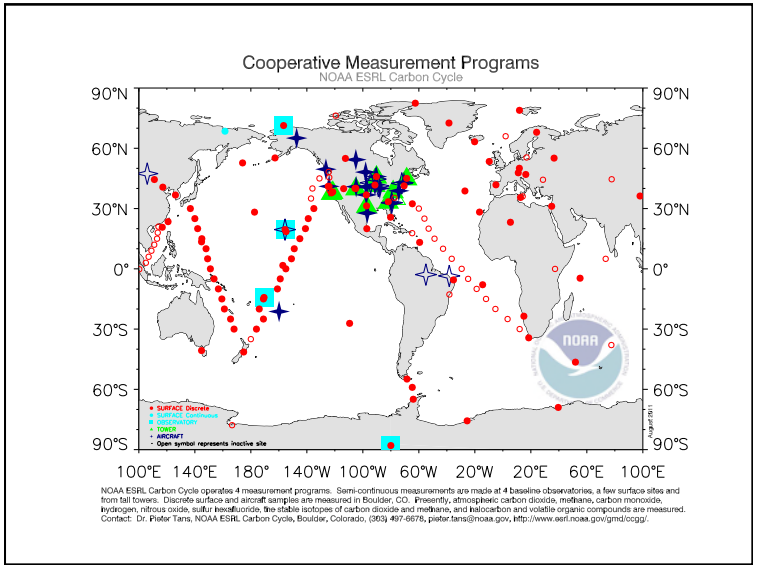
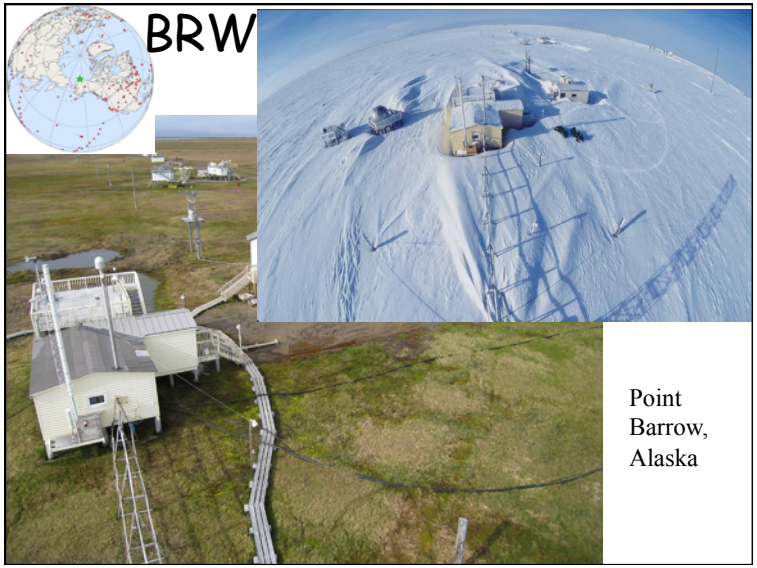
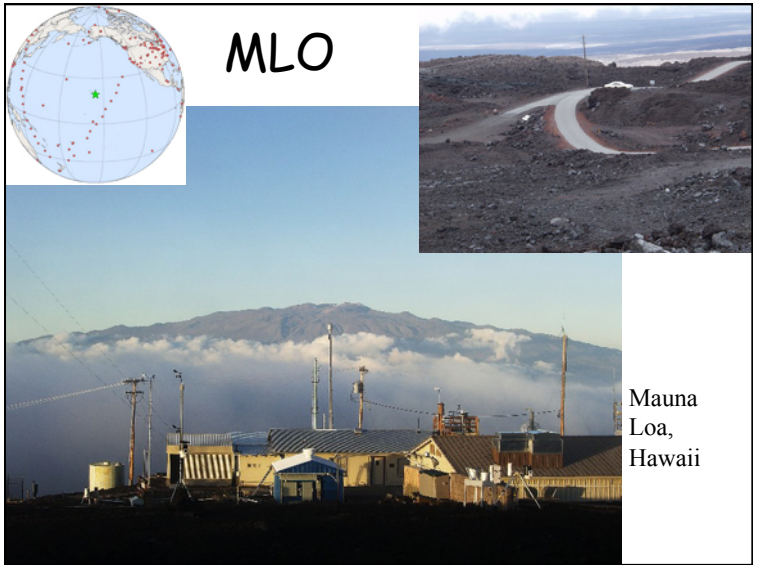
Atmospheric CO_2 Observations (in-situ)

