Announcements:

Mon Oct 27

- Sunspots!
- Reports for extra credit
- Note on readings (pdf files on web):

  read Lorius article

  don't worry about Modeling Chap (will cover in lectures)

Today and Tomorrow:

- climate sensitivity (feedback factor, Earth's radiation budget)
- three main feedbacks for Earth system
- modeling the Earth system

Wed: Bob Charlson: scientific history of global warming

Thurs: global warming forecast
review for midterm

Friday: MIDTERM (go to sections as normal)
- review sheet coming (probably tomorrow)
- test will be combination of
  - definitions
  - short answer
  - problems (reading graphs, applying concepts/equations)
  - essay (explaining a set of concepts)

upcoming talks

TUESDAY 28 October

12:30 ATG 310c, Weather discussion, Prof Durran

2:30 A-118 PAA (Physics/Astronomy Auditorium)
"Origins and Creation"

THURSDAY 30 October

11:30 14 QRC Conf Room #154
(Quarternary Research Center - basement)
Dr Peter Huybers, MIT
"Towards a test of the orbital theory of glaciation"

Climate sensitivity - 1

Climate sensitivity answers the question (for example):
"If we double atmospheric CO_2, how much will the Earth's average surface temperature go up?"

We know:

The forcing associated with doubled CO_2:
change in energy balance, $\Delta F = 4\ W/m^2$

The temperature change for a no-feedbacks Earth:
from Stefan-Boltzmann Law, $\Delta T_0 = 1.2$ K (or 1.2 ºC)

We don't know:

How the feedbacks in the Earth system will play out.

Thus,

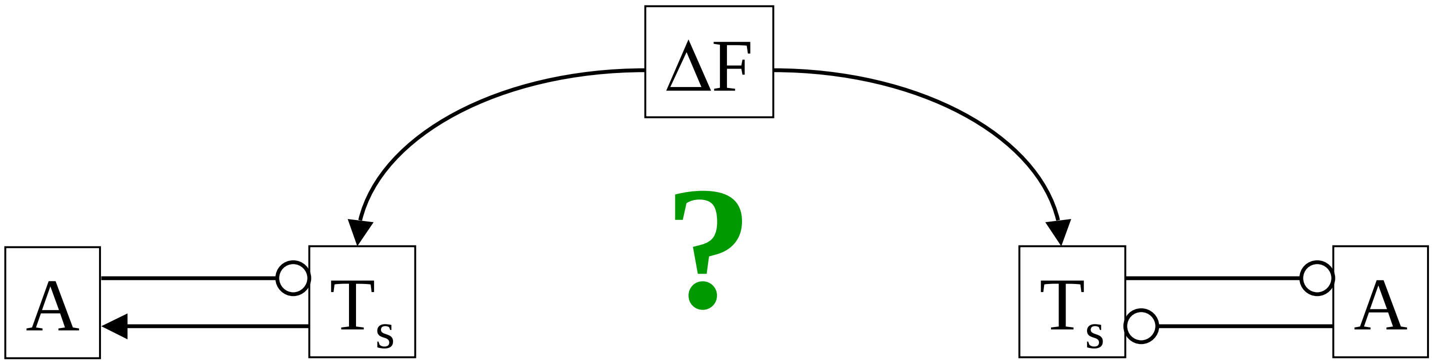
Climate sensitivity is all about feedbacks.

Feedbacks and Climate Sensitivity

$$\Delta T_s = \lambda \, \Delta F$$

ΔT_s = response (K) λ = climate sensitivity $\{K/(W/m^2)\}$ ΔF = forcing (W/m^2)

Consider any feedback that involves A, the Earth's albedo
(e.g. changes in snow cover, sea ice, or clouds):



negative feedback loop
low sensitivity
small temperature change

positive feedback loop
high sensitivity
large temperature change

Climate sensitivity - 2

$$\Delta T_s = \lambda \, \Delta F$$

ΔT_s = response (K) λ = climate sensitivity {K/(W/m^2)} ΔF = forcing (W/m^2)

Climate sensitivity...

- depends on **feedbacks** (full complexity of the climate system)
- is primarily estimated using **climate models**
- however...

Arrhenius made a good estimate more than 100 years ago (in 1896)

- before computers (but then it took him a year to do the calculations)
- more on this on Wednesday

Can be estimated **empirically** if we have measurements of ΔT_s and ΔF:

$$\lambda = \Delta T_s / \Delta F$$

- basis of Lorius et al. article on ice-ages and climate sensitivity
- to do this for industrial-era warming, need better knowledge of forcings

Climate sensitivity - 3

Feedback factor, f:

(used by text and by Lorius et al.)

$$\Delta T_{eq} = \Delta T_0 + \Delta T_f$$

ΔT_{eq} = equilibrium response (K)
ΔT_0 = initial response (K)
ΔT_f = additional change (positive or negative) due to feedbacks

$$f = \Delta T_{eq} / \Delta T_0$$

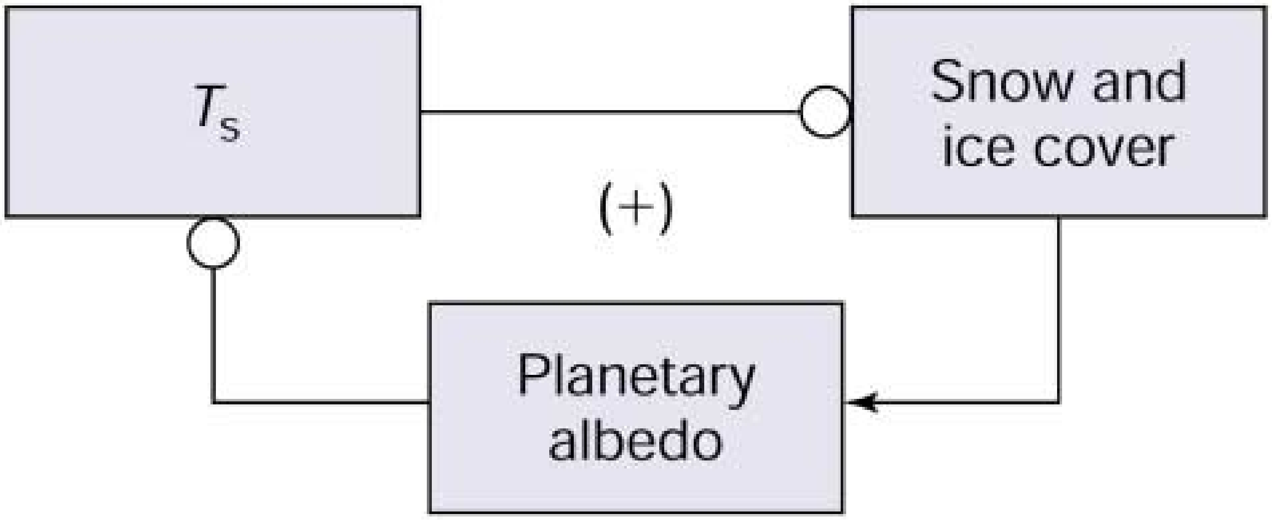
For doubled CO_2

$\Delta T_0 = 1.2$ K

ΔT_{eq} (from models): 1.5 - 4.5 K

What is the range of possible feedback factors according to these models?

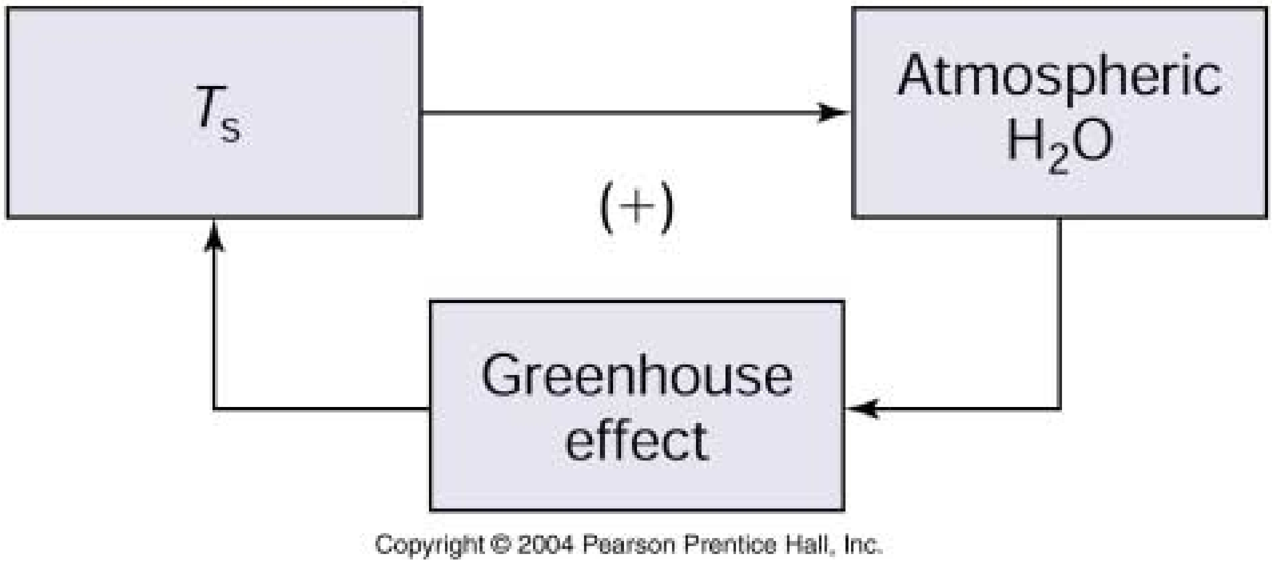
ice-albedo feedback



physical basis?

Why doesn't this make the Earth's climate unstable? (What limits this positive feedback?)

water-vapor feedback



physical basis?

Why doesn't this make the Earth's climate unstable? (What limits this positive feedback?)

Announcements:

Tues Oct 28

- Sunspots are moving and exploding
- Reports for extra credit

    1-2 page summary: 10-20 points

    full 5-page report following format: 50-100 points

    Note: 100 extra credit points = +10% on your grade (the limit)
- Global warming policy in the news
- this week's lecture notes to web today
- HW #2 will be returned tomorrow

Today:

- clouds and the Earth's radiation budget
- modeling the Earth system

Wed: Bob Charlson: scientific history of global warming

in-class activity will be your questions

Thurs: global warming forecast

review for midterm

Friday: Midterm (go to your normal section)

Feedback factor recap

Climate sensitivity: addresses the question,

"For a given level of forcing, how much will Earth's surface temperature change?"

To make this concrete and relevant,

estimate ΔT_s for doubled CO_2

Climate sensitivity can be expressed in terms of the feedback factor.

The text and the Lorius et al. article use the same definition of f, but use different symbols for the ΔT terms:

text: $$f = \frac{\Delta T_{eq}}{\Delta T_0} = \frac{\text{equilibrium response (K)}}{\text{initial, blackbody response (K)}}$$

Lorius: $$f = \frac{\Delta T_s}{\Delta T_e} = \frac{\text{observed surface temp. change (K)}}{\text{calculated, blackbody response (K)}}$$

Clouds and Cloud Feedback

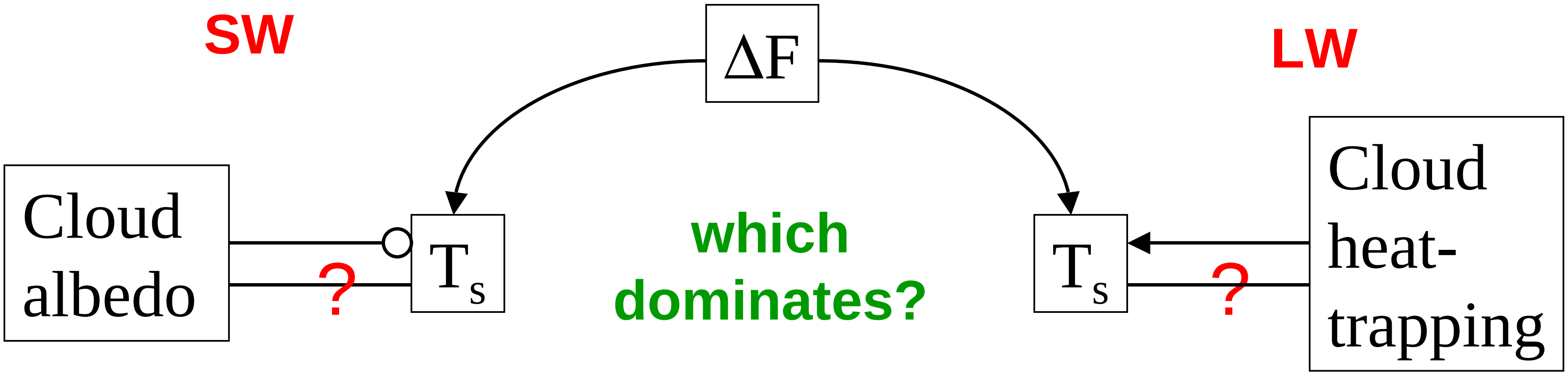
Cloud feedback:

How will temperature changes affect clouds?
How will these cloud changes affect Earth's energy budget?

