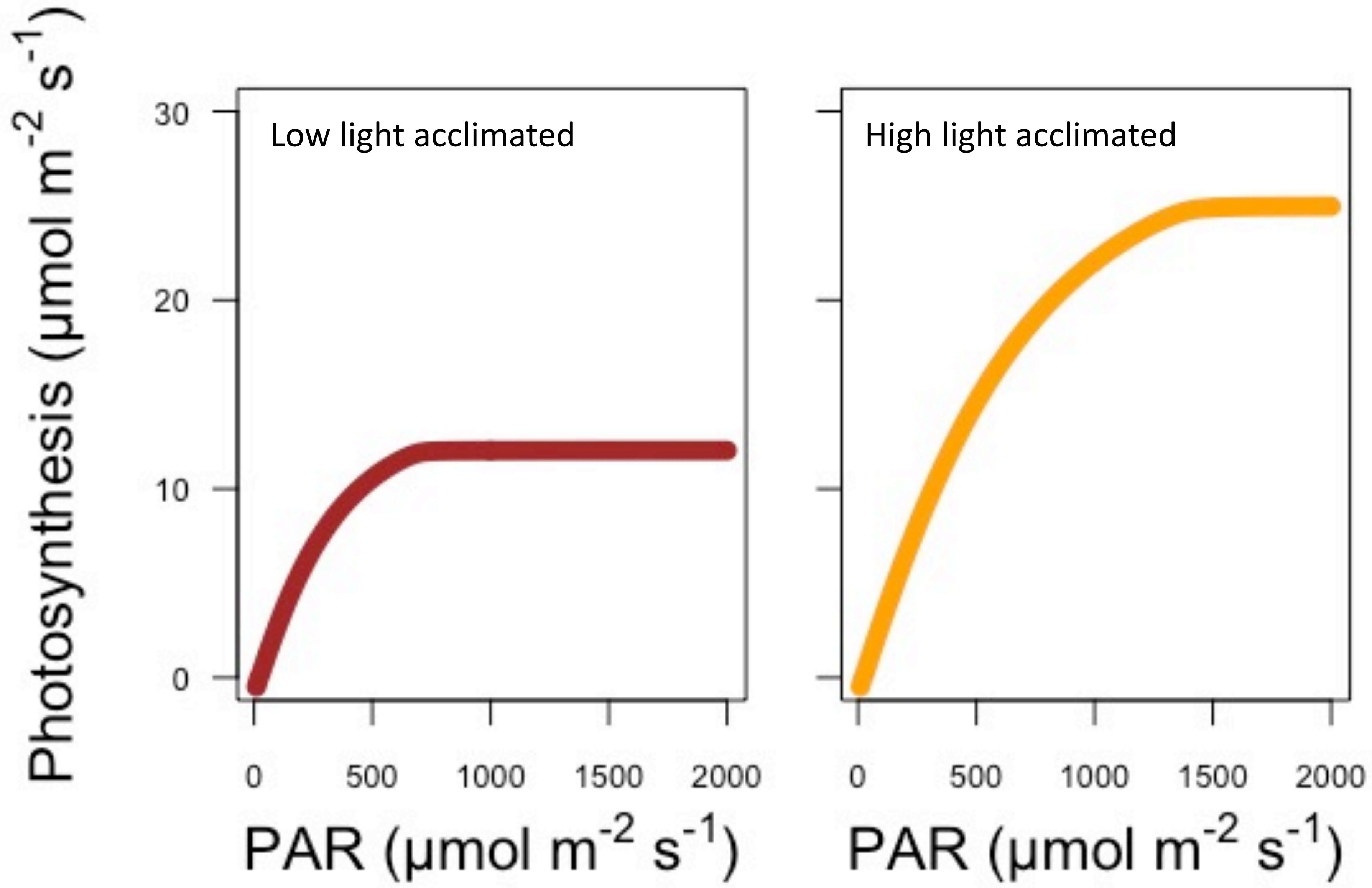
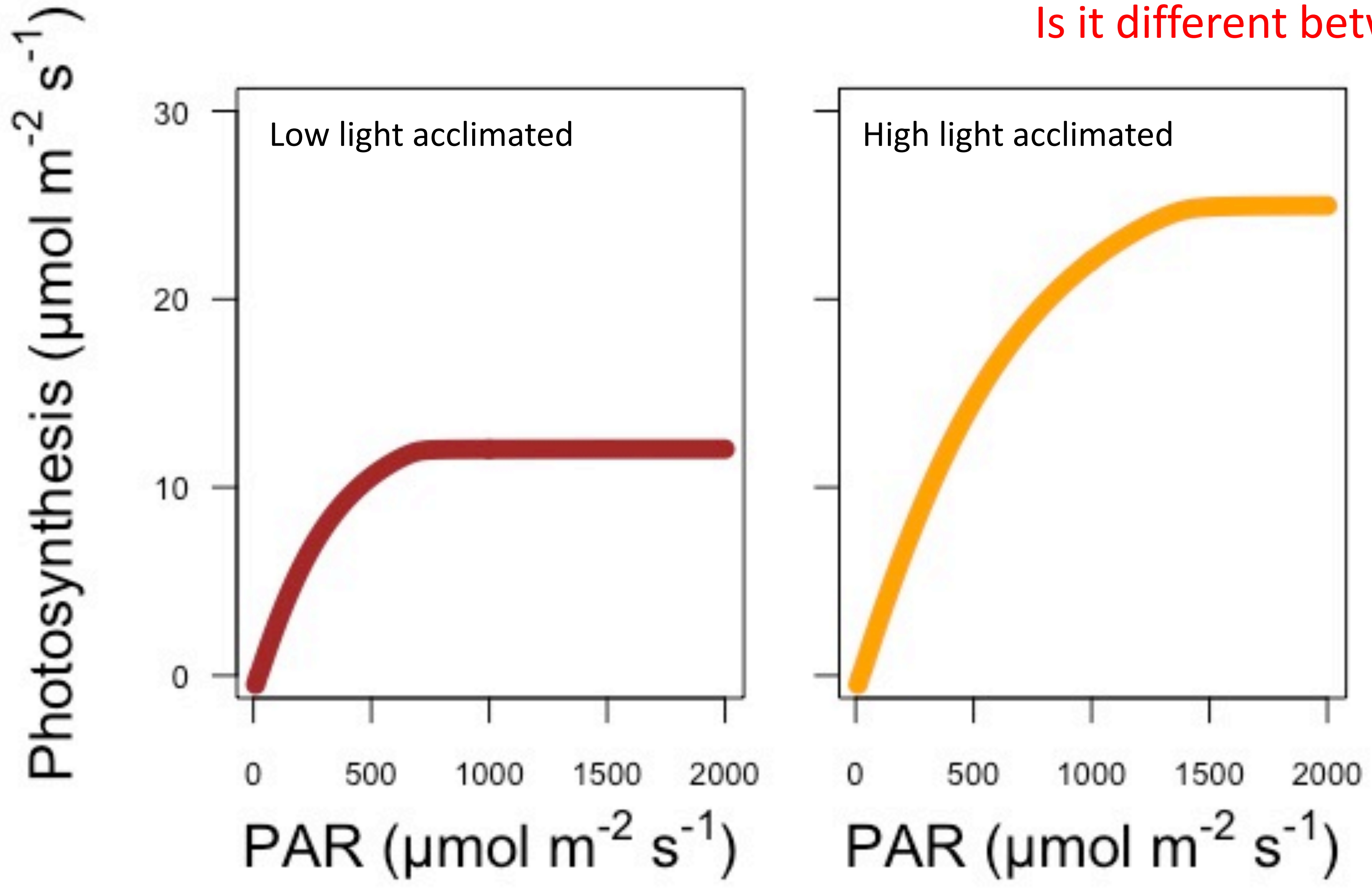
Primary two dimensions of scaling are temporal and spatial

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

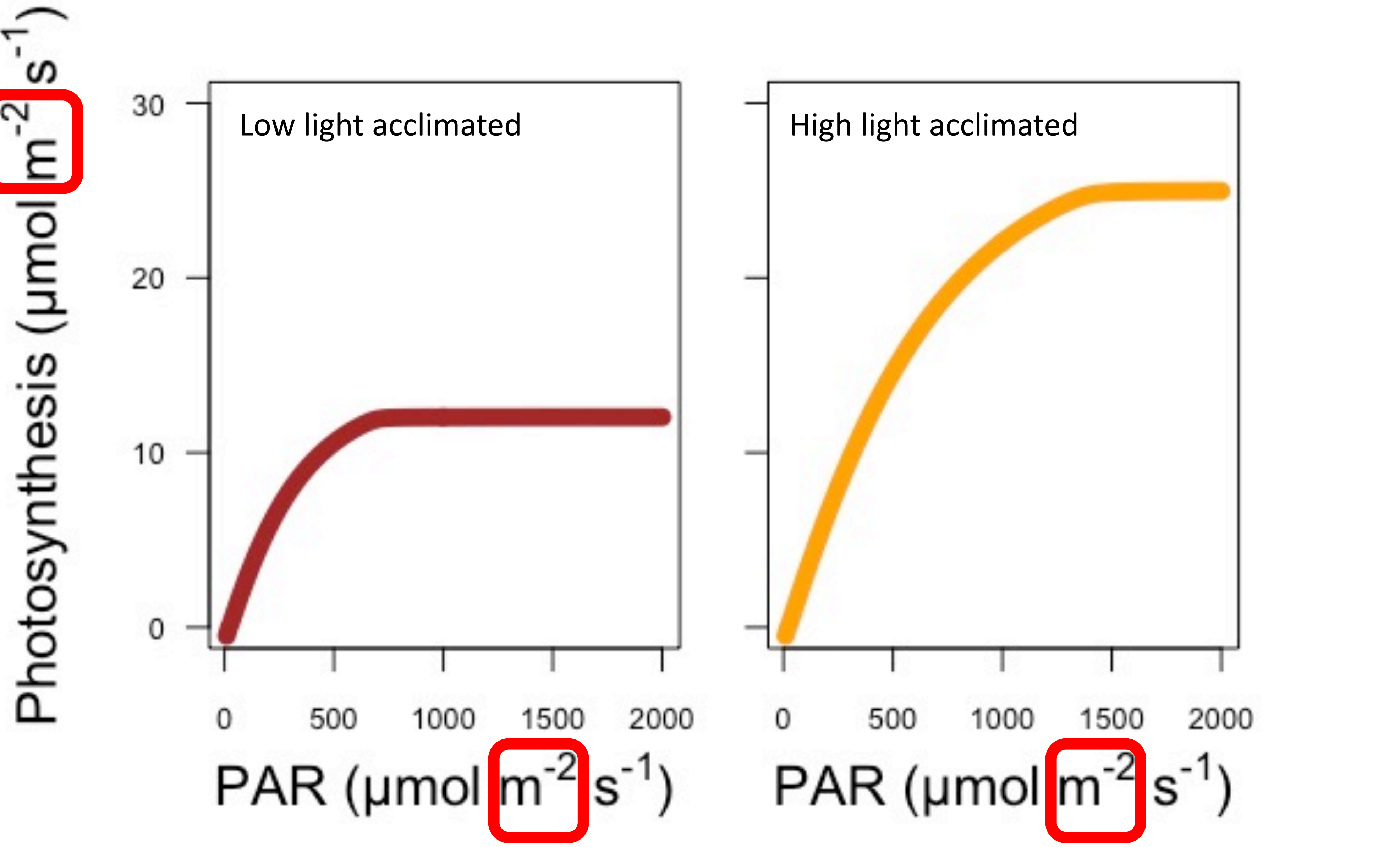


m = meters (single leaf), s = second

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

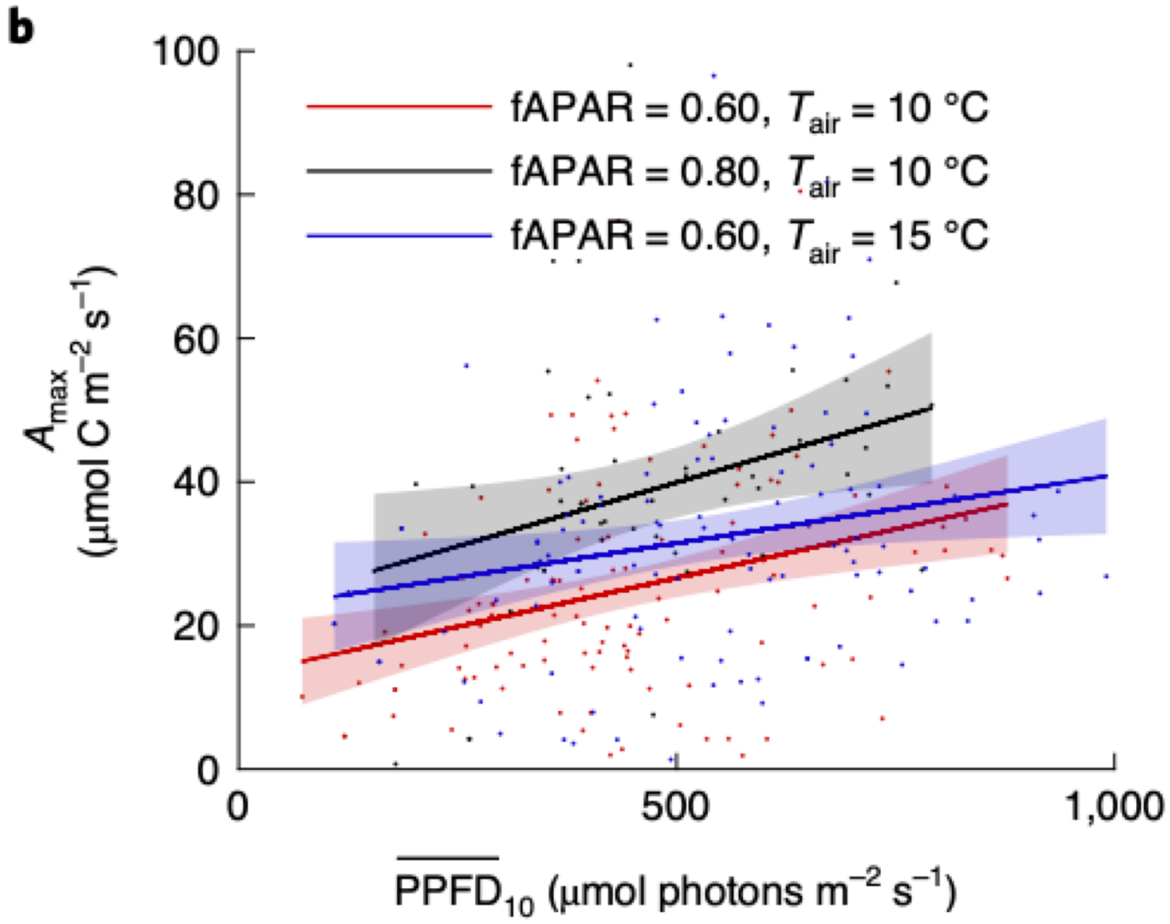


m = meters (single leaf), s = second



m = meters (single leaf), s = second

Example: testing similar processes at different scales



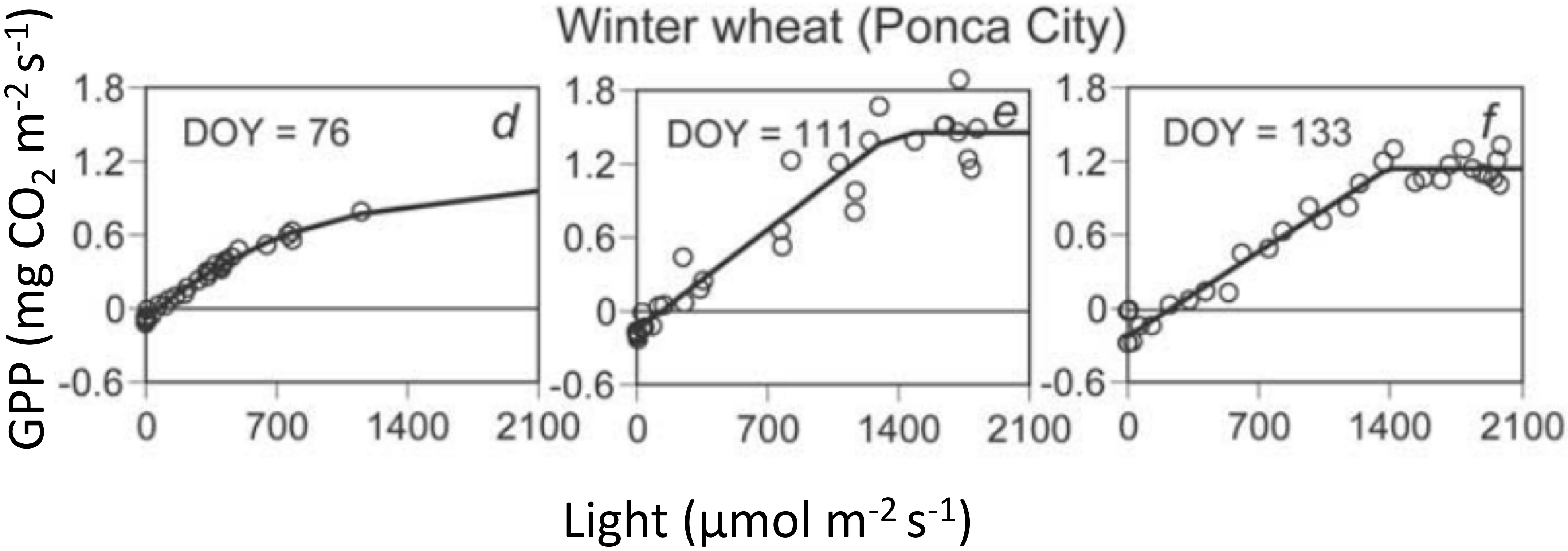
nature ecology & evolution
ARTICLES
https://doi.org/10.1038/s41559-020-1258-7
Check for updates

