

Mathematics and Climate

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Why This Talk?

Mathematics Awareness Month - April 2009

Mathematics and Climate

Discover how math and science are used to address questions of climate change:



How long will the summer Arctic sea ice pack survive?

How much will sea level rise as ice sheets melt?

Are hurricanes getting stronger?

How do human activities impact global warming?

How is climate monitored on a global scale?

How can we improve our understanding of climate change and what can we do about it?

$$\frac{\partial \rho}{\partial t} + (\mathbf{u} \cdot \nabla) \rho = -\nabla \cdot \mathbf{F} = \rho \nabla \cdot \mathbf{u}$$
$$\frac{\partial \theta}{\partial t} + (\mathbf{u} \cdot \nabla) \theta = 0$$

Committee Chair: Kenneth Gribben (University of Utah)

Steve Freeman (GDOT),
Wagner Schemm (Earthlink),
Ken Thompson, Jr. (University of Utah),
Mary Lou Thompson (Brandeis)

Yoon-Pyng YU (Brandeis),
David Williams (MIT),
David Neuber (MIT),
Joy Doolittle (MIT)

www.mathaware.org

Joint Policy Board for Mathematics: American Mathematical Society, Mathematical Association of America, Society for Industrial and Applied Mathematics, American Statistical Association

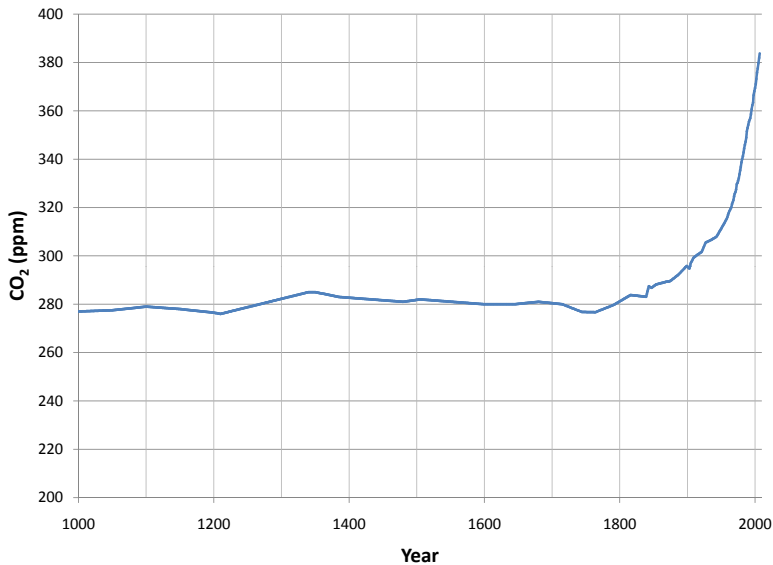
Images: Climate Change: NASA; Hurricane: NOAA; Arctic: NASA; Sea Level Rise: NASA; Global Warming: NASA; Climate Change: NASA; Global Warming: NASA; Climate Change: NASA; Global Warming: NASA

● Mathematics Awareness Month

- How long will the summer Arctic sea ice pack survive?
 - Are hurricanes and other severe weather events getting stronger?
 - How much will sea level rise as ice sheets melt?
 - How do human activities affect climate change?
 - How is global climate monitored?
- Discuss what I do.
 - Discuss what YOU have done.

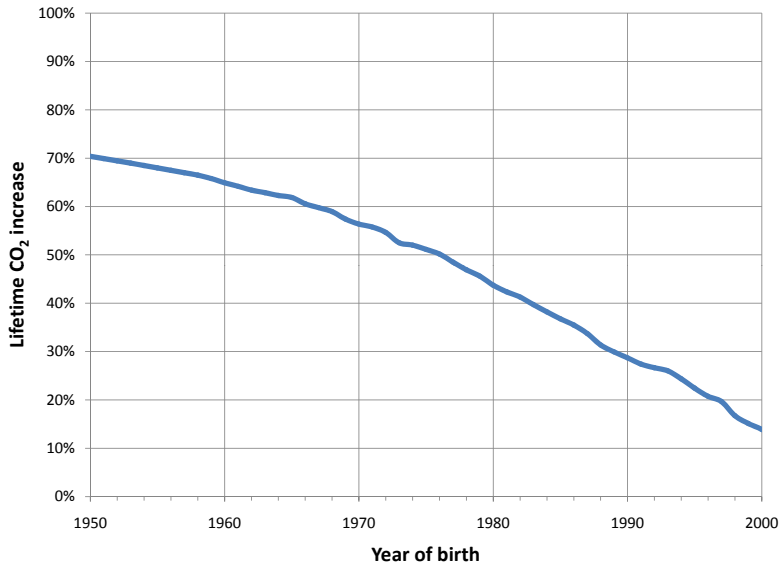
- 1 Rising CO₂ and its consequences
- 2 Modeling forest carbon uptake
- 3 Recent results from the literature
 - High-latitude ecosystems
 - Changes in the annual temperature cycle
 - Sea-ice predictions
 - The evolution of climate models