What do you think are some of the factors involved???

Clouds and Cloud Feedback

Clouds play a major role in both the SW and LW portions of the energy budget

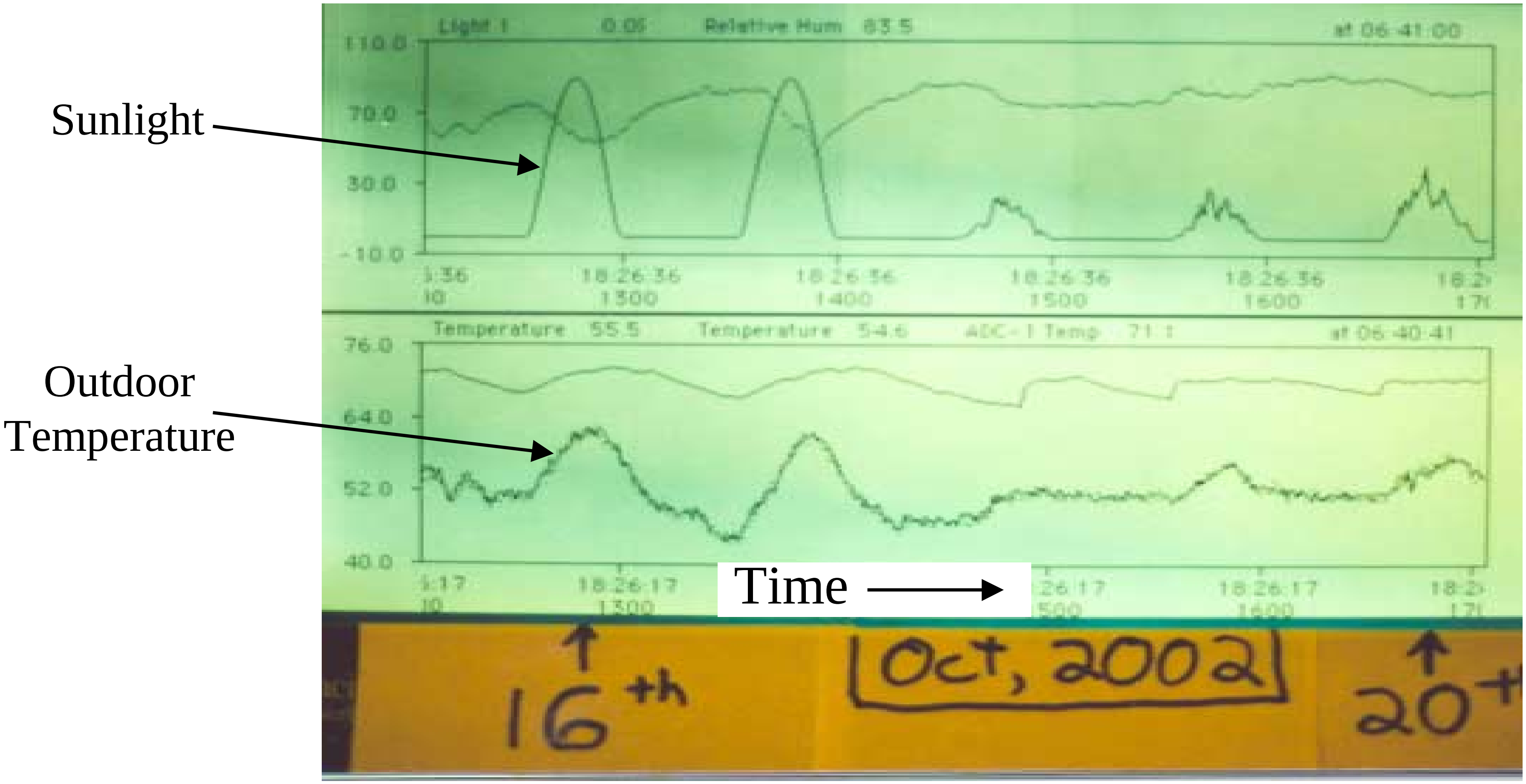


At least three questions must be answered, as indicated above.

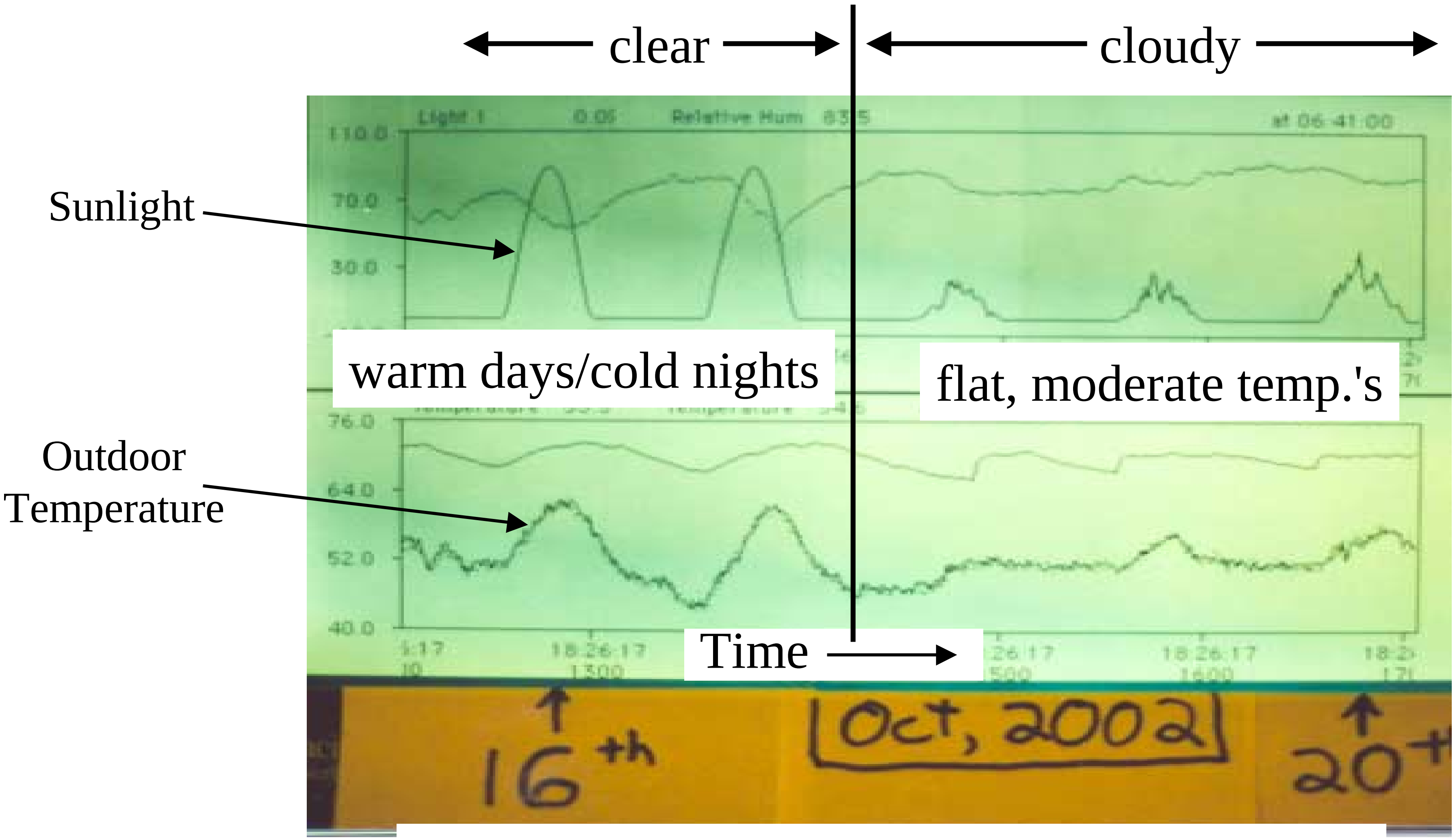
How do high and low clouds figure into the answers?

Home Weather record - 1

Where on these plots do you see the SW effect of clouds?
Where do you see the LW effect of clouds?



