

Ocean Biogeochemistry in the Earth System

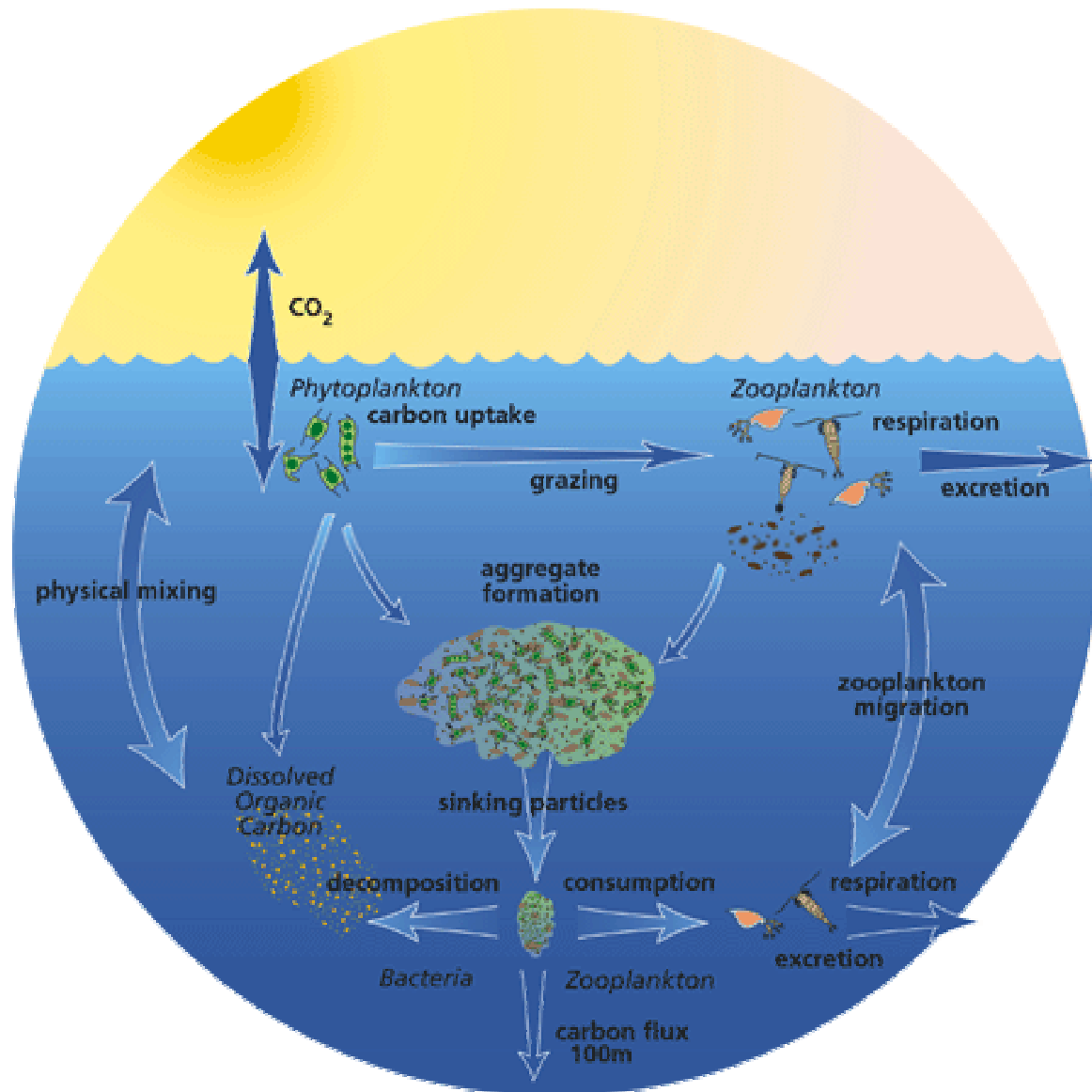
Berrien Moore III
Institute for the Study of Earth, Oceans, and Space
University of New Hampshire



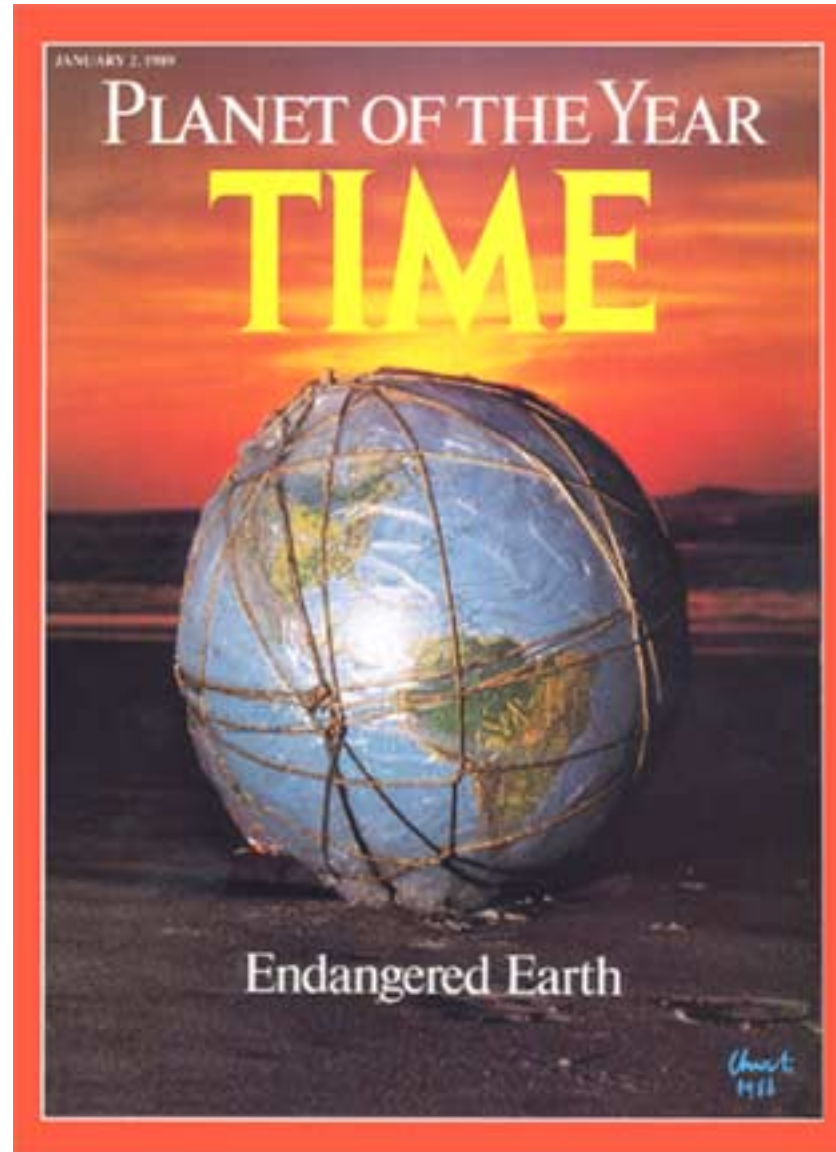
Open Science Conference: JGOFS

8 May 2003



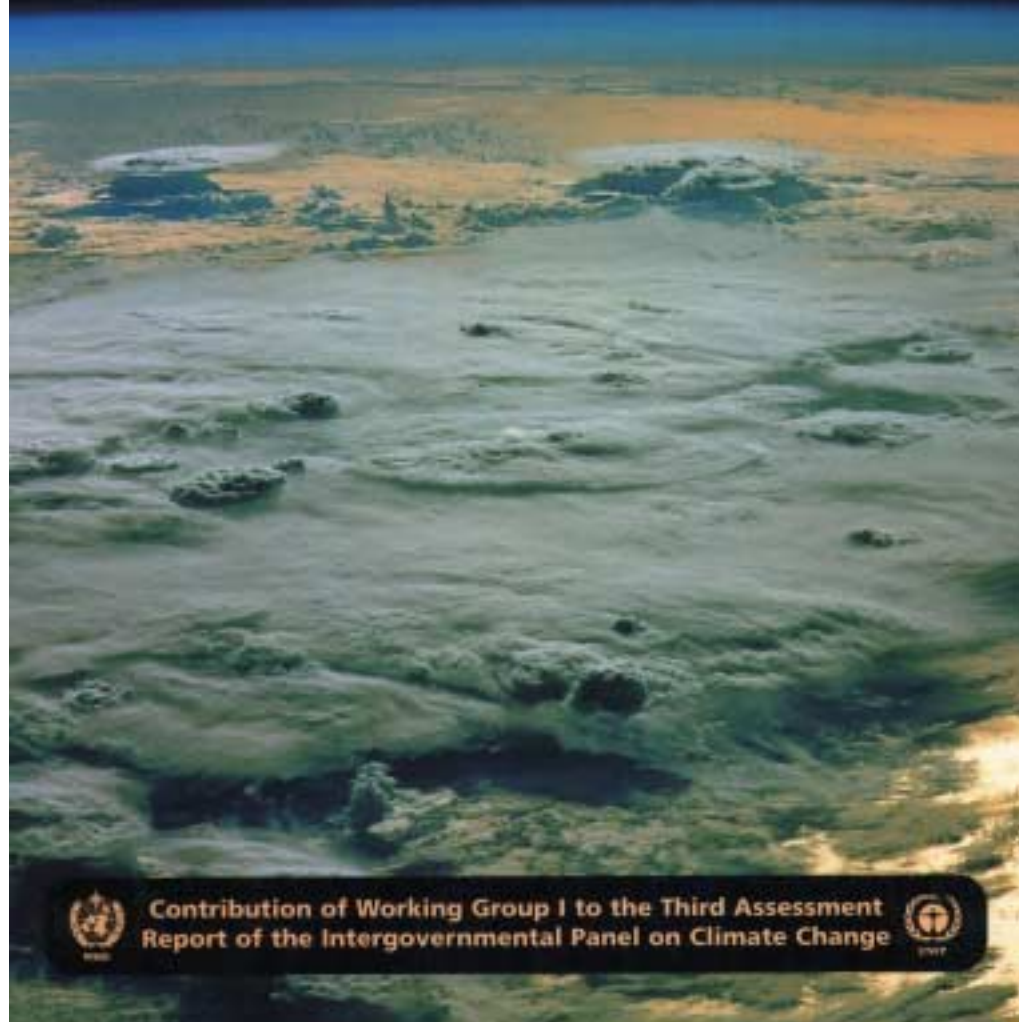


Source: JGOFS



CLIMATE CHANGE 2001

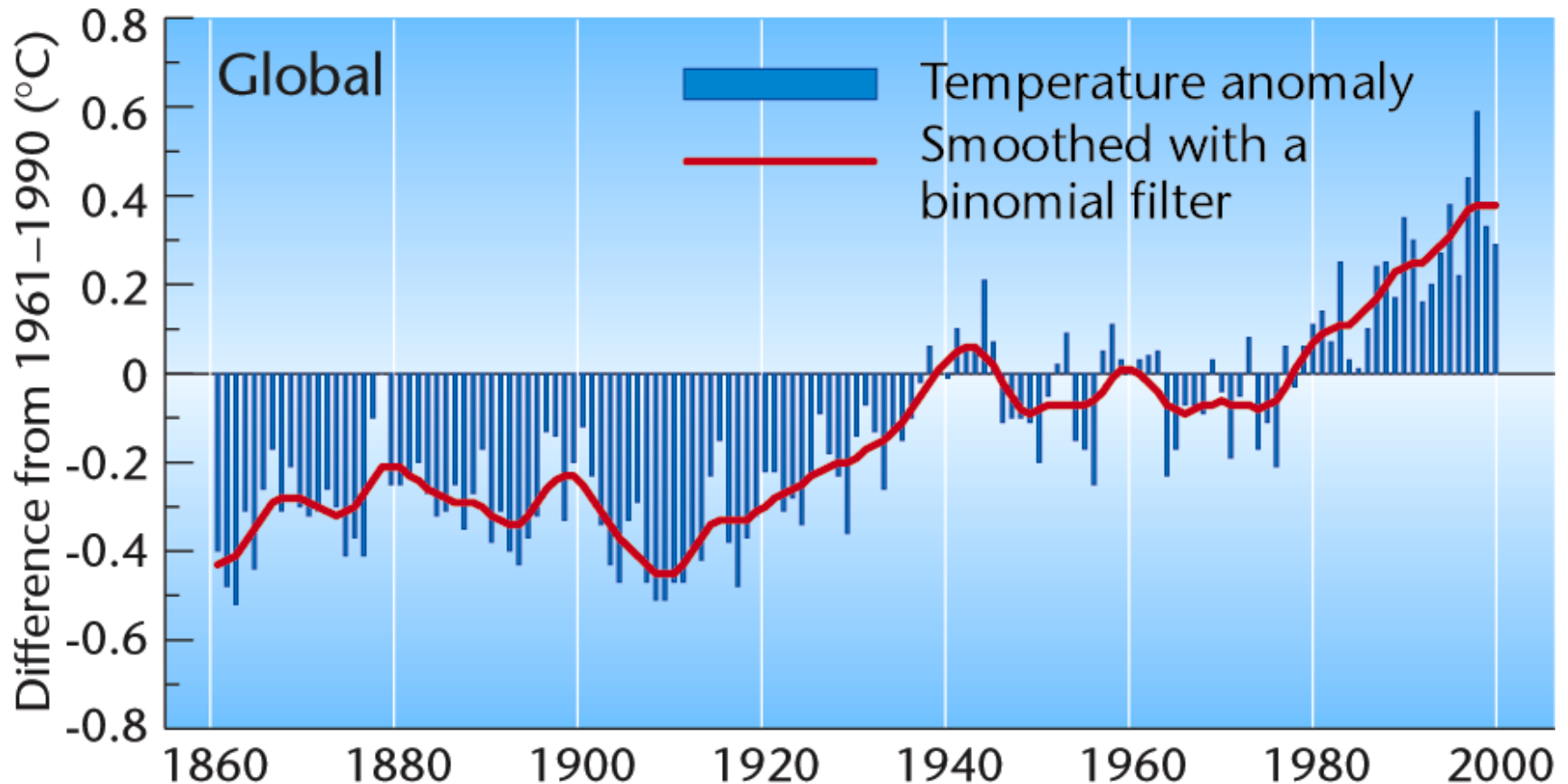
The Scientific Basis



Contribution of Working Group I to the Third Assessment
Report of the Intergovernmental Panel on Climate Change



Global mean surface temperature has increased more than $.5^{\circ}\text{C}$ since the beginning of the 20th century, with this warming likely being the largest during any century over the past 1,000 years for the Northern hemisphere.

