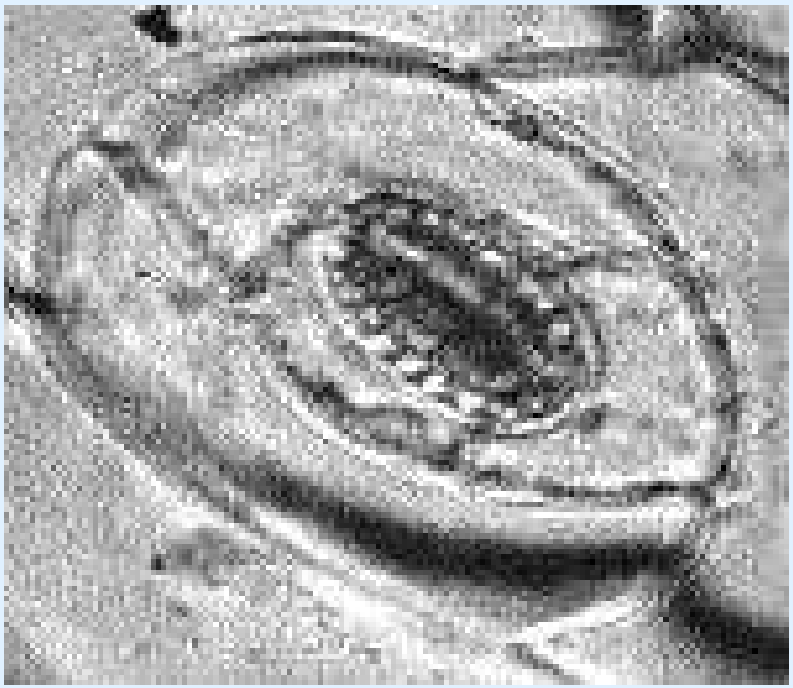
The Role of Ecosystems in the Climate System

Peter Cox

University of Exeter
Met Office Chair in Climate System Dynamics
Mathematics Research Institute

Effects of Ecosystems on Climate

- **Physiological Controls *(minutes-days)*** : stomatal pores on plant leaves open and close in response to environmental factors (light, temperature, CO_2, soil water etc.), controlling surface-atmosphere fluxes of CO_2 and water.



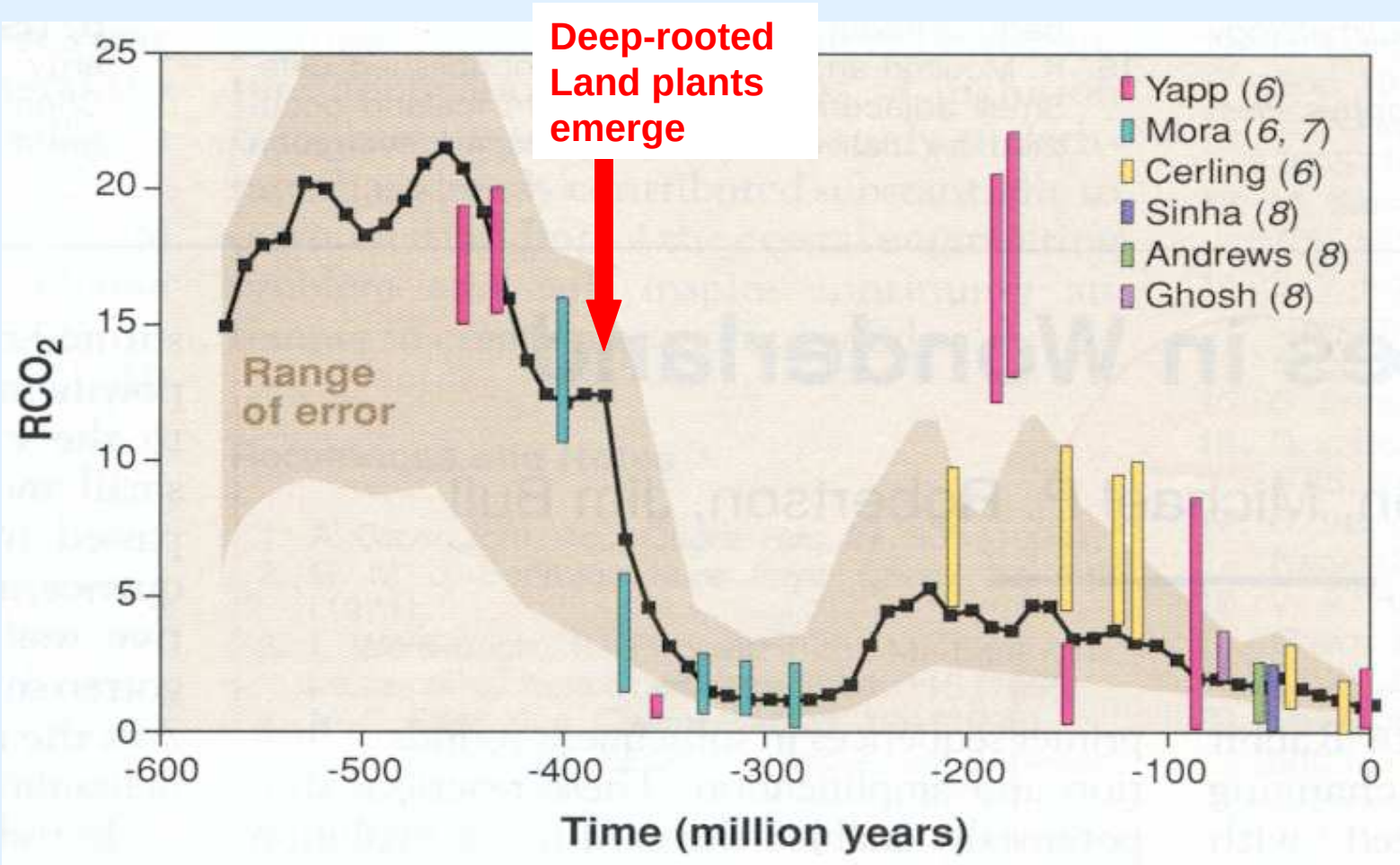
Source: Mike Morgan (www.micscape.simplenet.com/mag/arcticles/stomata.html)

Effects of Ecosystems on Climate

- **Biophysical Vegetation Feedbacks *(years-centuries)*** : Changes in the distribution and structural characteristics of vegetation (e.g. height, leaf area index), change the physical properties of the land surface (e.g. albedo, aerodynamic roughness).

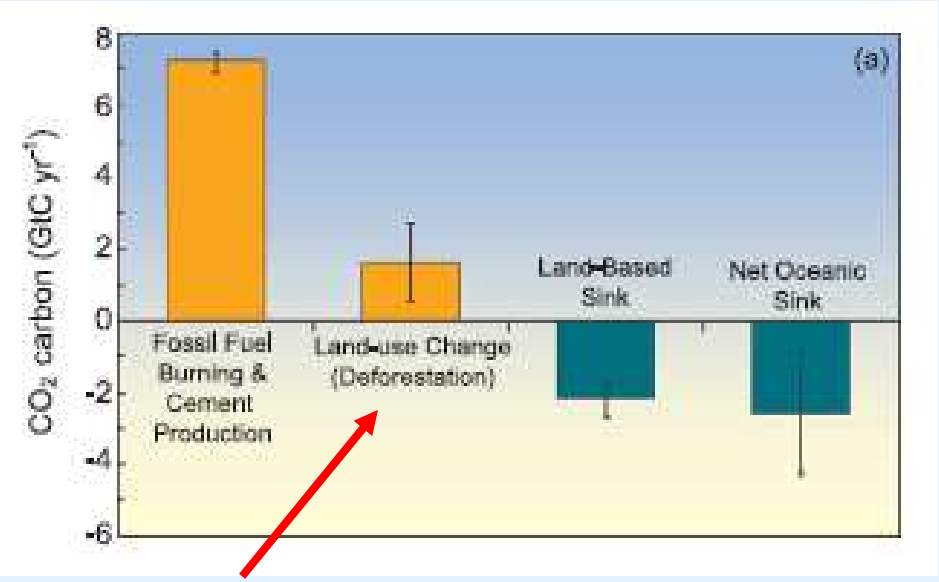
Effects of Ecosystems on Climate

- **Rock Weathering** *(>100 kyr)* : Land biota are believed to accelerate rock weathering (which is the ultimate sink for CO_2)



Effects of Ecosystems on Climate

- **Carbon Cycle *(years-centuries)*** : Currently only about half of human emissions of CO_2 remain in the atmosphere - the ocean and land ecosystems are absorbing the remainder.



Deforestation Accounts for about 20% of Global CO_2 emissions

….and results in very significant loss of biodiversity…..

