Can Ocean Models Help to Understand the Role of the Ocean in Absorbing Human-Produced Carbon Dioxide?

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Intergovernmental Panel on Climate Change (IPCC):
[the 4th report (AR4) in 2007 won the Nobel Peace Prize]

- Climate change over last 50 years as “unequivocal”

- Changes are 95% likely to be the result of human activity

The report predicted serious negative consequences if we continue to increase CO_2 concentrations in the atmosphere

It is important to understand the types of tools that are currently being used by the climate research community to study this problem

Generally speaking, there are two groups of climate researchers:

- **Observational community: collect data at sea, etc.**
- **Modeling Community (construction and use of climate models)**

In fact both groups use models and data, but in distinct ways.

Other speakers at this symposium have focused on the work of the first group

I would like to convey the way in which the second group contributes to climate research

Earth System Models: used to understand climate change

- Best thought of as consisting as a number of sub-models that represent:

  Physical processes (ocean and atmosphere each as a separate model); These models have at their core "physical laws", such as Newton's Law (F=ma)

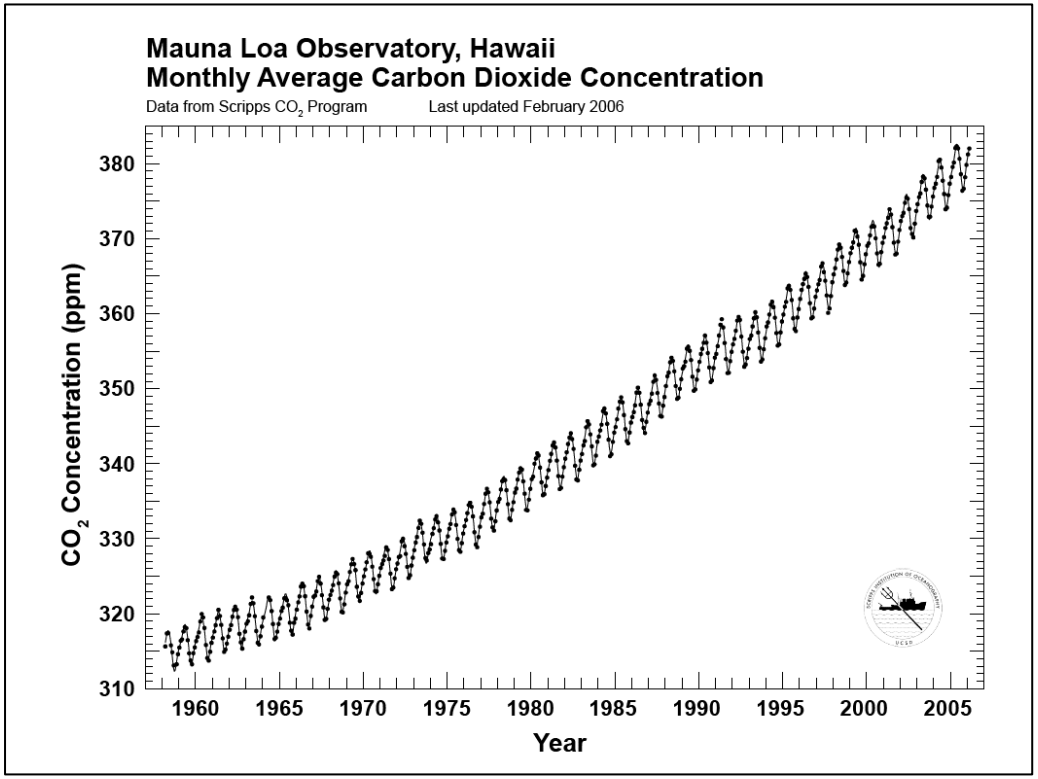
  Ecosystem Models/Carbon cycle models (ocean/land treated separately):
  Building models of biological systems is very difficult!
  As a result of our lack of understanding, these models have less "skill" than dynamical models

- In contrast to "statistical models" used by observational community, Earth System Models try to capture the real physical cause of relationships between component systems and variables

Why do we need models?

Can't we understand future climate change based on work of observational community?

- Consider changes in atmospheric CO_2 recorded at Mauna Loa (Hawaii) over the time interval since 1959:



- Can ask question: given that temperatures have changed 0.5-1.0° C over a time interval where atmospheric CO_2 concentrations have increased by 70 ppm over 50 years, doesn't this give us a way to predict how climate will change if atmospheric CO_2 increases by (for example) 140 ppm over the next 50 years?

The Earth System should be assumed to be “nonlinear”

- **For “linear” systems, multiplying the perturbation by a factor of two results in the amplitude of the response being twice as large**

  For example, by Newton’s Law (F=ma), a train will accelerate twice as fast if the locomotive exerts twice the force in pulling the train (ignoring friction etc.)

