Pyrogeography
&
The Physics of Climate Change

Brad Marston
KITP & Brown University

May 27, 2008

KITP Program Focii:

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- Clouds

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- Ecosystems

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- Clouds
- Ecosystems
- Large-scale circulation

Questions

Clouds:

- How to model low (planetary boundary layer) clouds?
- How to think about the probability distribution of cloud types, and how might it shift with climate change?
- How to model the fraction of cloud cover and what are better parameterizations? Total cloud albedo is amazingly constant -- why?
- How to combine models with a good vertical resolution with an account of micro and macro-turbulence?
- Can cloud cover be viewed as a problem of optimization? Maximum entropy ideas?
- To what degree are precipitation extremes controlled by properties of clouds?
- Aerosols and cloud nucleation processes?

Ecosystems:

- Are in-situ experiments that modify temperature, CO_2, and/or moisture realistic simulations of a changing climate?
- How can carbon-cycle models be verified? Over what time and spatial scales?
- What is the best model of the biosphere that we can realistically hope for?
- Measurements of CO_2 in a vertical column are needed (large diurnal oscillations in surface CO_2 concentrations due to plant photosynthesis / respiration).
- Do we need to worry about species instead of just plant functional types?

Ice:

- Pressing need to model ice flow over surfaces (ie. the Greenland and Antarctic ice sheets). How can this be done?

Macroturbulence:

- Do statistical closures exist that reproduce, at least qualitatively, the main features of extratropical circulation? Quantitatively?
- What is the basic mechanism of Madden-Julian oscillations that determines their period and the speed of propagation?
- Origin of power law scaling in mesoscale turbulence.
- Moisture: Effect of water vapor and latent heat on large-scale eddies.
- Simple models of the monsoon -- can they be constructed? What are the basic drivers?

Models:

- Hierarchy of important processes -- how to organize? How to calculate?
- Tipping points? Do they exist? If so, how to detect? Are toy models useful?

Oceans:

- Are there locations where the formation of deep water could keep CO_2 away from the atmosphere for > 100 years?
- To what degree is mixing a function of climate? What sets rate of vertical mixing rates? What controls heat transport?

Sunlight = Infrared Radiation

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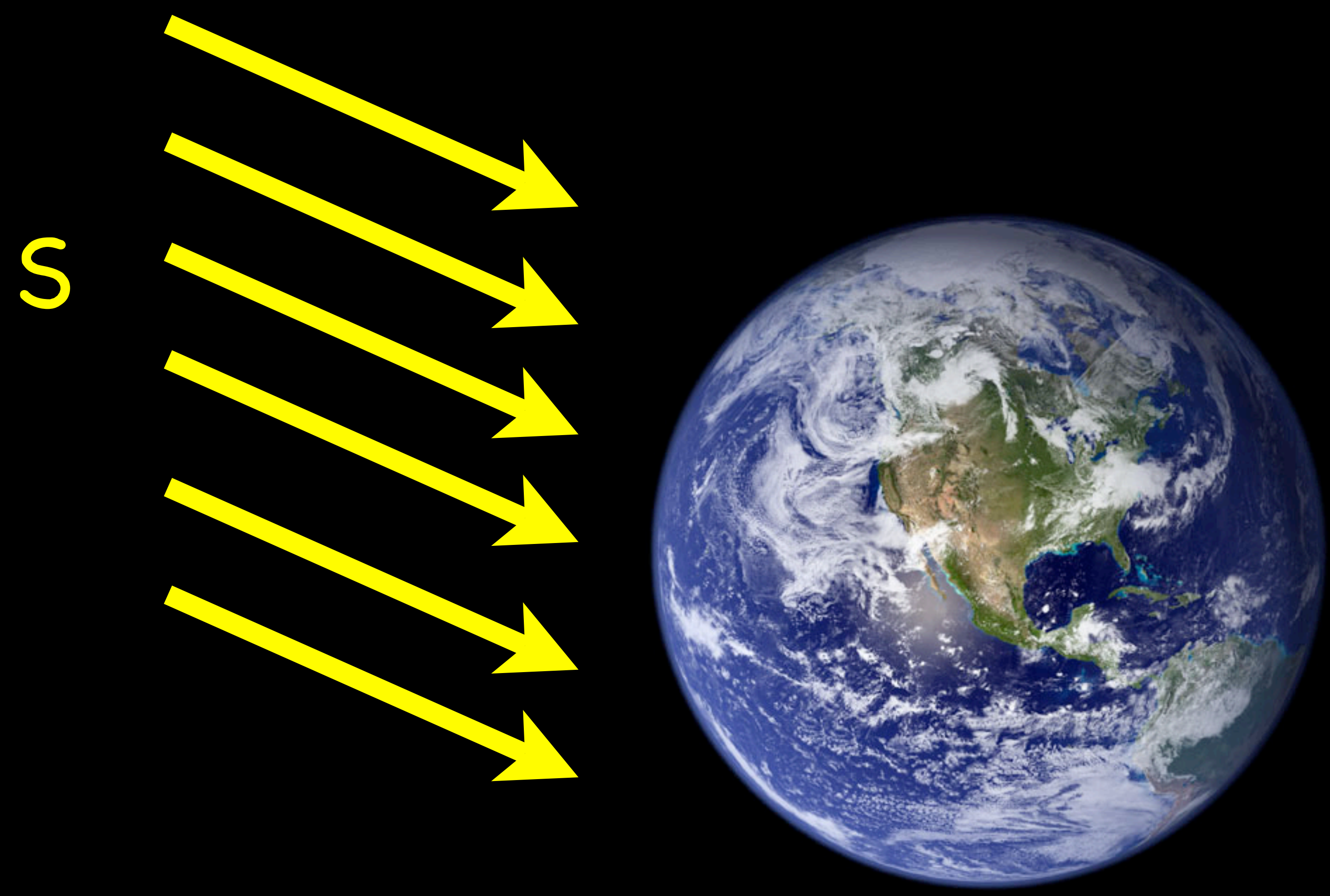
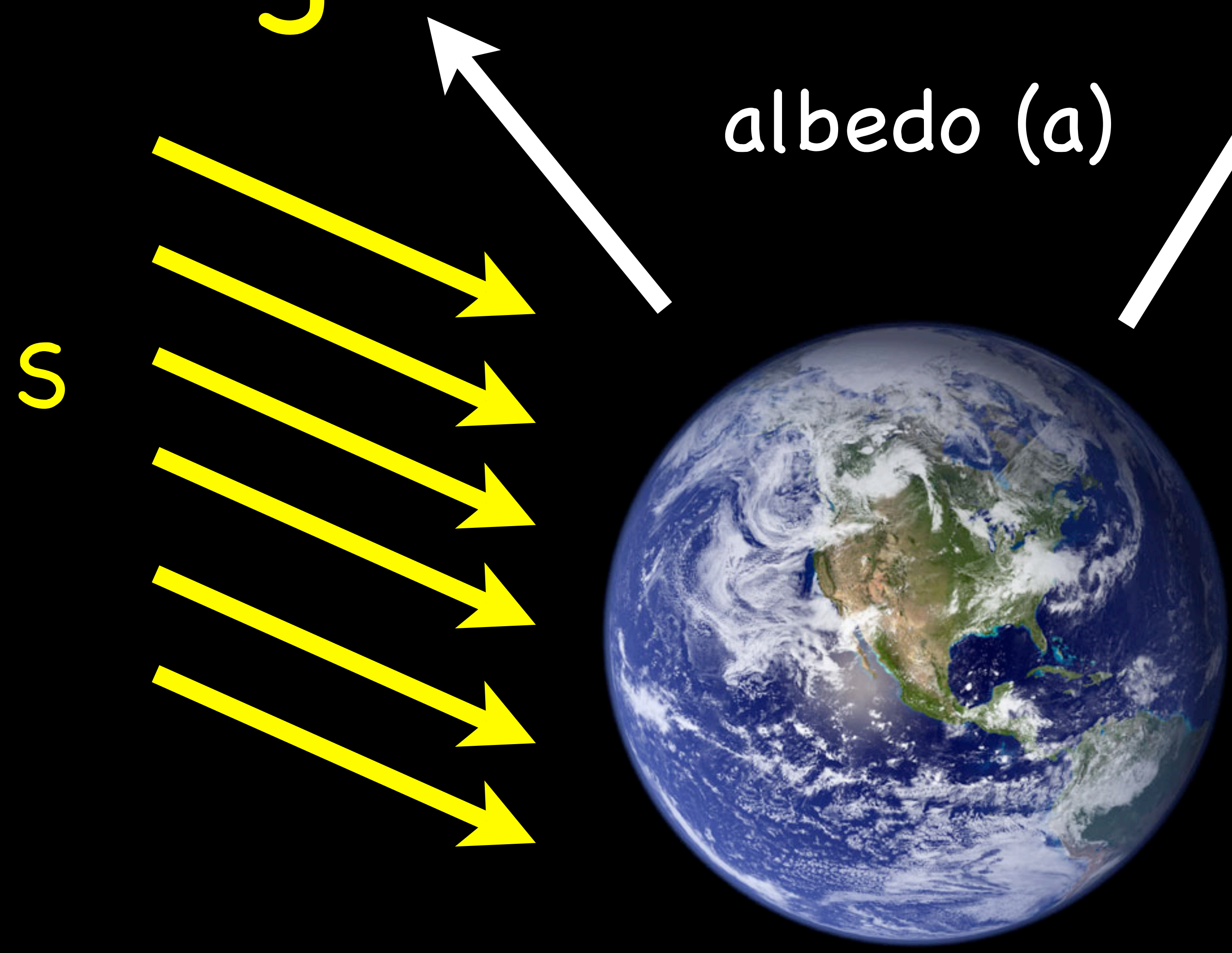
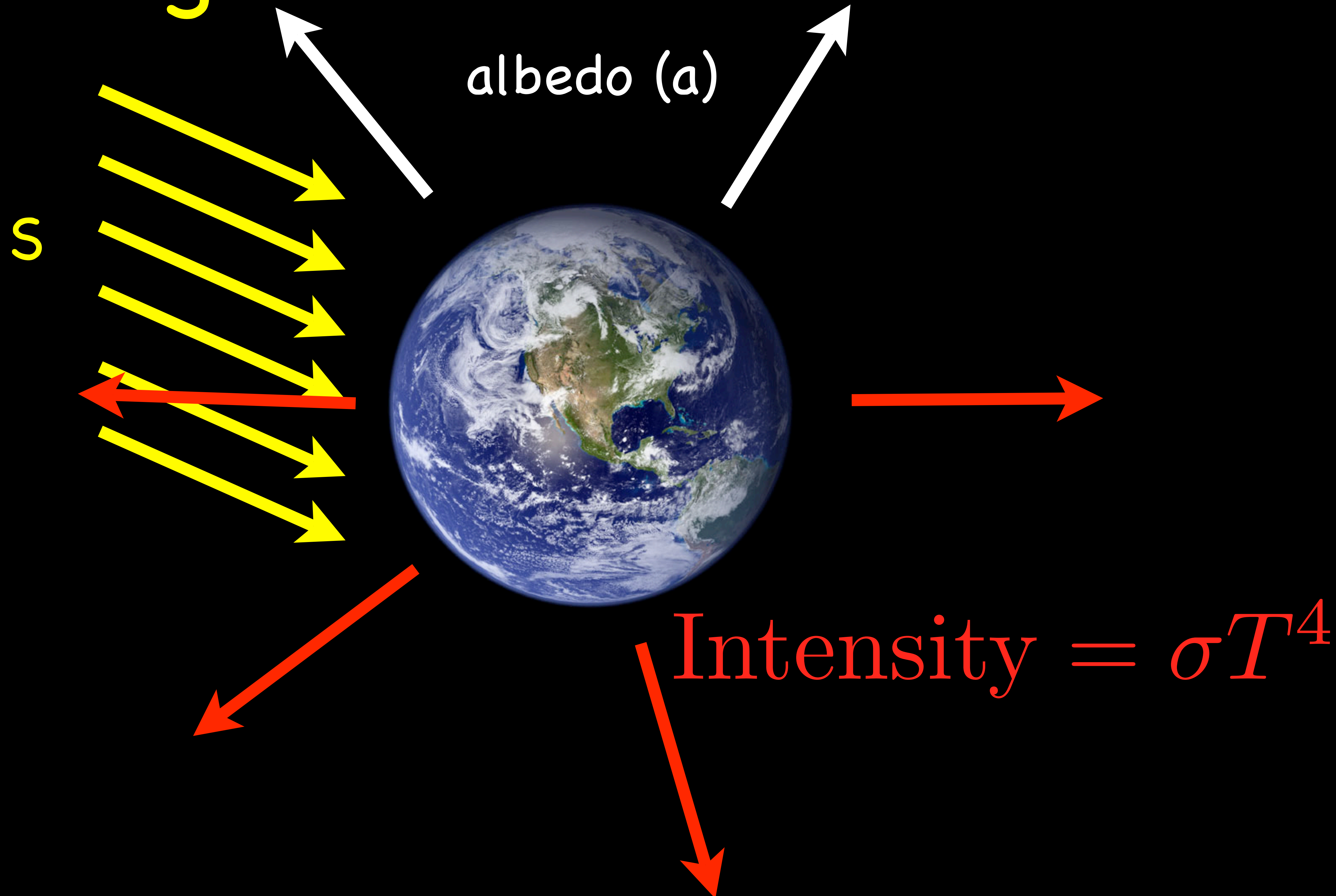


