

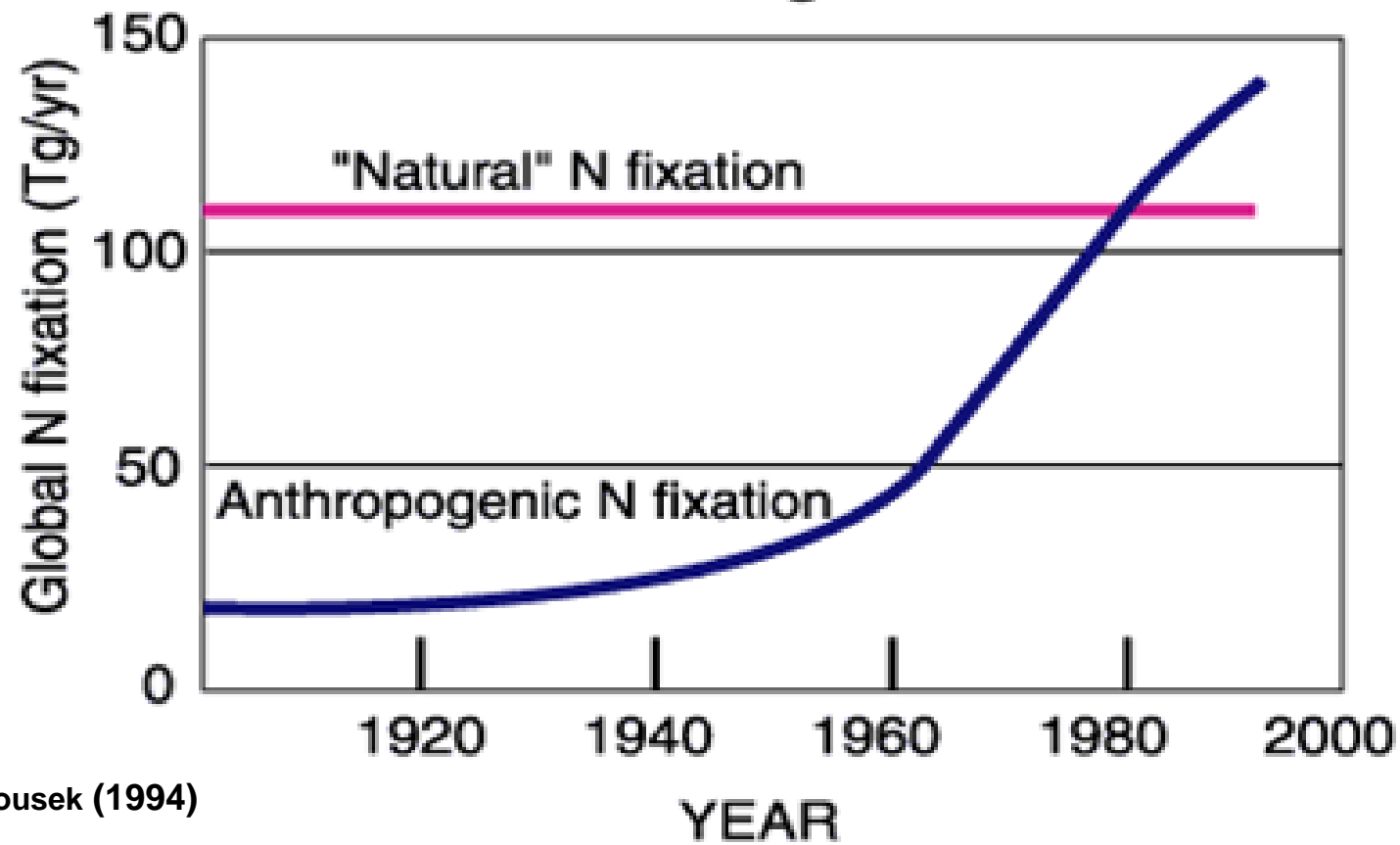


- During the past 3 centuries human population has increased tenfold to 6000 million and fourfold in the 20<sup>th</sup> century
- Cattle population increased to 1400 million (one cow/family); by a factor of 4 during the past century
- Urbanisation grew more than tenfold in the past century; almost half of the people live in cities and megacities
- Industrial output increased 40 times during the past century; energy use 16 times
- Almost 50 % of the land surface has been transformed by human action
- Water use increased 9 fold during the past century to 800 m<sup>3</sup> per capita; 65 % for irrigation, 25 % industry, ~10 % households

- Human appropriation of terrestrial net primary productivity ~ 30%, but with large uncertainties, Vitousek et al., Science, 494, 1997, Rojstaczer et al., Science, 2549, 2001
- Fish catch increased 40 times
- The release of SO<sub>2</sub> (160 Tg/year) by coal and oil burning is at least twice the sum of all natural emissions; over land the increase has been 7 fold, causing acid rain, health effects, poor visibility, and climate changes due to sulfate aerosols
- Releases of NO to the atmosphere from fossil fuel and biomass burning is larger than its natural inputs, causing high surface ozone levels over extensive regions of the globe
- Several climatically important "greenhouse gases" have substantially increased in the atmosphere, eg. CO<sub>2</sub> by 30 %, CH<sub>4</sub> by more than 100 %.

- Humanity is also responsible for the presence of many toxic substances in the environment and even some which are not toxic at all, but which have, nevertheless, led to the ozone hole.
- Among the „greenhouse gases“ are also the almost inert CFC (chlorofluorocarbon) gases. However, their photochemical breakdown in the stratosphere gives rise to highly reactive chlorine atoms, which destroy ozone by catalytic reactions. As a consequence UV-B radiation from the sun increases, leading for instance to enhanced risk of skin cancer.

## Nitrogen



Vitousek (1994)

## Man the Eroder

- Man-caused erosion (crop tillage, land conversion for grazing and construction): 15 times natural erosion
- At current rate anthropogenic soil erosion would fill the Grand Canyon in 50 years.

According to Wilkinson (Geology) March 2005.

