Plants and Climate Change

Soo-Hyung Kim, PhD

Assistant Professor

School of Forest Resources, University of Washington

Plant Science Will Save the Planet

Logo from Chicago Botanic Garden

CHICAGO BOTANIC GARDEN

Readings and Resources

- **UW Climate Impacts Group (2008)** The Washington climate change impacts assessment (http://cses.washington.edu/cig/res/ia/waccia.shtml)

- **Chapin F.S., Randerson J.T., McGuire A.D., Foley J.A. & Field C.B. (2008)** Changing feedbacks in the climate-biosphere system. *Frontiers in Ecology and the Environment,* ***6, 313-320.***

- **Walther G.R., Post E., Convey P., Menzel A., Parmesan C., Beebee T.J.C., Fromentin J.M., Hoegh-Guldberg O. & Bairlein F. (2002)** Ecological responses to recent climate change. *Nature,* ***416, 389-395.***

- **Parmesan C. (2006)** Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology Evolution and Systematics,* ***37, 637-669.***

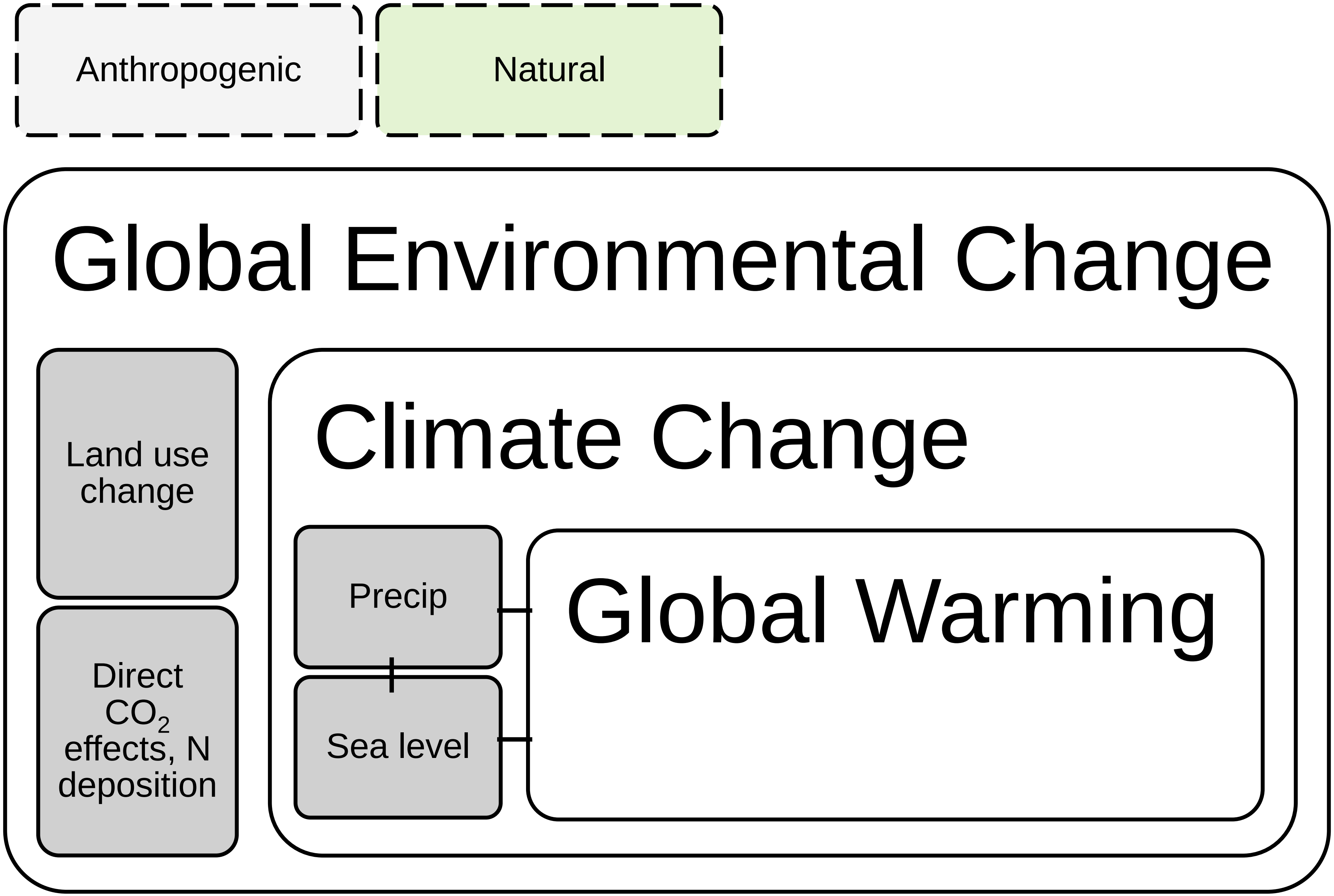
- Intergovernmental Panel on Climate Change (http://www.ipcc.ch/)

- US Global Change Research Information Office (http://www.gcrio.org/library/2008/)

Overview

- Climate change
  - Global and regional projections
  - Paleoclimate analogue
- Plant responses to climate change
  - Physiological responses
  - Ecological responses
  - Biosphere-atmosphere interactions

Climate Change, Global warming, or Global Change?



Some questions

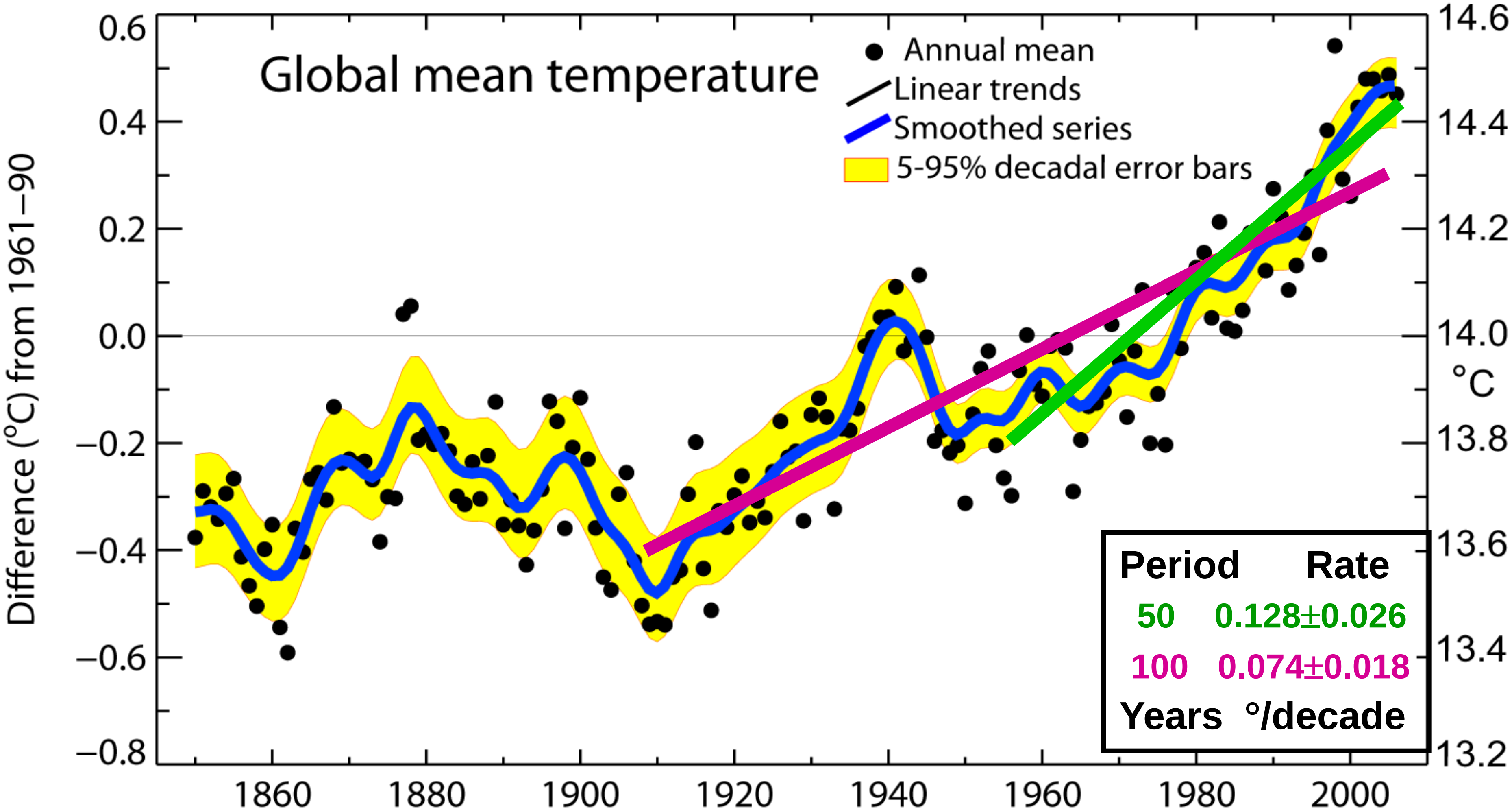
A. Is climate change happening? How?

B. Is it mostly anthropogenic?

C. What are biological and ecological implications?

D. Was there a time that earth experienced similar climate change in the past? When was it?

Global surface mean temperature



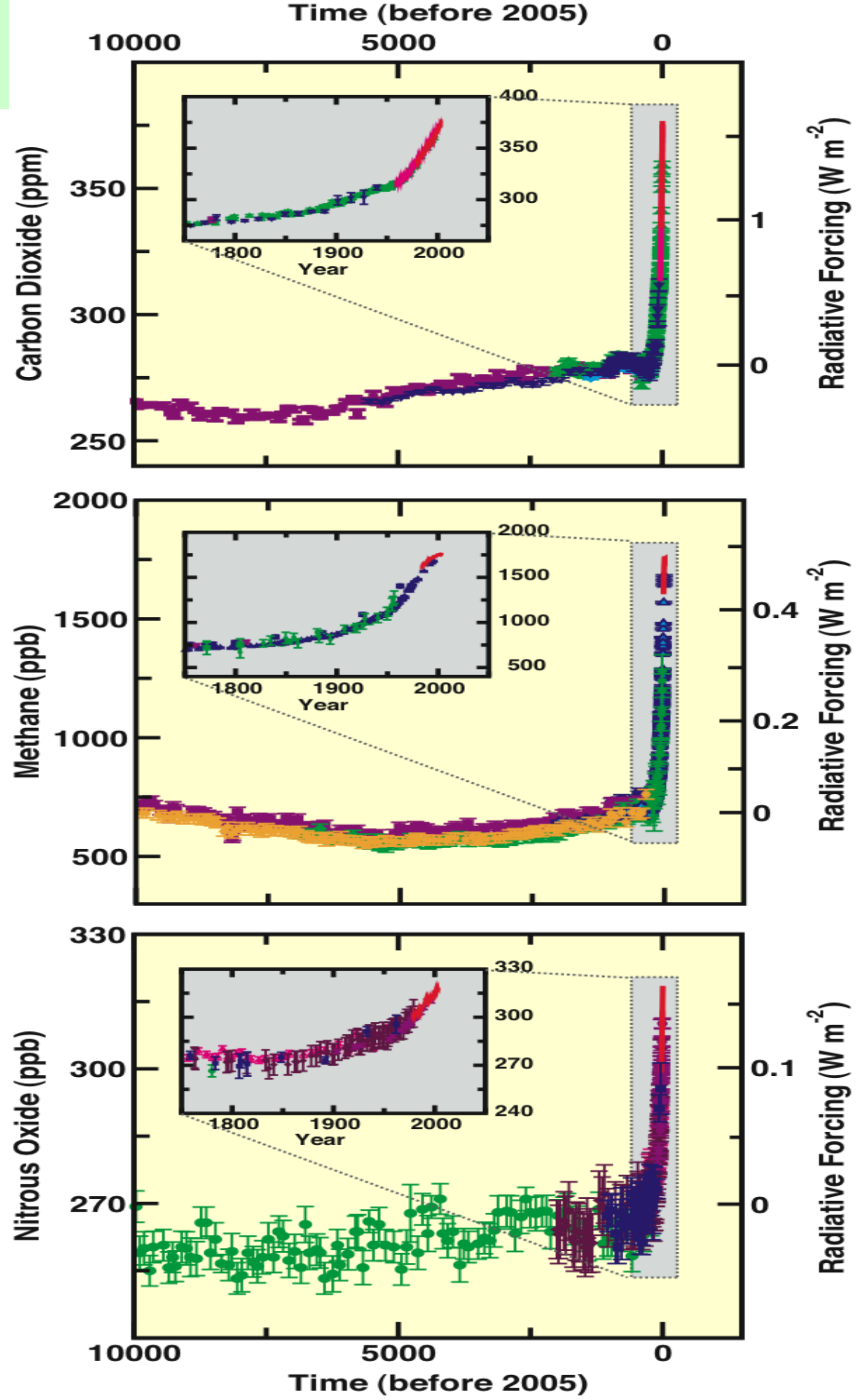
Greenhouse gases

A. Radiation absorbing gases (CO_2, CH_4, N_2O, and halocarbons) dramatically increased in last 250 years

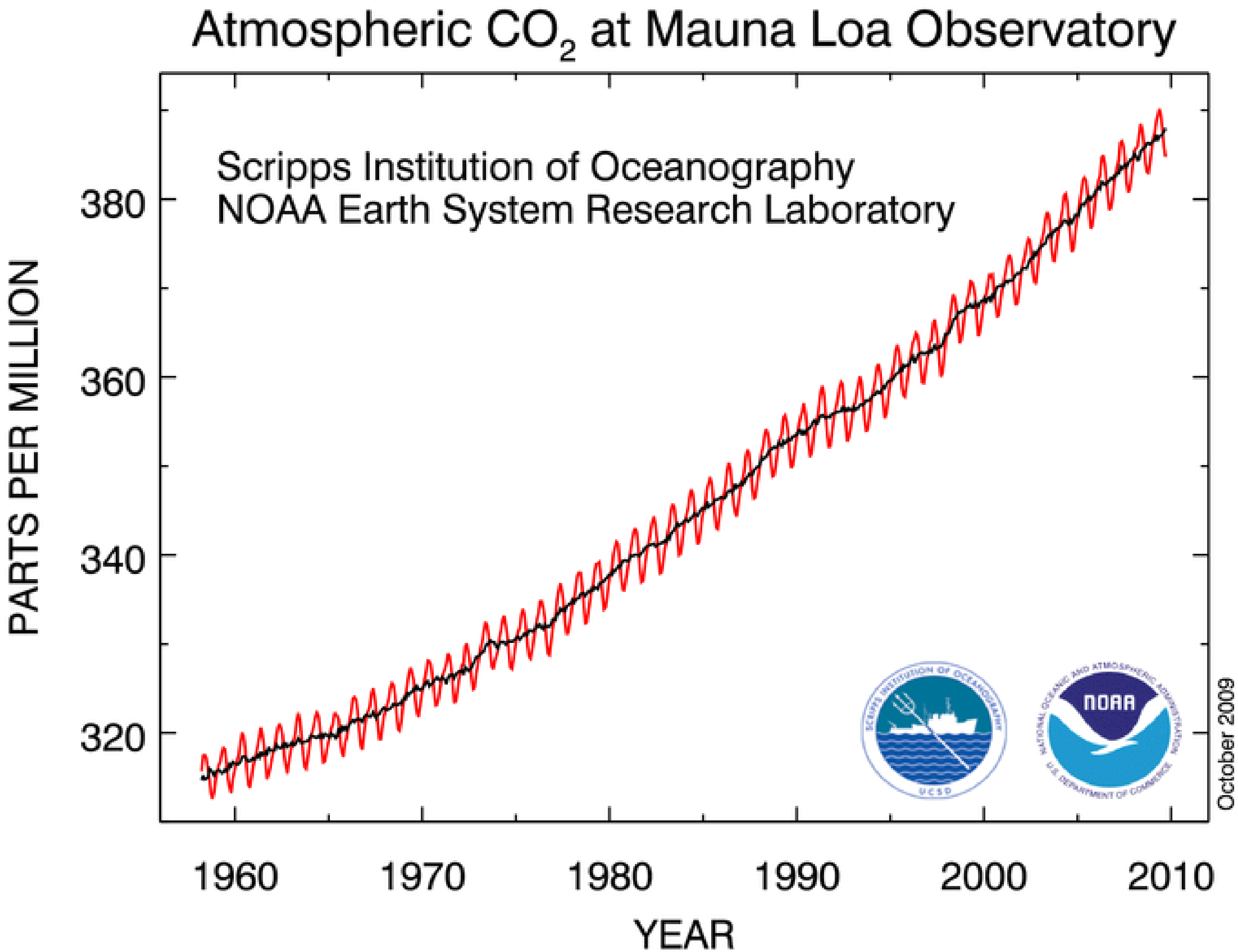
B. This results in a radiative forcing → global warming