Sunlight = Infrared Radiation



Sunlight = Infrared Radiation



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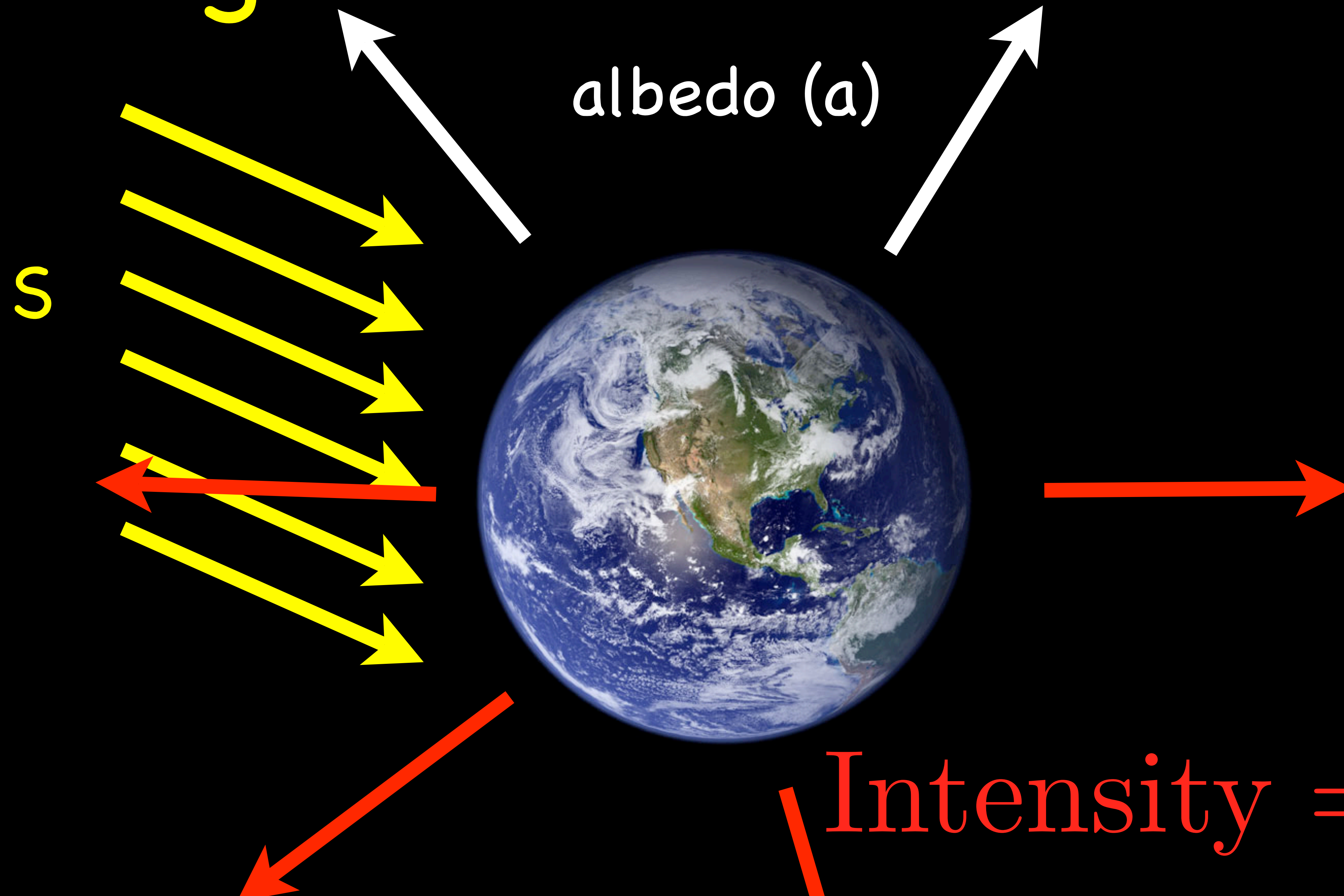

$$\text{Intensity} = \sigma T^4$$

$$\sigma = \frac{2\pi^5 k_B^4}{15 h^3 c^2} = 5.67 \times 10^{-8}\ \mathrm{W/m^2K^4}$$

Temperature of the Earth

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$$\left.\begin{array}{c} S = 1,366\ \text{W/m}^2 \\ a \approx 30\% \end{array}\right\} \quad \begin{array}{rcl} T & = & 255\text{K} \\ & = & -18^\circ\text{C} \end{array}$$

Terrestrial Planets

Planet
calculated temperature
actual temperature
greenhouse warming

Terrestrial Planets

Planet	Earth
calculated temperature	-18 ^{0}C
actual temperature	15 ^{0}C
greenhouse warming	33 ^{0}C

Terrestrial Planets

Planet	Earth	Mars
calculated temperature	-18 ^{0}C	-56 ^{0}C
actual temperature	15 ^{0}C	-53 ^{0}C
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Terrestrial Planets