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, $PPFD_{10}$ = light over the past 10 days

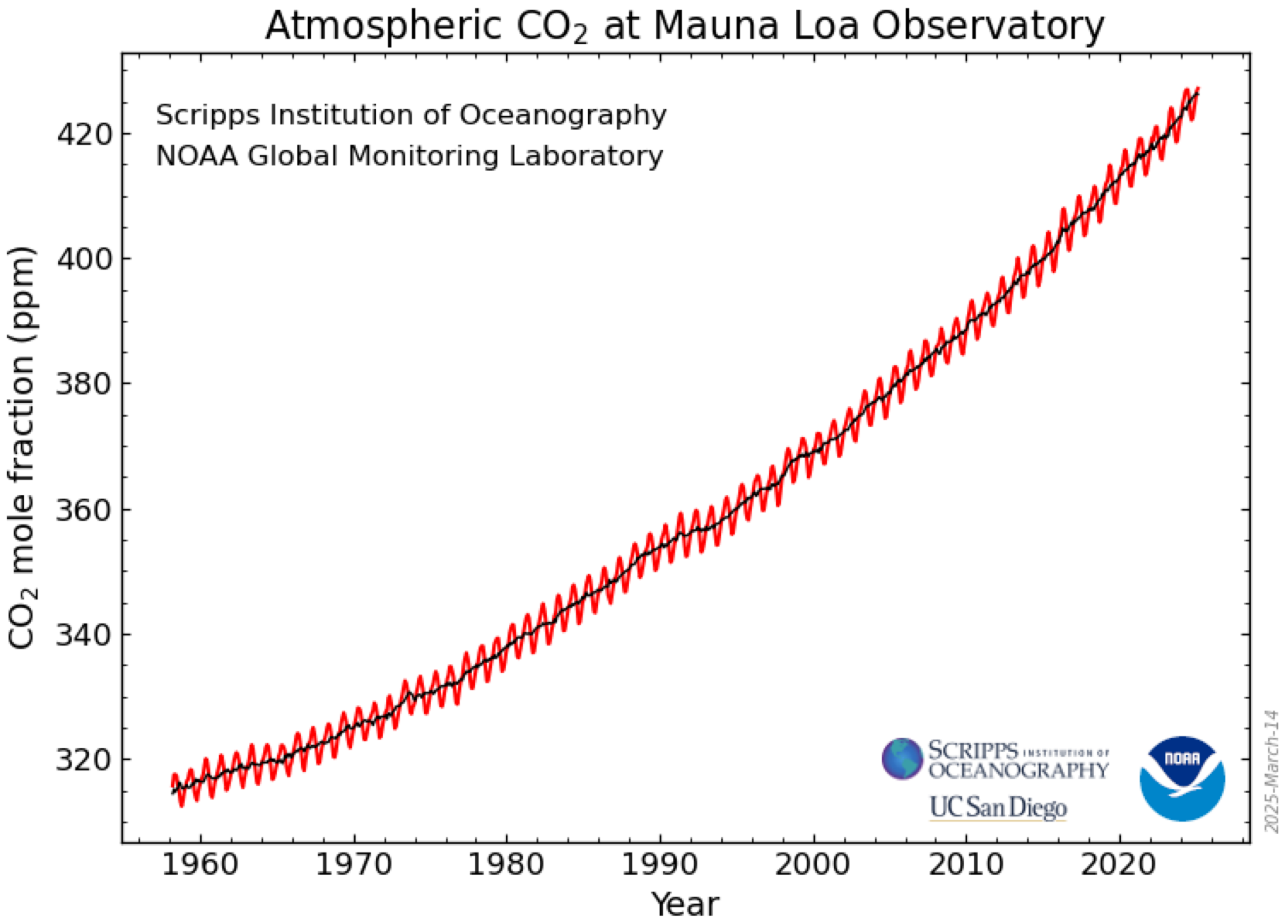
Example: testing similar processes at different scales



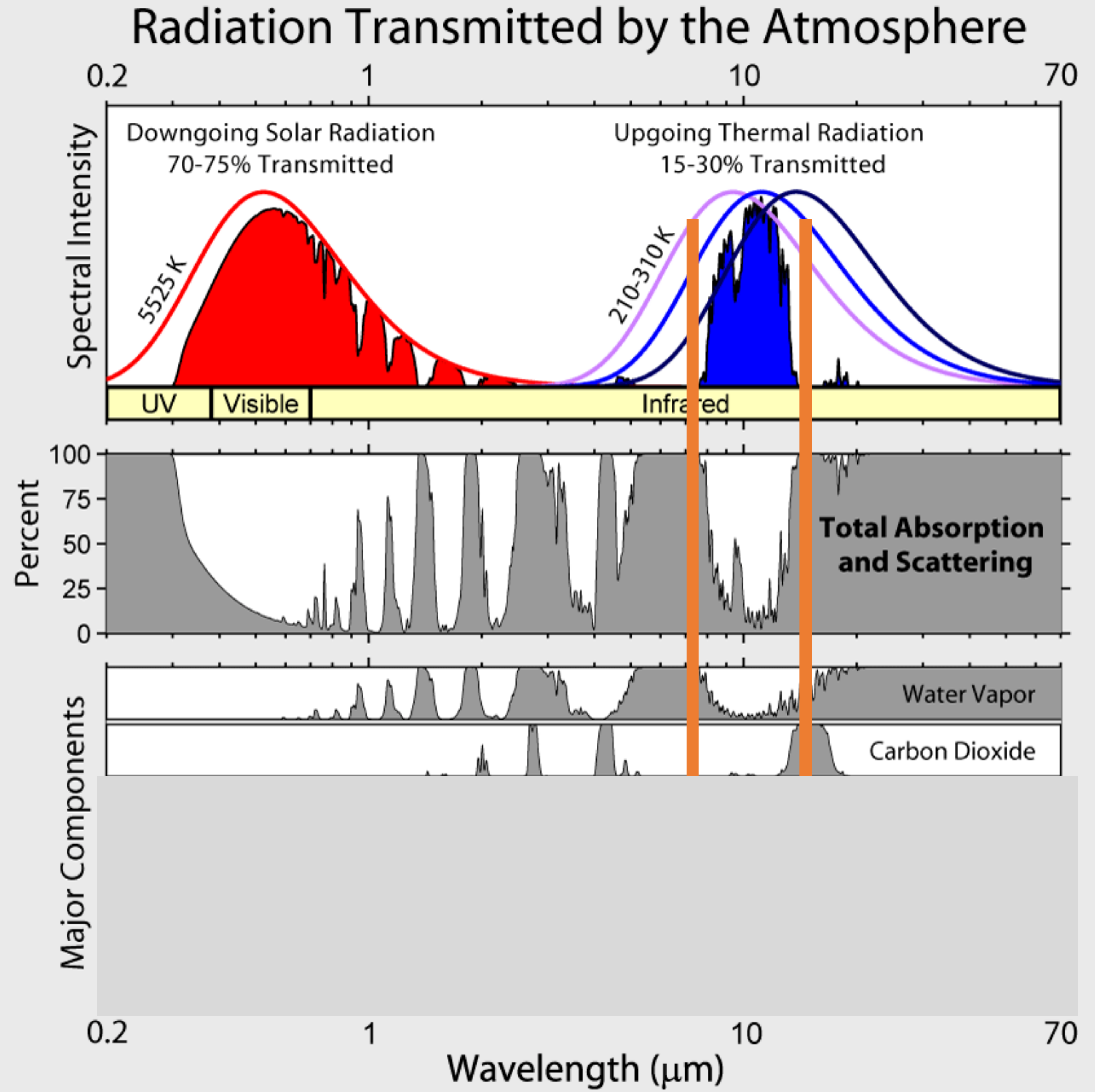
m = meters (ground), s = second

Gilmanov et al. (2003)

The importance of scaling: an example exercise

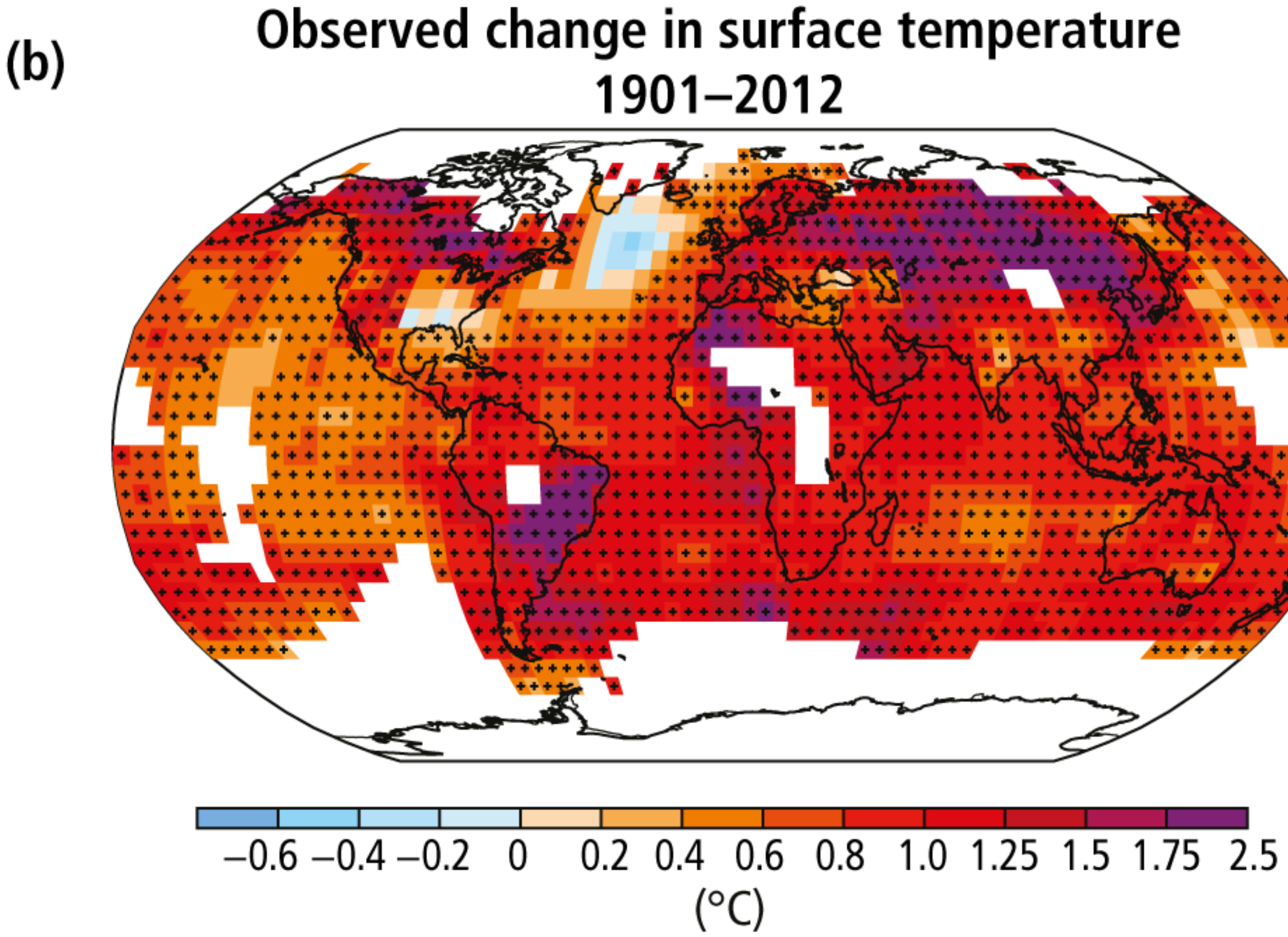


Going up 1.5 ppm / year



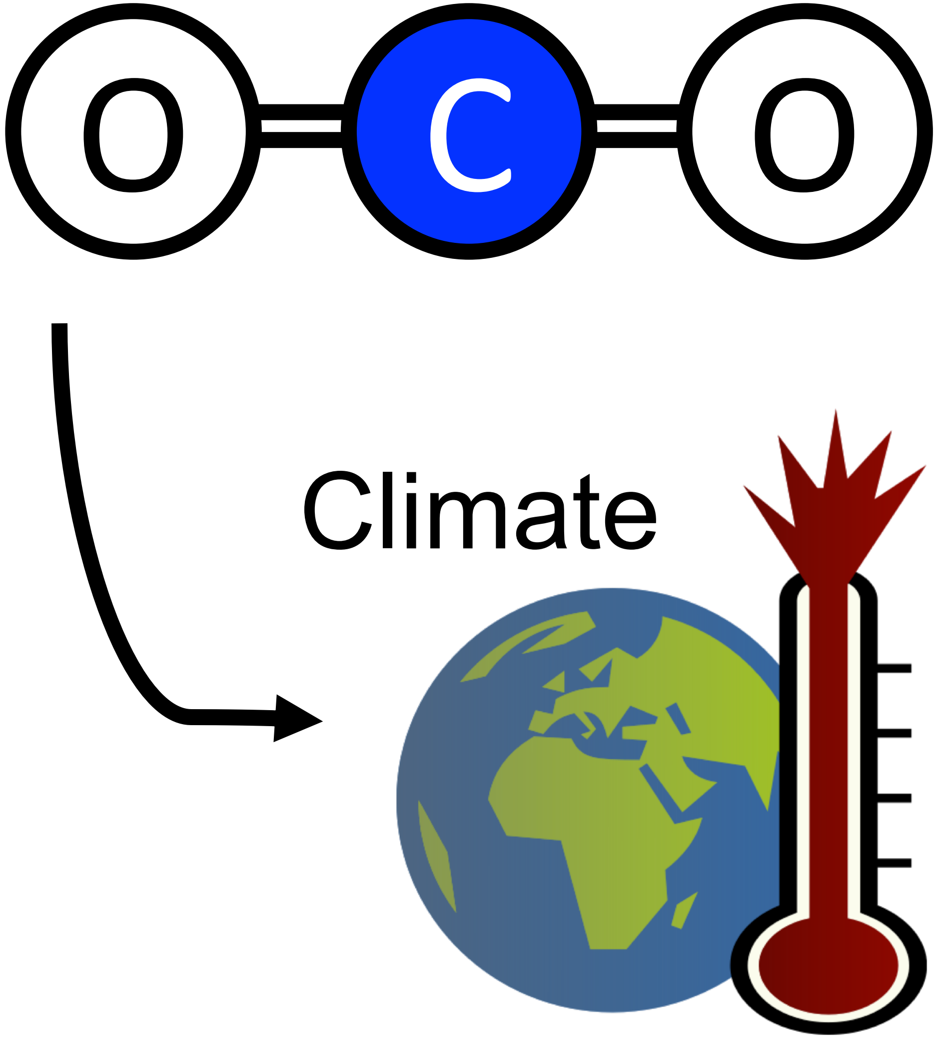
Radiation Transmitted by the Atmosphere
0.2
1
10
70
Spectral Intensity
Downgoing Solar Radiation
70-75% Transmitted
Upgoing Thermal Radiation
15-30% Transmitted
5525 K
210-310 K
UV
Visible
Infrared
Percent
100
75
50
25
0
Total Absorption
and Scattering
Major Components
Water Vapor
Carbon Dioxide
Wavelength (μm)