   1. 2.4 Wm^{-2} since 1750

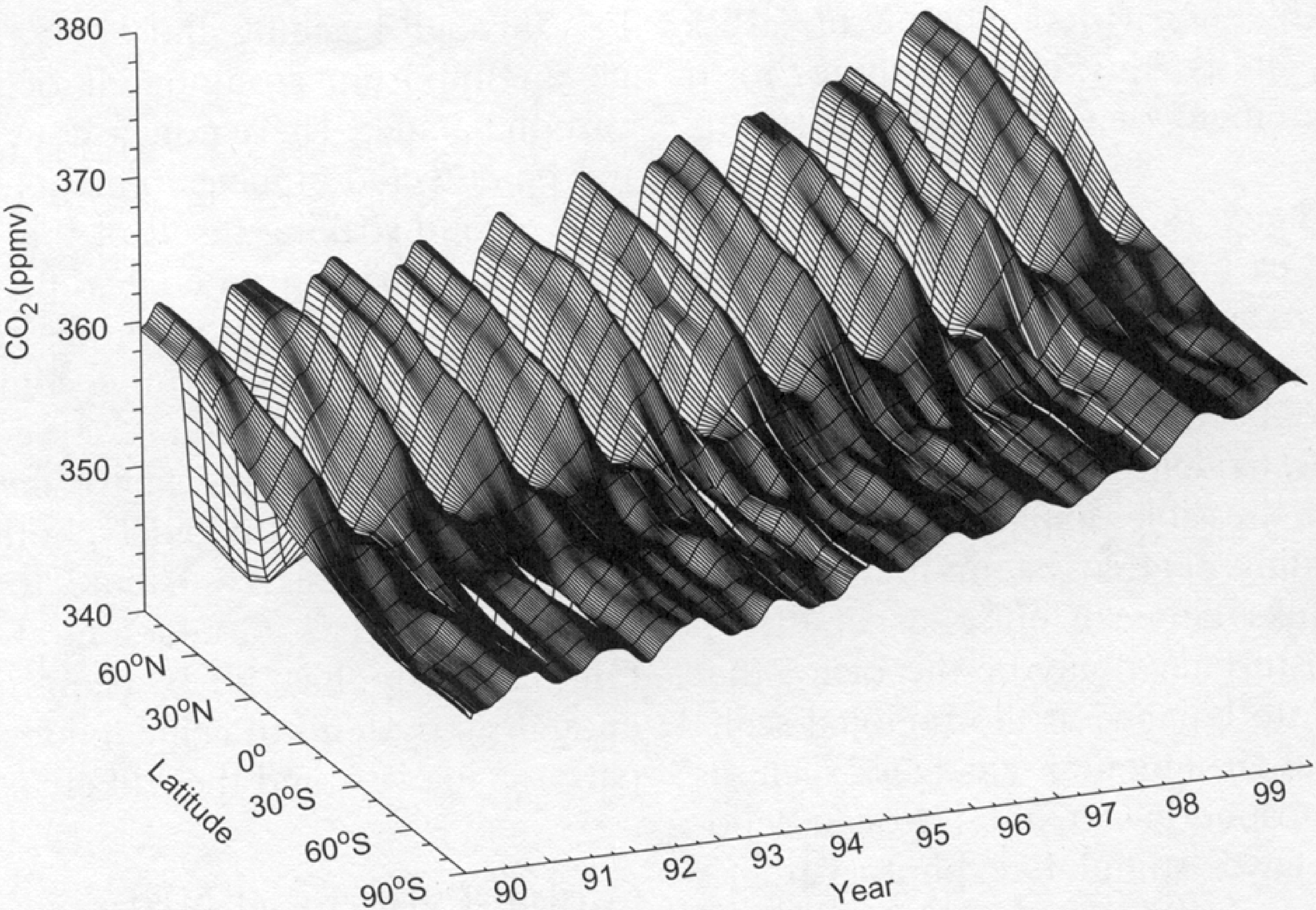
C. Is water vapor a greenhouse gas?



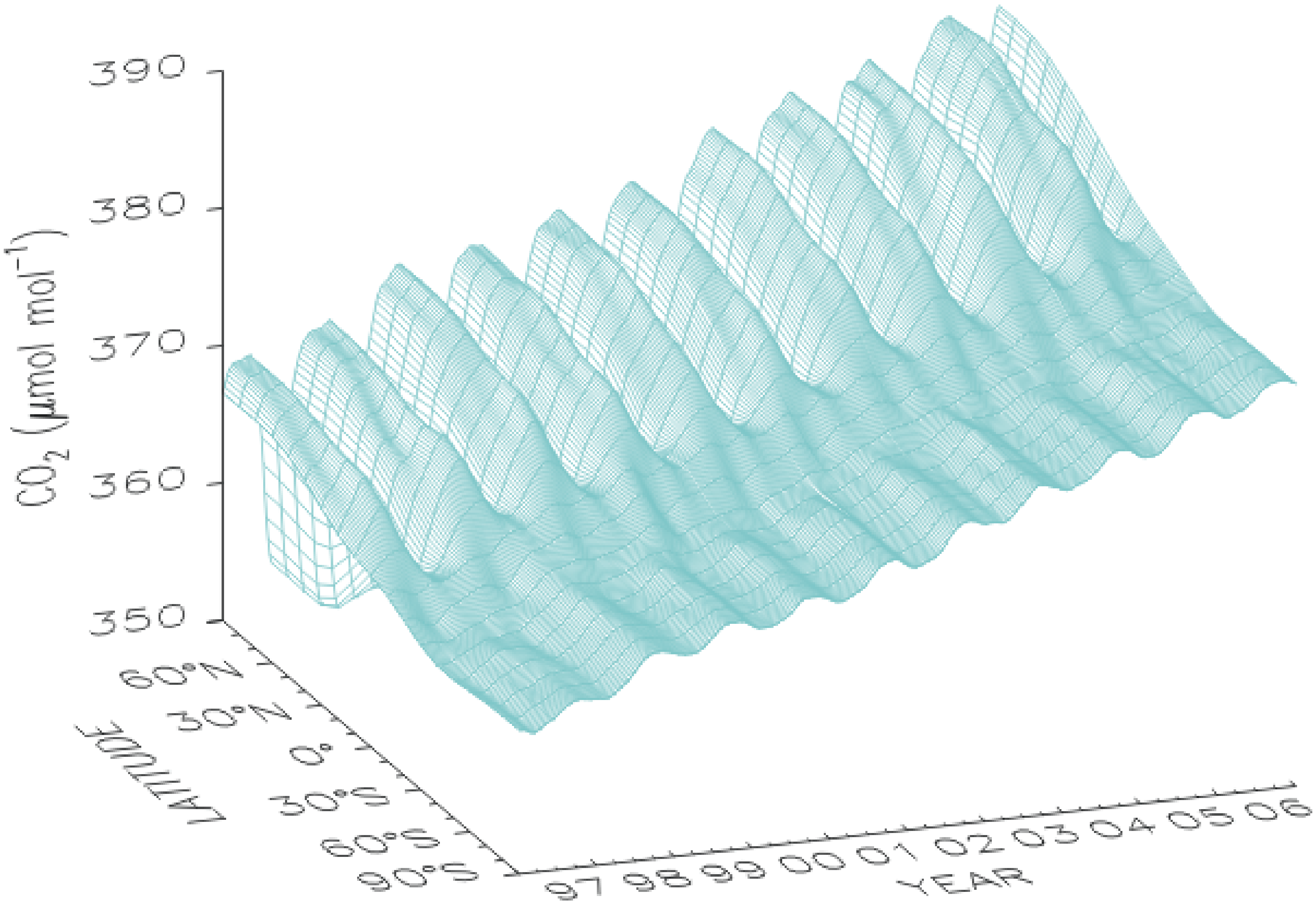
Global mean CO_2 trend



Seasonal patterns of $[CO_2]$ and latitude

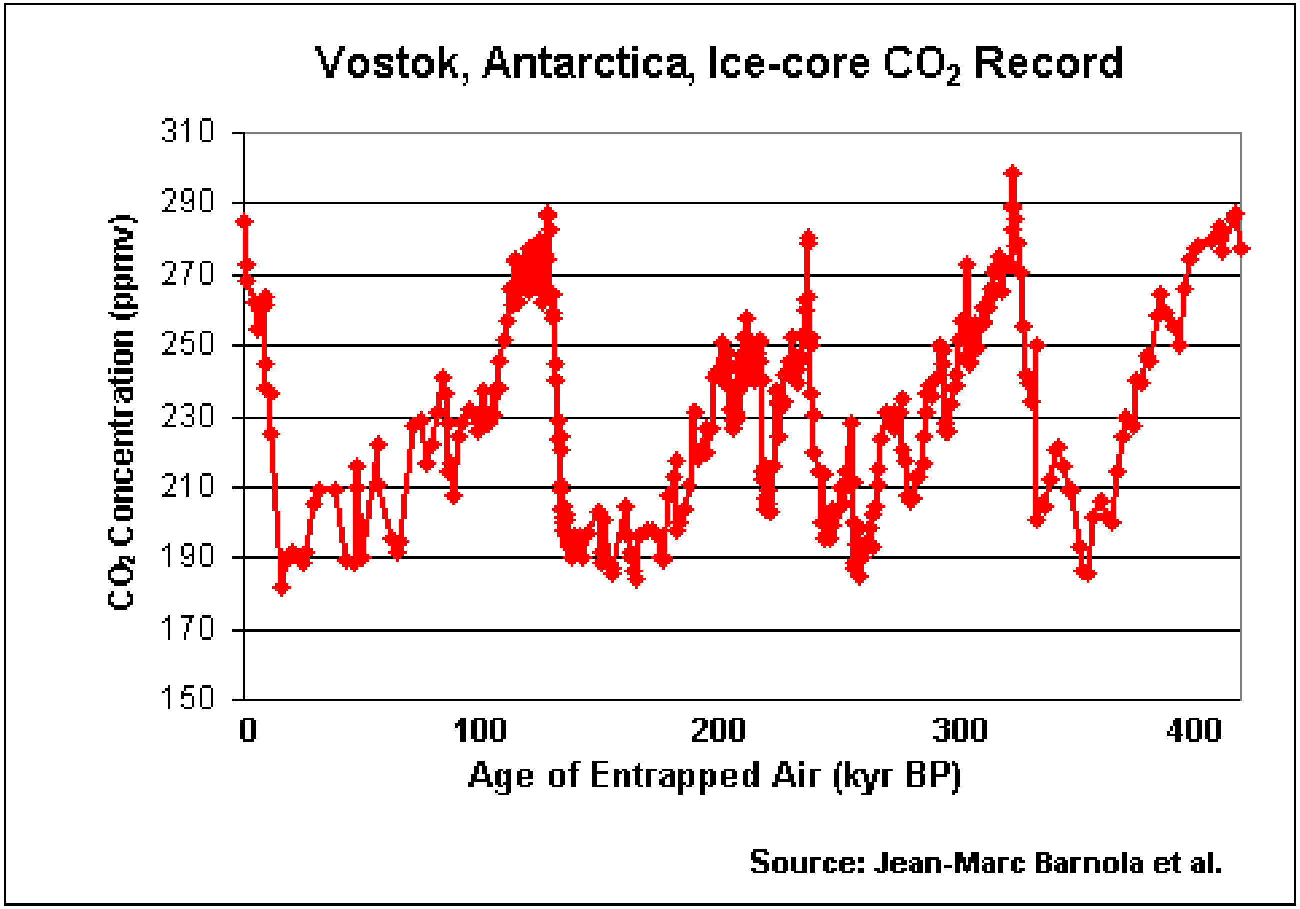


Seasonal patterns of [CO_2] and latitude (cont'd)



http://www.esrl.noaa.gov/gmd/ccgg/globalview/co2/co2_description.html

Historical CO_2 record from ice core



Future global climate projections

By 2100:

A. Emission scenarios

B. Elevated CO_2

  1. AR4: Project it to be between 730 and 1020 μmol mol^{-1}
  2. TAR: Had projected between 540 and 970 μmol mol^{-1}

C. Elevated surface air temperatures

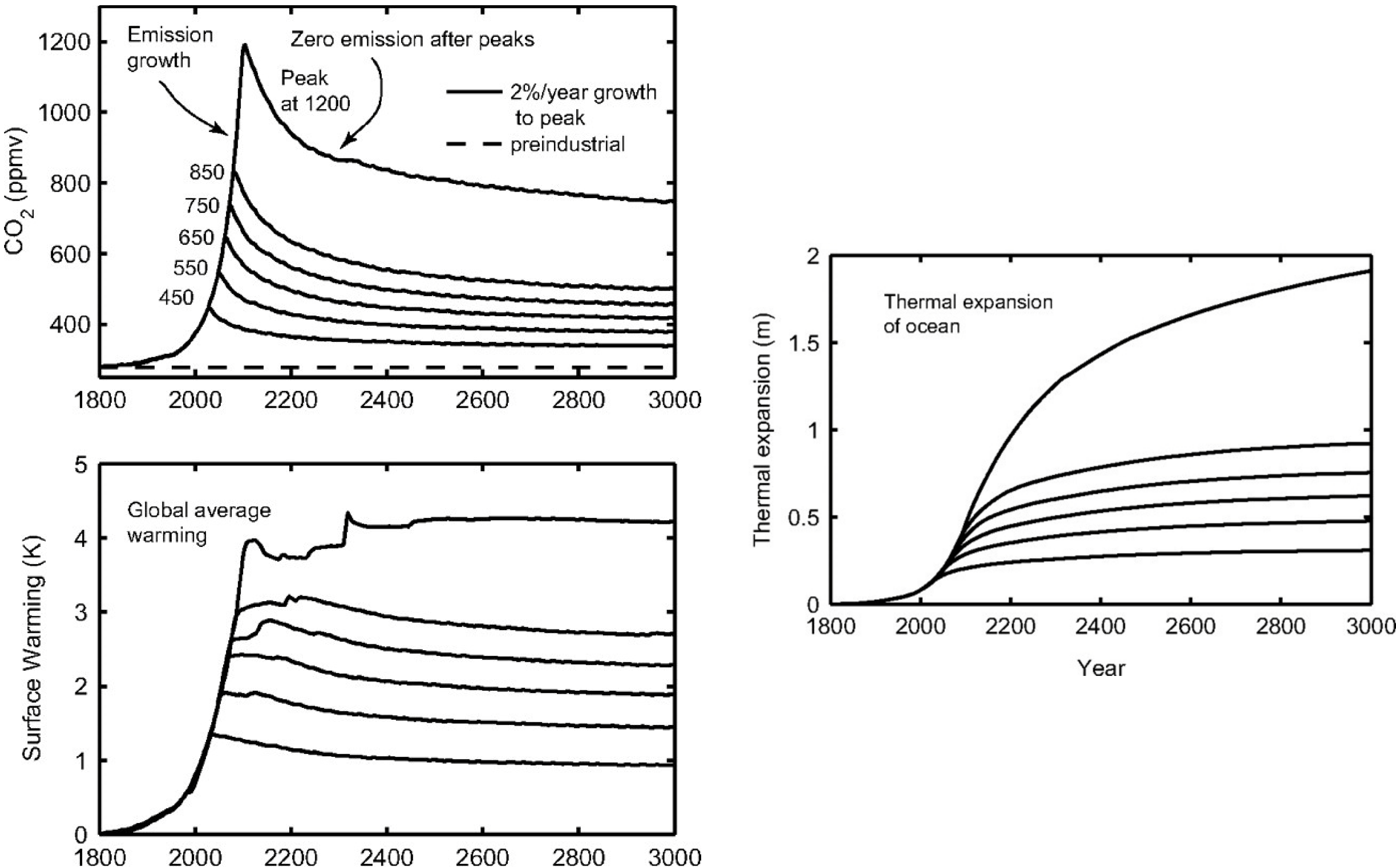
  1. Mean global warming by 1.8 to 4.0 C with associated uncertainty rages from 1.1 to 6.4 C

D. Slightly wetter in the northern hemisphere

E. More frequent and intense extreme weather events

F. The 4th IPCC Assessment Synthesis Report (Nov 17, 2007)

Carbon dioxide and global mean climate system changes



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Solomon S. et.al. PNAS 2009;106:1704-1709

PNAS

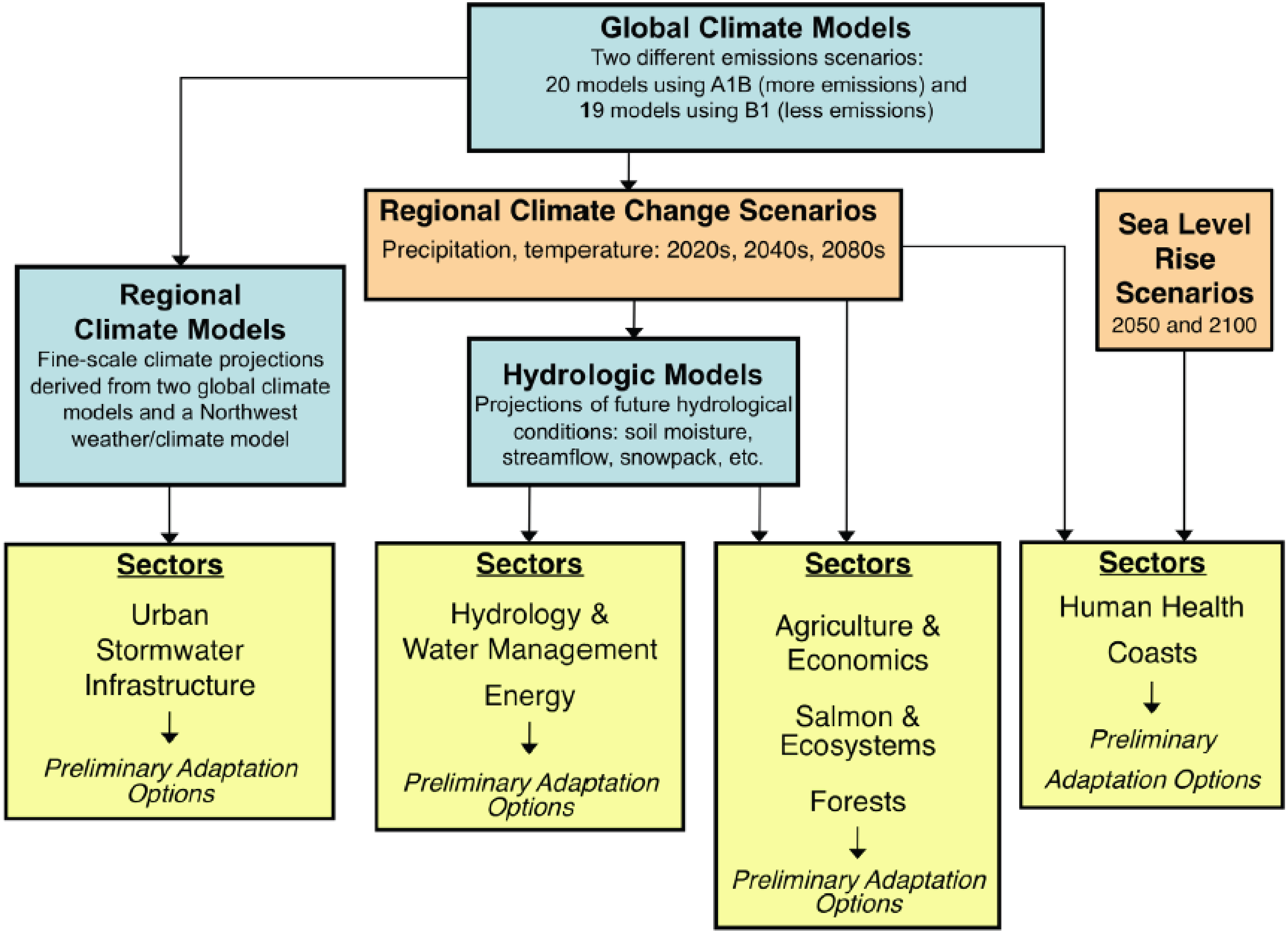
Climate projections for Pacific Northwest

A. The Washington Climate Change Impacts Assessment (UW-CIG, 2009)

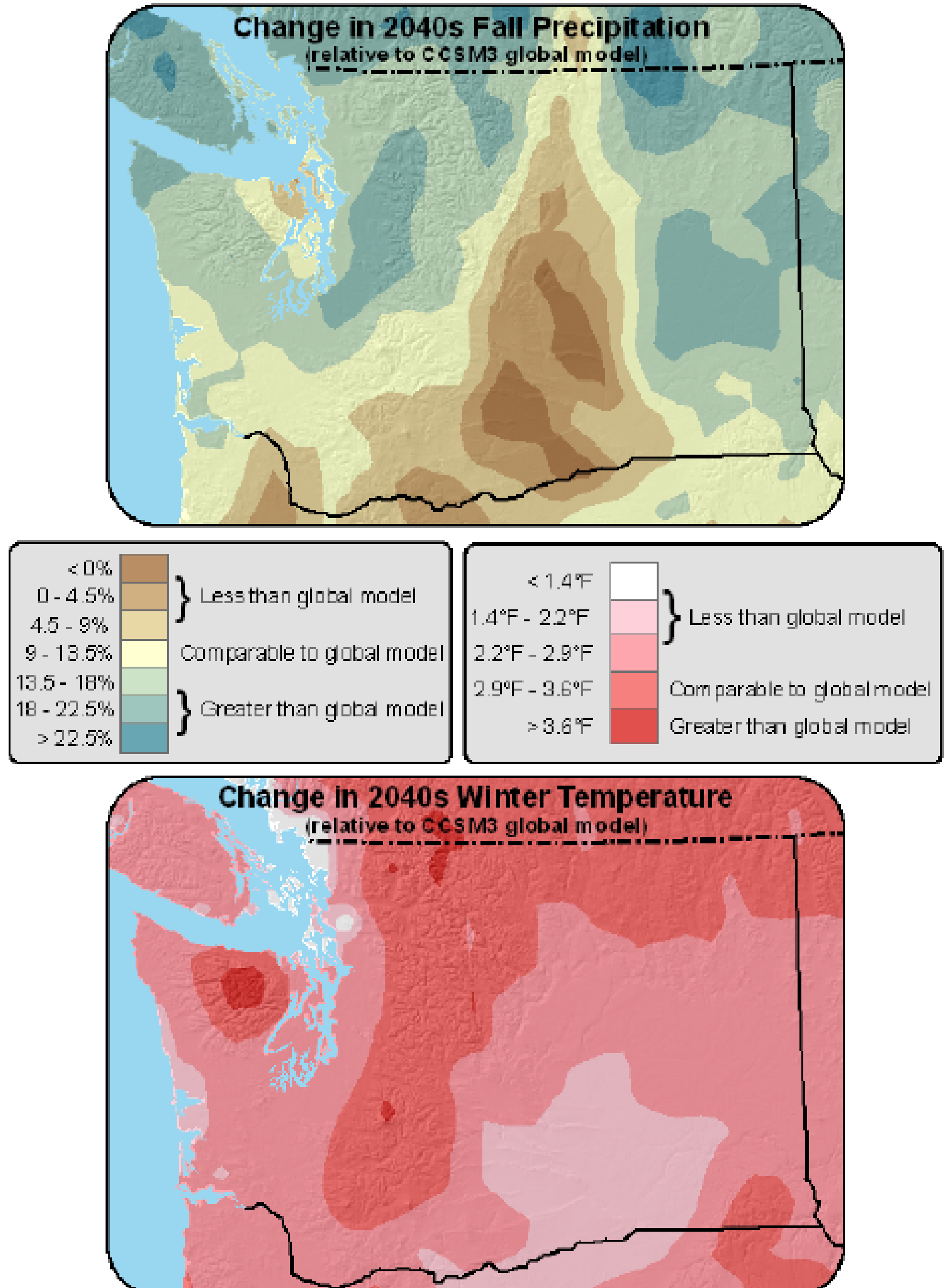
- http://cses.washington.edu/cig/res/ia/waccia.shtml

1. Increased annual temperature 2.0 F by 2020, and 5.3 F by 2080
2. Similar annual precipitation but wetter autumns and winters and drier summers