Planet	Earth	Mars	Venus
calculated temperature	-18 ^{0}C	-56 ^{0}C	-39 ^{0}C
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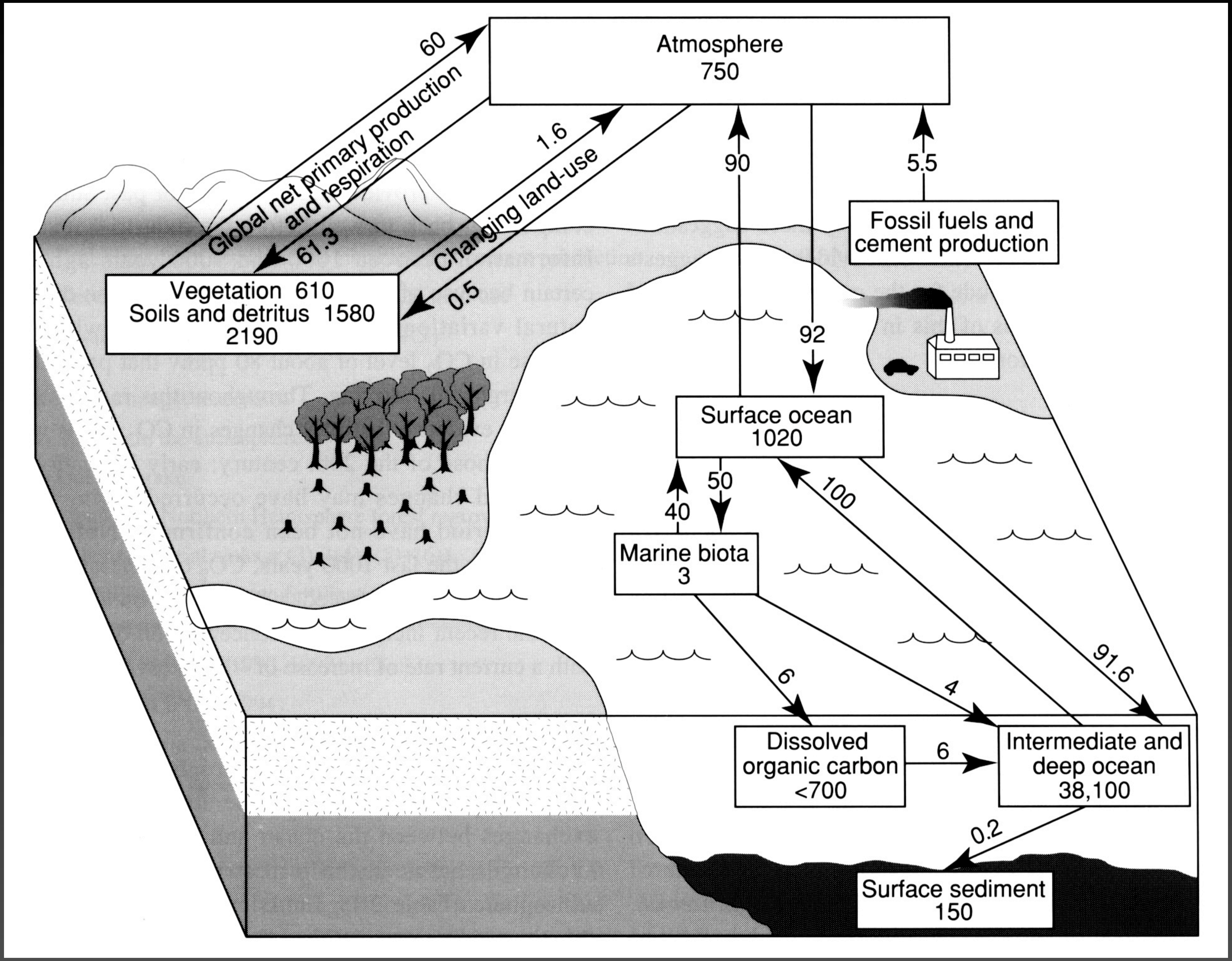
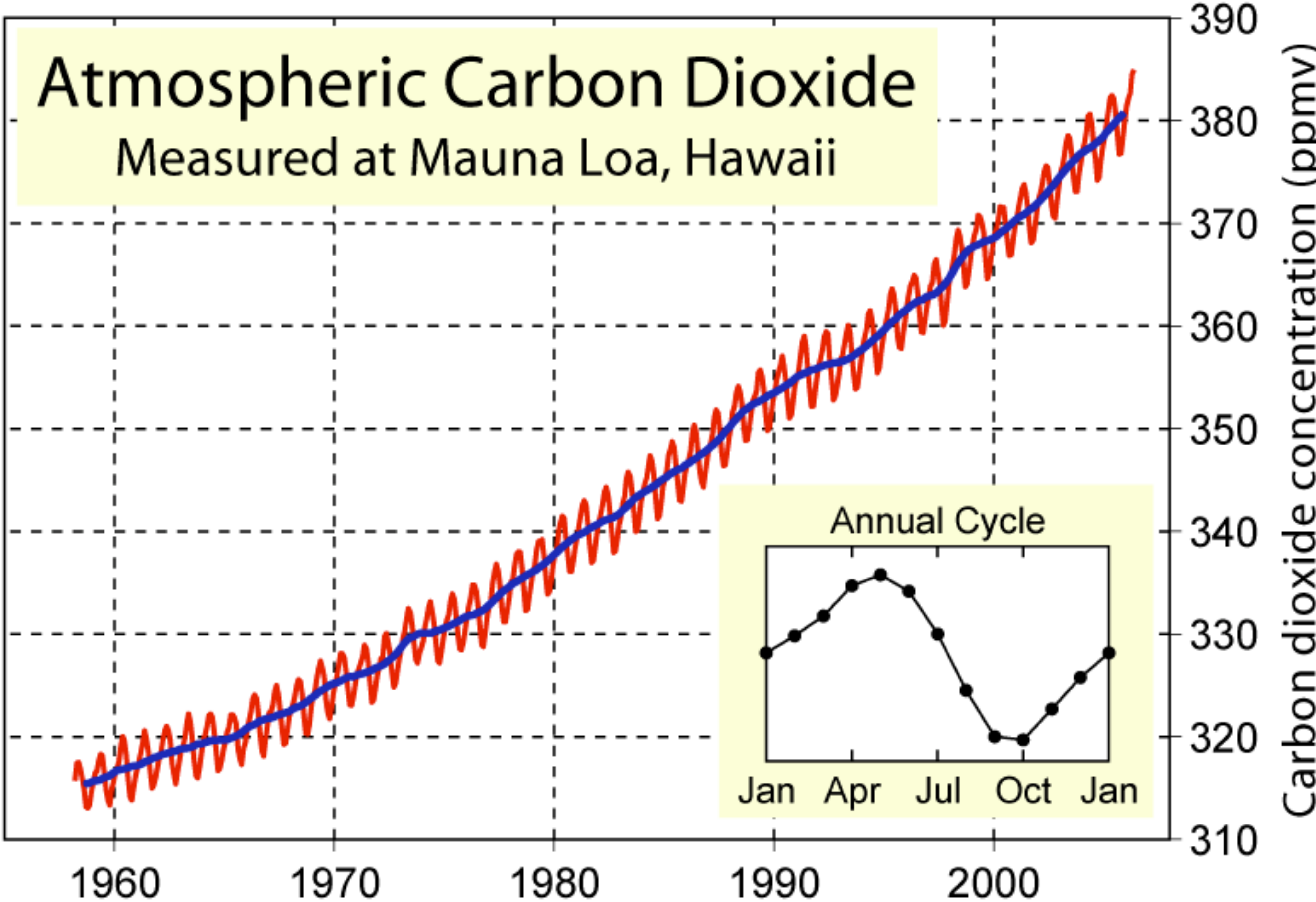
Water Vapour: 65%   Carbon Dioxide: 21%

Vast Reservoirs of Carbon & Enormous Fluxes

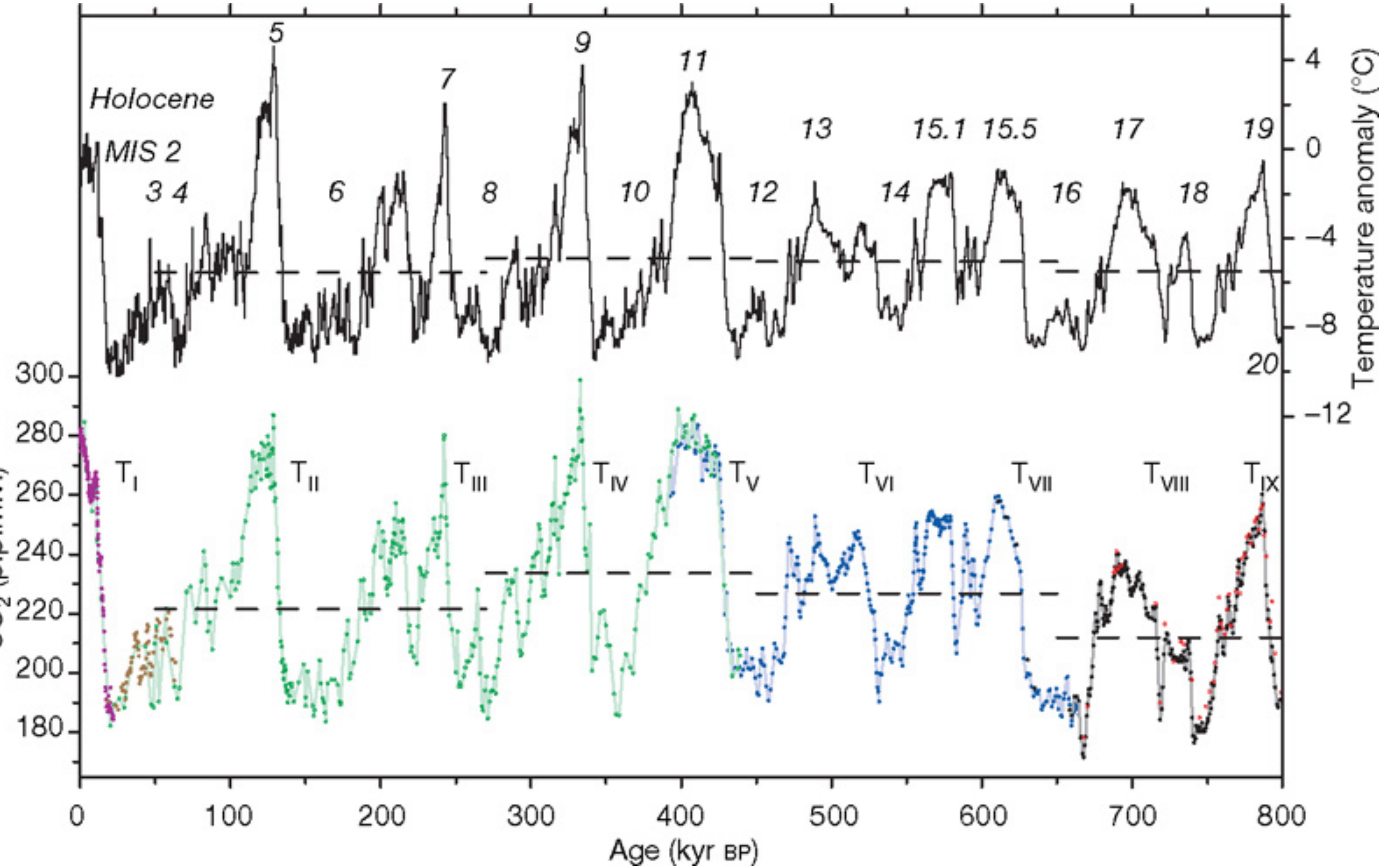


Source: *Climate Change 1995*



Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii
Annual Cycle
Jan
Apr
Jul
Oct
Jan
390
380
370
360
350
340
330
320
310
Carbon dioxide concentration (ppmv)
1960
1970
1980
1990
2000

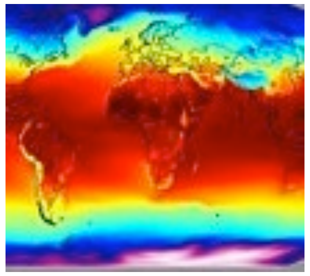
D. Lüthi *et al.* Nature **453,** 379 (2008)



KITP Conference: Frontiers of Climate Science (May 6-10, 2008)

Sponsored, in part, by BP.

Coordinators: Paul Kushner, Brad Marston, Chris Still
Scientific Advisors: Jean Carlson, Gregory Falkovich, John Harte, Ray Pierrehumbert



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Speakers: Please see us about file upload for your slides.

