15.023J / 12.848J / ESD.128J Global Climate Change: Economics, Science, and Policy
Spring 2008

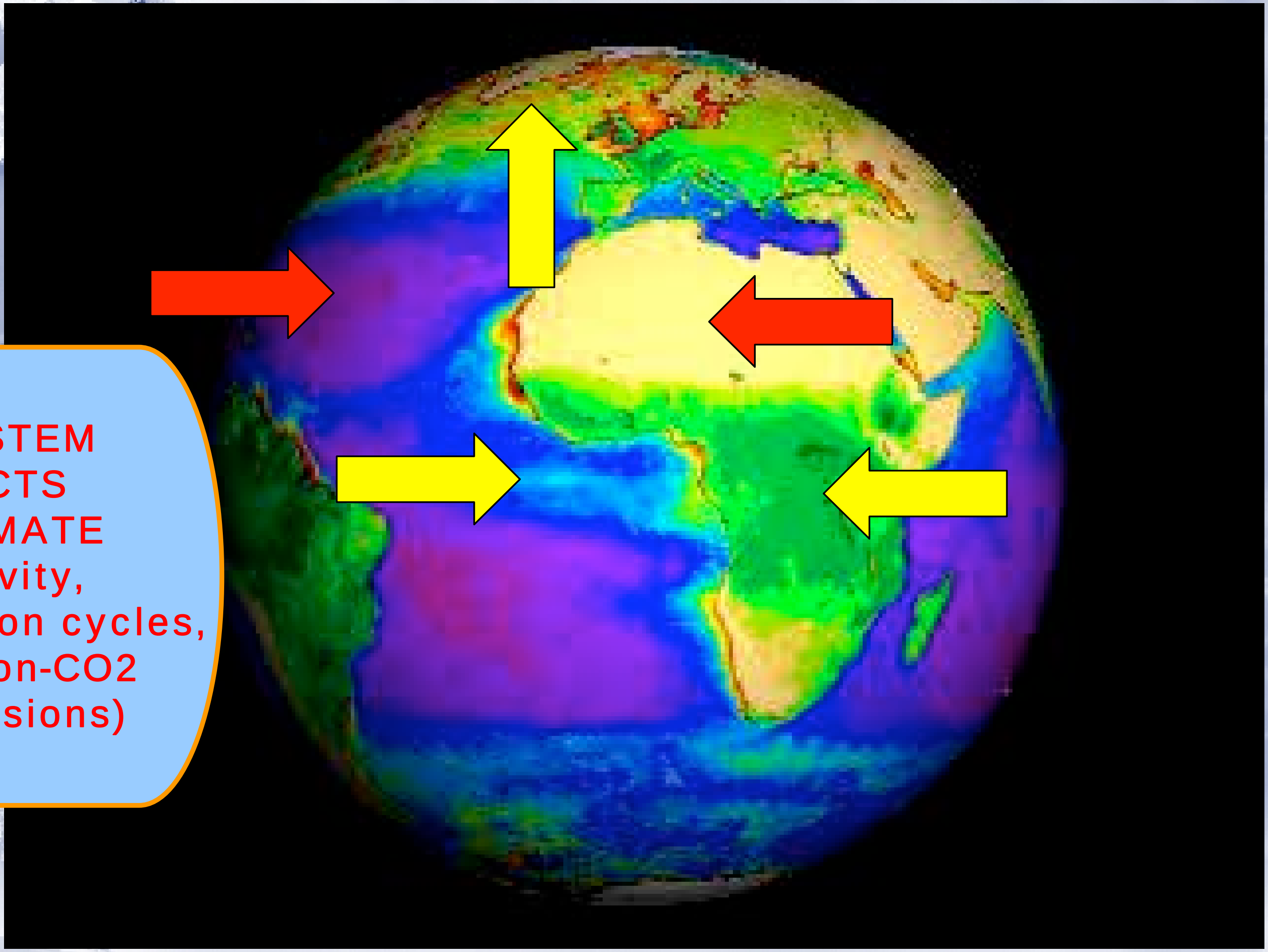
THE CLIMATE MACHINE III :