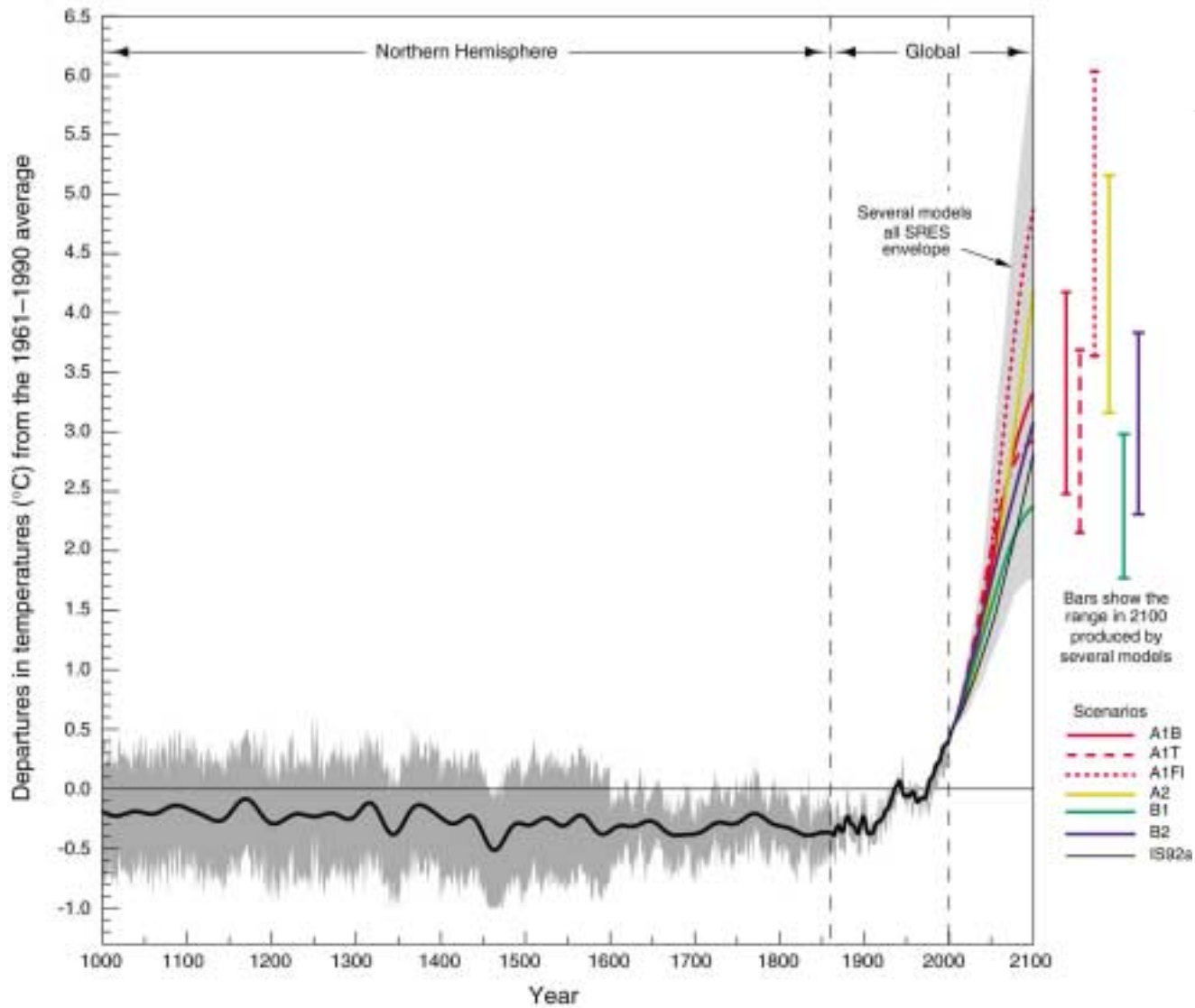


Source: IPCC Third Assessment Report, WG1

An increasing body of observations of climactic and other changes in physical and ecological systems gives a collective picture of a warming world



Source of text: IPCC Third Assessment Report, WG1



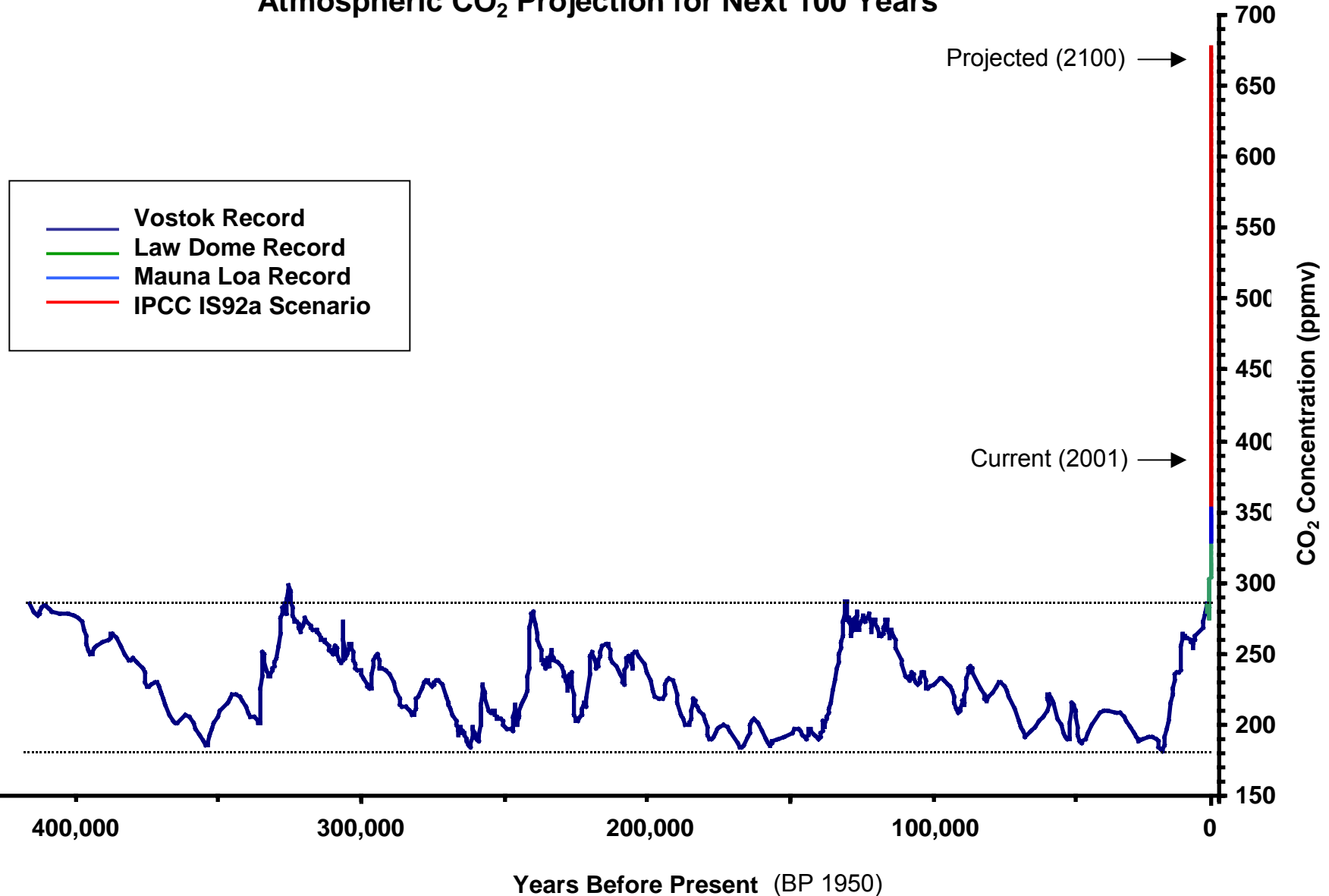
Global temperature will rise from 1.4-5.8°C over this century unless greenhouse gas emissions are greatly reduced

Source: IPCC Third Assessment Report, WG1

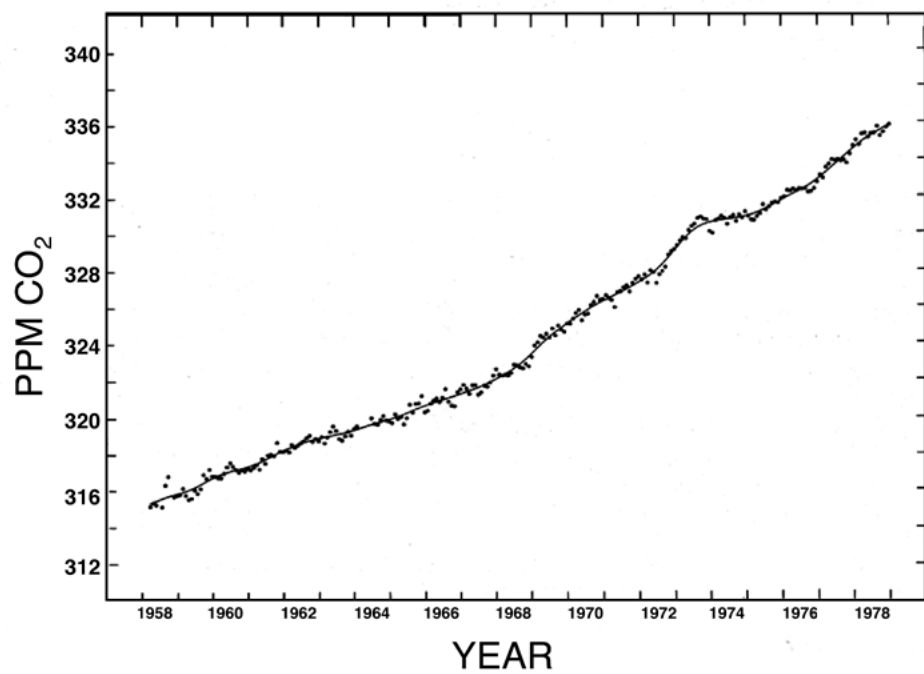
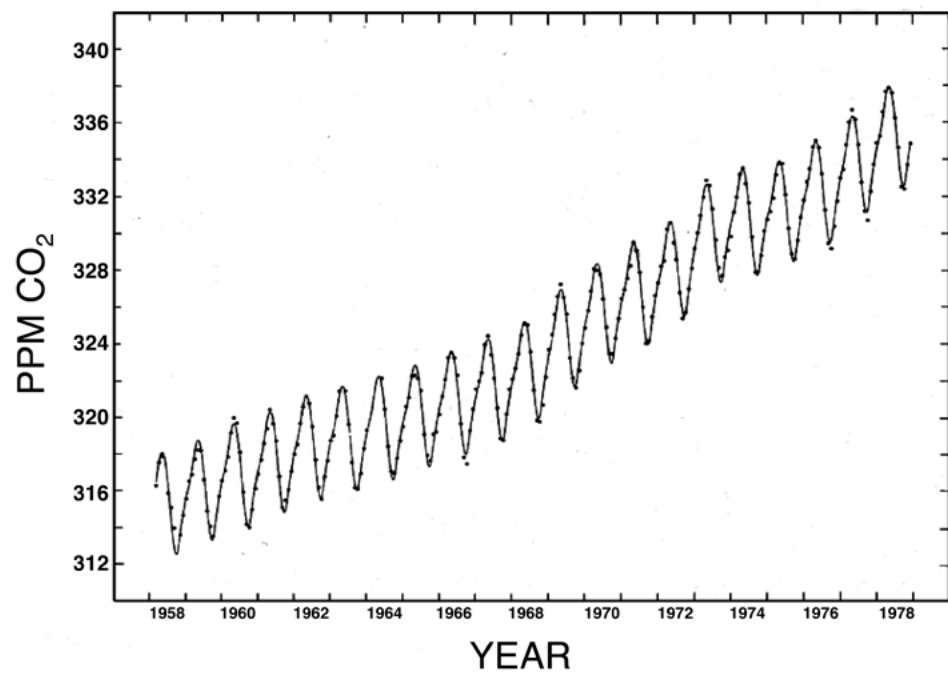
There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.



CO₂ Concentration in Ice Cores and Atmospheric CO₂ Projection for Next 100 Years



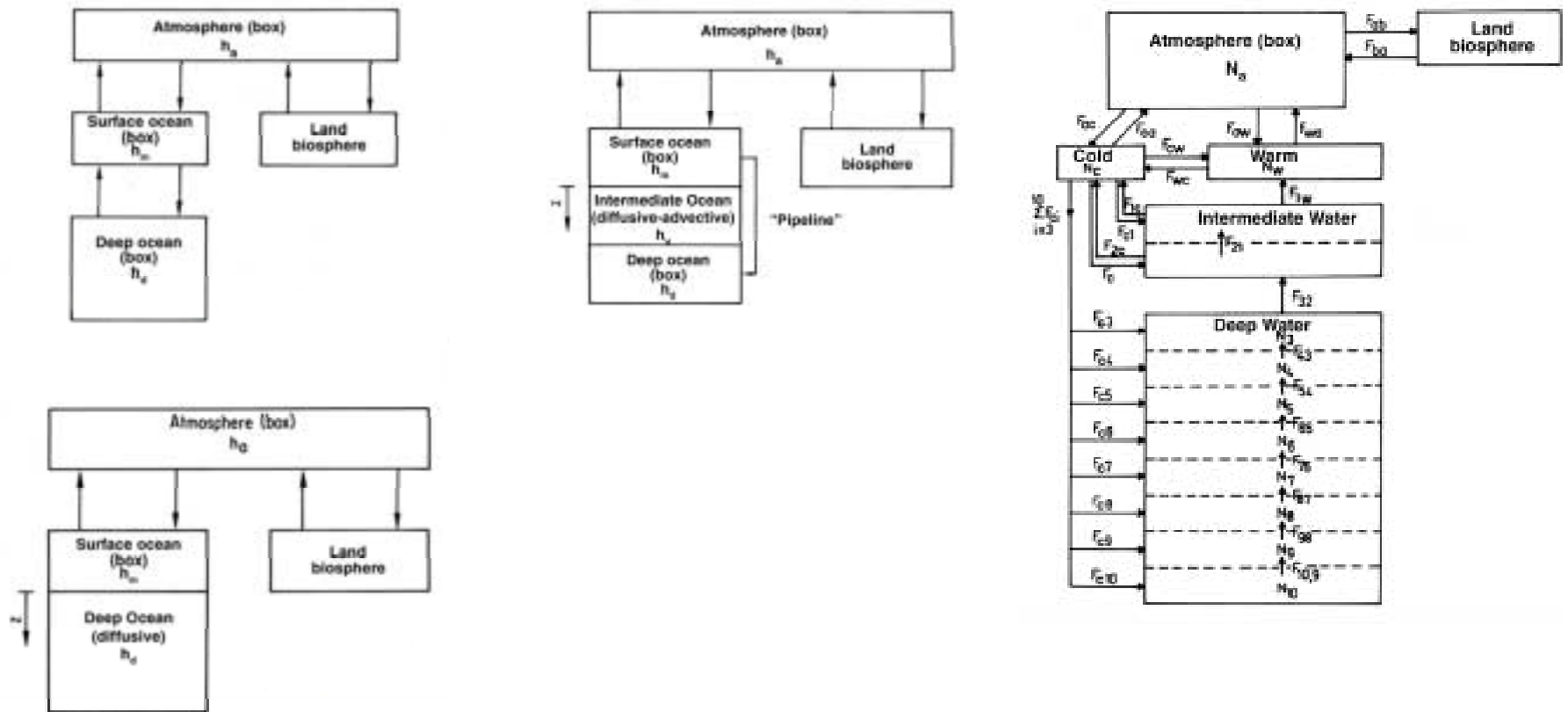
Source: C. D. Keeling and T. P. Whorf; Etheridge *et.al.*; Barnola *et.al.*; (PAGES / IGBP); IPCC