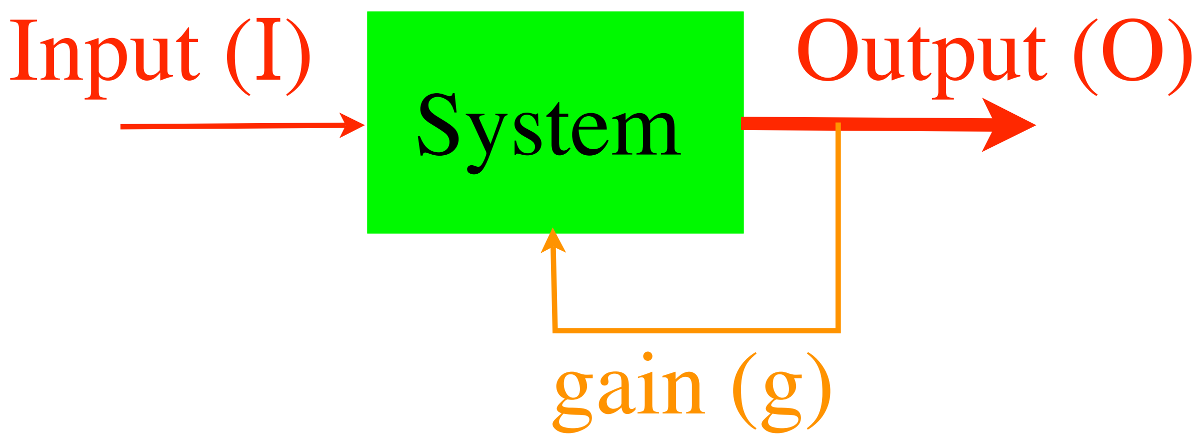
Tuesday, May 06, 2008

Ecosystems and Climate I
Morning Session Chair: Matthew Huber (Purdue)
[Perspective talks are 45 min + 15 min discussion]
[Regular talks are 30 min + 15 min discussion]

8:50am	David Gross (KITP Director)	Welcome [Podcast][Aud][Cam]
9:00am	John Harte (UC Berkeley)	Problems and Prospects at the Intersection of Ecology and Climate [Slides][Podcast][Aud][Cam]
10:00am	David Noone (Univ. Colorado, ATOC)	Exchanges at the Interface Between Terrestrial Ecosystems, the Water Cycle and Climate [Podcast][Aud][Cam]
10:45am	MORNING BREAK	
11:15am	Zhengyu Liu	On The Abrupt Change of the Northern Africa

KITP

John Harte (Berkeley & KITP): Physics of Feedbacks



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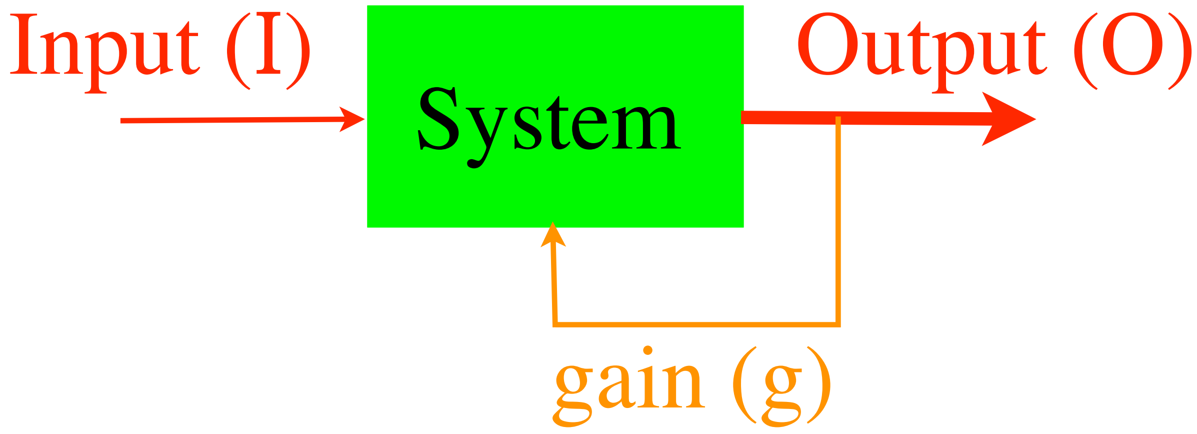

$$\mathcal{O} = \mathcal{I} + g\mathcal{I} + gg\mathcal{I} + \cdots$$
$$= \frac{\mathcal{I}}{1-g} \quad \text{if } g < 1$$

$$g = \sum_i \left(\frac{\partial T}{\partial p_i}\right)\left(\frac{\partial p_i}{\partial T}\right)$$

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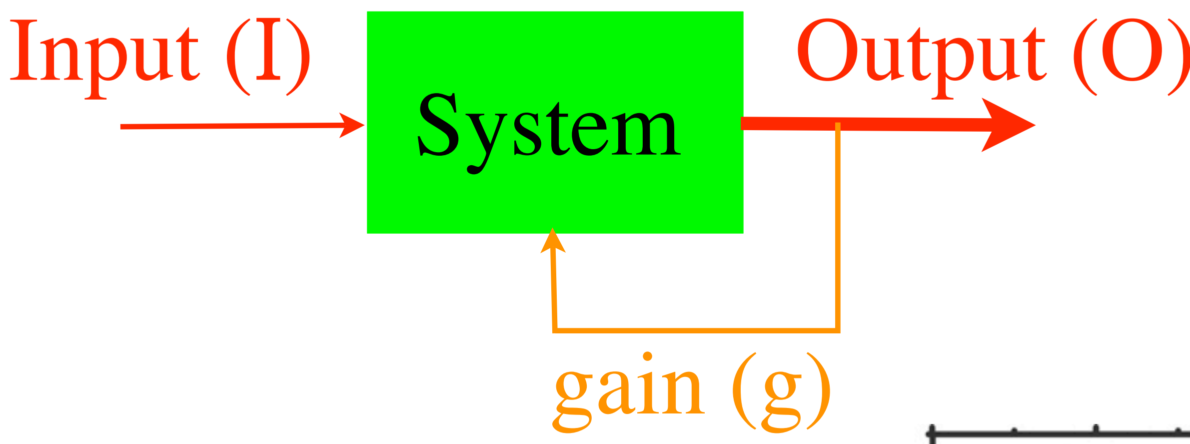

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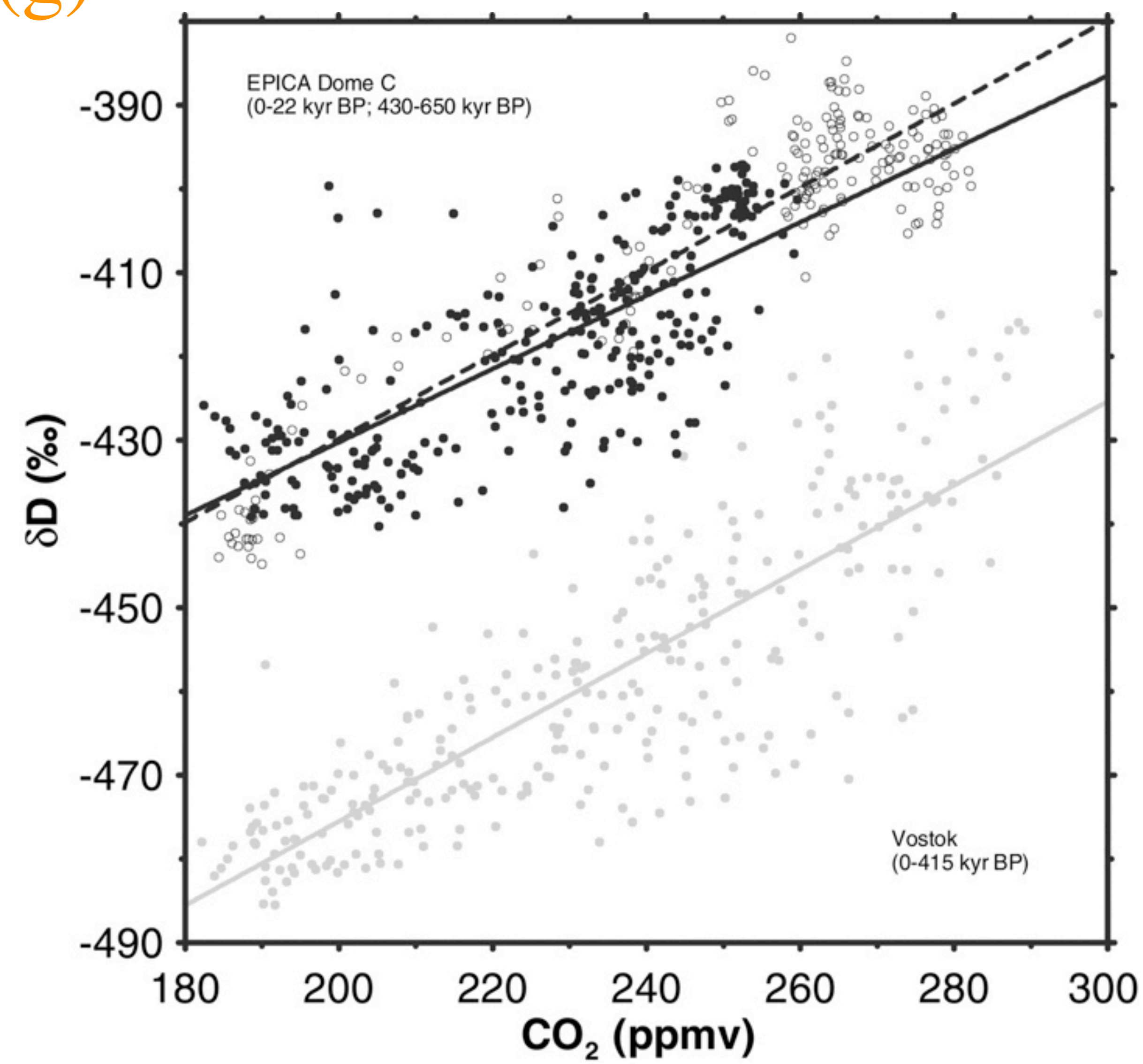