- **It is known that there are a great number of “nonlinear” processes in the different components of the Earth System, and thus the climate system needs to be treated in general as a nonlinear system**

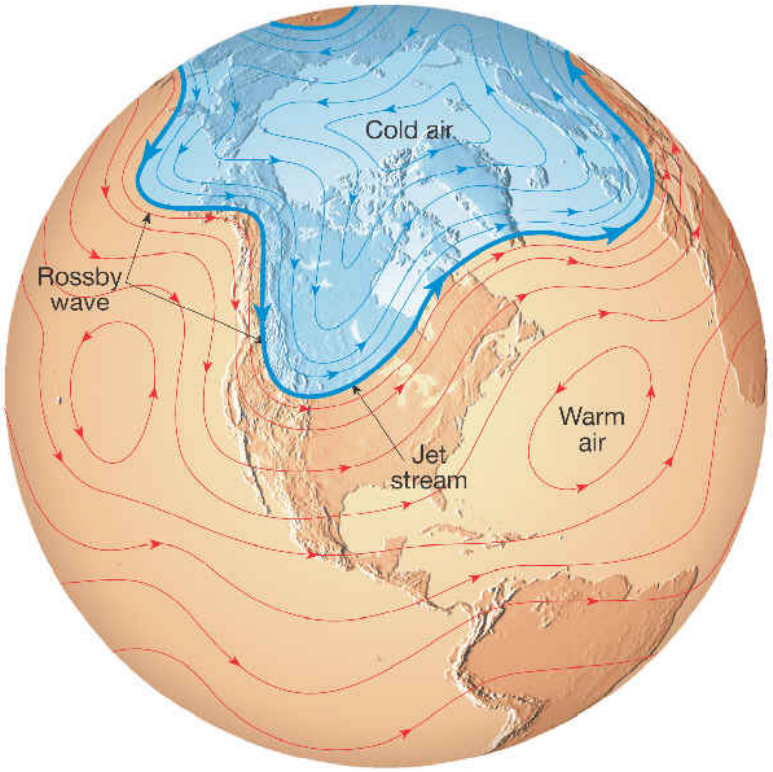
  For example, increasing atmospheric CO_2 concentrations by 70ppm from current values could lead to changes larger than 1° C

Thus "Earth System Models" are recognized as being critical part of climate research, and Earth System Models are being developed at a number of climate centers in response to the understanding gained through the IPCC process

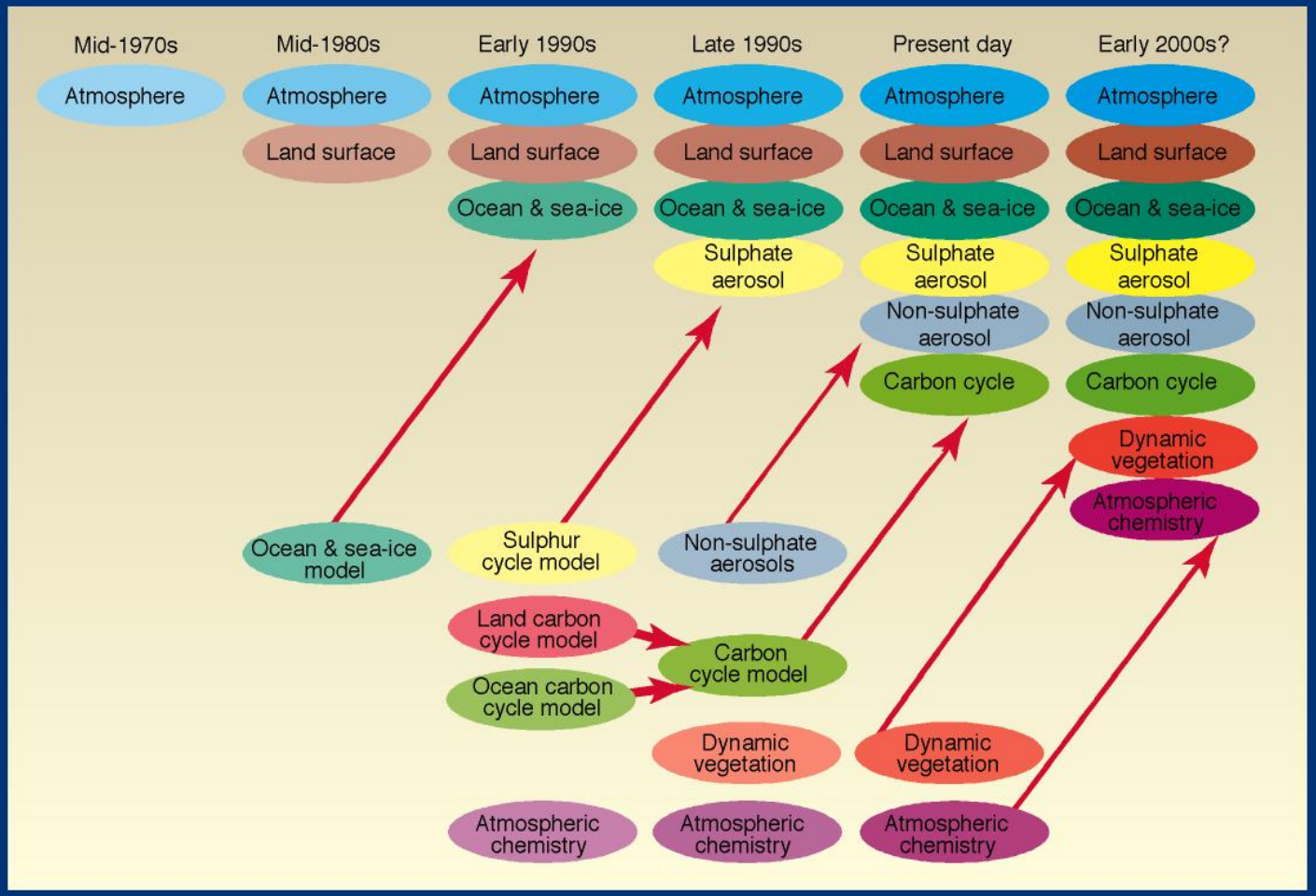
- **Historically numerical models first focused on "weather prediction" (1950s-1960s)**