CARBON and the BIOSPHERE



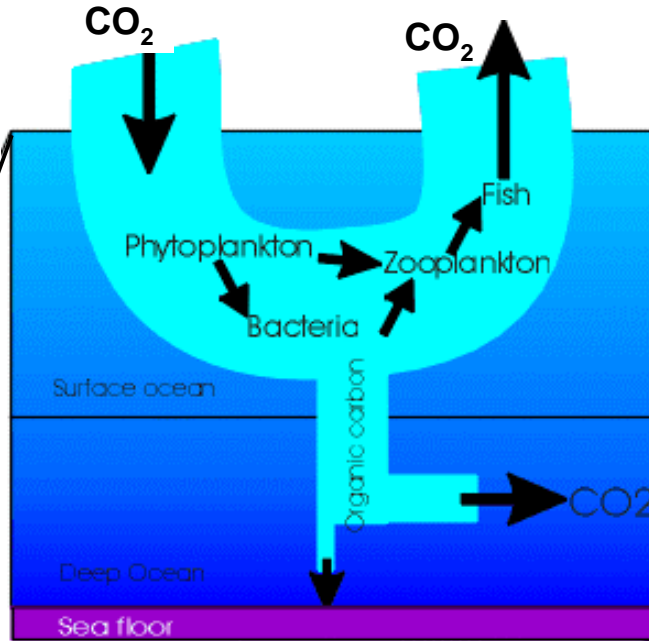
Technical Information Center, Office of Information Services
UNITED STATES ATOMIC ENERGY COMMISSION



Biological Pump

Preindustrial CO₂:

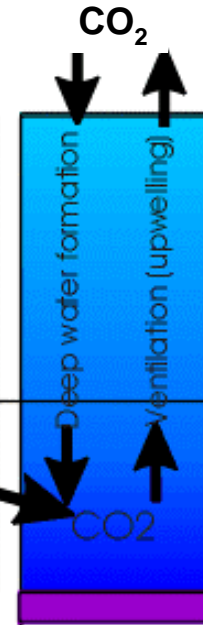
maximum strength bio pump: 160 ppm



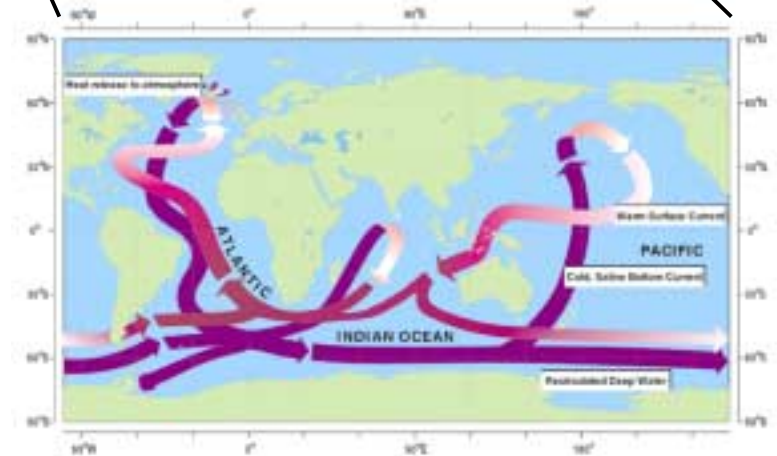
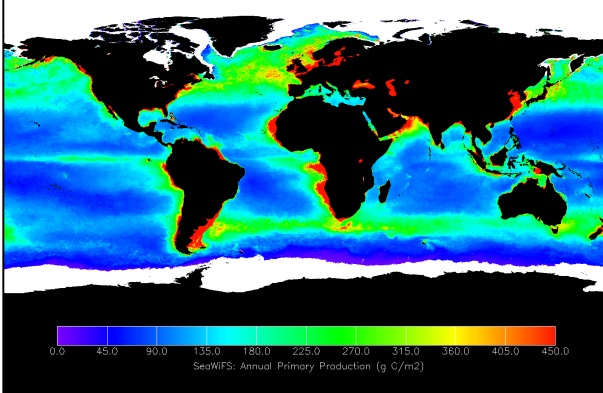
Physical (solubility) Pump

Preindustrial CO₂:

Physical pump alone: 400 ppm

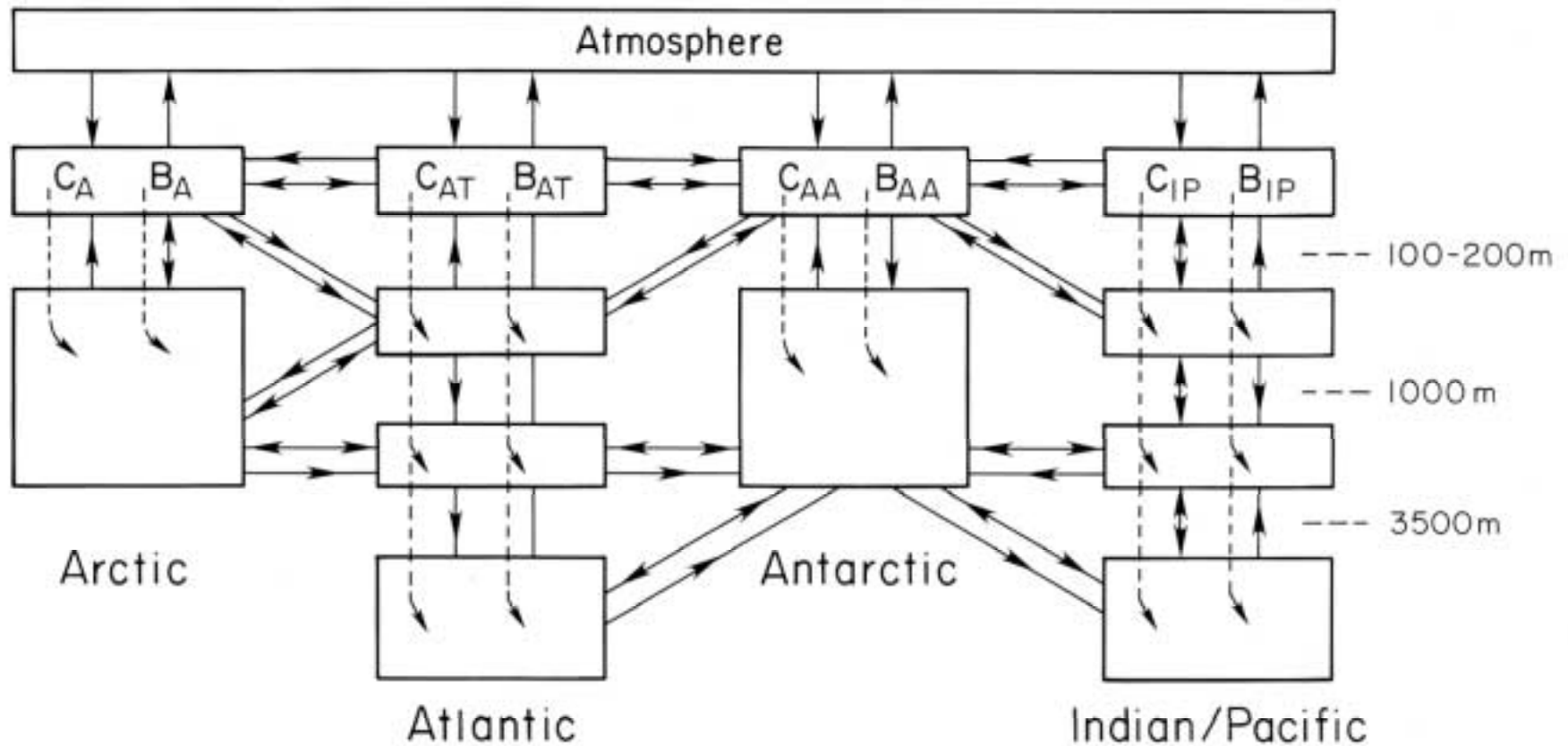


Oceanic Primary Production: Sept. 97 – Aug. 98

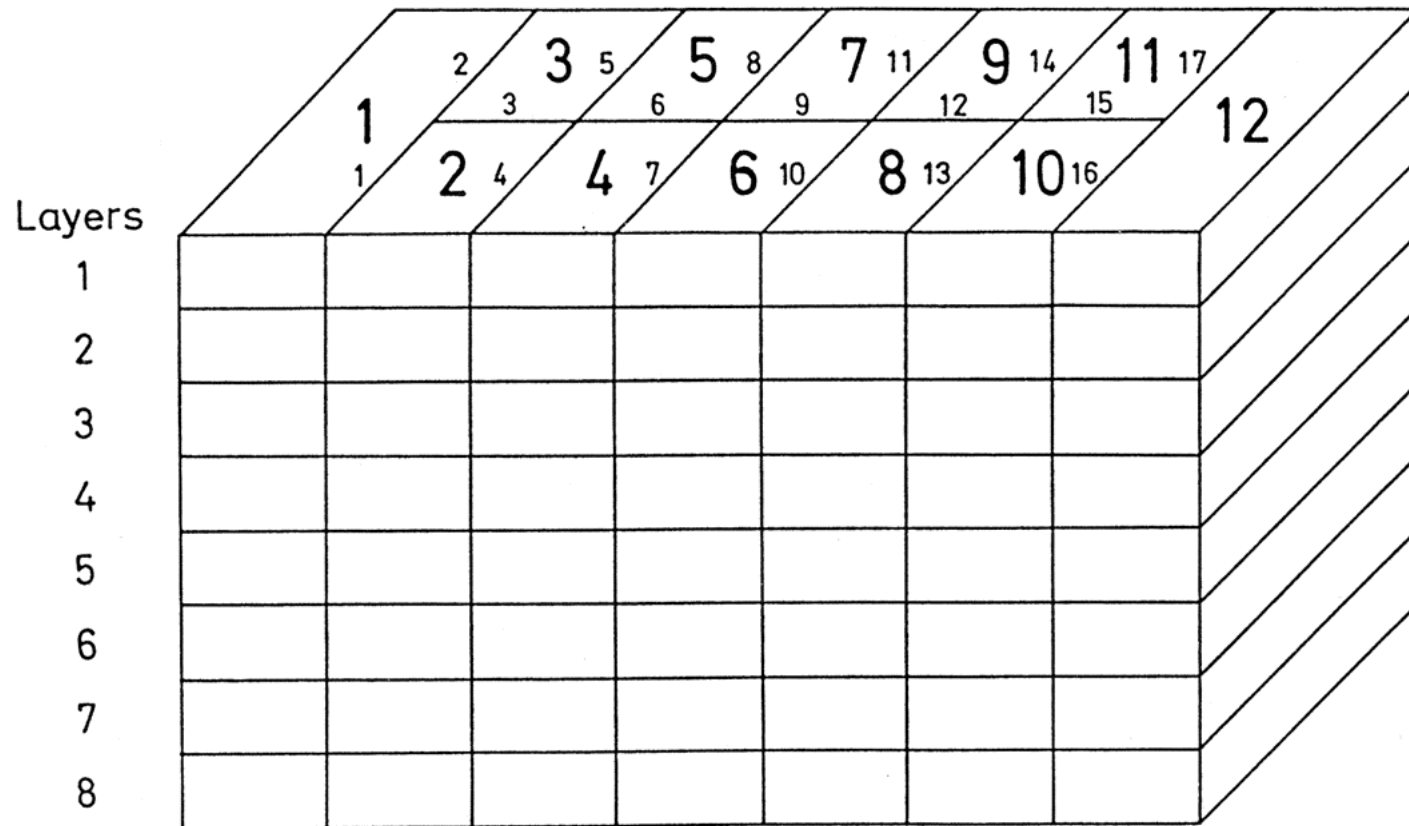


Source: JGOFS / IGBP

12 Box Model of Bolin et al. (1983)

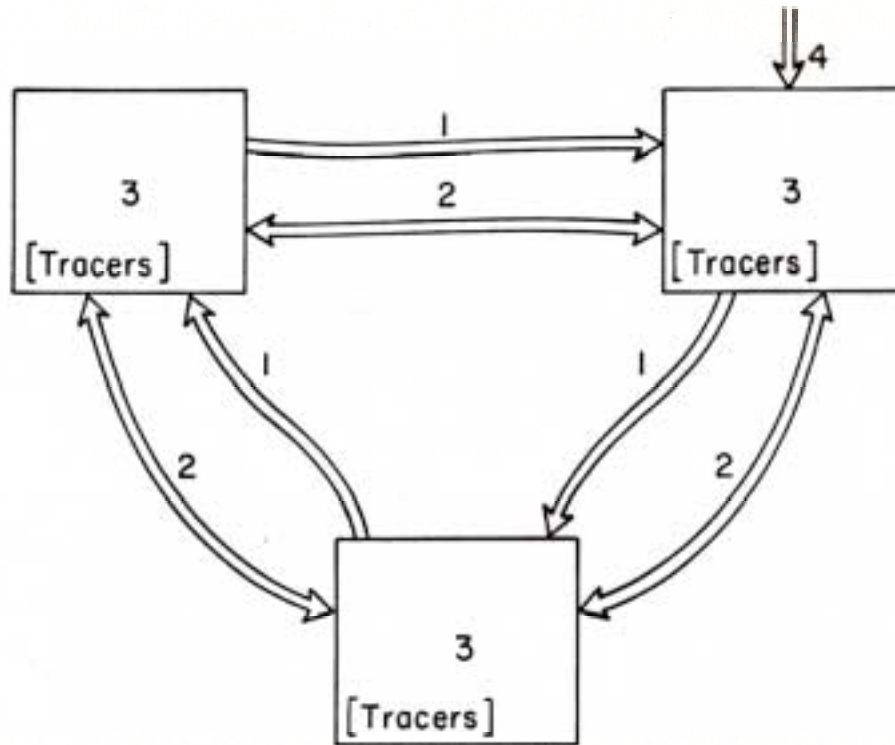






INVERSE METHODOLOGY

Basis: Conservation of “material”



1. Advective flux across internal boundaries (unknown)
2. Turbulent mixing across internal boundaries (unknown)
3. Within box:
 - Radioactive decay (known)
 - Biochemical processes (unknown)
4. Flux across external boundaries (known)

This leads to inverting

$$Ax = b$$

Under constraints

$$Gx \geq H$$

Where $A=(910, 630)$ is one

Badly ill-conditioned, sparse unstructured matrix . . .

