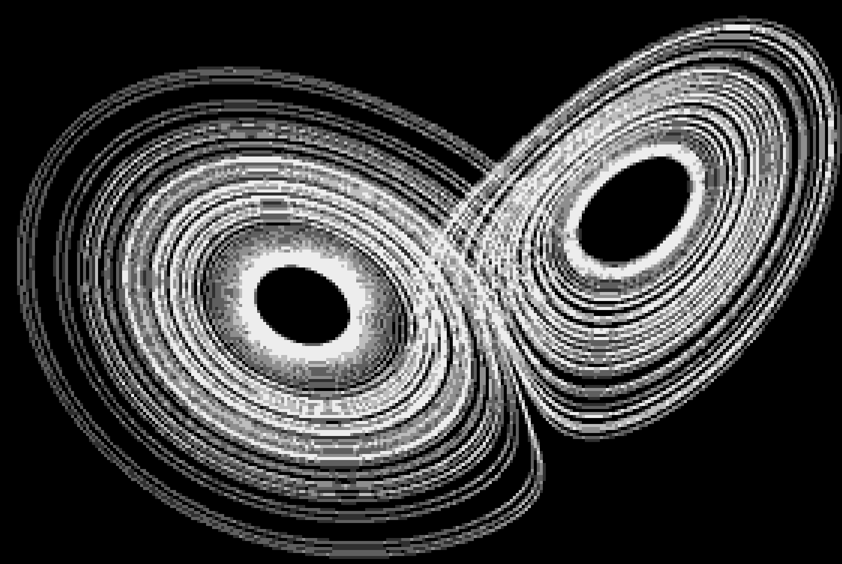
Chaos and the Lorenz attractor



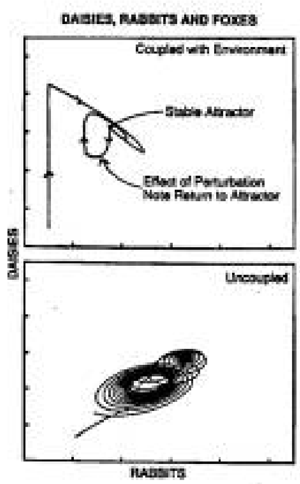


Figure 1.5 Comparison of the stability of a Daisyworld that included rabbits to eat the daisies and foxes to cull the rabbits (upper panel) with the instability of a population biology model of daisies, rabbits, and foxes (lower panel). The model in the upper diagram included environmental feedback; that in the lower diagram did not.

Metastability: Thresholds and Surprises

1. Observed climate variability and‘switching’
2. External vs. internal drivers of variability
3. The thermohaline circulation collapse
4. Ice sheet collapse

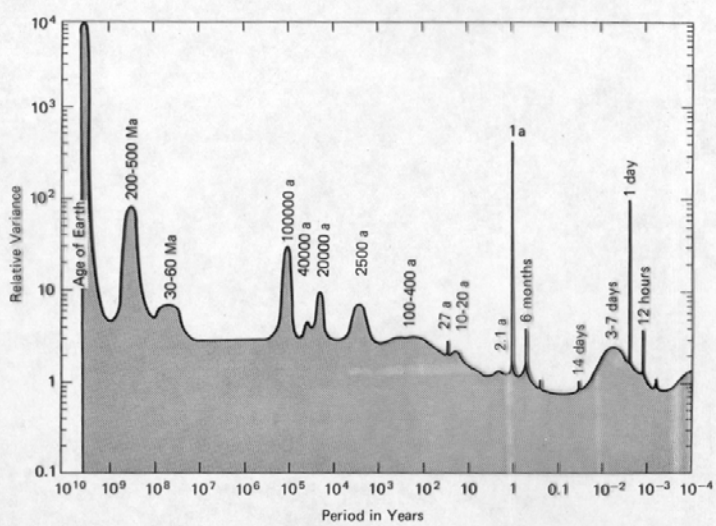


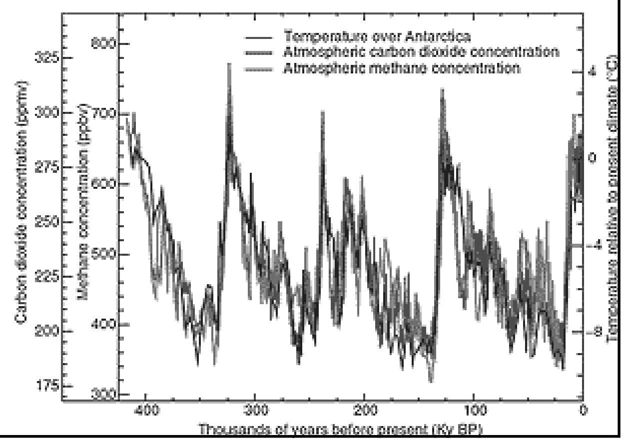
Fig. 11.1. Estimate of global climatic variability on all time scales (after Mitchell, 1976). The position of the peaks indicated is relatively well known, but not their relative height and width. Units of time are abbreviated as 1 year = 1a and 10^6 years = 1Ma.