CO₂: a modern problem



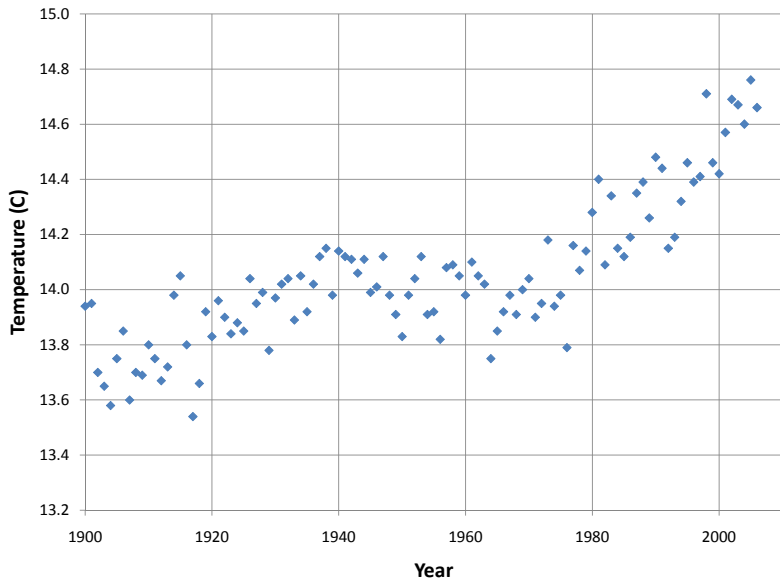
CO₂ data from NOAA

CO₂: a modern problem

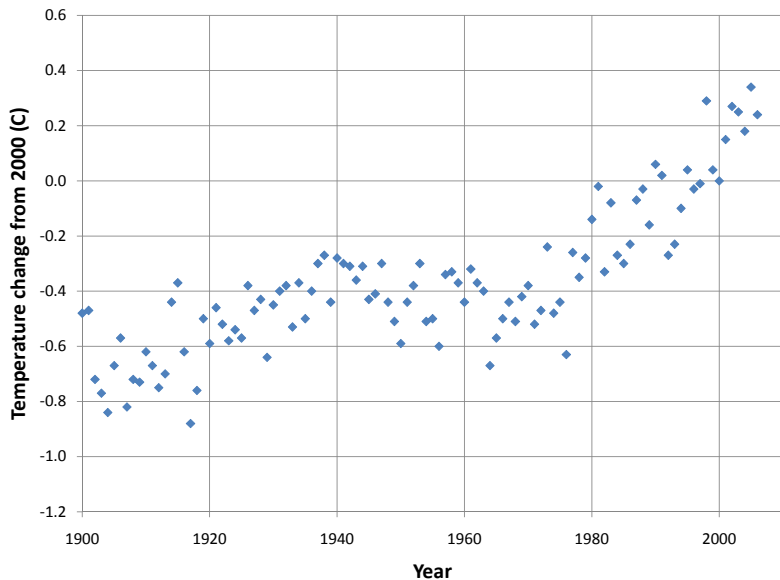


CO₂ data from NOAA

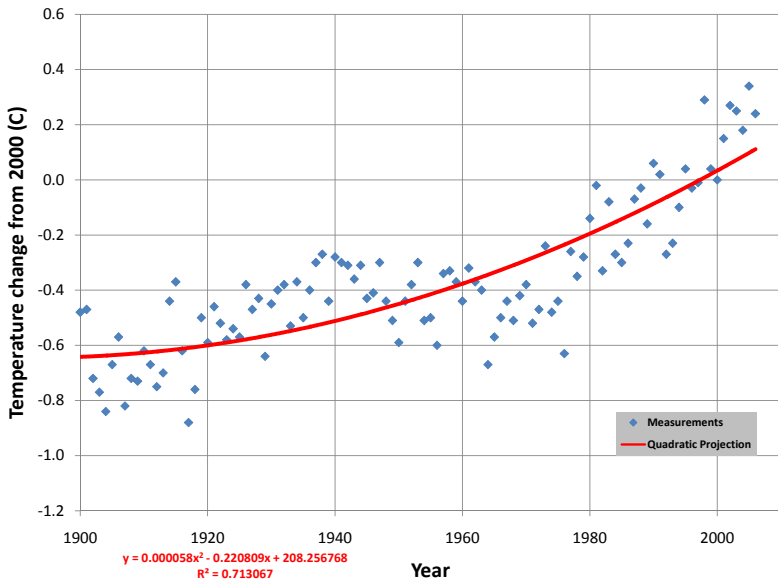
Changes in global temperature



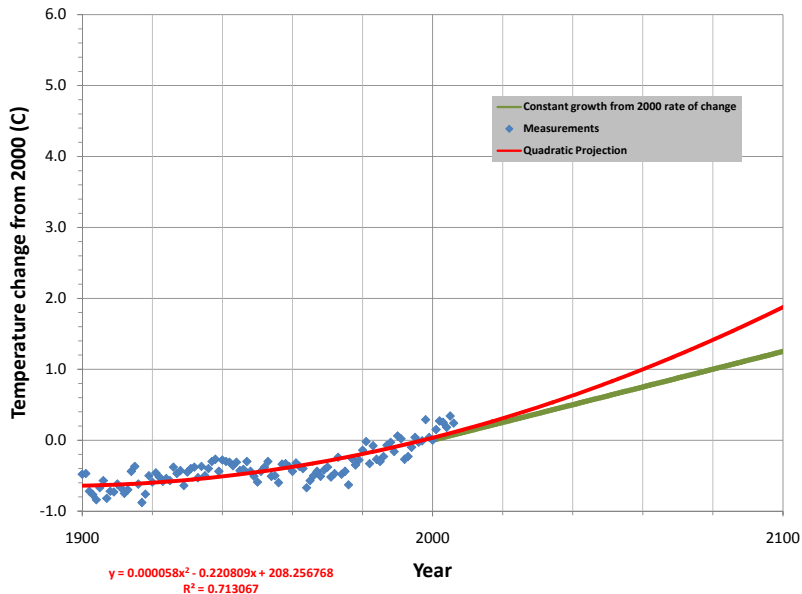
Changes in global temperature



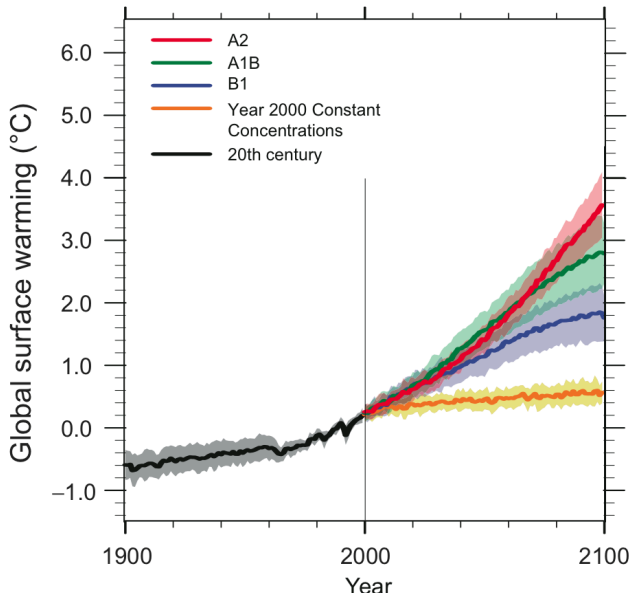
Changes in global temperature