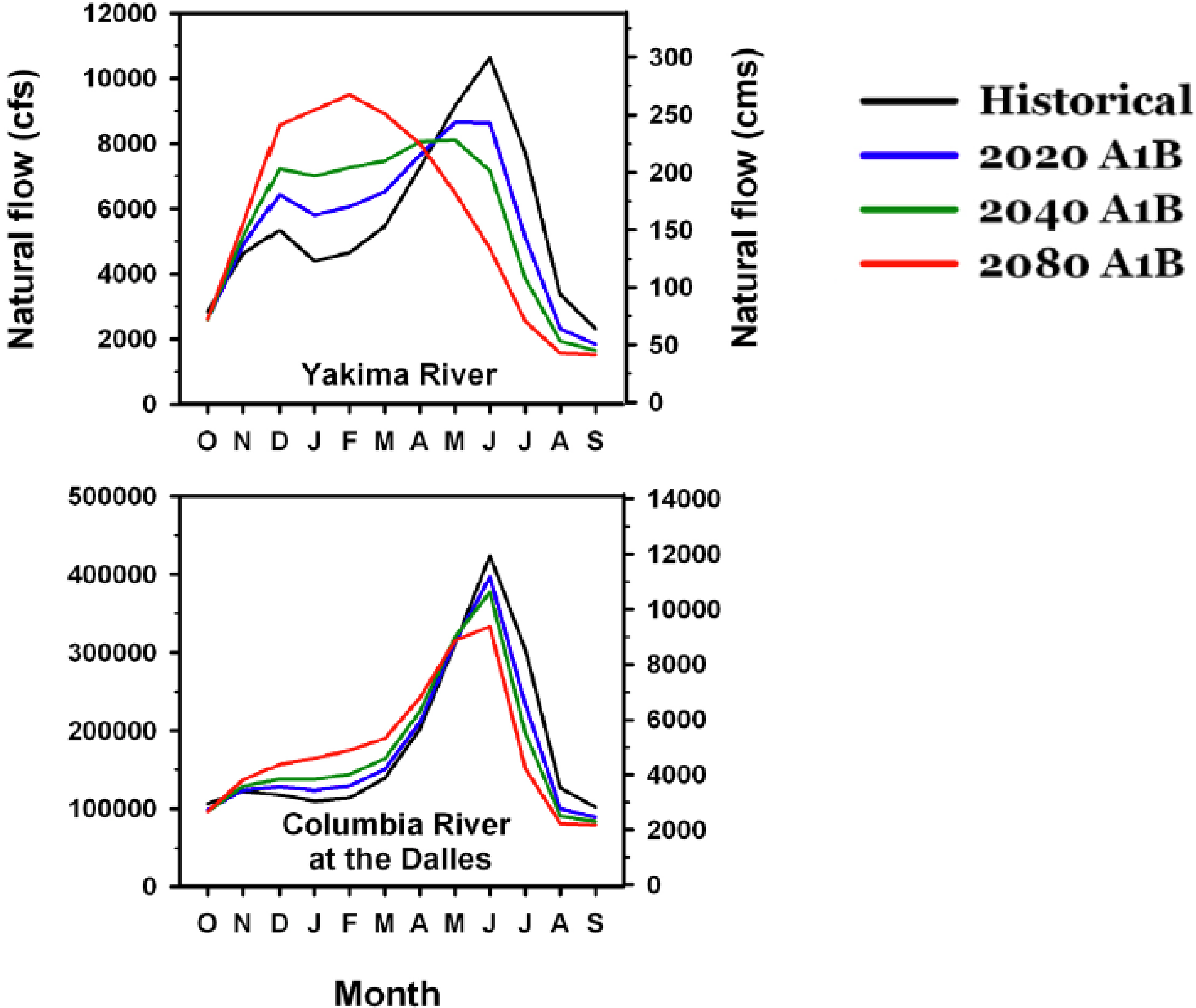
Assessment Approach



Projections



Projected hydrographs



Probable impacts on Washington ecosystems

A. Snowpack to decrease by 59% by 2080

B. Detrimental water shortage in the Yakima basin

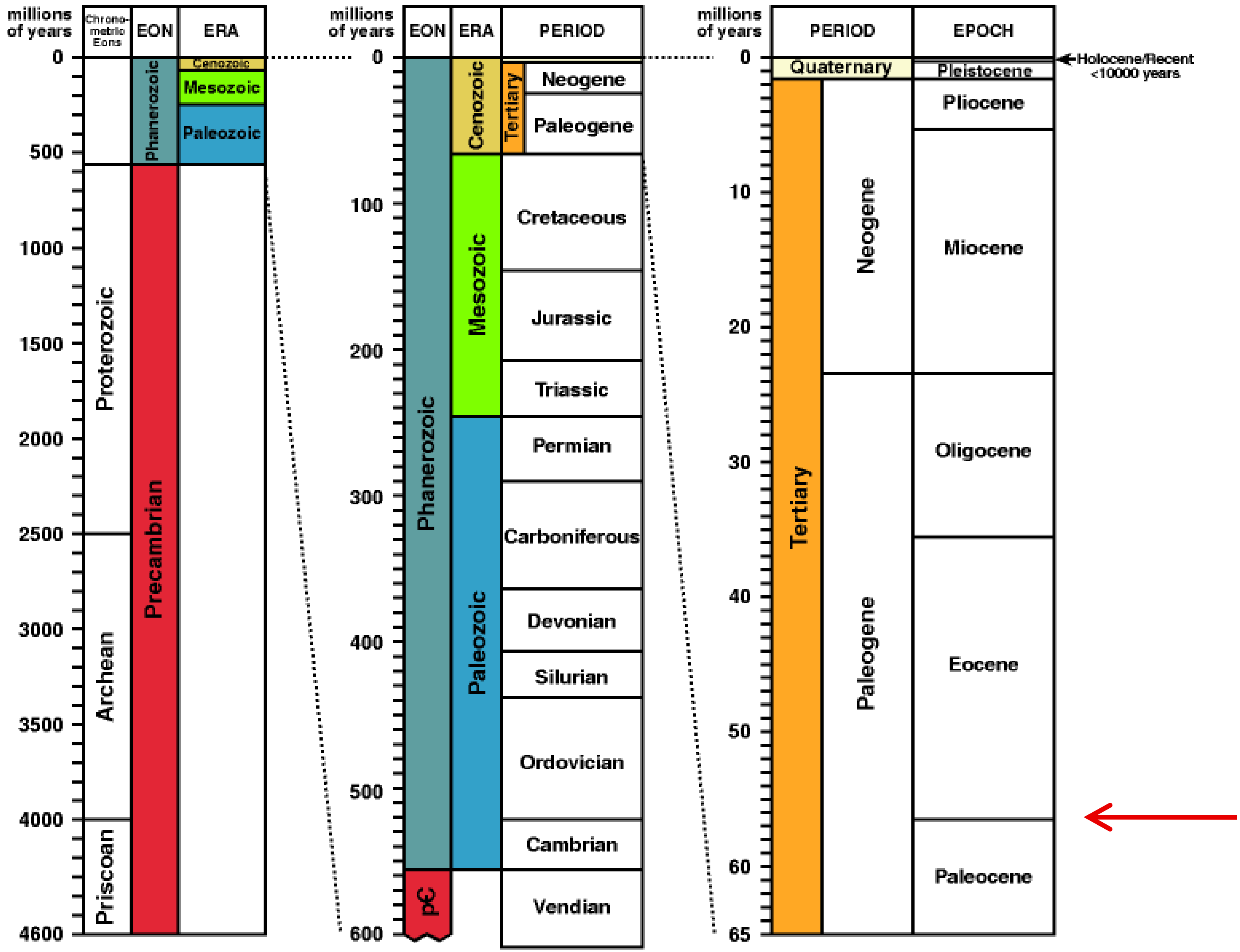
C. Rising stream temperature impacting salmon habitat

D. Increased regional fire frequency

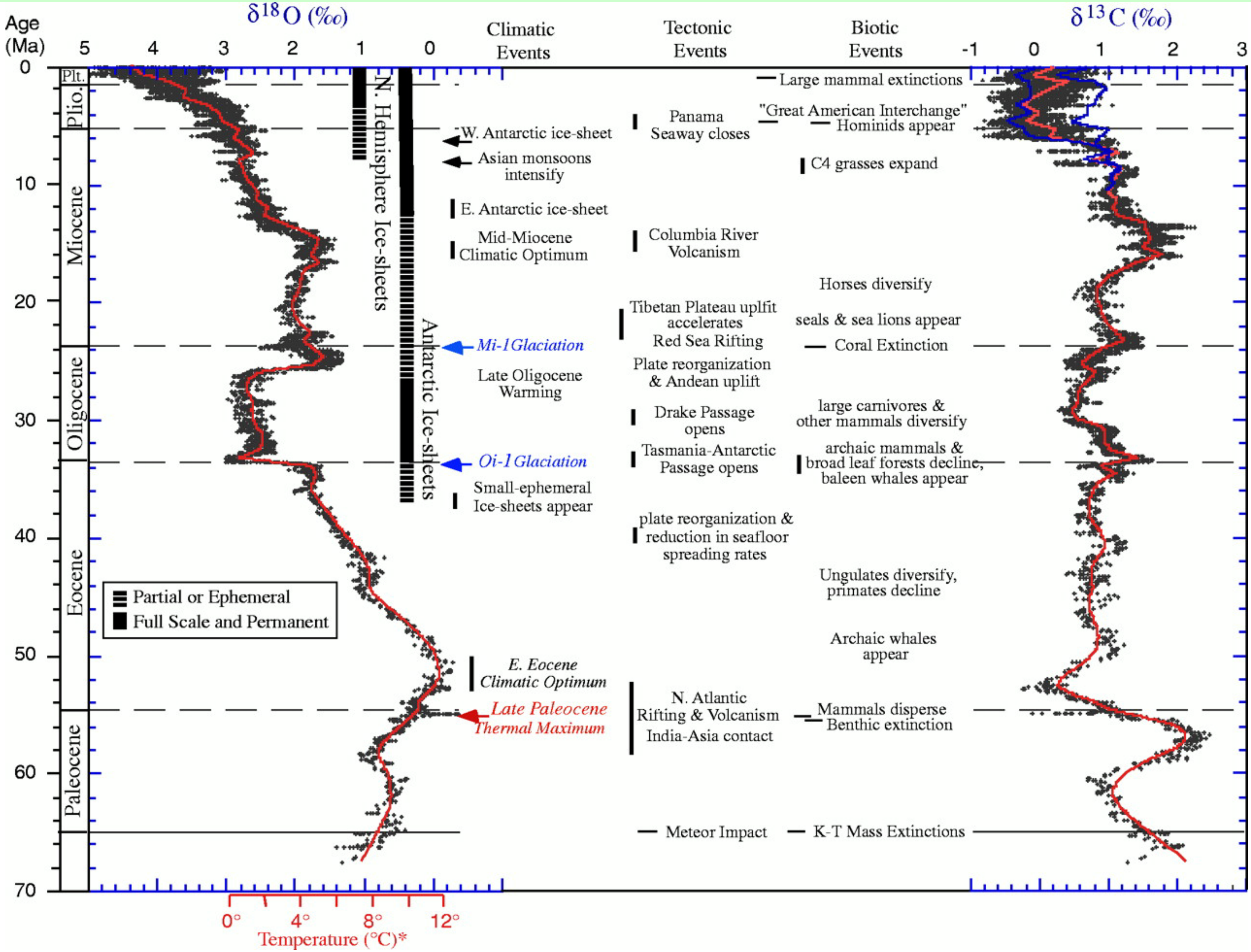
E. Increase in extreme high precipitation around Puget Sound

F. Public health impacts: More heat- and air pollution-related deaths

Has this happened before?



Paleocene-Eocene Thermal Maximum (PETM)



What happened in PETM?

A. PETM is considered an analogue to current anthropogenic global warming
    1. Rapid global warming of 5 to 10 C in less than 10,000 yrs
    2. Similar rates and magnitudes of CO_2 and CH_4 increase in the atmosphere
    3. Acidification of the ocean

B. Notable range shifts and migration evidences in terrestrial flora
    1. Legumes appear to have flourished

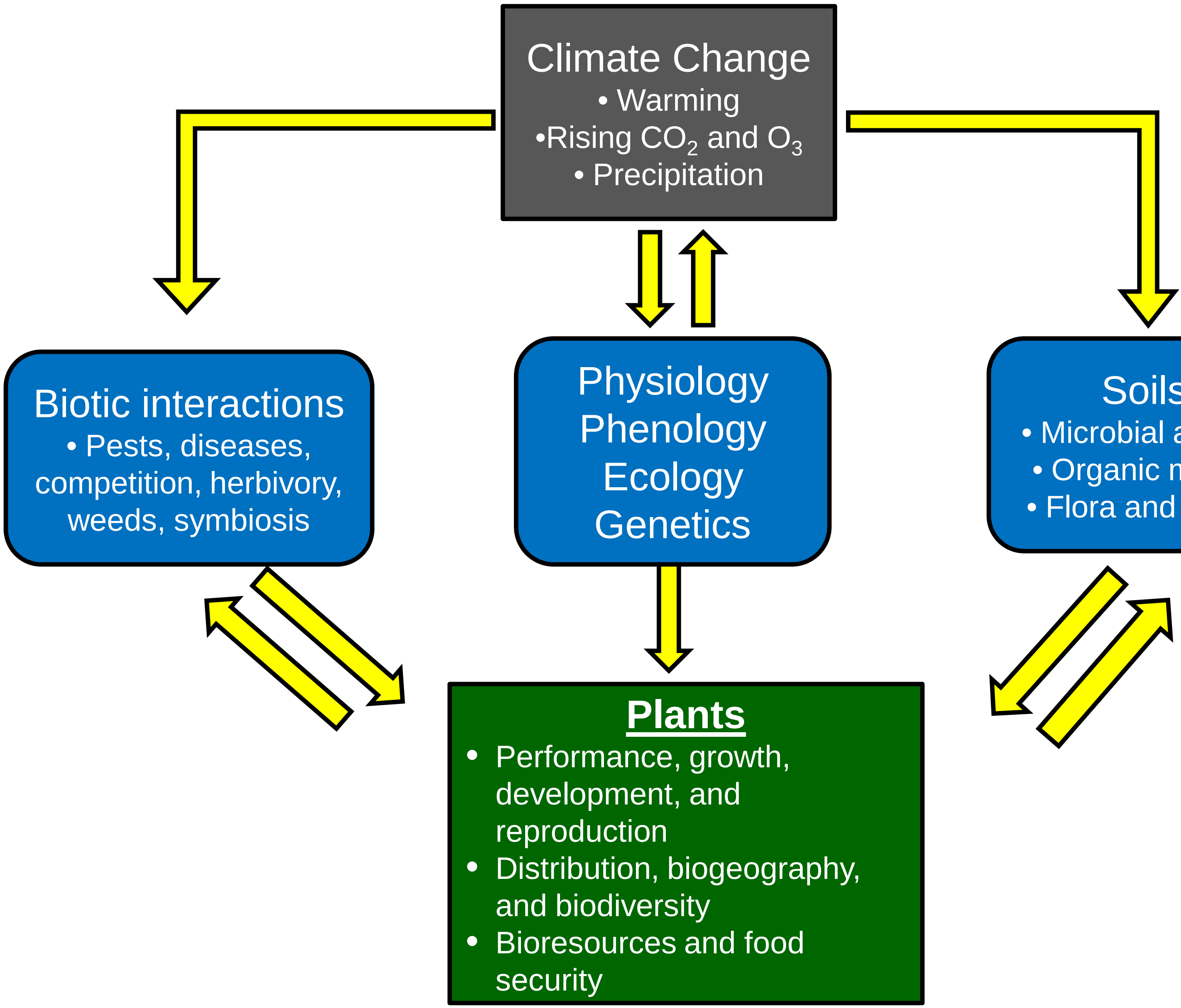
C. Shifts in composition of terrestrial vertebrate fauna

D. Extinction and shifts in marine flora and fauna

References: Wing et al., (2005) Science; Zachos et al. (2005) Science

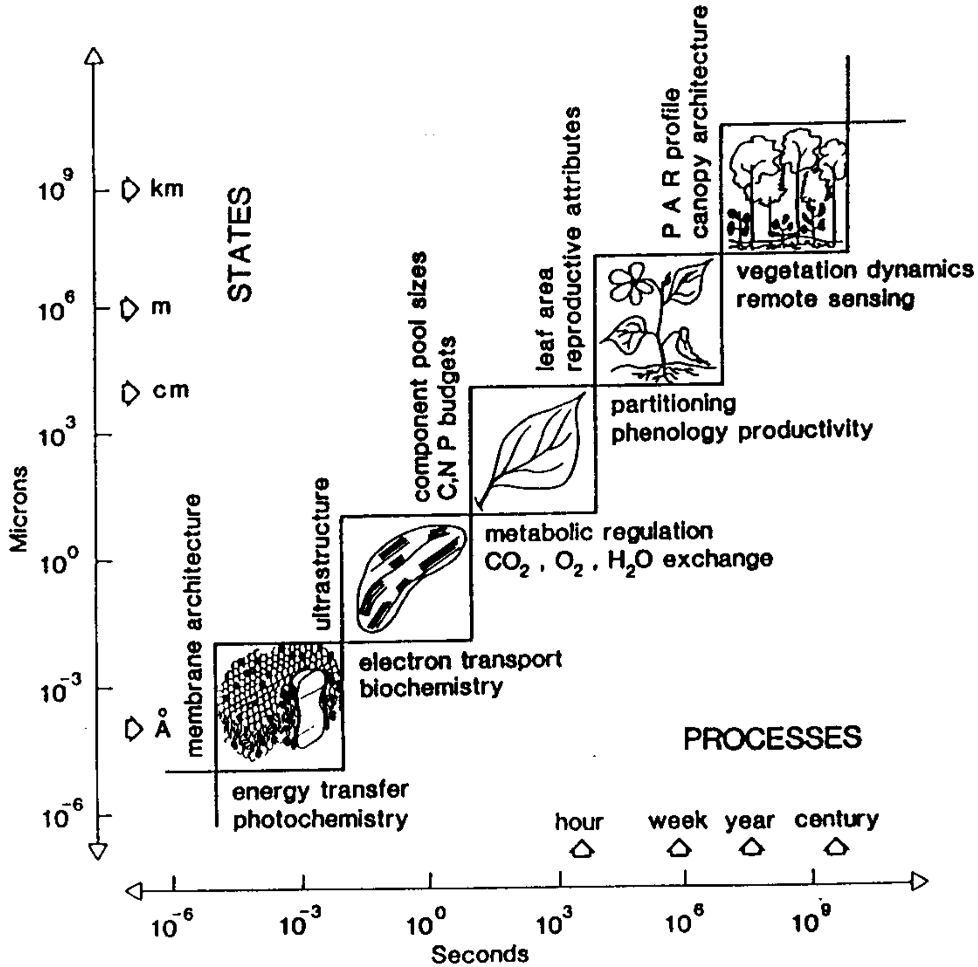
Plant Responses to Climate Change

How climate change will impact plants?