Climate has certainly changed abruptly over the last million years.

Much of this variation can be explained by orbital geometry.

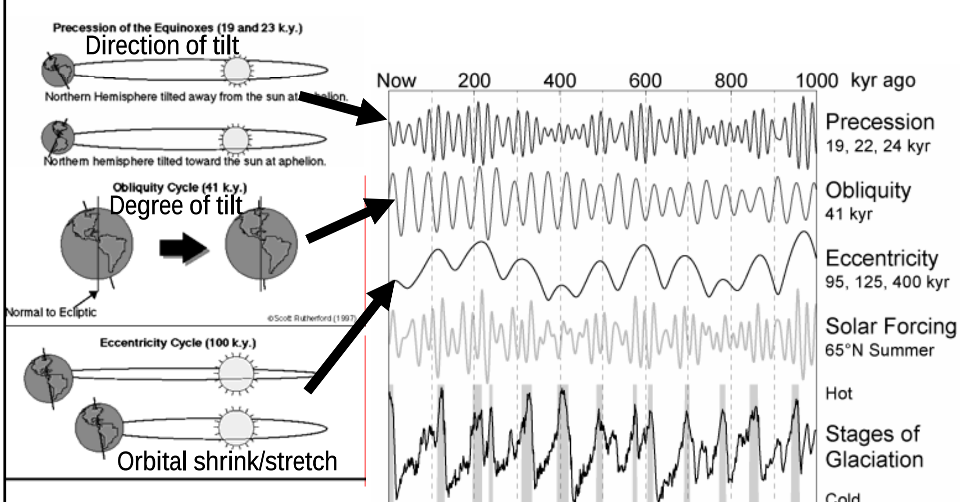
Much can't (see high frequencies)

Greenhouse gas changes in parallel, but hard to resolve which is leading and which lagging



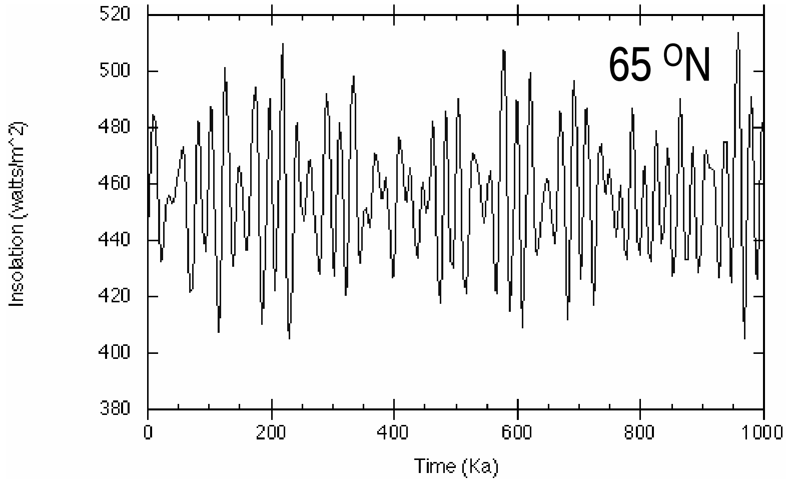
Global Scale, 10^4 - 10^6 yr time scales:

Large variations due to variation in Earth's motion relative to the Sun (Milankovitch cycles)



Adapted from Berger (1991)

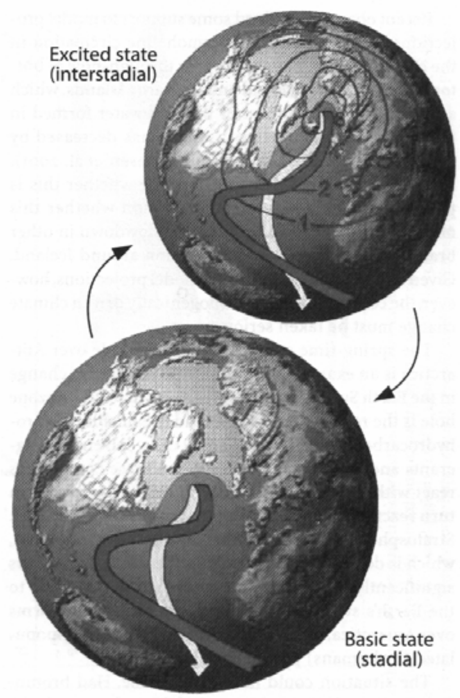
Milankovitch cycles create up to 20% variation in solar radiation incident on earth.