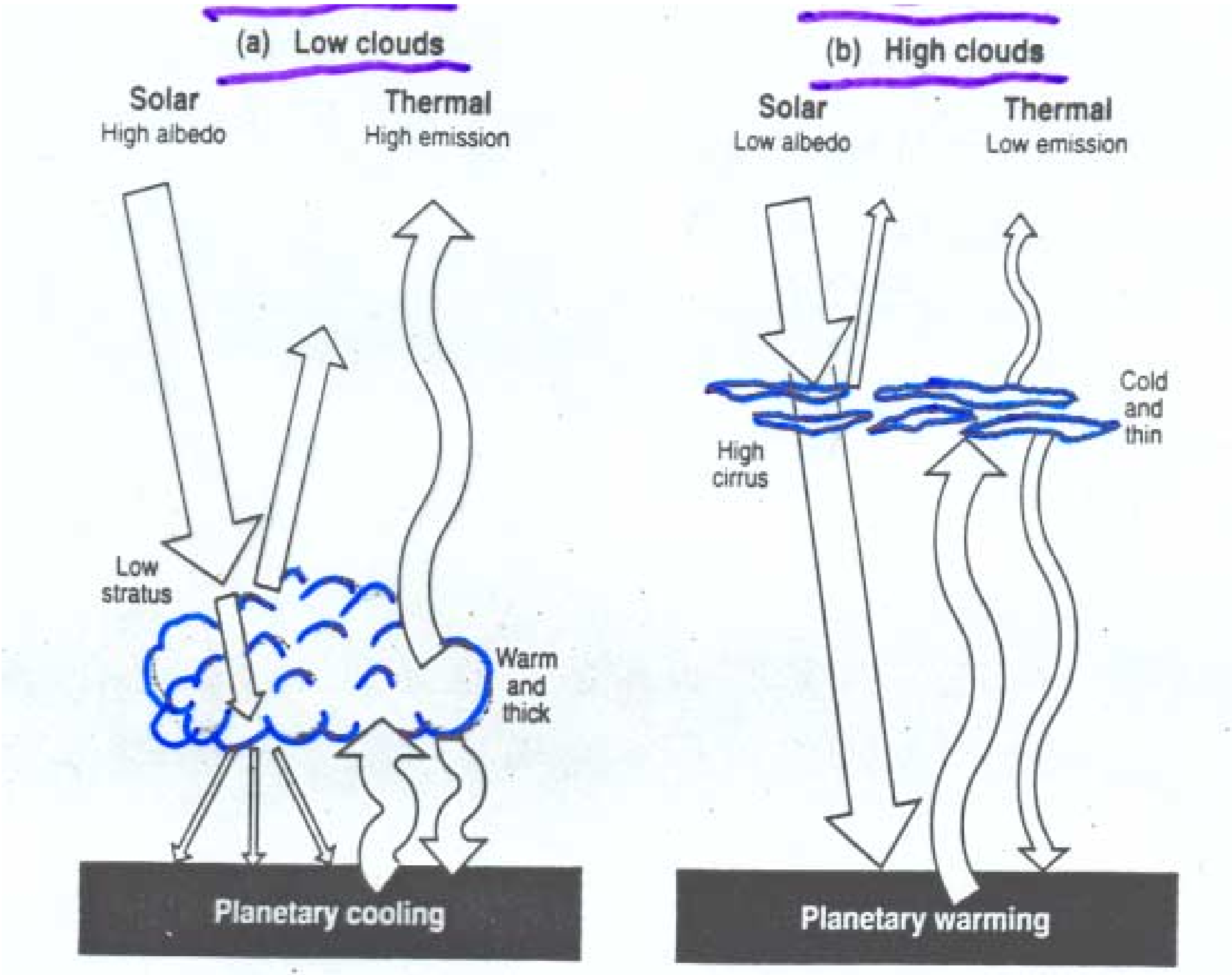
Home Weather record - 2



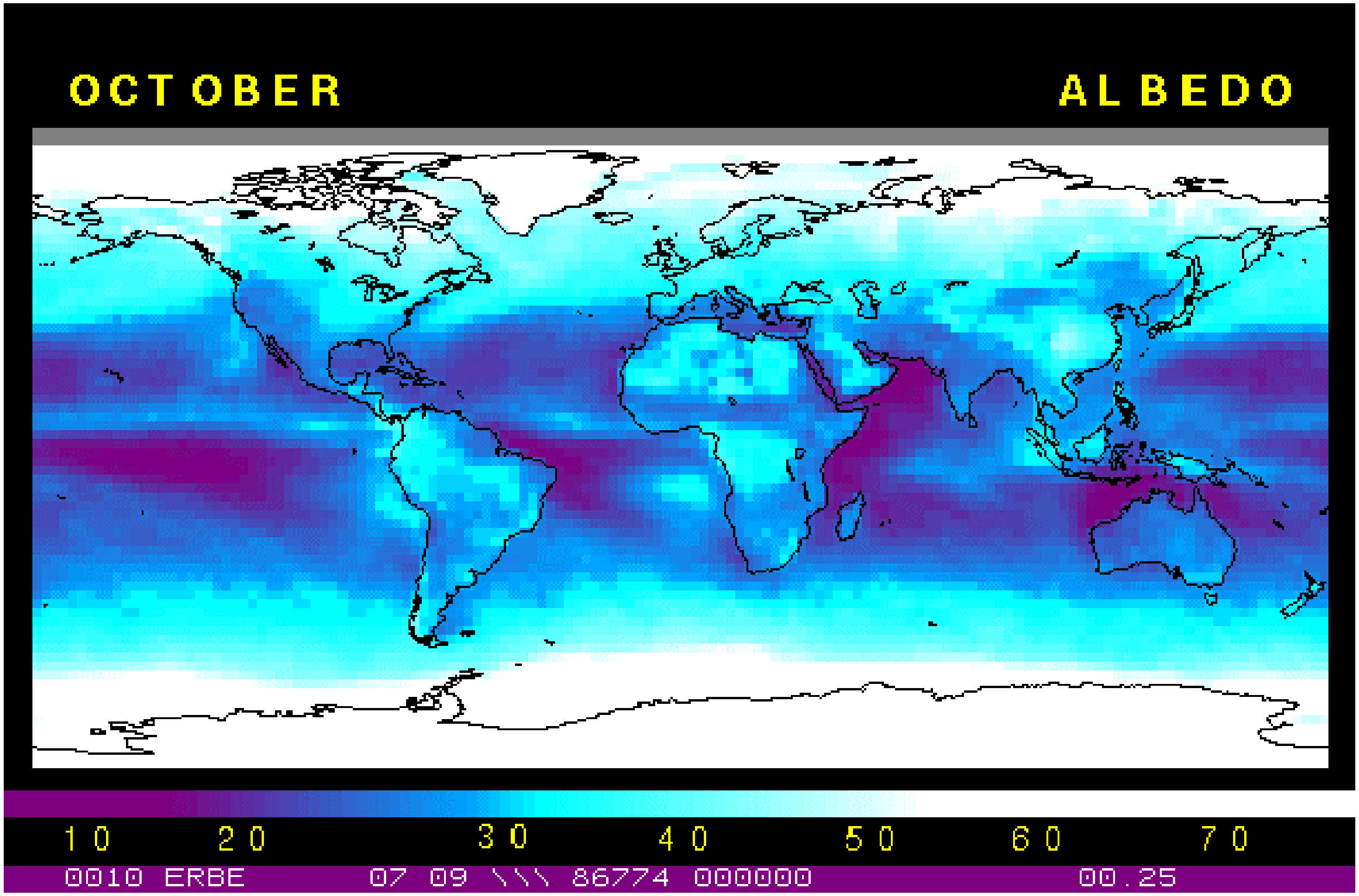
SW effect: prevents sunlight from reaching the surface, thus prevents warming during the day

LW effect: traps surface emissions of IR radiation, thus prevents cooling during the night

High vs Low Clouds graphic

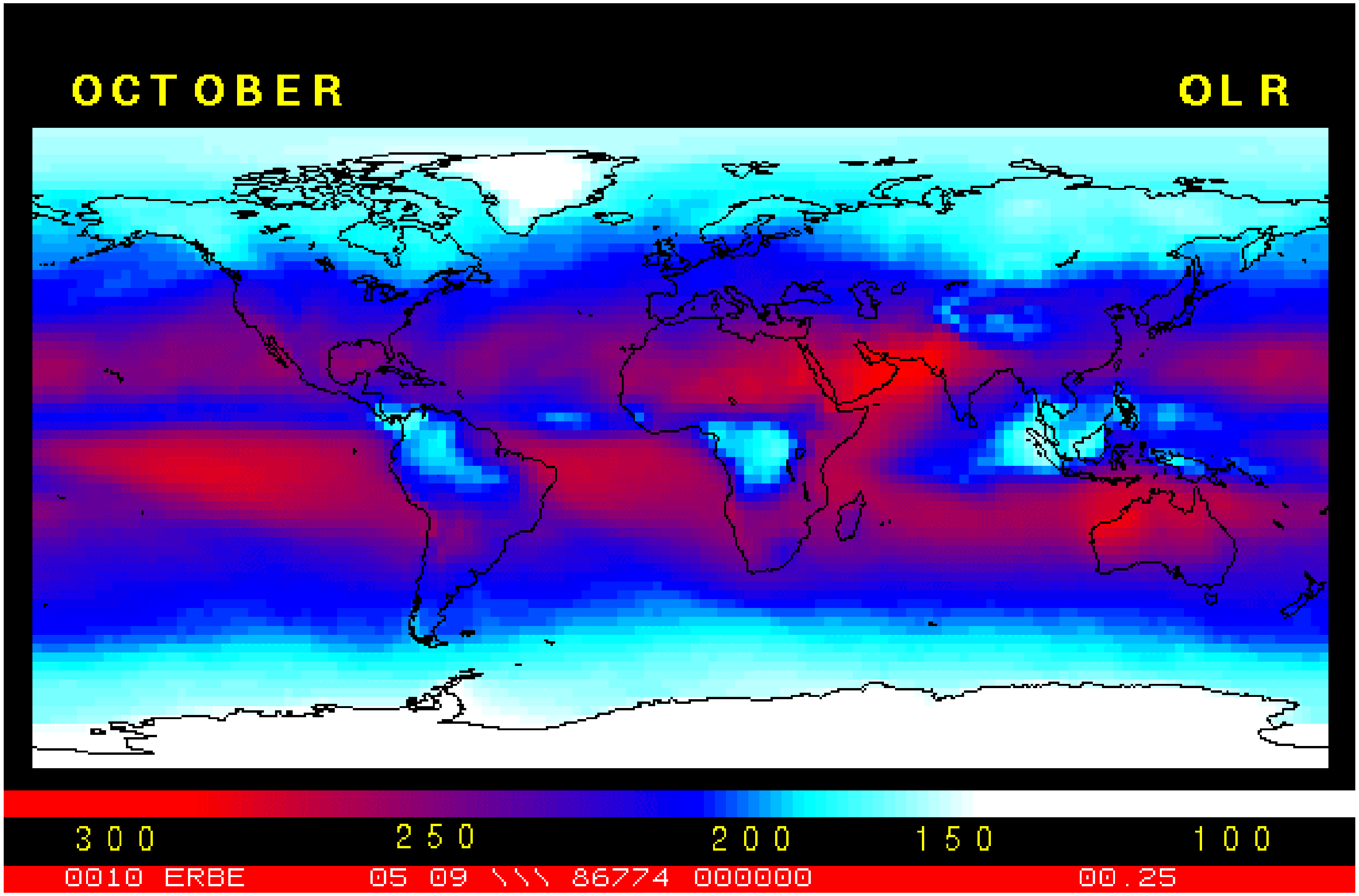


Earth Radiation Budget Experiment: SW (Albedo)



web: itg1.meteor.wisc.edu/wxwise/museum/a2main.html

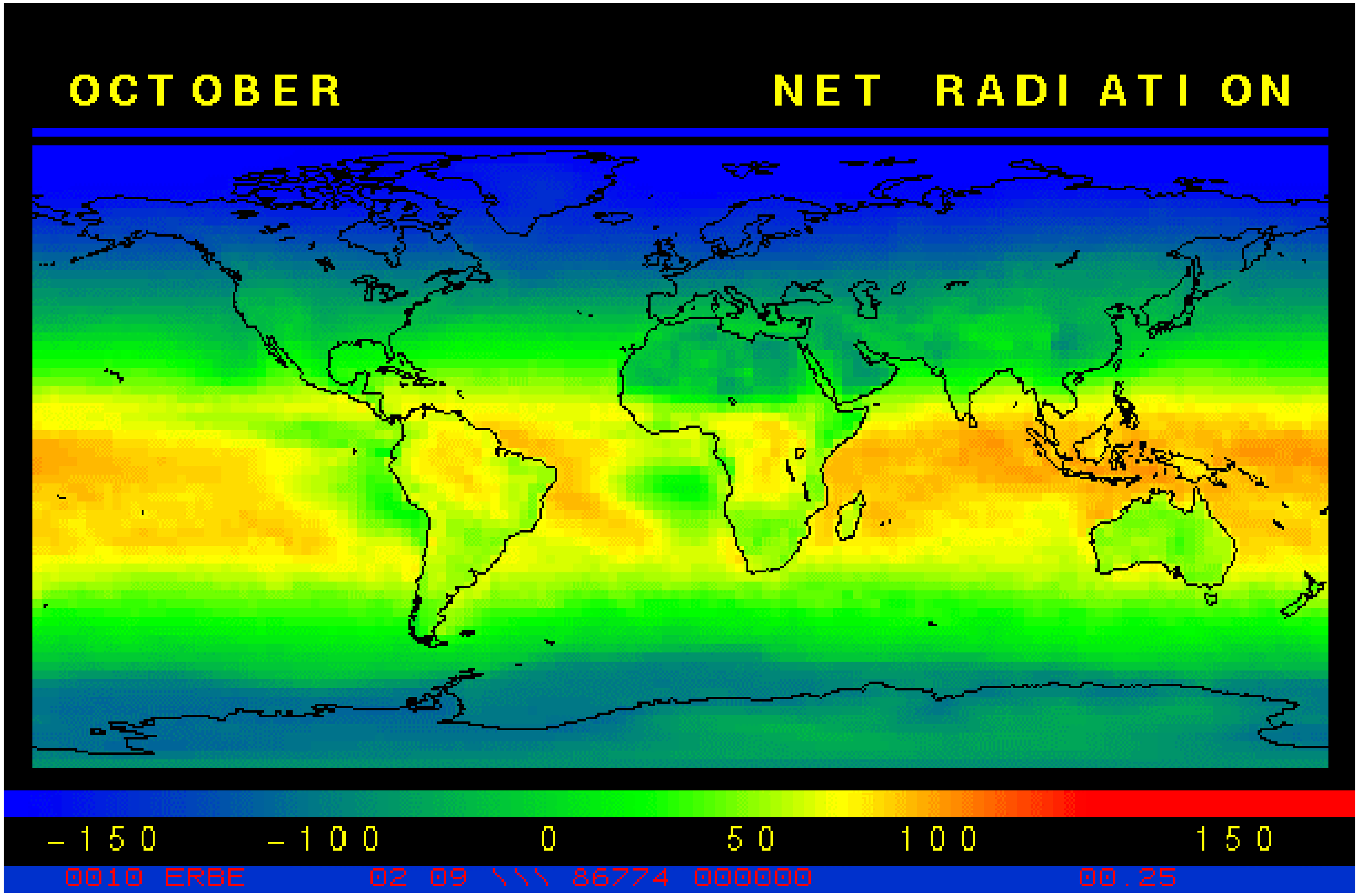
Earth Radiation Budget Experiment: LW (OLR)