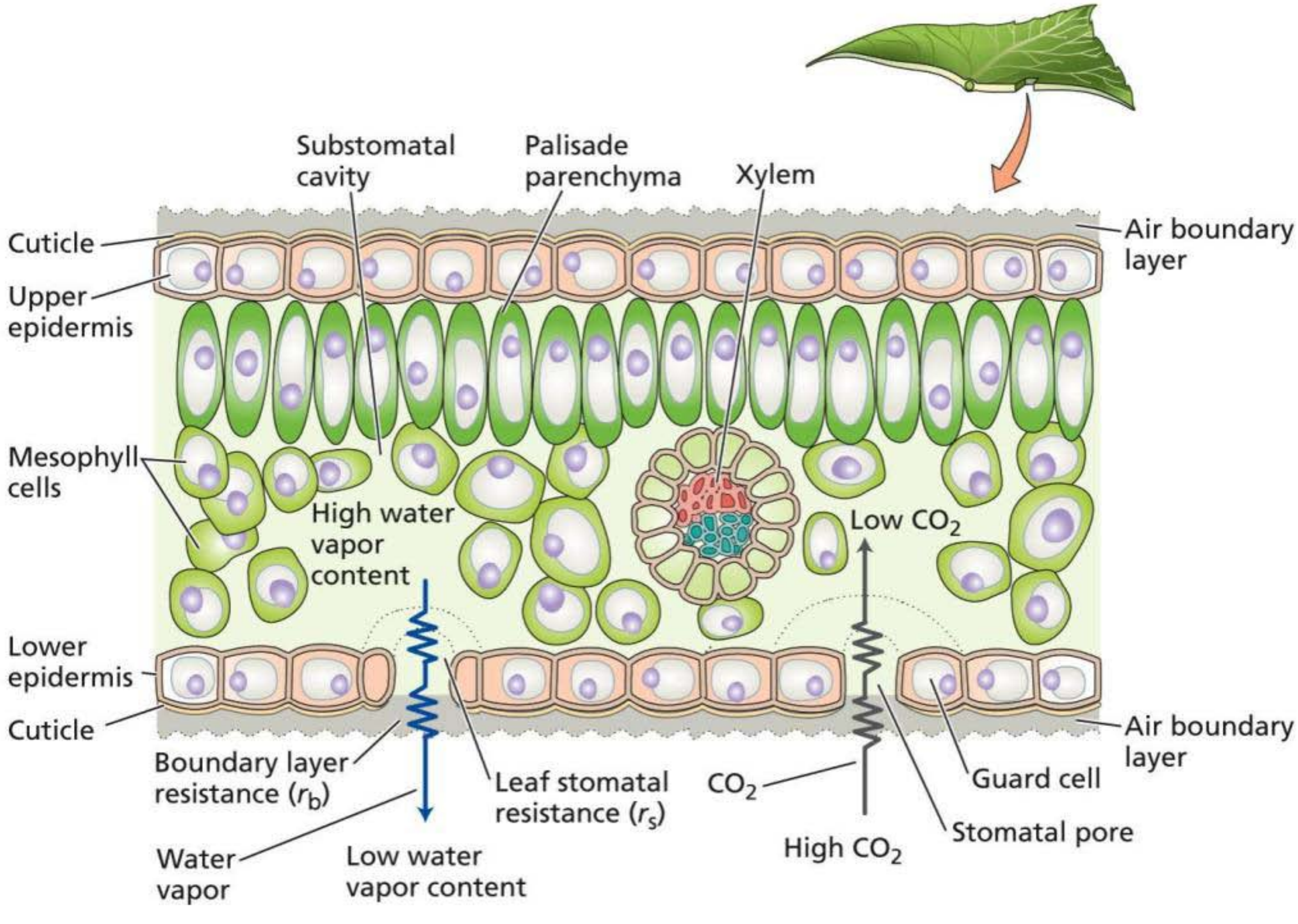
Scales in plant response to climate change

A. Molecular level
B. Cellular processes
C. Organ-level responses
D. Whole-plant responses
E. Plant-to-plant interactions
F. Community and ecosystem responses
G. Global responses
H. Evolutionary changes



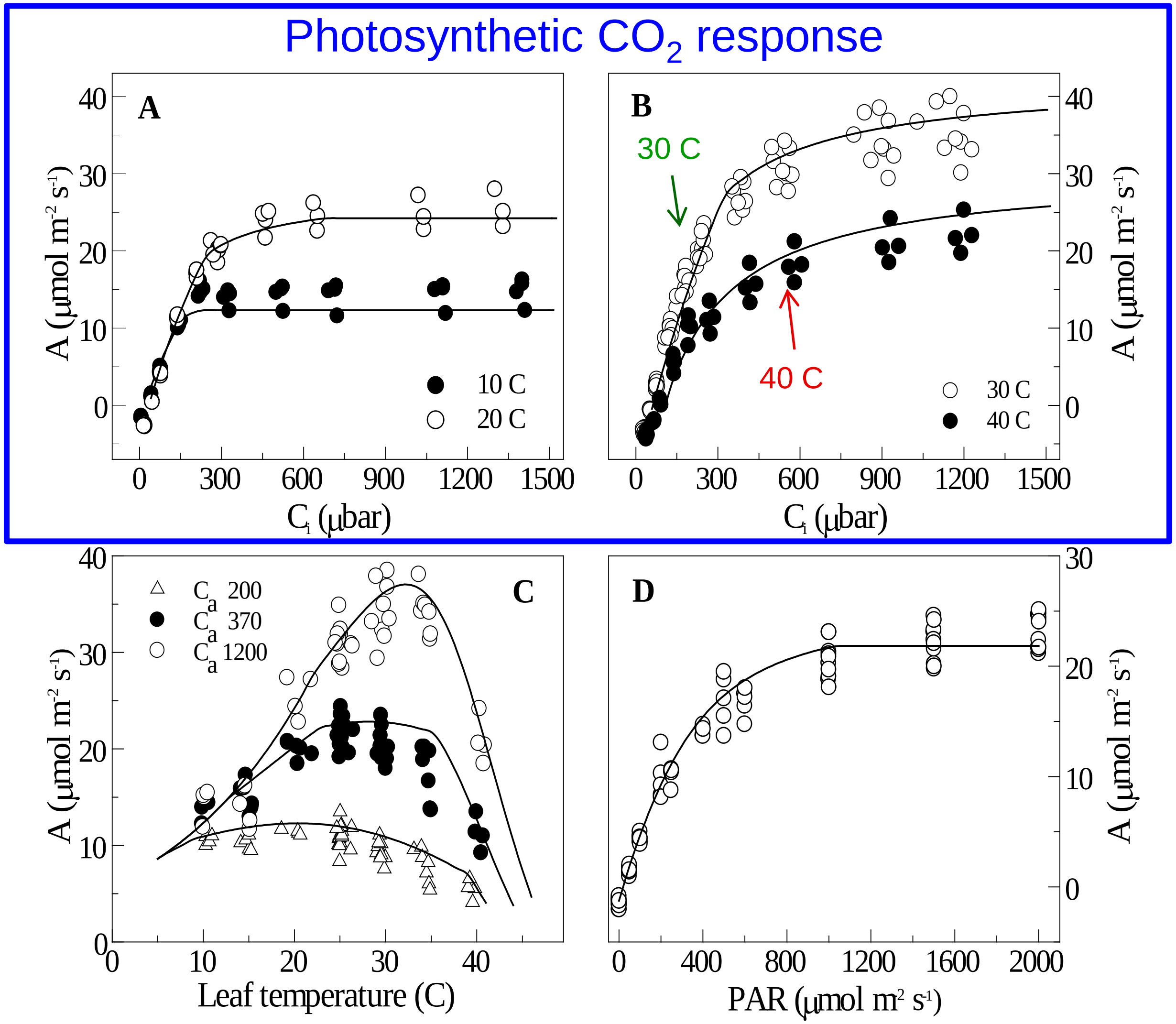
Plants respond directly to CO_2: Gas exchange

A. *"Almost all of the scientific focus is on CO_2 as a "warming" gas; Yet the impact of CO_2 by itself will be significant with respect to plant biology – and consequently, to all living things. "* – Dr. Lew Ziska, USDA-ARS



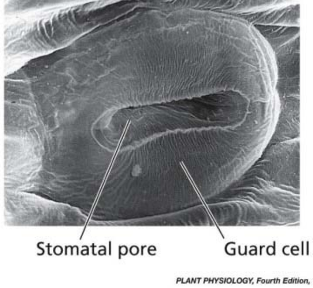
Effect of CO_2 and temperature on photosynthesis

A. Photosynthesis saturates at high CO_2; The response depends on temperature



Kim & Lieth (2003) Ann. Bot.

Stomatal response to high CO_2



A. Stomatal conductance

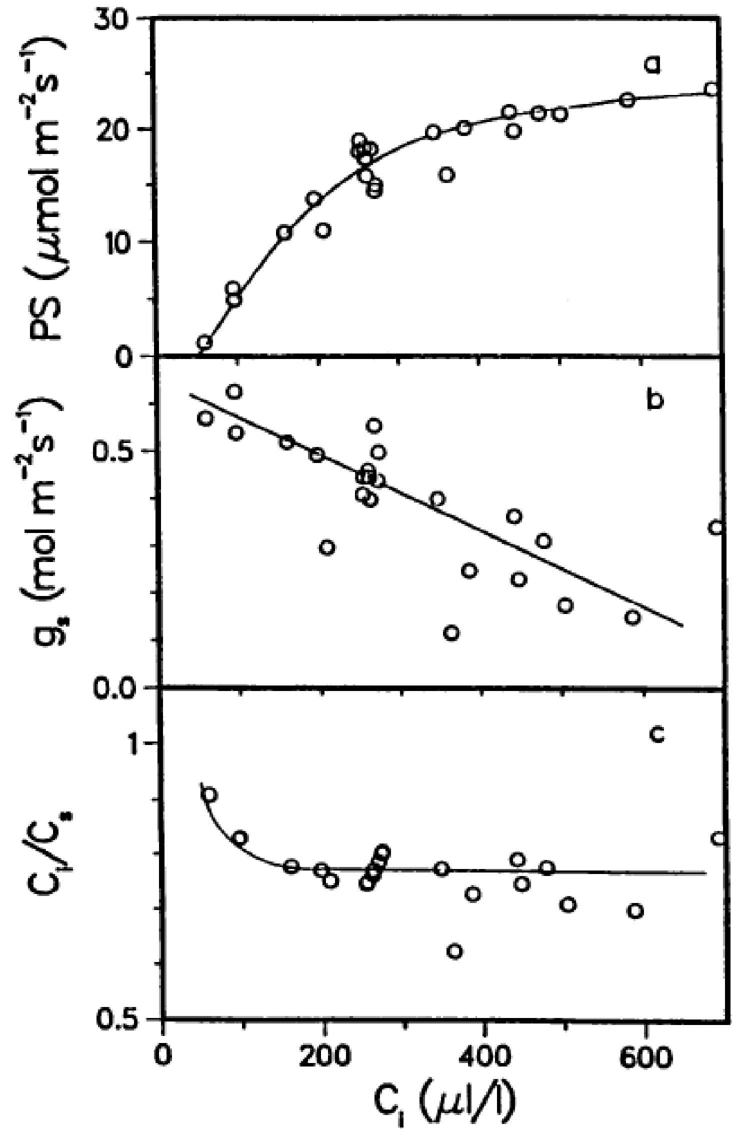
1. Determined by stomatal aperture (e.g., opening and closing) and frequency
    1) *Operate to increase* ***Water Use Efficiency***
2. ***Stomata close under high CO_2***

B. Stomatal development

1. Woodward (1987) Nature 327:617
    1) Stomata number decreases in high CO_2
2. Genes: *HIC, TMM, SDD1, YODA*

C. Signals from old to new leaves

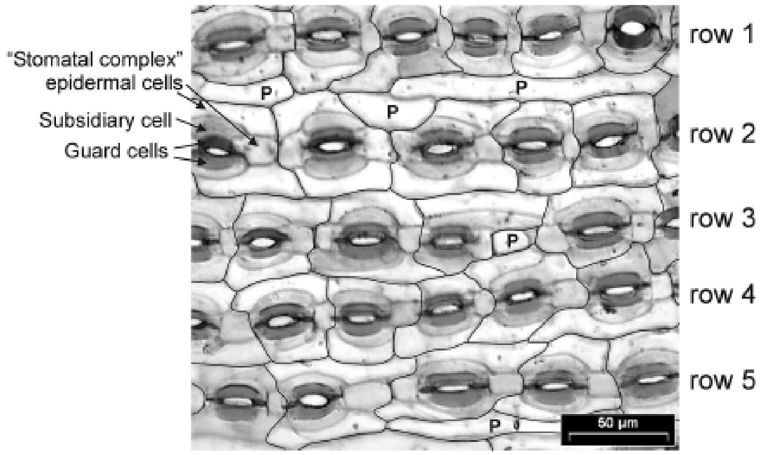
1. Old leaves sense the level of CO_2 and adjust the number of stomata in new leaves
2. Confirmed in *Arabidopsis* and *Populus*