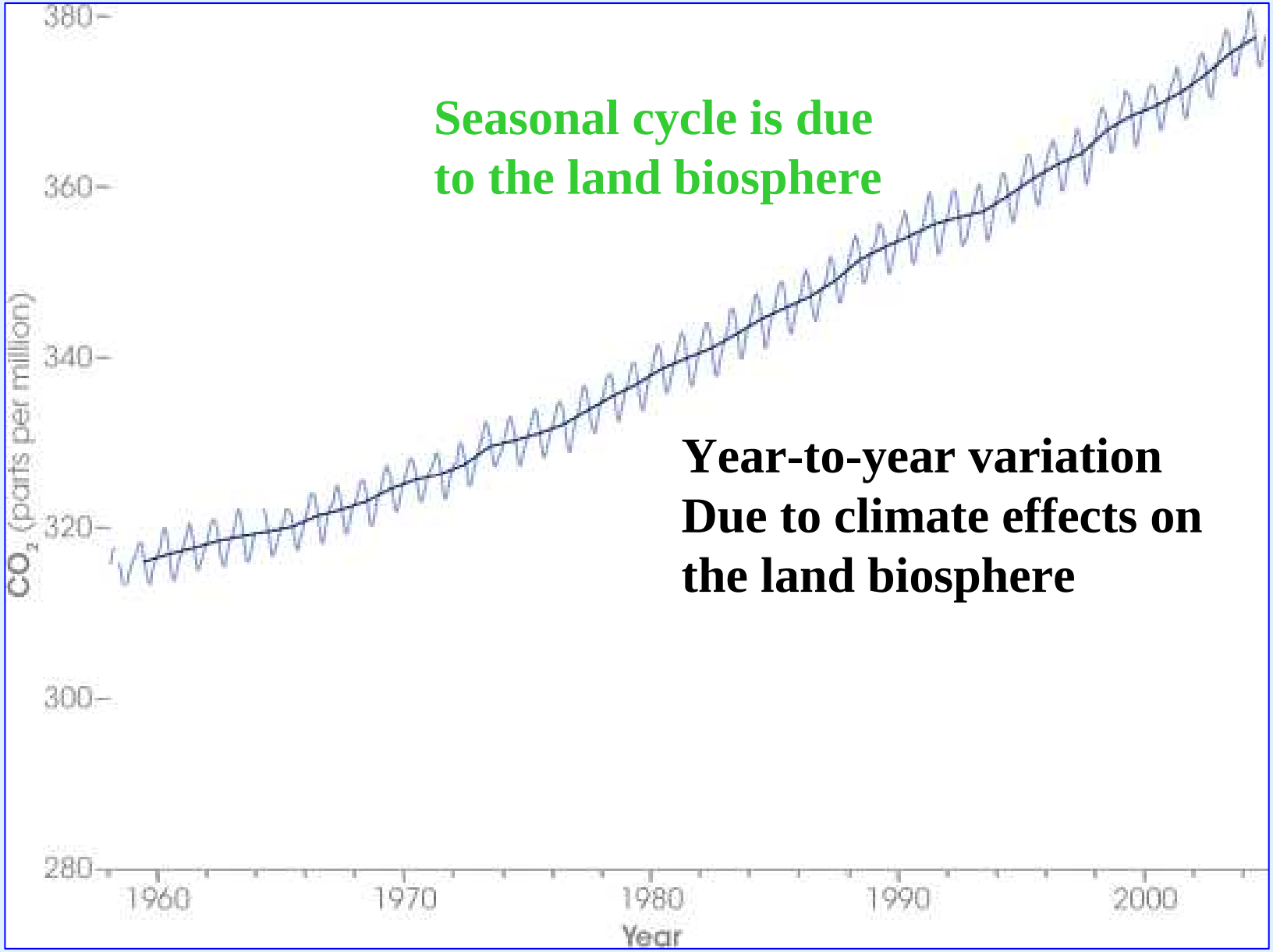
Estimated Global Carbon Balance for 2000-2005 (IPCC AR4)

The Carbon Cycle and Climate Change

- Currently only about half of human emissions of CO_2 remain in the atmosphere - the ocean and land ecosystems are absorbing the remainder.

- Atmosphere-land and atmosphere-ocean fluxes of CO_2 are sensitive to climate.

The “Keeling Curve”



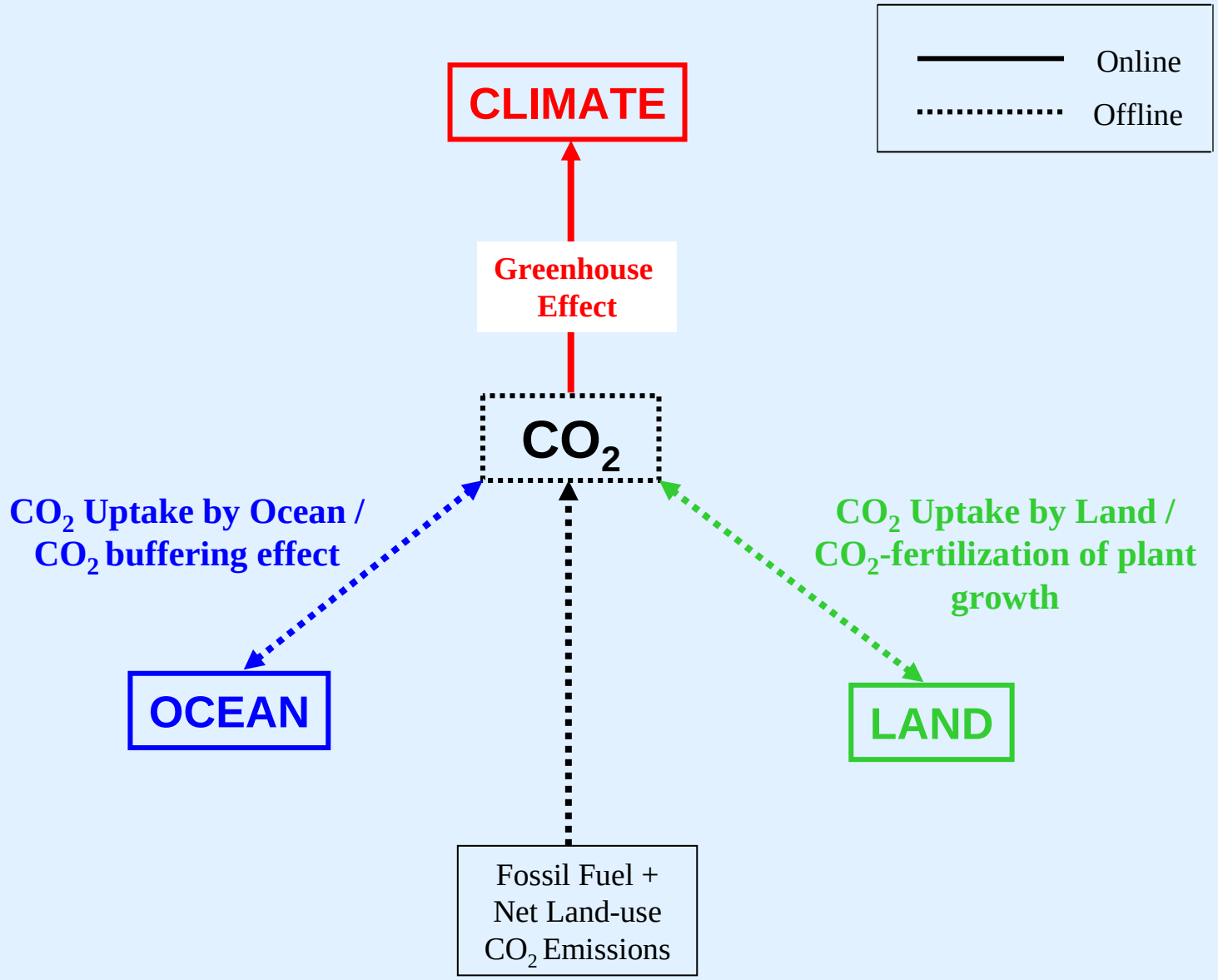
The Carbon Cycle and Climate Change

- Currently only about half of human emissions of CO_2 remain in the atmosphere - the ocean and land ecosystems are absorbing the remainder.

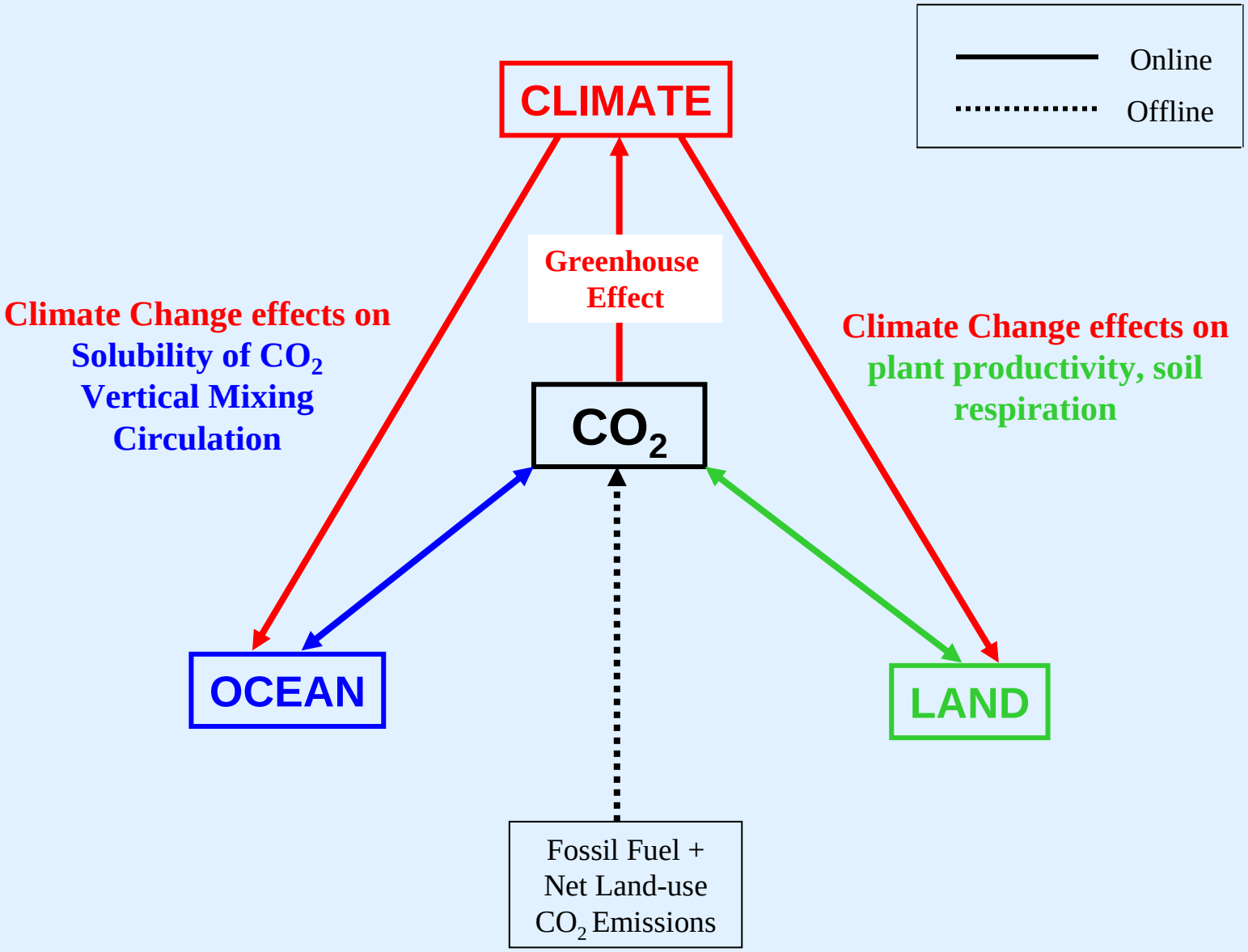
- Atmosphere-land and atmosphere-ocean fluxes of CO_2 are sensitive to climate.