Almost certainly drives climate variability, but degree of response is not clear due to 'internal' climate variability.

Adapted from Berger (1991) Model

Thermohaline Circulation:
A metastable climate?



Global warming -> ice cap melting -> seawater freshening -> floating pool of bouyant seawater, shutting off northernmost loop of heat conveyor.

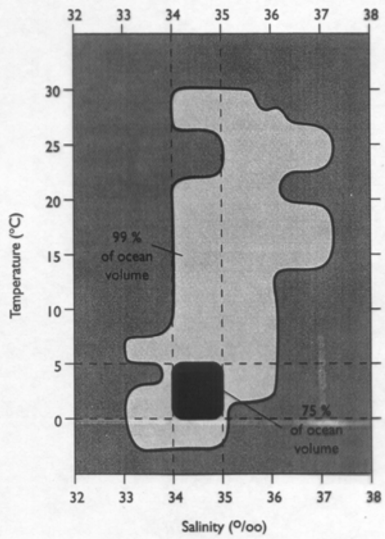
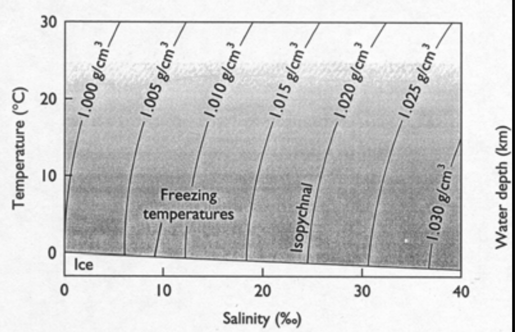


FIGURE 5-13

Temperature-salinity range of seawater. Seawater is a remarkably uniform solution, with 75 percent of the total ocean volume having a temperature range of zero to 5°C and a salinity range of 34 to 35%. [Adapted from R. B. Montgomery, Deep Sea Research 5 (1958): 134–148.]



(a) SEAWATER DENSITY

(b)

FIGURE 4-13

Density of seawater. (a) This plot shows the variation of sea-water de isopycnals (lines of equal density) indicate that temperature has a gr parcels of different temperatures may have identical densities, provid sity, the oceans can be separated into a three-tiered structure, with t

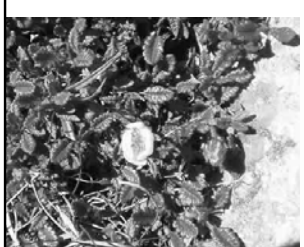
How can humans cause a collapse of the thermohaline circ?

1. **Global warming leads to increased arctic/polar melting**
2. **This freshens seawater**
3. **Fresh seawater is more bouyant than salty water**
4. **Disrupts the sinking loop in the N. Atlantic**
5. **Shifts loop to the far south**
6. **N. America and Europe cools drastically – as in Younger Dryas.**

The younger dryas constitute one of our best resolved examples of extremely rapid climate change

7°C cooling in perhaps 50 years!

Likely a switch of The THC



Dryas octapetala

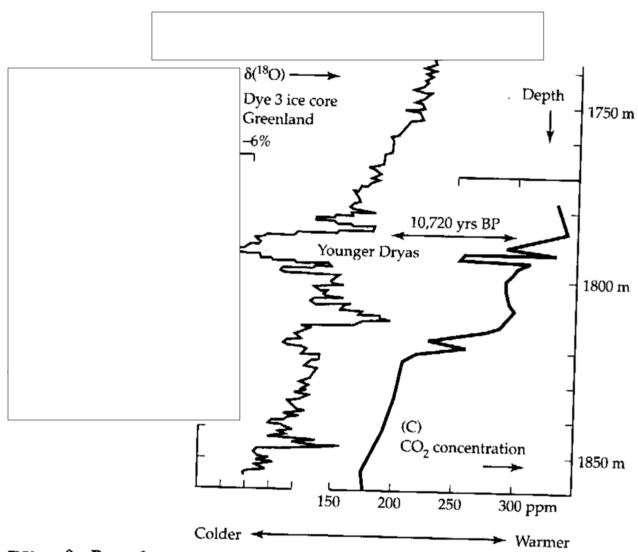
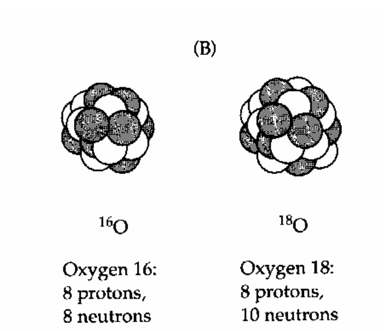


FIGURE 9 Records of the late glacial transition and the Younger Dryas cold event. (A) δ18O measurements from Lake Gerzen, Switzerland. (B) δ18O along a 120-meter core from Dye 3, Greenland. (C) Atmospheric CO_2 concentration from gas trapped in polar ice. (After Dansgaard et al., 1989.)