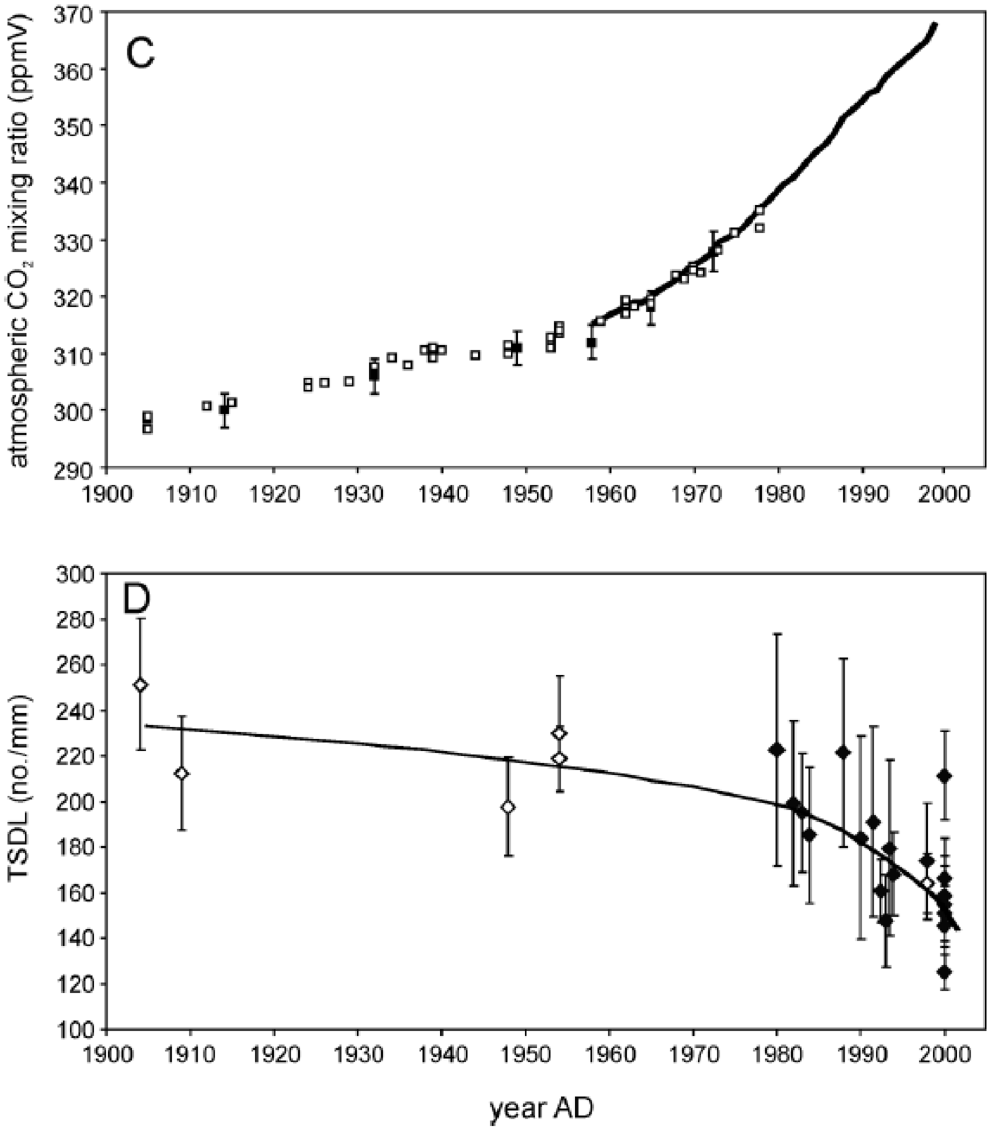


Stomata of Western hemlock at Mt. Rainier and CO_2 history

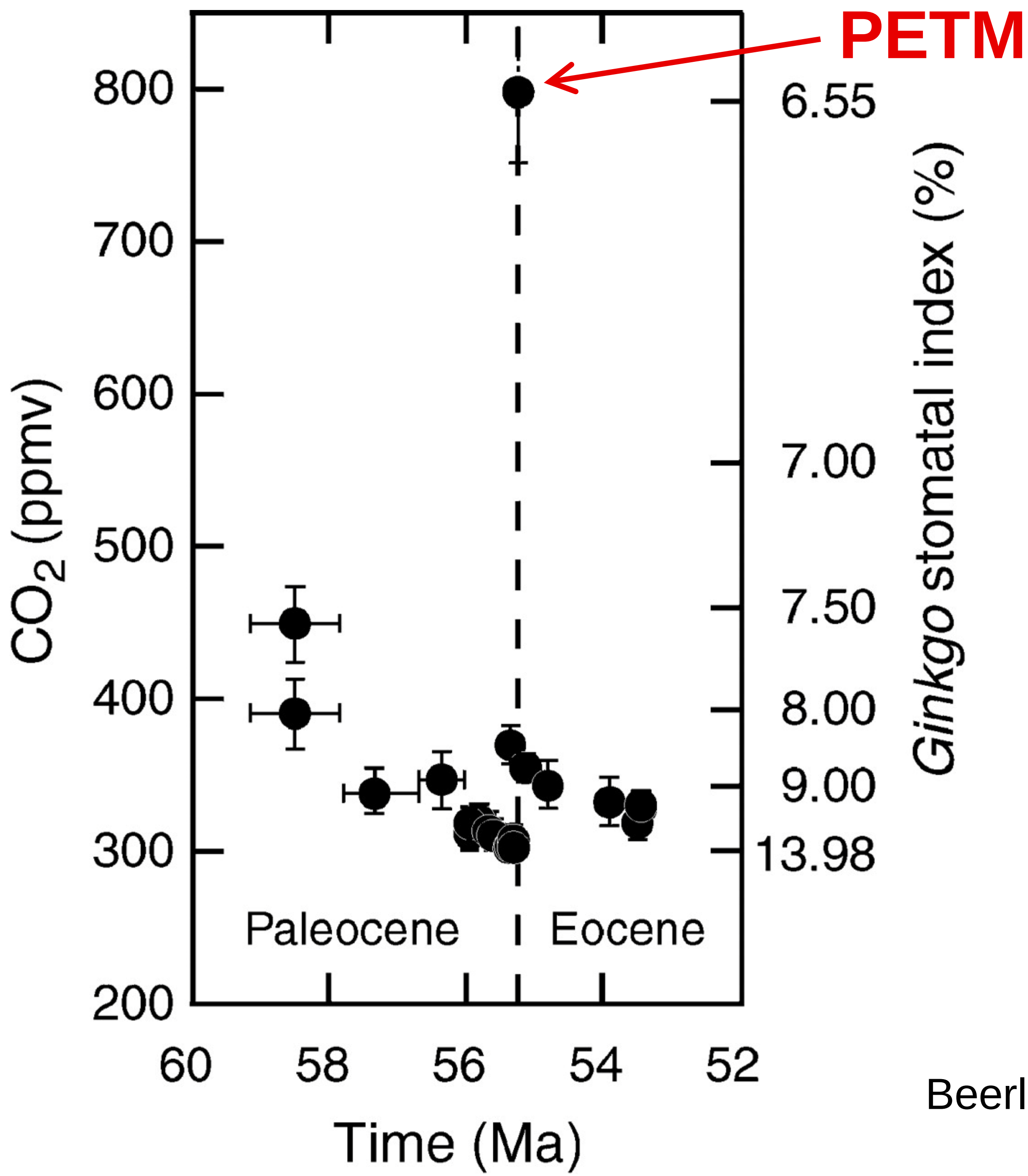
A. Kouwenberg et al. (2003) *AmJBot*, **90:** 610

B. Stomatal frequency of conifers sensitive to changes in CO_2





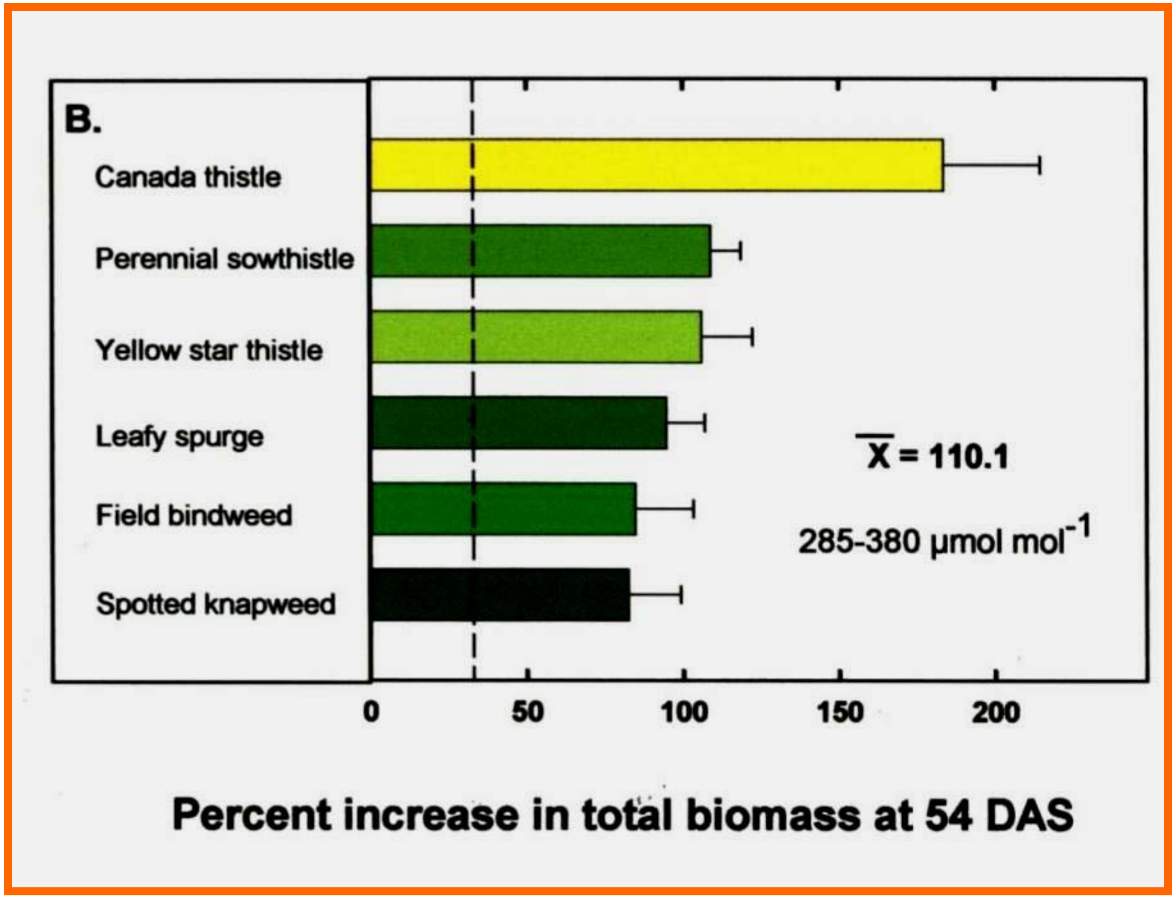
Paleo – CO_2 reconstruction from Ginkgo stomata



Beerling et al. (2002)

Weeds capitalize the benefits of rising CO_2

A. Weeds (esp. invasives) seem to be more responsive to CO_2



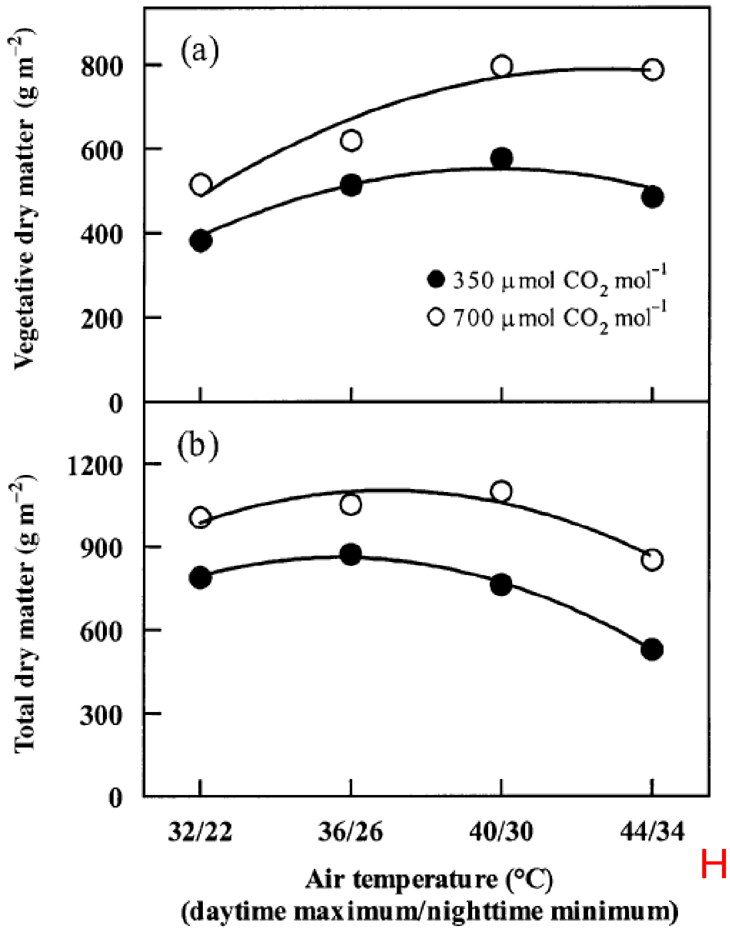
Also more resistant to herbicides

Ziska (2003) J. Exp. Bot

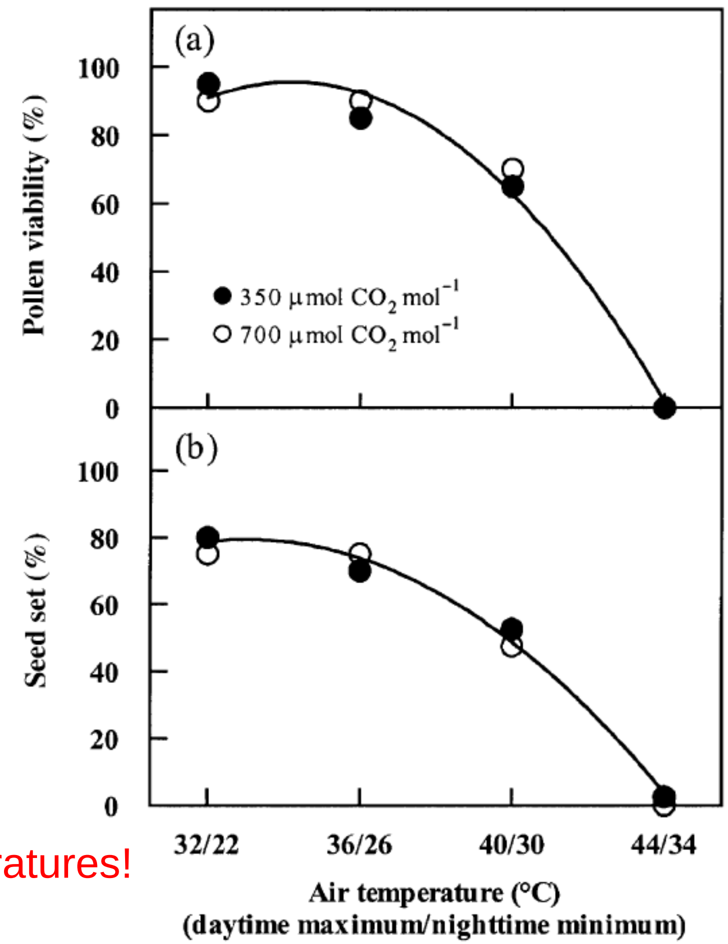
Plant reproduction and rising temperatures

A. Reproductive biology is more sensitive to high temperatures

Vegetative responses



Reproductive responses

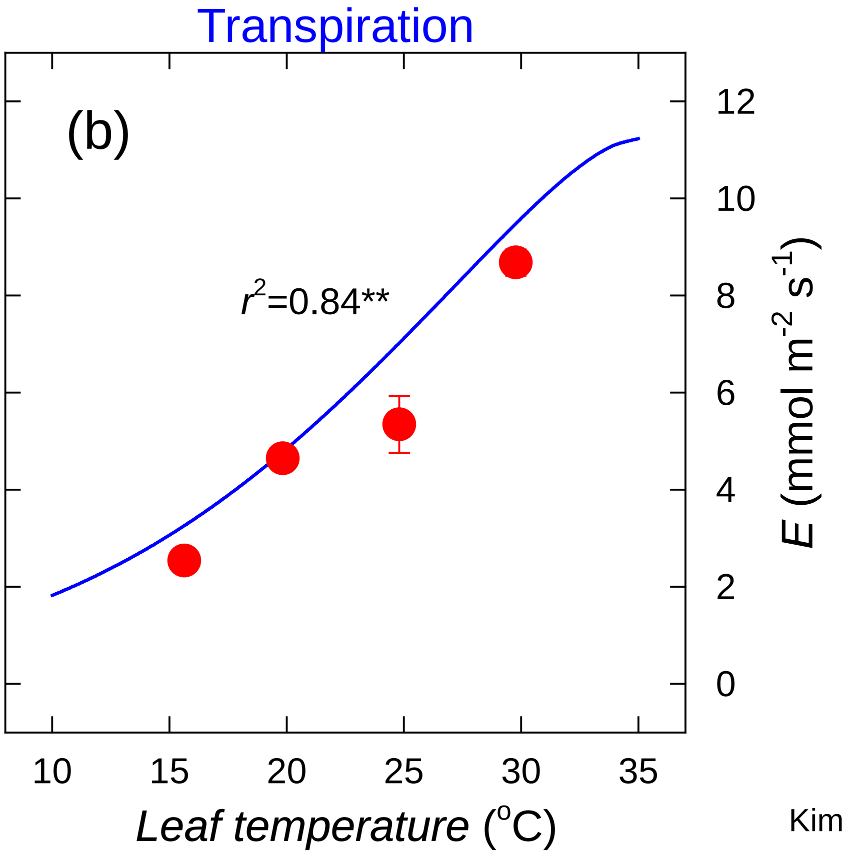


Hot temperatures!