- Most climate models prescribe atmospheric CO_2 and therefore neglect climate-carbon cycle feedbacks.

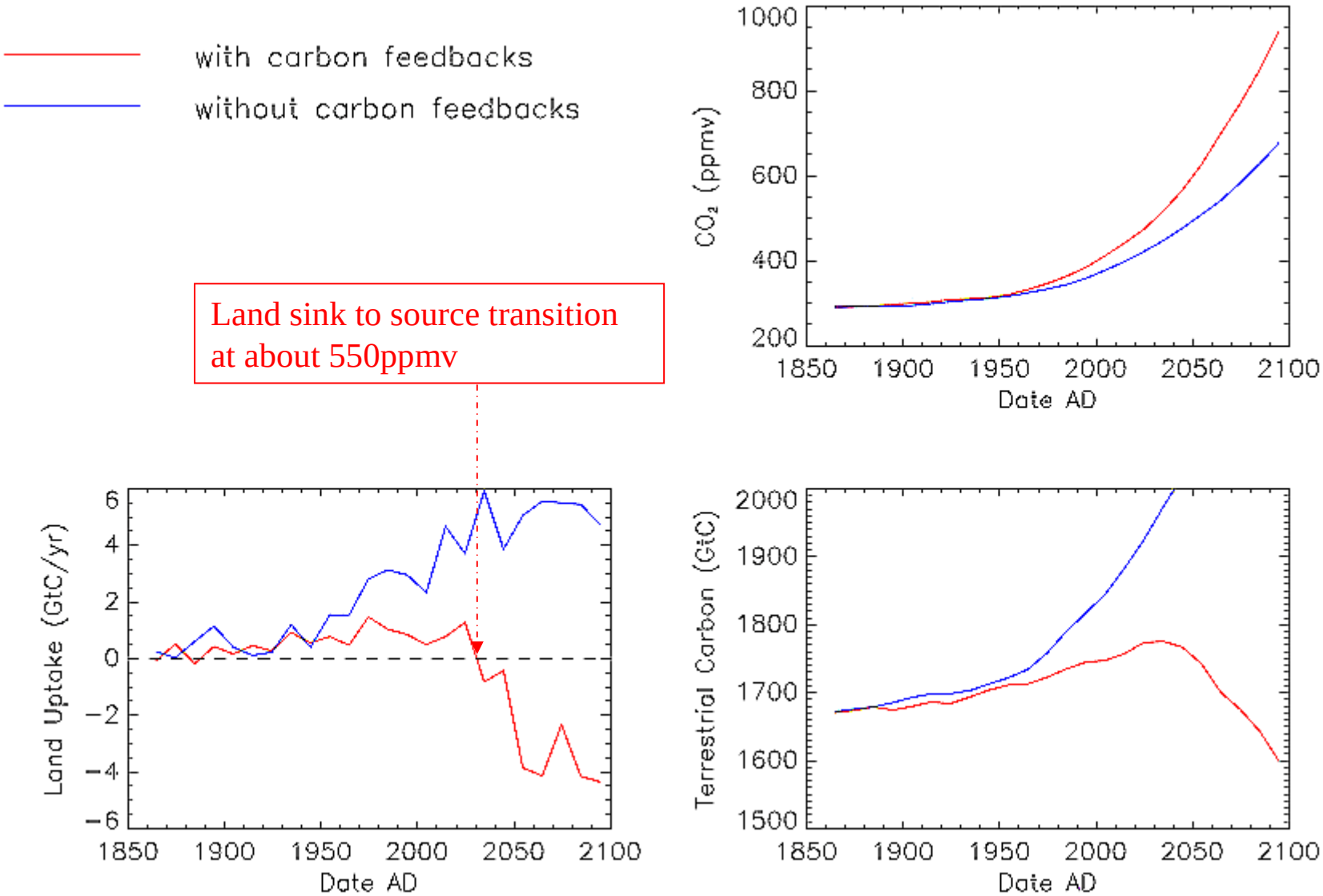
Standard Climate Change Predictions



Climate Change Predictions including Carbon Cycle Feedbacks



Modelled Impact of Climate-Carbon Cycle Feedbacks on Future CO_2 and Land Carbon (Cox et al., 2000)



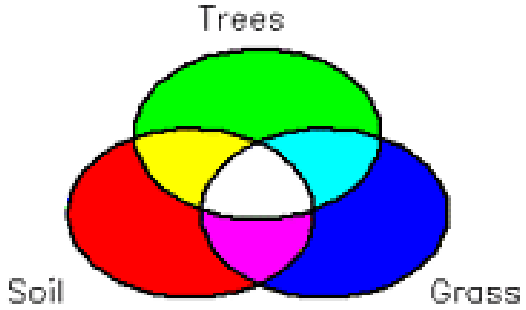
Transient Changes in Vegetation Distribution

Primary colours denote land cover type increases of > 1% of area:

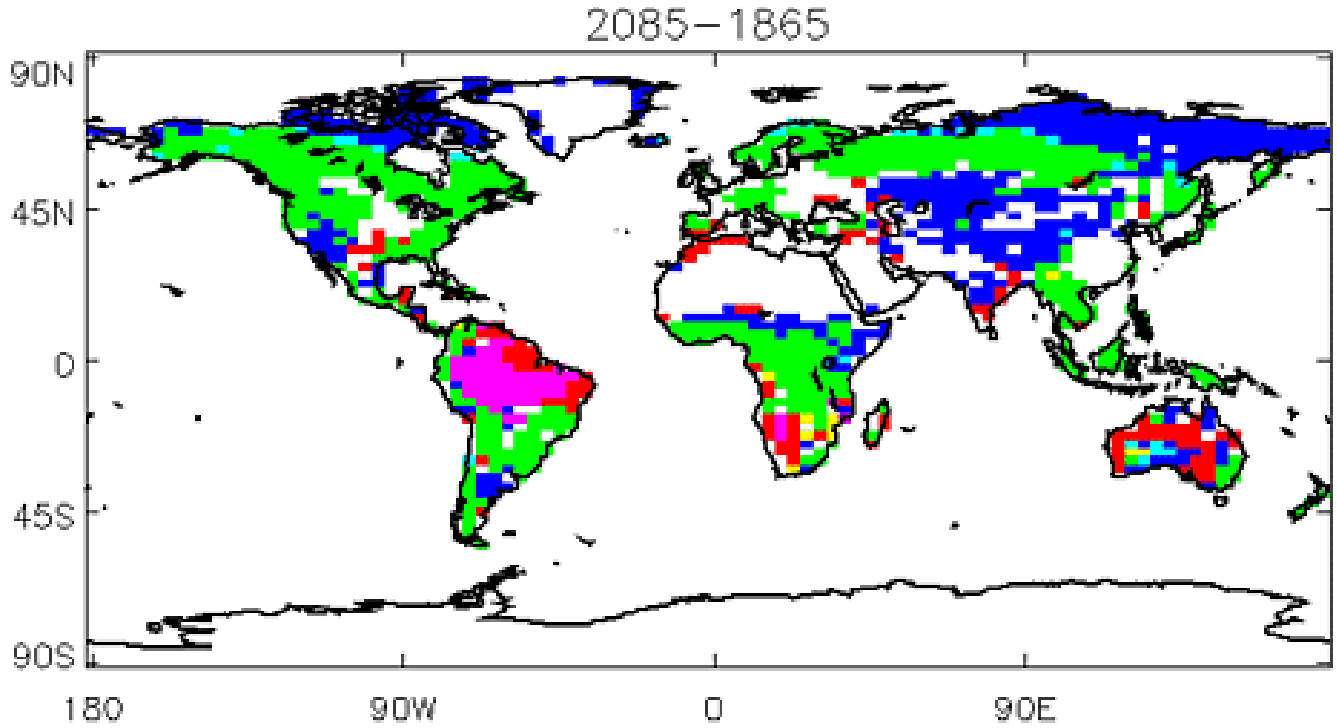
- green – trees (broadleaf + needleleaf)
- blue – grass (C3 + C4 + shrub)
- red – bare soil