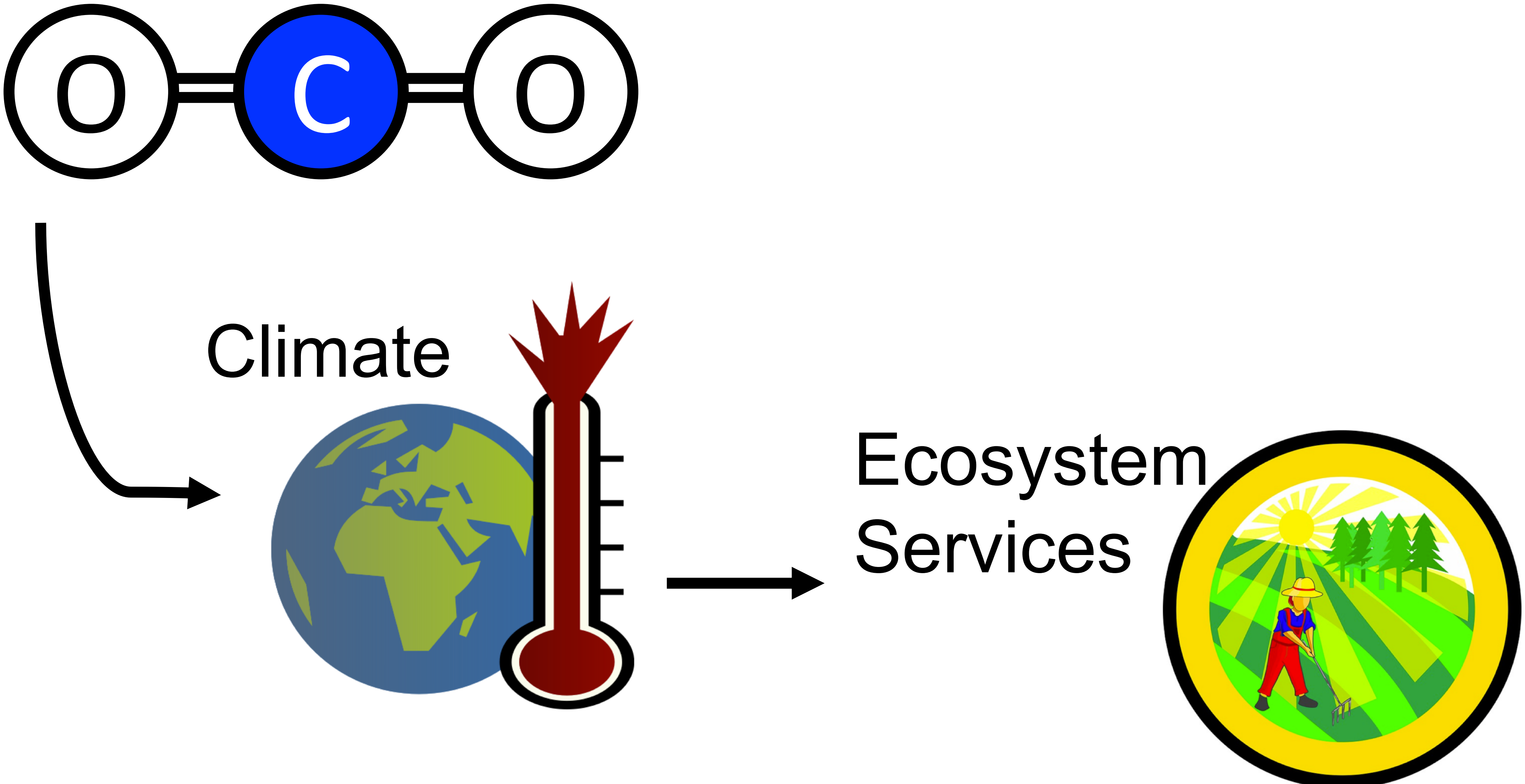
The climate is warming



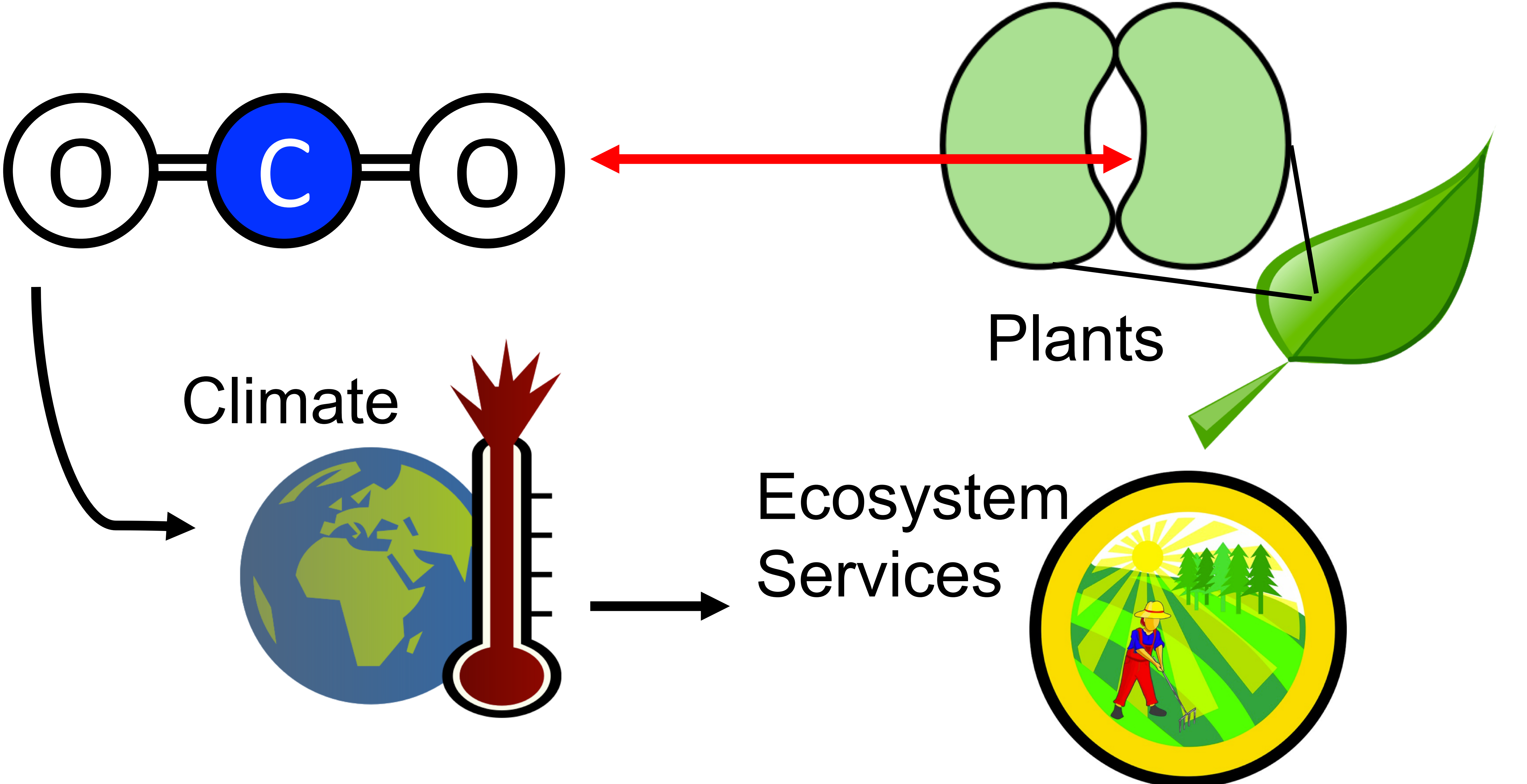
Poles and land are warming the fastest

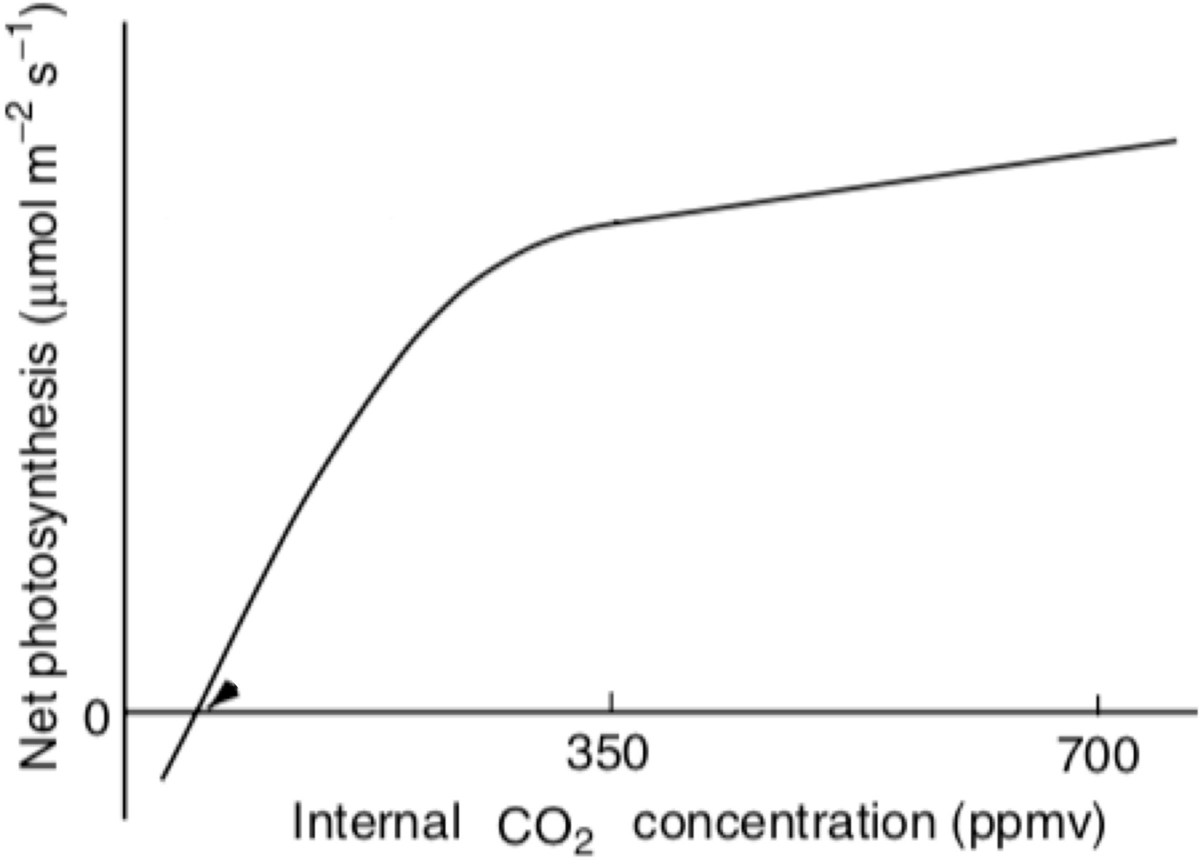
IPCC (2013)