Interaction of the Atmosphere, Oceans and Biosphere

R. PRINN, March 17, 2008

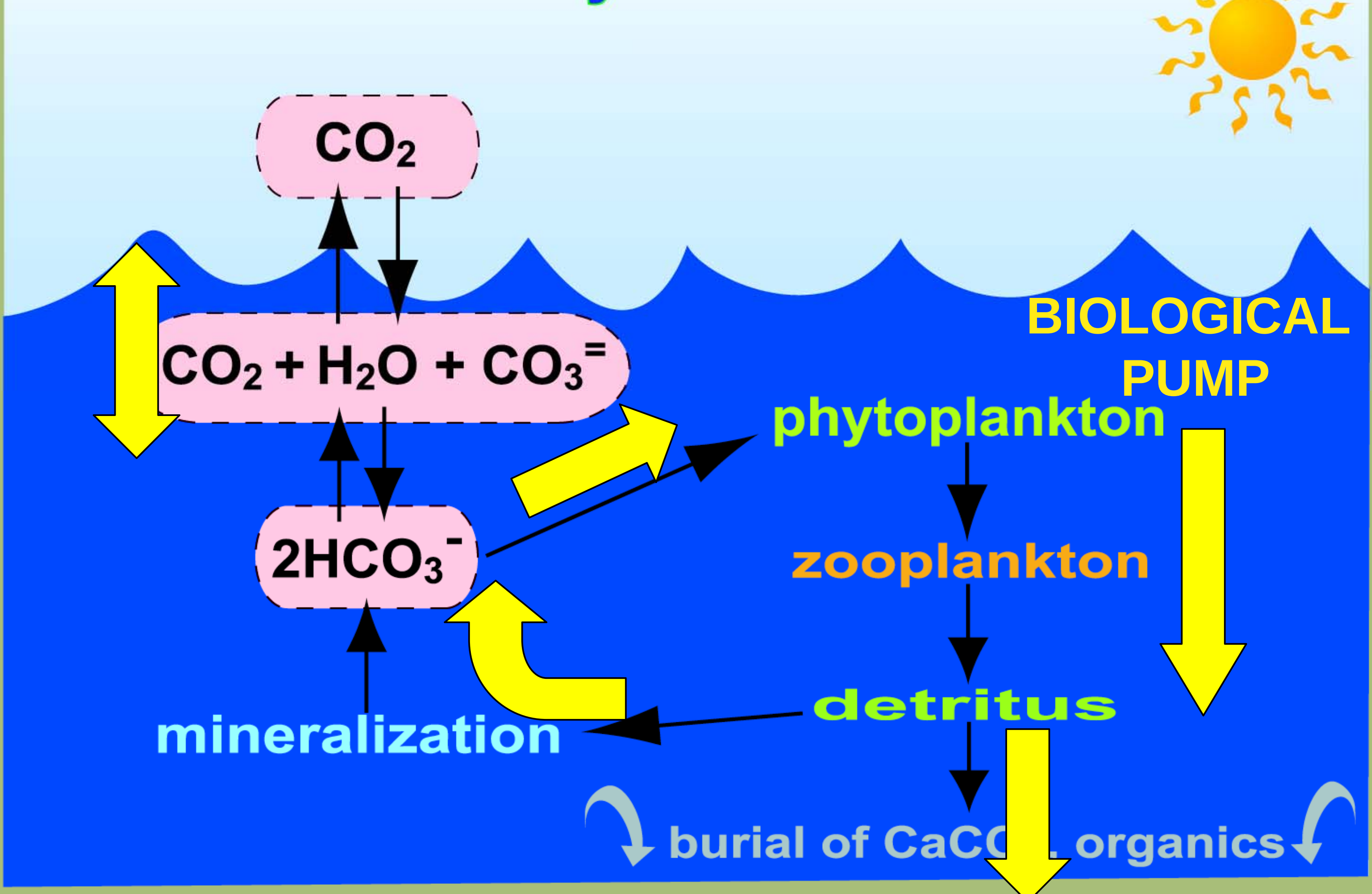
1. Ocean & Land Ecosystems
2. Coupling Ecosystems/climate/chemistry
3. Integrated Global System Model
4. Reference Forecasts (IGSM 1)
5. What does stabilization mean?
6. Reference Forecasts (IGSM 2)

OCEAN and LAND BIOSPHERES PLAY A SIGNIFICANT ROLE IN CLIMATE

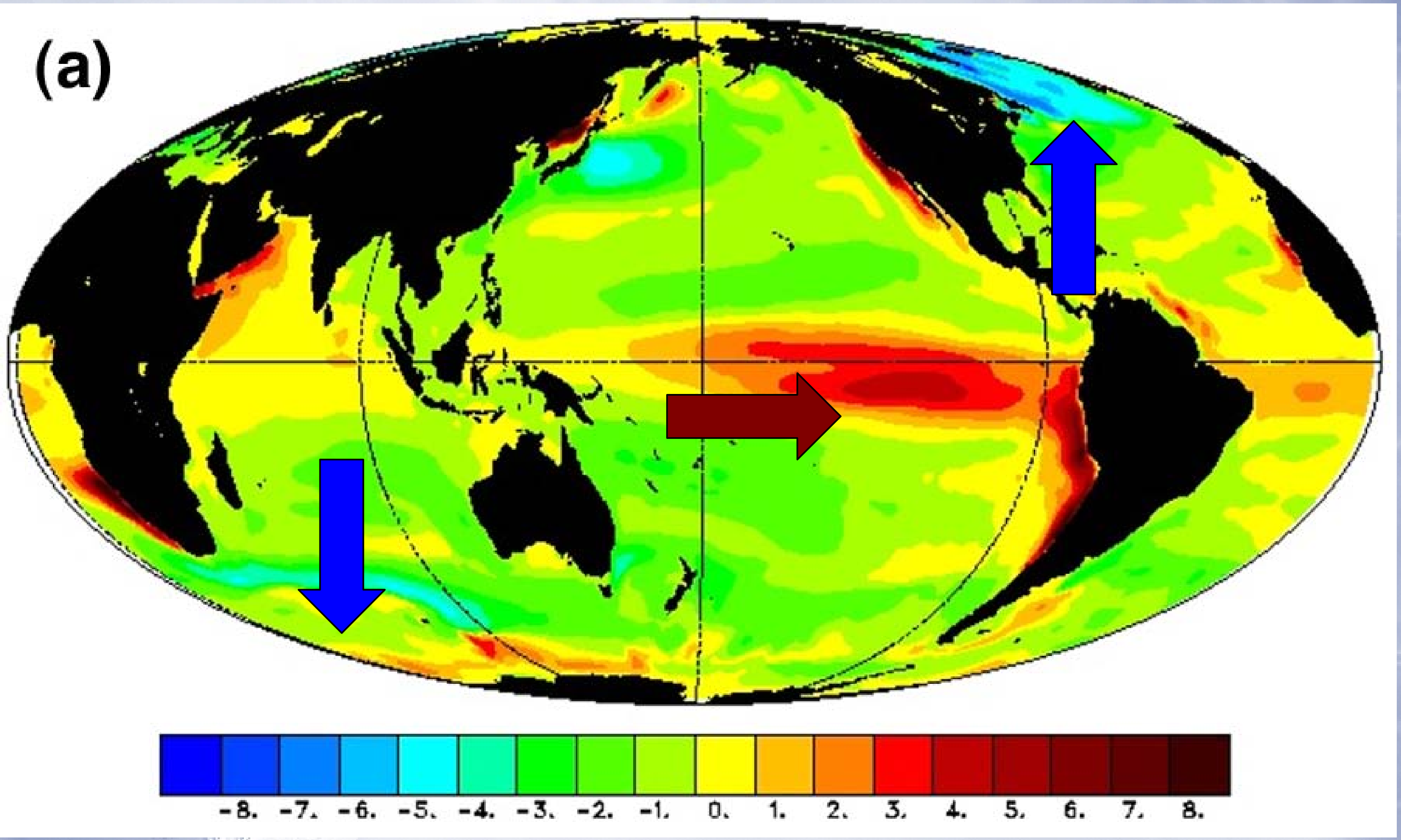


ECOSYSTEM
IMPACTS
ON CLIMATE
(reflectivity,
water & carbon cycles,
natural non-CO2
gas emissions)