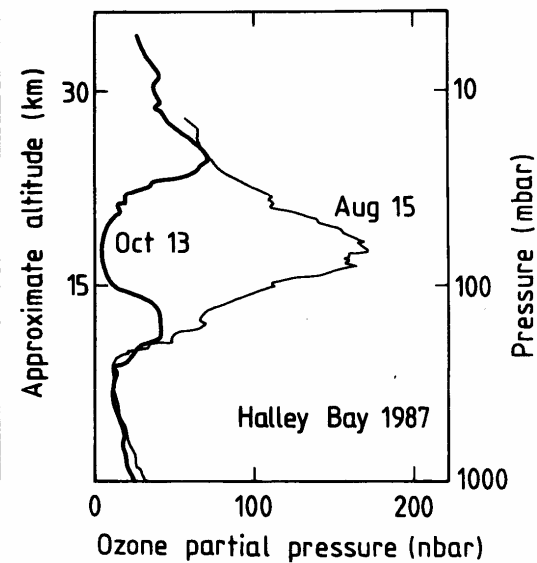
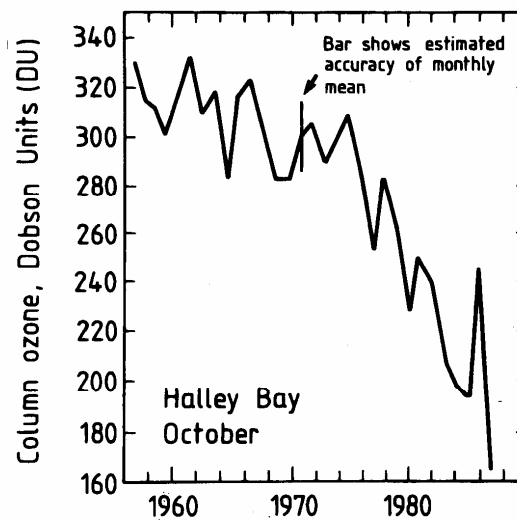
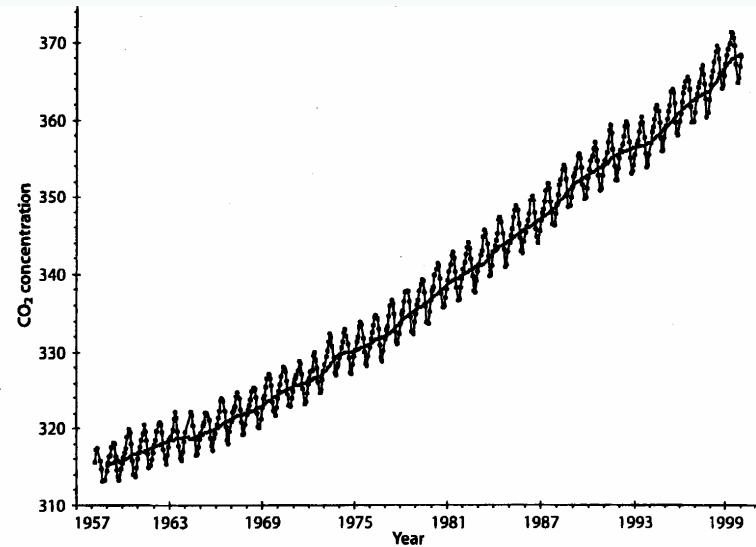
- E.O. Wilson “Before humans existed, the species extinction rate was (very roughly) one species per million species per year. Estimates for current species extinction rates range from 100 to 10,000 times that, but most hover close to 1,000 times prehuman levels (0.1% per year)

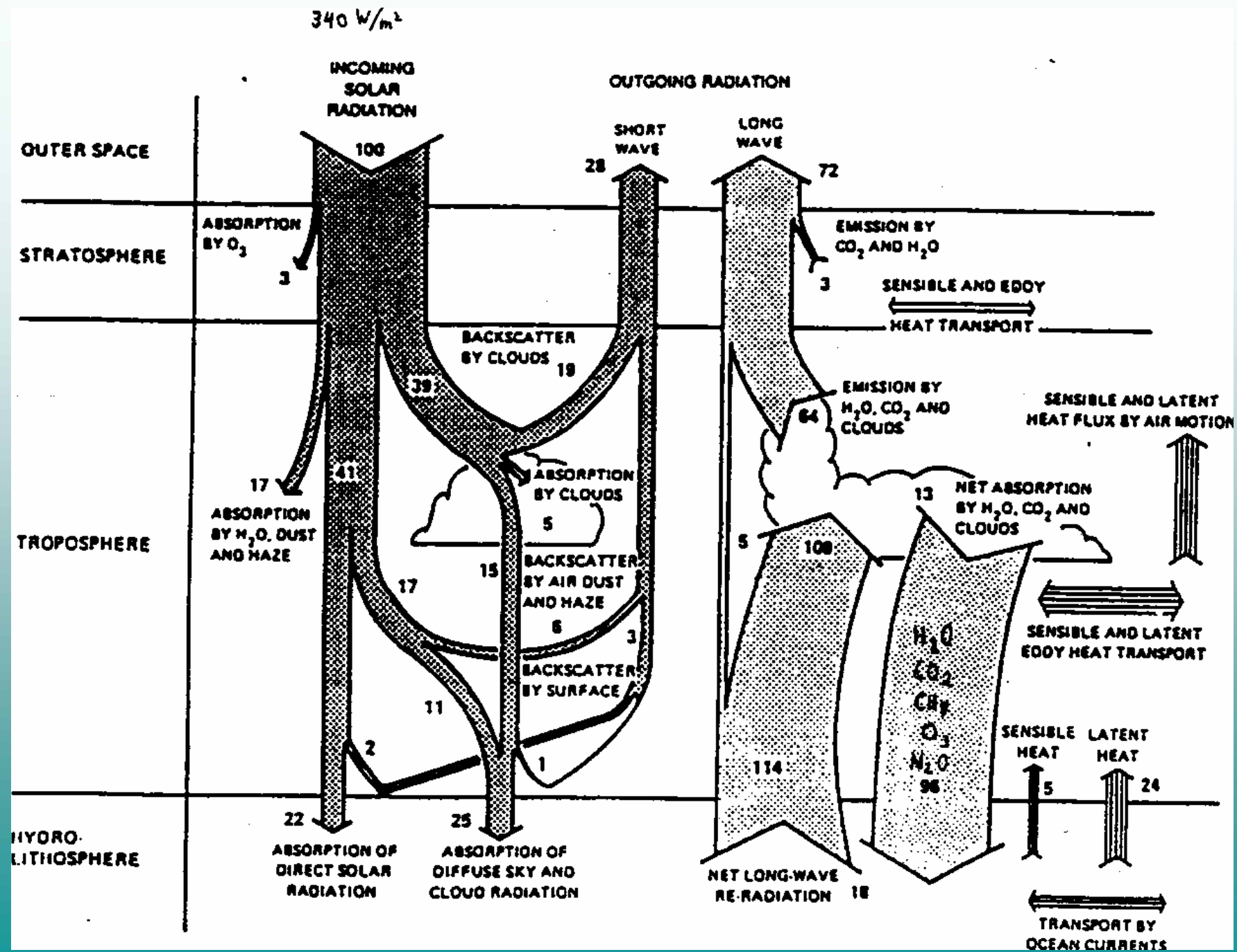
- In an article titled “Humans as the World’s Greatest Evolutionary Force“, Palumbi (Science, 7 September 2001) states that mankind also effects evolutionary change in other species, especially in commercially important, pest, and disease organisms, through antibiotics and pesticides. This accelerated evolution costs at least \$33 billion to \$50 billion a year in the United States.