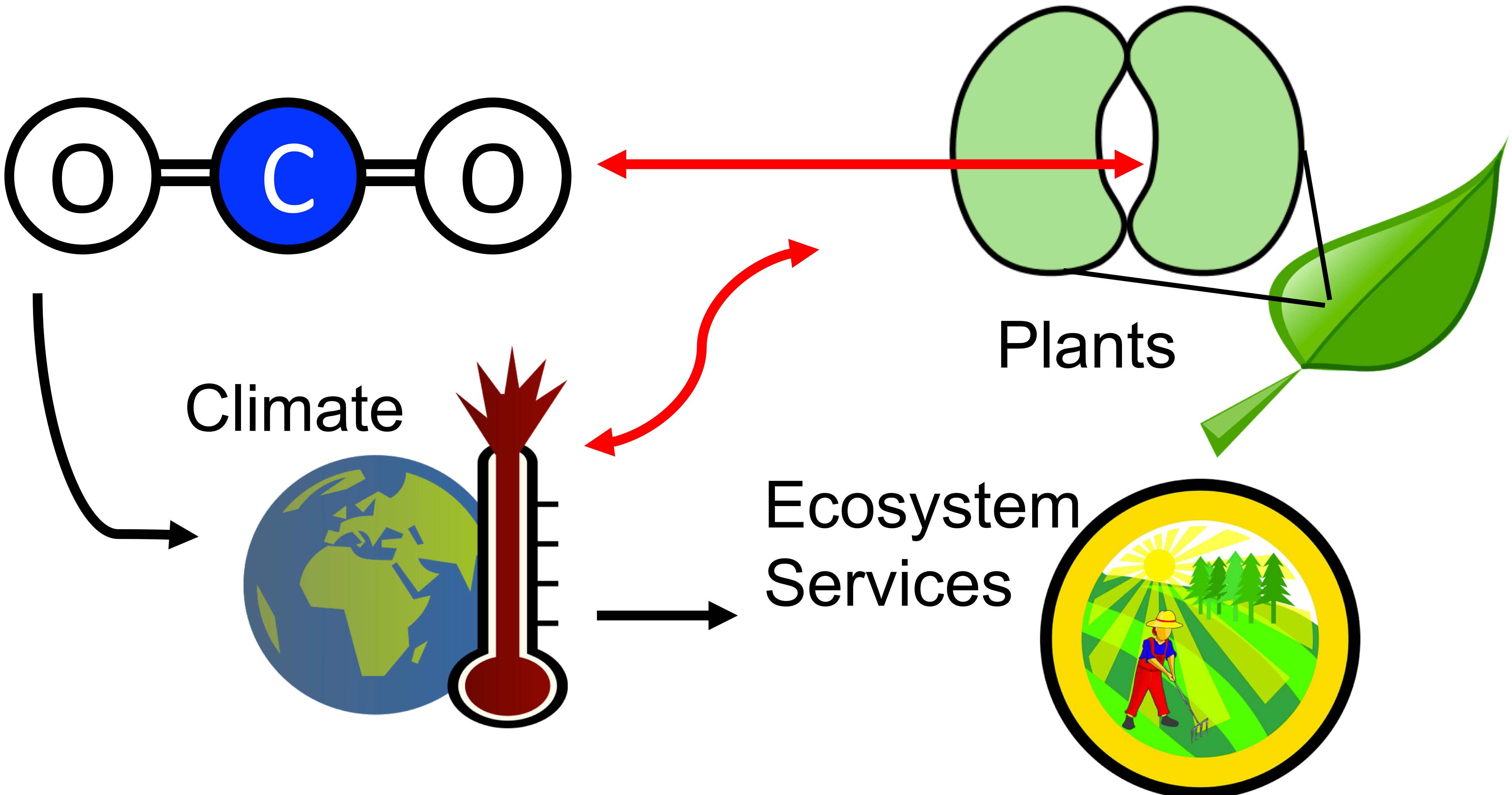

O
C
O
Climate



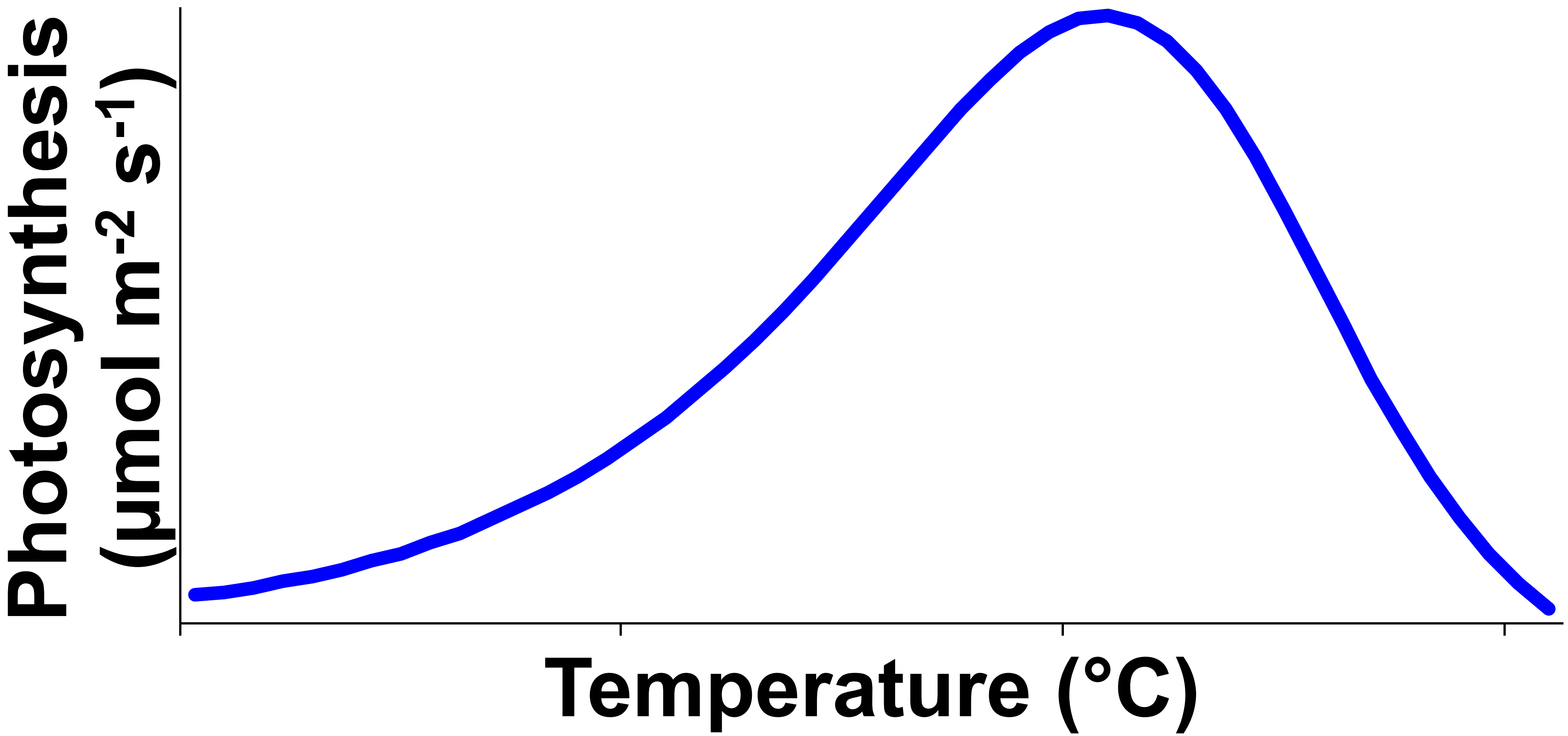
O
C
O
Climate
Ecosystem
Services

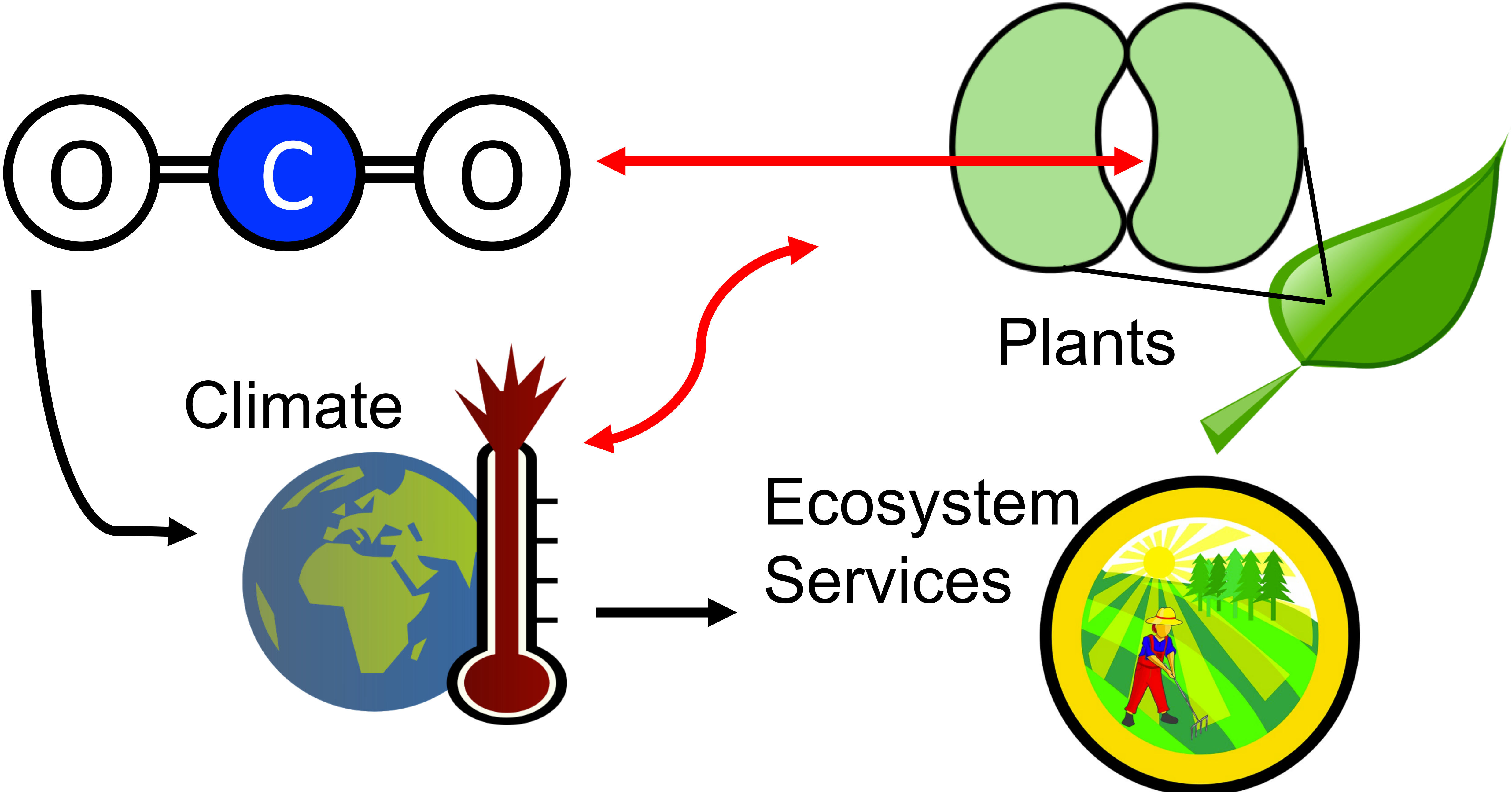

O
C
O
Plants
Climate
Ecosystem
Services

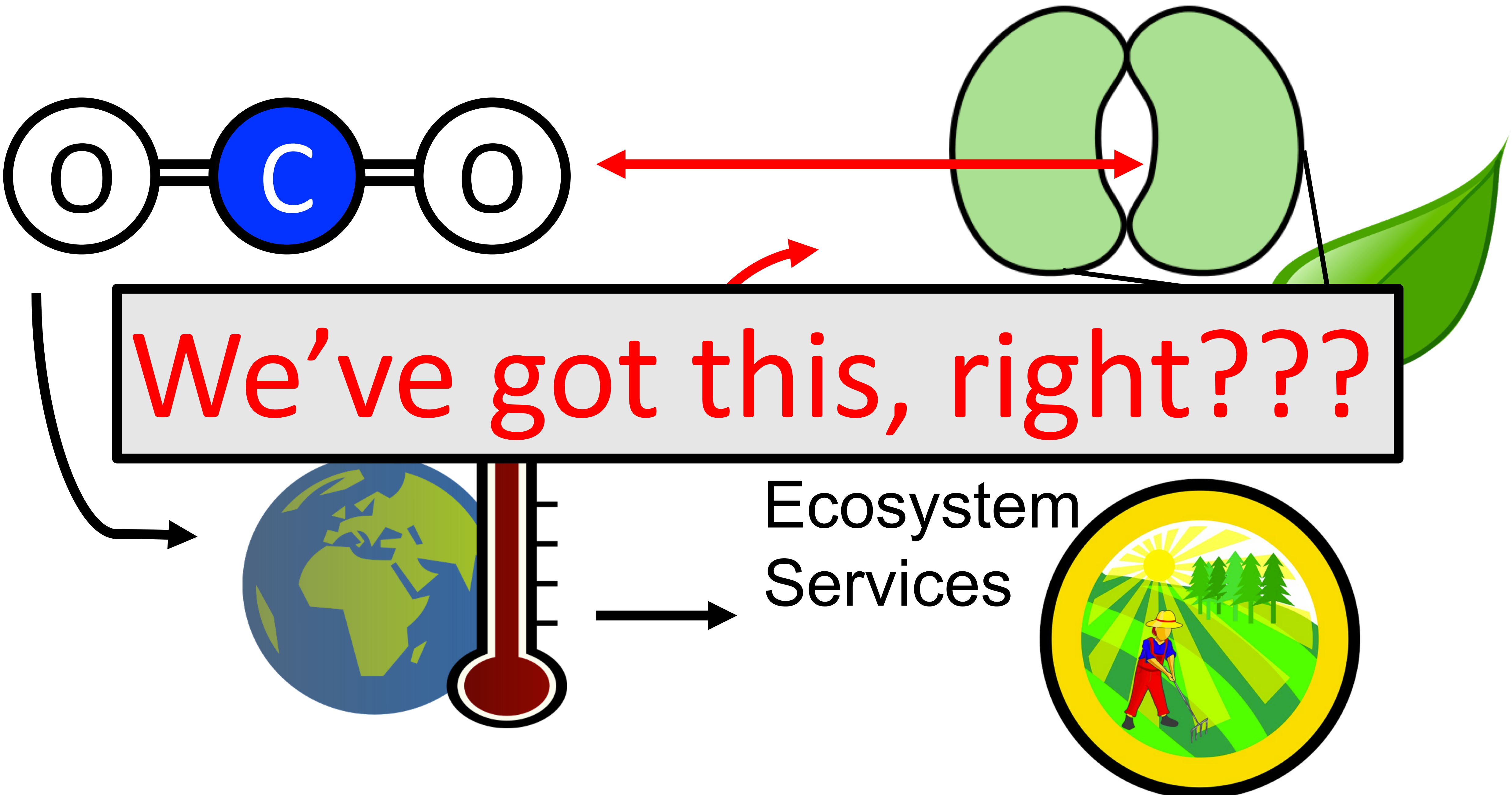

Net photosynthesis (μmol m⁻² s⁻¹)
0
350
700
Internal CO2 concentration (ppmv)



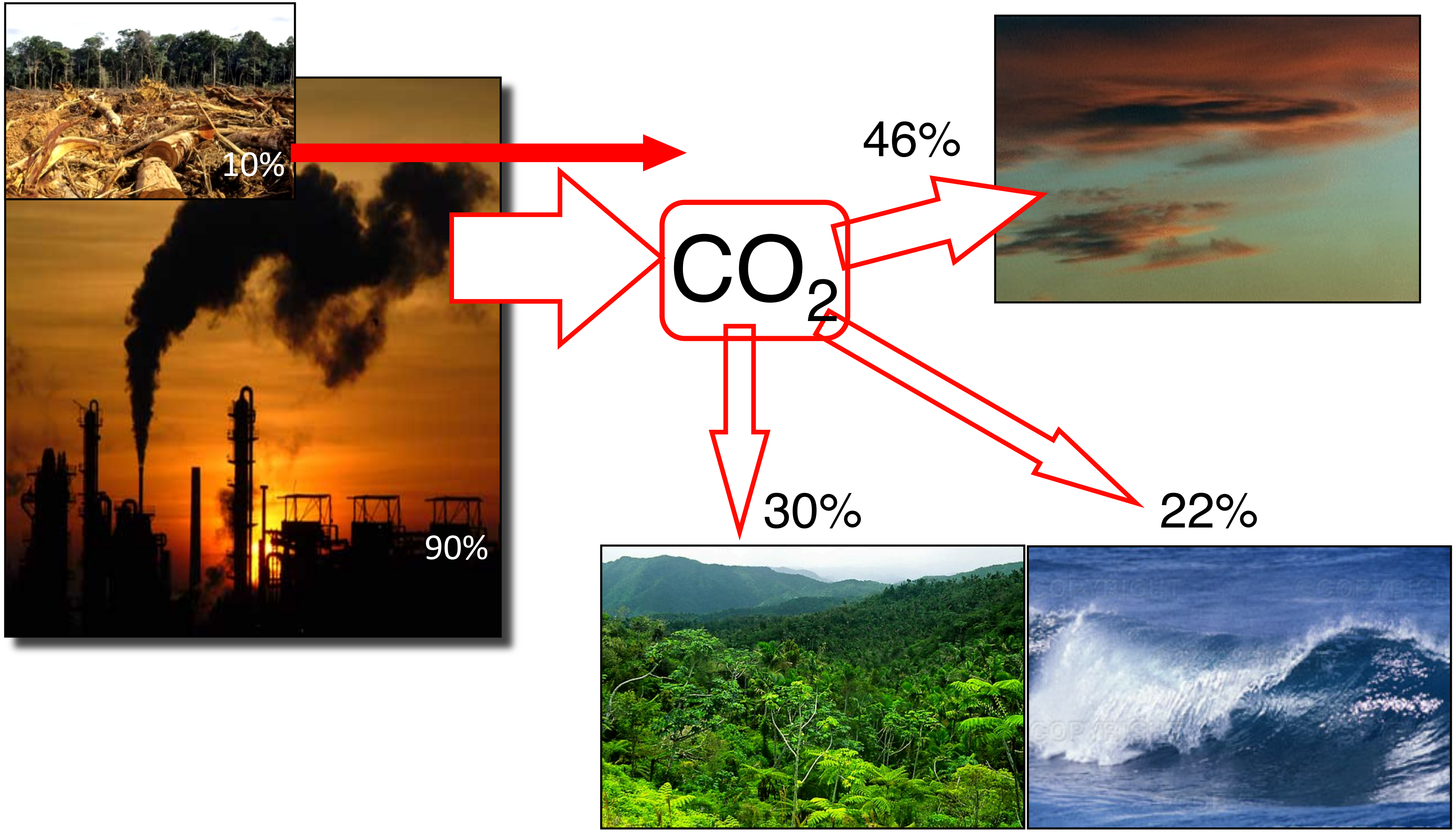
O
C
O
Plants
Climate
Ecosystem
Services


Photosynthesis
(µmol m-2 s-1)
Temperature (°C)