Changes in global temperature

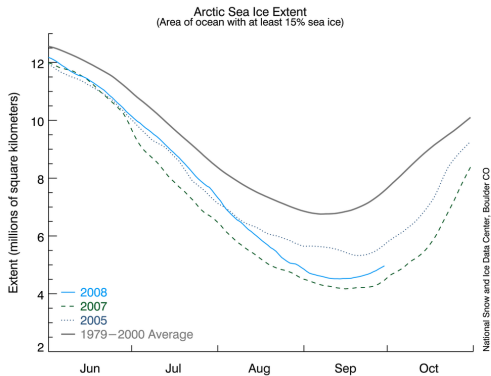
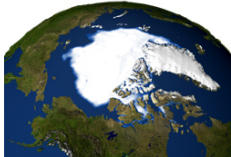


Modeling global temperature



Yearly Sea Ice Extent

Sea Ice Minimum 2005

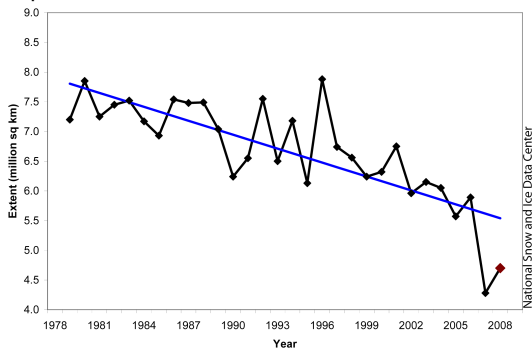


<http://nsidc.org/arcticseaicenews/>

Yearly Sea Ice Extent

Arctic Sea Ice from NASA:

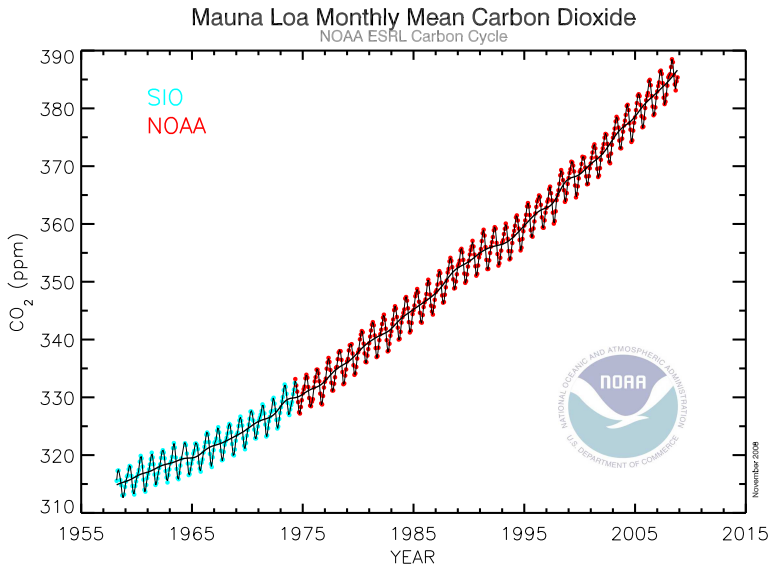
September sea-ice extent:



<http://nsidc.org/arcticseaicenews/>

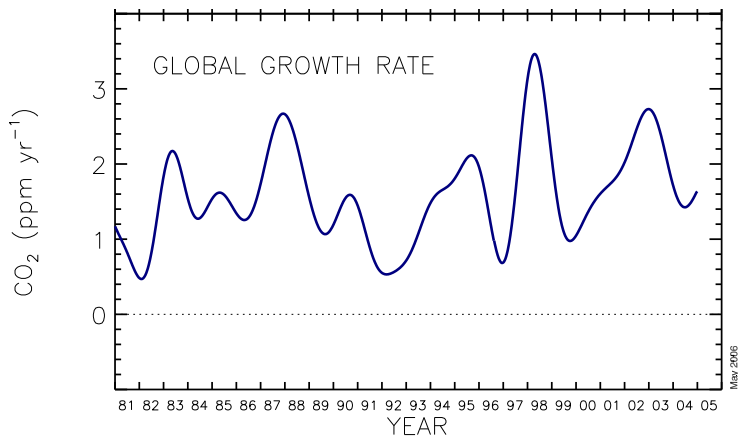
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Modern CO₂ measurement record



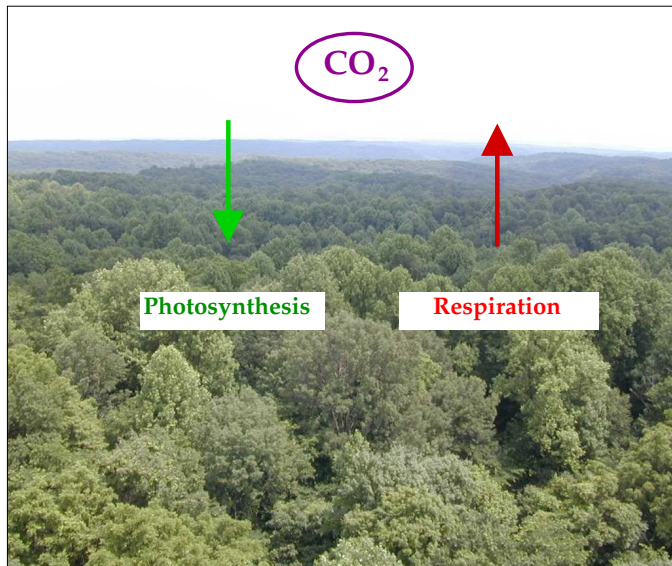
Atmospheric carbon dioxide monthly mean mixing ratios. Data prior to May 1974 are from the Scripps Institution of Oceanography (SIO, blue), data since May 1974 are from the National Oceanic and Atmospheric Administration (NOAA, red). A long-term trend curve is fitted to the monthly mean values. Contact: Dr. Pieter Tans, NOAA ESRL Carbon Cycle, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, and Dr. Ralph Keeling, SIO GRD, La Jolla, California, (858) 534-7582, rkeeling@ucsd.edu.

Climate change and CO₂



<http://www.cmdl.noaa.gov/ccgg>

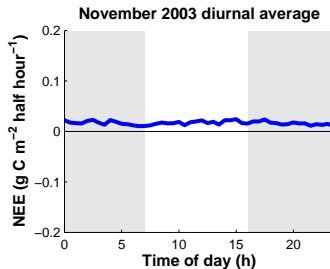
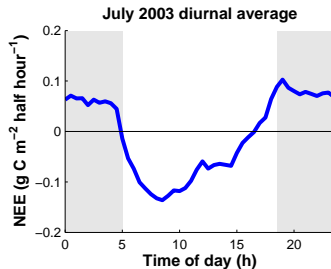
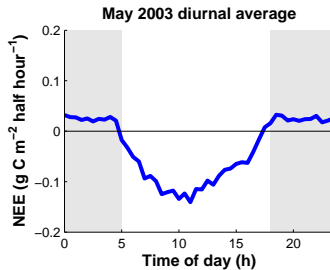
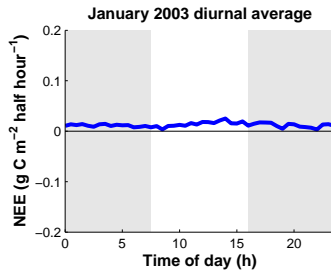
Forest carbon uptake



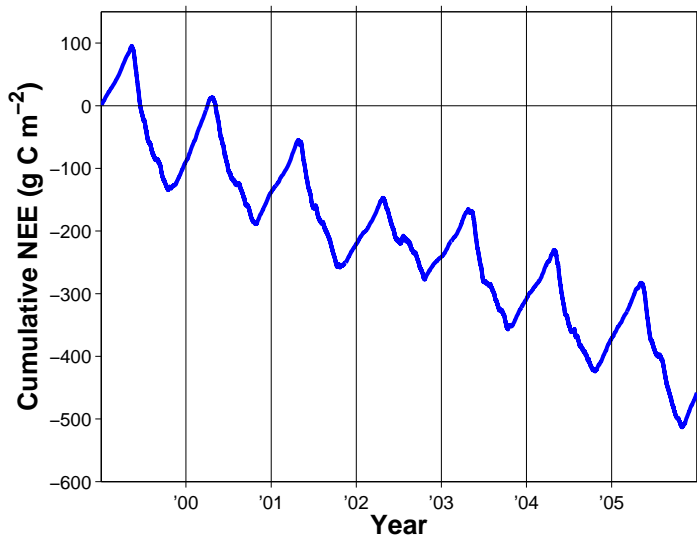
Niwot Ridge, Colorado

- Subalpine forest
 - Subalpine fir (*A. lasiocarpa*)
 - Engelmann spruce (*P. engelmannii*)
 - Lodgepole pine (*P. contorta*)
- 3050 m (10,000 ft) elevation
- Mean annual precipitation: 800 mm
- Mean annual temperature is 1.5 °C.