web: itg1.meteor.wisc.edu/wxwise/museum/a2main.html

Earth Radiation Budget Experiment: Net

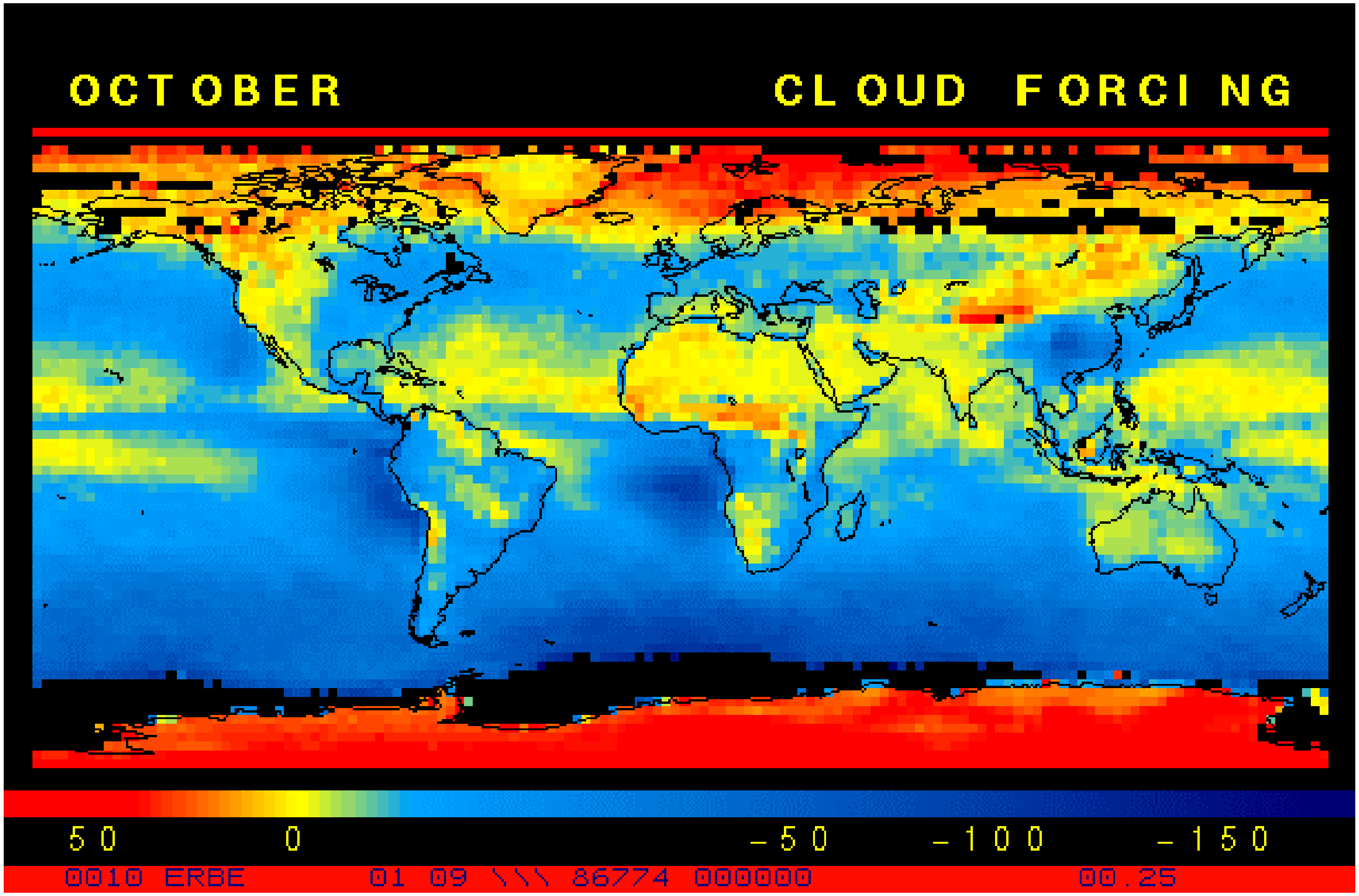
local energy balance



web: itg1.meteor.wisc.edu/wxwise/museum/a2main.html

Earth Radiation Budget Experiment: Cloud Effect on Net

effect of clouds on **local energy balance**



web: itg1.meteor.wisc.edu/wxwise/museum/a2main.html

Climate sensitivity recap

There are three major feedbacks that control the Earth's response to a change in energy balance (forcing):

- water vapor feedback
- ice-albedo feedback
- cloud feedback

The net effect of all feedbacks determines the Earth's climate sensitivity.

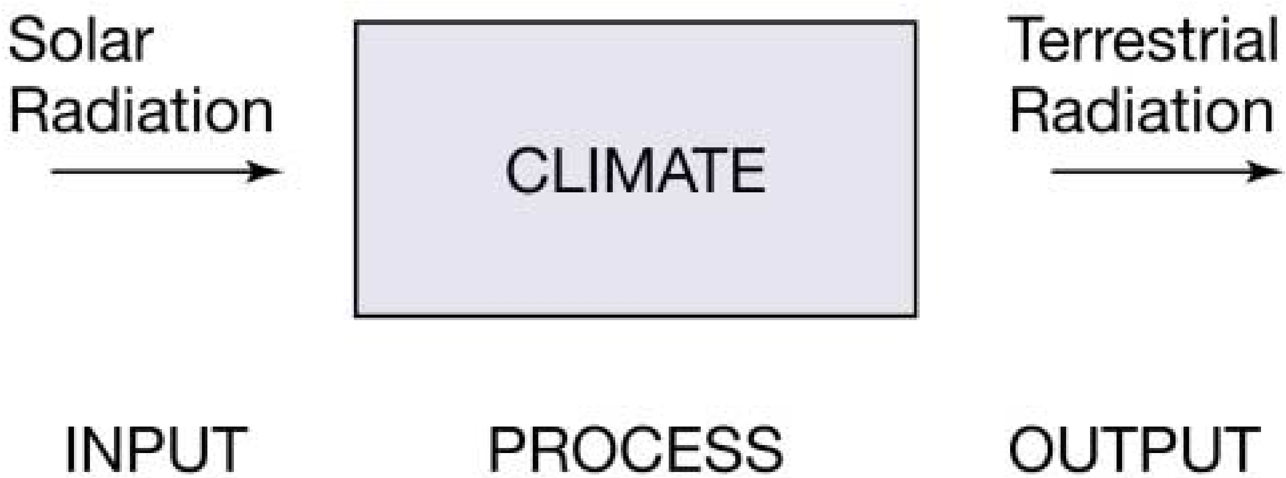
Climate sensitivity can be expressed in terms of the feedback factor.

text: $$f = \frac{\Delta T_{eq}}{\Delta T_0} = \frac{\text{equilibrium response (K)}}{\text{initial, blackbody response (K)}}$$

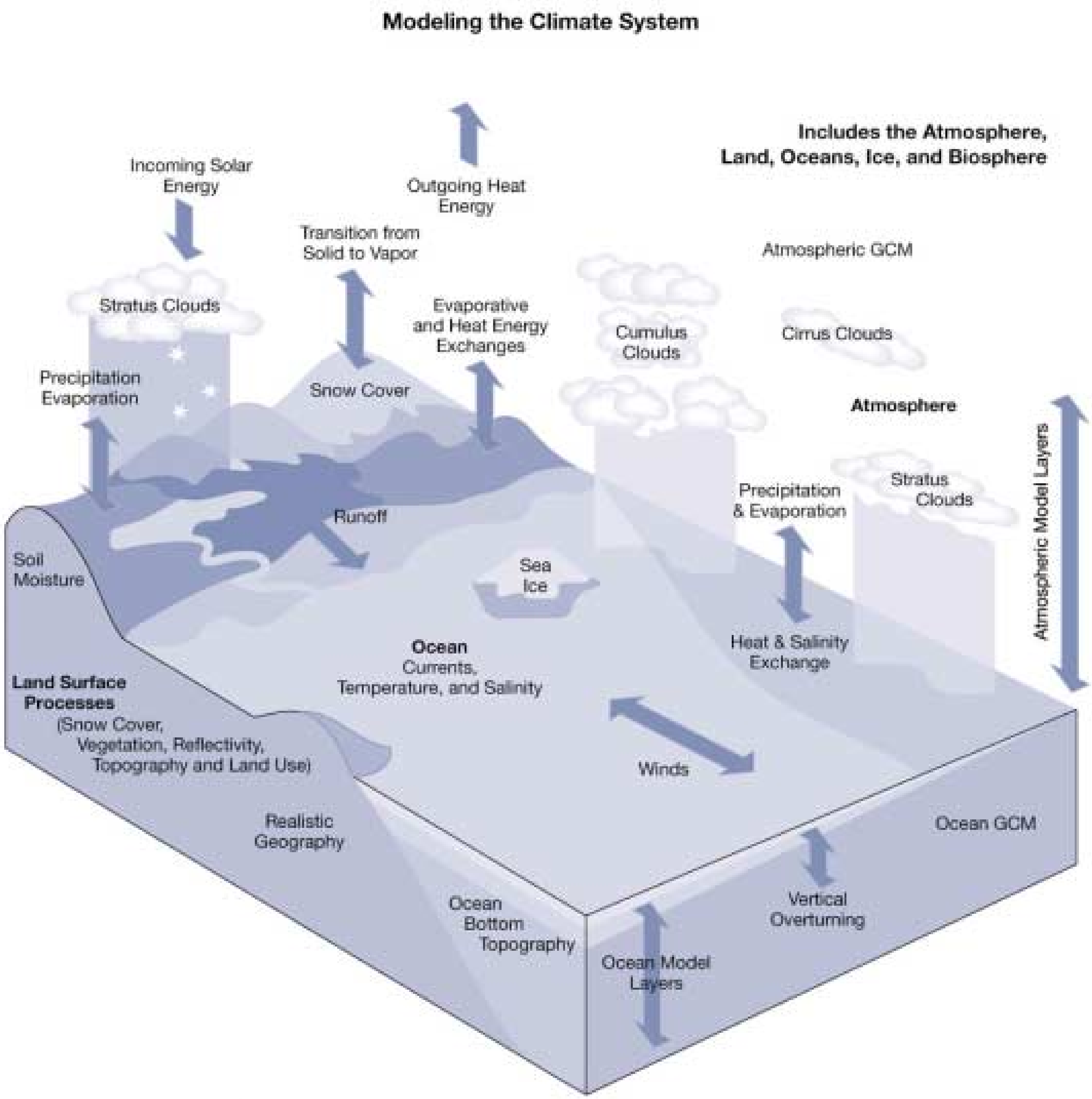
If f > 1, the overall feedback is positive and tends to amplify the initial temperature change. (Conversely if f < 1).

Attempts to quantify climate sensitivity involve "climate models".