Some Feedbacks Already Included in Models

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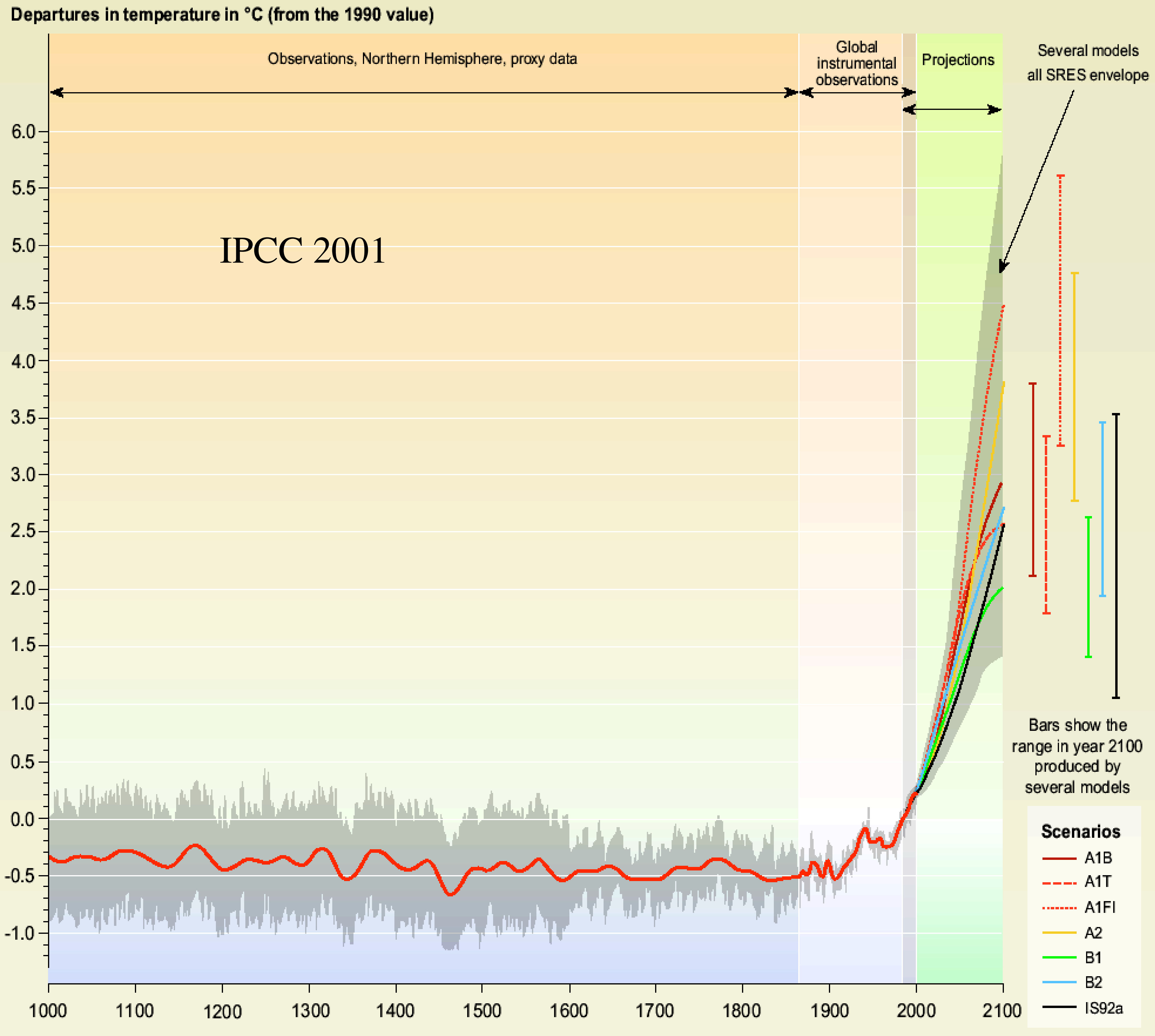
$$\Delta T \approx 1^{\circ}C/(1-0.71) \approx 3.4^{\circ}C$$

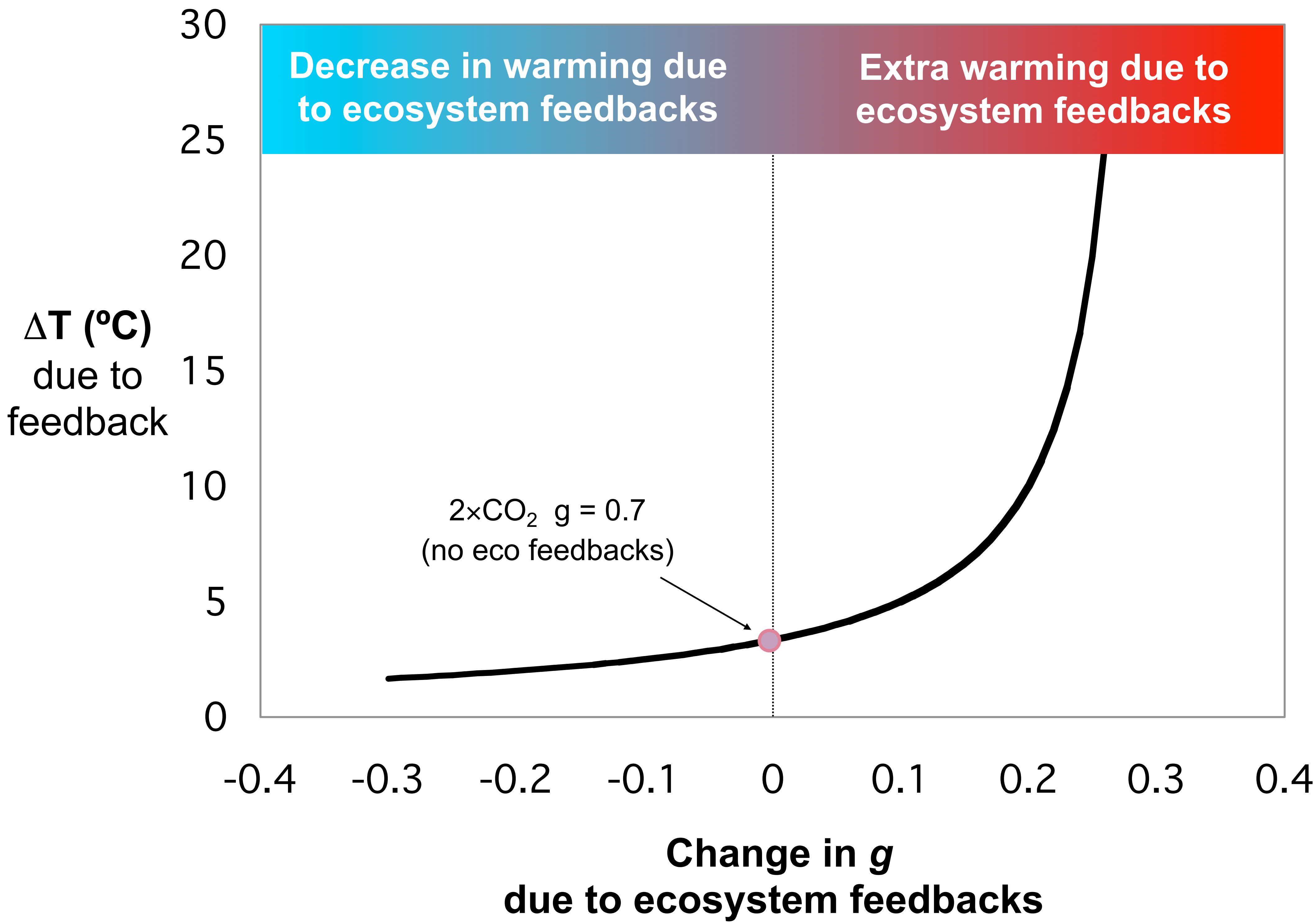
Variations of the Earth's surface temperature: years 1000 to 2100



Global Carbon Cycle

Small change in g causes large ΔT

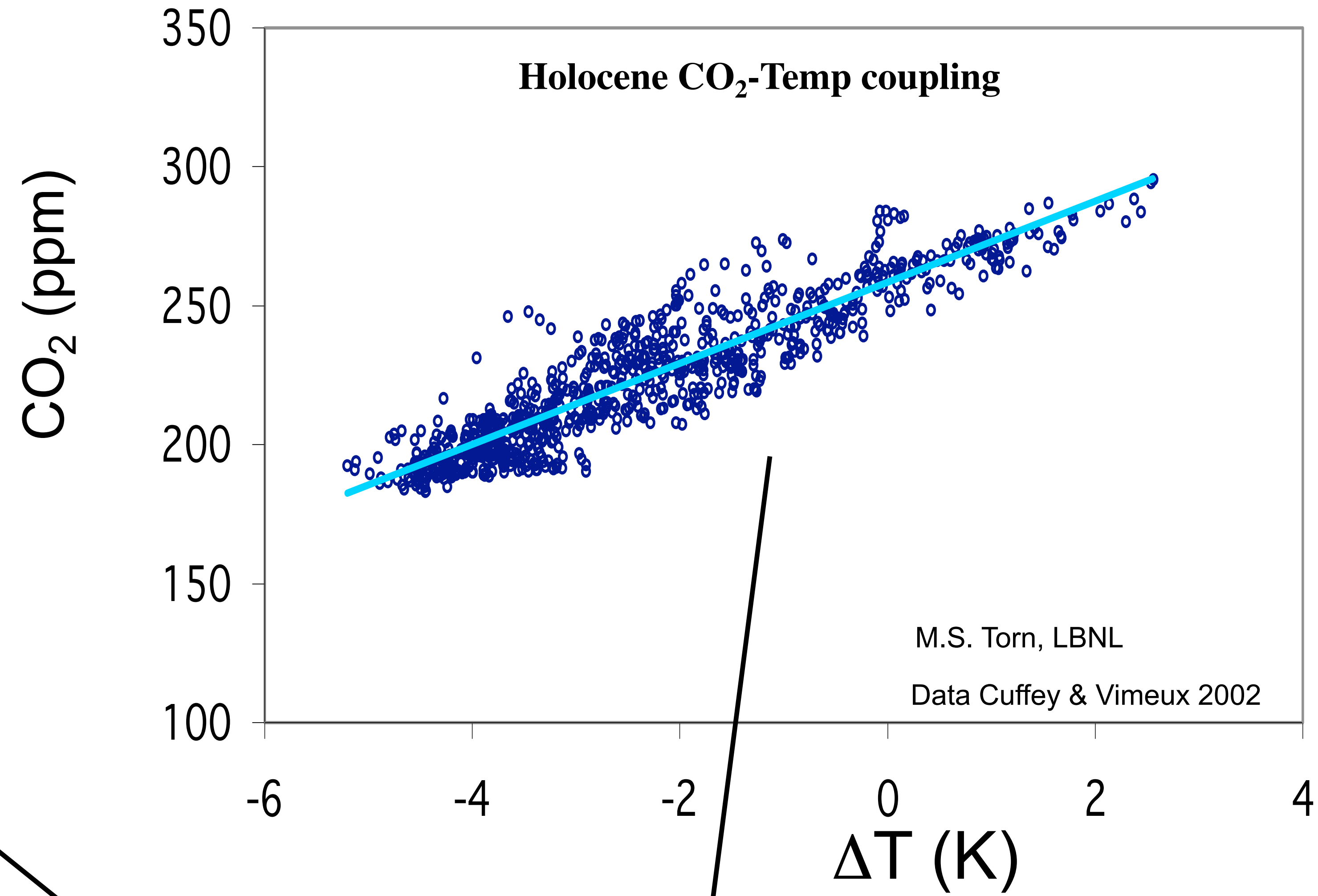
Asymmetries



M.S. Torn, LBNL

An estimate of the contribution to g from Vostok core data:

Torn and Harte, GRL **33**, L10703 (2006)