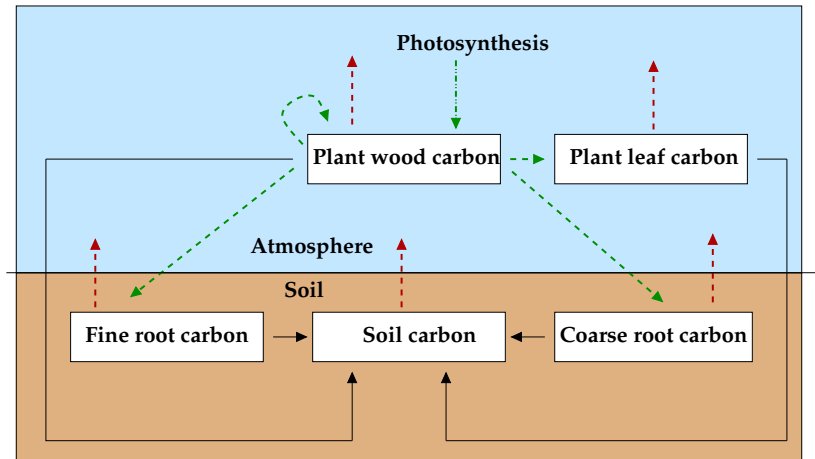
NEE seasonal variability



NEE long term variability



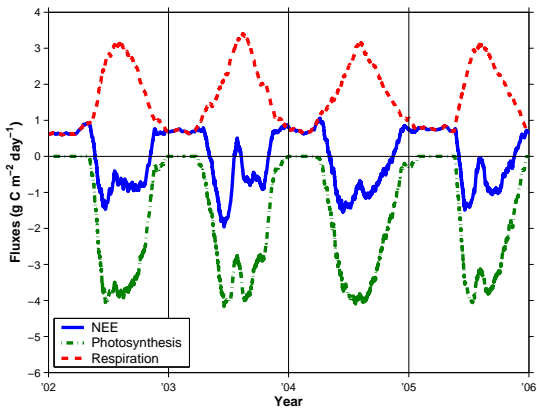
Ecosystem model (structure)