Demonstrated clearly the key role of "waves" in determining the behavior of atmosphere for *weather*;

Subsequent work has demonstrated conclusively that related wave behavior in both the ocean and the atmosphere is critical to understanding El Nino (*climate* variability)



The development of climate models, past, present and future



WG1 - TS BOX 3
FIGURE 1

Three dimensional models: physical

Models of the physics of the atmosphere and the ocean are typically defined on a three dimensional “lattice” structure

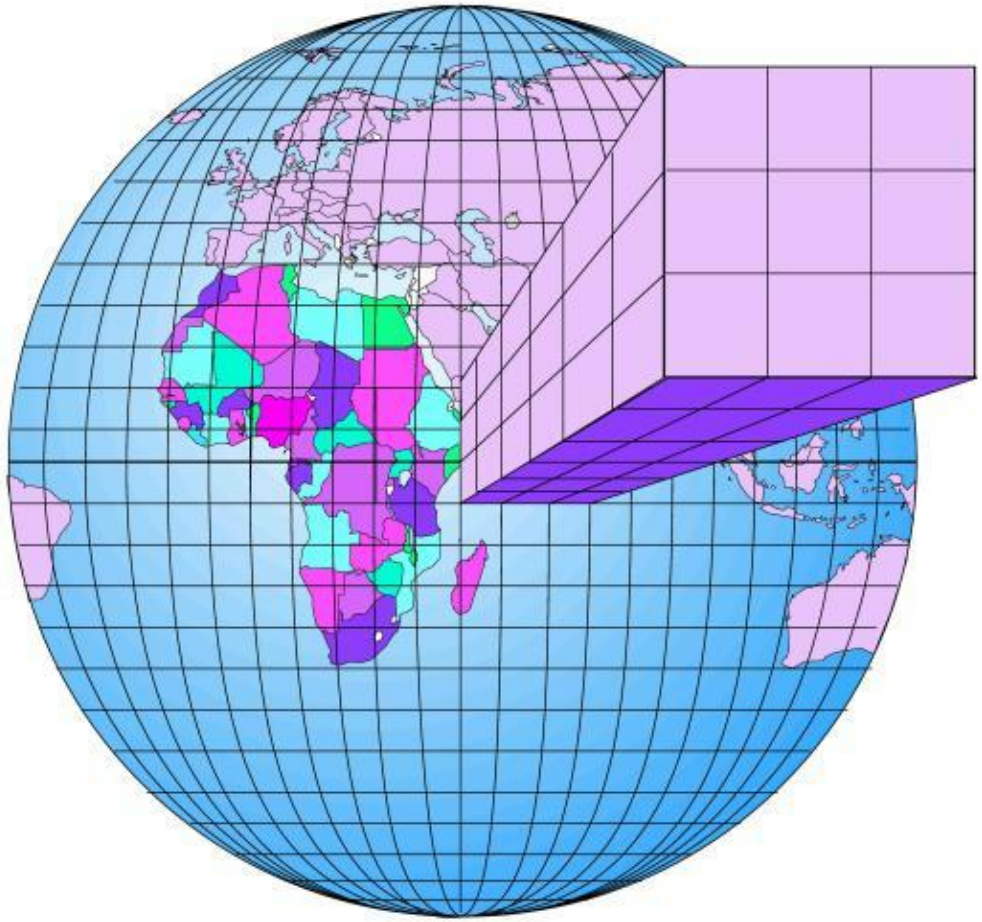
This may consist for each medium (ocean and atmosphere) of

- **40 levels (boxes)**
- **180 latitudinal boxes**
- **360 longitudinal boxes**

and thereby

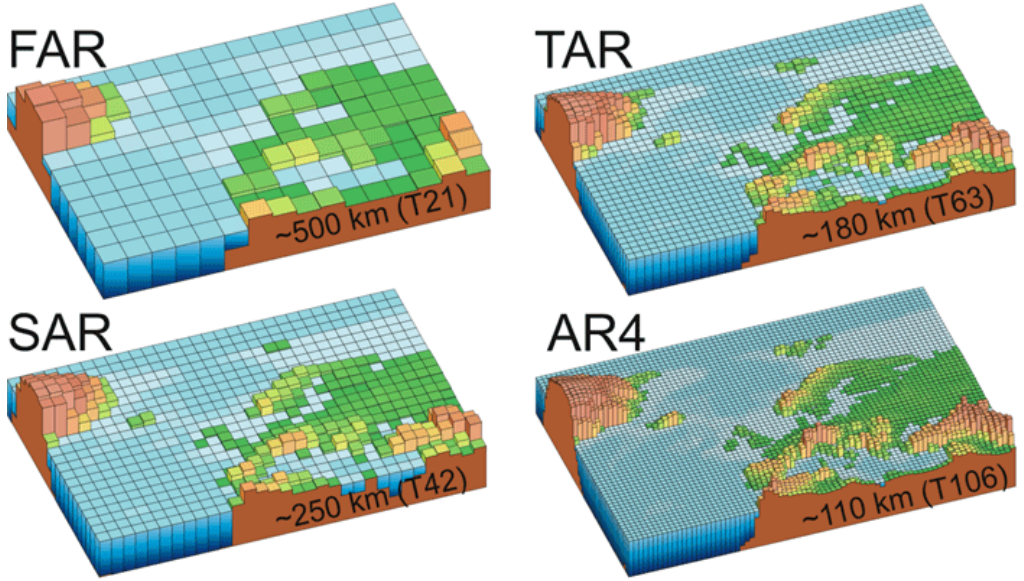
40x180x360=2.5 million boxes !!!