**Having lost sight of our objective,
we redoubled our effort . . .**

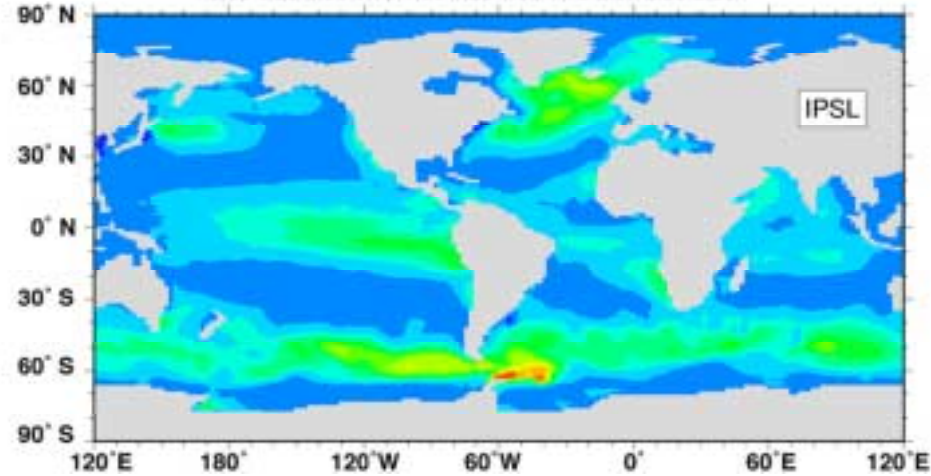
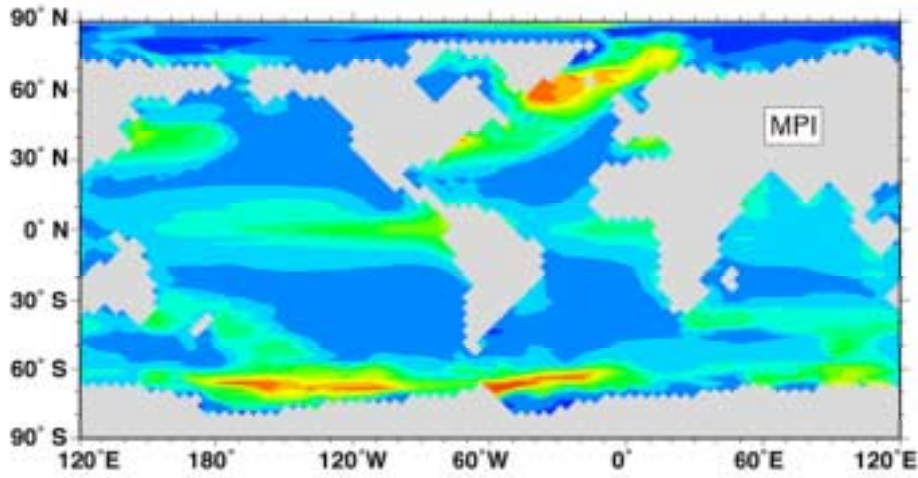
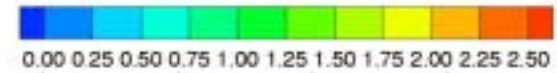
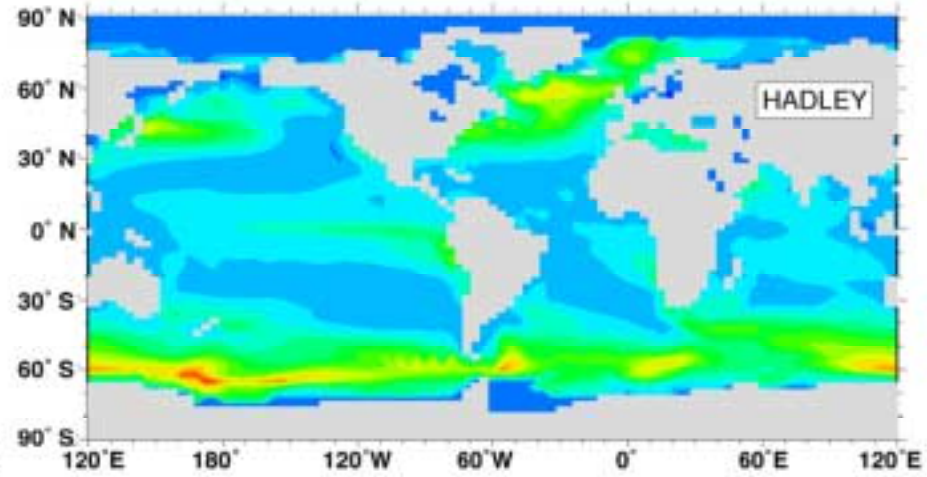
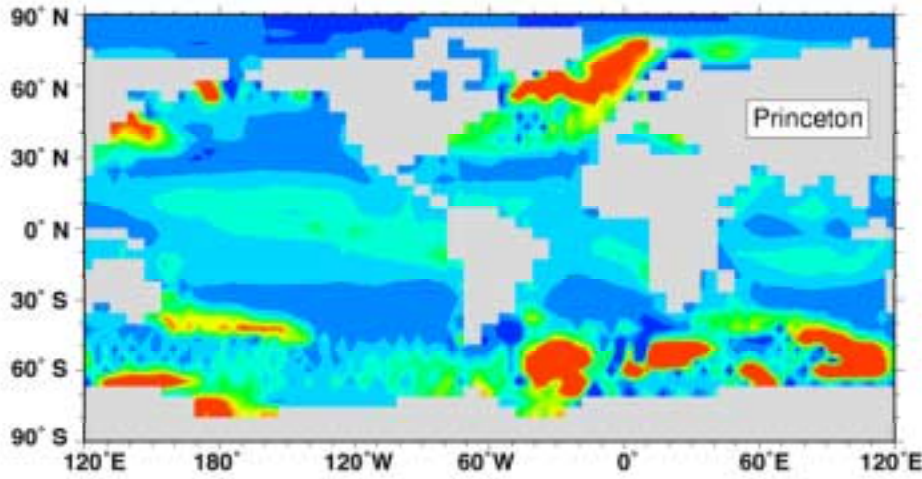
Remembrance of Things Past

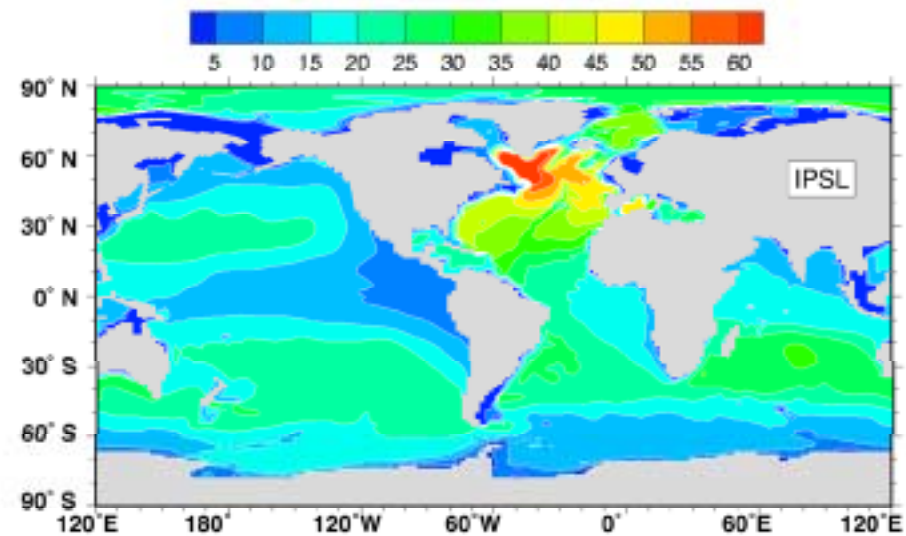
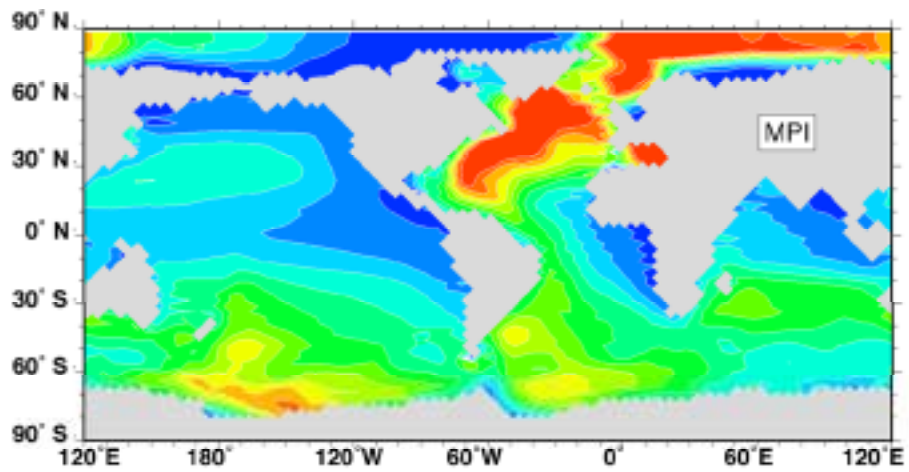
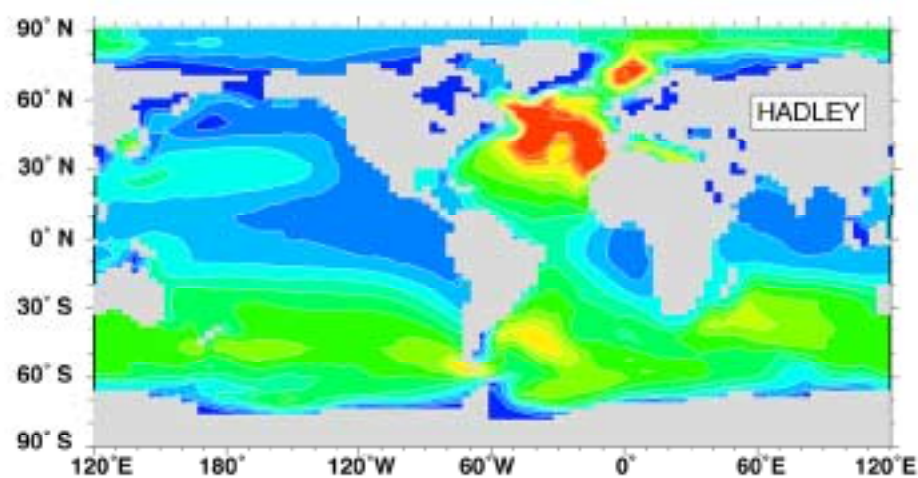
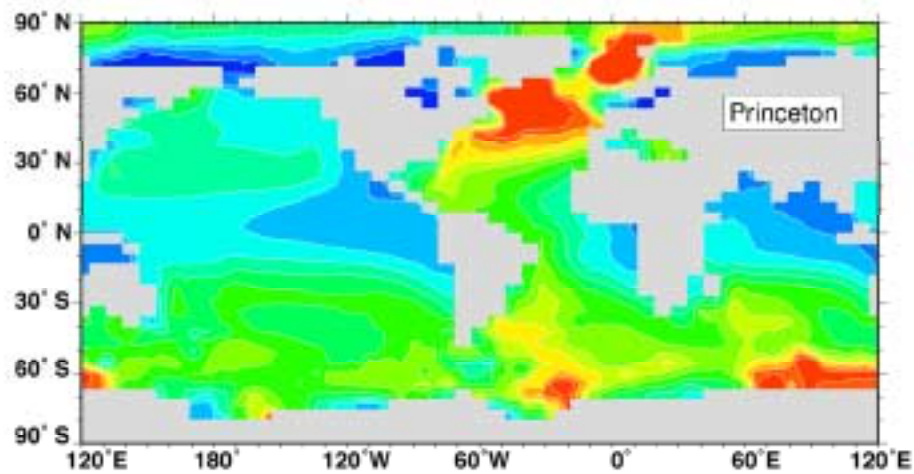
	1970s
Atmospheric increase	3 ± 0.1
Emissions (fossil fuel, cement)	5 ± 0.3
Ocean-atmosphere flux	-2.5 ± 0.3
Land-atmosphere flux	$2 \pm 3??$

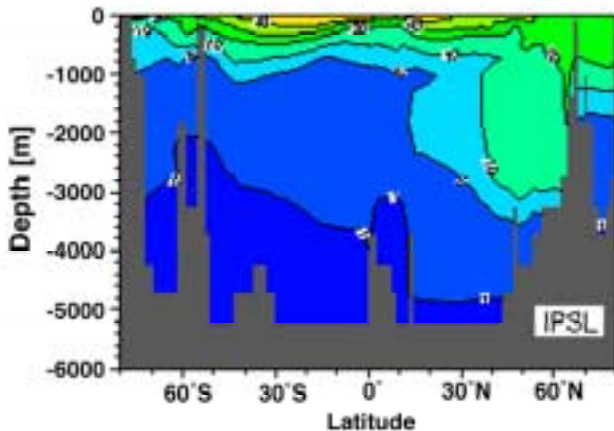
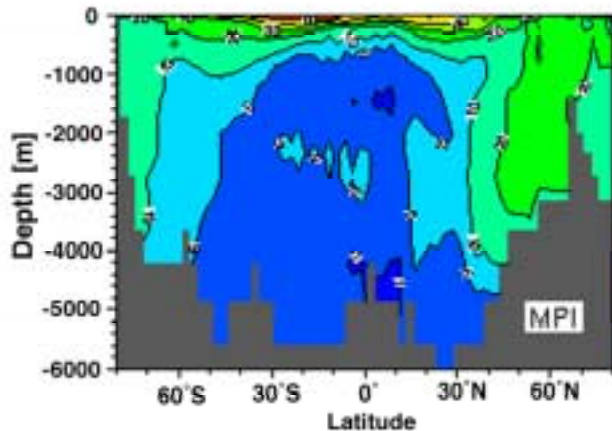
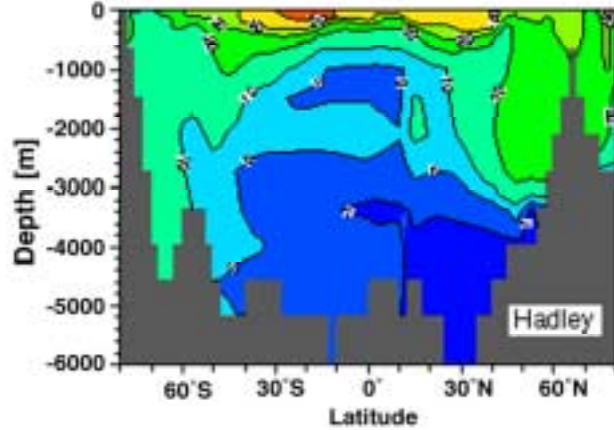
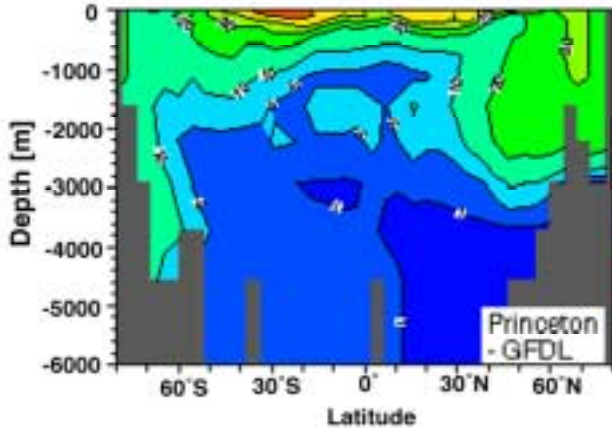
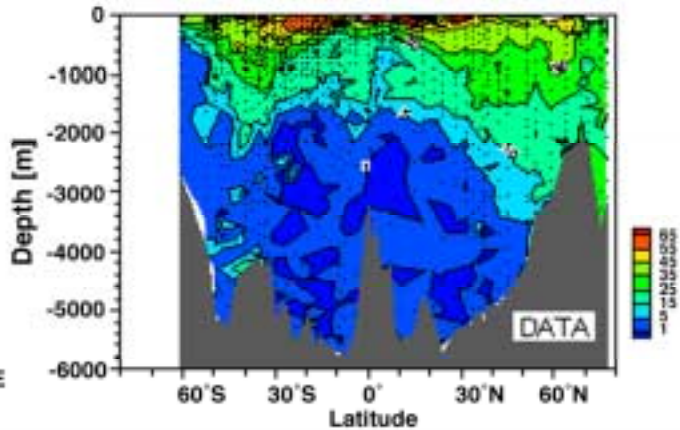
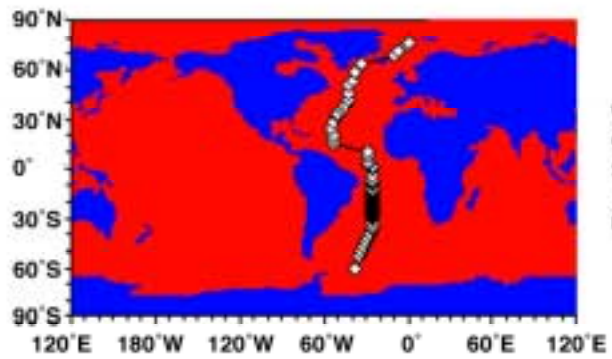
Source: Parchment