Secondary colours denote a combination of changes

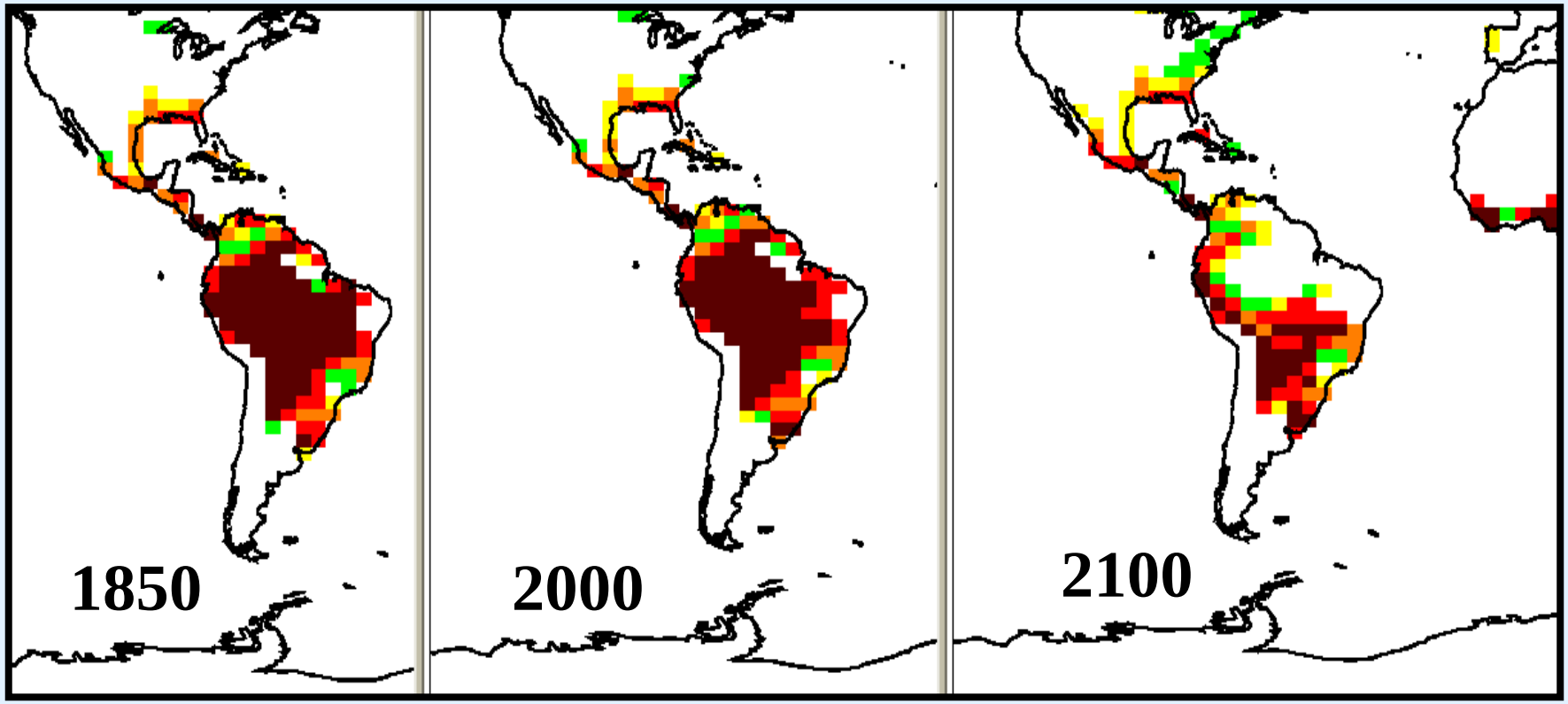
- e.g. magenta = savanna (grass/shrub and soil mix)



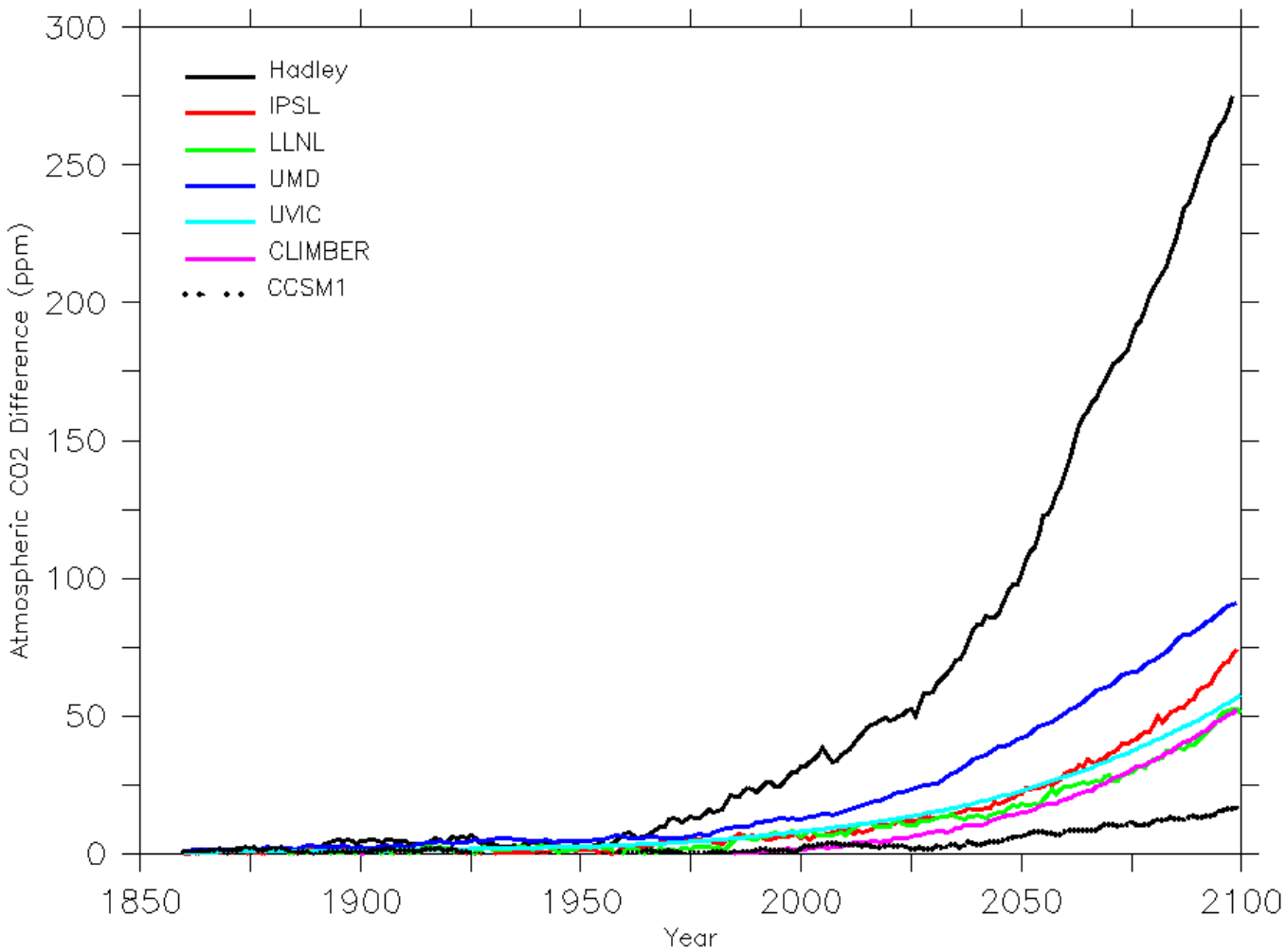
note the northward propagation of the boreal forests, and replacement of the Amazon rainforest, first by savanna, then by bare soil



Prediction of Amazonian Forest Dieback due to Climate Change

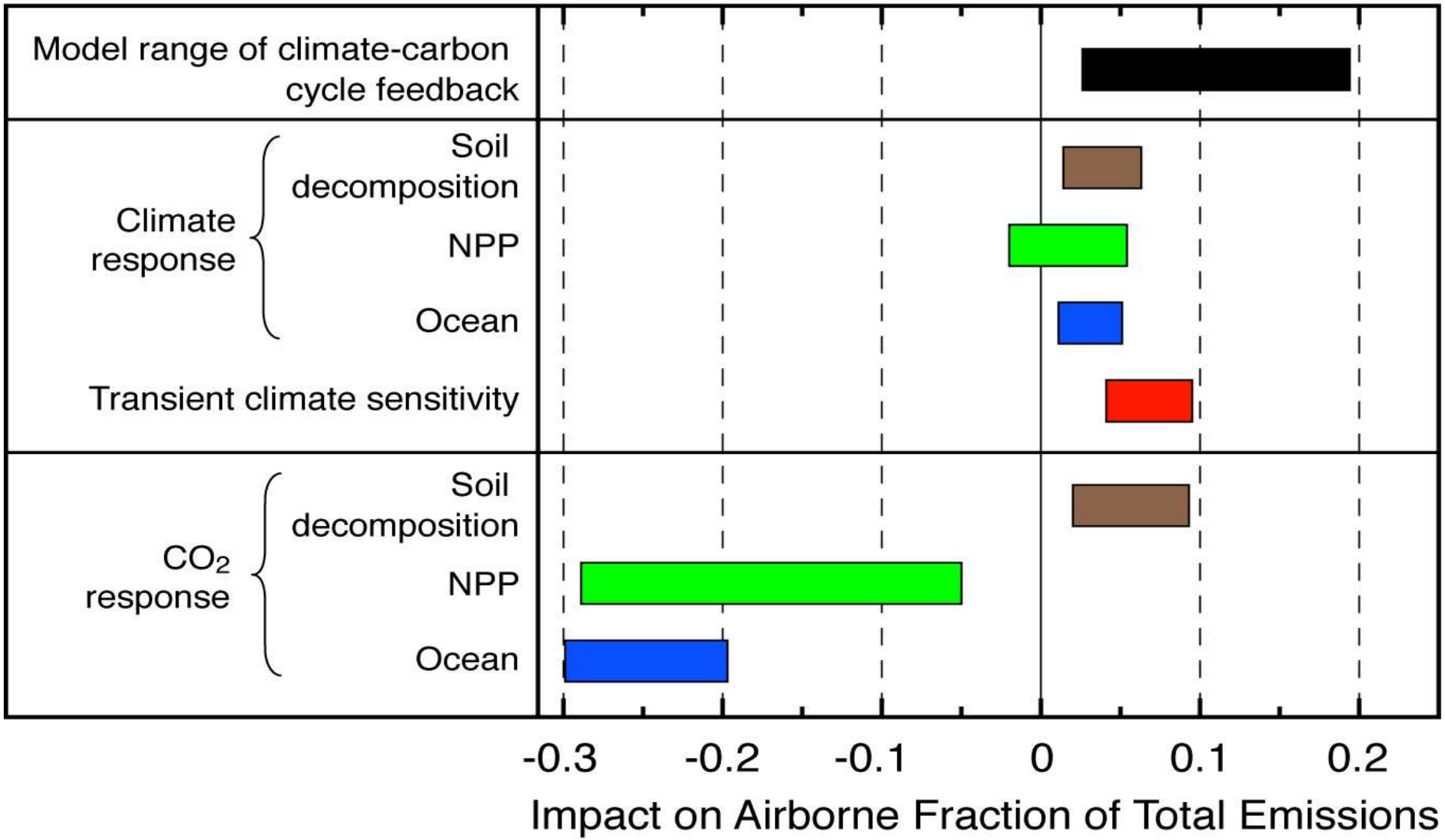


Predictions of extra CO_2 due to climate effects on the carbon cycle



All models simulate a positive feedback, but with very different magnitudes..