An aside: how are oxygen isotopes a paleothermometer?

The lighter isotope (^{16}O) evaporates increasingly more readily then ^{18}O as temperature increases. The water left behind is relatively more enriched with 18O at higher temperatures, and Tiny marine organisms incorporate this into their skeletons.



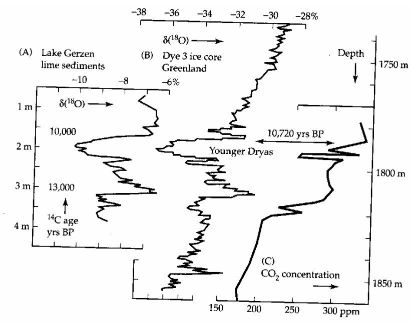


FIGURE 9 Records of the late glacial transition and the Younger Dryas cold event. (A) $\delta^{18}O$ measurements from Lake Gerzen, Switzerland. (B) $\delta^{18}O$ along a 120-meter core from Dye 3, Greenland. (C) Atmospheric CO_2 concentration from gas trapped in polar ice. (After Dansgaard et al., 1989.)

Threshold behavior of the global climatic environment:

Thermohaline Circulation Collapse

An Abrupt Climate Change Scenario and Its Implications for United States National Security
October 2003

By Peter Schwartz and Doug Randall

Commisioned by US Defense Dept. (Pentagon)

Imagining the Unthinkable

The purpose of this report is to imagine the unthinkable – to push the boundaries of current research on climate change so we may better understand the potential implications on United States national security.

We have interviewed leading climate change scientists, conducted additional research, and reviewed several iterations of the scenario with these experts. The scientists support this project, but caution that the scenario depicted is extreme in two fundamental ways. First, they suggest the occurrences we outline would most likely happen in a few regions, rather than on globally. Second, they say the magnitude of the event may be considerably smaller.

We have created a climate change scenario that although not the most likely, is plausible, and would challenge United States national security in ways that should be considered immediately.

Executive Summary

There is substantial evidence to indicate that significant global warming will occur during the 21st century. Because changes have been gradual so far, and are projected to be similarly gradual in the future, the effects of global warming have the potential to be manageable for most nations. Recent research, however, suggests that there is a possibility that this gradual global warming could lead to a relatively abrupt slowing of the ocean's thermohaline conveyor, which could lead to harsher winter weather conditions, sharply reduced soil moisture, and more intense winds in certain regions that currently provide a significant fraction of the world's food production. With inadequate preparation, the result could be a significant drop in the human carrying capacity of the Earth's environment.

The research suggests that once temperature rises above some threshold, adverse weather conditions could develop relatively abruptly, with persistent changes in the atmospheric circulation causing drops in some regions of 5-10 degrees Fahrenheit in a single decade. Paleoclimatic evidence suggests that altered climatic patterns could last for as much as a century, as they did when the ocean conveyor collapsed 8,200 years ago, or, at the extreme, could last as long as 1,000 years as they did during the Younger Dryas, which began about 12,700 years ago.

Tipping point with ice sheets?:

Greenland, antarctica accumulate ice as temperature warms, but then begin to lose ice more and more rapidly because of temperature increases with decreasing altitude. (10ºC/km)

To build ice sheets back up requires much more colder temperatures than to maintain them