Using such models requires computers significantly larger than consumer laptops/desktops

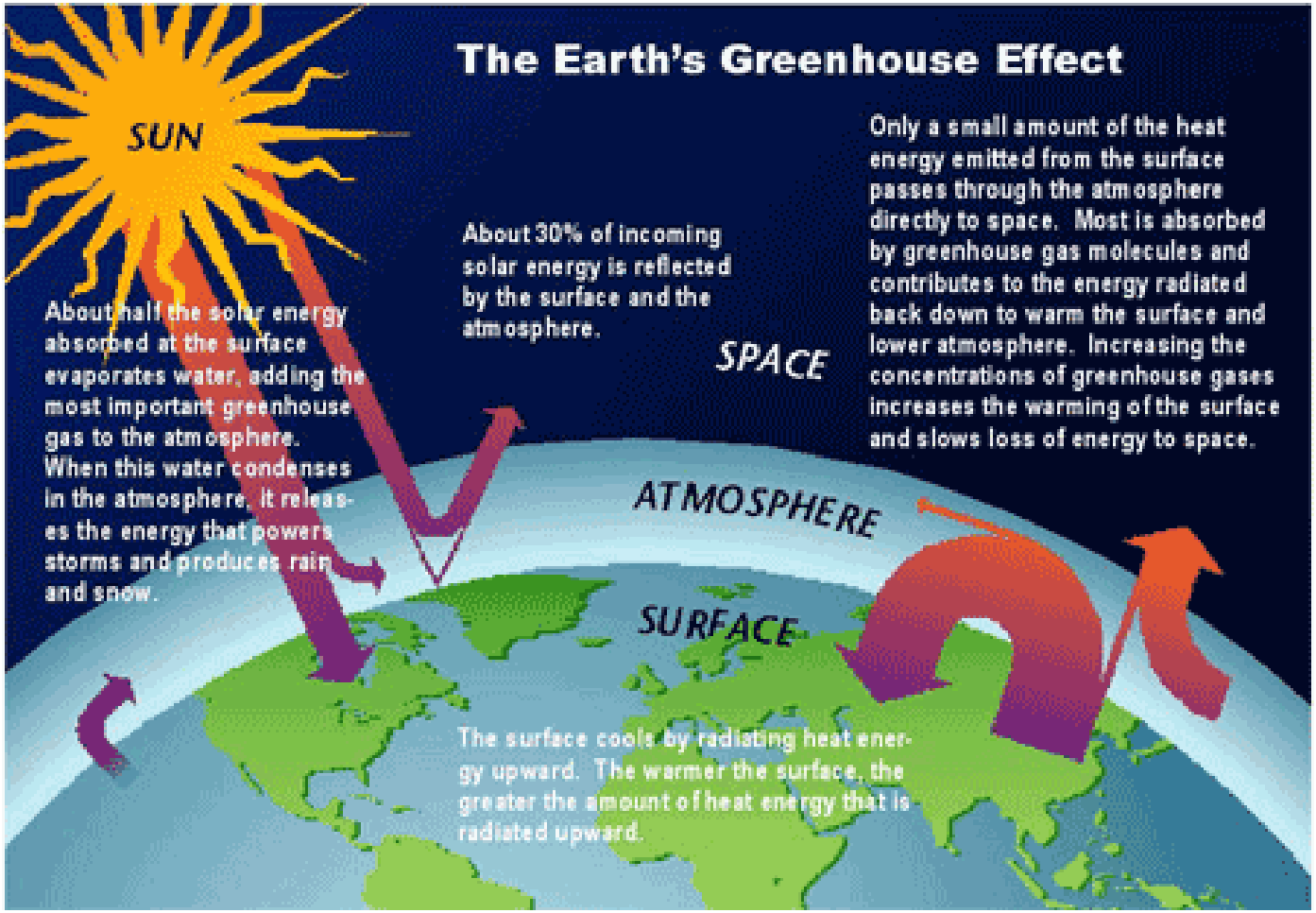


Evolution of typical atmospheric model (horizontal) resolution during history of IPCC project

- First assessment report (1980s)
- Second assessment report (1995)
- Third assessment report (early 2000s)
- Fourth assessment report (2007)