Uncertainties in Carbon Cycle Feedbacks



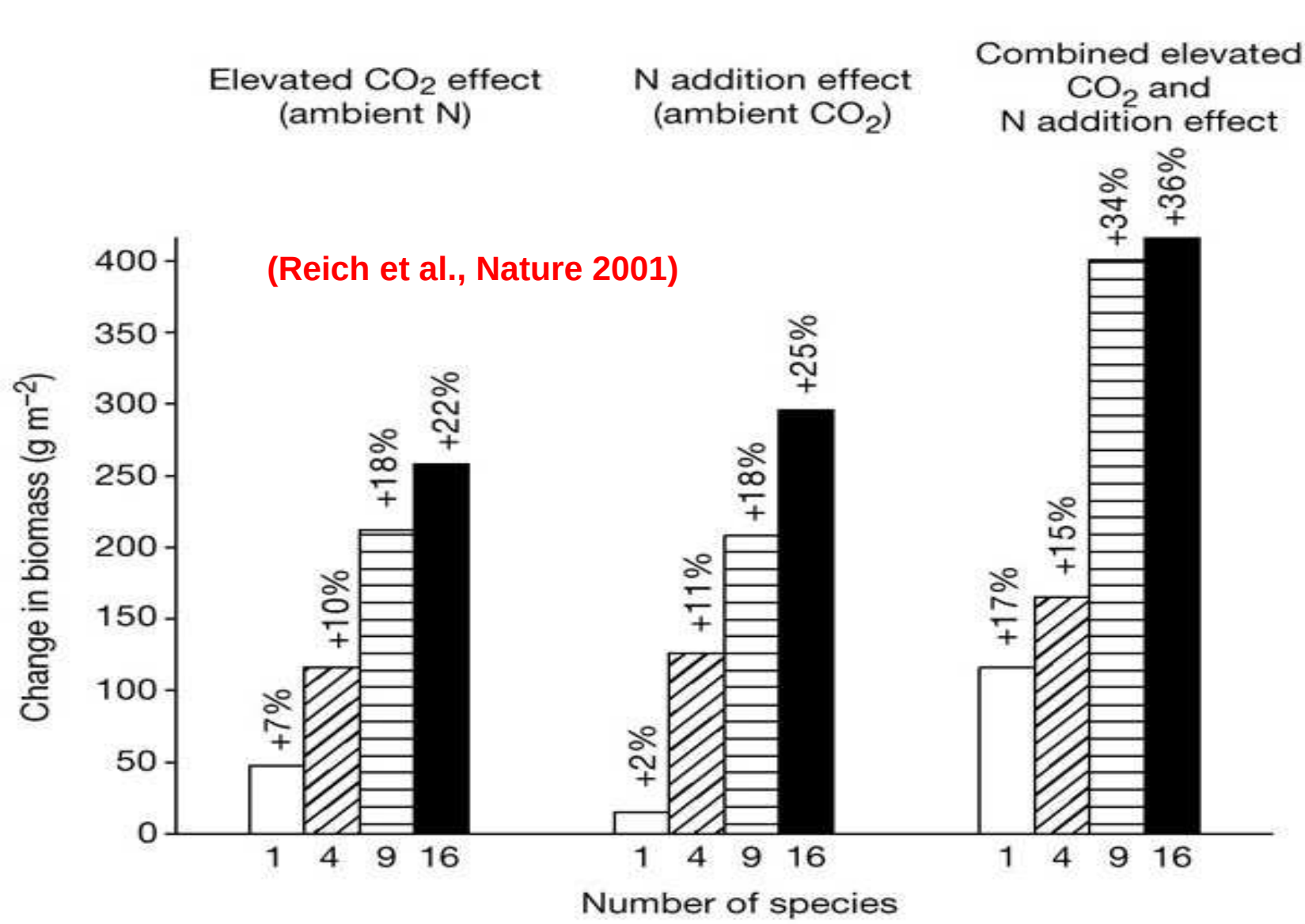
Biodiversity and Ecosystem Resilience

- Biodiversity underlies the goods and services provided by ecosystems that are crucial for human survival and well being.

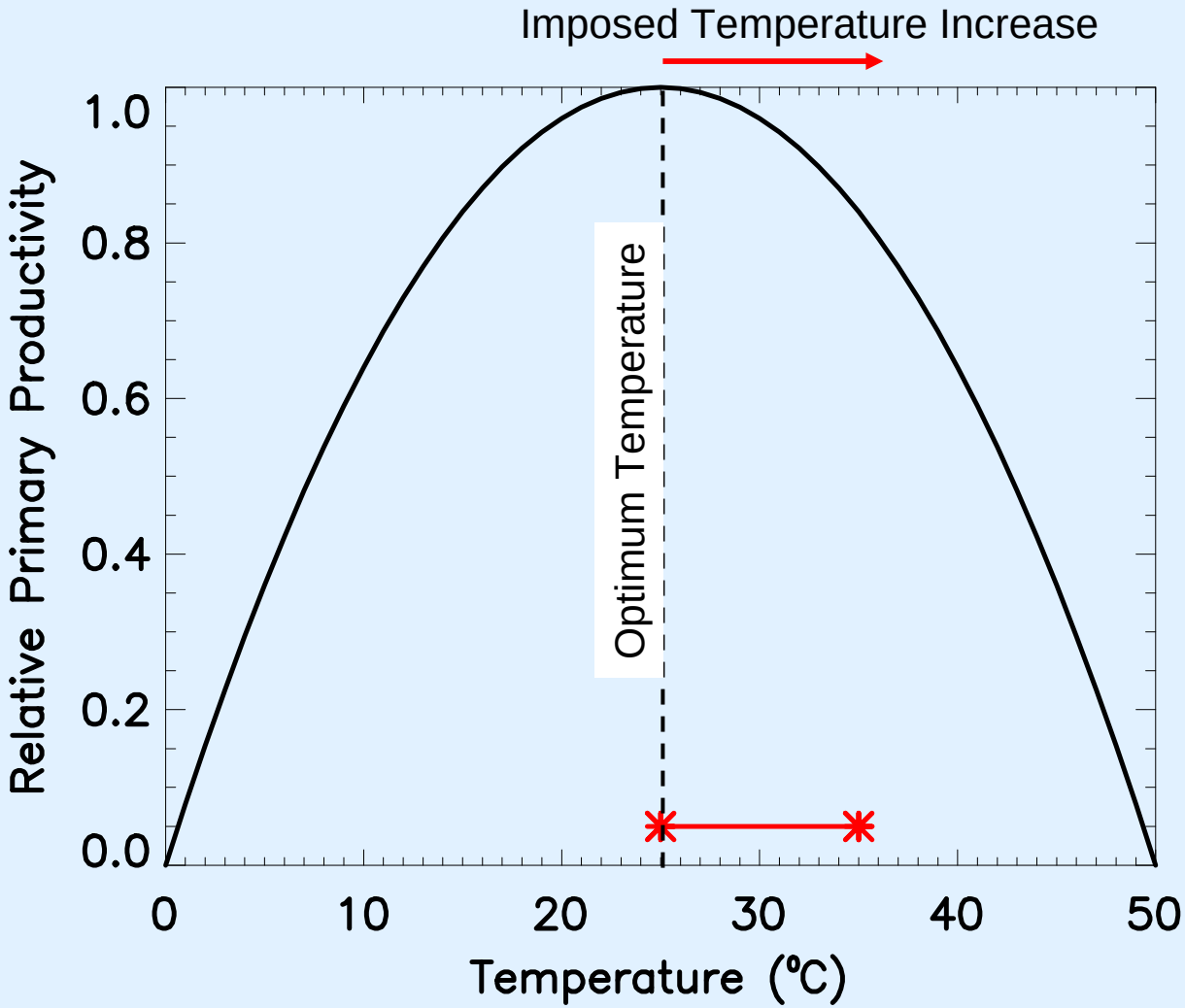
- For a given ecosystem, functionally diverse communities are more likely to adapt to climate change and climate variability than impoverished ones.

Source: Convention on Biodiversity webpages

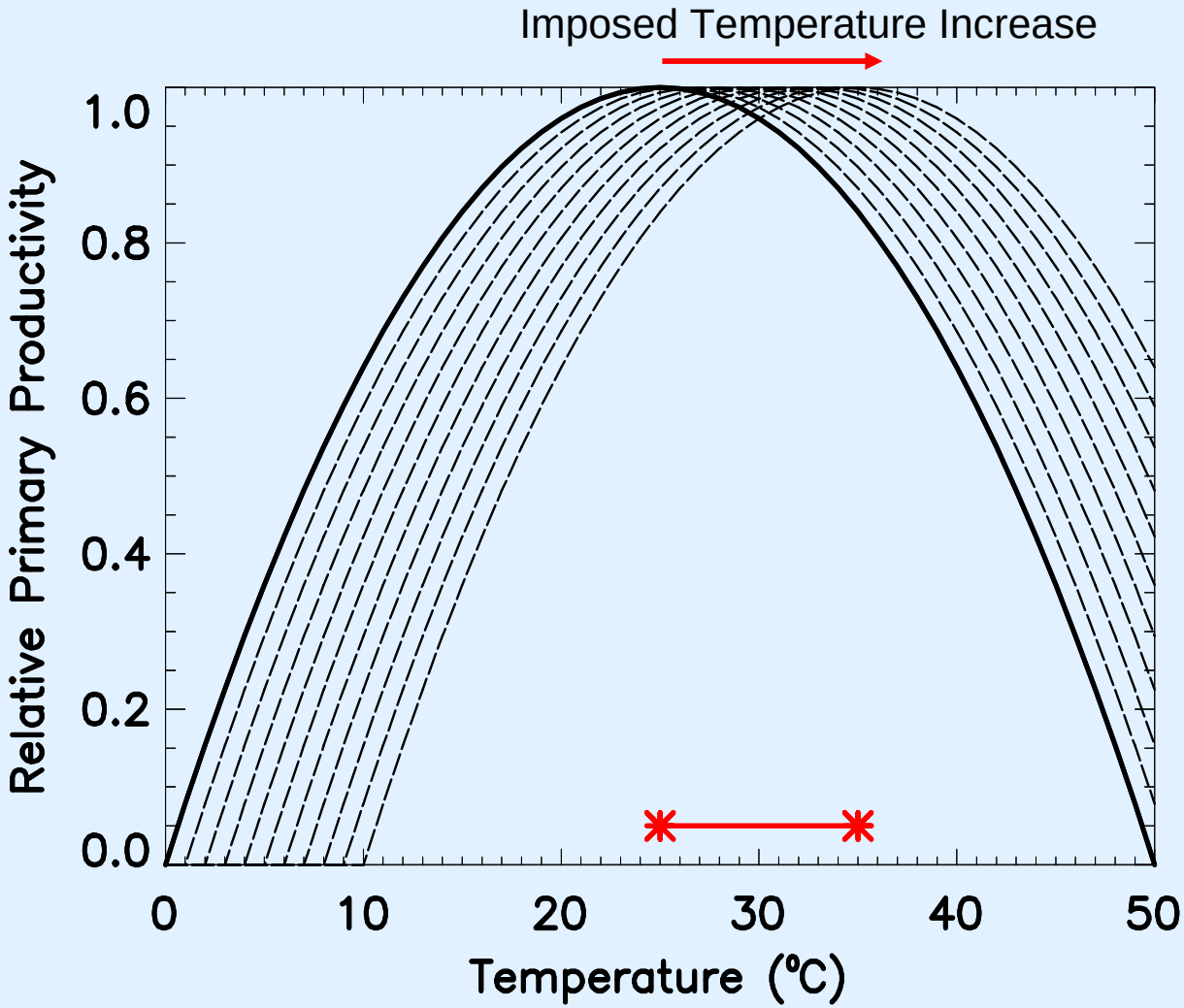
Plant diversity enhances ecosystem responses to elevated CO_2 and nitrogen deposition