Prasad et al. (2003) Global Change Biology

Plant water use and rising temperatures

A. More water loss as a result of increased evapotranspiration demand in the air at higher temperatures



Kim et al. (2007) Sci. Hort.

Phenology and global warming

A. Phenology: Timing of life-cycle events

B. Concept of thermal time: Cumulative temperatures (i.e., thermal units) are developmental clock in plants (a.k.a., Growing degree days)

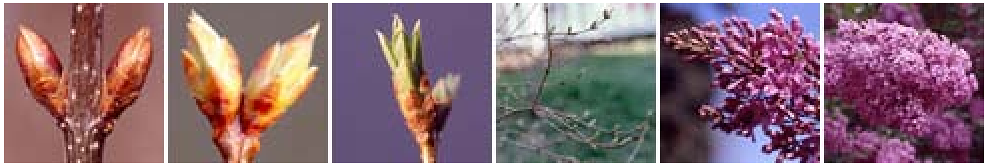


Photo: www.budburst.org

C. Will global warming impact phenology of plants and animals?

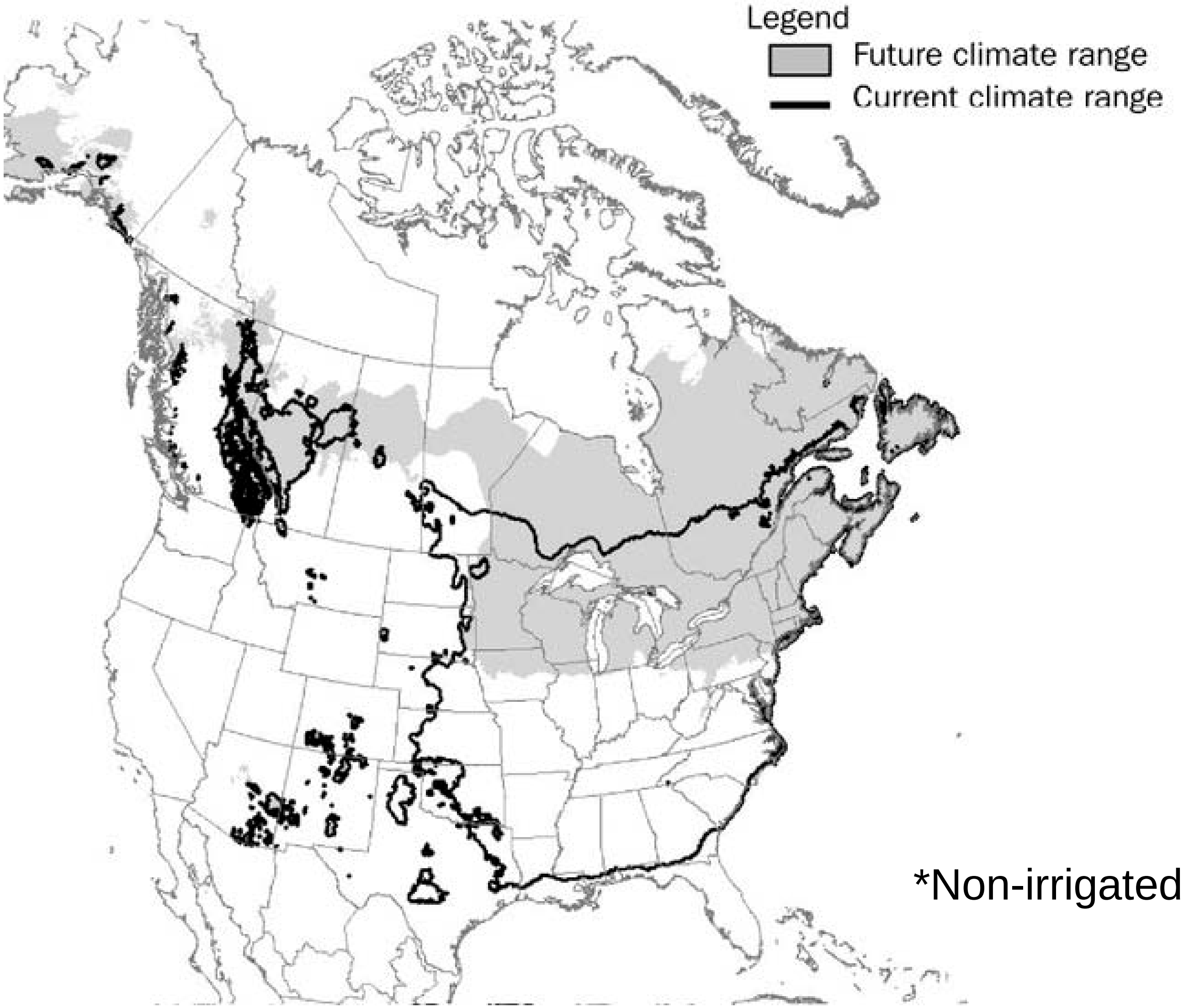
  1. In many species, yes and this will alter interactions with other organisms (e.g., Insects, pathogens, birds etc.)
  2. Plants usually have more than one way to perceive time of year
     1) Chilling requirement
     2) Cumulative thermal units requirement
     3) Photoperiodism
     4) These factors interact and work as safety device

D. National Phenology Network

  1. Project BudBurst (http://www.budburst.org)

Ecological Responses and Implications

Species Range Shift Example – *Acer saccharum*



*Non-irrigated conditions

McKenney et al. (2007) BioScience

Accelerated phenology in urban environments

A. Changes in phenology are already apparent especially in urban climates

Beijing, China

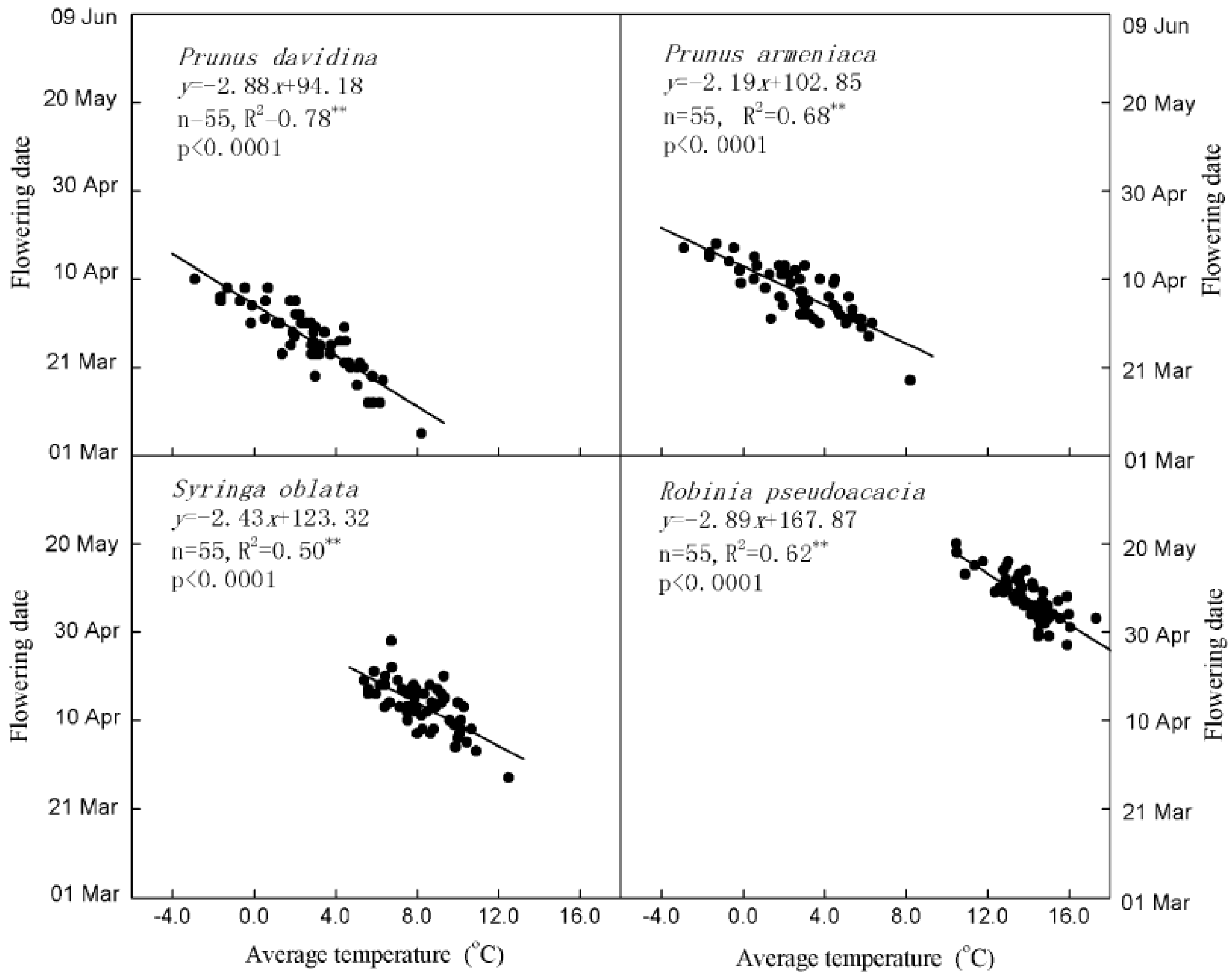


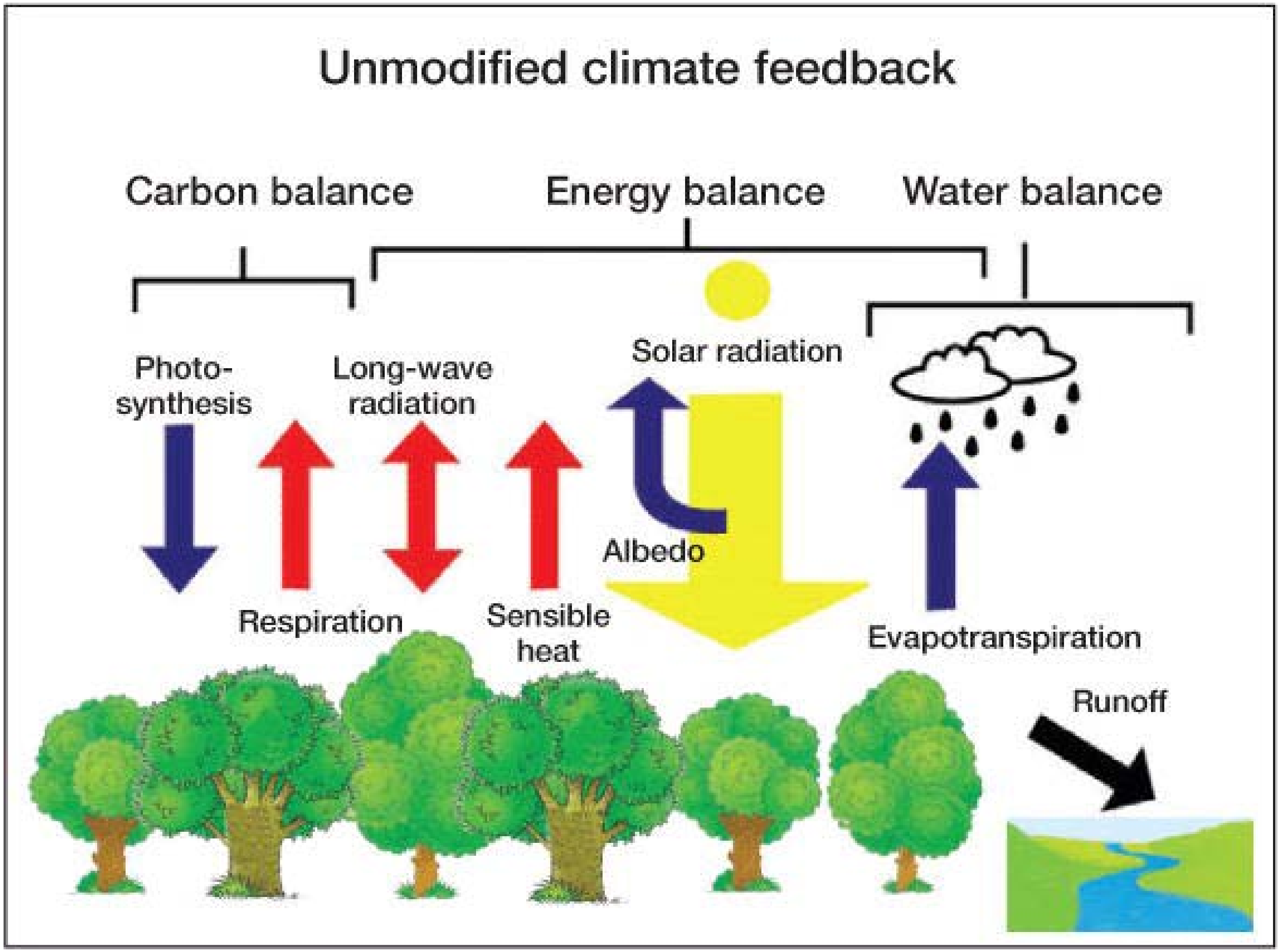
Fig. 6. Relation between flowering dates and average temperatures over the 30-day period before average blossom date (1950–2004).

Lu et al. (2006) Ag. Forest. Meteorol.