General Circulation Models

$$g_{\mathrm{CO_2}} = \frac{\partial T}{\partial [CO_2]} \cdot \frac{\partial [CO_2]}{\partial T} = \frac{1^\circ C}{275 ppmv} \cdot \frac{14.6 ppmv}{1^\circ C} = 0.053$$

1°C/(1 - .71) = 3.4°C

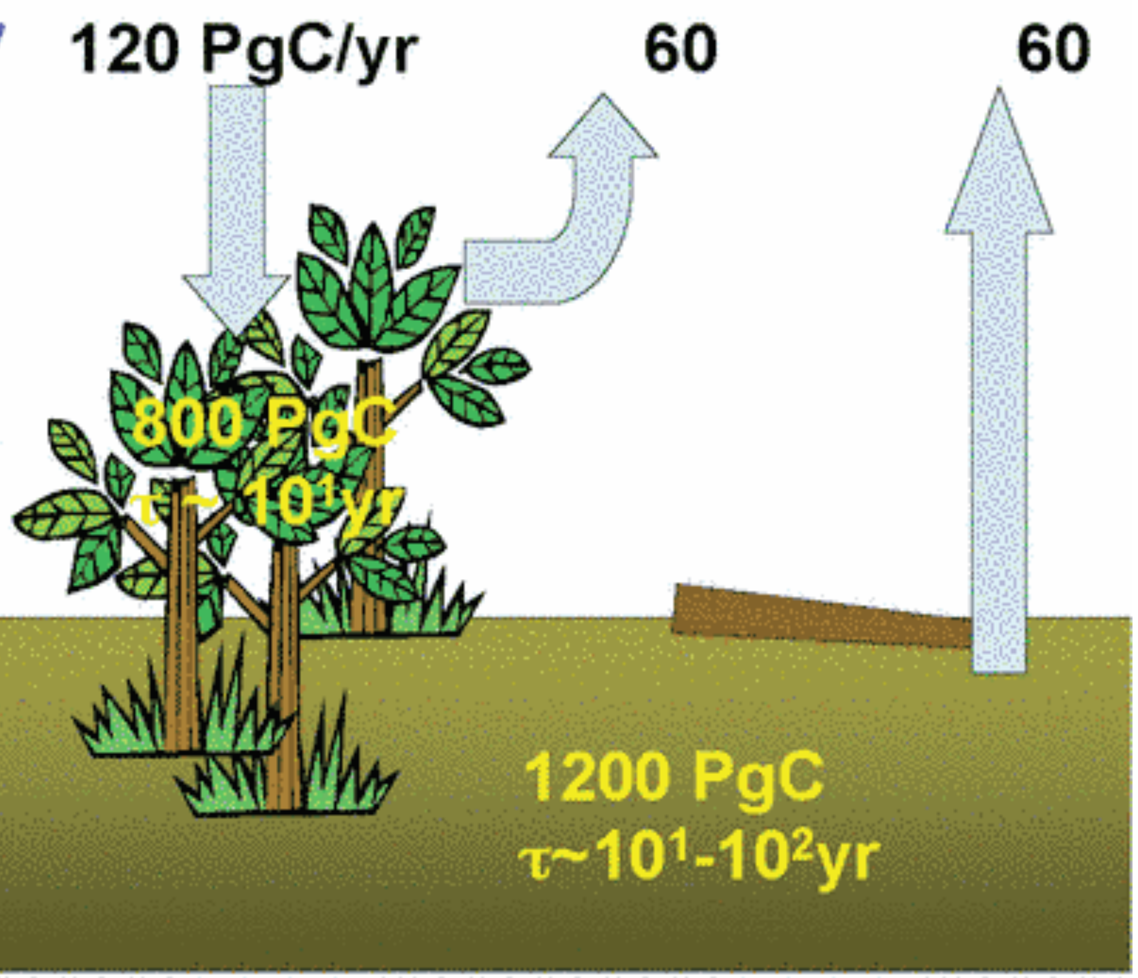
1°C/(1 - .71 – .05) = 4.2°C

But where is the carbon coming from?

Inez Fung (Berkeley)

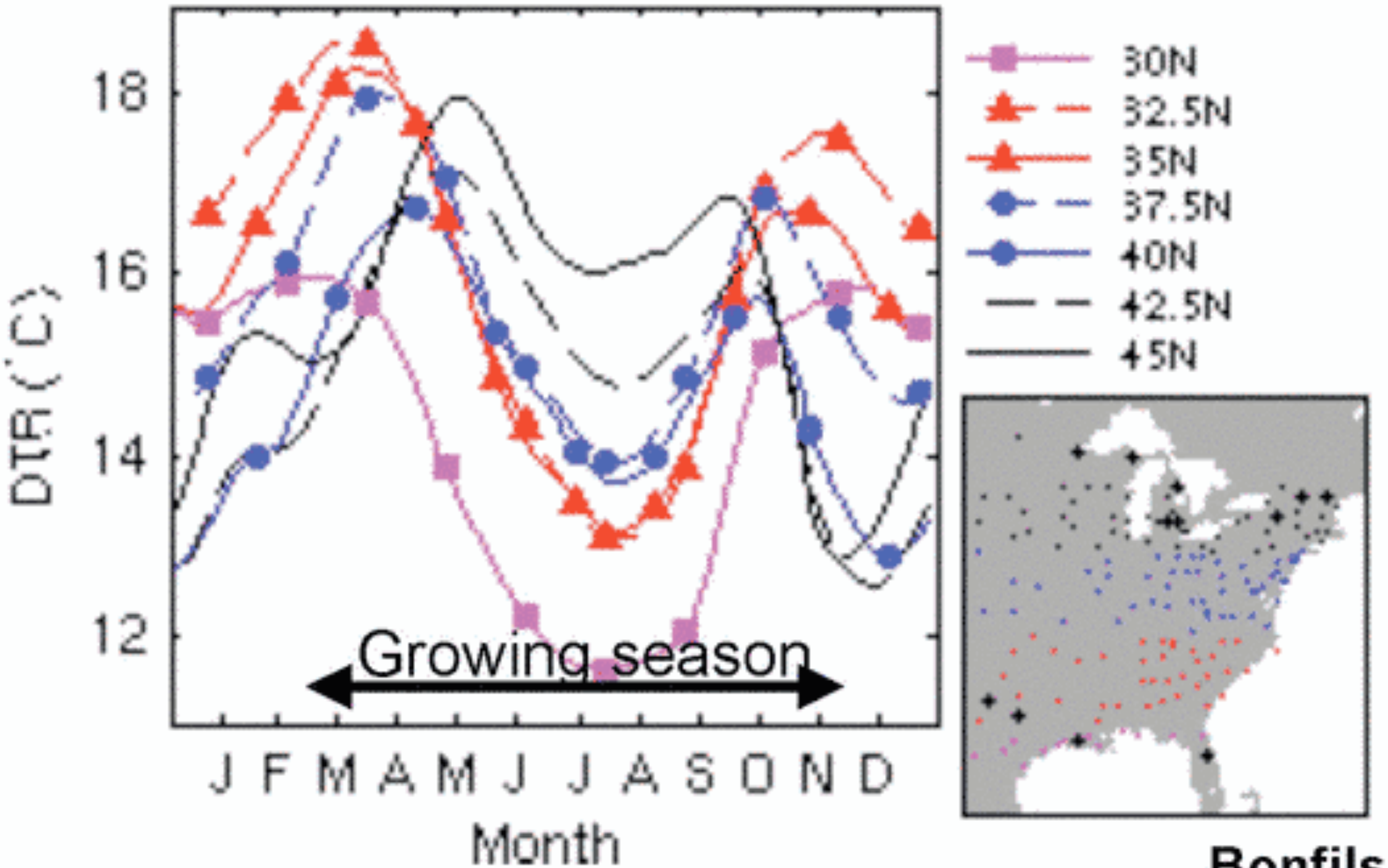
(2) What? [lifecycle traced by C cycle]

- Growth, mortality, decay
- Population: {ages}
- Photosynthesis (climate, CO_2, soil H_2O, resource limitation)
- Decay (T, soil H_2O,..)



Diurnal Temperature Range: coupling of energy-water-carbon fluxes

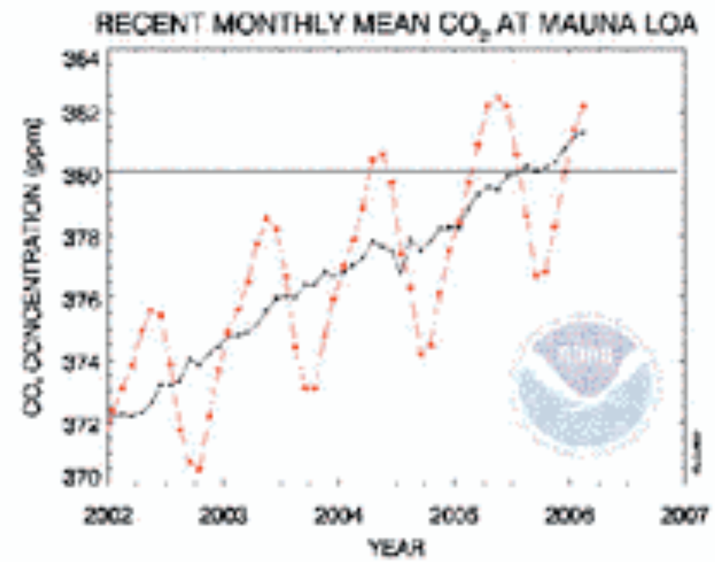
$$C\frac{\partial T_g}{\partial t} = SW \updownarrow + LW \updownarrow \underbrace{-SH}_{\text{warms PBL}} - \underbrace{LH}_{\text{cools PBL}}$$