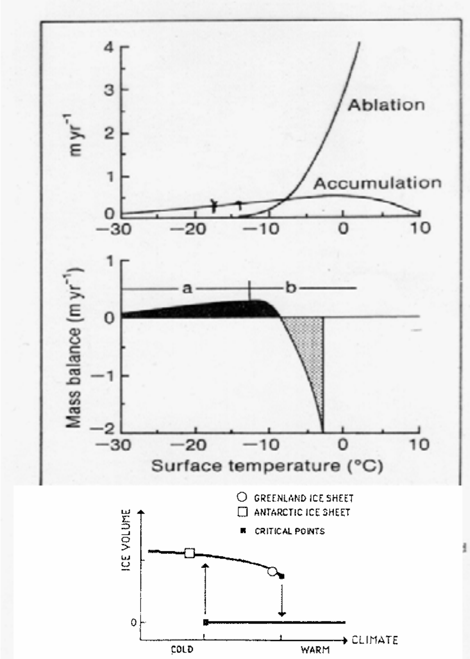
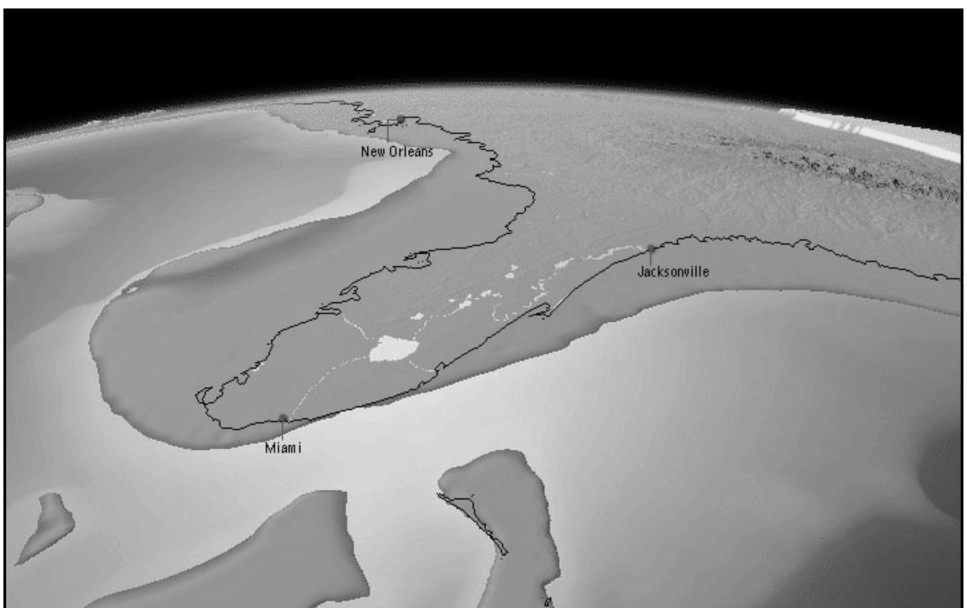
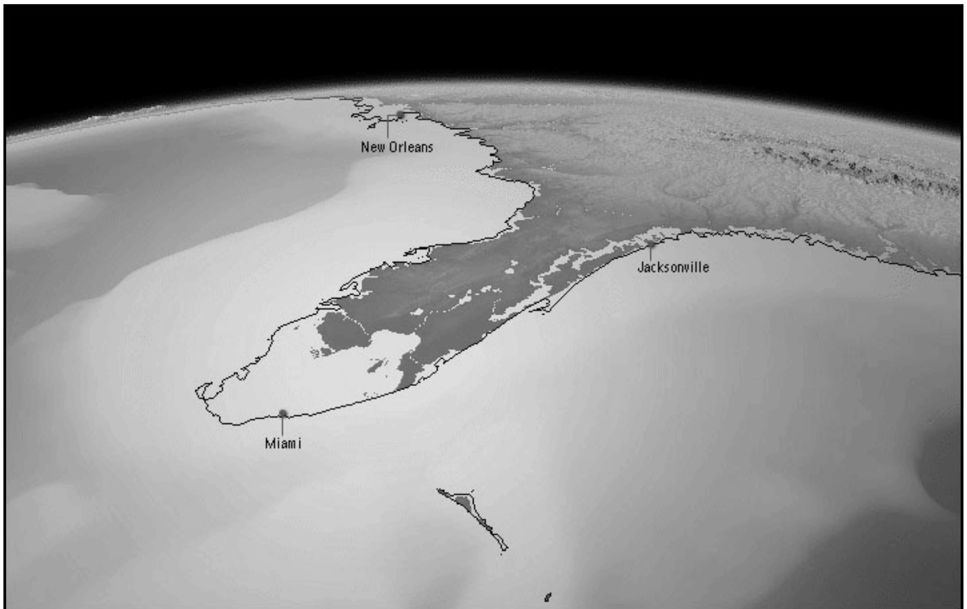