O
C
O
Plants
Climate
Ecosystem
Services

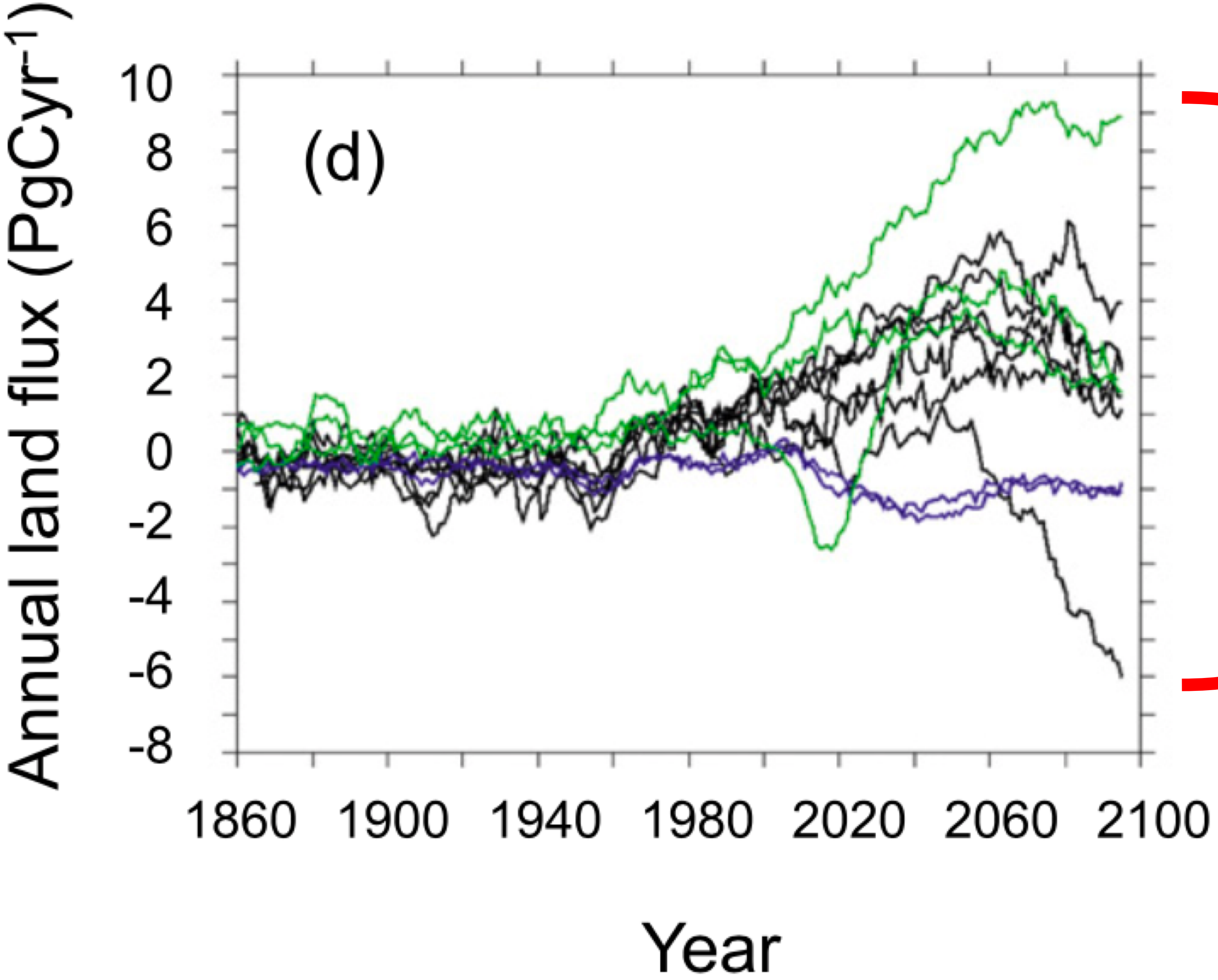

O
C
O
We’ve got this, right???
Ecosystem
Services

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



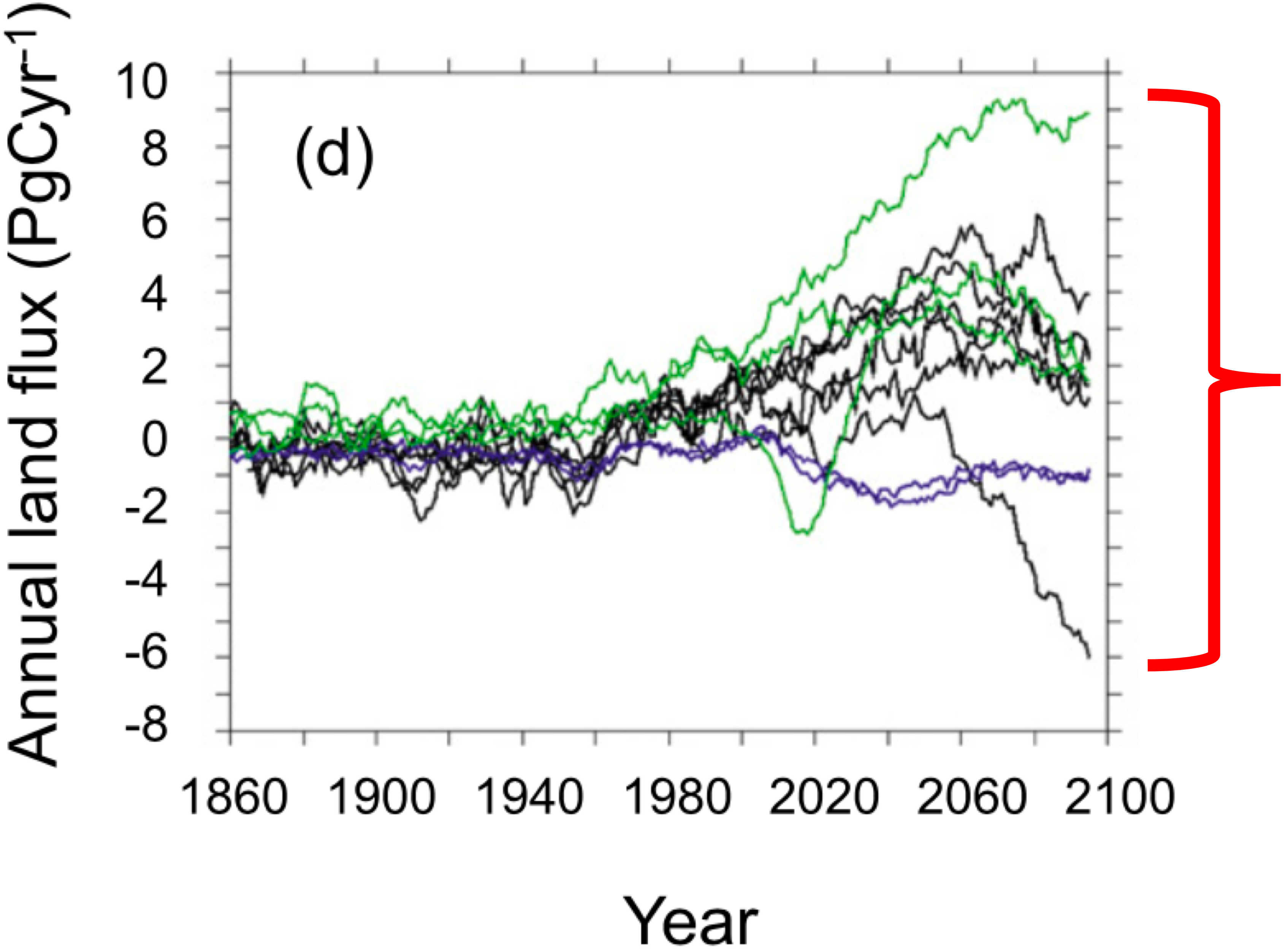
LeQuere 2015

LeQuere et al. (2020)



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

Friedlingstein et al. (2014)

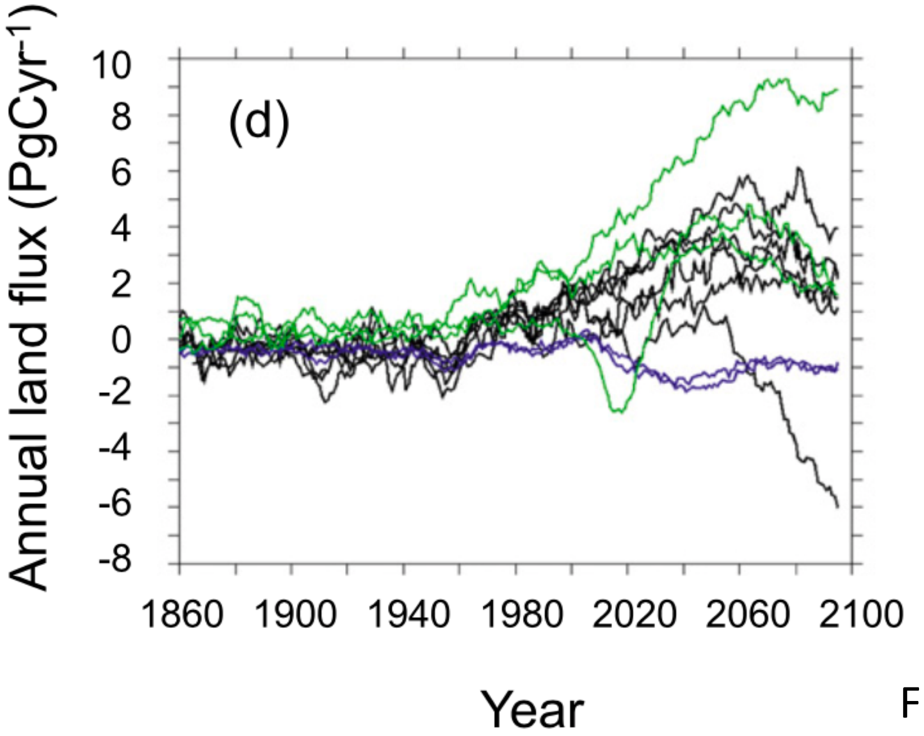


Land carbon sink correlates well with photosynthesis on land ($r^2 > 0.9$)

Friedlingstein et al. (2014)

Class activity

- In teams of three, answer the following question: If photosynthesis drives the land carbon sink strength and temperature and CO_2 responses of photosynthesis are well characterized, why is the future carbon sink so uncertain?
- Hint: this is a scaling issue



Friedlingstein et al. (2014)

Working across scales: measurements

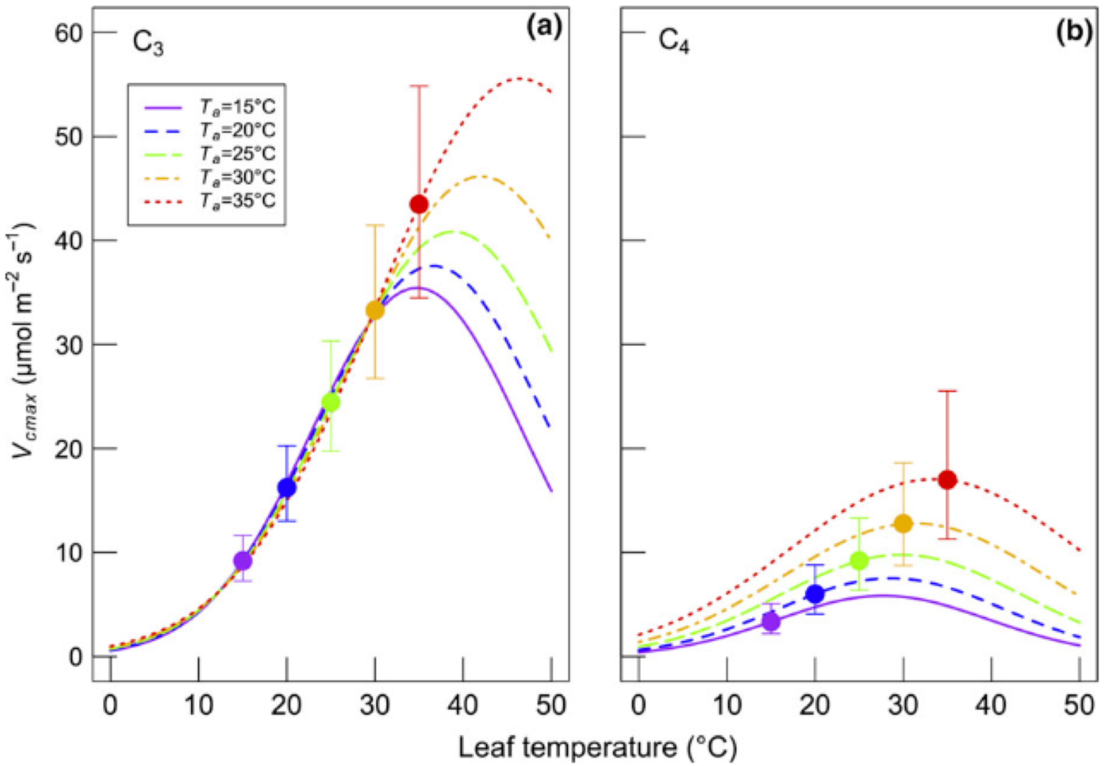
Scale tradeoff

- 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

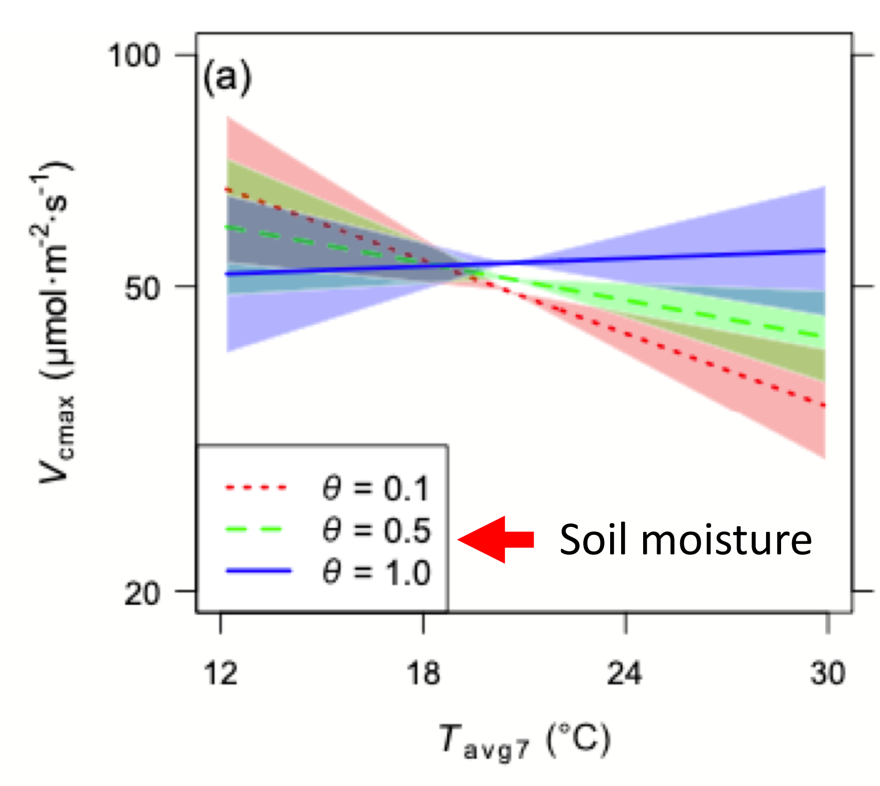
- Controlled environment
  - Pro: can measure ecophysiological process response while holding all conditions constant

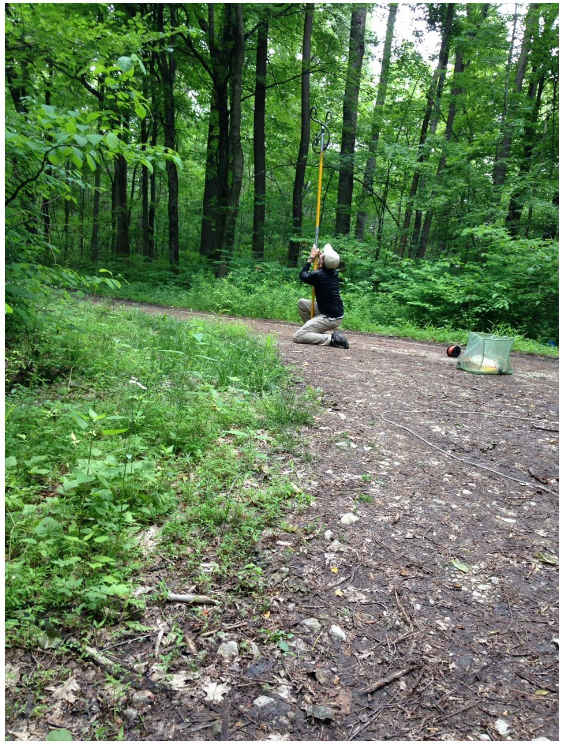


Smith and Dukes (2017)