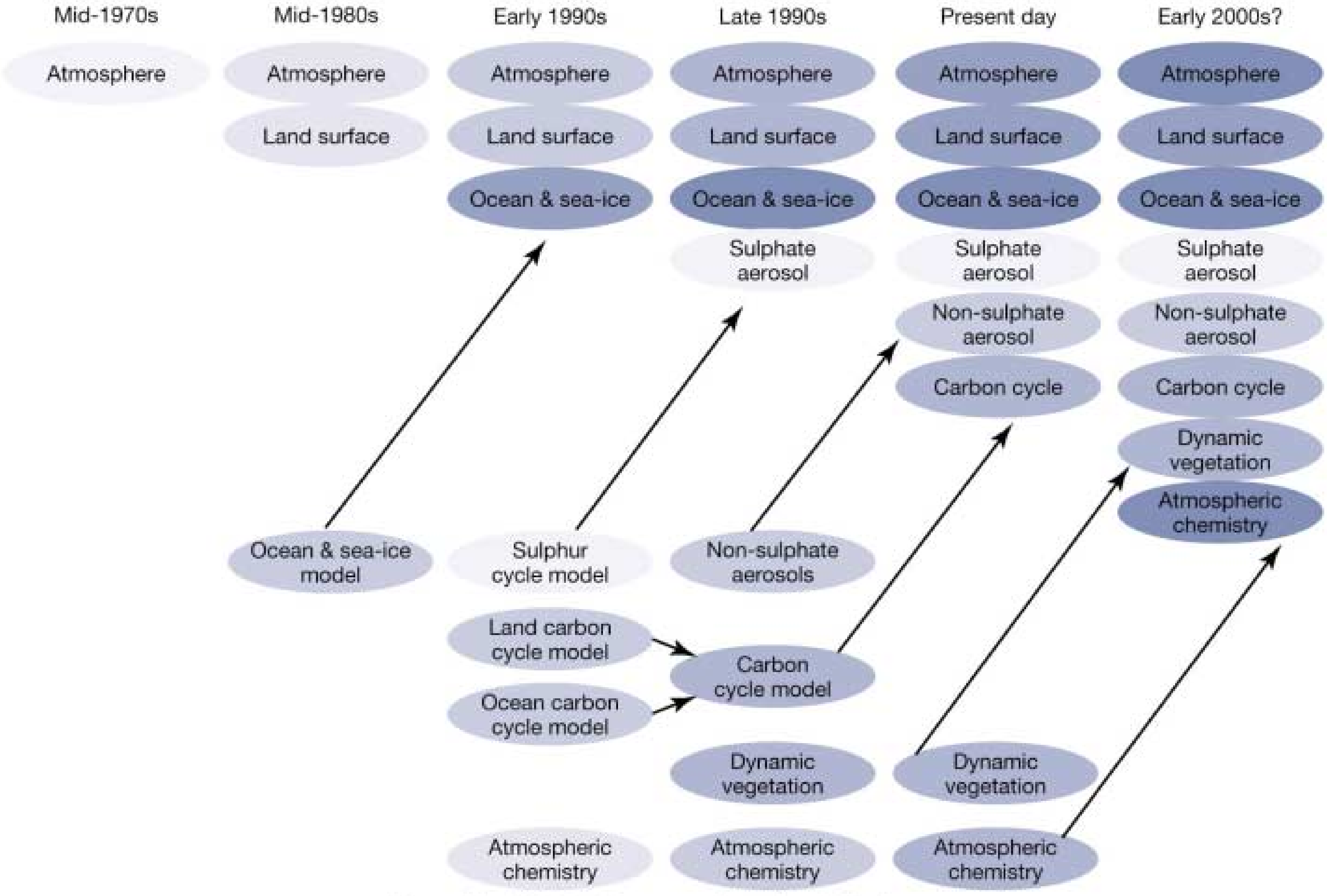
Modeling the Climate System
Fig 06-01



Modeling the Climate System Fig 06-03



Development of Climate Models: Fig 06-04



Thurs Oct 30

Announcements:

- Sunspot update
- brouhaha in GW Science: paleo record challenged

Today:

- note on E_{IN}
- feedback factor in a climate model (also, lag time)
- GW forecast considerations
- review for midterm

Friday: Midterm (go to your normal section)

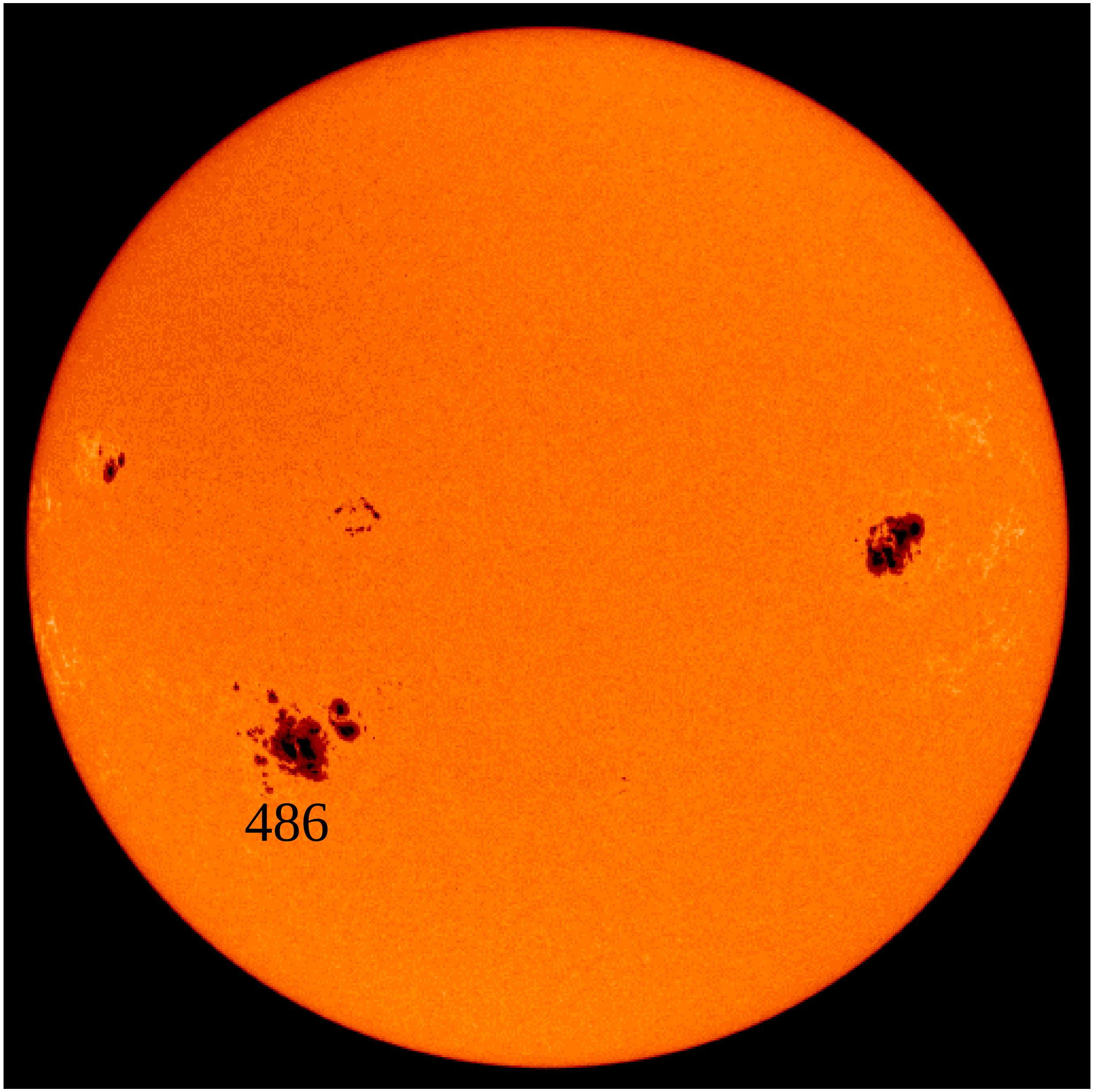
section AA 10:30am 064 JHN

section AB 11:30am 435 GLD

(see me if you don't know your section)