	1980s	1990s
Atmospheric increase	3.3 ± 0.1	3.2 ± 0.1
Emissions (fossil fuel, cement)	5.4 ± 0.3	6.3 ± 0.4
Ocean-atmosphere flux	-1.9 ± 0.6	-1.7 ± 0.5
Land-atmosphere flux*	-0.2 ± 0.7	-1.4 ± 0.7
*partitioned as follows		
Land-use change	1.7 (0.6 to 2.5)	N/A
Residual terrestrial sink	-1.9 (-3.8 to 0.3)	N/A

Source: IPCC Third Assessment Report

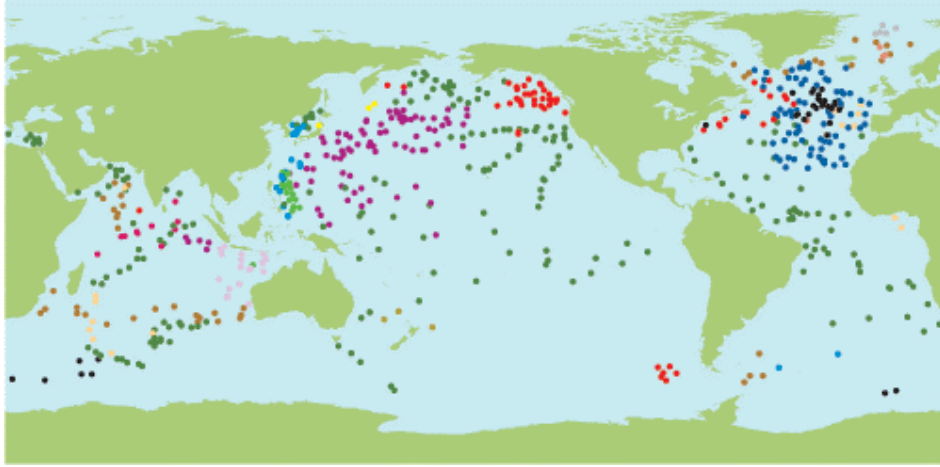








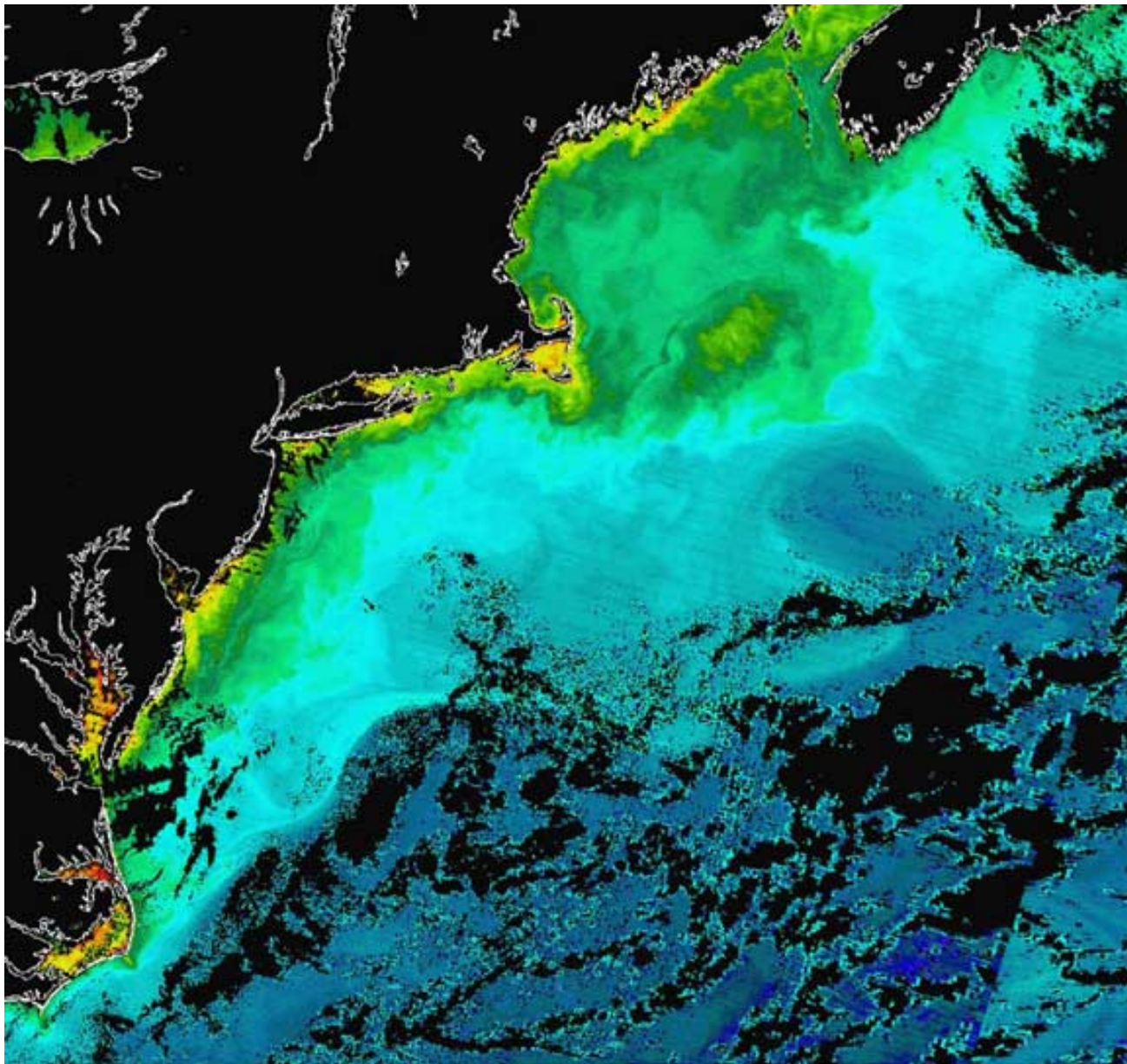
R/V Roger Revelle



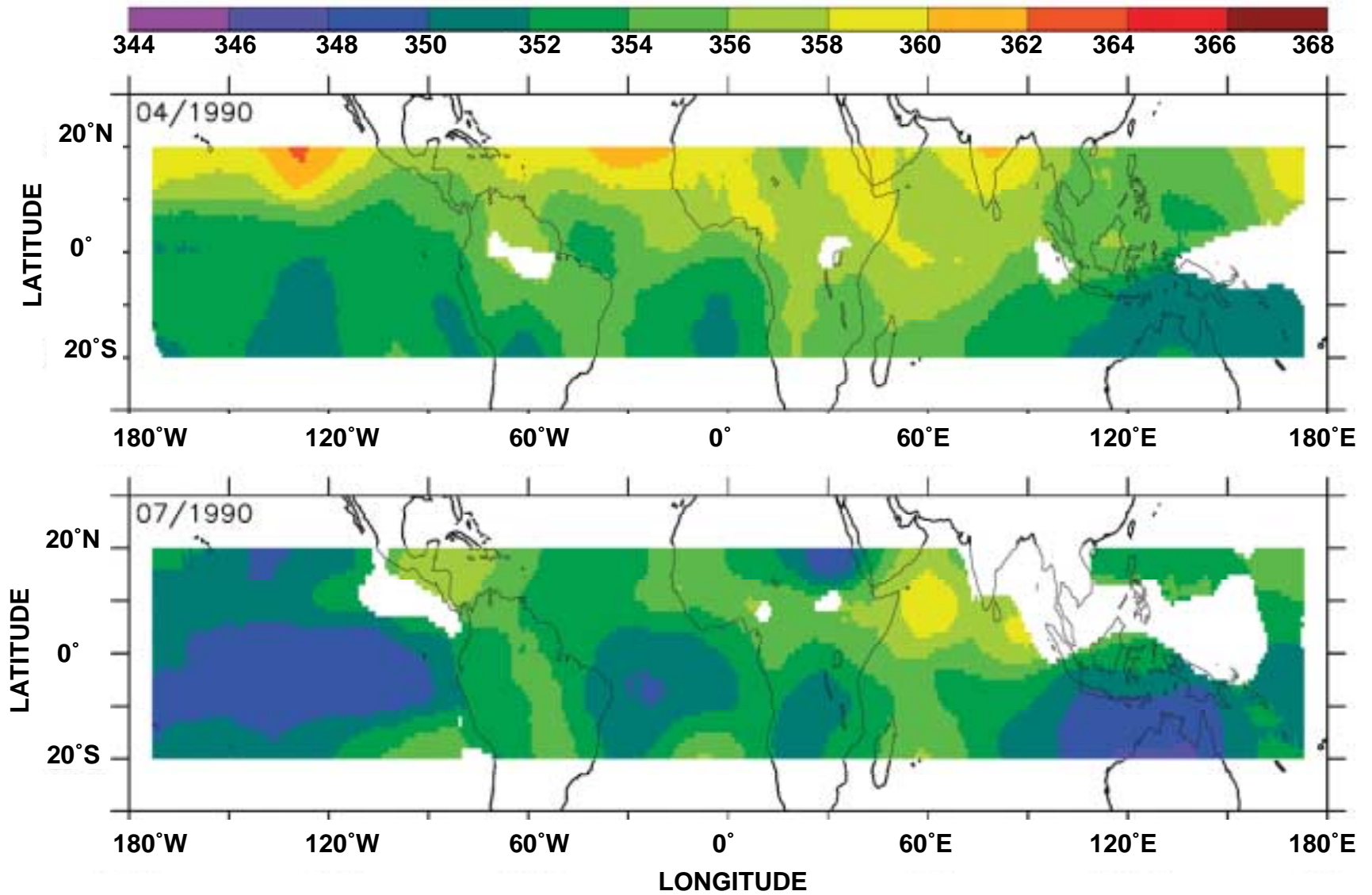
620 ARGO Floats, as of January 2003

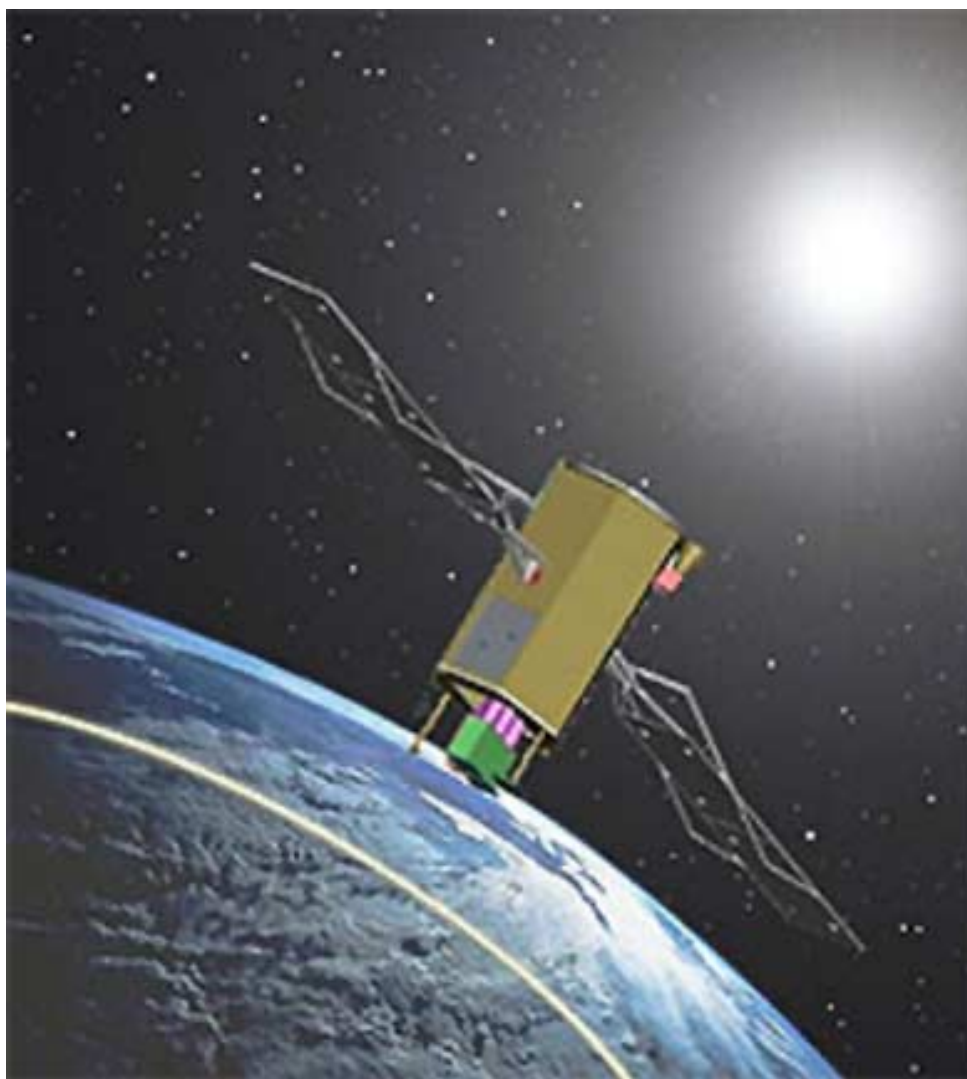


Multi-tiered System

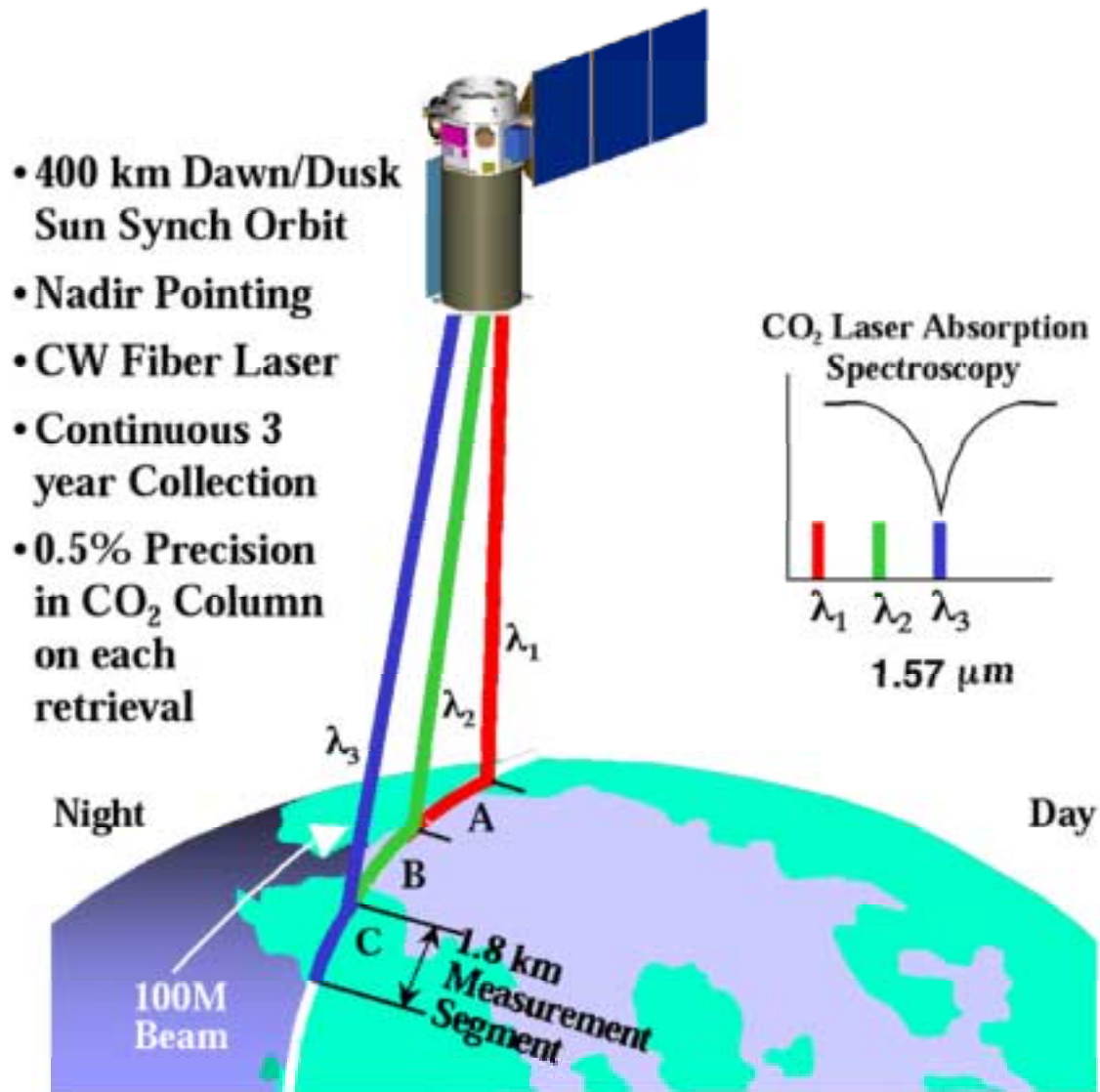


MODIS Ocean Chlorophyll





Orbiting Carbon Observatory - JPL



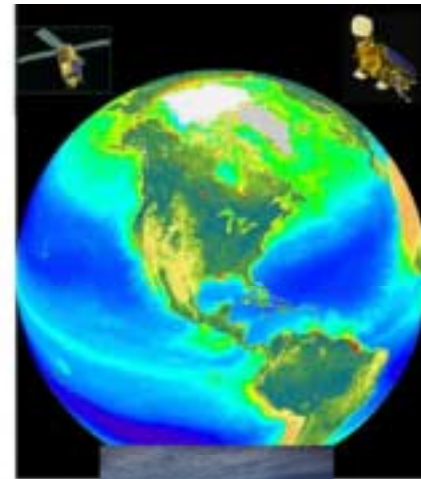
An Active Carbon Dioxide Mission: CELSIUS