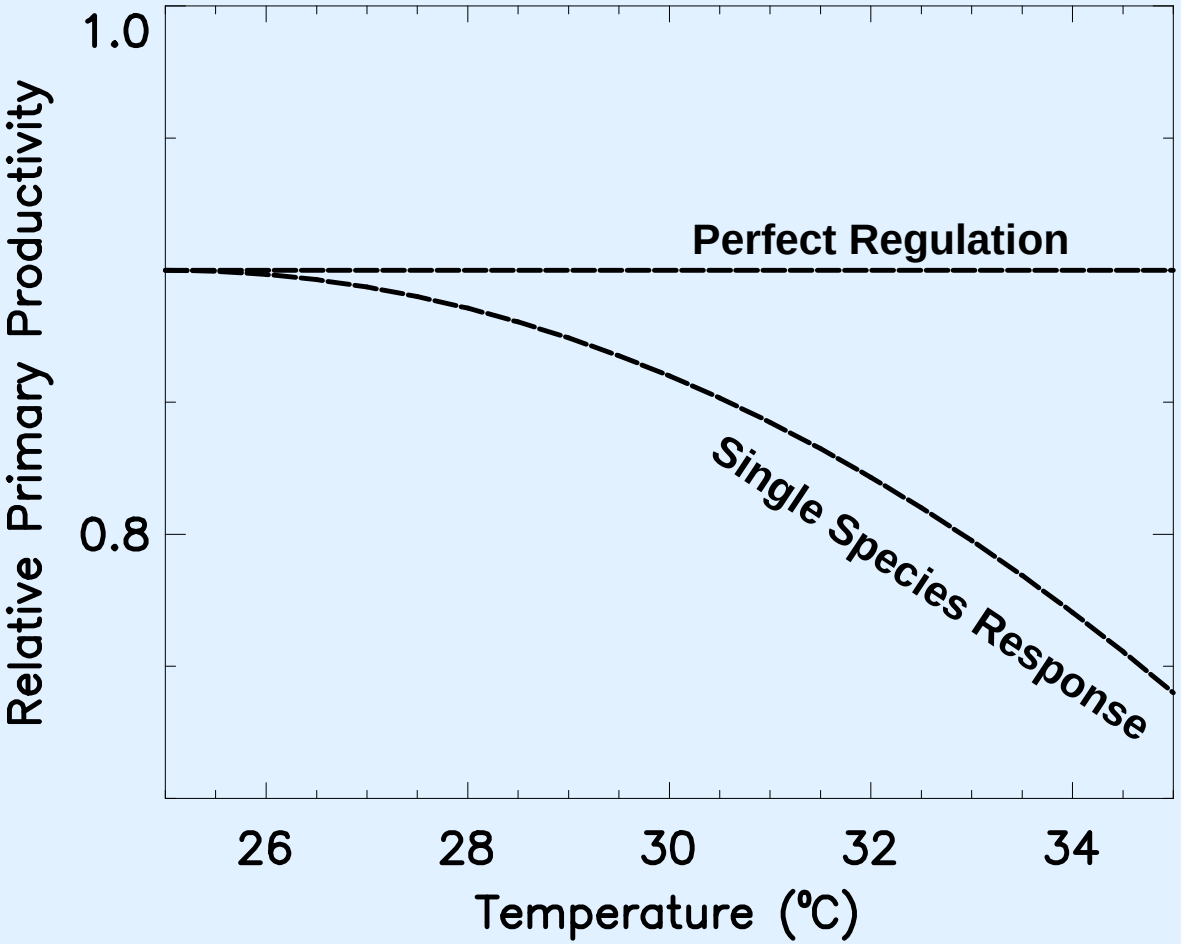
Schematic of Single Species Response to Climate



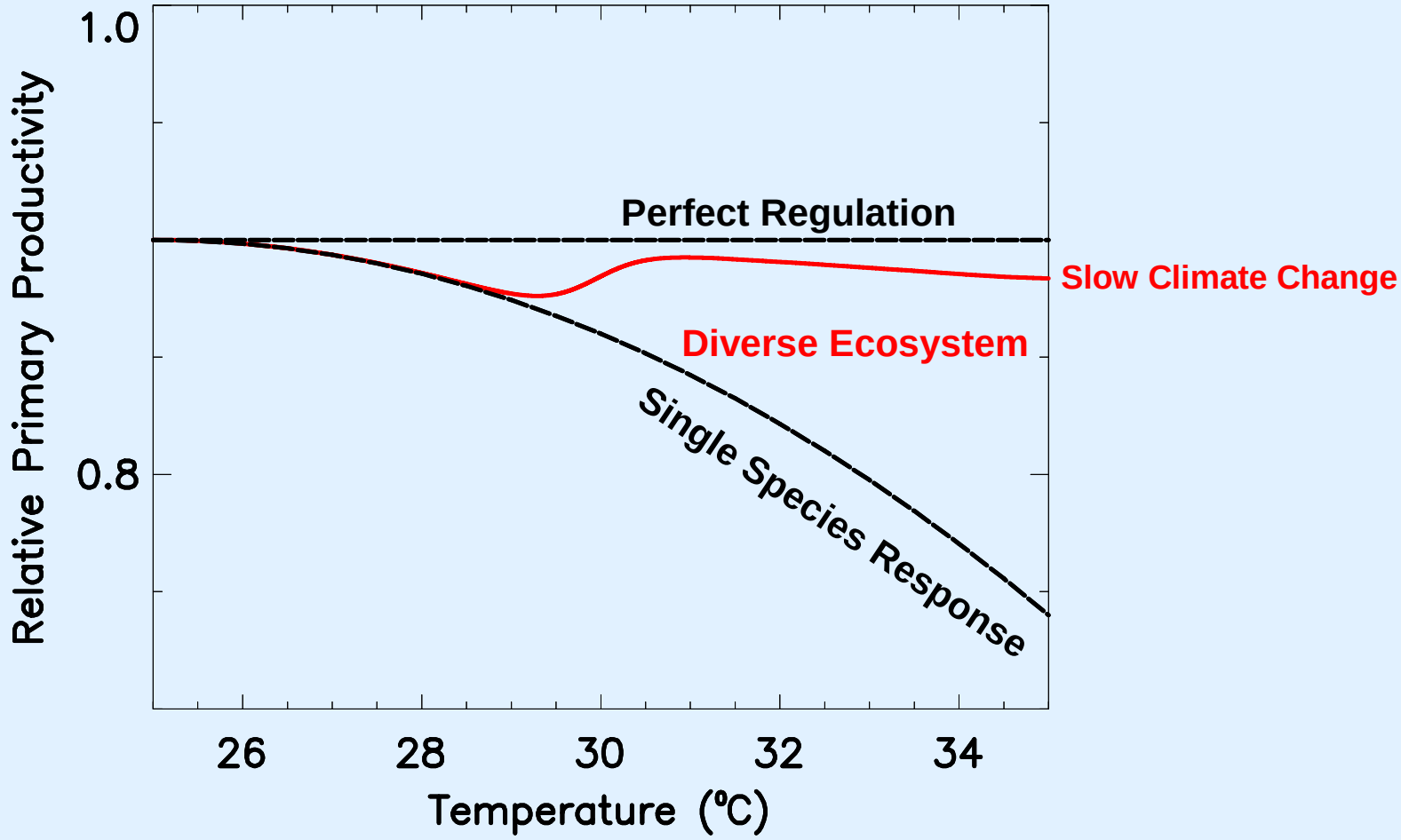
Schematic of a "Diverse Ecosystem" Response to Climate