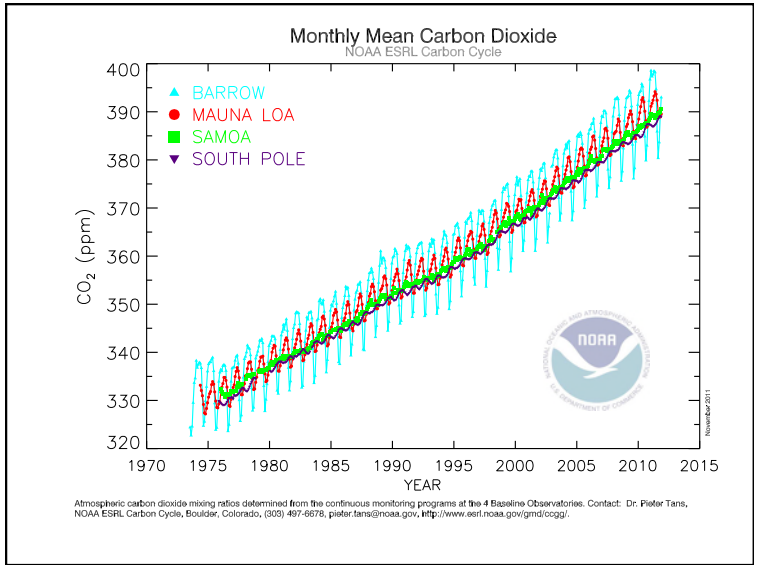


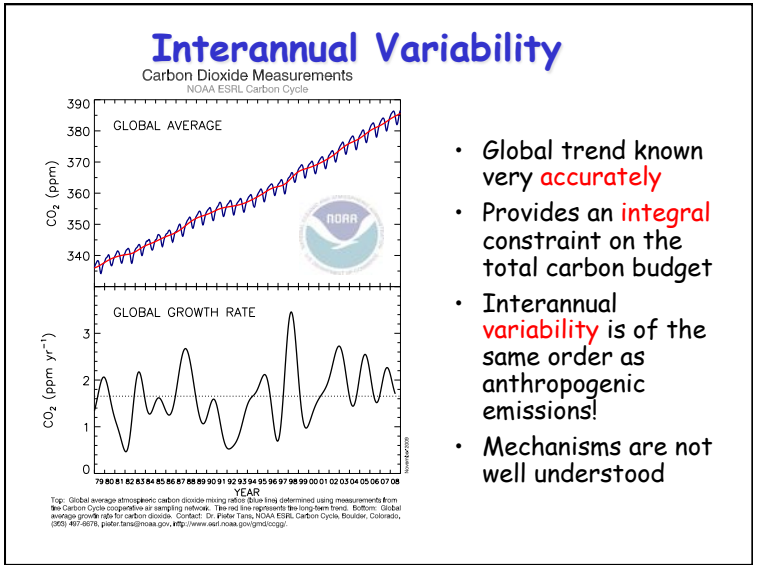




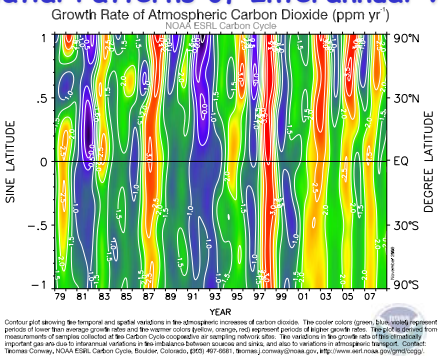

SMO
American
Samoa


SPO
Sou
Pole


Monthly Mean Carbon Dioxide
NOAA ESRL Carbon Cycle
BARROW
MAUNA LOA
SAMOA
SOUTH POLE
CO2 (ppm)
YEAR
Atmospheric carbon dioxide mixing ratios determined from the continuous monitoring programs at the 4 Baseline Observatories. Contact: Dr. Pieter Tans, NOAA ESRL Carbon Cycle, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, http://www.esrl.noaa.gov/gmd/ccgg/.