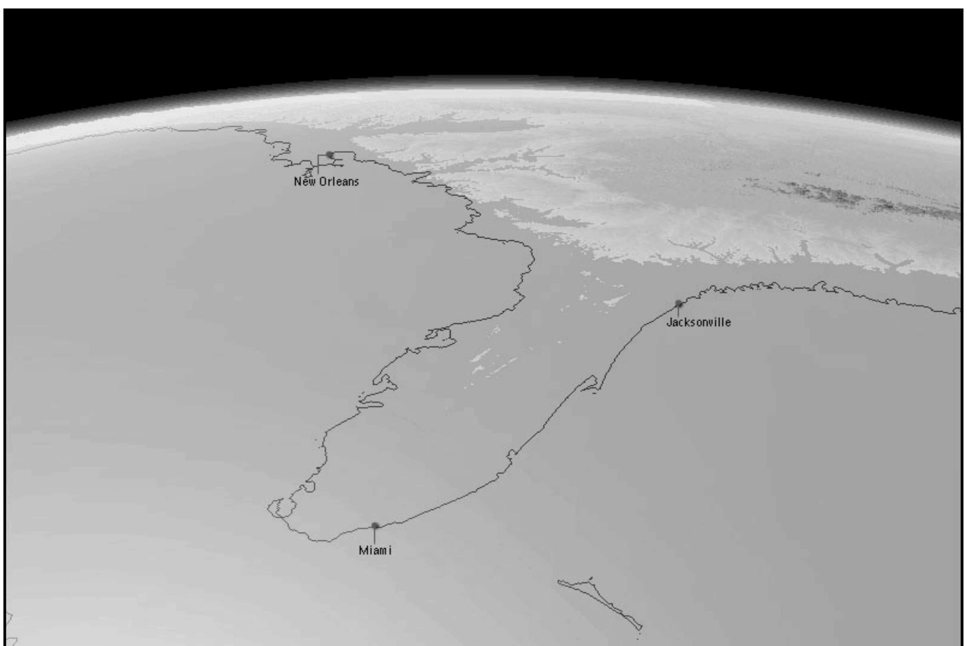
Fig. 2. A general representation of the steady states of an ice sheet on a bounded continent. i dependence of climatic conditions. The Greenland and Antarctic ice sheets can be placed in th diagram. When the Greenland ice sheet would melt, much colder conditions are required to buil it up again. The nonlinear behaviour is due to the altitude – mass balance feedback.



20,000 years ago – 400 feet below today(from pbs.org)

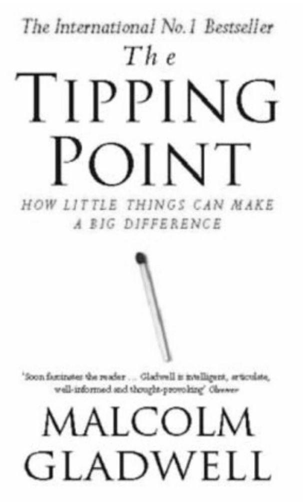


If west antarctic ice sheet melted – 17 feet above today



If east antarctic ice sheet melted – 170 feet above today

Threshold behavior of the global climatic environment:



Debate on Climate Shifts to Issue of Irreparable Change

Some Experts on Global Warming Foresee 'Tipping Point' When It Is Too Late to Act

By Juliet Eilperin
Washington Post Staff Writer
Sunday, January 29, 2006; Page A01

Now that most scientists agree human activity is causing Earth to warm, the central debate has shifted to whether climate change is progressing so rapidly that, within decades, humans may be helpless to slow or reverse the trend.

This "tipping point" scenario has begun to consume many prominent researchers in the United States and abroad, because the answer could determine how drastically countries need to reduce their greenhouse gas emissions in the coming years. While scientists remain uncertain when such a point might occur, many say it is urgent that policymakers cut global carbon dioxide emissions in half over the next 50 years or risk the triggering of changes that would be irreversible.

Smoothness and Patchiness of Atmospheric Constituents

- Mean Residence Time

MRT = Pool size / Flux Rate

- Amelia Drinking Water

Some biogeochemical cycles integrate from organism to globe, while others are more localized.

Mean Residence time In atmosphere =

Pool Size (kg)/ Flux (kg/yr)

The lower the MRT, the more spatially variable the biogeochemical is in the atmosphere – policy implications

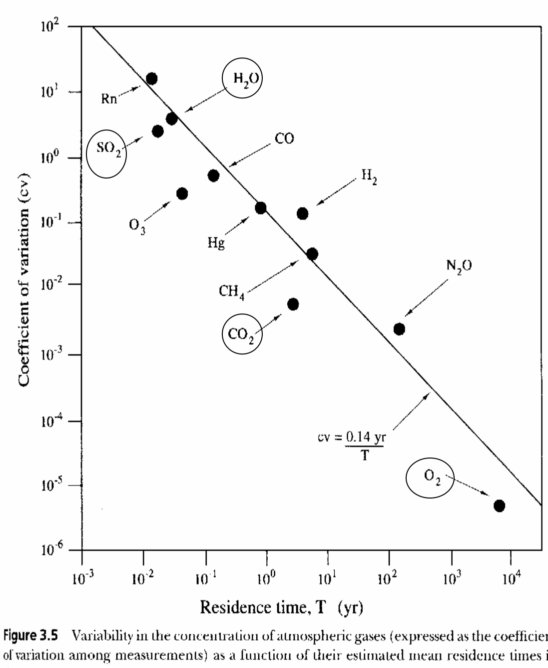
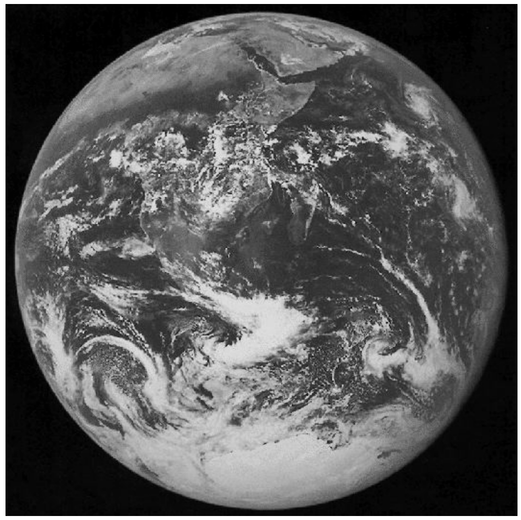