Since the beginning of the 19th Century, by its own growing activities, Mankind opened a new geological era: the Anthropocene

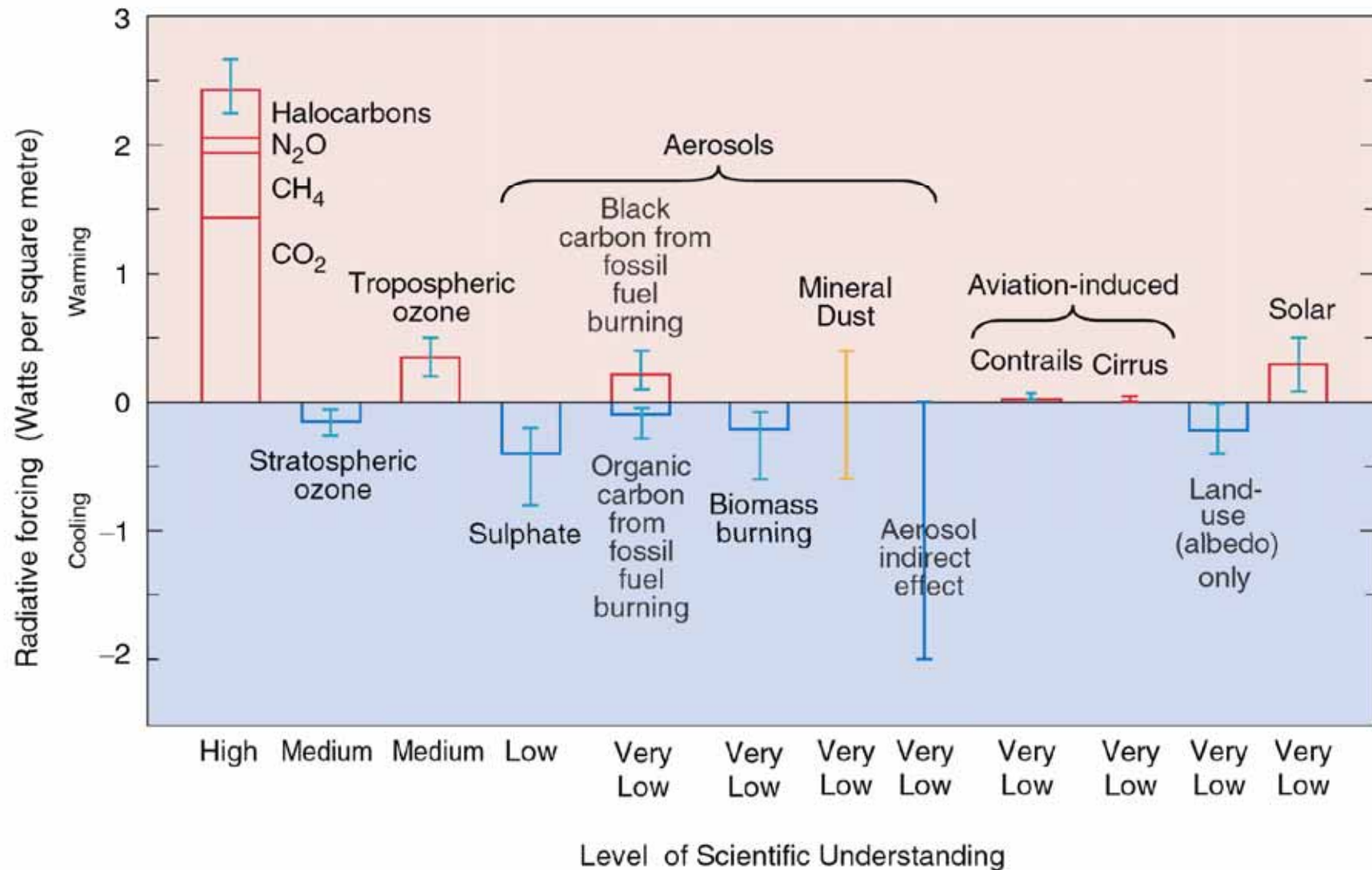


The "Keeling curve", showing the steady increase in atmospheric  $\text{CO}_2$  concentration recorded monthly at Mauna Loa in Hawaii, 1958-1999 (adapted from Keeling and Whorf 2000)