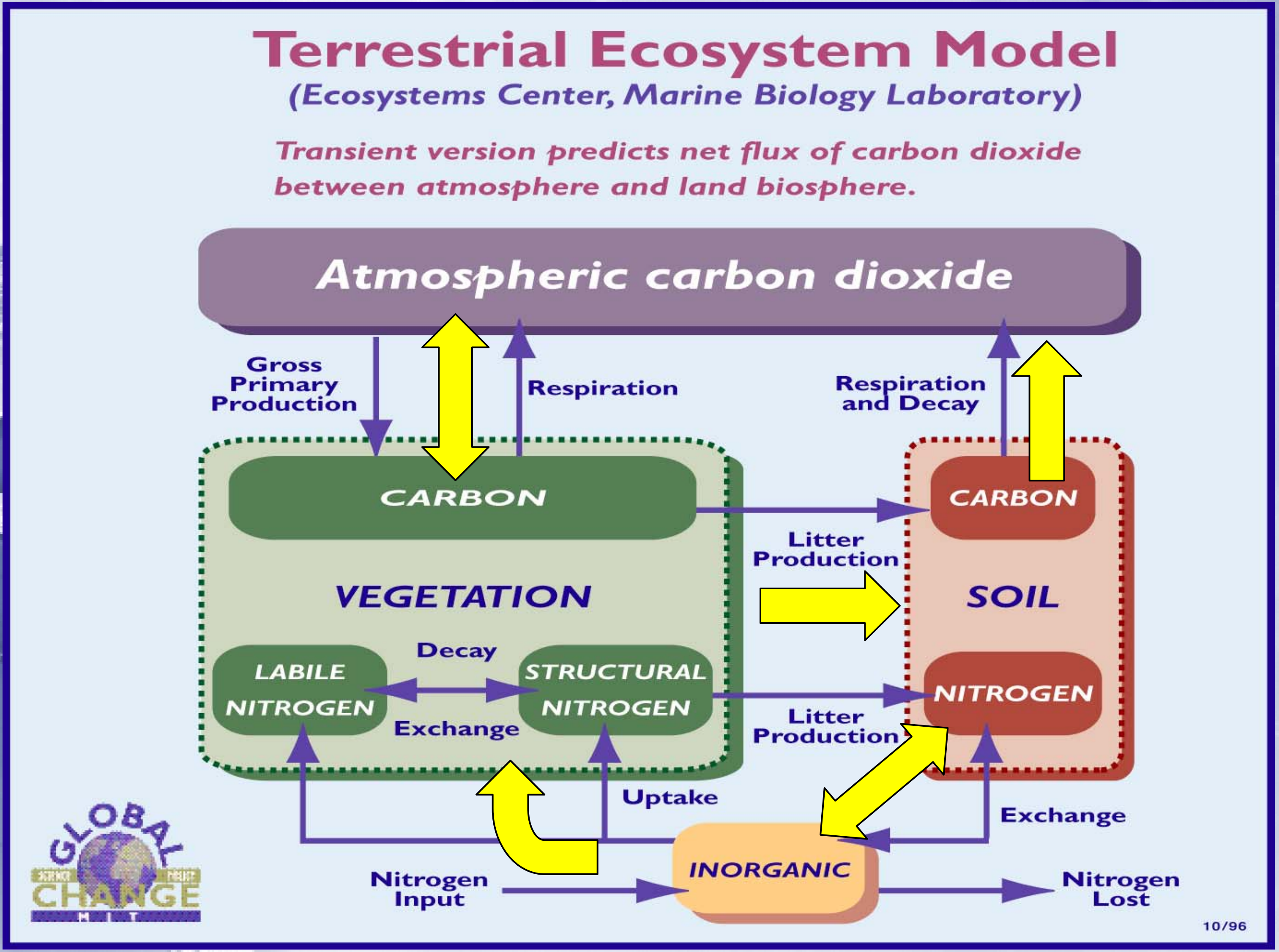
Carbon Cycle in Ocean



AIR-SEA FLUX of CO_2 (1980-1999, mol m^{-2} yr^{-1})



Ref: from the model of McKinley et al. (2003, 2004). The offline biogeochemical ocean model was driven by time varying circulation state estimates from the ECCO group (http://www.ecco-group.org; Section 2.3.1) and included representations of ocean carbon and oxygen cycles with a simplified representation of export production.



NPP = NET PRIMARY PRODUCTION

= GPP (PHOTOSYNTHESIS) - PLANT RESPIRATION

NEP = NET ECOSYSTEM PRODUCTION

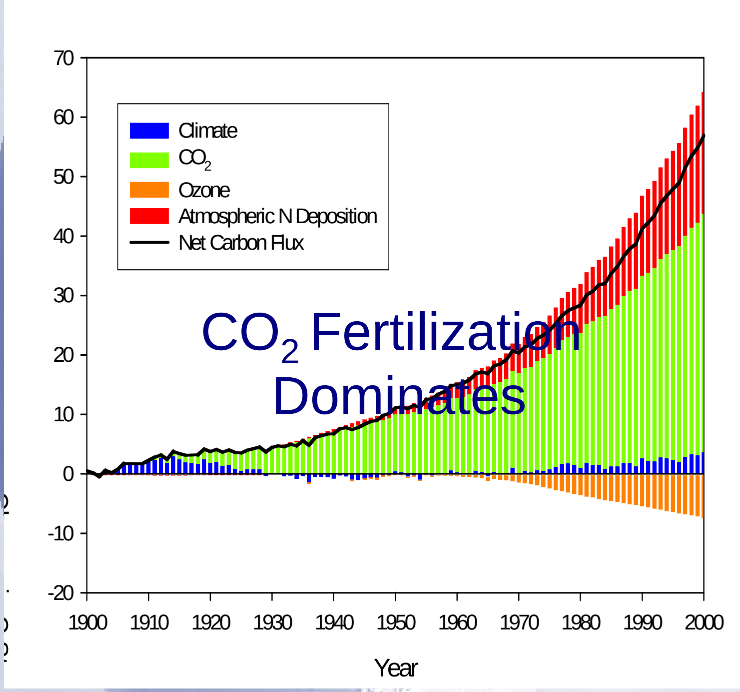
= NPP - SOIL RESPIRATION & DECAY

LAND CARBON BUDGET: NET PRIMARY PRODUCTION (NPP)

(NPP = PHOTOSYNTHESIS - PLANT RESPIRATION)

Image removed due to copyright restrictions.
Global map of net primary production, ranging from 0 to 1550 gC/m2/yr, source unknown.