www.spaceweather.com

Sun Spots Oct 26, 2003

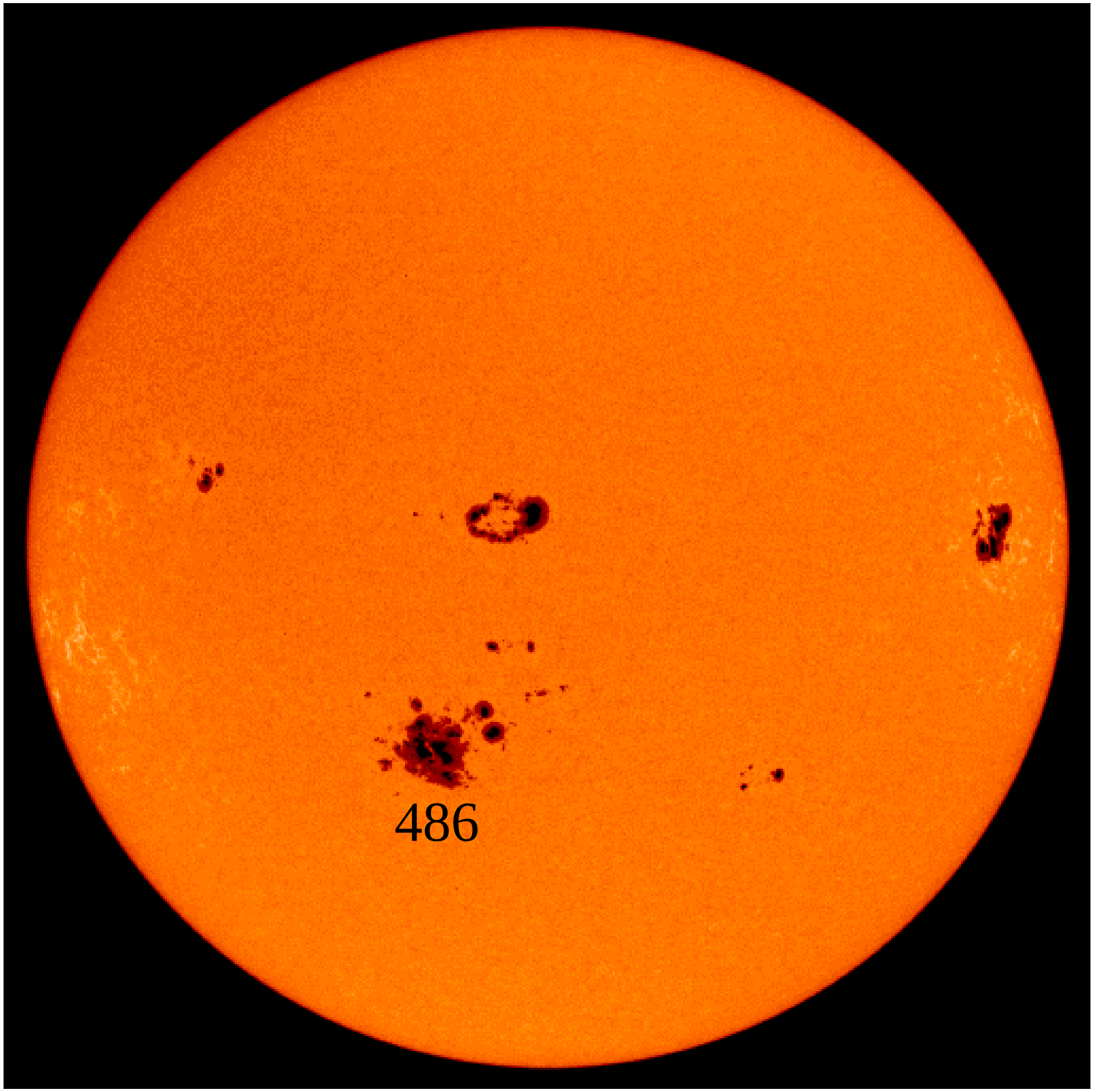


www.spaceweather.com

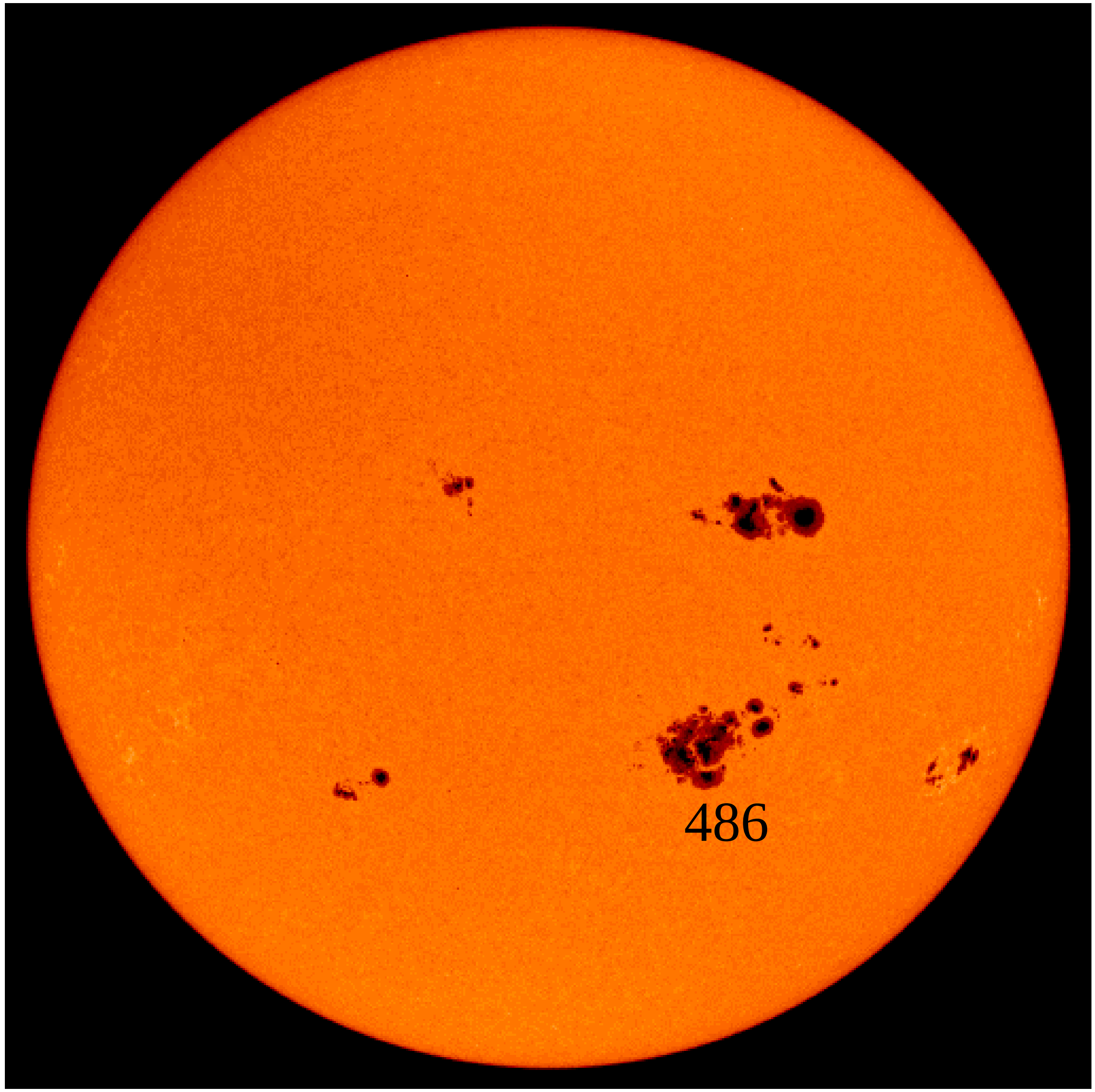
Sun Spots Oct 28, 2003

28Oct, 2003, 1110 UT:

"one of the most power solar flares in years... erupted from sunspot 486."

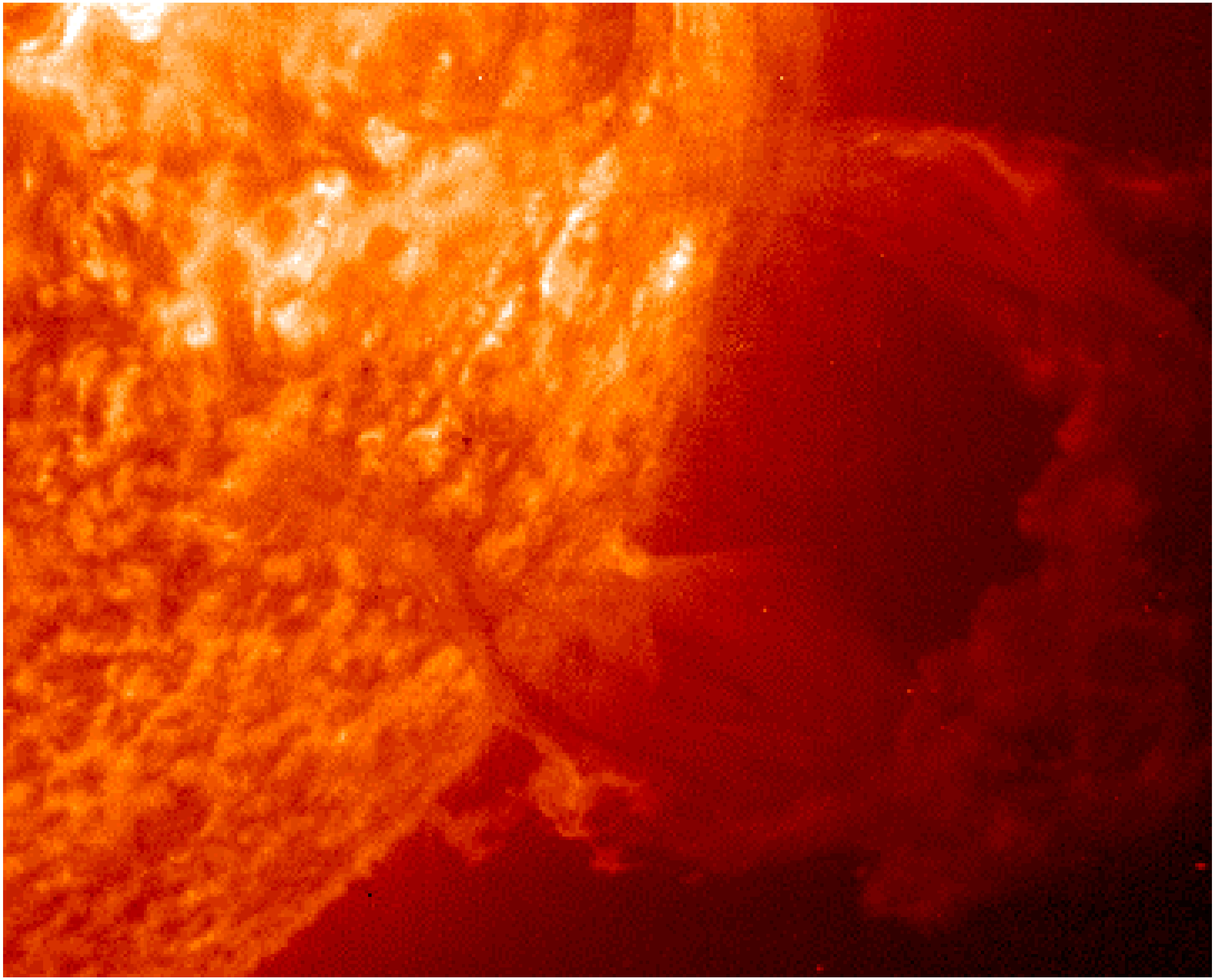


Sun Spots Oct 30, 2003



www.spaceweather.com

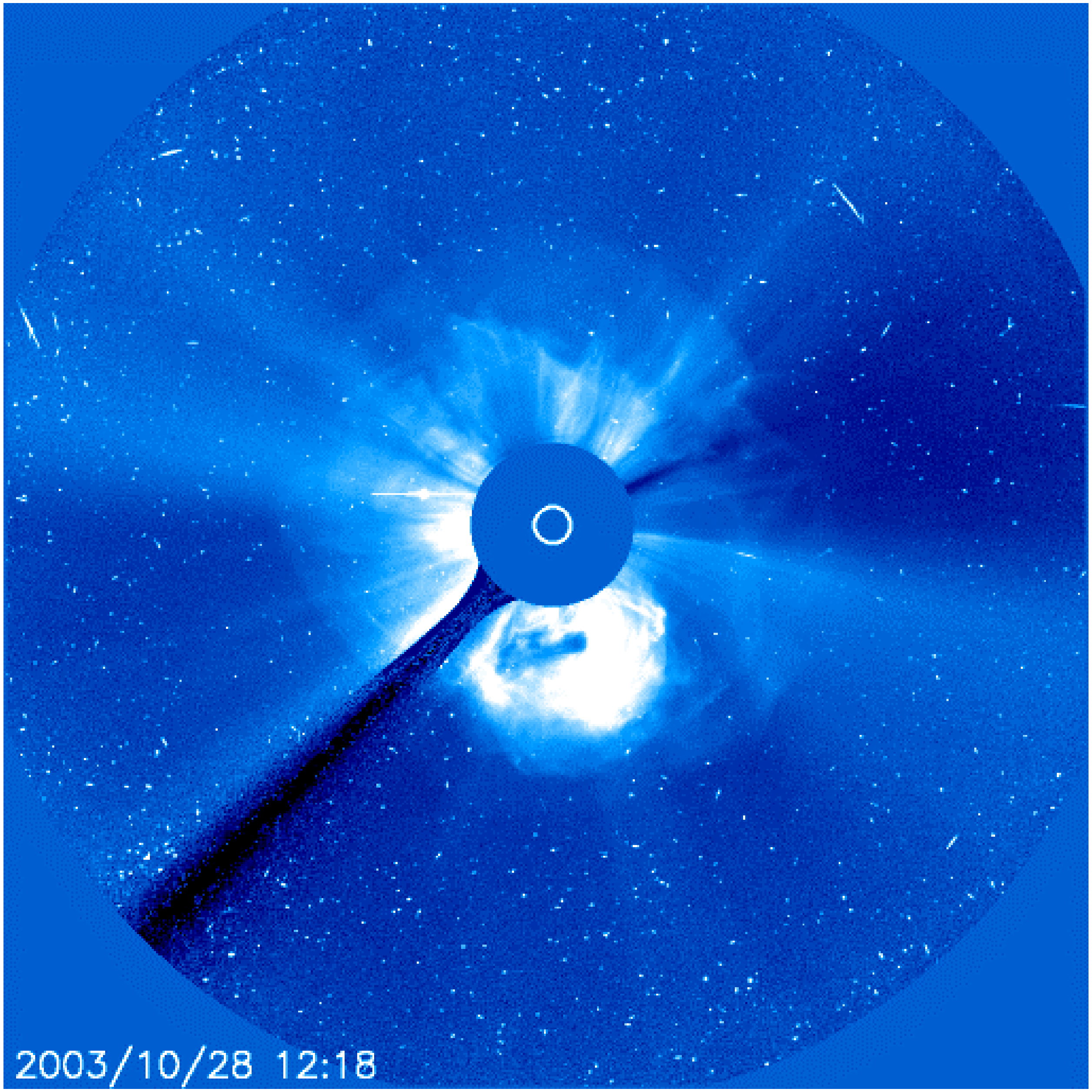
Solar Flare Oct 26, 2003



www.spaceweather.com

Solar Flare Oct 28, 2003

coronograph image



Northern Lights, Dover Oklahoma, 29 Oct, 2003 (50-sec exposure)

McIntyre and McKitrick, 2003, Energy and Environ., 14, 751-771

CORRECTIONS TO THE MANN et. al. (1998) PROXY DATA BASE AND NORTHERN HEMISPHERIC AVERAGE TEMPERATURE SERIES

Stephen McIntyre

512-120 Adelaide St. West, Toronto, Ontario Canada M5H 1T1;

Ross McKitrick

Department of Economics, University of Guelph, Guelph Ontario Canada N1G2W1.