## The global mean radiative forcing of the climate system for the year 2000, relative to 1750



**Δ**

**Greenhouse gas forcing       $\approx 2.7 \text{ W/m}^2$   
(since pre-industrial times)**

**Heating of the ocean       $\approx 0.3 \text{ W/m}^2$**

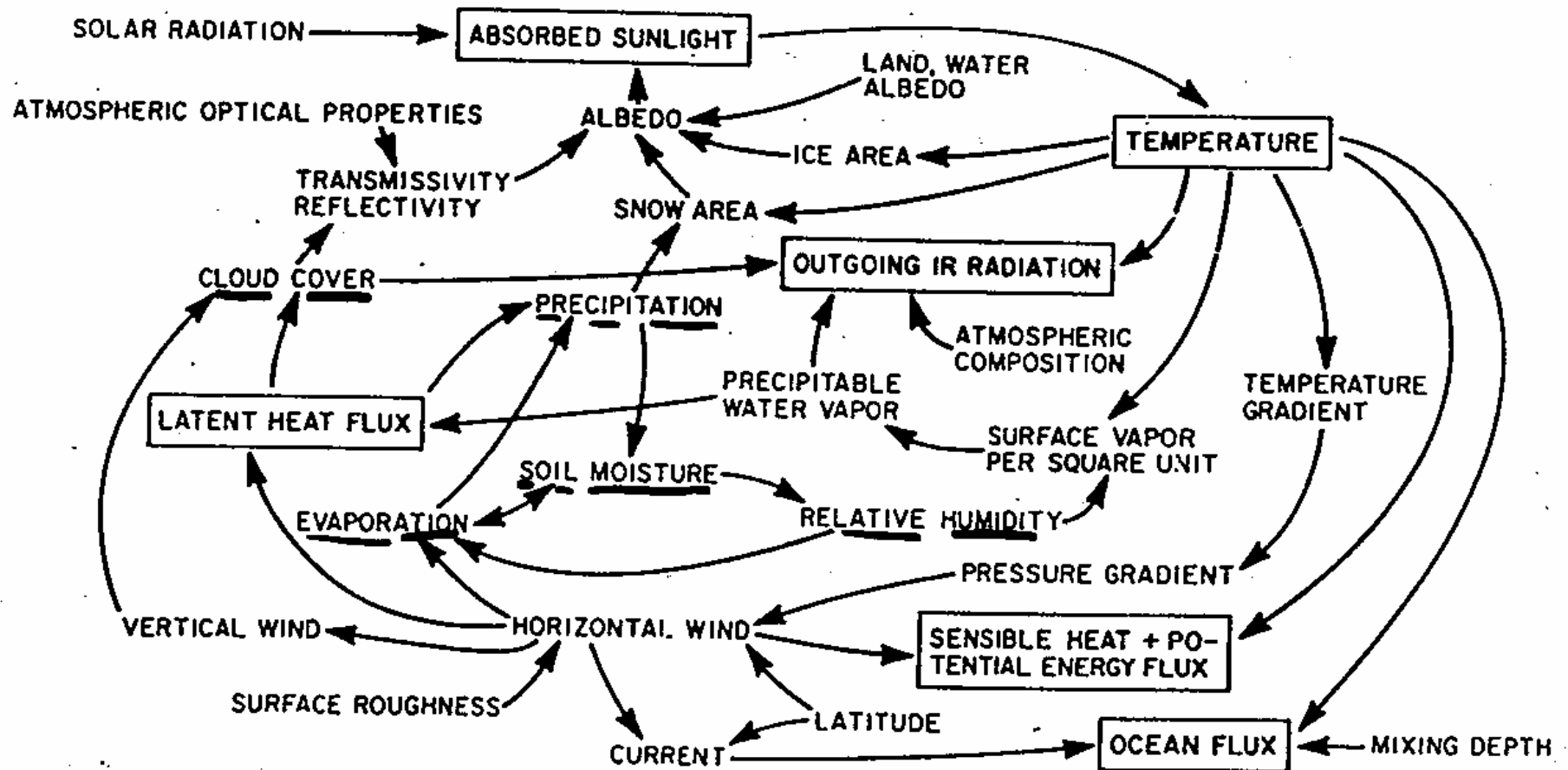
**Increased upward IR       $\approx 1 \text{ W/m}^2$   
(from hotter surface of earth)**

**∴**

**Increased albedo effect       $\approx 1.4 \text{ W/m}^2$   
( $\approx 50\%$  of GHF)**

**Heat release to atmosphere  $0.025 \text{ W/m}^2$   
from fossil fuel burning (1995)**

# CLIMATIC CAUSE-AND-EFFECT (FEEDBACK) LINKAGES



“The balance of evidence suggests a discernable human influence on global climate“ (IPCC, 1995)

„There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities“ (IPCC, 2001)

Average Global Temperature Rise: 1.4 – 5.8 ° C from 1999 to 2100 (includes cooling effects by sulfate aerosol)

Sea level rise: + 9 – 88 cm until 2100.

+ 0.5 – 10 m until ~ 3000.

Redistribution of precipitation

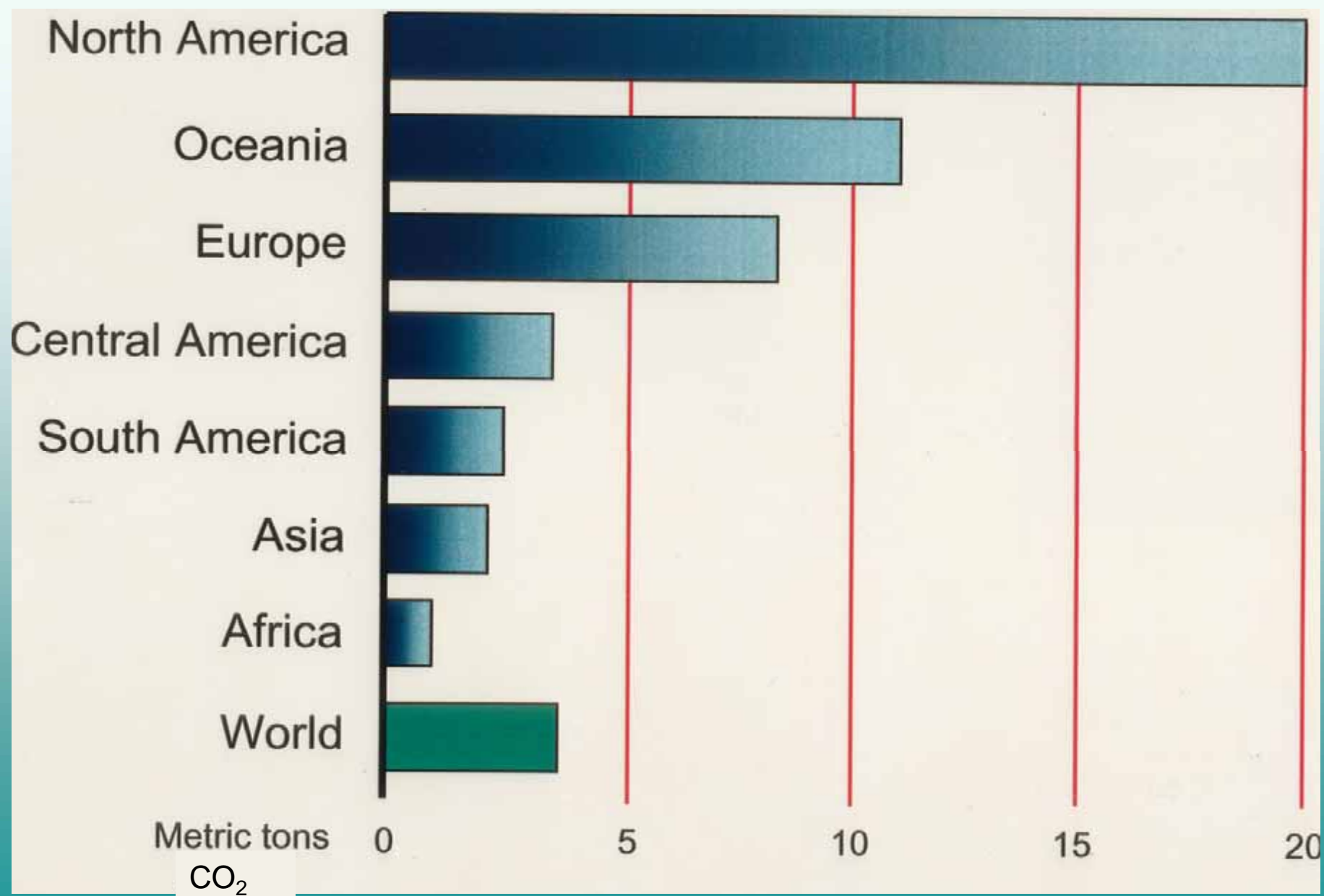
Enhanced risk for extreme weather (flooding, desertification)?