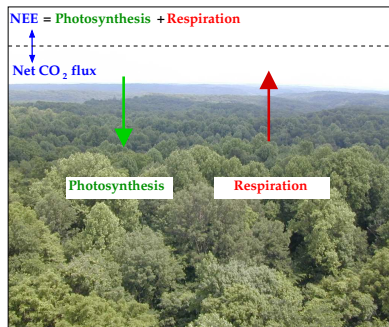
Zobitz et al. (2008), *Ecosystems*

Litter/turnover

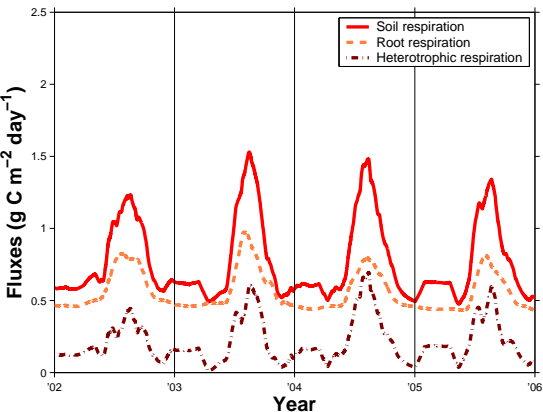
Results: Whole-ecosystem partitioning



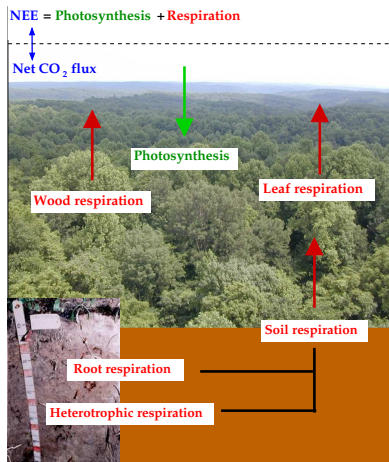
Zobitz et al. (2008) *Ecosystems*



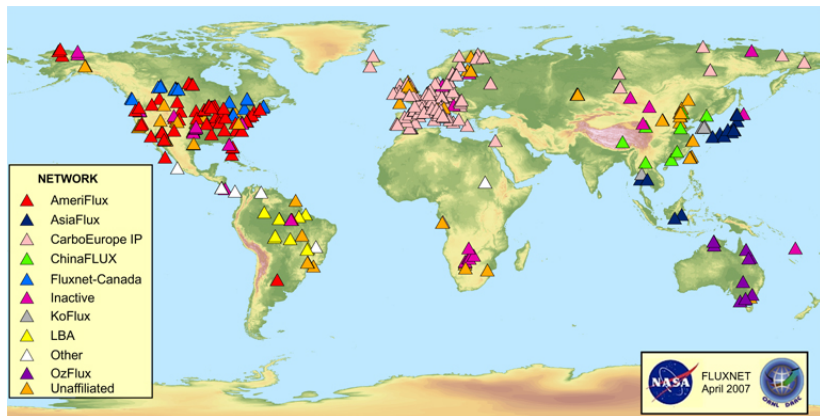
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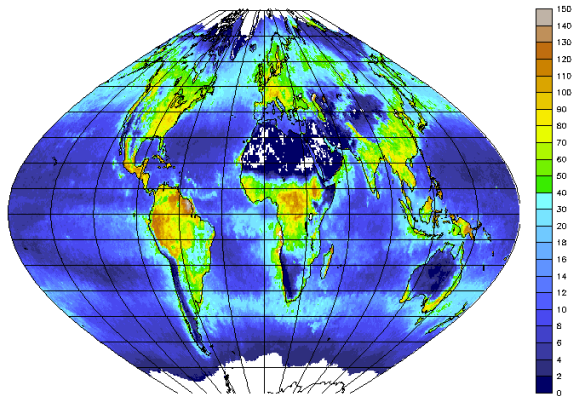
Global measurement network



- www.fluxnet.ornl.gov
- As of January 2009: 500 sites = 2600 site years of data
- Some sites provide 15 years of continuous data.
- \approx 40 million half-hourly measurements of biosphere-atmosphere carbon exchange
- All data are **FREE** and publicly available.

Global NPP

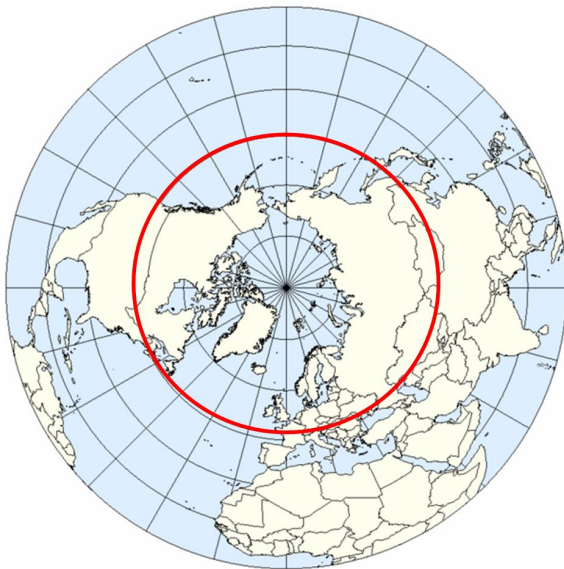
NPP



SEP 1997

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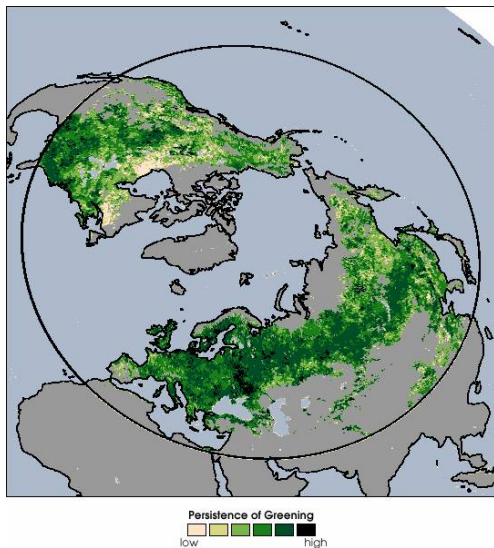
High latitude ecosystems



High latitude ecosystems



High latitude greening



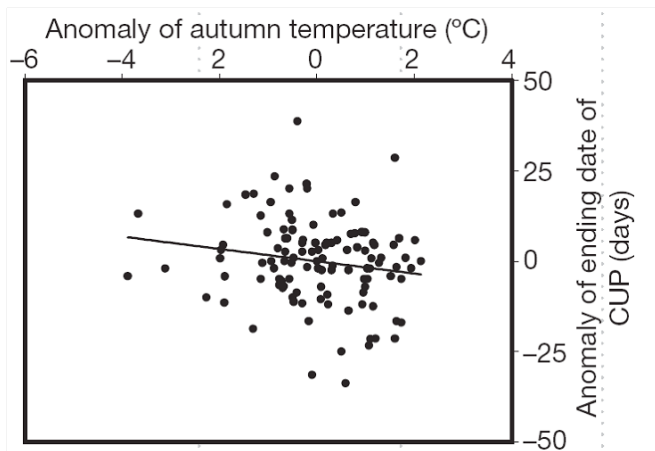
Courtesy of Liming Zhou

CO₂ is life

www.nasa.gov

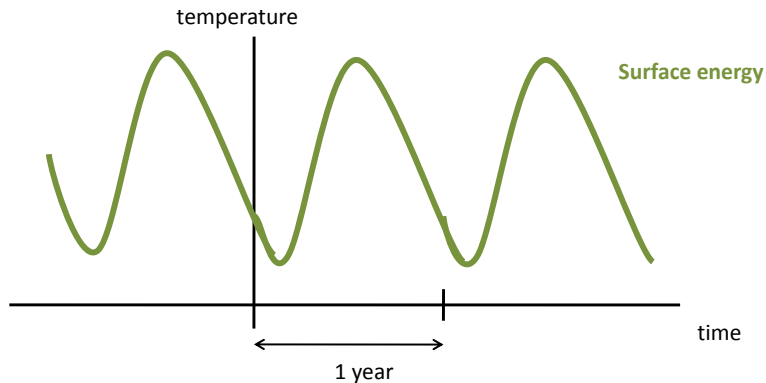
Carbon uptake in high latitude ecosystems