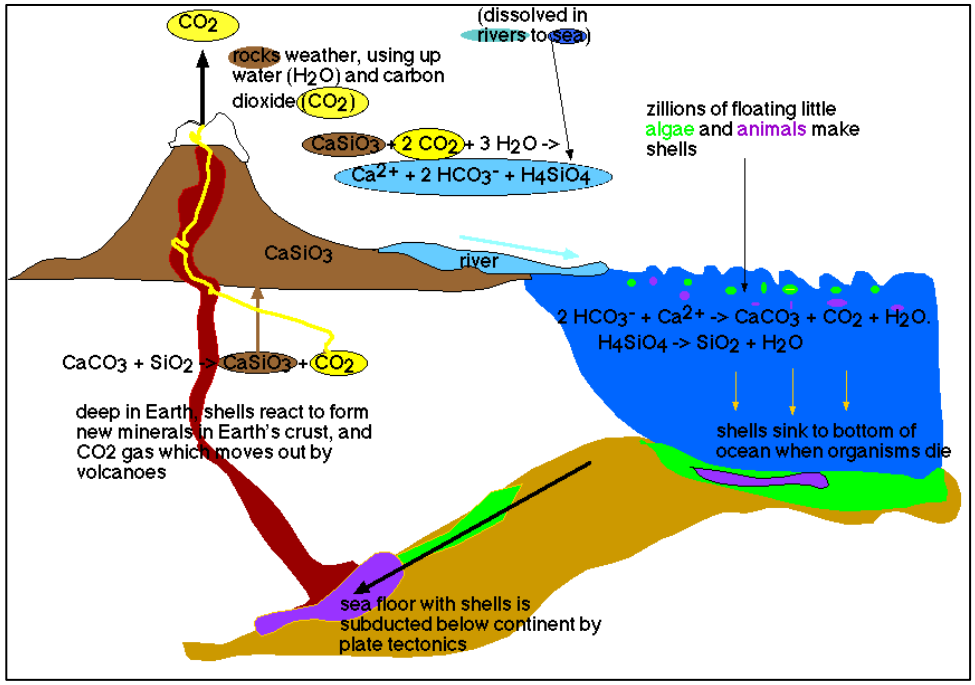
Why is CO_2 important for climate?



First described quantitatively by Svante Arrhenius in 1896

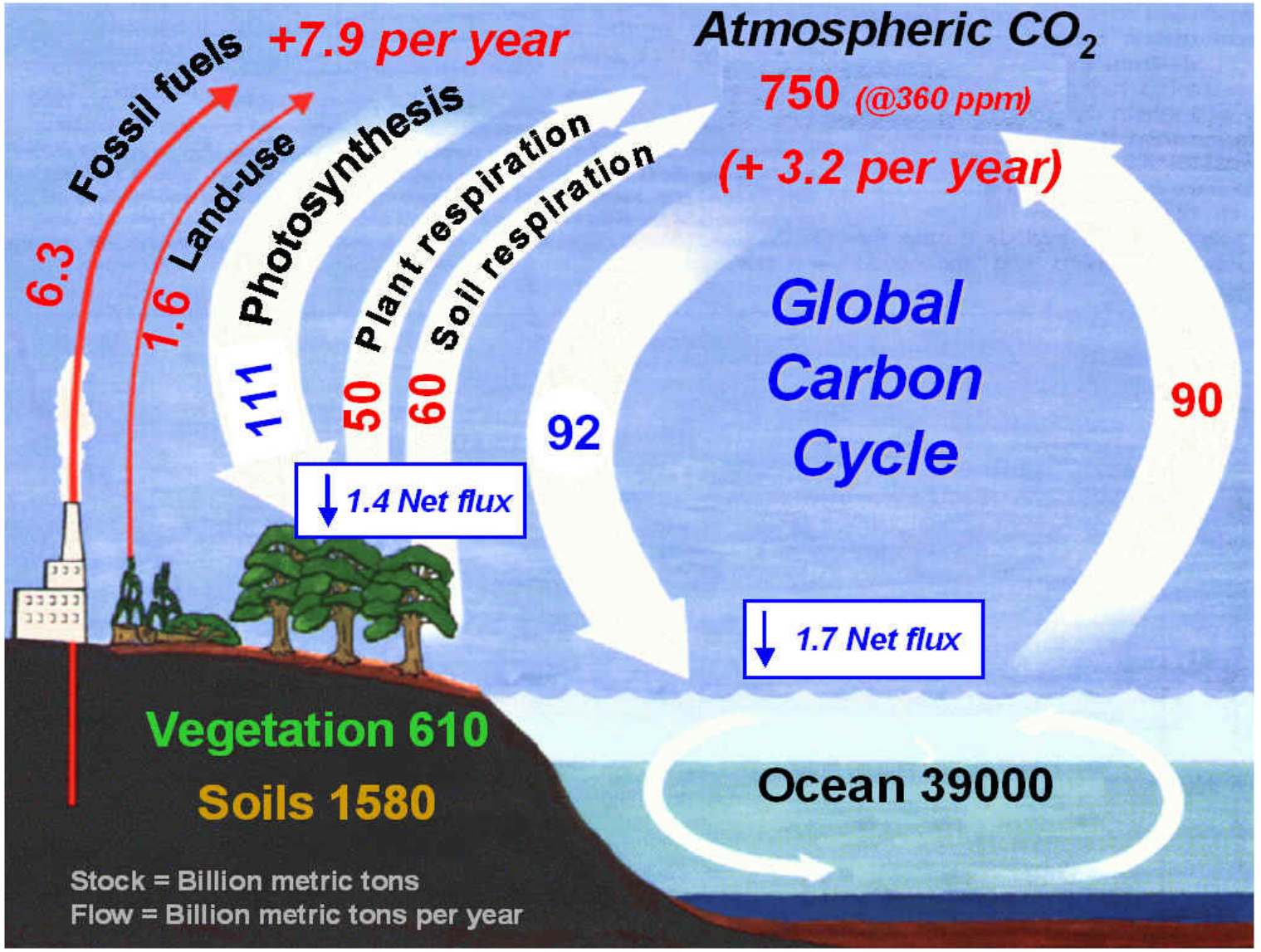
Carbon has been a key component of life and carbon cycling throughout geological history, and it carbon cycle research focuses on a wide range of "timescales"

- Very Long Timescales (tectonics and volcanism)