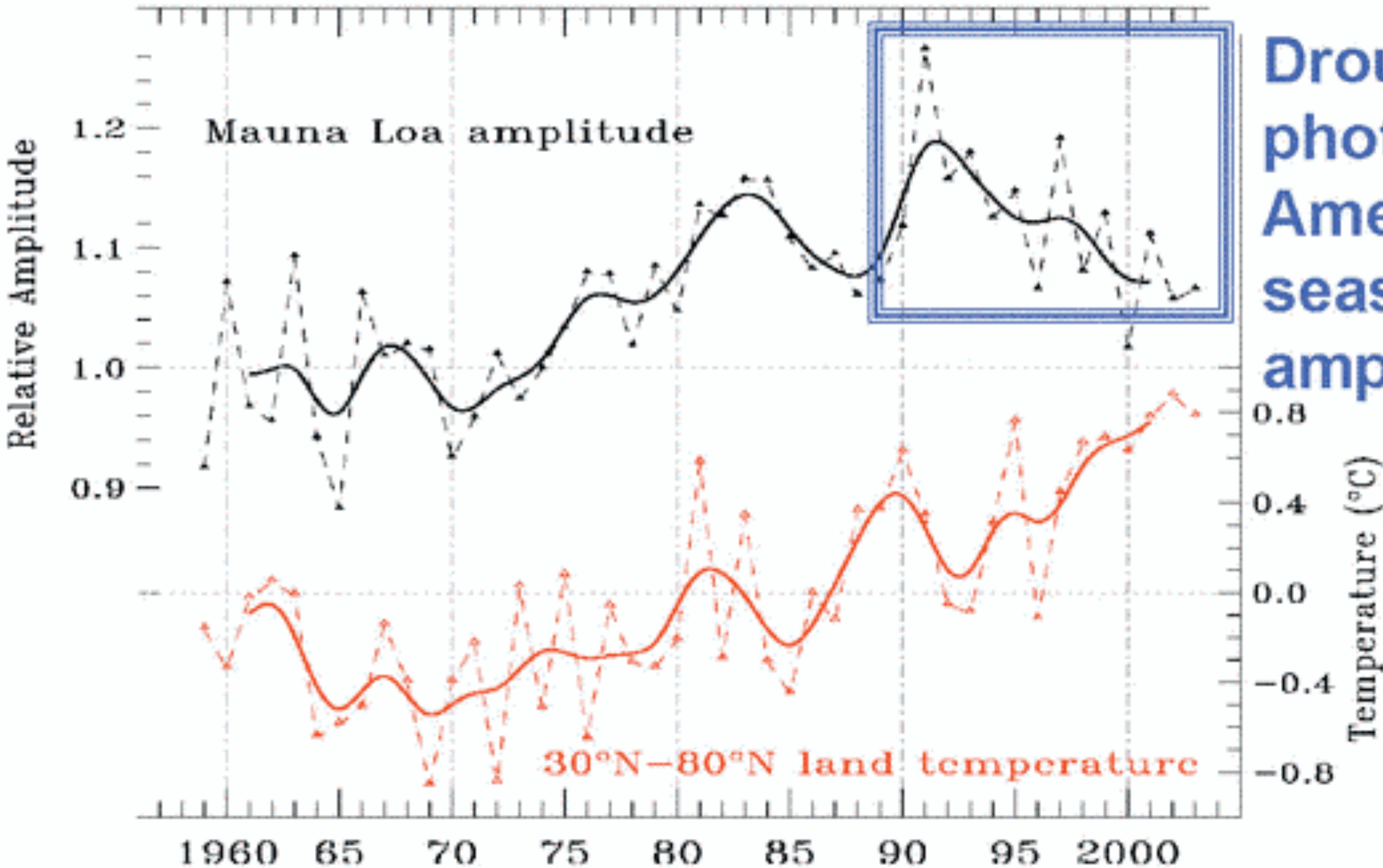


Spring chill when growing season starts

Bonfils et al. GRL 2005

Evidence for slowing NH land sink: Changes in MLO Amplitude since 1990





Droughts reduced photosyn in N America and seasonal CO2 amplitude at MLO

Buermann et al. PNAS 2007

How would CO_2 and climate co-vary?

Suppose there is warming…

Atm CO_2 would increase because:

- Warming may enhance decomposition
- Increased ocean stratification → more carbon in mixed layer → reduced air-to-sea flux
- ….

Atm CO_2 would decrease because:

- warming may enhance photosynthesis
- Enhanced marine productivity and export

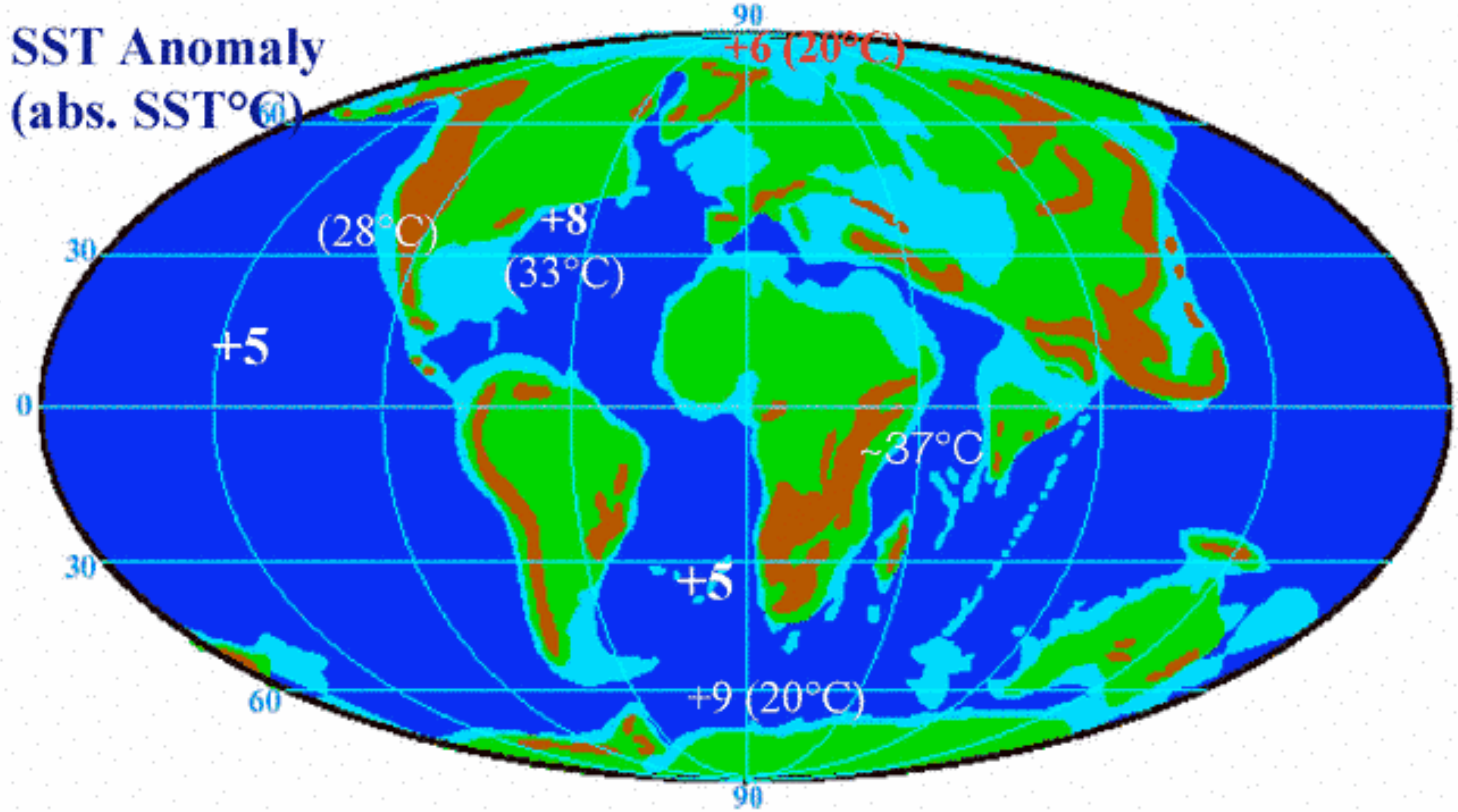
In model, three flavors of CO2:

- CO2_tracer(x,y,z,t)
- CO2_bgc=CO2_tracer(x,y,lowest layer,t)
- CO2_rad=CO2_tracer(x,y,column,t)

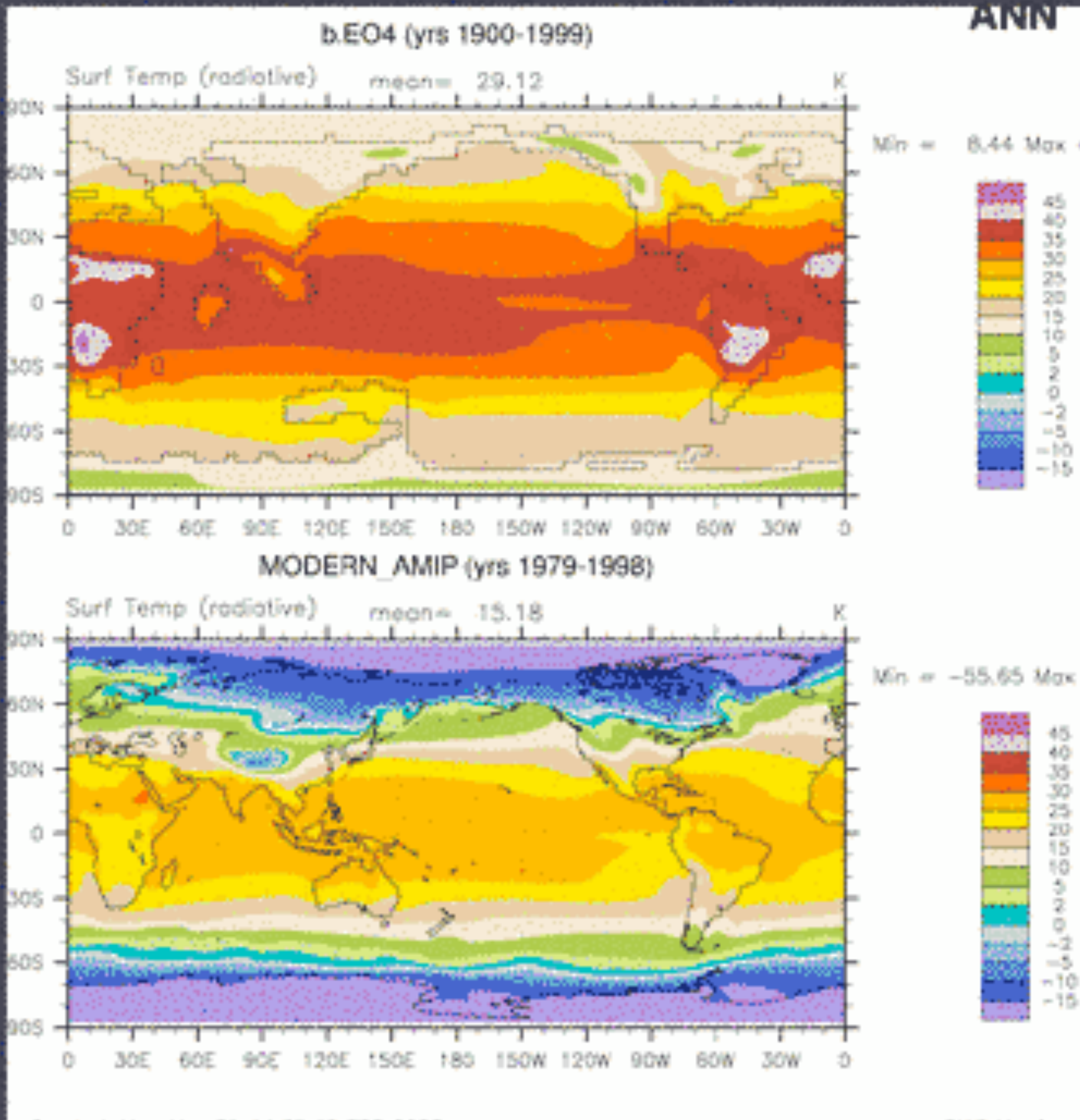
Models expts:
BGC coupling,
Radiative coupling