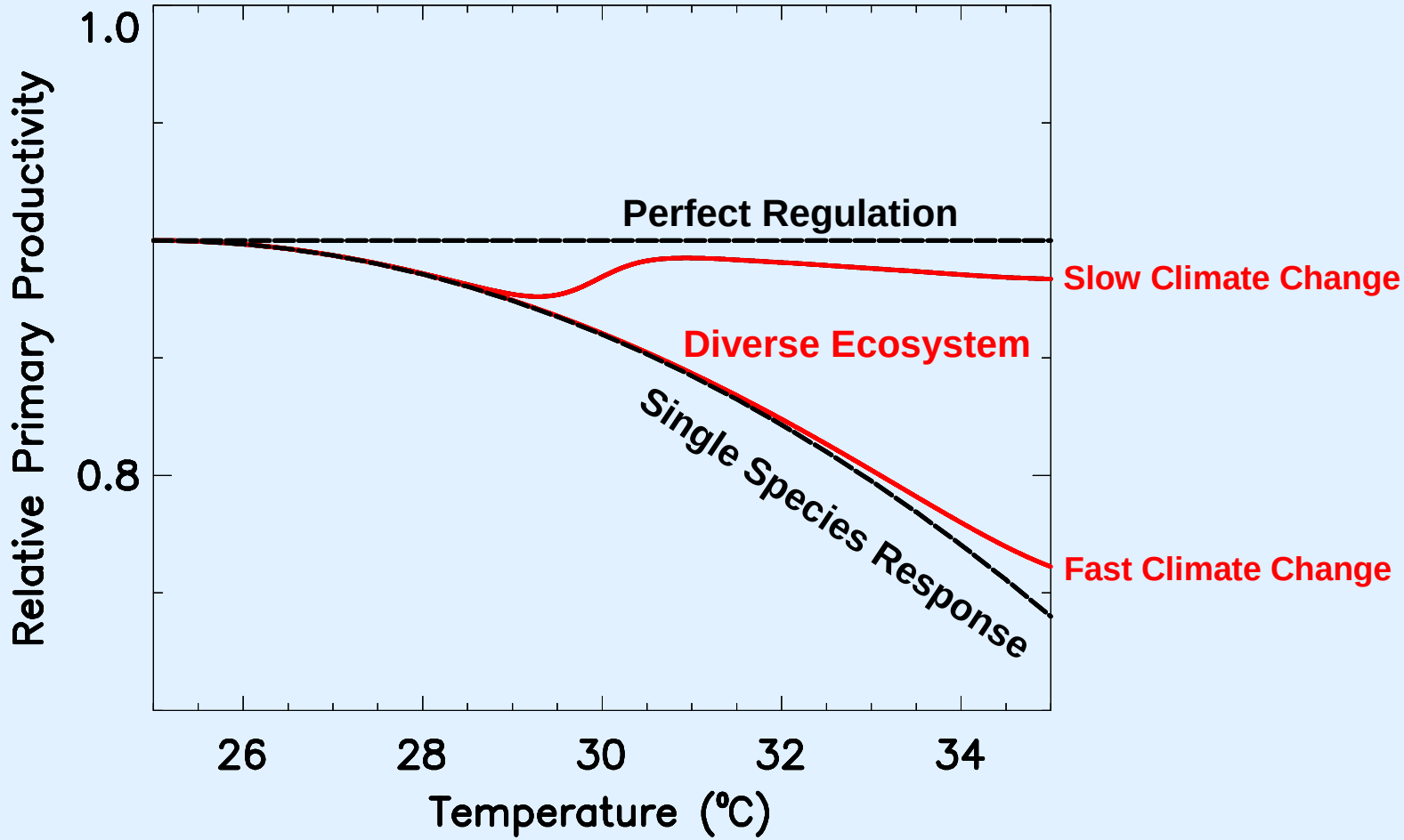
Schematic Sensitivity of Primary Productivity to Climate



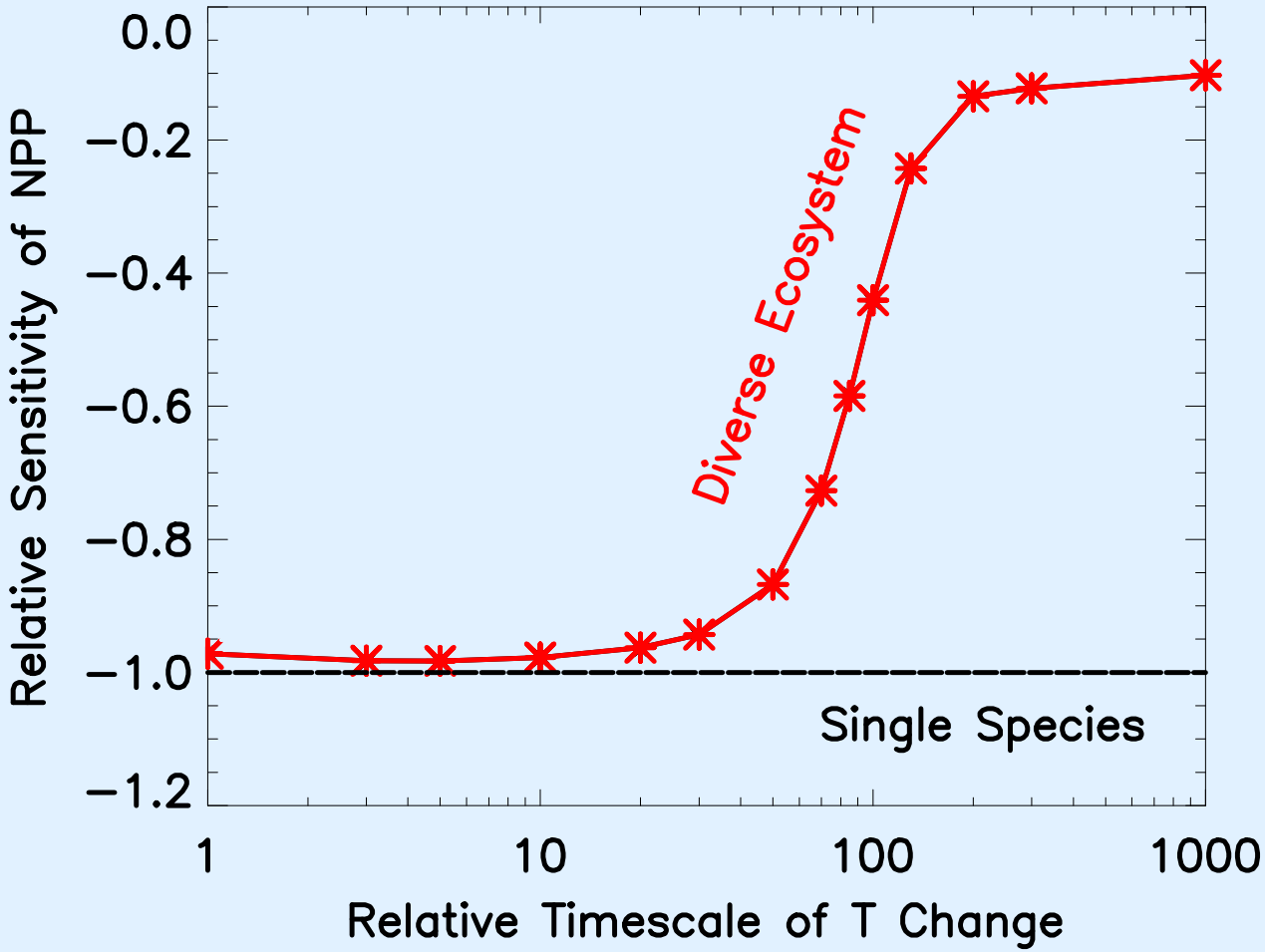
Impact of Diversity on Sensitivity of Primary Productivity to Climate Change



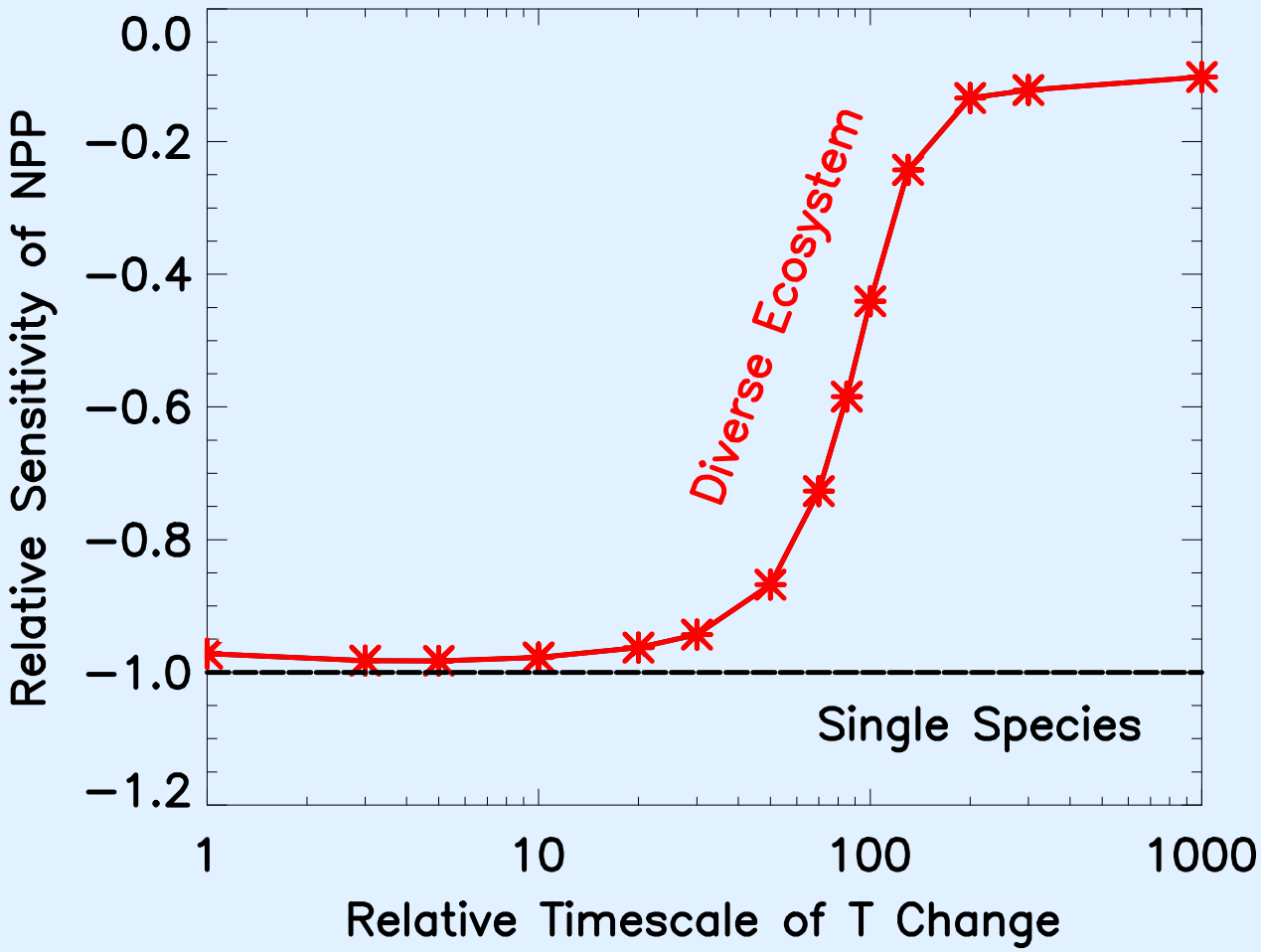
Impact of Diversity on Sensitivity of Primary Productivity to Climate Change – Importance of Rate of Change