Increase in heat waves in Europe, as in the summer of 2003?

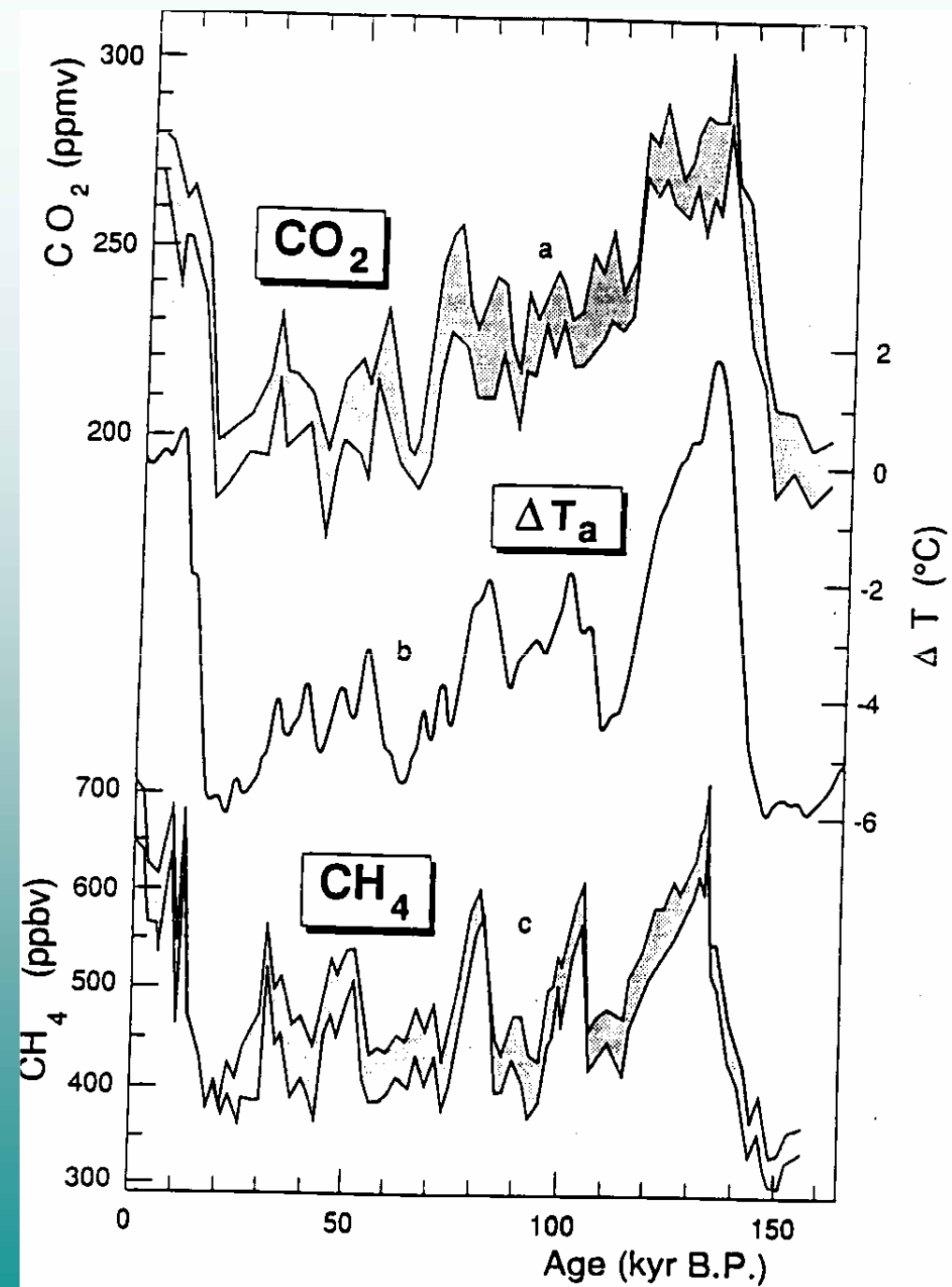
Too rapid climate changes, so that ecosystems cannot adapt.

*Stabilisation of Atmospheric Concentrations. Reductions in the human-made emission required to stabilise concentrations at current levels*

Greenhouse Gas	Reduction Required
Carbon Dioxide	> 60%
Methane	(achieved, but long term stabilisation is uncertain for instance by thawing of permafrost)
Nitrous Oxide	70-80%
CFC-11	achieved
CFC-12	achieved







## Stability of Earth Climate?

Unknowns?



UNSTABLE

Surprises?

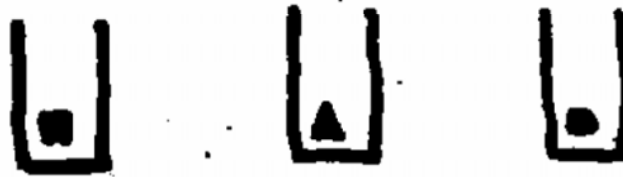


METASTABLE

Non-linear chaotic  
system?