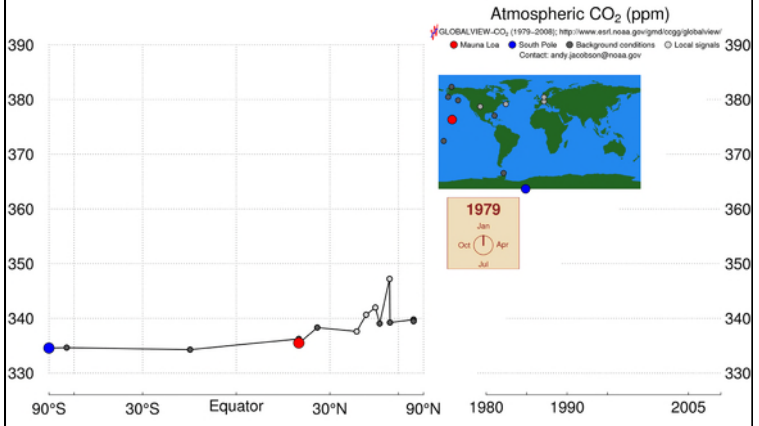

Interannual Variability
Carbon Dioxide Measurements
NOAA ESRL Carbon Cycle
GLOBAL AVERAGE
GLOBAL GROWTH RATE
CO2 (ppm)
CO2 (ppm yr-1)
YEAR
Top: Global average atmospheric carbon dioxide mixing ratios (blue line) determined using measurements from the Carbon Cycle cooperative air sampling network. The red line represents the long-term trend. Bottom: Global average growth rate for carbon dioxide. Contact: Dr. Pieter Tans, NOAA ESRL Carbon Cycle, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, http://www.esrl.noaa.gov/gmd/ccgg/.
• Global trend known very accurately
• Provides an integral constraint on the total carbon budget
• Interannual variability is of the same order as anthropogenic emissions!
• Mechanisms are not well understood

Spatial Patterns of Interannual Variability

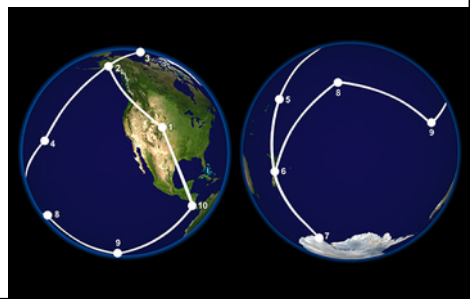


- 1987-88 pulse originated in tropics, propagated to higher latitudes
- Minima in 1989, 92, 96, 99 mostly in NH
- Huge pulse in 1998 was global
- Recent fluctuations driven strongly in NH

Atmospheric Carbon Observations



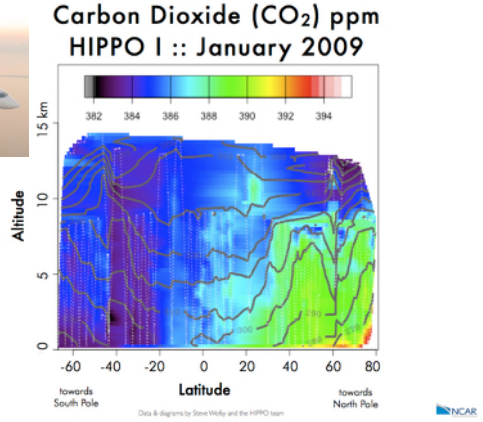
HIAPER Pole-to-Pole Observations (HIPPO)