Global patterns of climate change impacts on natural systems

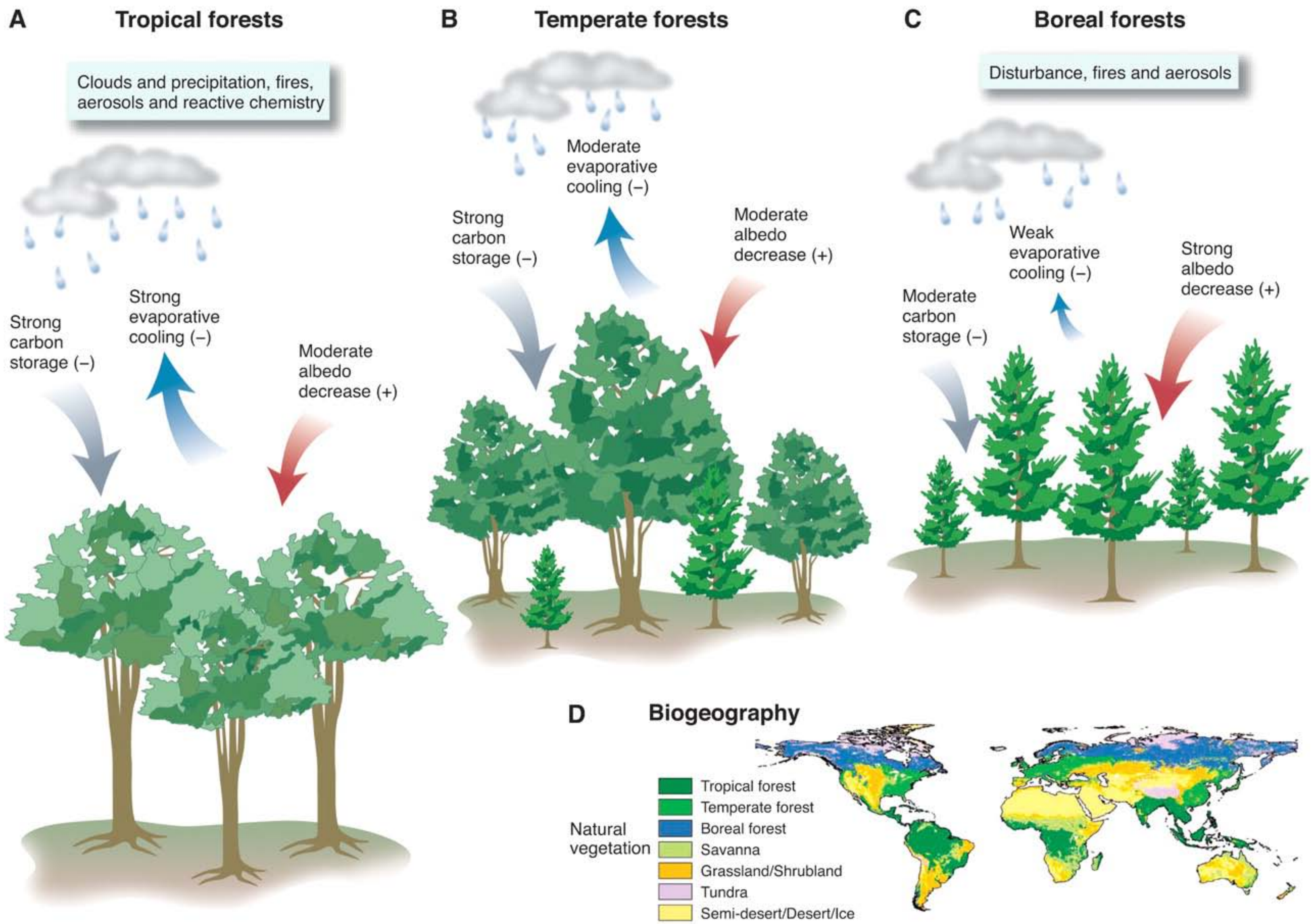
- Poleward range shifts averaging 6.1 km per decade
- Significant advancement of spring events by 2.3 days per decade (bud burst, flowering, breaking hibernation, migrating, breeding)
- Increased asynchrony in predator-prey and insect-plant systems
- Shifts in abundances and ranges of parasites and their vectors impacting human disease dynamics
- Range contractions of polar and mountaintop species
- Little evidence of genetic shifts to prevent species extinction

Interactions between vegetation and atmosphere



Chapin et al. (2008)

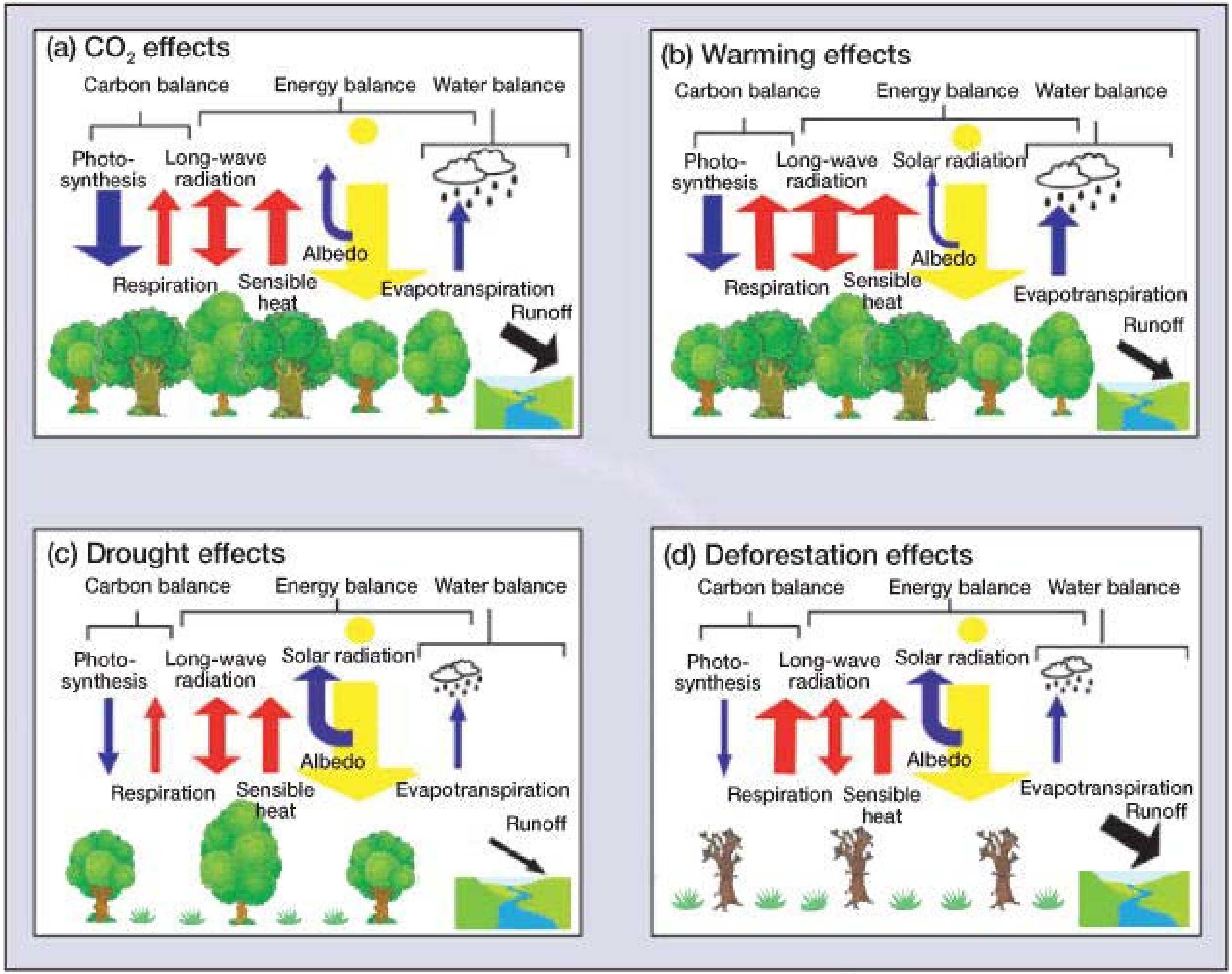
Climate services in (A) tropical, (B) temperate, and (C) boreal forests



Published by AAAS

G. B. Bonan Science 320, 1444 -1449 (2008)

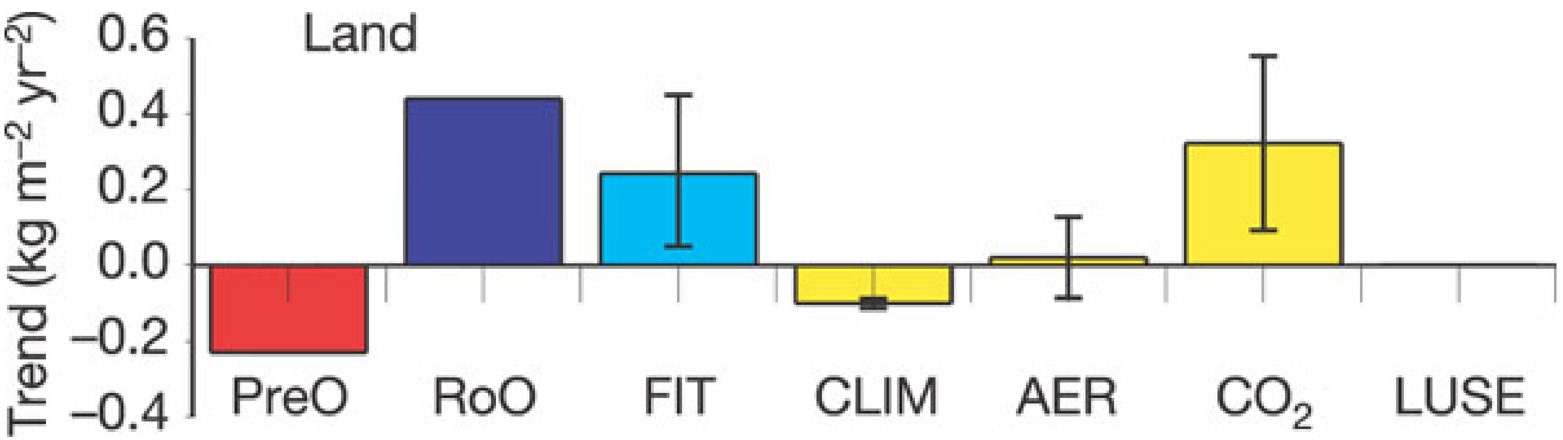
Human modifications of climate feedbacks



Ecophysiological control of global hydrologic processes

A. Gedney et al. (2006) Detection of a direct carbon dioxide effect in continental river runoff records. *Nature*, **439**, 835-838.

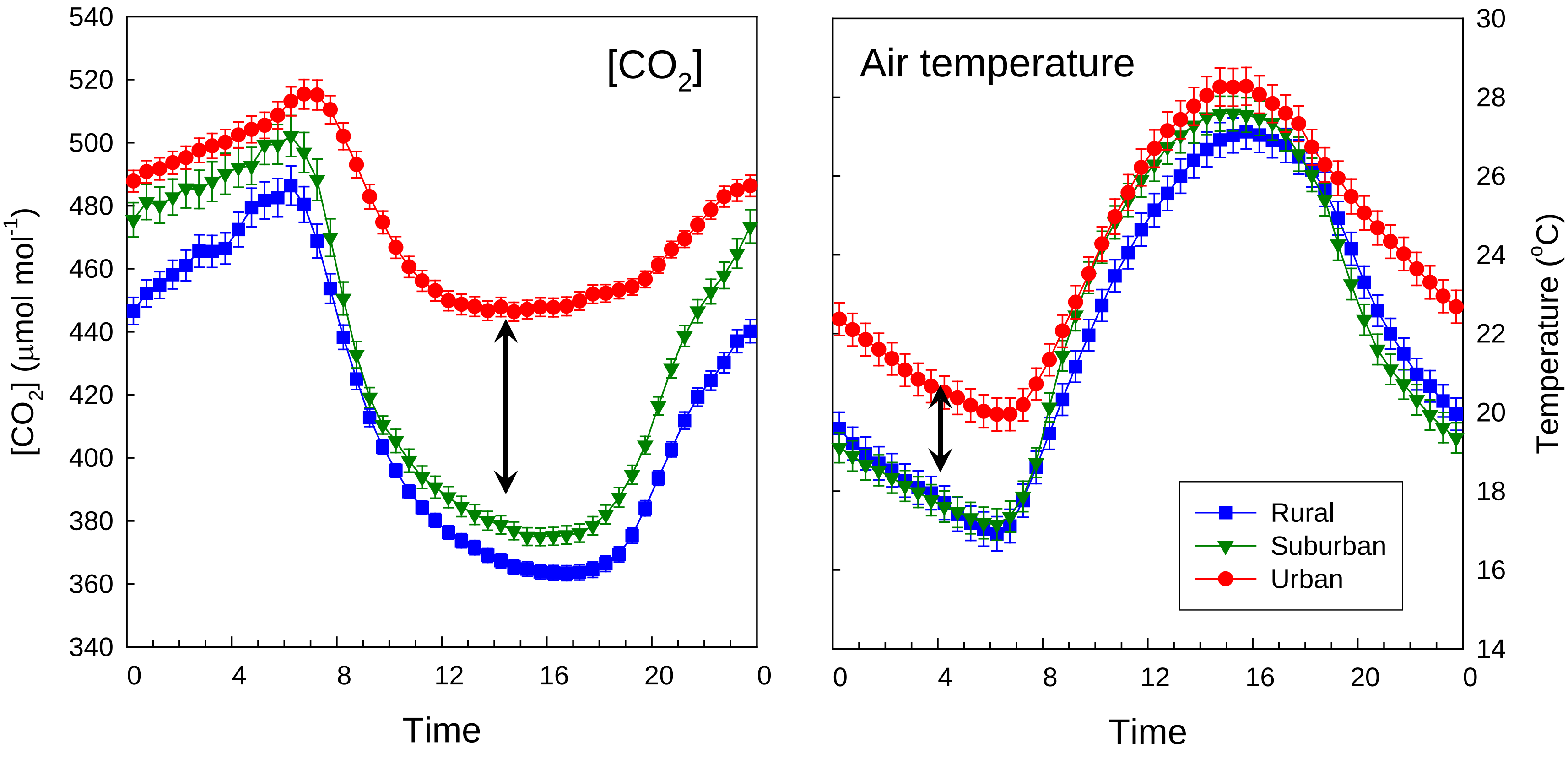
1. Continental river runoff is approx. equal to the difference between land precipitation and evapotranspiration.
2. Stomata close partially under increased CO_2, suppressing transpiration and providing a mechanism by which CO_2 increase could lead directly to increases in continental runoff



Urban climate is similar to future climate?

A. Baltimore urban-rural gradient (Ziska et al., (2004) *Oecologia* 139:454)

1. Increased night temperatures and day [CO_2]
2. Longer growing season
3. Figures below represent diurnal patterns averaged over growing season



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