Terrestrial Ecosystem Models address impacts of Climate Change & Air Pollution on Carbon Cycle



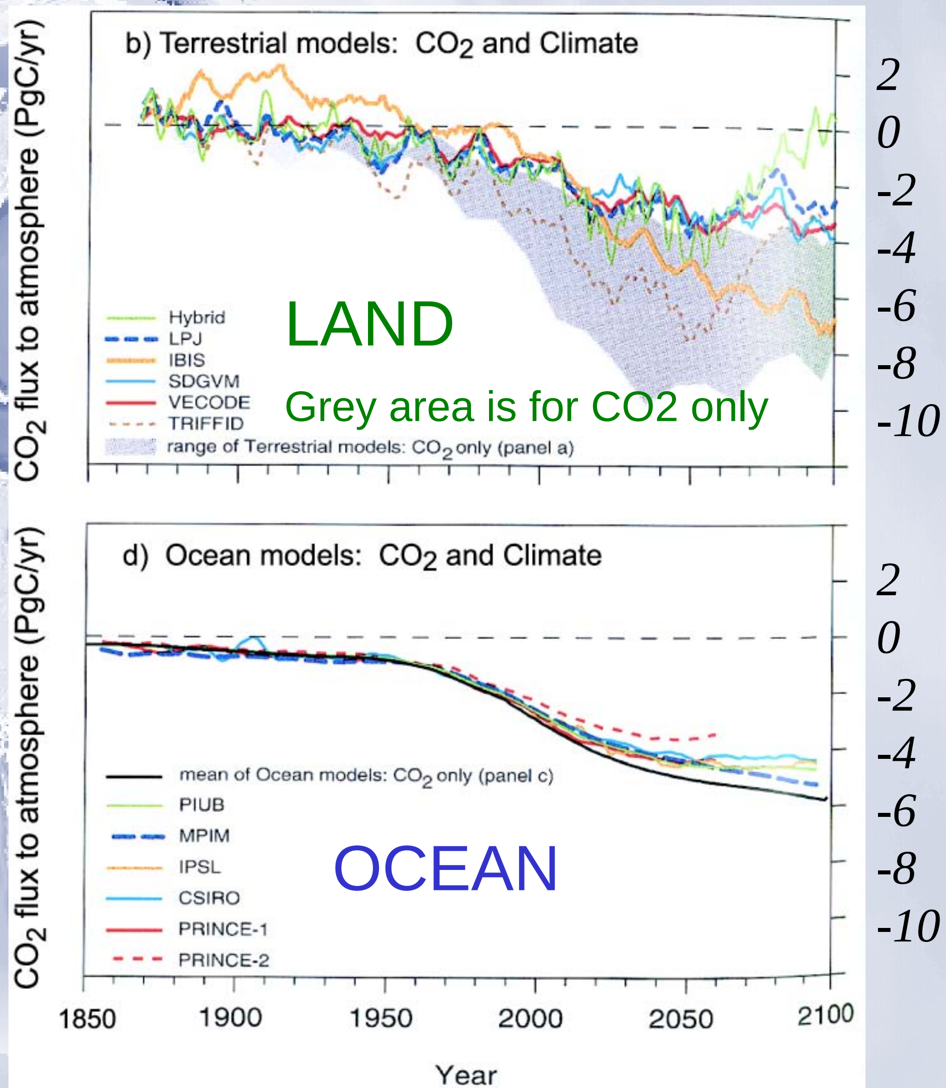
e.g. Carbon Accumulation in Global Ecosystems since 1900 (PgC)

Image removed due to copyright restrictions. Global map showing net carbon flux, with values from -30 to 90 gC/m2/yr.

e.g. Net Carbon Flux (NEP =NPP -Soil Resp. & Decay) into Natural Ecosystems during the 1990s (TEM 6.0)

Ref: Melillo et al, 2005

Model Projections of Carbon Uptake by Land and Ocean (GtC/year)*



The Carbon Cycle fluxes & Climate are closely coupled

*** Source:** IPCC, ***Climate Change 2001: The Scientific Basis***, Chap. 3 (Prentice *et al*., 2001)

MUST INCLUDE THE INTERACTIONS BETWEEN ECOSYSTEMS AND CLIMATE THROUGH TRACE GAS EXCHANGE

e.g. Predicted increases in natural emissions of N_2O and CH_4 driven by climate & soil C changes

Shown are emissions of N_2O and CH_4 in the Natural Emissions Model (NEM) runs driven by the indicated climate model runs and (for N_2O) also by the indicated climate plus Terrestrial Ecosystem Model (TEM) runs (the latter denoted by the addition of C_T to the run designation).