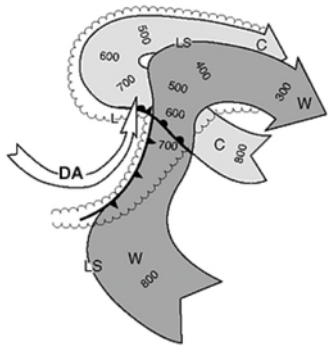
HIPPO boat: NCAR Gulfstream V "HIAPER"

GV launch in the rain, Anchorage, January, 2009 (HIPPO-1)

HIAPER Pole-to-Pole Obs



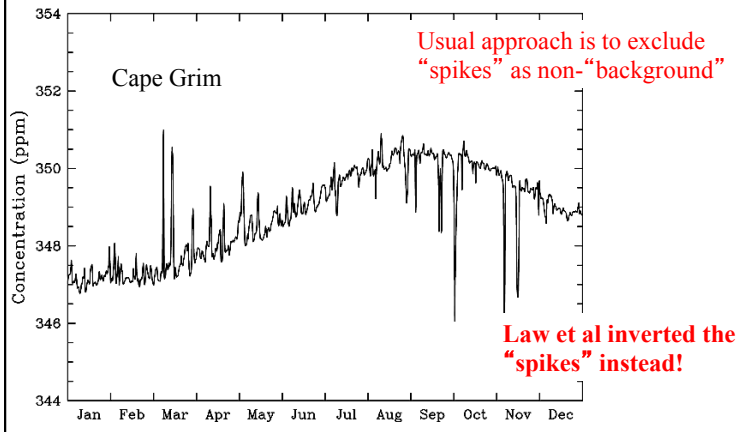
The Warm and Cold Conveyor Belts



[Bader et al 1995, adapted from Carlson, 1980]

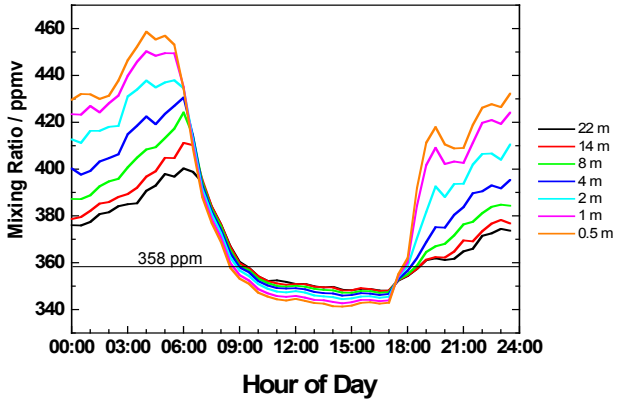
Signal? Noise? Which is which?