Sensitivity of Primary Productivity to Temperature versus Timescale of Climate Change



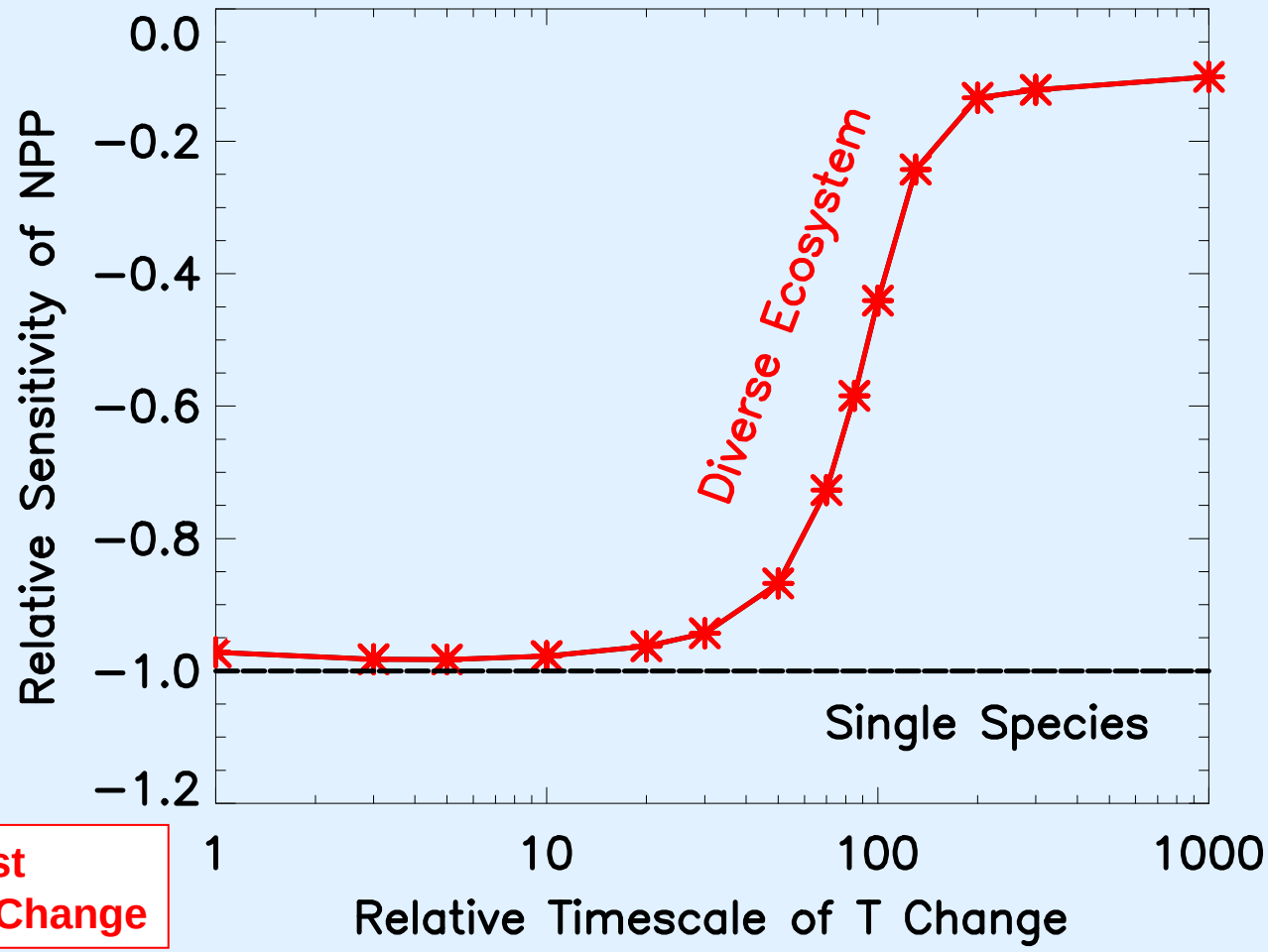
Diversity leads to greater resilience (i.e. less sensitivity) to climate change…



High Resilience

Low Resilience

Diversity leads to greater resilience (i.e. less sensitivity) to climate change…



Fast Climate Change

Slow Climate Change

…but only if the climate change is slower than the ecosystem adaptation timescale

Conclusions

- Ecosystems play important roles in the climate system ranging from the impact of land plants on the albedo of the land-surface and the intensity of the hydrological cycle, to the influence of ocean and land ecosystems on the long-term evolution of Earth's atmospheric composition.

- In the context of contemporary climate change, the "natural" carbon cycle is currently providing a vital service for humankind by absorbing about 50% of anthropogenic CO_2 emissions.

- Ecosystem processes are responsible for the land carbon sink and much of the ocean carbon sink, so changes in biodiversity have the potential to affect the rate of future climate change by affecting the land and ocean carbon sinks.

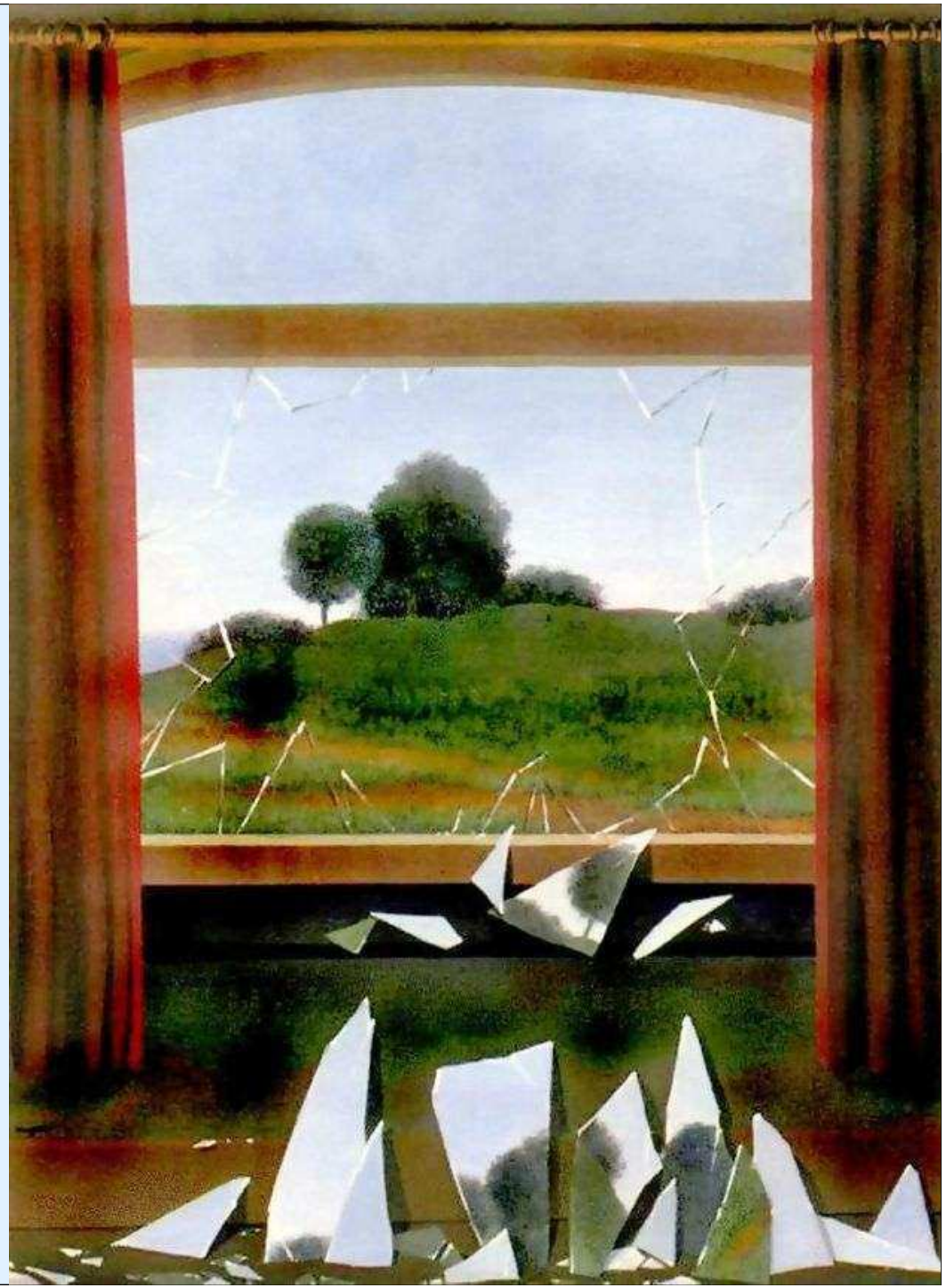
- First generation coupled climate-carbon cycle models suggest that natural carbon sinks (especially on the land) may be vulnerable to climate change, which implies a higher airborne fraction of anthropogenic CO_2 emissions in the future and faster climate change.

Conclusions

- Some models (most notably the Hadley Centre HadCM3-based models) also suggest that climate change could lead to “dieback” of the Amazonian rainforest, with potentially devastating impacts on biodiversity.

- However, coupled climate-carbon cycle models currently have a small number of plant functional types (typically 5 to 15) and an even smaller number of marine phytoplankton types (typically 0 to 1). It isn’t yet clear whether a better representation of biodiversity would lead to a greater ecosystem resilience in these models.

- Simple modelling suggests that greater biodiversity does result in greater resilience of ecosystem services (such as primary production) to climate change, but only if the rate of climate change is slow relative to the typical species lifetime.

- Therefore it is likely to be more important to model diversity in fast turnover ecosystems (such as soil microbial and marine phytoplankton communities), than in slow turnover ecosystems (such as forests).

THE END !