Figure 3.5 Variability in the concentration of atmospheric gases (expressed as the coefficient of variation among measurements) as a function of their estimated mean residence times in the atmosphere. Modified from Junge (1974), as updated by Slinn (1988).

This explains why water is so patchy…



H20 Atmospheric MRT = (27 mm) / (3 mm/day) = 9 days
Compared to ~ 1 year atmospheric mixing time

… why O2 is evenly distributed (21%), why CO2 (MRT ~ 2 yrs) is somewhat variable but more evenly distributed than water.

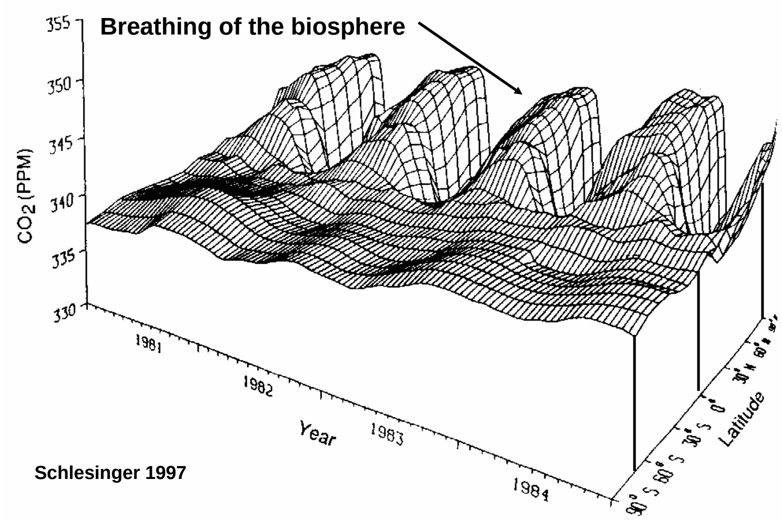
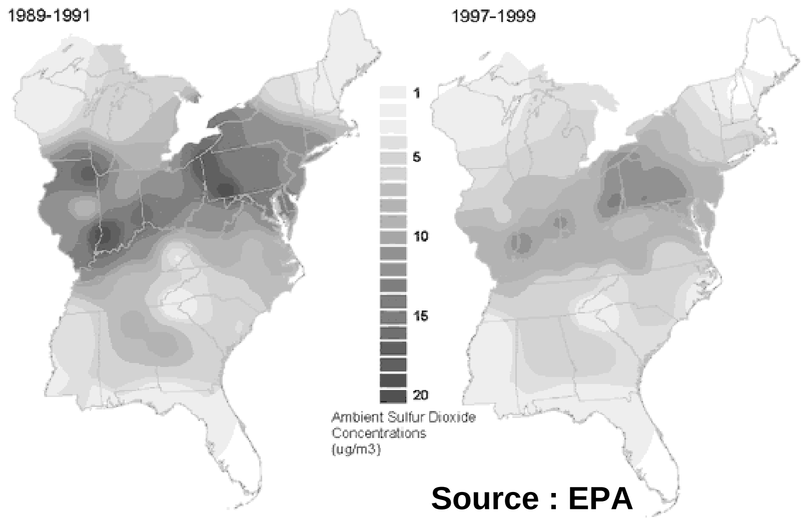


Figure 3.6 Seasonal fluctuations in the concentration of atmospheric CO_2 (1981–1984), shown as a function of 10° latitudinal belts (Conway et al. 1988). Note the smaller amplitude of the fluctuations in the southern hemisphere, reaching peak concentrations during northern

why acid deposition (nitric, sulfuric acid) hits the Northeast states particularly hard. (MRT ~ 3-5 days)…



Source : EPA

And why aerosol pollutants are a localized (albeit worldwide) problem (MRT ~ 3-5 days)…