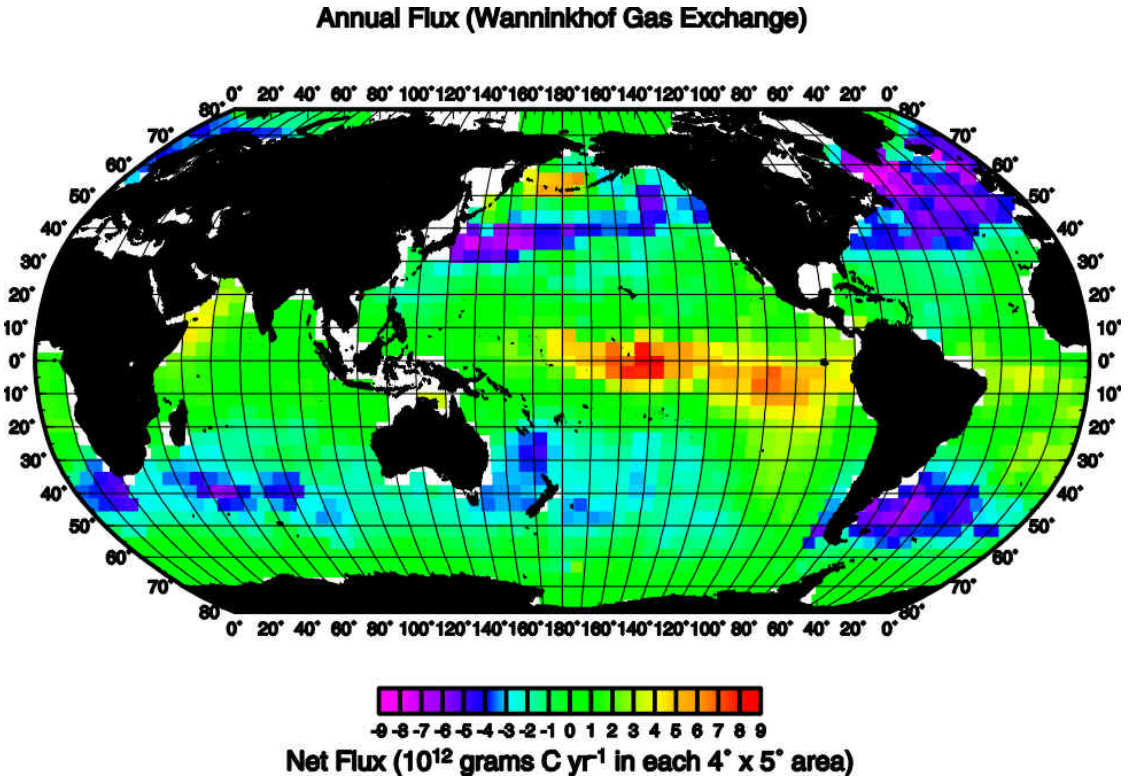


- Human timescales (decades to centuries): main focus of IPCC

What is the role of the ocean in the global carbon cycle over timescales of decades to centuries?



Where is carbon going in the ocean?
Data-based estimate of Takahashi et al. (2002)