LAW ET AL.: USING HIGH TEMPORAL FREQUENCY DATA FOR CO_2 INVERSIONS

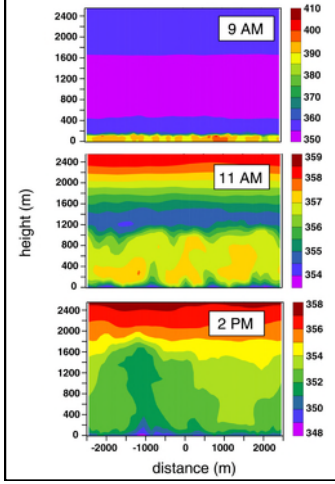


Effects of height-time concentration variation near the ground

- OASIS, Oct 1995, Wagga, NSW



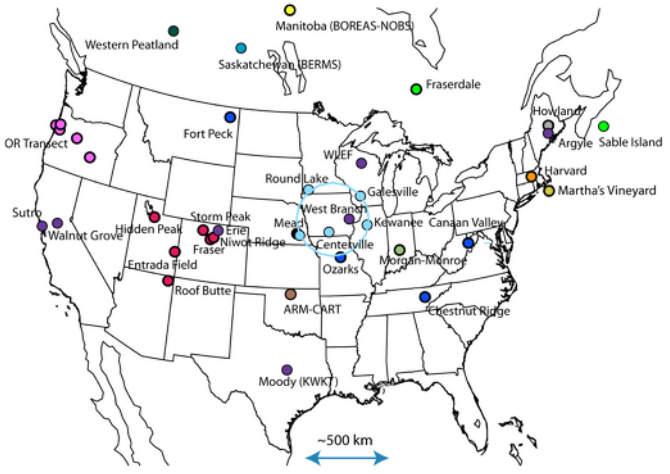
Simulated PBL CO_2

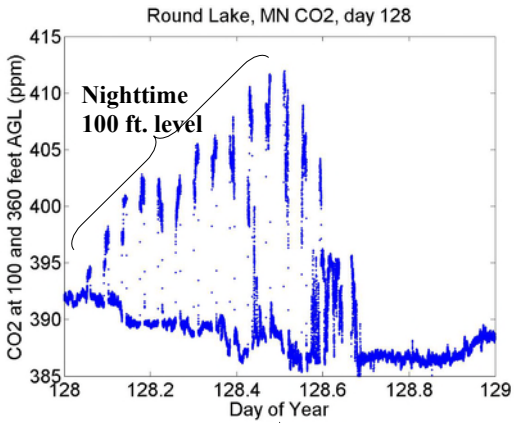


- SiB2 coupled to CSU RAMS
- Nocturnal respiration produces extremely high concentrations in morning stable layer
- Surface heating and TKE generation causes entrainment of lower-CO_2 air from aloft
- Photosynthesis depletes CO_2 in surface layer
- Buoyant plumes of low-CO_2 air fill the convective boundary layer

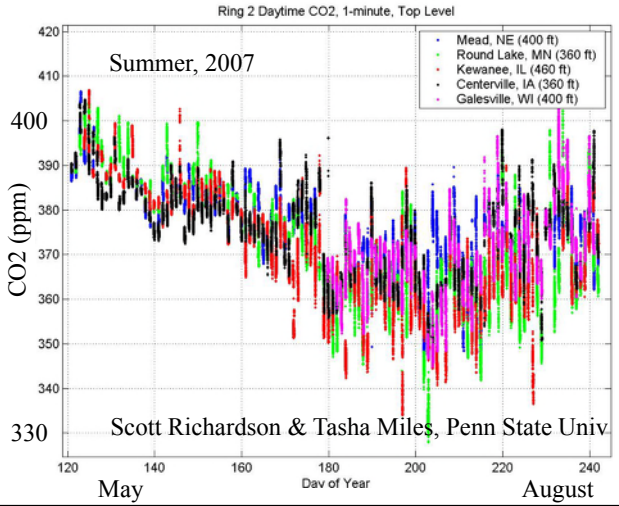
Continuous, Well-Calibrated CO_2 Measurements in North America

2008





Corn, as seen from 100 m



Transport

- Advection:
  - Stuff that was "upstream" moves here with the wind:

$$\frac{\partial q}{\partial t} = -u\frac{\partial q}{\partial x} - v\frac{\partial q}{\partial y} - w\frac{\partial q}{\partial z} + Source(q)$$

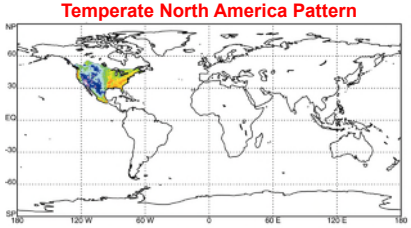
  - To predict the future amount of q, we simply need to keep track of gradients and wind speed in each direction
- What spatial scales are involved?
- Can we resolve advective transports by turbulent eddies and convective clouds (thunderstorms) in a global model?
  - (No)

Synthesis Inversion Procedure ("Divide and Conquer")