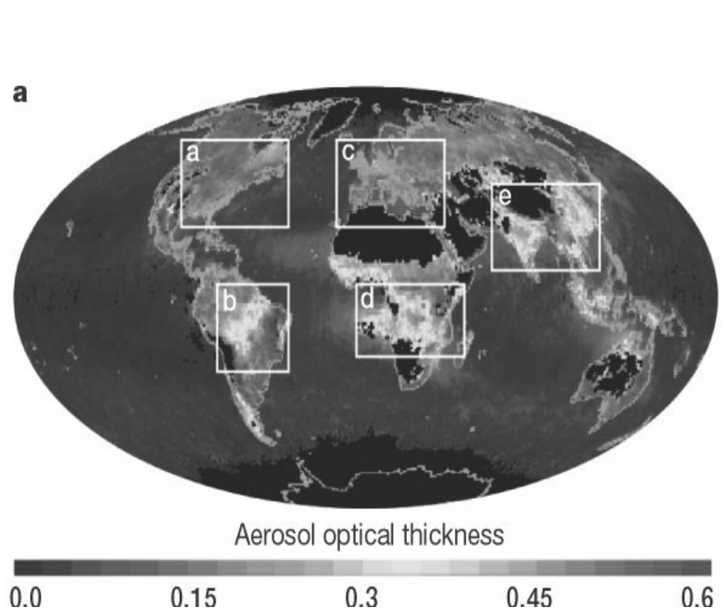
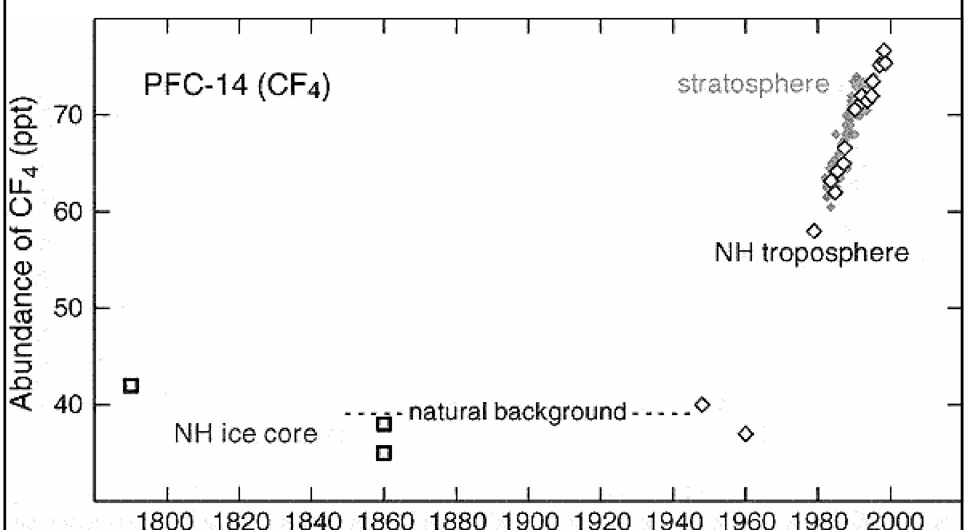


Table 4.1(a): Chemically reactive greenhouse gases and their precursors: abundances, trends, budgets, lifetimes, and GWPs.

Chemical species	Formula	Abundance[a] ppt 1998	Abundance[a] ppt 1750	Trend ppt/yr[a] 1990s	Annual emission late 90s	Life-time (yr)	100-yr GWP[b]
Methane	CH_4 (ppb)	1745	700	7.0	600 Tg	8.4/12[c]	23
Nitrous oxide	N_2O (ppb)	314	270	0.8	16.4 TgN	120/114[c]	296
Perfluoromethane	CF_4	80	40	1.0	~15 Gg	>50000	5700
Perfluoroethane	C_2F_6	3.0	0	0.08	~2 Gg	10000	11900
Sulphur hexafluoride	SF_6	4.2	0	0.24	~6 Gg	3200	22200
HFC-23	CHF_3	14	0	0.55	~7 Gg	260	12000
HFC-134a	CF_3CH_2F	7.5	0	2.0	~25 Gg	13.8	1300
HFC-152a	CH_3CHF_2	0.5	0	0.1	~4 Gg	1.40	120

Perfluourocarbons: almost wholly anthropogenic (aluminum smelting, semiconductors)



IPCC WGI Fig. 4.4

Other chemically active gases directly or indirectly affecting radiative forcing							
Tropospheric ozone	O_3 (DU)	34	25	?	see text	0.01-0.05	–
Tropospheric NO_x	$NO + NO_2$	5-999	?	?	~52 TgN	<0.01-0.03	–
Carbon monoxide	CO (ppb)[d]	80	?	6	~2800 Tg	0.08 - 0.25	d
Stratospheric water	H_2O (ppm)	3-6	3-5	?	see text	1-6	–

[a] All abundances are tropospheric molar mixing ratios in ppt (10^{-12}) and trends are in ppt/yr unless superseded by units on line (ppb = 10^{-9}