The Carbon System

The source and sinks and controlling processes will only be determined within an integrated approach where point-wise *in situ* surface measurements can be scaled up using global satellite datasets and models, **and then constrained and verified by atmospheric CO₂ concentration measurements.**

Approach

Remote Sensing
|
Aircraft Surveys
|
Trans-basin Sections
|
VOS Surface Observations
|
Time-series sites and Moorings
|
Process Studies



Scale

Global

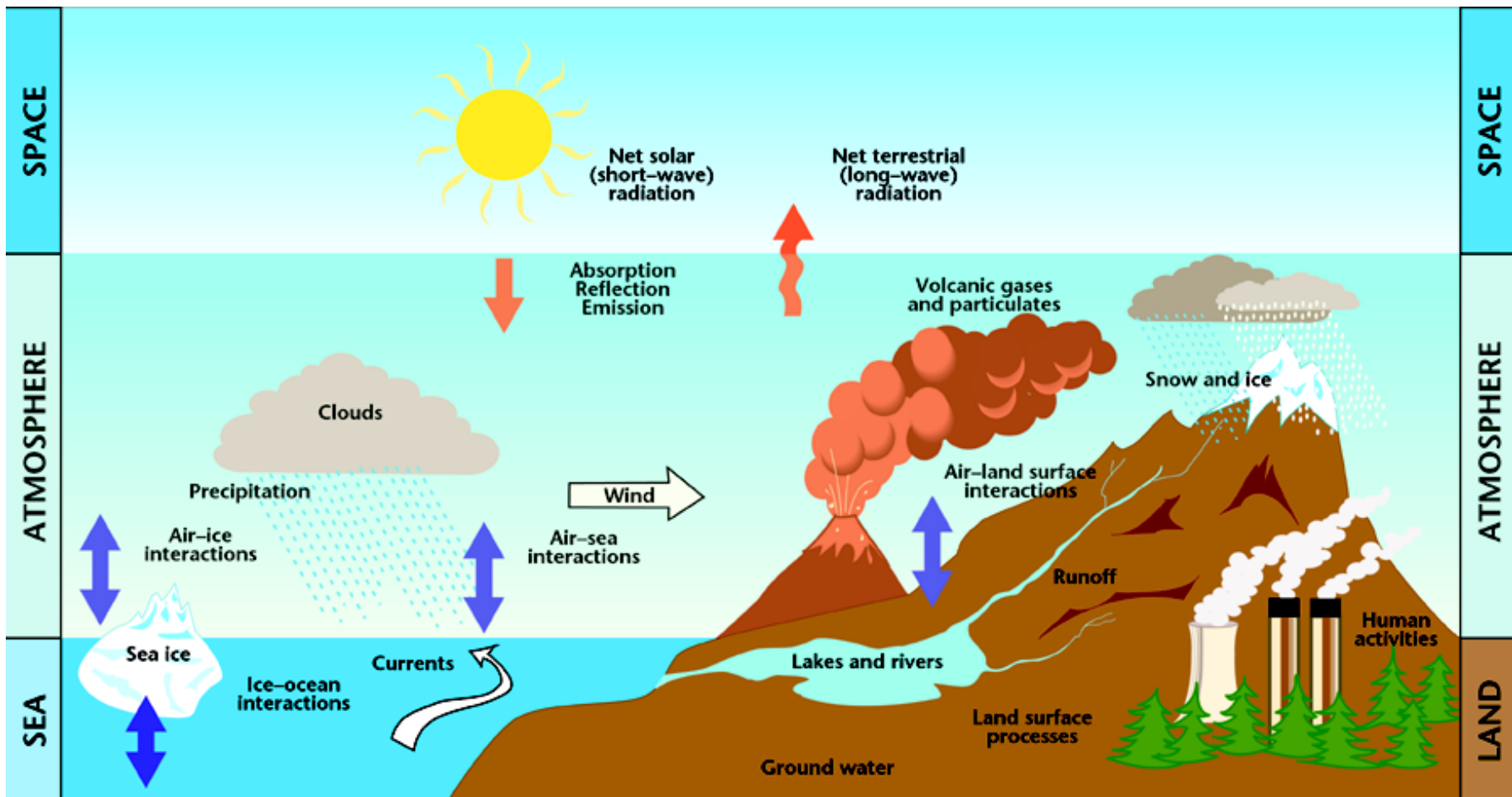
Ocean Basin

Regional

1 km²

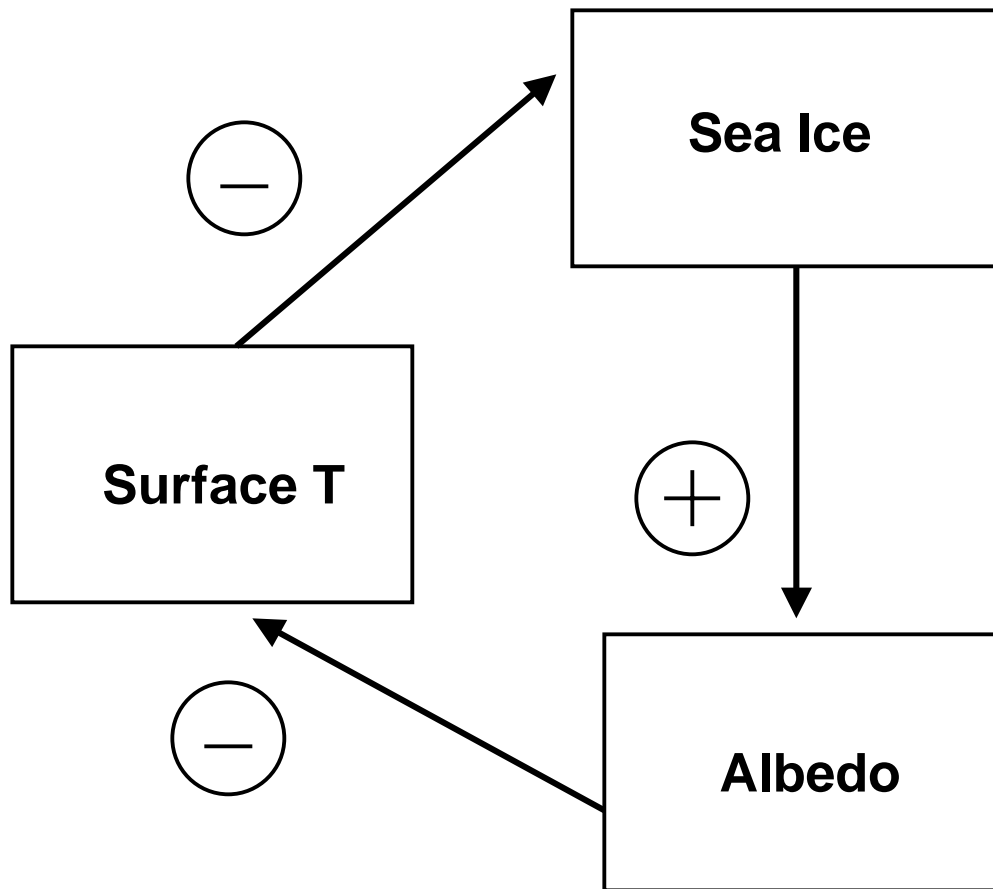
1 m²

A Hierarchy of Approaches and Scales



Source: WCRP



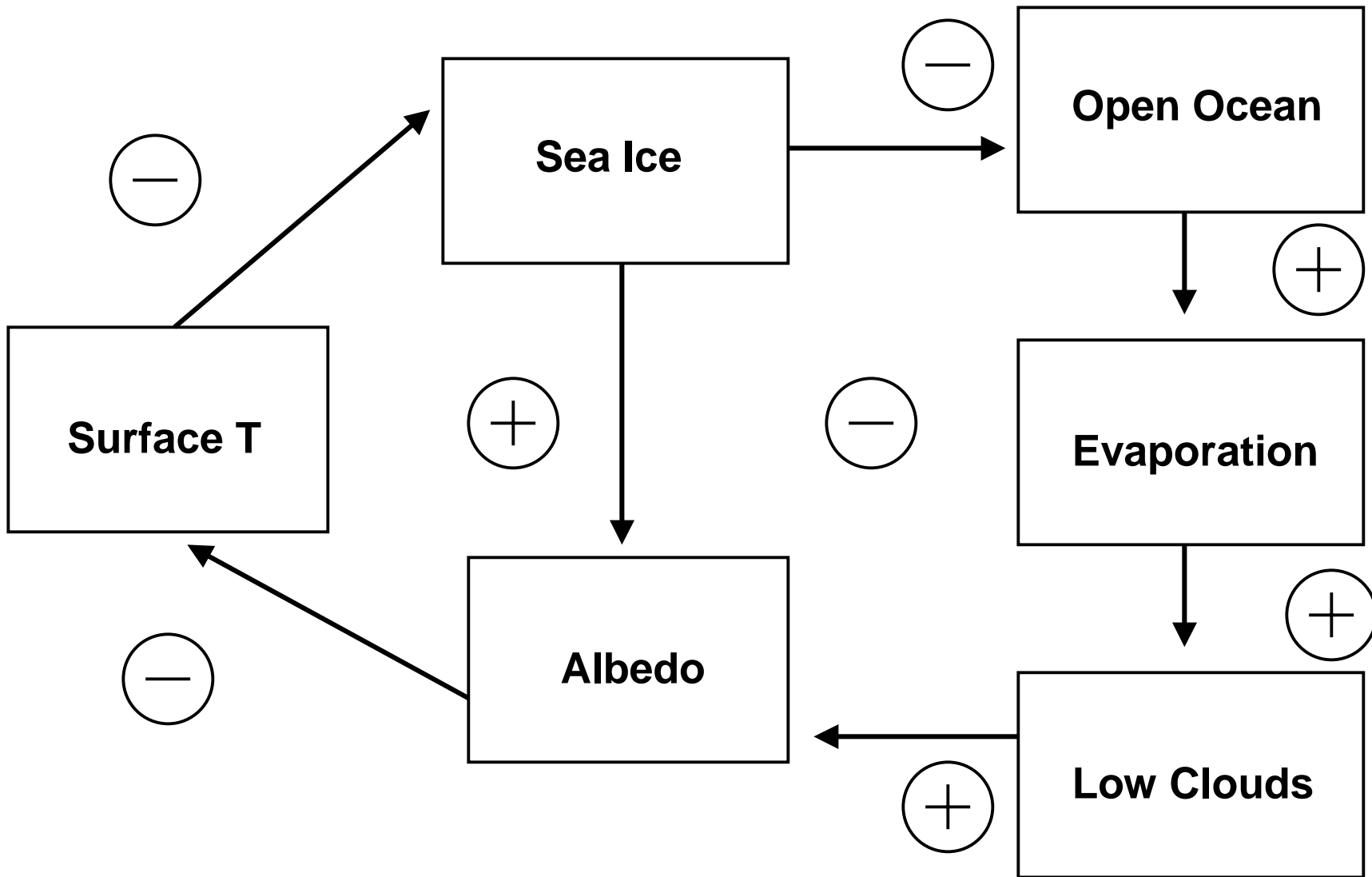


Source: IPCC Third Assessment Report

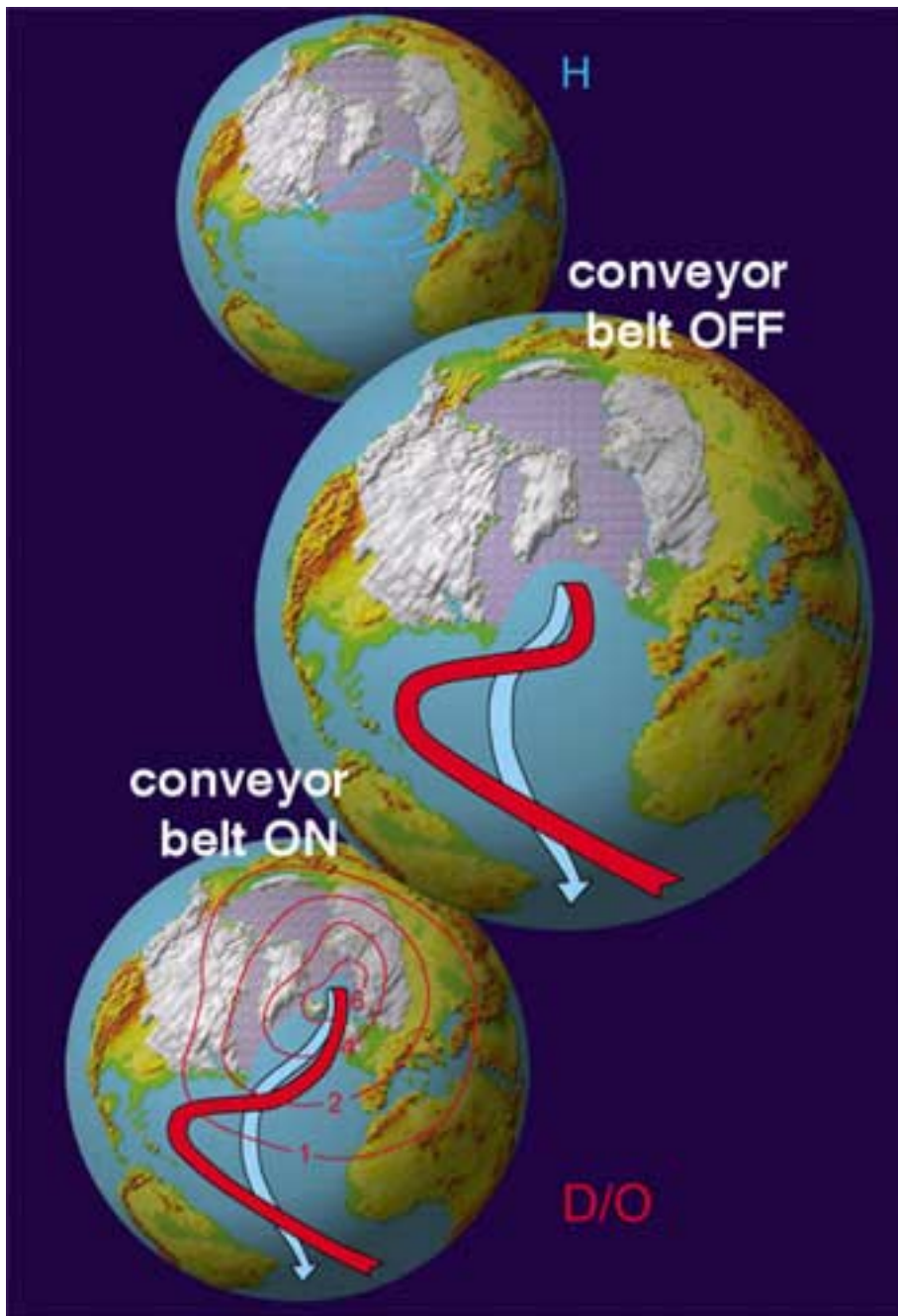




Source: WCRP

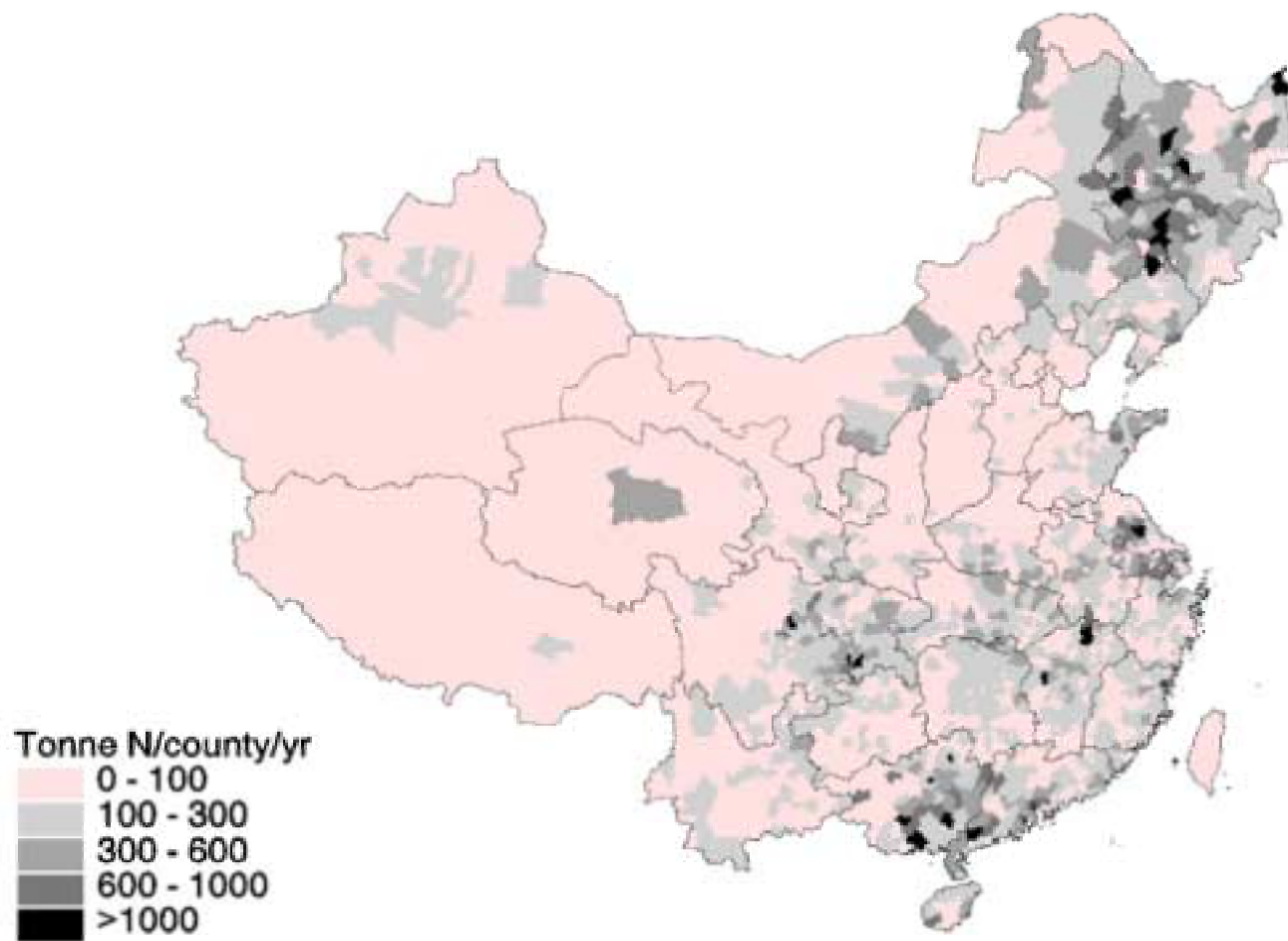


Source: IPCC Third Assessment Report