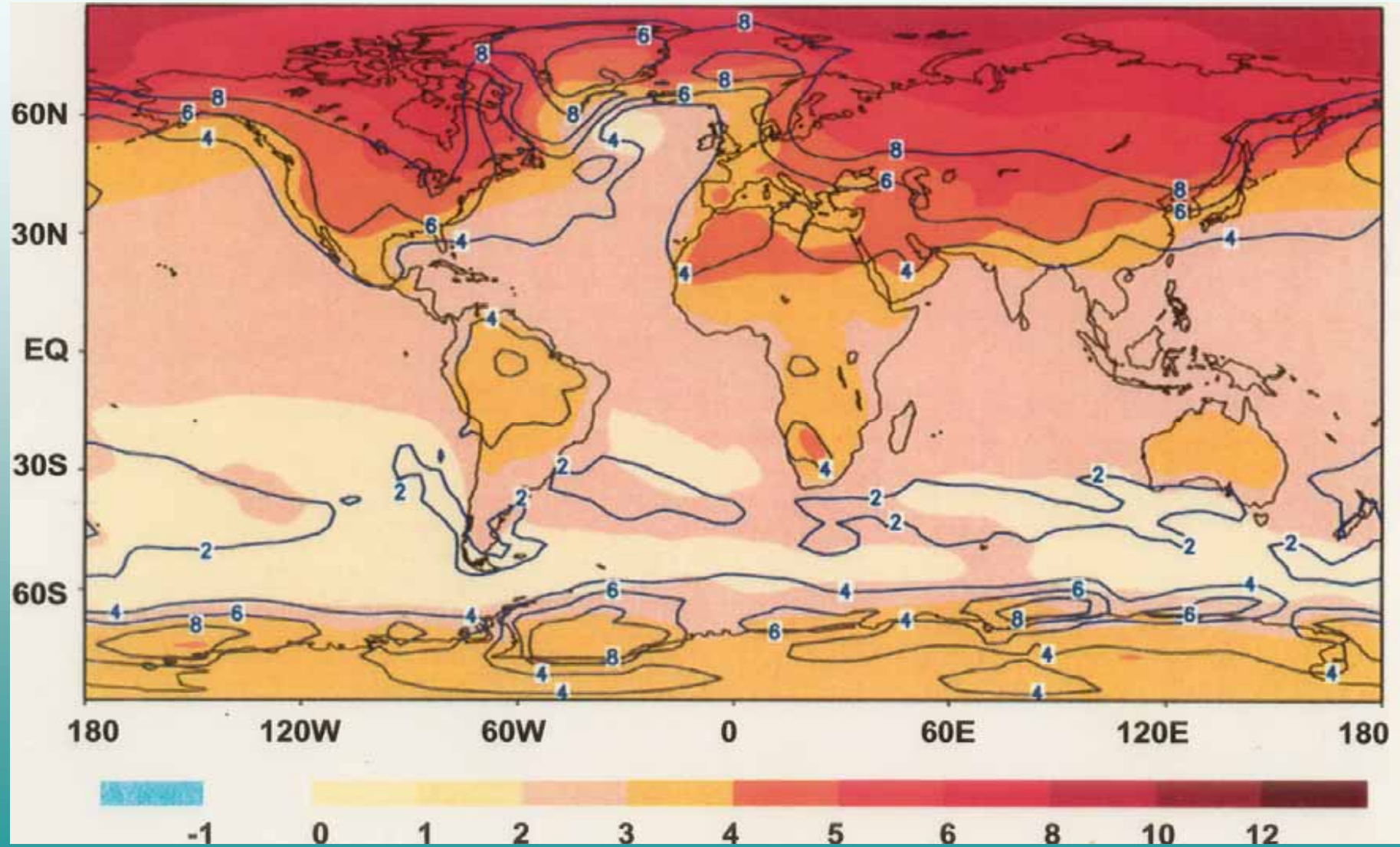
EQUILIBRIUM



STABLE

**Climate of the polar regions is most sensitive**

**Model calculated temperature charges for a doubling of atmospheric CO<sub>2</sub> content**



- „New studies indicate that the Arctic oceans ice cover is about 40% thinner than 20-40 years ago“. Levy, Physics Today, January 2000.

- There is dramatic climate change happening in the Arctic, about 2-3 times the pace for the whole globe: Robert Corell, Chairman of the Arctic Climate Impact Assessment, November 2004.

# Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms

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Today's surface ocean is saturated with respect to calcium carbonate, but increasing atmospheric carbon dioxide concentrations are reducing ocean pH and carbonate ion concentrations, and thus the level of calcium carbonate saturation. Experimental evidence suggests that if these trends continue, key marine organisms—such as corals and some plankton—will have difficulty maintaining their external calcium carbonate skeletons. Here we use 13 models of the ocean-carbon cycle to assess calcium carbonate saturation under the IS92a 'business-as-usual' scenario for future emissions of anthropogenic carbon dioxide. In our projections, Southern Ocean surface waters will begin to become undersaturated with respect to aragonite, a metastable form of calcium carbonate, by the year 2050. By 2100, this undersaturation could extend throughout the entire Southern Ocean and into the subarctic Pacific Ocean. When live pteropods were exposed to our predicted level of undersaturation during a two-day shipboard experiment, their aragonite shells showed notable dissolution. Our findings indicate that conditions detrimental to high-latitude ecosystems could develop within decades, not centuries as suggested previously.

## MELTING TOWARD A COLD SNAP?

As global warming continues to heat up the planet, many scientists fear that large pulses of freshwater melting off the Greenland ice sheet and other frozen northern landmasses could obstruct the so-called North Atlantic conveyor, the system of ocean currents that brings warmth to Europe and

strongly influences climate elsewhere in the world. A conveyor shutdown—or even a significant slowdown—could cool the North Atlantic region even as global temperatures continue to rise. Other challenging and abrupt climate changes would almost certainly result.

### CONVEYOR ON

Salty ocean currents (red) flowing northward from the tropics warm prevailing winds (large arrows) as they blow eastward toward Europe. The heat-bearing currents, which are dense, become even denser as they lose heat to the atmosphere. Eventually the cold, salty water becomes dense enough to sink near Greenland. It then migrates southward along the seafloor (blue), leaving a void that draws more warm water from the south to take its place.