Ecophysiological scale consideration 1: controlled versus uncontrolled conditions

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

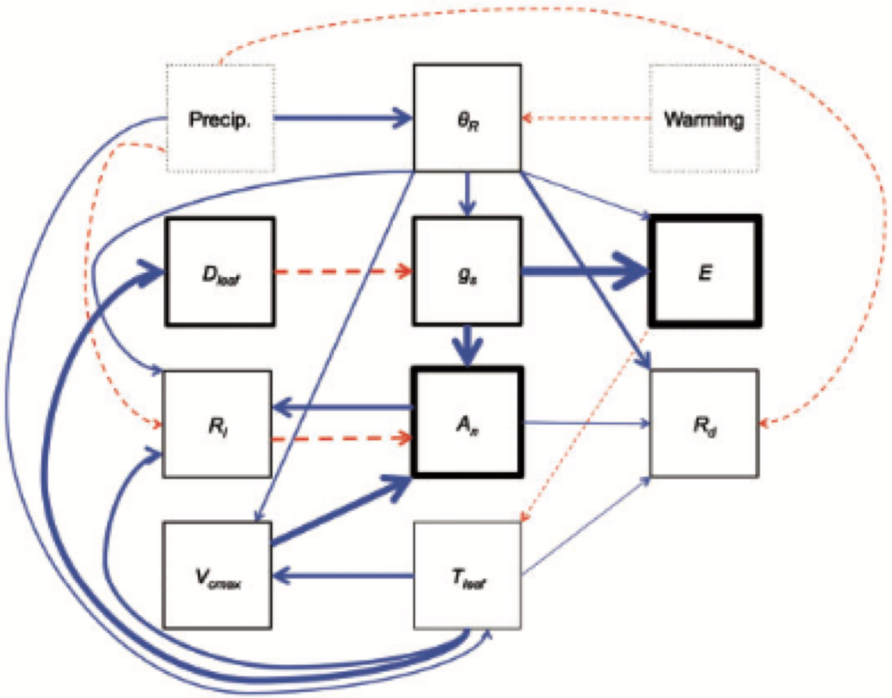


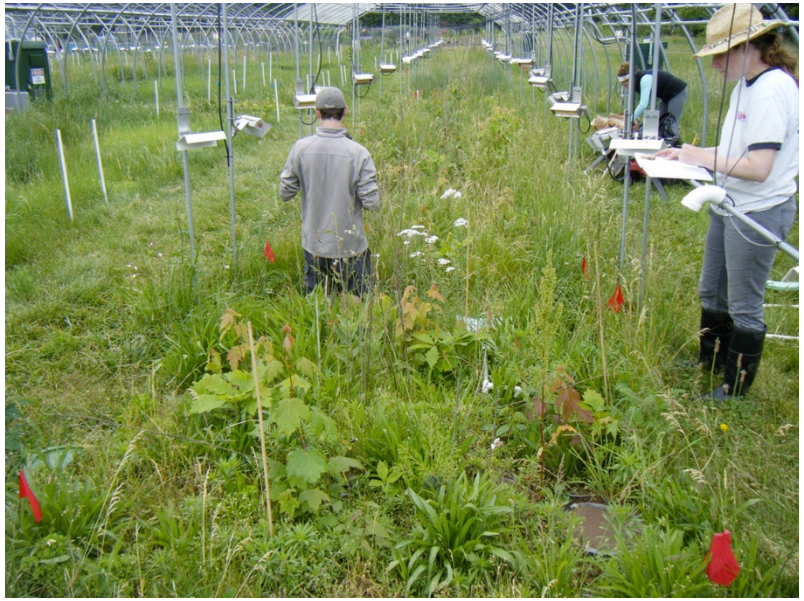


Smith and Dukes (2018)

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





Smith et al. (2016)

Ecophysiological scale consideration 2: organ versus ecosystem

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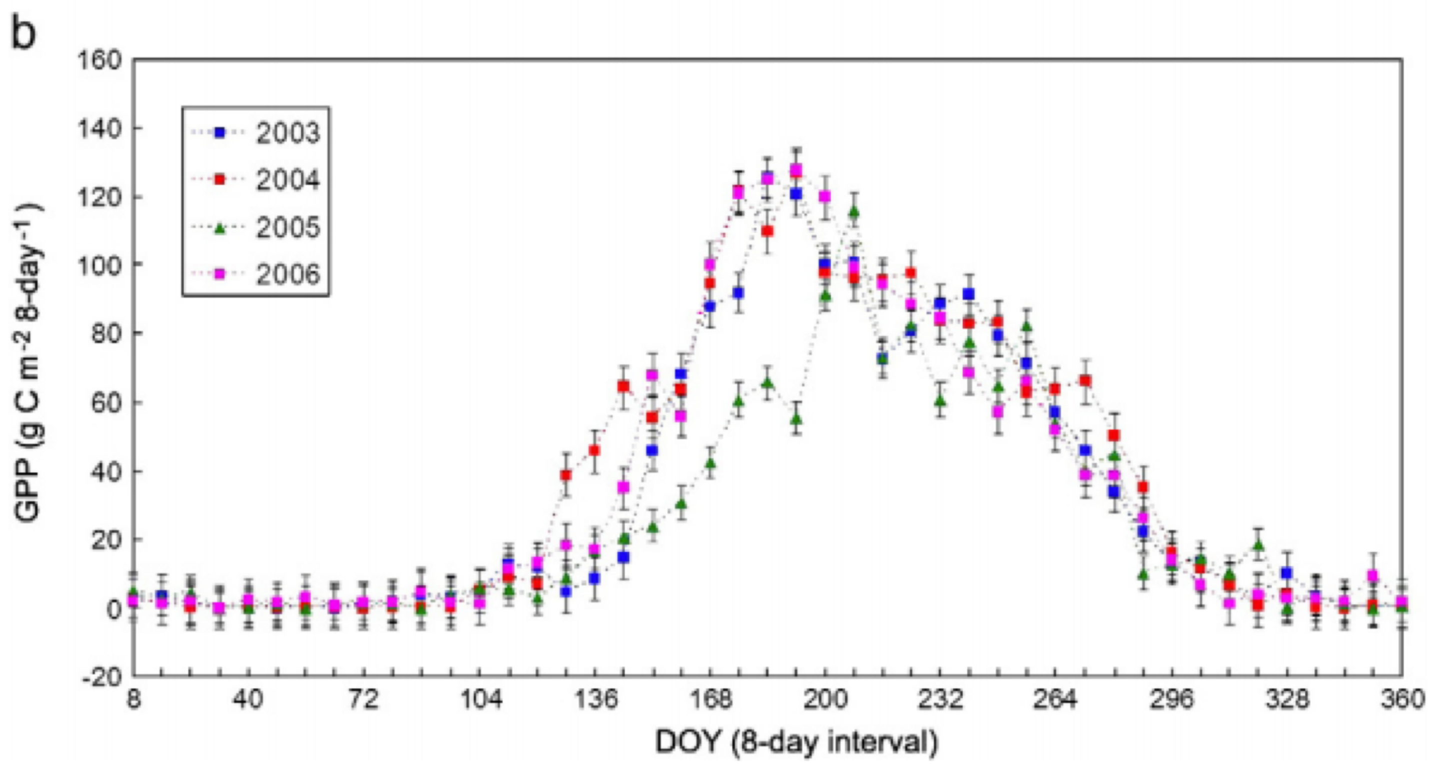
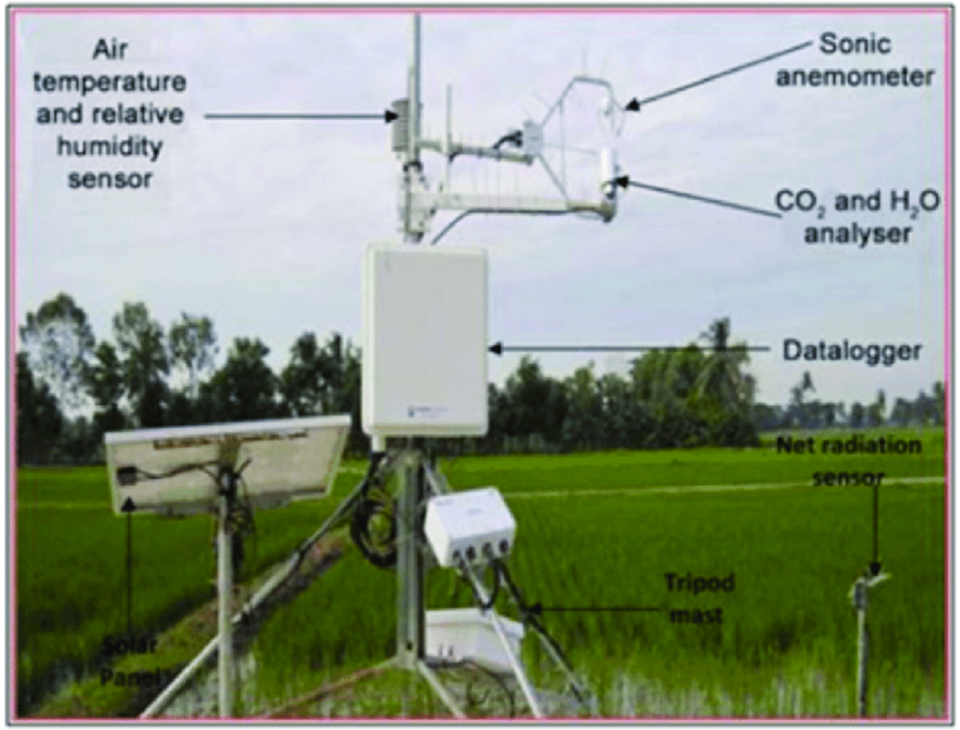
- Ecosystem-scale measurements
  - Pro: measure the impact on more important scale



Wu et al. (2010)

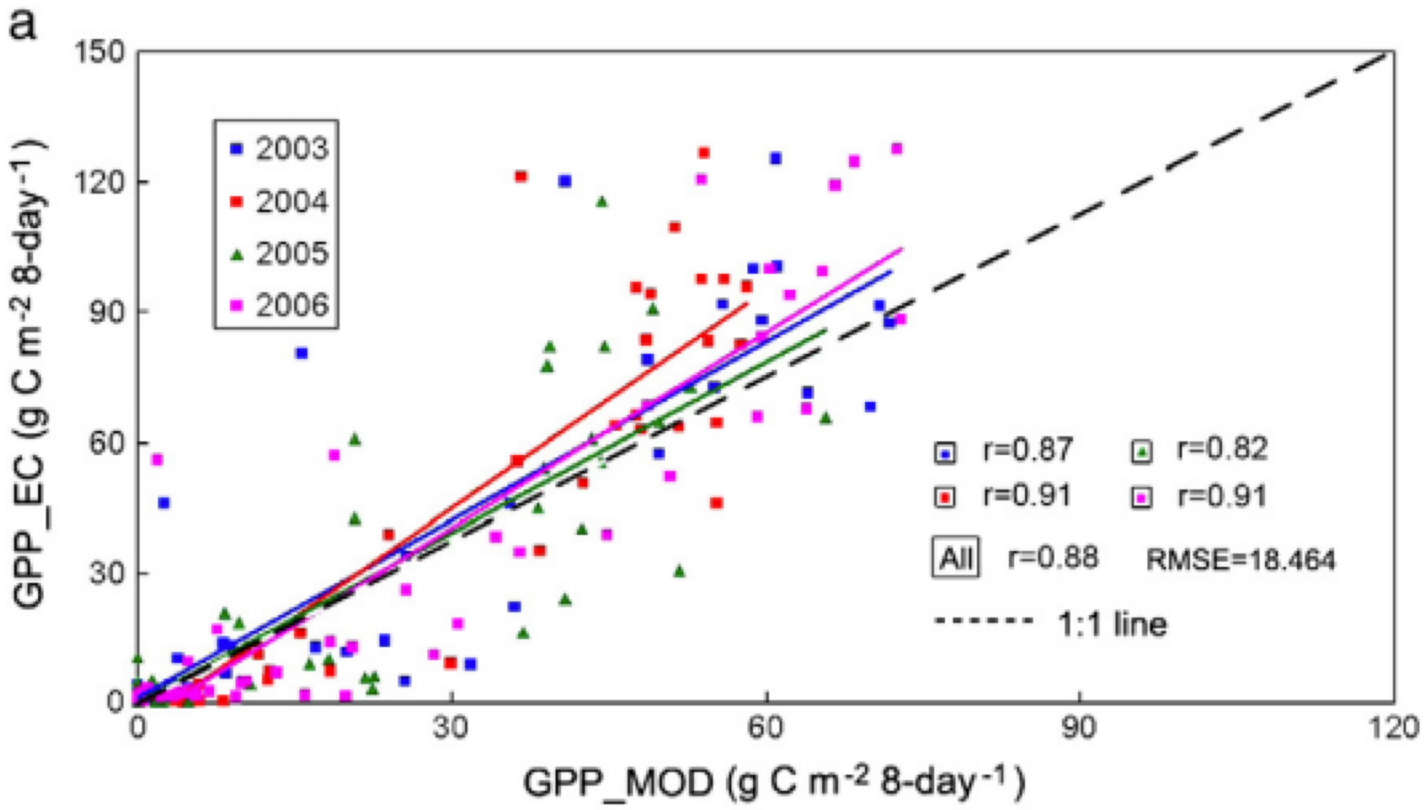
Ecophysiological scale consideration 2: organ versus ecosystem

- 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



Wu et al. (2010)

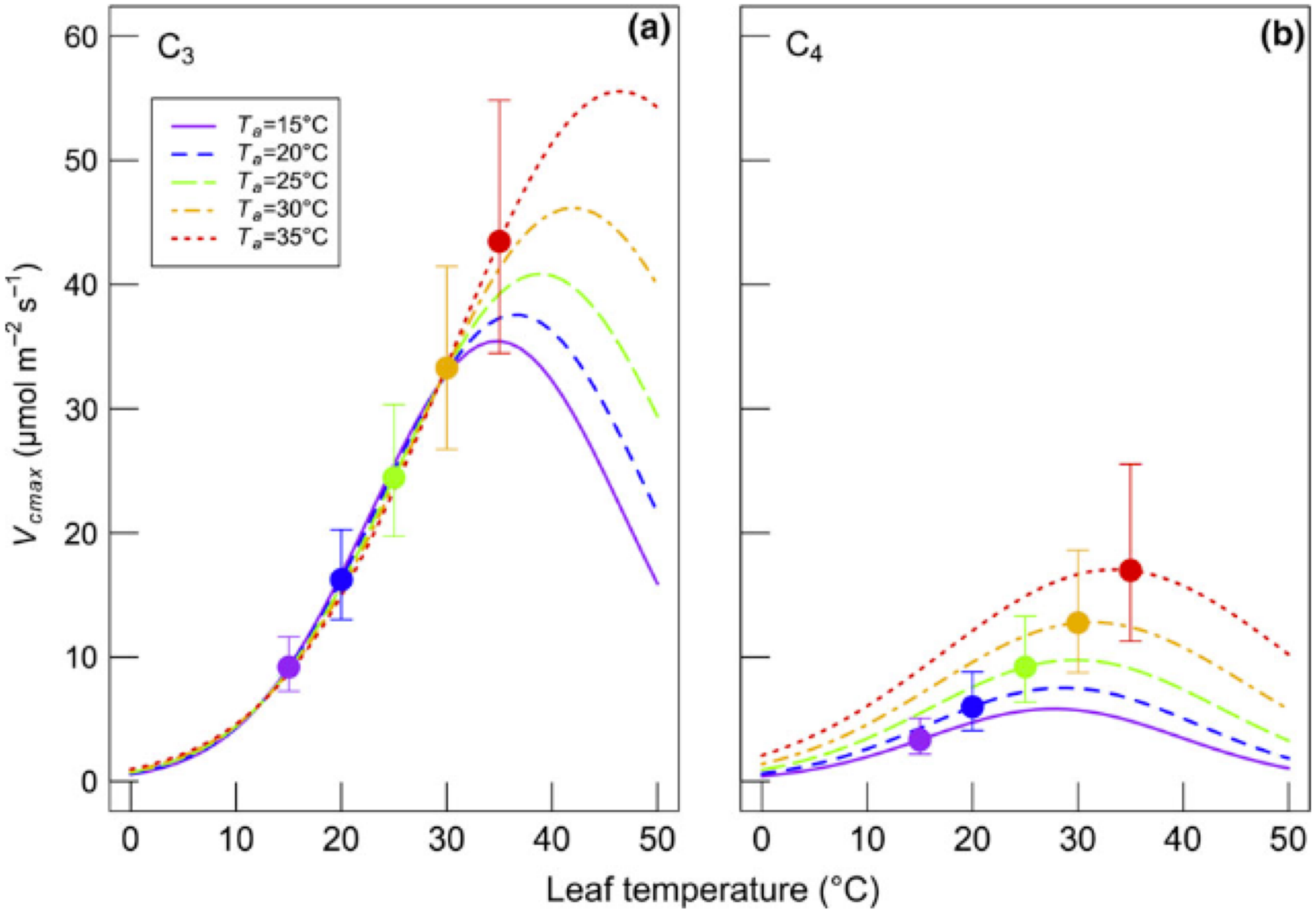
Working across scales: modeling

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)