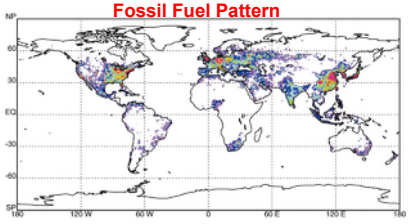
1. Divide carbon fluxes into subsets based on processes, geographic regions, or some combination
   1. Spatial patterns of fluxes within regions?
   2. Temporal phasing (e.g., seasonal, diurnal, interannual?)
2. Prescribe emissions of unit strength from each "basis function" as lower boundary forcing to a global tracer transport model
3. Integrate the model for three years ("spin-up") from initially uniform conditions to obtain equilibrium with sources and sinks
4. Each resulting simulated concentration field shows the "influence" of the particular emissions pattern
5. Combine these fields to "synthesize" a concentration field that agrees with observations

Forward Transport Step

Temperate North America Pattern

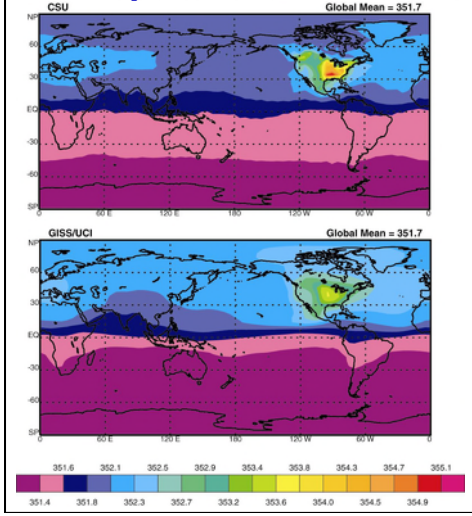


Fossil Fuel Pattern



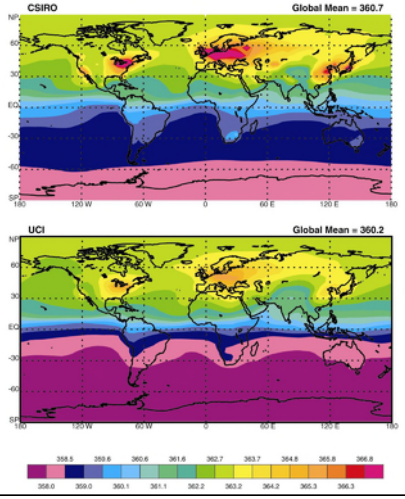
- Discretize emissions into spatial and seasonal "basis functions"
- Obtain archived winds from NWP reanalysis, or run a full GCM
- Advection by resolved winds
- Specify convective transports: HOW?

Responses to Unit Flux from N.A.



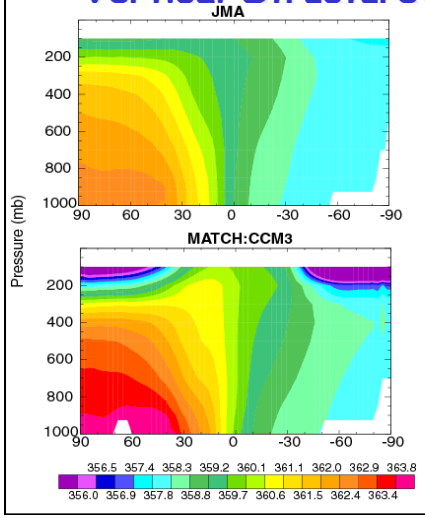
- Some models (e.g., CSU) show stronger gradients near source region
- Others (e.g., GISS) appear more thoroughly "mixed"

Fossil Fuel Response Functions



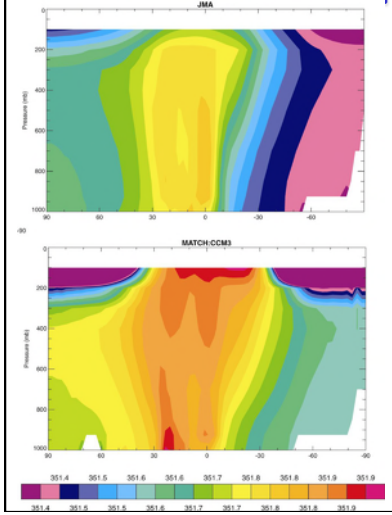
- Some models (e.g., CSIRO) show stronger gradients near source region
- Others (e.g., UCI) appear more thoroughly "mixed"