ABSTRACT

The data set of proxies of past climate used in Mann, Bradley and Hughes (1998, "MBH98" hereafter) for the estimation of temperatures from 1400 to 1980 contains collation errors, unjustifiable truncation or extrapolation of source data, obsolete data, geographical location errors, incorrect calculation of principal components and other quality control defects. We detail these errors and defects. We then apply MBH98 methodology to the construction of a Northern Hemisphere average temperature index for the 1400-1980 period, using corrected and updated source data. The major finding is that the values in the early 15th century exceed any values in the 20th century. The particular "hockey stick" shape derived in the MBH98 proxy construction – a temperature index that decreases slightly between the early 15th century and early 20th century and then increases dramatically up to 1980 — is primarily an artefact of poor data handling, obsolete data and incorrect calculation of principal components.

revised paleo record: McIntyre 2003

Energy & Environment · Vol. 14, No. 6, 2

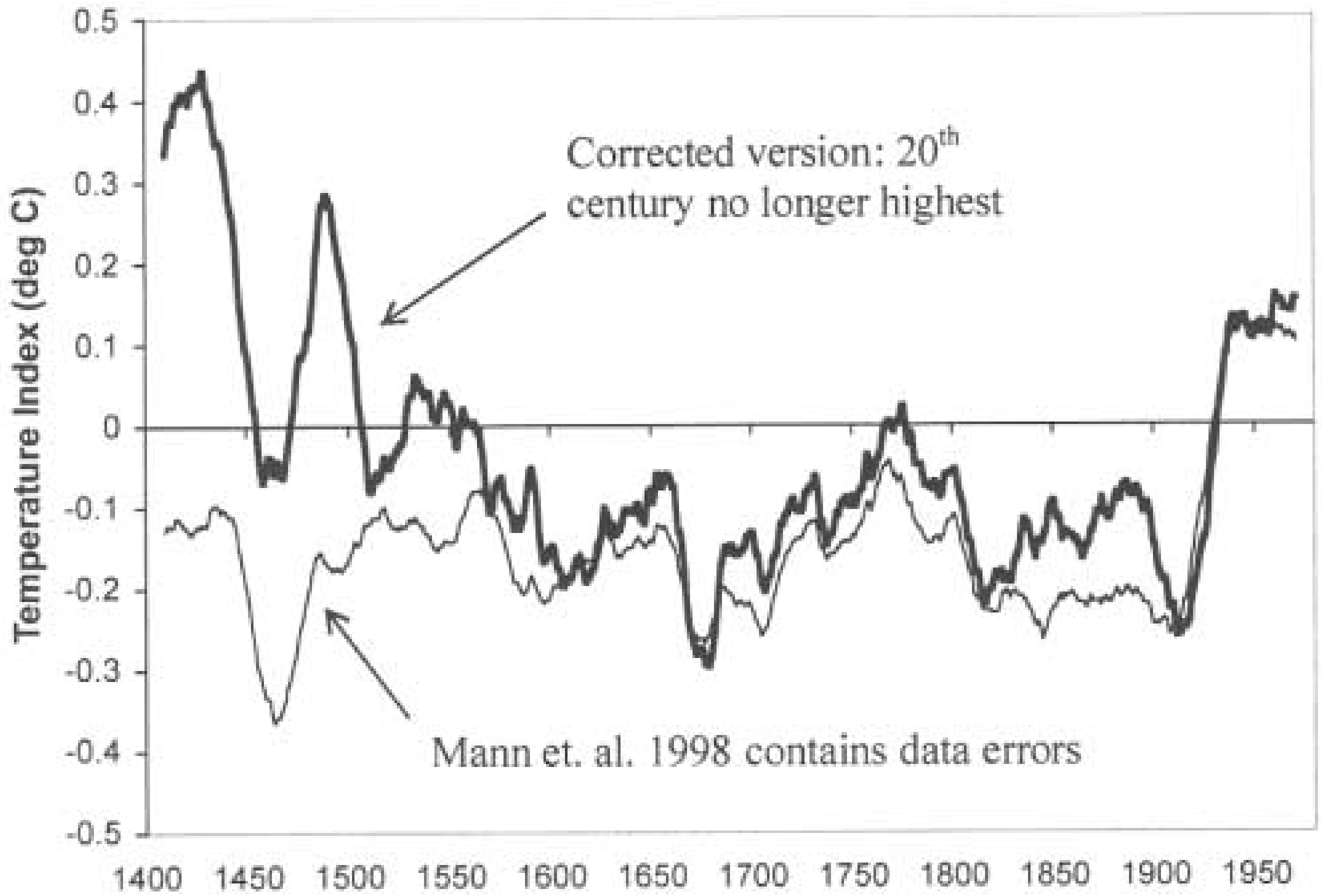
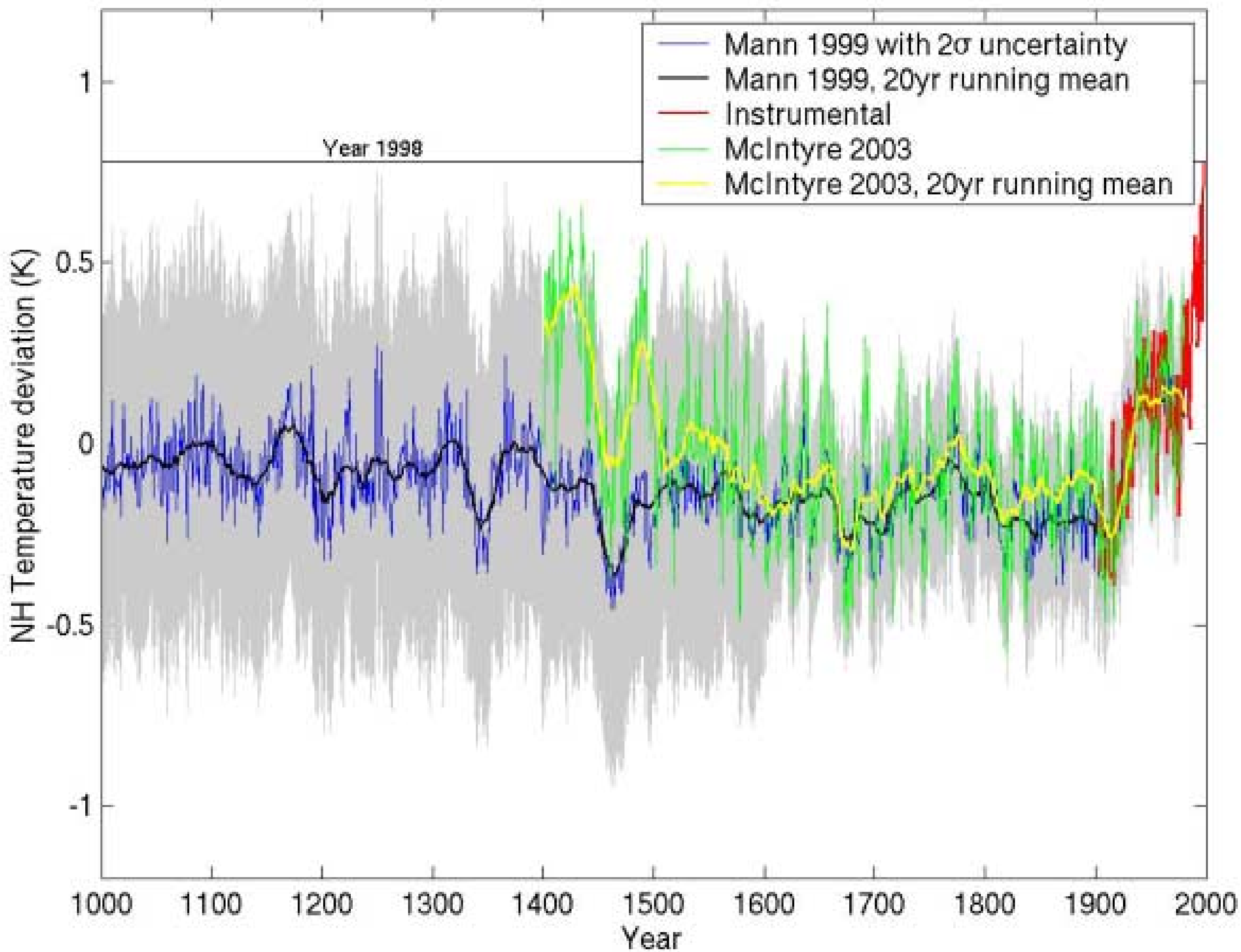


Figure 8. As Figure 7, using 20-year running mean to smooth.

Mann et al vs McIntyre



Clarification on E_{IN} and T_e

$E_{IN} = E_{OUT}$

Solar energy IN = Earth energy OUT at equilibrium

$$E_{IN} = \frac{S_0}{4}(1-A)$$

← Note: no dependence on T_e

$$E_{OUT} = \sigma T_e^4$$

Combining the above equations allows us to solve for T_e if we know S_0 and A:

$$\frac{S_0}{4}(1-A) = \sigma T_e^4$$

$$T_e = \left[\frac{S_0}{4\sigma}(1-A)\right]^{0.25}$$

Climate sensitivity recap

1. Climate sensitivity is all about feedbacks.

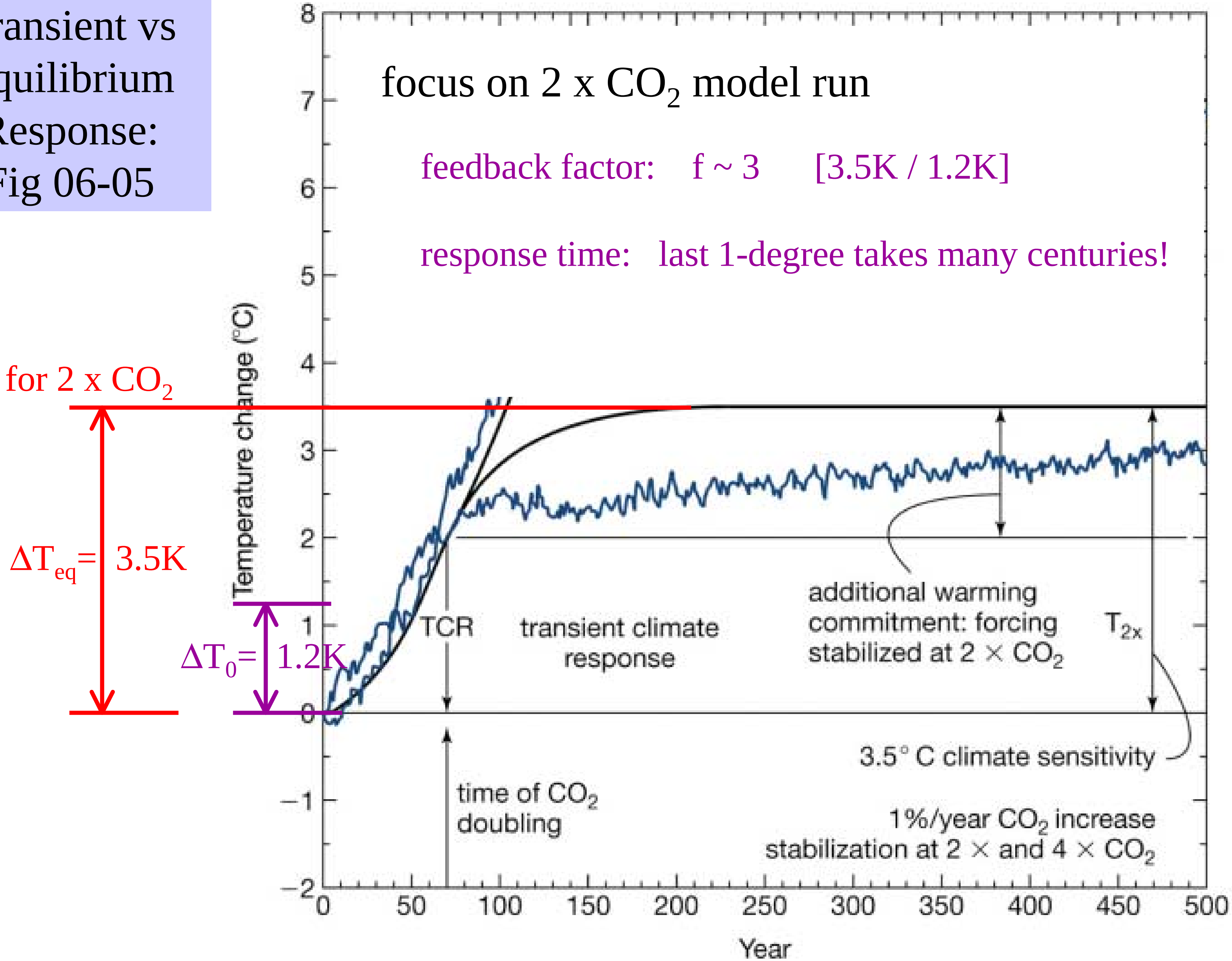
2. Three major feedbacks for Earth System:
   - water vapor feedback
   - ice-albedo feedback
   - cloud feedback

3. Climate sensitivity can be expressed in terms of the feedback factor.

text: $$f = \frac{\Delta T_{eq}}{\Delta T_0} = \frac{\text{equilibrium response (K)}}{\text{initial, blackbody response (K)}}$$