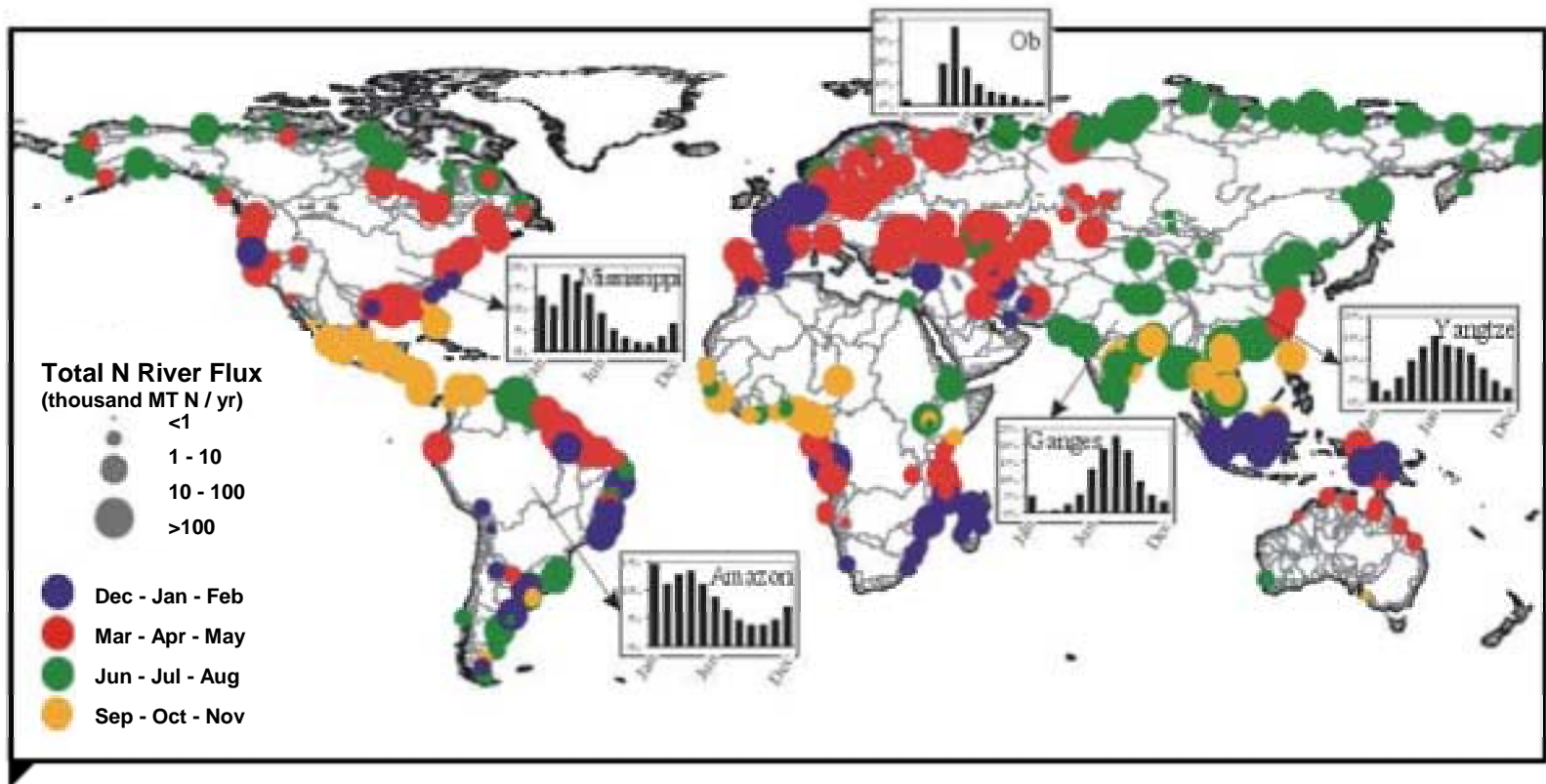
An example of the ocean's impact of climate change: *the switching on and off of the Atlantic thermohaline circulation (THC) causing three different modes of planetary operation during glacial times.*

Rahmstorf (2001) Spek. der Wiss.



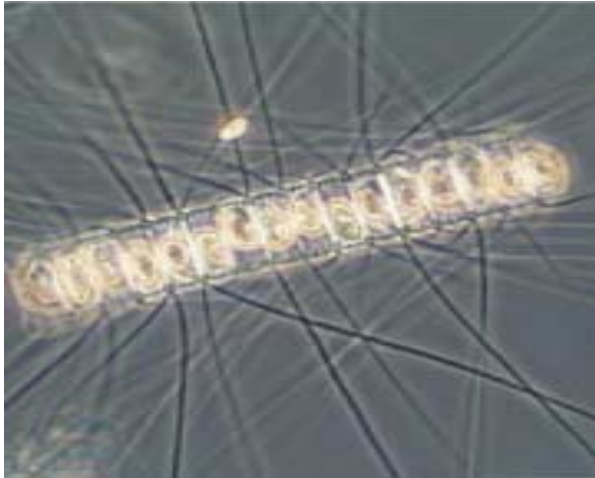






Seasonal fluxes of total N predicted by a non-linear statistical model. A geospecific, aquatic transport model will be used to predict coupled water, sediment, C, and N fluxes through individual gridded river networks at 0.1° (long/lat) resolution as part of this proposed work.

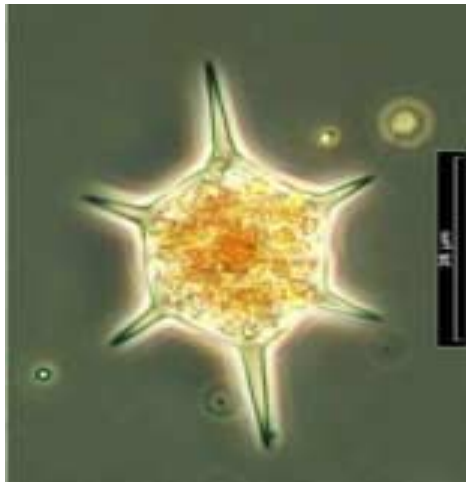
Which consequences have changes in species composition?



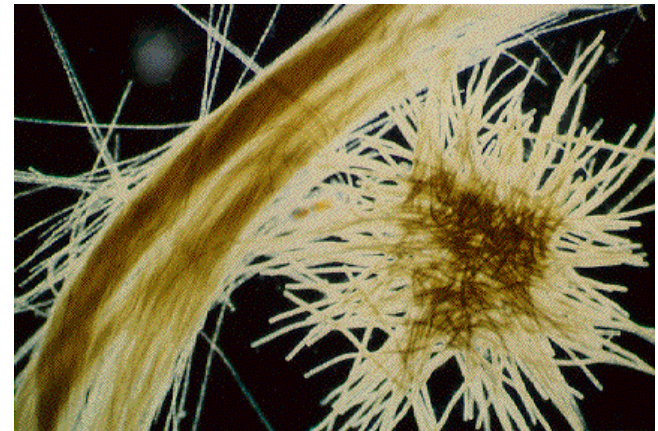
Chaetoceros costatus
(Diatom)



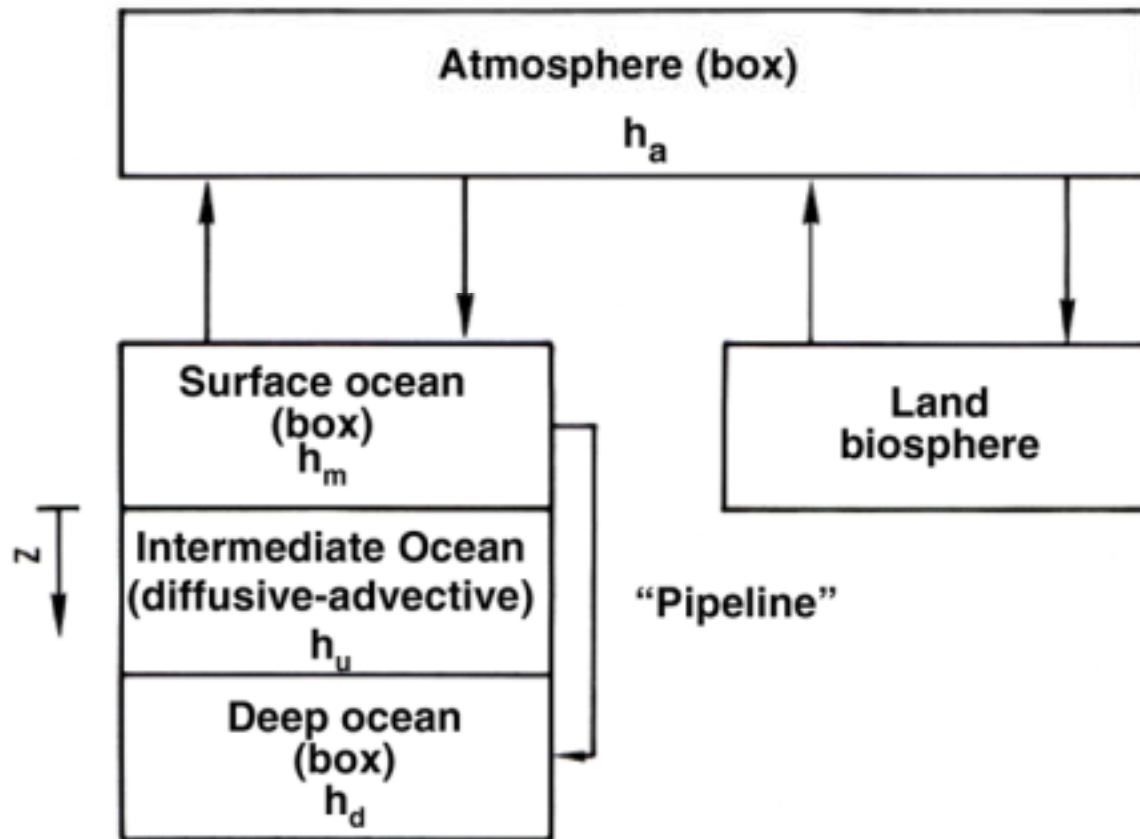
Emiliana huxleyi
(Coccolithophorids)