Vertical Structure: FF Response



- Annual mean latitude-pressure cross sections show strong sensitivity to vertical mixing
- Strong vertical gradient in NH
- "Barrier" to cross-equator transport
- Reversed vertical gradient in SH
- Most of NS structure at surface in in NH subtropics

Vertical Transport is Crucial



- Some models treat convection as "diffusive mixing" between adjacent layers
- Others treat convection as penetrative updrafts and downdrafts ("express elevators")
- Much of the surface structure actually related to vertical mixing

Meridional Gradients (Tans et al, 1990)

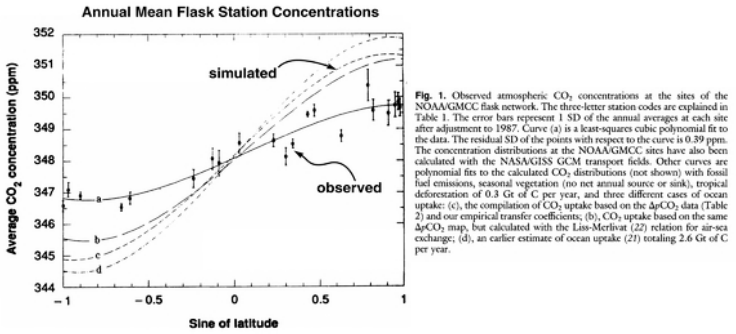
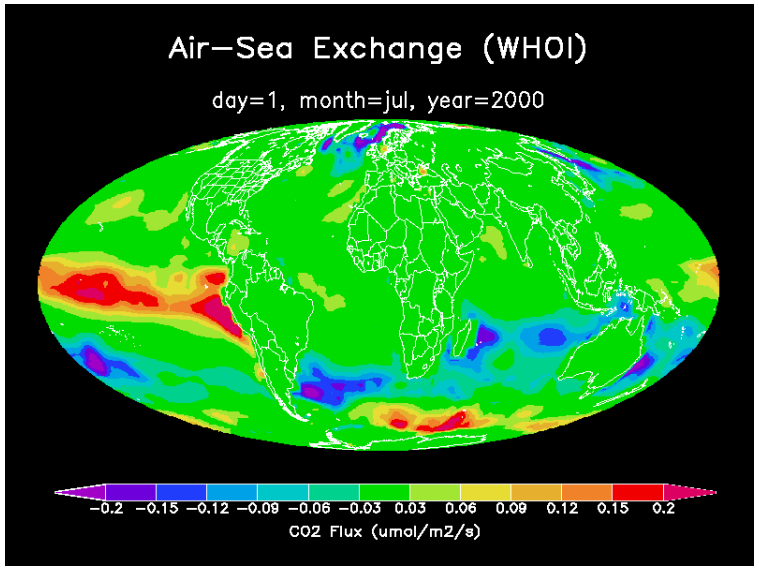
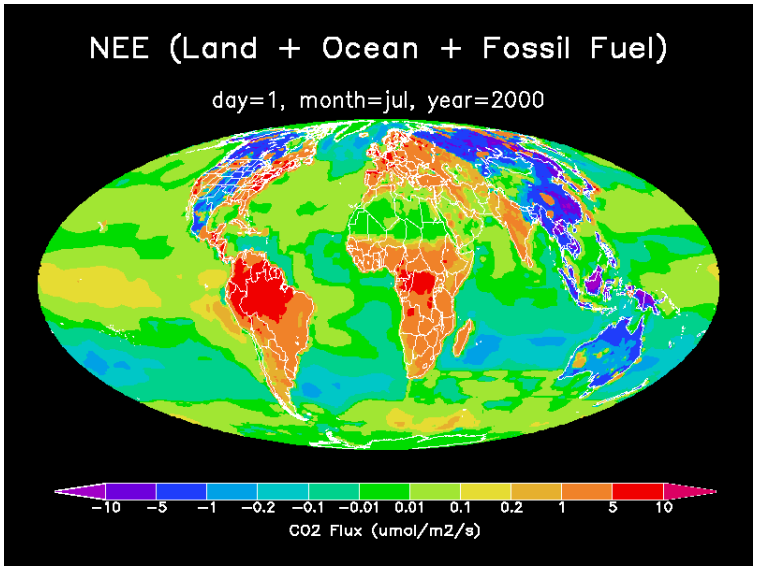
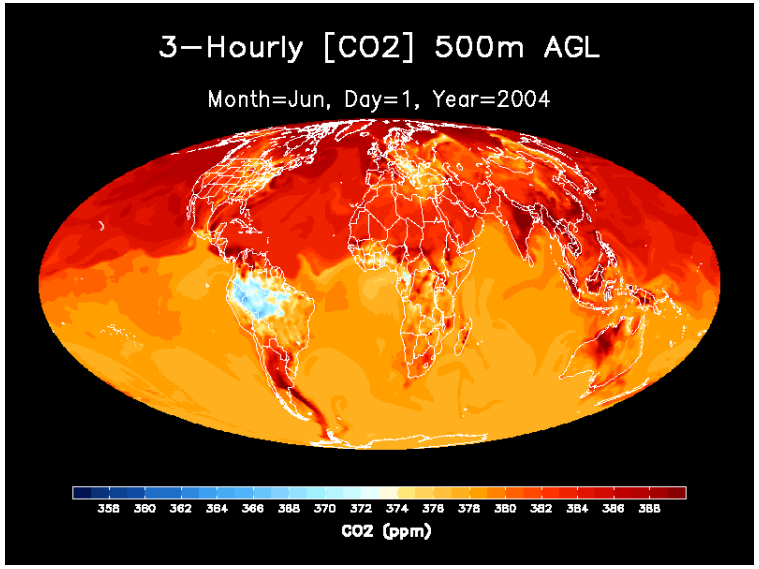