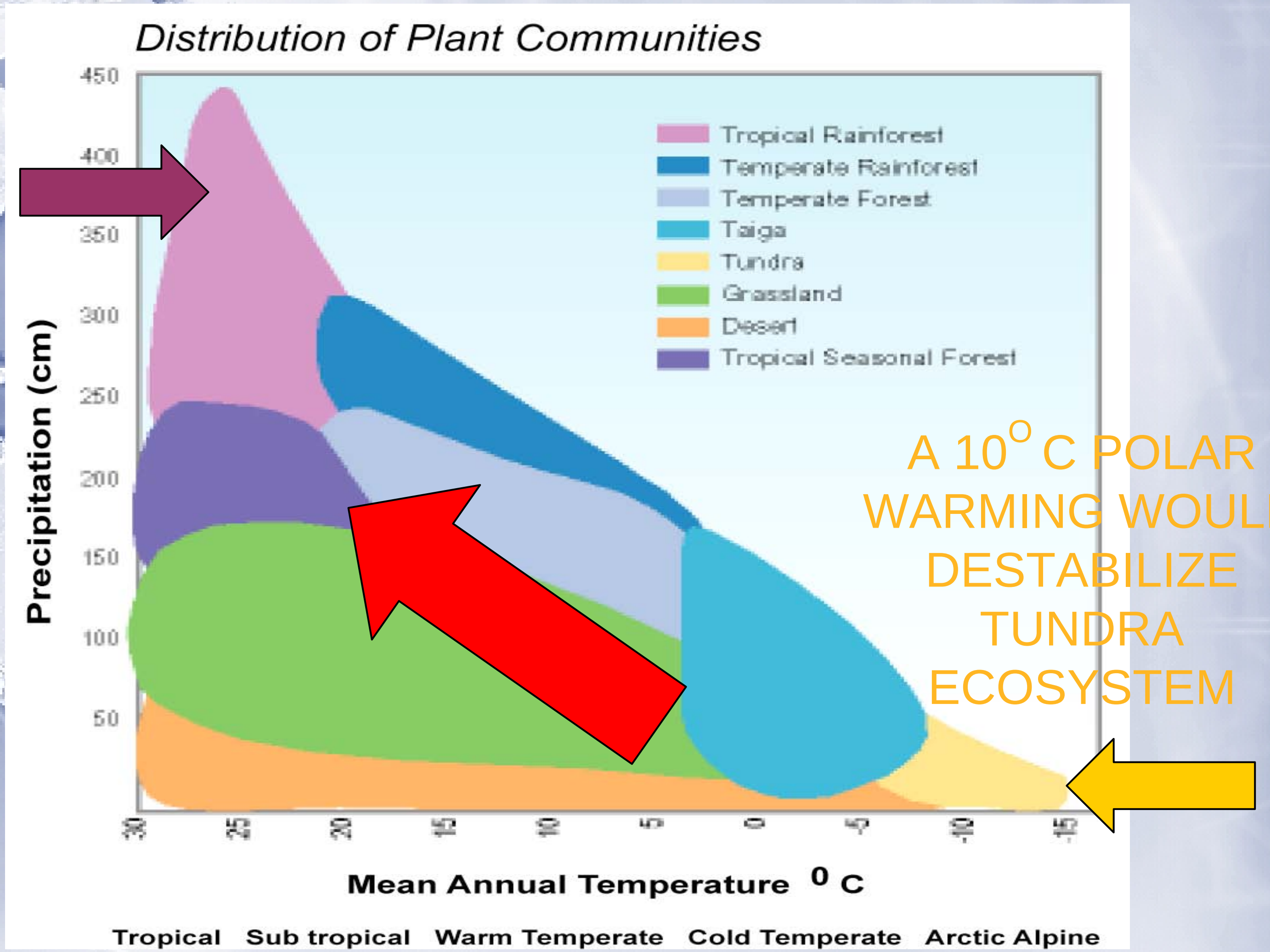
Ref: Prinn et al, Climatic Change,1999

In both cases emissions increase about 30% with a 2.6^{o}C global warming

Images removed due to copyright restrictions. See Figure 33 in:

Prinn, R., et al. "Integrated Global System Model for Climate Policy Assessment: Feedbacks and Sensitivity Studies." *Climatic Change* 41, no. 3/4 (1999): 469-546.

CLIMATE CHANGE IMPACTS ON ECOSYSTEMS



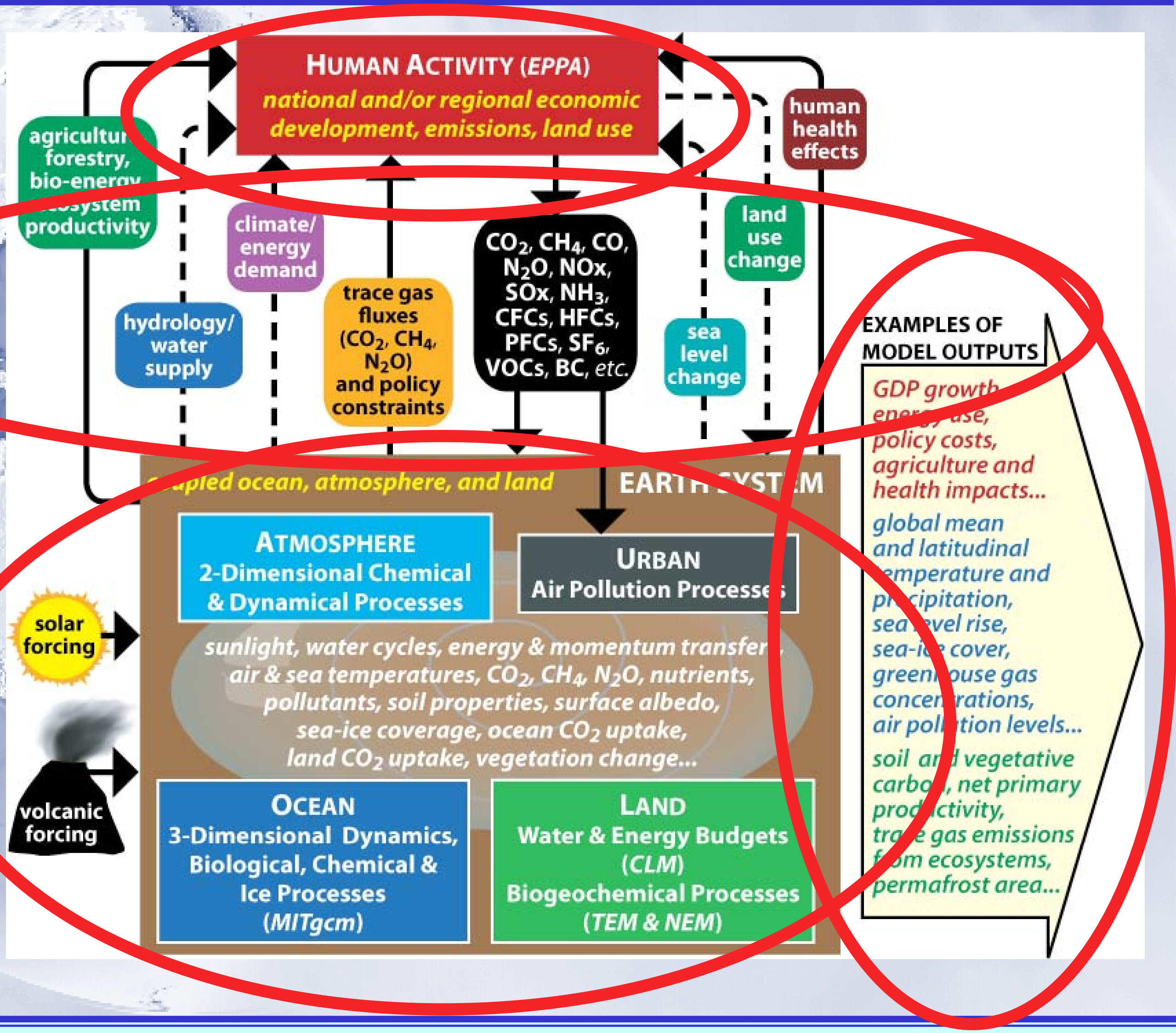
National Assessment Synthesis Team, Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change (Washington, DC: U.S. Global Change Research Program, 2000). Courtesy of The U.S. Global Change Research Program (USGCRP). Used with permission.