4. Our best knowledge about climate sensitivity comes from "climate models".

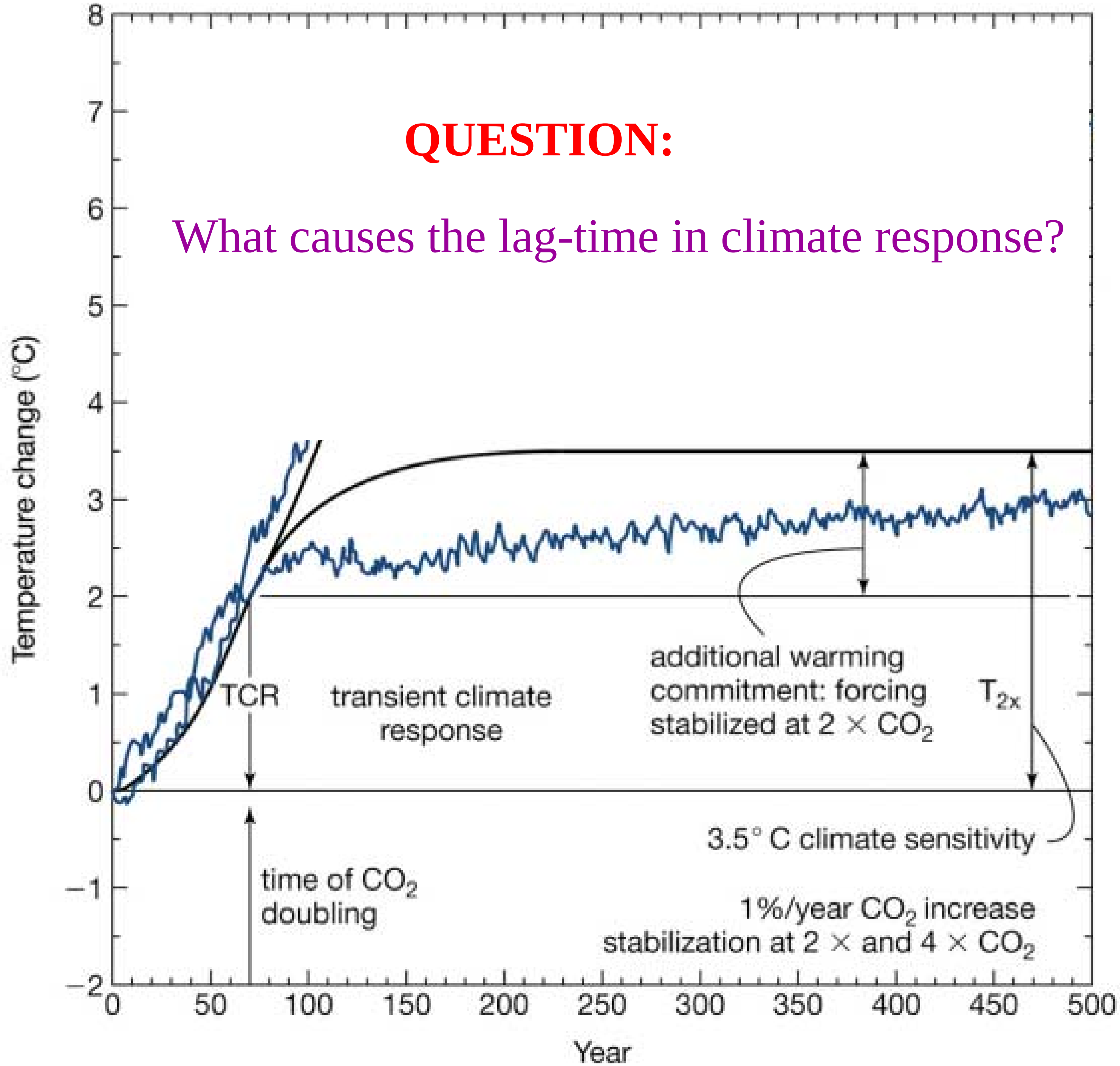
Transient vs Equilibrium Response: Fig 06-05



Transient vs Equilibrium Response: Fig 06-05

QUESTION:

What causes the lag-time in climate response?



Year 2050 global warming forecast: considerations

$$\Delta T_s = \lambda \, \Delta F$$

ΔT_s = response (K) λ = climate sensitivity {K/(W/m^2)} ΔF = forcing (W/m^2)

Forcing ...

- depends mostly on CO2 emissions
- can we bound the emissions?

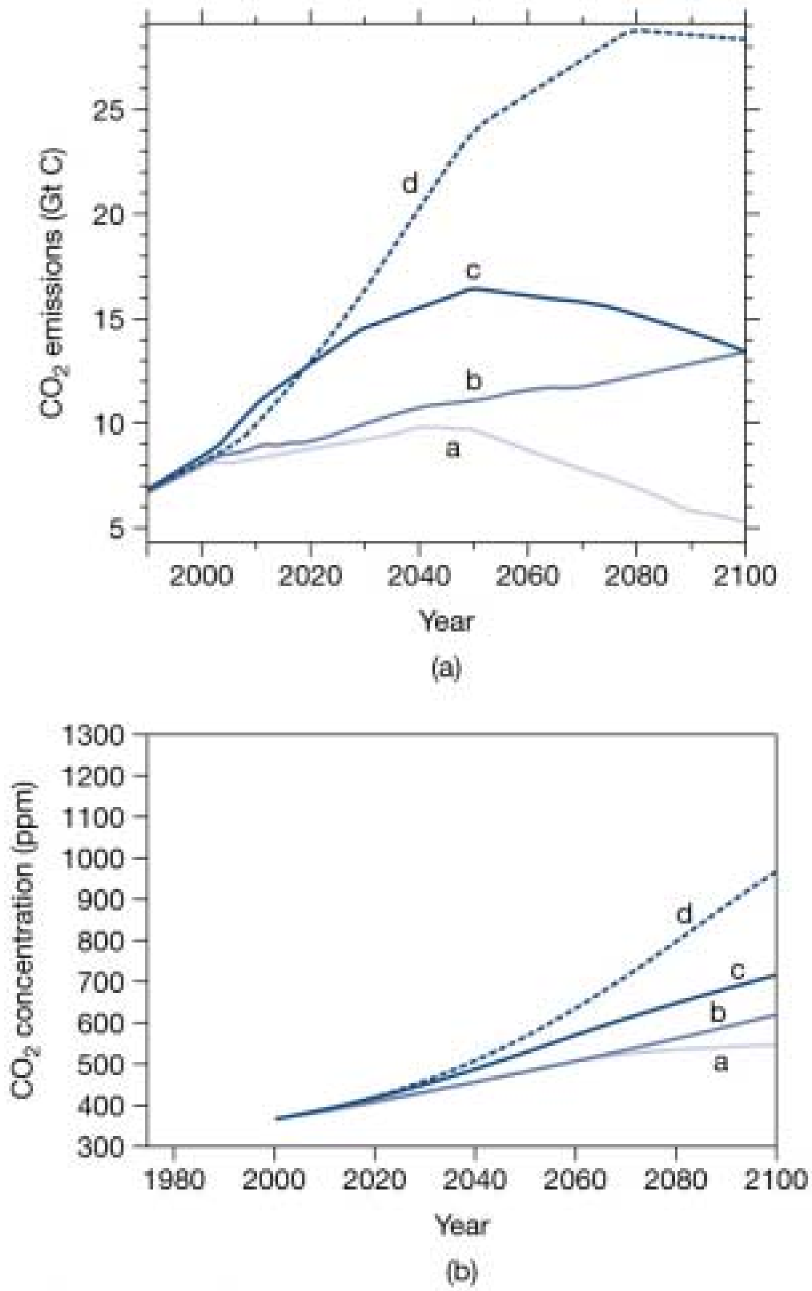
upper: i. entire world achieves US per capita emissions by 2050 and world population grows to 10 billion

ii. world continues at present rate of increase

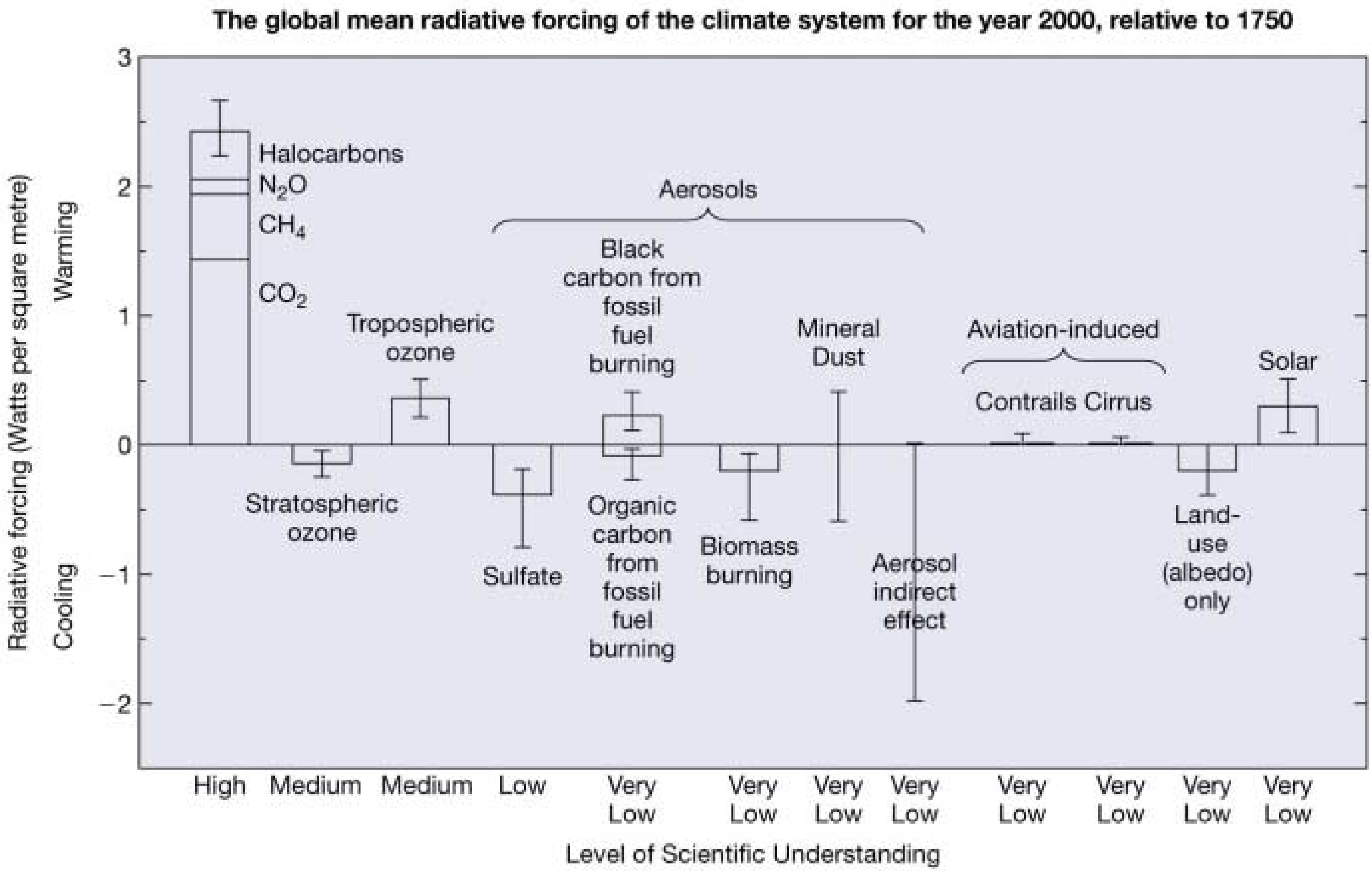
lower: i. world economy collapses and emissions go to zero

ii. emissions decline to 1990 levels by 2010, then gradually decrease to 20% of 1990 levels by end of century

projections of CO2 emissions and concentration



other climate forcings (in the past) ...



Year 2050 global warming forecast: considerations

$$\Delta T_s = \lambda \, \Delta F$$

ΔT_s = response (K) λ = climate sensitivity {K/(W/m^2)} ΔF = forcing (W/m^2)

Climate sensitivity ...

- best knowledge comes from climate models
- in terms of equilibrium warming from doubling CO2:

  upper: about 4.5 K

  lower: about 1.5 K