Smith and Dukes (2017)

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

Planta 149, 78–90 (1980)

Planta

A Biochemical Model of Photosynthetic CO_2 Assimilation in Leaves of C_3 Species

G.D. Farquhar[1], S. von Caemmerer[1], and J.A. Berry[2]

[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

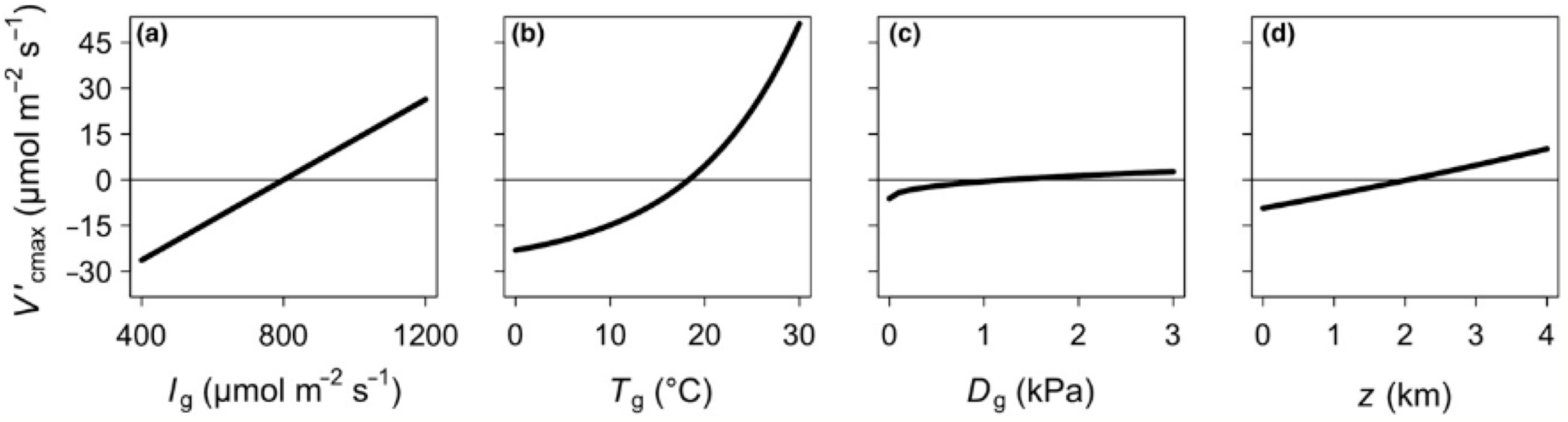
ECOLOGY LETTERS
Ecology Letters, (2019) **22**: 506–517 doi: 10.1111/ele.13210

LETTER

Global photosynthetic capacity is optimized to the environment

Nicholas G. Smith,[1,2*]

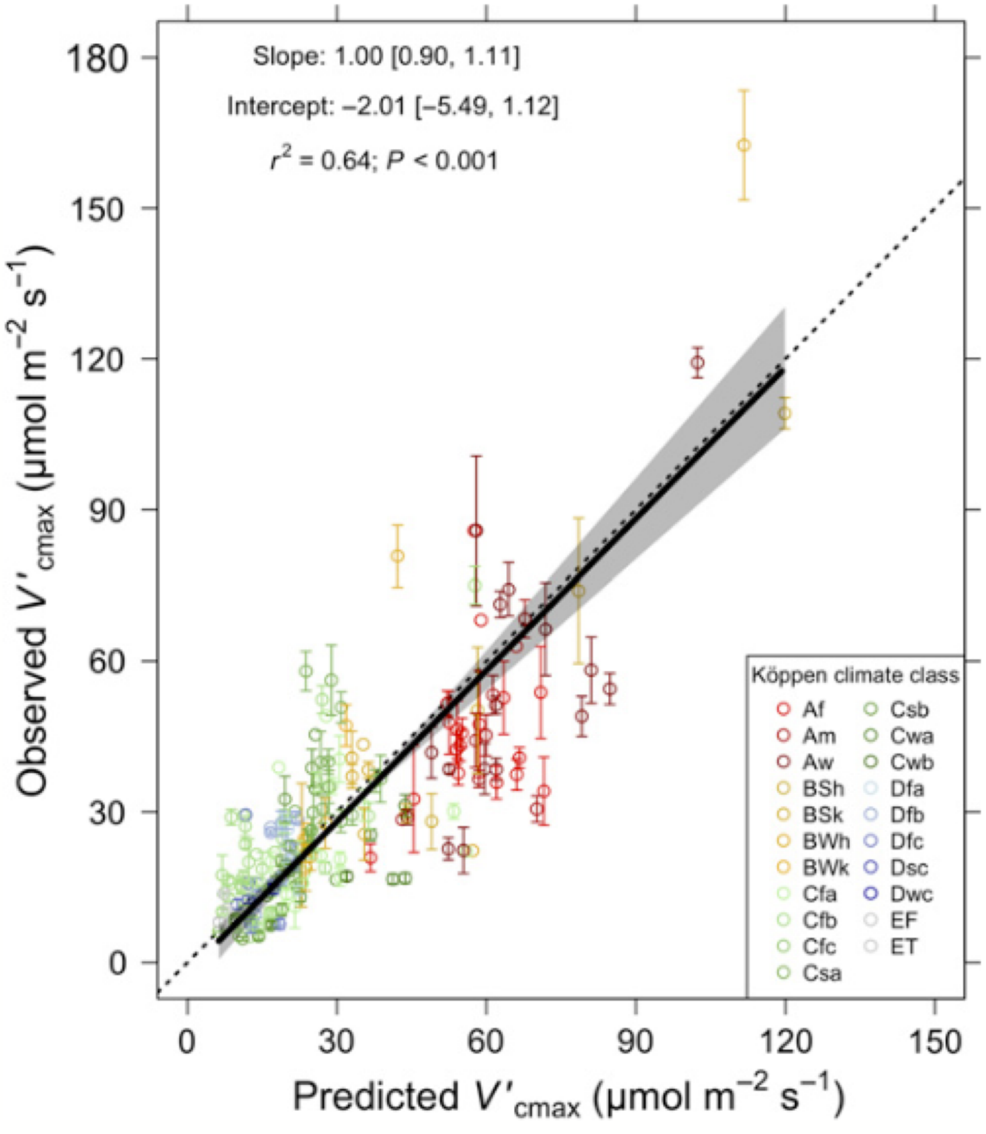
Abstract
Earth system models (ESMs) use photosynthetic capacity, indexed by the maximum Rubisco car-



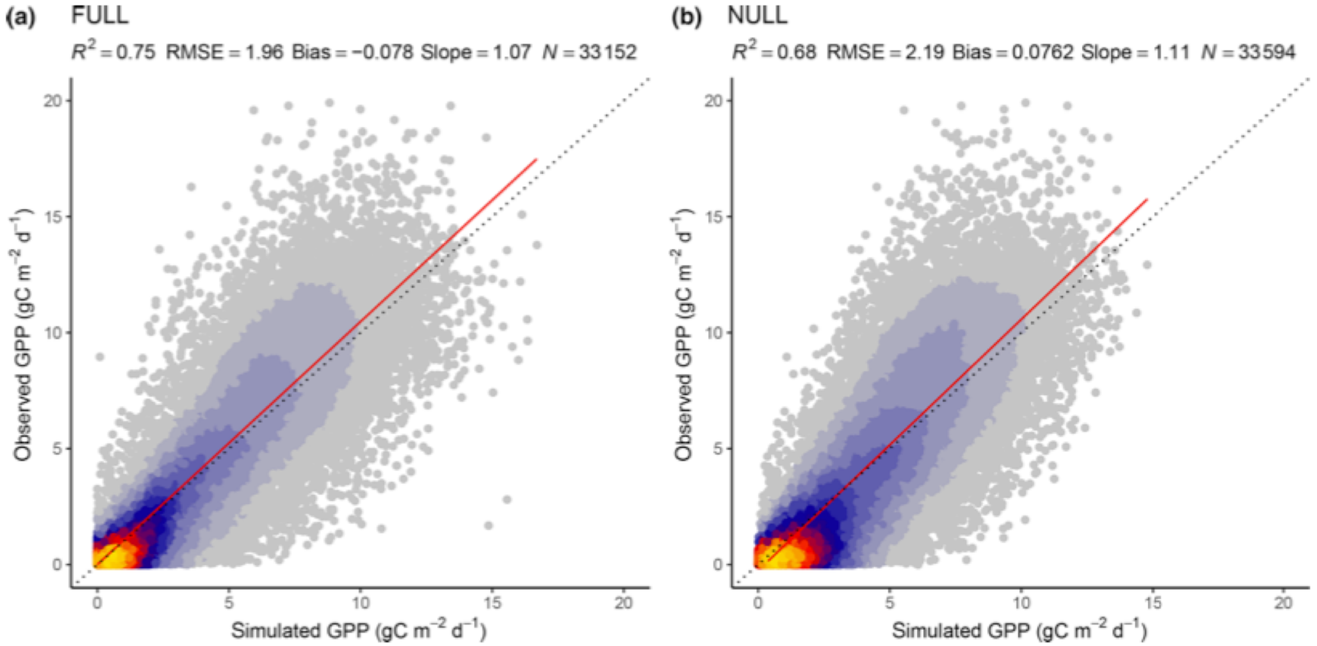
Models provide a way to assess the scalability of mechanisms

Steps involved

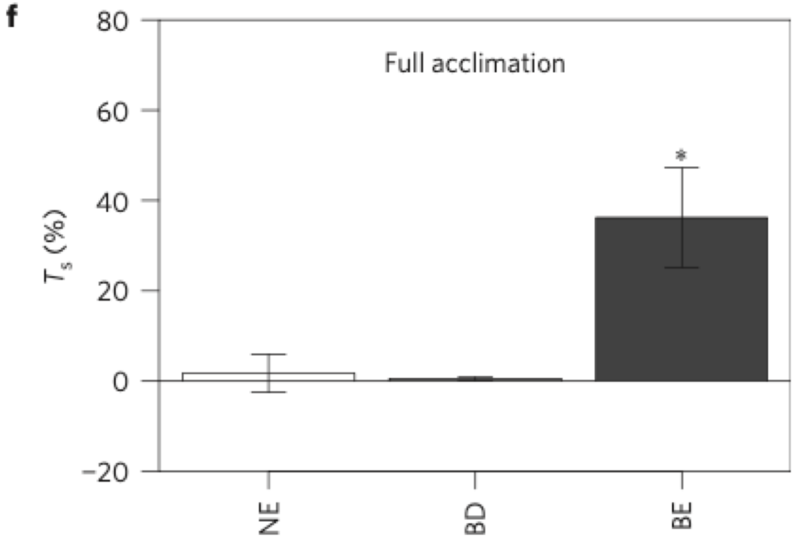
1. Evaluate process mechanisms under highly controlled conditions (small scale)
2. Develop a theory for process and it’s environmental response
3. Quantify the theory and build a model
4. Simulate similar or connected processes that can be measured at larger scales



Smith et al. (2019)



Stocker et al. (2020)



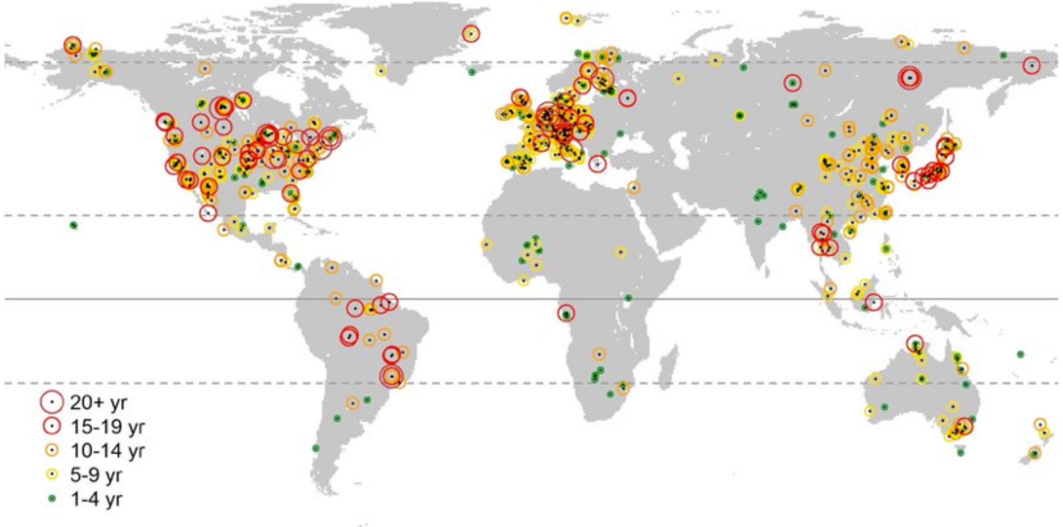
Smith et al. (2016)

Improved scaling: coordinated research networks

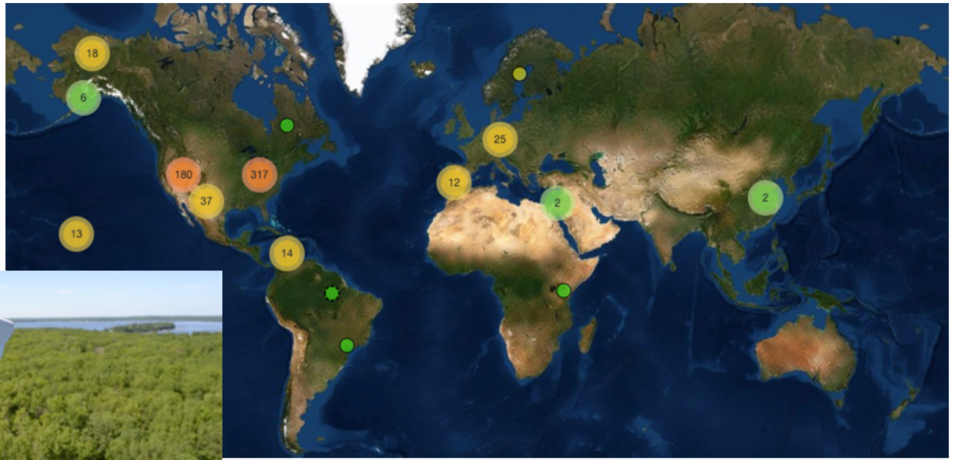
	Consistent methodology	Causal inference	Realistic complexity	Environmental gradients	Site-specific design
Single-site experiments	✓	✓	?	?	✓
Observational networks	✓		✓	✓	
Process-based models	✓	✓		✓	✓
Empirical/statistical models	✓		?	✓	✓
Meta-analyses		?	✓	✓	
Distributed experiments	✓	✓	✓	✓	

Borer et al. (2013) Meth. Ecol. Evo.