WHAT SUB-MODELS OF THE EARTH SYSTEM ARE NEEDED TO FORECAST CLIMATE?

HOW MUCH COMPLEXITY IS NEEDED?

ARE THERE LIMITS TO THE COMPLEXITY THAT CAN BE INCLUDED?

TO FORECAST CLIMATE CHANGE
WE NEED TO COUPLE THE HUMAN &
NATURAL COMPONENTS OF THE EARTH SYSTEM.



MIT INTEGRATED GLOBAL SYSTEM MODEL VERSION 2

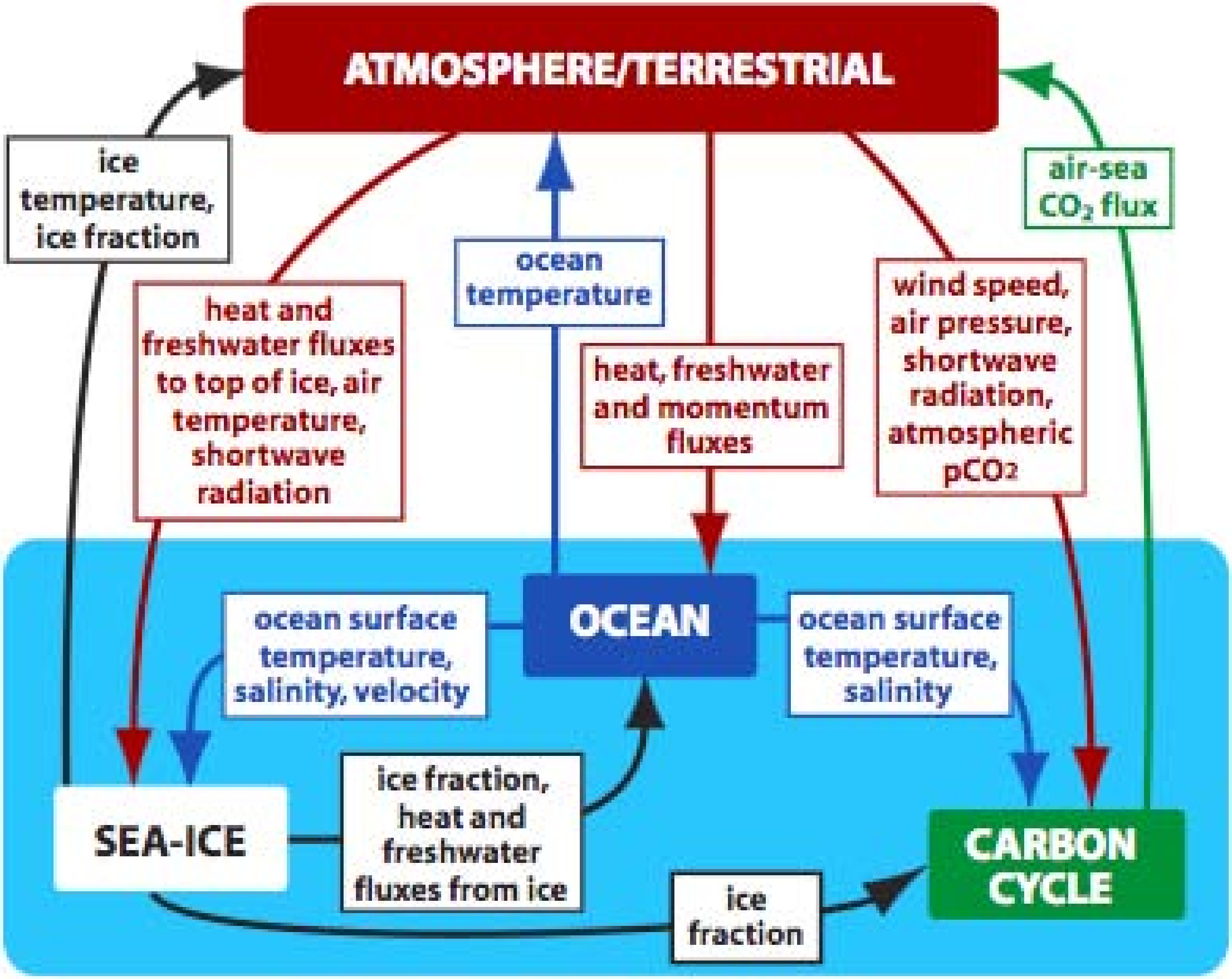


Figure 2. Schematic of the ocean model component of the IGSM2.