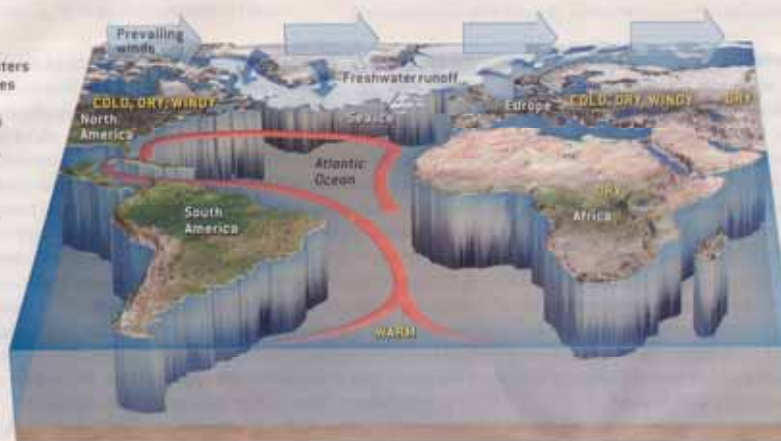


### RESULTING CLIMATE

When the North Atlantic conveyor is active, temperate conditions with relatively warm winters enable rich agricultural production in much of Europe and North America. Seasonal monsoons fuel growing seasons in broad swaths of Africa and the Far East. Central Asia is wet, and Antarctica and the South Atlantic are typically cold.

### CONVEYOR OFF

If too much freshwater enters the North Atlantic, it dilutes the salty currents from the south. Surface waters no longer become dense enough to sink, no matter how cold the water gets, and the conveyor shuts down or slows. Prevailing winds now carry frigid air eastward (large arrows). This cold trend could endure for decades or more—until southern waters become salty enough to overwhelm the fresher water up north, restarting the conveyor in an enormous rush.



### RESULTING CLIMATE

As the conveyor grows quiet, winters become harsher in much of Europe and North America, and agriculture suffers. These regions, along with those that usually rely on seasonal monsoons, suffer from droughts sometimes enhanced by stronger winds. Central Asia gets drier, and many regions in the Southern Hemisphere become warmer than usual.

Richard B. Alley: Abrupt climate change  
Scientific American, November 2004





*Patrick Zimmerman of the U.S. National Center for Atmospheric Research escapes to safety with a flask containing a sample of air from burning grass and brush in Brazil's Amazon region. Biomass burning is commonly practiced by farmers in tropical countries for land clearing and pesticide control; its effects on the atmosphere can be detected half a world away.*