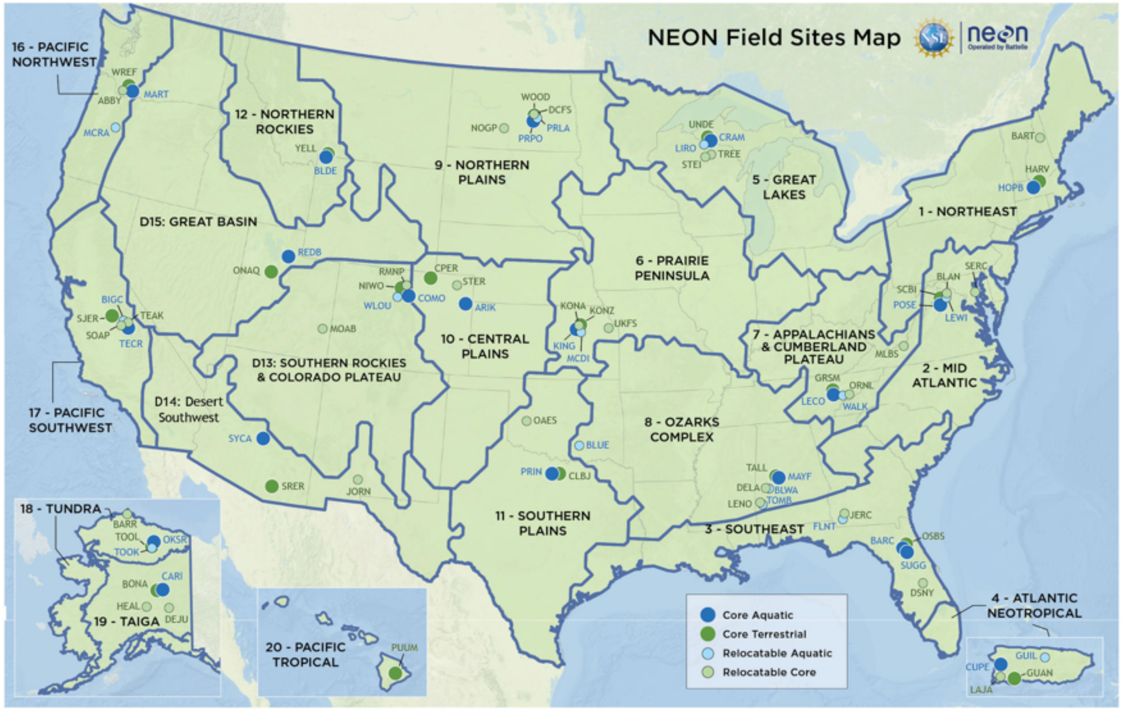




PhenoCam Network



The National Ecological Observatory Network (NEON)



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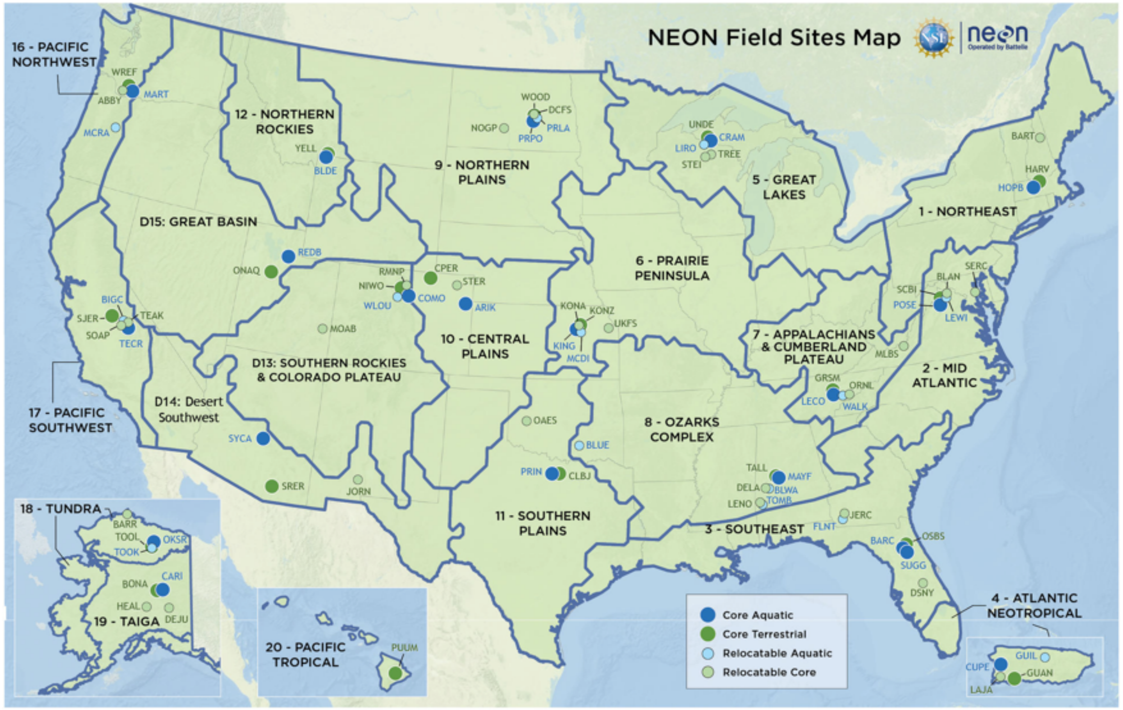


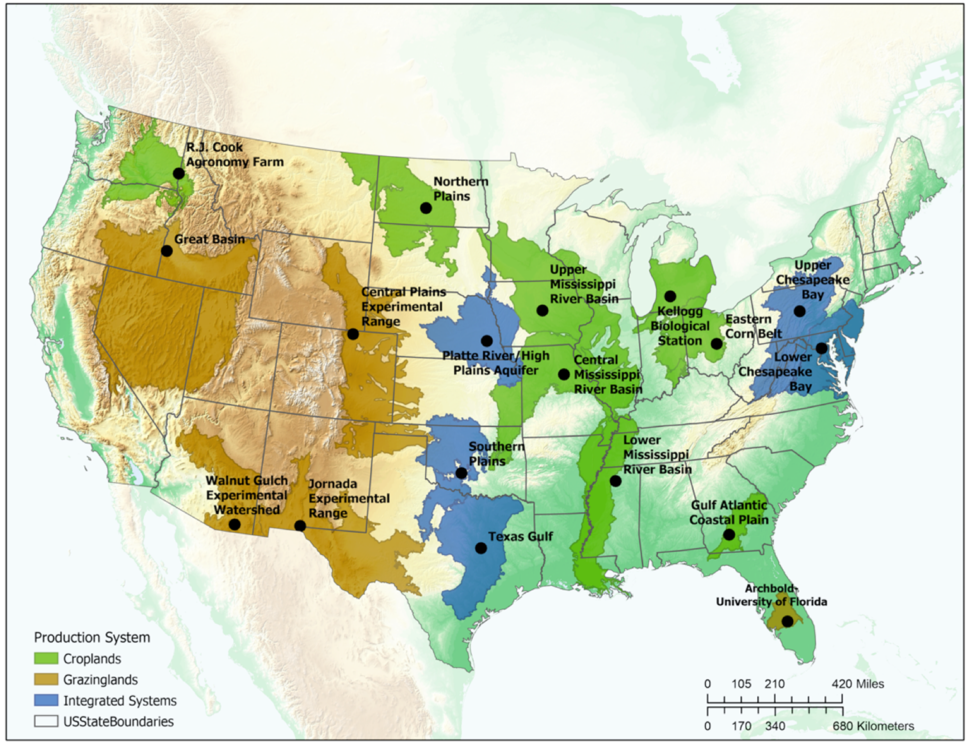
Viewpoint

Reimagining NEON Operations: We Can Do Better

ALAN K. KNAPP AND SCOTT L. COLLINS

BioScience (October 2019)

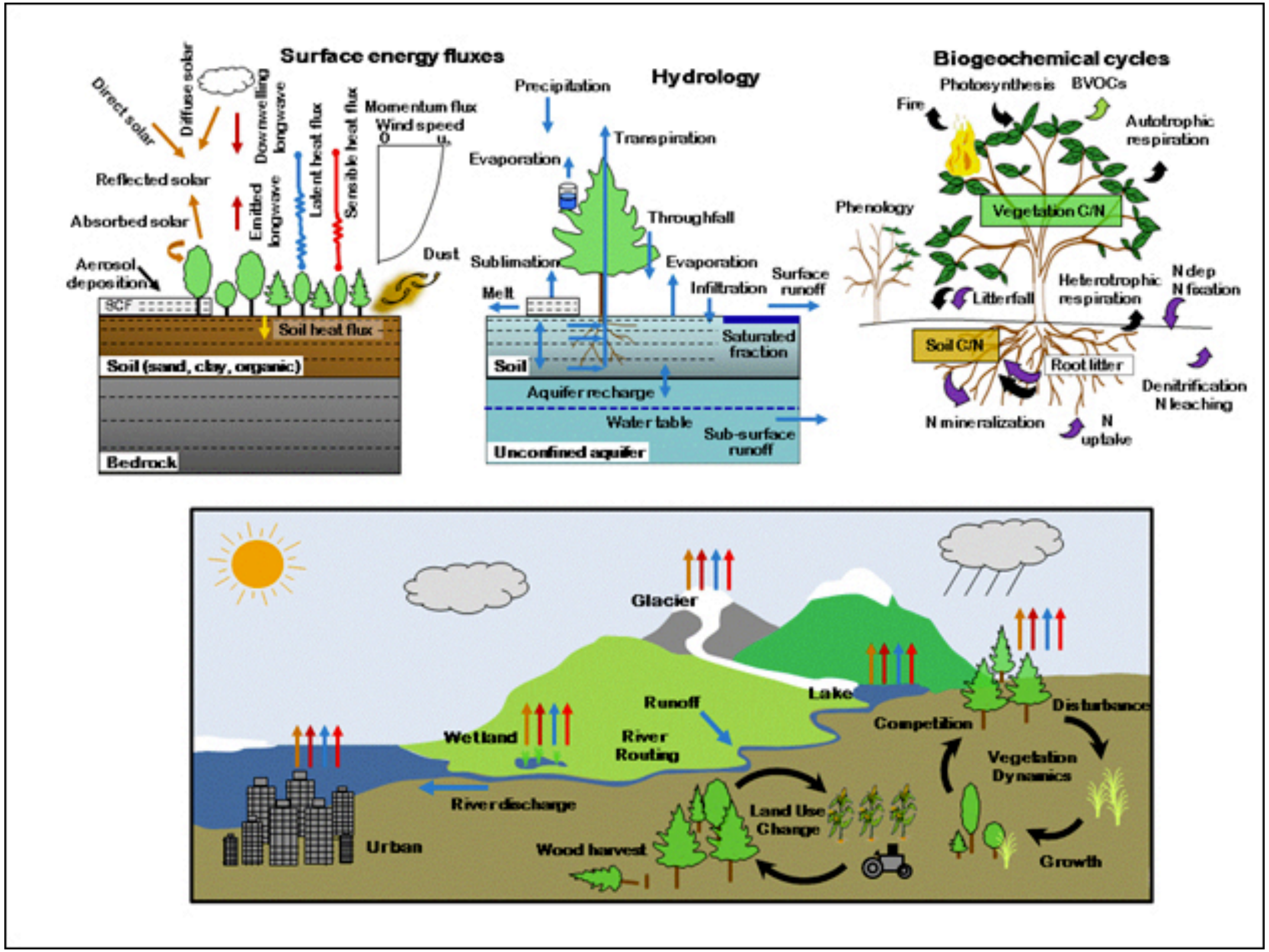
Long-term ecological and agricultural research sites (LTER and LTAR)



Measurements not coordinated

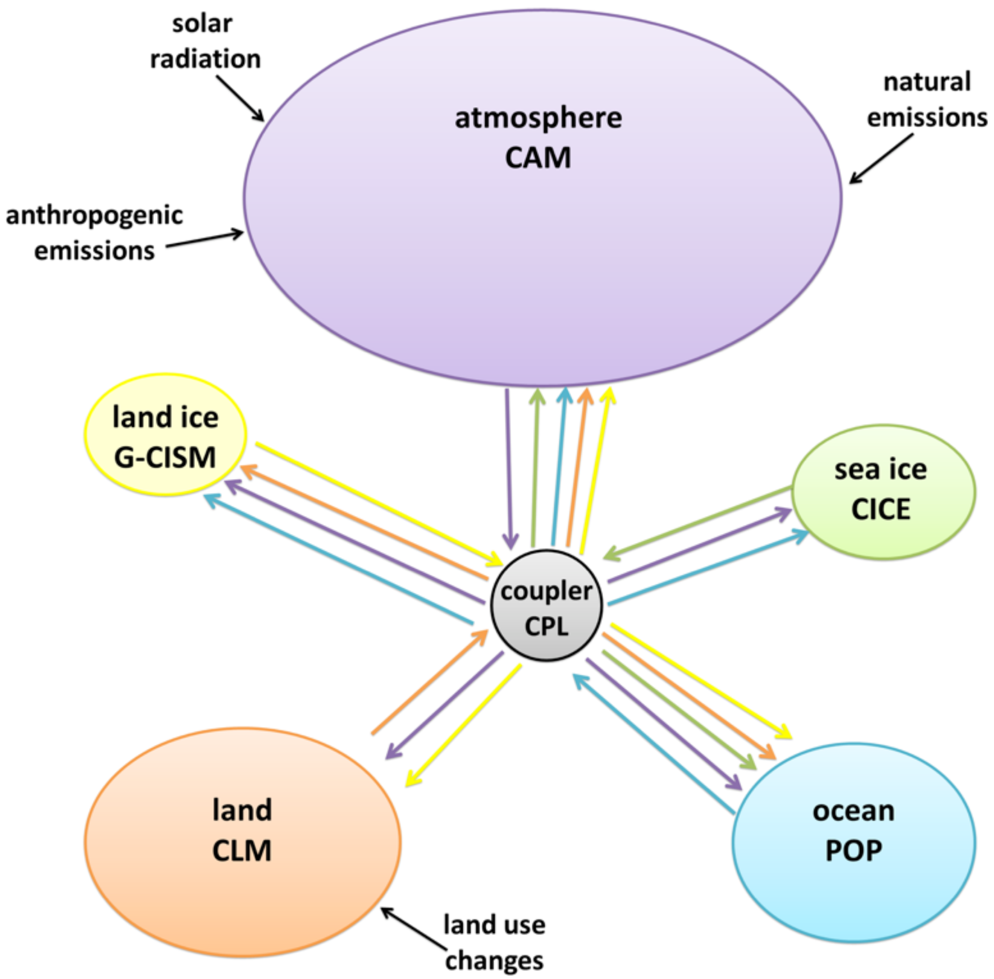
Future predictions: large-scale models

Land surface models



UCAR

Earth System Models



Dr. Kaitlin Naughten

Future predictions: realism versus reliability

Atmos. Chem. Phys., 15, 5987–6005, 2015
www.atmos-chem-phys.net/15/5987/2015/
doi:10.5194/acp-15-5987-2015

Atmospheric Chemistry and Physics
Open Access

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

I. C. Prentice[1,2], X. Liang[3], B. E. Medlyn[2,4], and Y.-P. Wang[5]

Adding processes to models may improve their realism…

Atmos. Chem. Phys., 15, 5987–6005, 2015
www.atmos-chem-phys.net/15/5987/2015/
doi:10.5194/acp-15-5987-2015

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

I. C. Prentice[1,2], X. Liang[3], B. E. Medlyn[2,4], and Y.-P. Wang[5]

…but may also make them more unreliable and uncertain

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