Biogeophysical and Biogeochemical Pathways in the IGSM Global Land System (GLS)

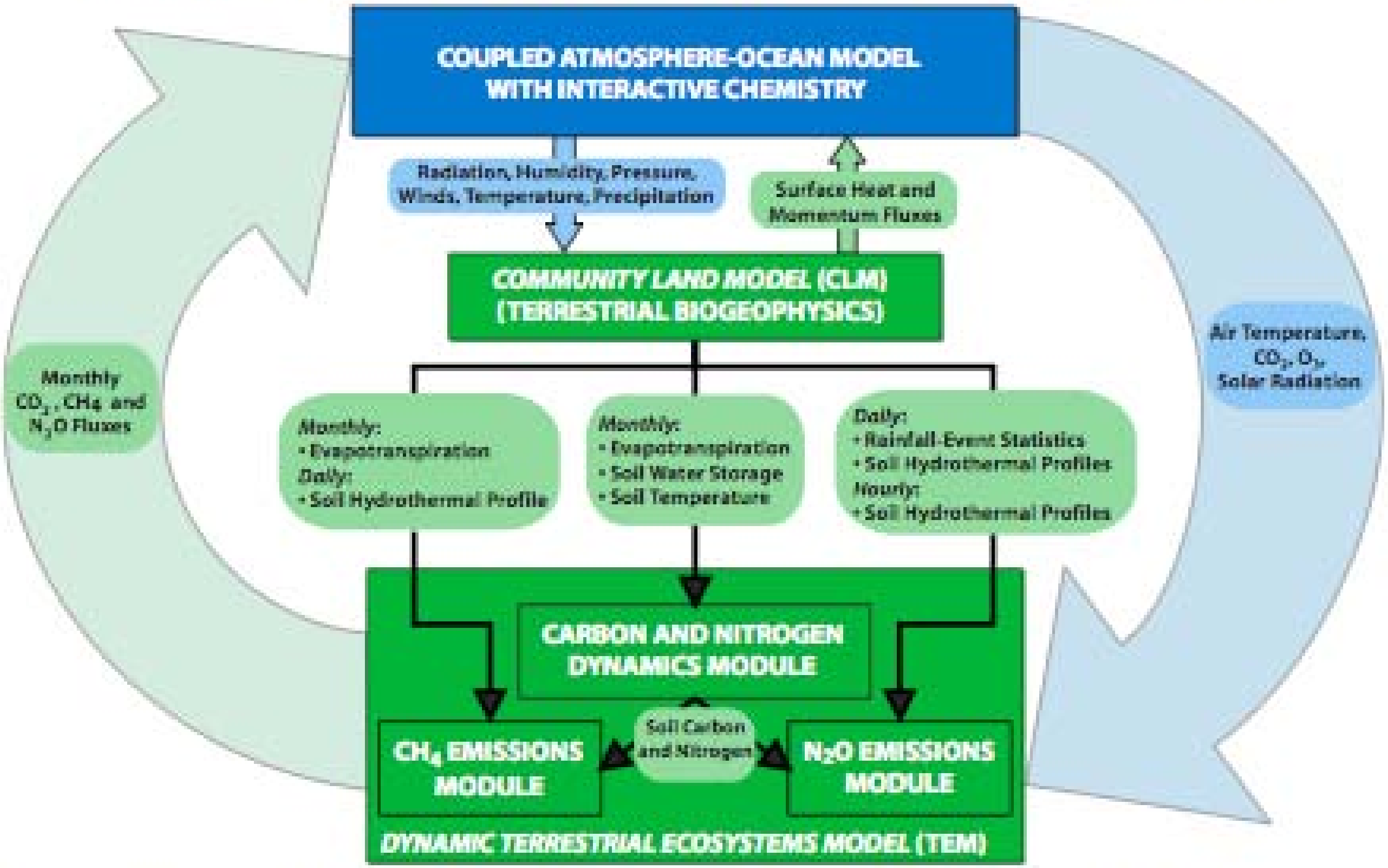


Figure 3. Schematic of coupling between the atmospheric model (which also includes linkages to the air chemistry and ocean models) and the land model components of the IGSM2, also shown are the linkages between the biogeophysical (CLM) and biogeochemical (TEM) subcomponents. All green shaded boxes indicate fluxes/storage that are explicitly calculated/tracked by this Global Land System (GLS). The blue shaded boxes indicate those quantities that are calculated by the atmospheric model of the IGSM2.

IGSM VERSION 1 REFERENCE FORECAST FOR EMISSIONS (NO EXPLICIT POLICY)

Images removed due to copyright restrictions. See Figure 15 in:

Prinn, R., et al. "Integrated Global System Model for Climate Policy Assessment: Feedbacks and Sensitivity Studies." *Climatic Change* 41, no. 3/4 (1999): 469-546.

Annual EPPA (solid lines) and natural (dotted lines) emissions for the Reference Run.

Source: Prinn *et al*., ***Climatic Change***, 41, 469-546, 1999

IGSM 1 REFERENCE FORECASTS (NO EXPLICIT POLICY)

Images removed due to copyright restrictions. See Figure 16 in:

Prinn, R., et al. "Integrated Global System Model for Climate Policy Assessment: Feedbacks and Sensitivity Studies." *Climatic Change* 41, no. 3/4 (1999): 469-546.

Changes $(\Delta's)$ are from 1990 levels

Reference: Prinn, *et al*., **Climatic Change**, 41, 469-546, 1999

REFERENCE FORECAST FOR RADIATIVE FORCING (W/m^2, NO EXPLICIT POLICY)

NOTE EFFECT OF AEROSOL COOLING

Images removed due to copyright restrictions. See Figure 19 in:

Prinn, R., et al. "Integrated Global System Model for Climate Policy Assessment: Feedbacks and Sensitivity Studies." *Climatic Change* 41, no. 3/4 (1999): 469-546.

Reference: Prinn, *et al*., **Climatic Change**, 41, 469-546, 1999

POLES WARM FASTER THAN EQUATOR!