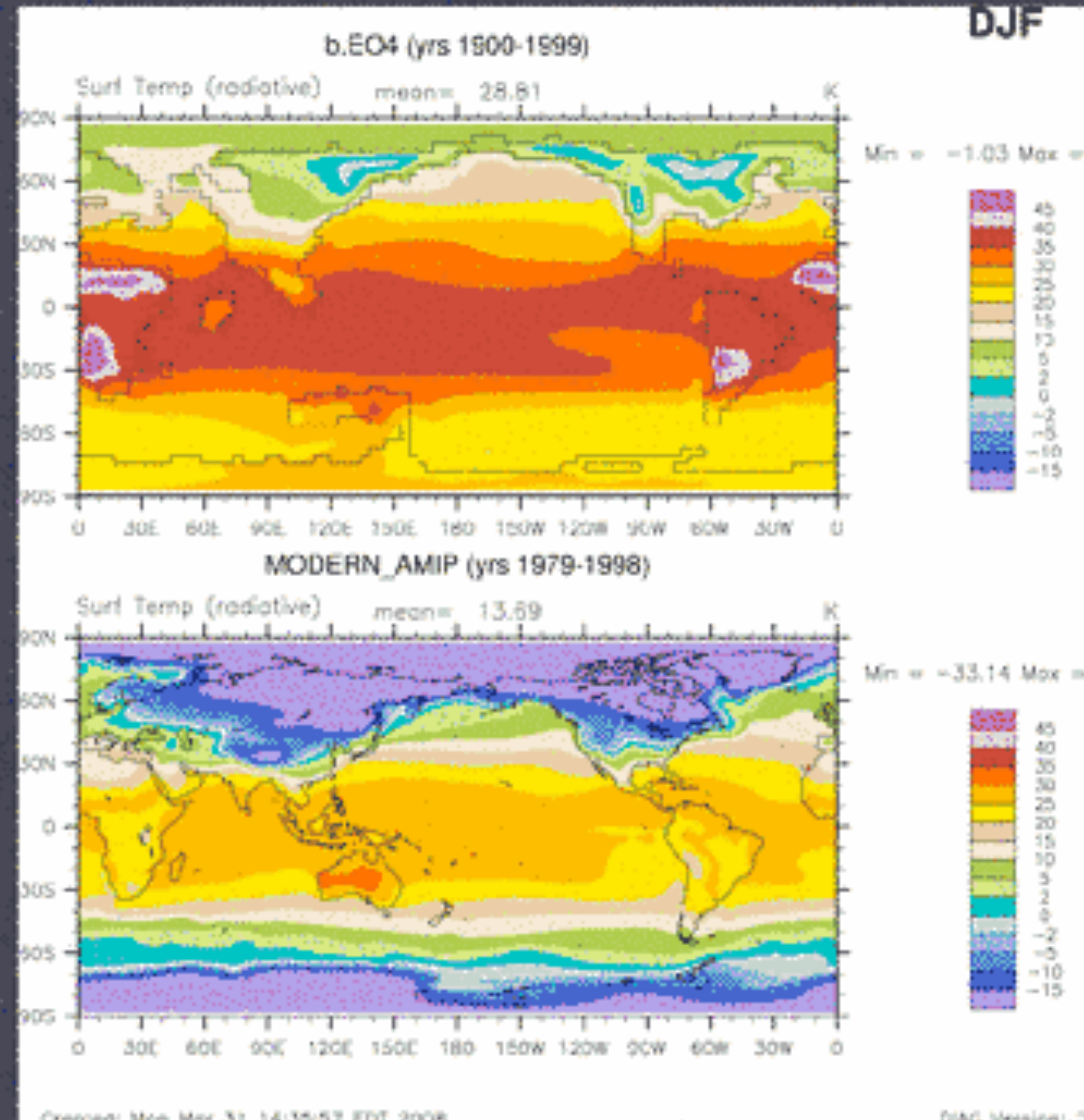
Matthew Huber (Purdue & KITP)

early Eocene temperature proxy records



courtesy of J. Zachos





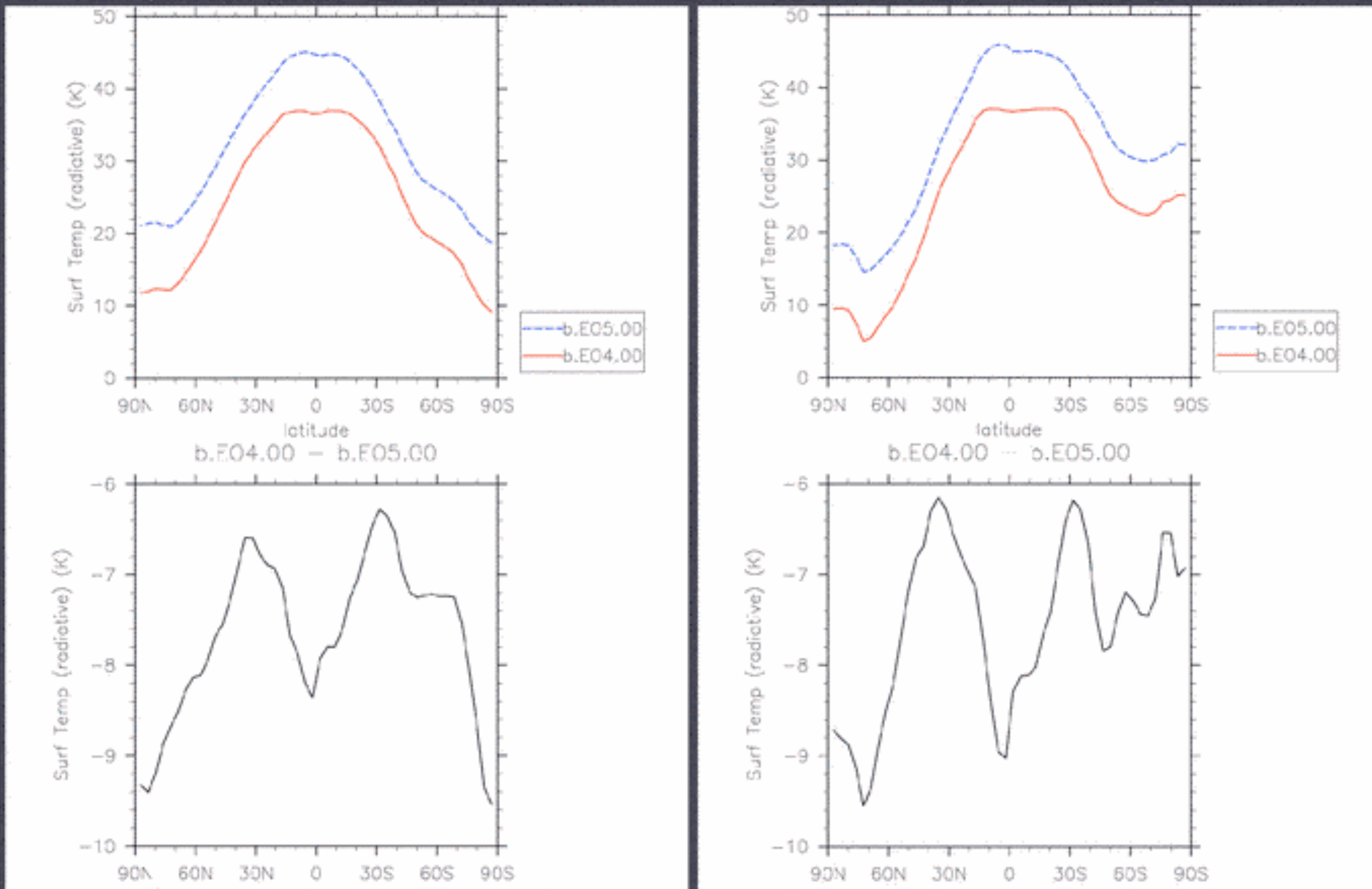
FIRST EOCENE SIMULATIONS TO APPROACH MIDDLE EOCENE CONDITIONS

HUBER IN PREP

temperature change for 5 doublings

REALLY HOT

temperature hot enough to kill plants in tropics



HOT MAT, HOT CMM

JUST PLAIN HOT, HOT, HOT

Data Assimilation for Wildland Fires

Ensemble Kalman filters in coupled atmosphere-surface models

Jan Mandel, Jonathan D. Beezley, Janice L. Coen, and Minjeong Kim

Abstract

Two wildland fire models are described, one based on reaction-diffusion-convection partial differential equations, and one based on empirical fire spread by the level let method. The level set method model is coupled with the Weather Research and Forecasting (WRF) atmospheric model. The regularized and the morphing ensemble Kalman filter are used for data assimilation.

Index Terms

Weather Research and Forecasting model, WRF, wildfire modeling, wildland fire, level set method, reaction-diffusion systems, ensemble Kalman filter, morphing, registration, data assimilation, position correction, regularization, data assimilation, parallel computing

A wildland fire is a complex multiscale process affected by nonlinear scale-dependent interactions with other Earth processes. Physical processes contributing to the fire occur over a wide range of scales. While weather processes with characteristic scales ranging over 5 orders of magnitude from the several-hundred-km scale of large weather systems to the m-scale of small-scale effects and eddies, the chemical reactions associated with the thermal decomposition of fuel and combustion occur at scales of centimeters or less to produce flamelengths up to 60-m tall. Firelines travel with average speeds on the order of a fraction of a meter per second, while producing bursts of flame that travel at 50 meters per second, and chemical reactions occur on the order of seconds or less. The wind and buoyancy produced by the fire are among the extremes of atmospheric phenomena. Weather is the major factor that affects fire behavior, and two way

ZACA INCIDENT
FINAL FIRE PERIMETER
CA-LPF-001087
September 2, 2007 1800
Public Information Map
Cuyama Valley
166
33
July 4
1030 hours
Zaca
101
154
Lake Cachuma
Santa Barbara County
Ventura County
Santa Barbara
Ojai
Completed Line
Incident Command Post
Fire Origin
Miles
0
2.5
5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