CUP = **C**arbon **U**ptake **P**eriod = summer length



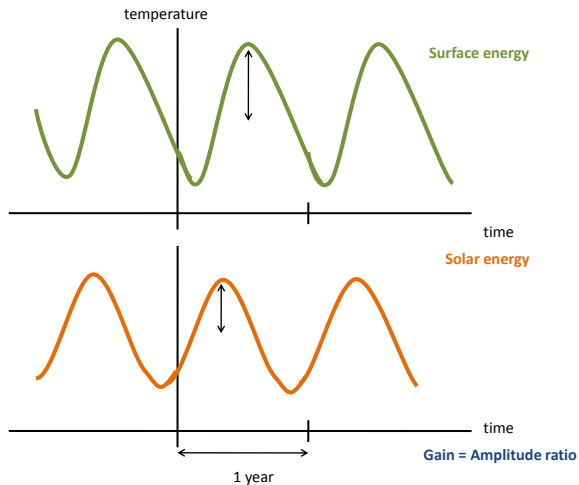
Cooler autumn = carbon uptake period increases
Piao et al. (2008), *Nature*

Changes in surface temperature



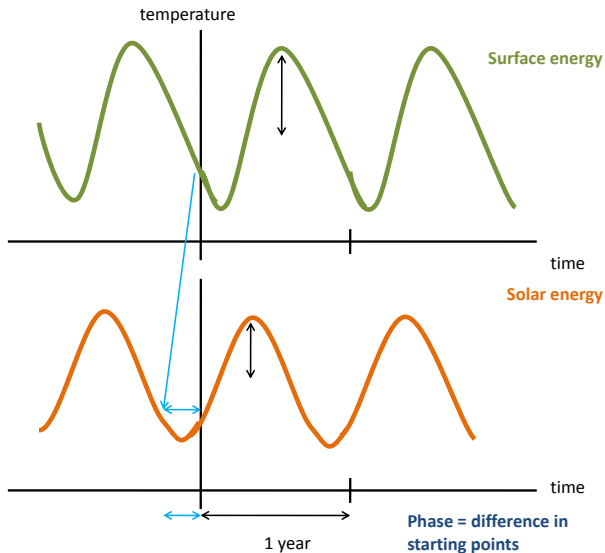
Stine et al. (2009)

Changes in surface temperature



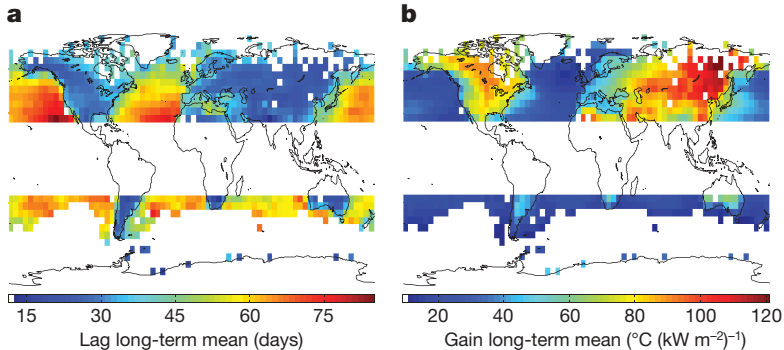
Stine et al. (2009)

Changes in surface temperature



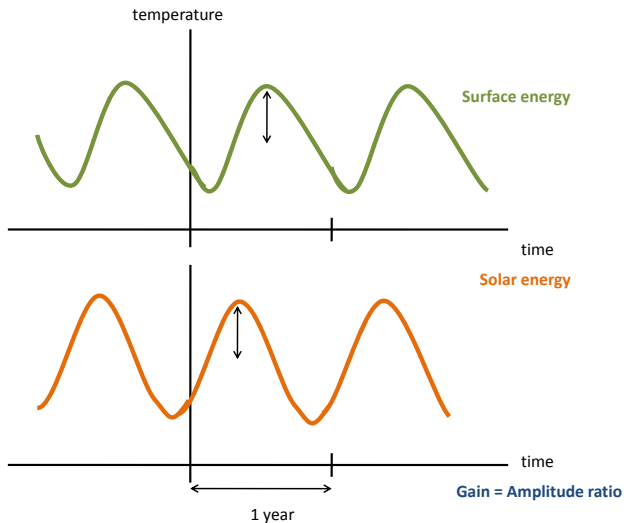
Stine et al. (2009)