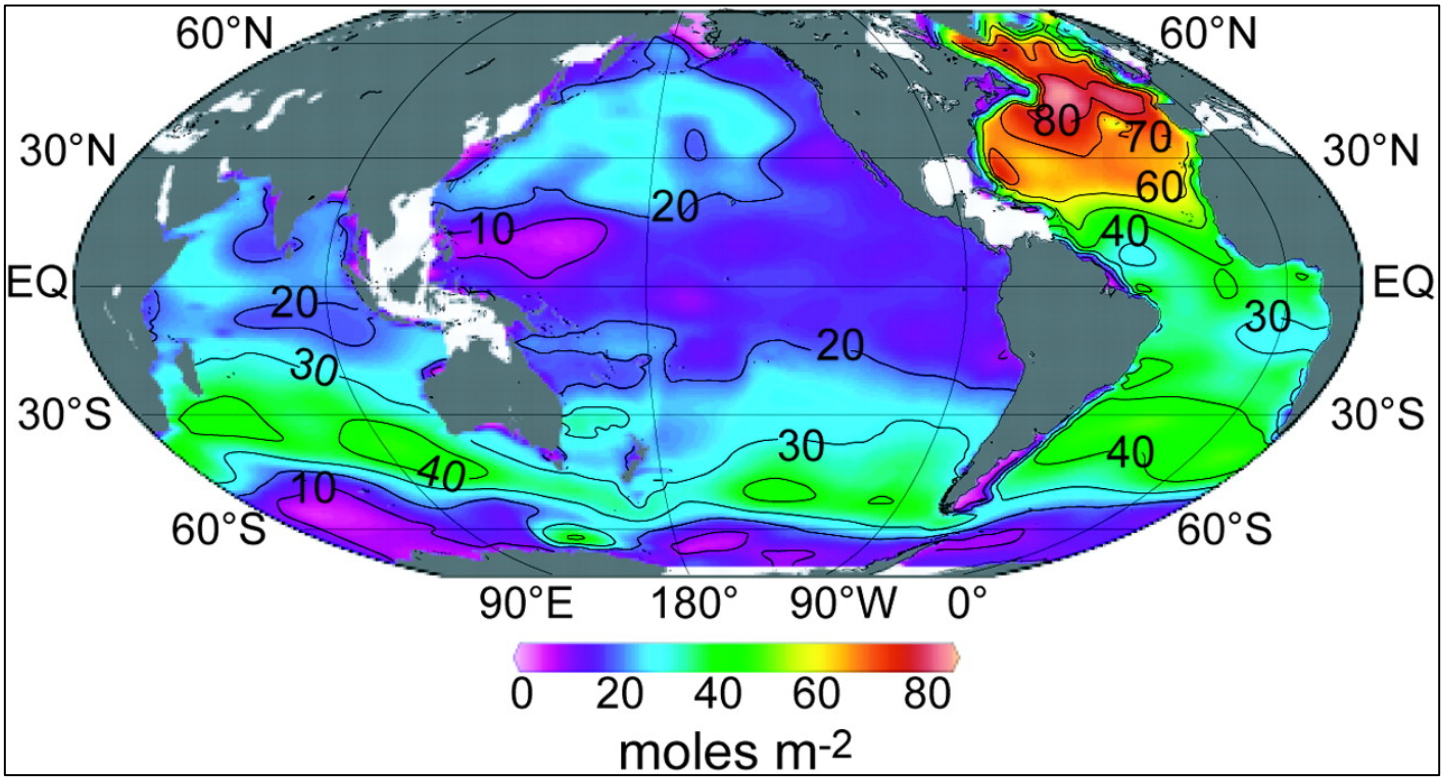


Blue regions: net transfer of CO_2 into the ocean

Red regions: net transfer of CO_2 to the atmosphere

Where is carbon accumulating in the ocean?

Data-based estimate of *Sabine et al.* [2004] for 1990s



A variety of methods indicate that for the recent past 1/3 of the CO_2 released through human activity has been absorbed by the ocean

How much CO_2 will be taken up by the ocean in the future?

- First step is to evaluate ocean model components of Earth System Models (evaluation of skill for modern climate); this is most effectively done with ocean-only models experiments where the ocean currents are intended to follow historical changes

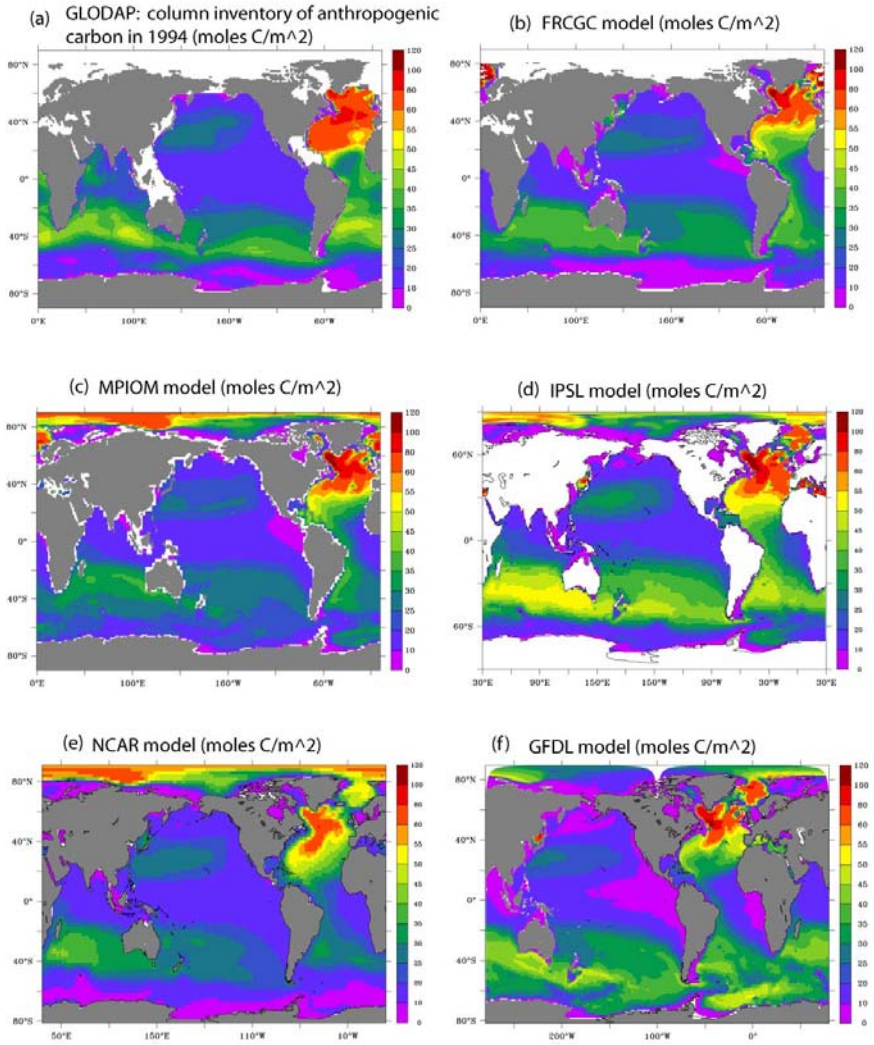
- Second step is to evaluate Earth System Models over prediction for 21st century changes

First step: compare ocean carbon uptake estimated by Sabine et al. [2004] with simulated uptake from available ocean carbon models

DATA

[*Sabine et al.*, 2004]

(mid-1990s)