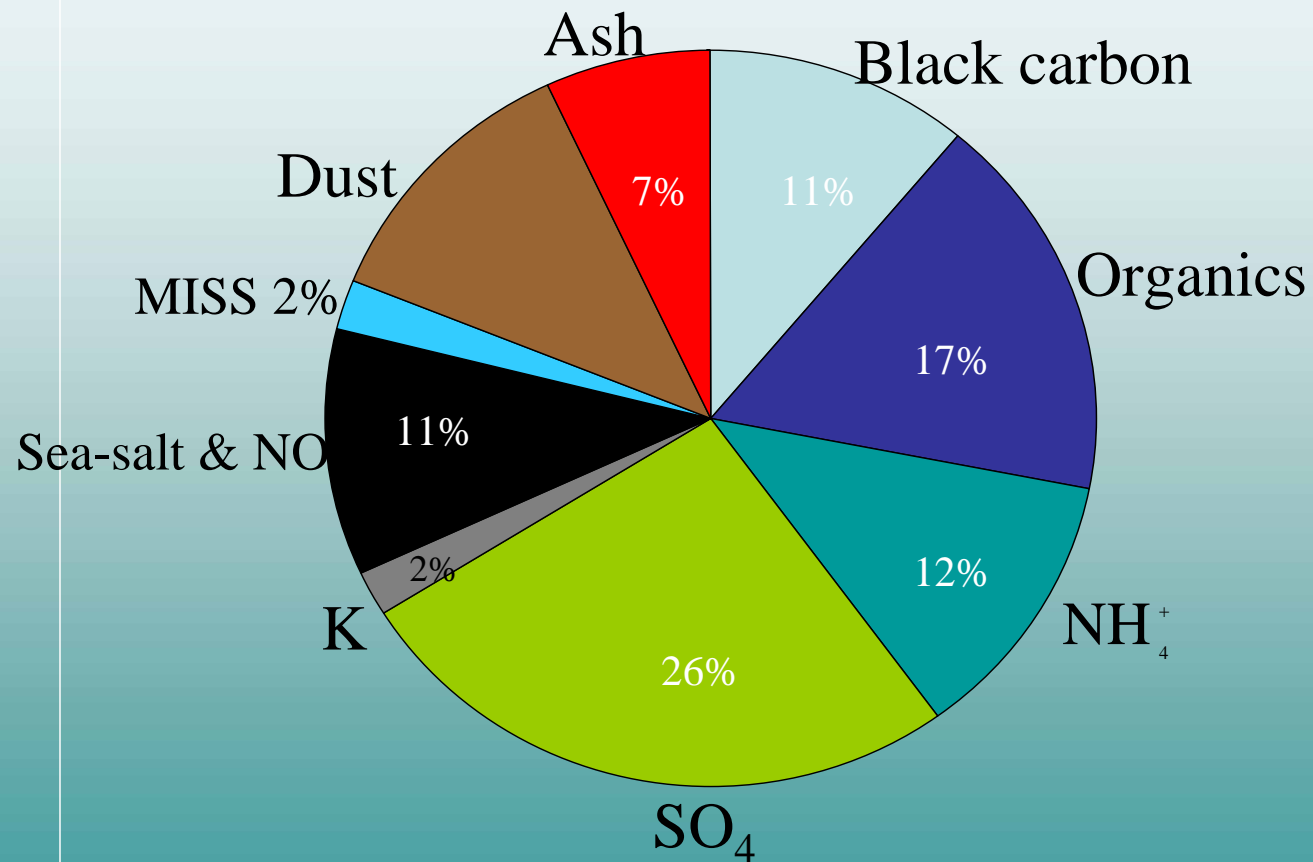
**Phaplu, Nepal; March 29, 2001**



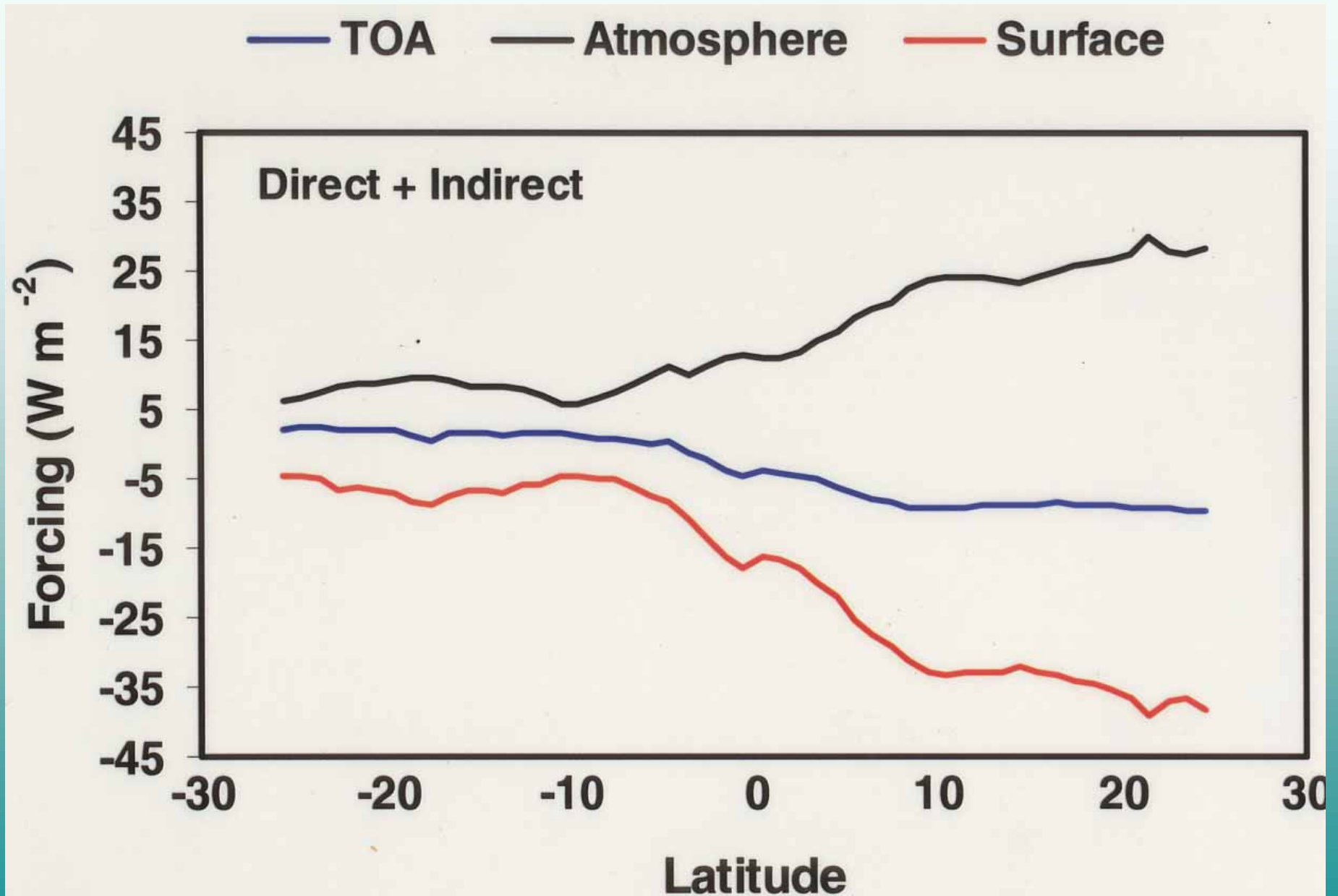


**Kaashidhoo under Haze Layer**

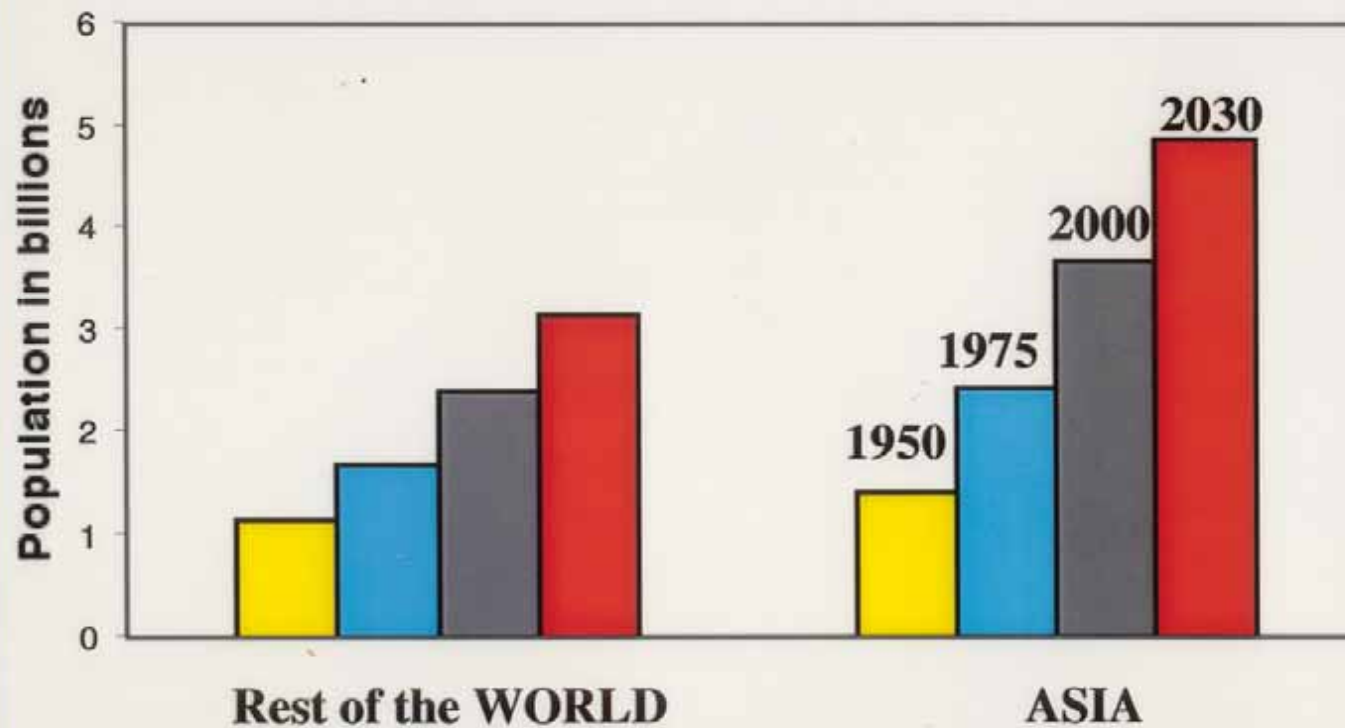
# The Composition of Aerosol



Shows the relative contribution of the various chemical species to the aerosol optical properties at visible wavelengths (Satheesh et al., 2000; Lelieveld et al., 2000)



## Population Growth



*Source: World Population Prospects: The 2000 Revision; United Nations New York*