Fig. 1. Observed atmospheric CO_2 concentrations at the sites of the NOAA/GMCC flask network. The three-letter station codes are explained in Table 1. The error bars represent 1 SD of the annual averages at each site after adjustment to 1987. Curve (a) is a least-squares cubic polynomial fit to the data. The residual SD of the points with respect to the curve is 0.39 ppm. The concentration distributions at the NOAA/GMCC sites have also been calculated with the NASA/GISS GCM transport fields. Other curves are polynomial fits to the calculated CO_2 distributions (not shown) with fossil fuel emissions, seasonal vegetation (no net annual source or sink), tropical deforestation of 0.3 Gt of C per year, and three different cases of ocean uptake: (c), the compilation of CO_2 uptake based on the ΔpCO_2 data (Table 2) and our empirical transfer coefficients; (b), CO_2 uptake based on the same ΔpCO_2 map, but calculated with the Liss-Merlivat (22) relation for air-sea exchange; (d), an earlier estimate of ocean uptake (21) totaling 2.6 Gt of C per year.

Simulated gradient way too steep for most emission scenarios


Air–Sea Exchange (WHOI)
day=1, month=jul, year=2000
−0.2 −0.15 −0.12 −0.09 −0.06 −0.03 0.03 0.06 0.09 0.12 0.15 0.2
CO2 Flux (umol/m2/s)


NEE (Land + Ocean + Fossil Fuel)
day=1, month=jul, year=2000
−10 −5 −1 −0.2 −0.1 −0.01 0.01 0.1 0.2 1 5 10
CO2 Flux (umol/m2/s)


3–Hourly [CO2] 500m AGL
Month=Jun, Day=1, Year=2004
358 360 362 364 366 368 370 372 374 376 378 380 382 384 386 388
CO2 (ppm)