Japanese ocean model

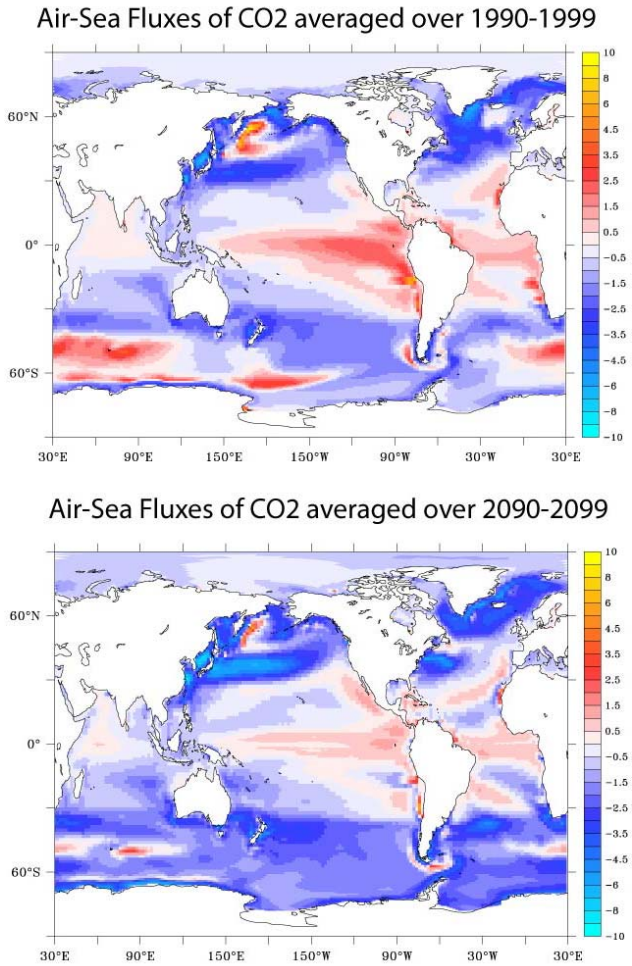
German ocean model

French ocean model

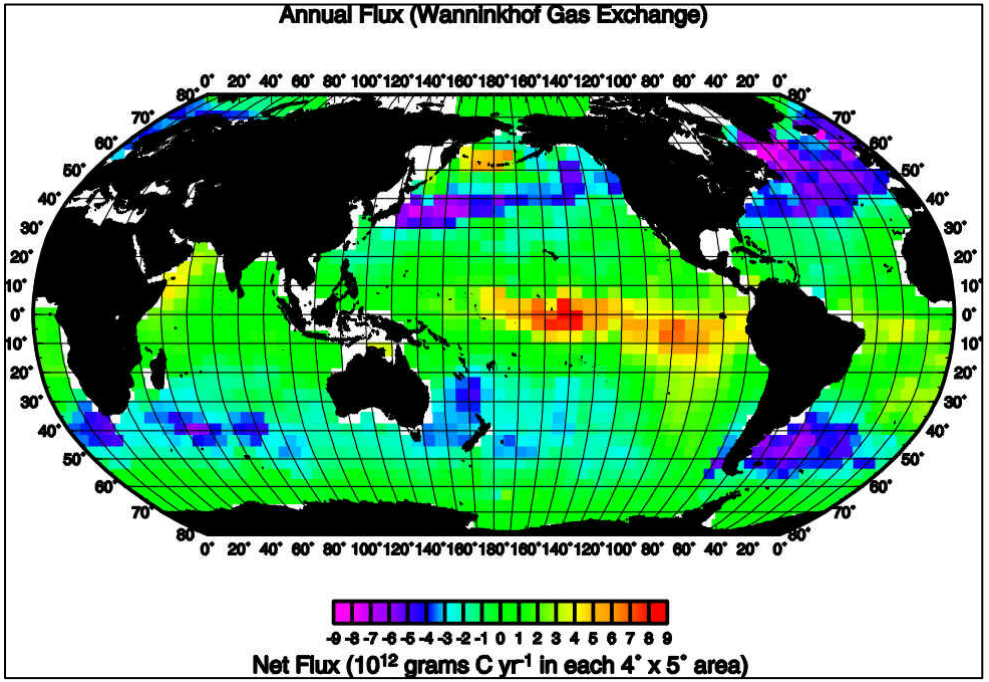
U.S. (NCAR) ocean model

U.S. (GFDL) Ocean model

Air-sea fluxes of CO_2 for French (IPSL) Earth System model



Air-sea fluxes of CO_2 based on Takahashi et al. [2002] data



Preliminary result from Earth System models: there are significant changes in carbon exchanges (between the ocean and atmosphere) over 21st century

Evidence that the ocean carbon cycle is changing

海洋の炭素循環が変わりつつあるという証拠

- **North Atlantic Ocean　北大西洋**

  Observational studies suggest that ocean uptake of CO_2 in the North Atlantic may be decreasing ;
  Ocean model studies are divided on this point

  観測によると、北大西洋のCO_2吸収は弱まっているらしい
  モデルによって、この点は肯定するものと否定するものとがある

- **Southern Ocean　南大洋**

  Recent modeling studies have raised the question of whether the Southern Ocean uptake of CO_2 may also be decreasing

  最近のあるいくつかのモデルによる研究では、南大洋のCO_2吸収が弱まっているのではないか、という問題が提起されている

Needs for future research　今後の研究に必要なこと

- **Earth System Models　地球システムモデル**

  Needed to predict future changes
  将来の変化の予測に必要

- **Observational Networks　観測ネットワーク**

  Needed to understand processes and constrain models
  プロセスを理解し、モデルを制御するために必要