Changes in surface temperature



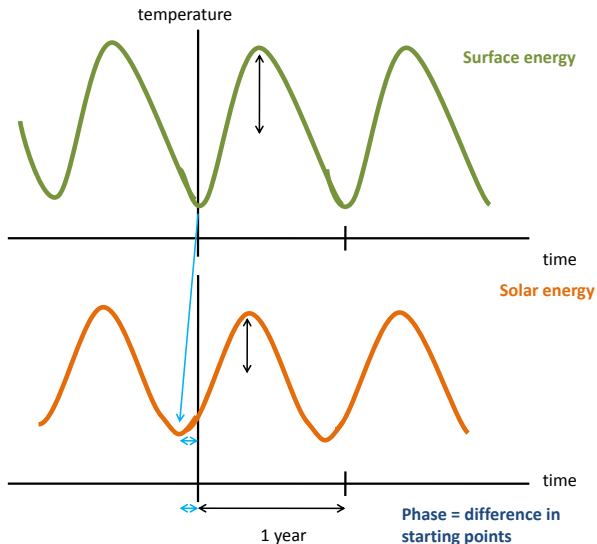
Stine et al. (2009)

Temperature range is *damped*



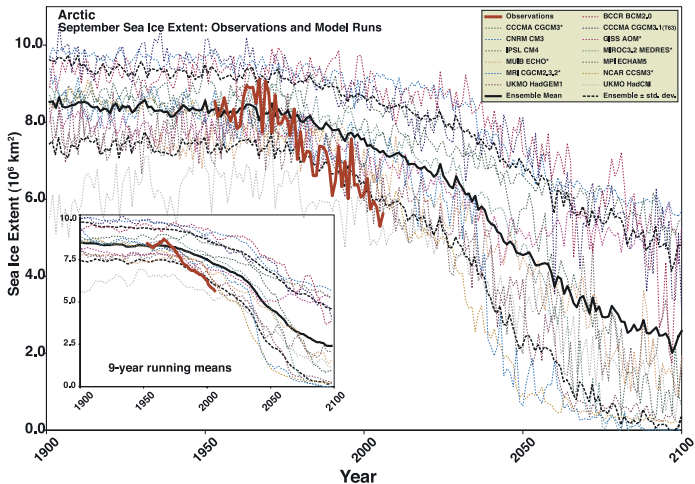
Stine et al. (2009)

Seasons are happening *earlier*



Stine et al. (2009)

Sea ice decline: faster than modeled

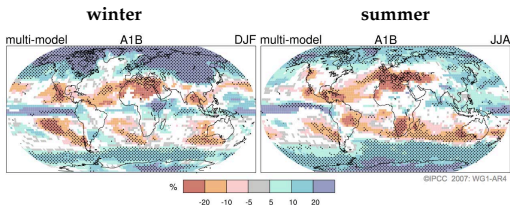
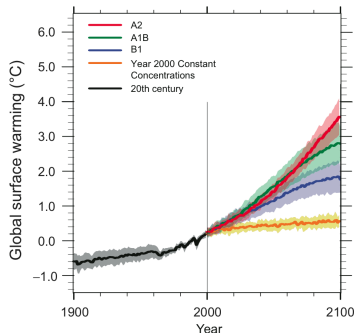


Stroeve et al. (2007)

Future climate changes

- Climate models predict both warming and change in global patterns of precipitation.
- How will climate change affect the world locally *and* globally?

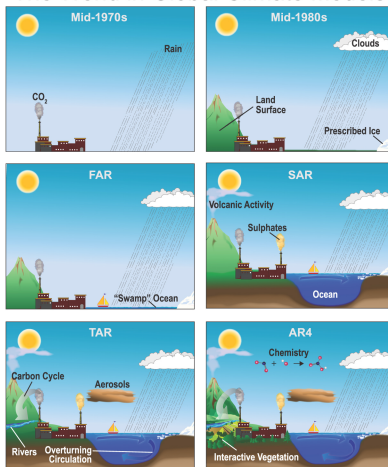
IPCC 4th Assessment Report (2007)



Precipitation changes 2090–2099, relative to 1980–1999

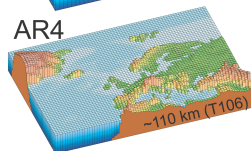
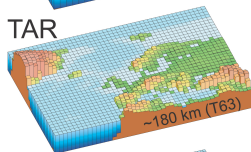
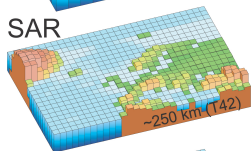
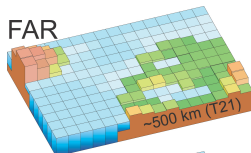
Climate models are becoming more realistic

The World in Global Climate Models



IPCC 4th Assessment Report (2007)

Climate models are becoming more realistic





Summary



Summary

- Math is an essential partner in understanding climate.
- Quantitative literacy is important to interpret climate results.

Acknowledgments

- YOU
- Undergraduate students: Andrew Bergeson
- Collaborators: David Schimel (UCAR), Russell Monson (University of Colorado), David Moore (King's College), Bill Sacks (University of Wisconsin).
- Sustainability Calculus
- NSF Utah IGERT Math Biology grant
- Augsburg College Mathematics Department
- Augsburg College NASA Space Grant

This talk will be available at my website:

<http://www.augsburg.edu/home/math/zobitz.html>