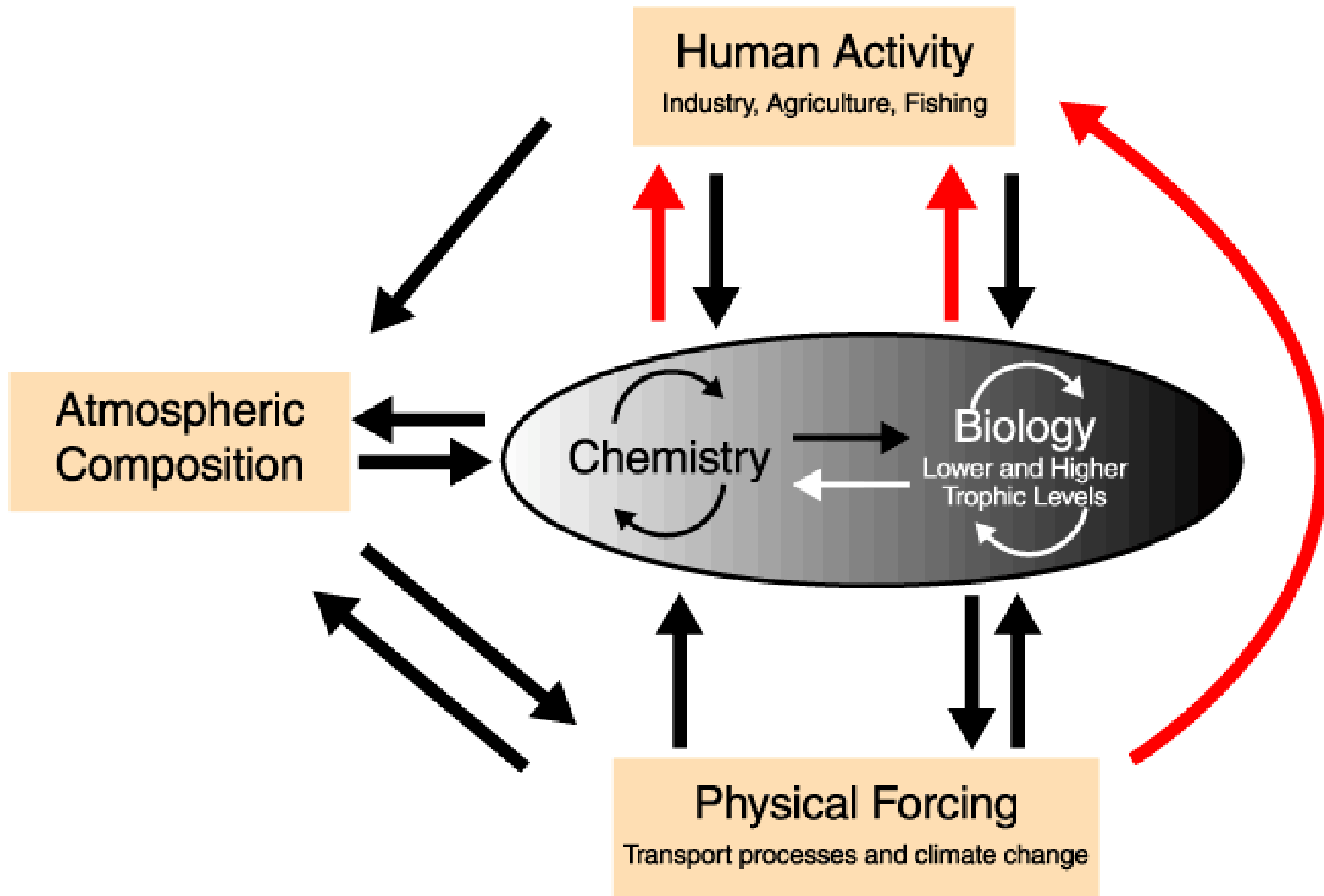


Distephanus speculum
(Silicoflagellate)

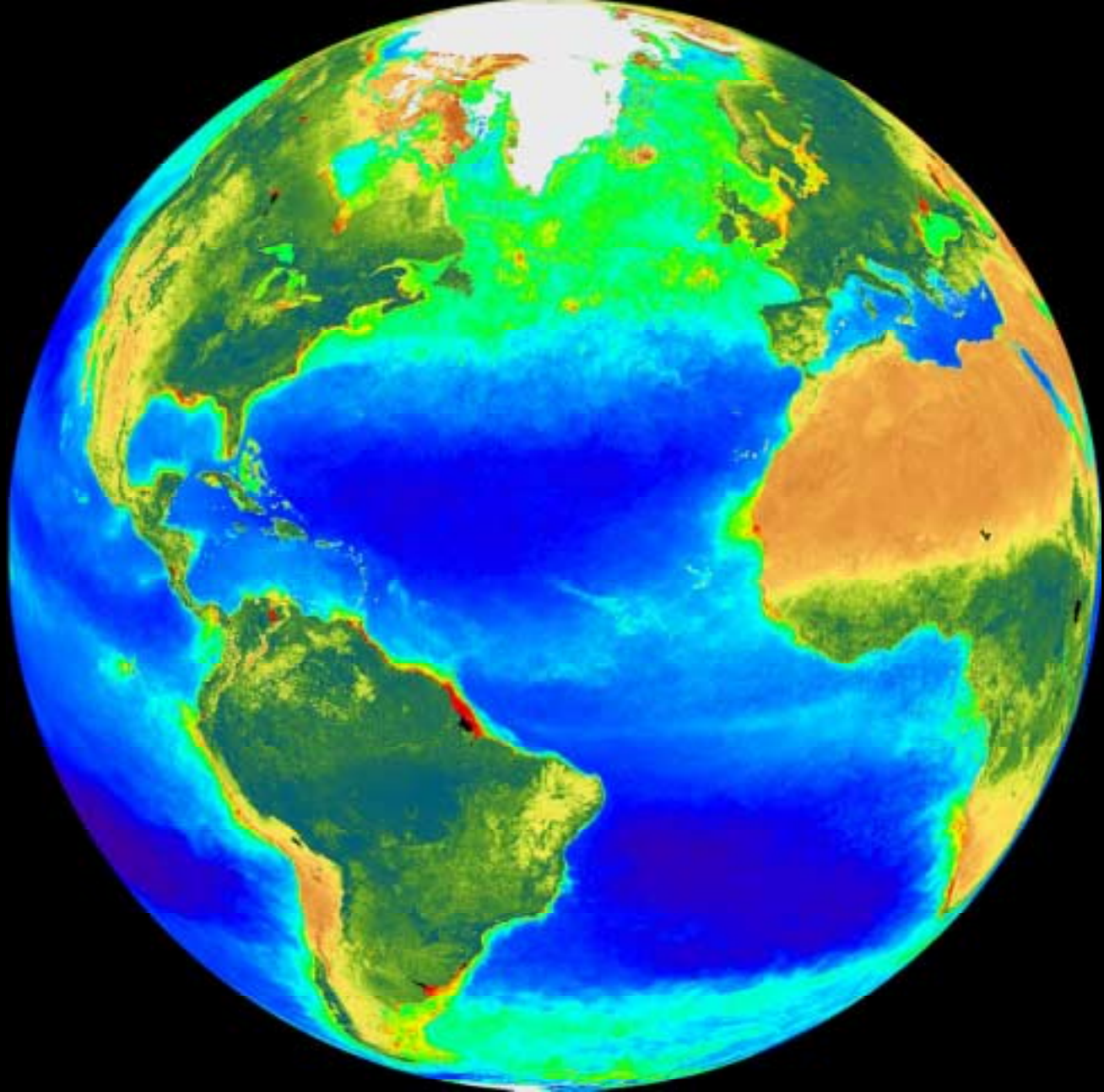


Trichodesmium
(Cyanobacterium)

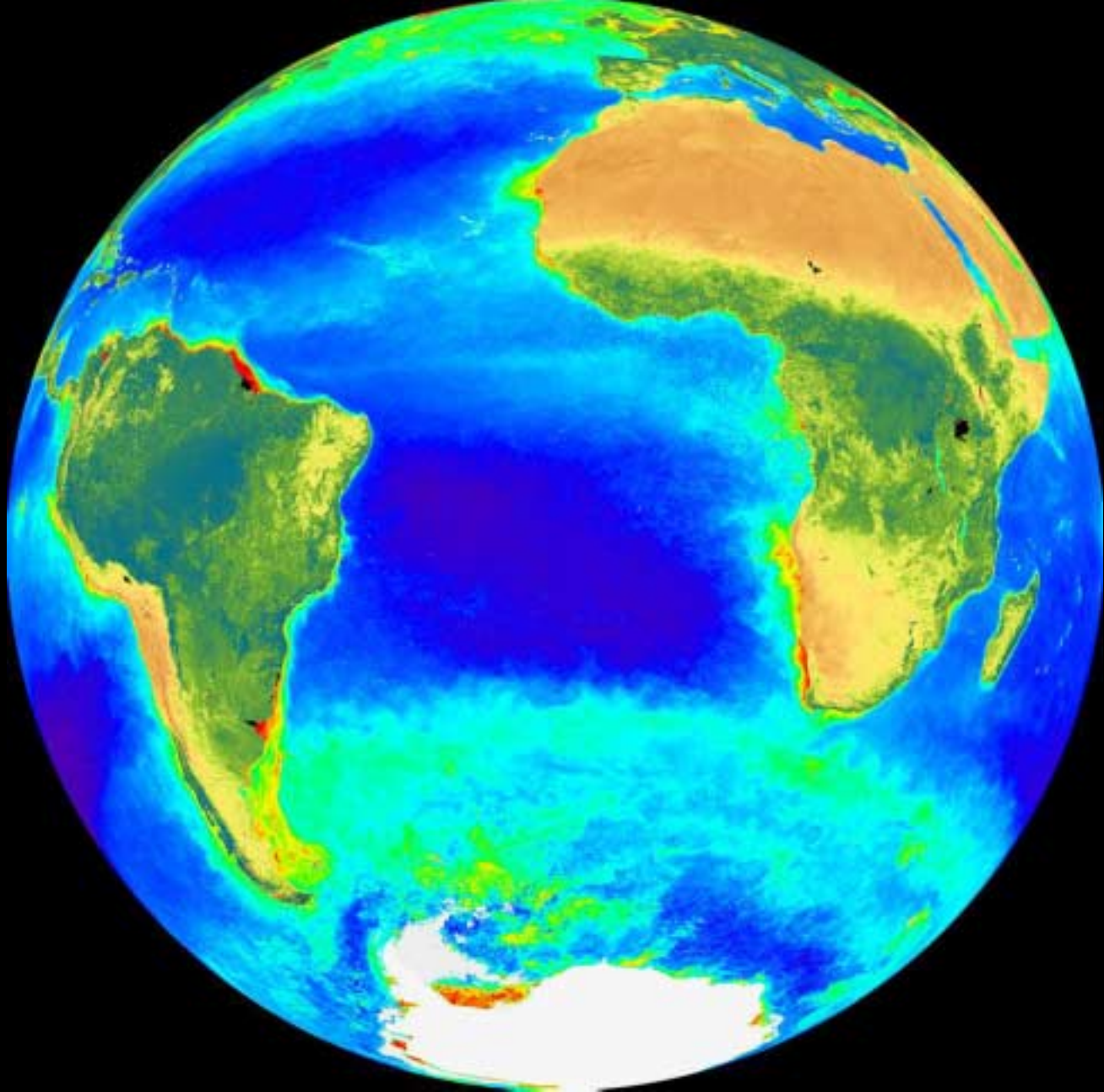




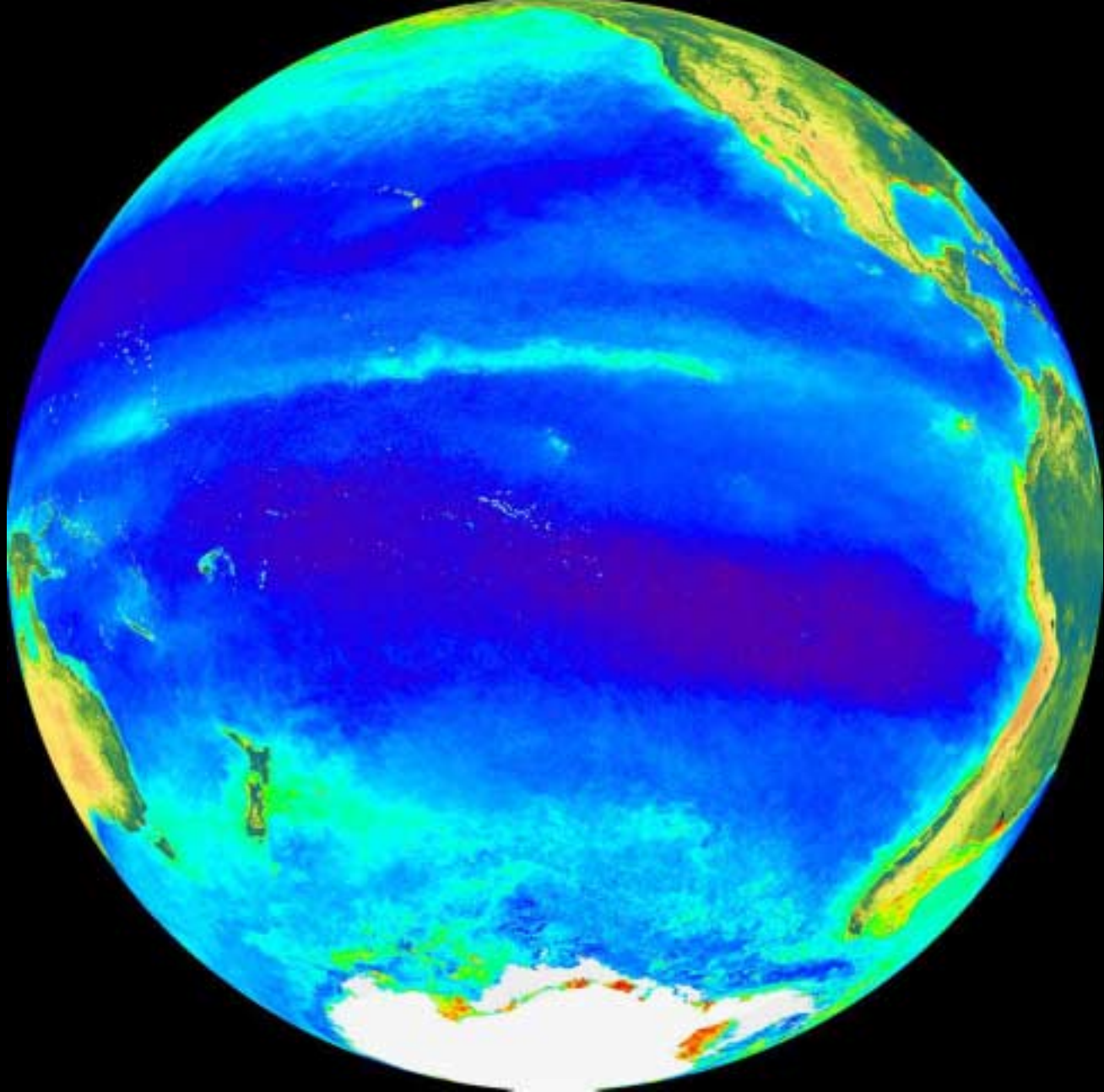
Source: K. Lochte, IGBP/SCOR Ocean Futures Document



Source: SeaWiFS / NASA



Source: SeaWiFS / NASA



Source: SeaWiFS / NASA