REFERENCE TEMPERATURE FORECAST FOR NO EXPLICIT POLICY

Images removed due to copyright restrictions. See Figure 20 in:

Prinn, R., et al. "Integrated Global System Model for Climate Policy Assessment: Feedbacks and Sensitivity Studies." *Climatic Change* 41, no. 3/4 (1999): 469-546.

NOTE EFFECT OF AEROSOL COOLING SMOOTHED BY N-S HEAT TRANSPORT

Reference: Prinn, *et al*., **Climatic Change**, 41, 469-546, 1999

WHAT IS THE ADVANTAGE OF A POLICY THAT STABILIZES CO_2 LEVELS AT TWICE PREINDUSTRIAL LEVELS (550 ppm)?

Compare:

Reference (RRR, no policy, with 740 ppm in 2100)

and

550 ppm Stabilization (SRR, 530 ppm in 2100)

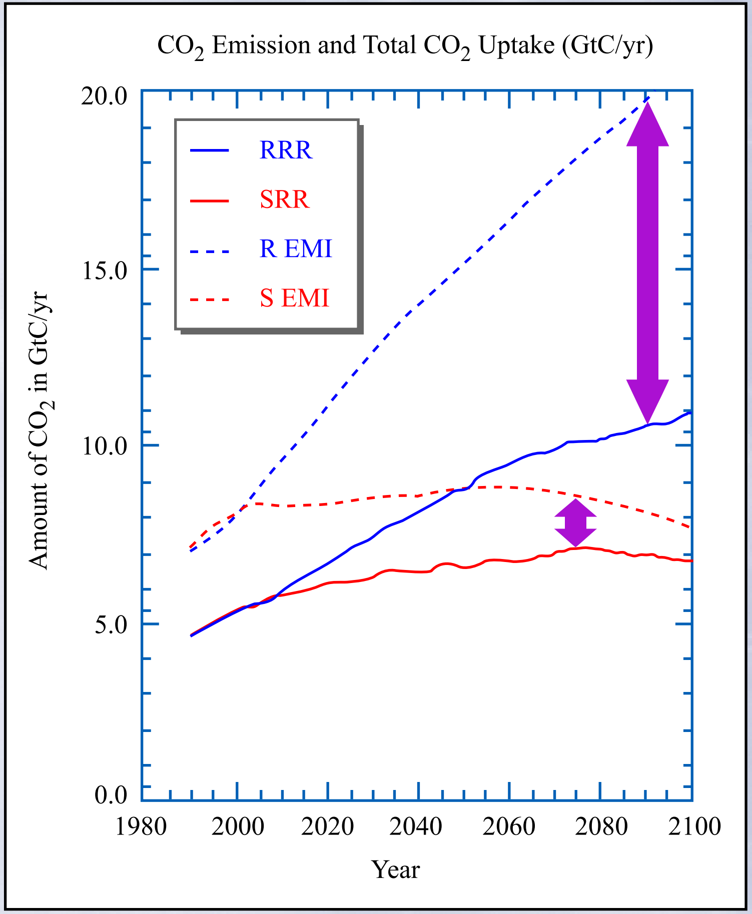


Figure by MIT OpenCourseWare.

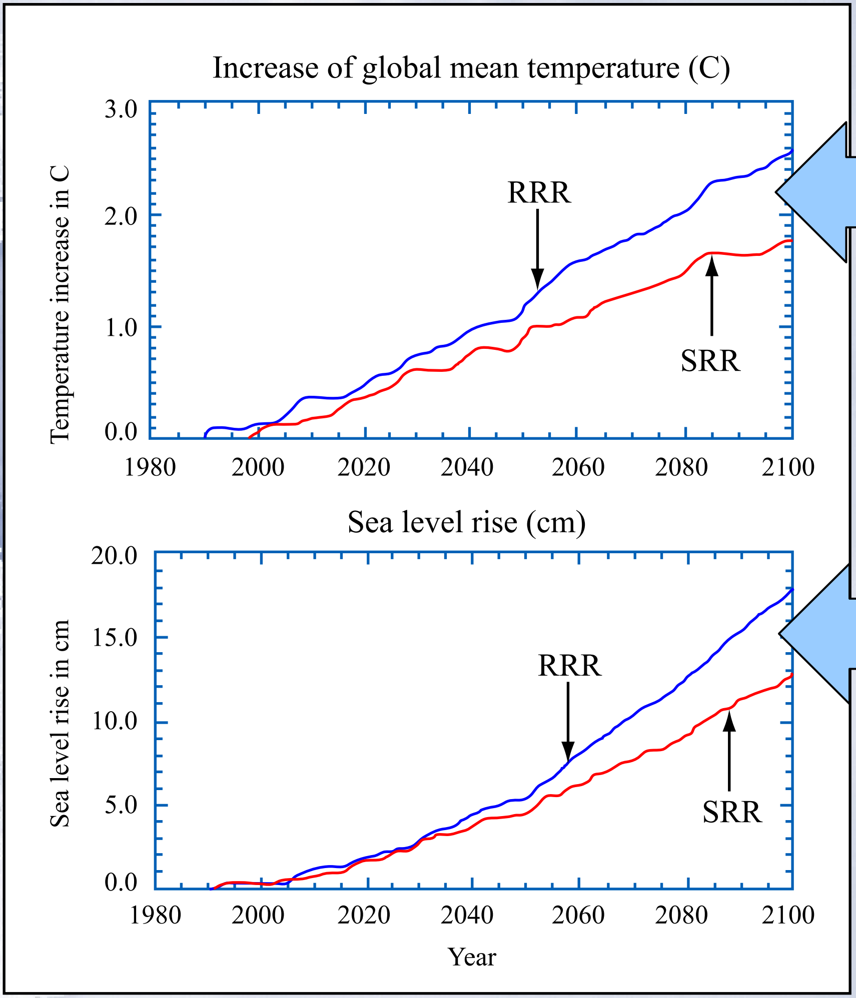


Figure by MIT OpenCourseWare.

Effect of Stabilization in 2100 is not dramatic due to ocean heat & carbon uptake.

COMPARISON OF RESULTS FROM IGSM 1 AND THE LATEST VERSION OF THE IGSM 2.2 (Sokolov et al, Joint Program Report 124, 2005)

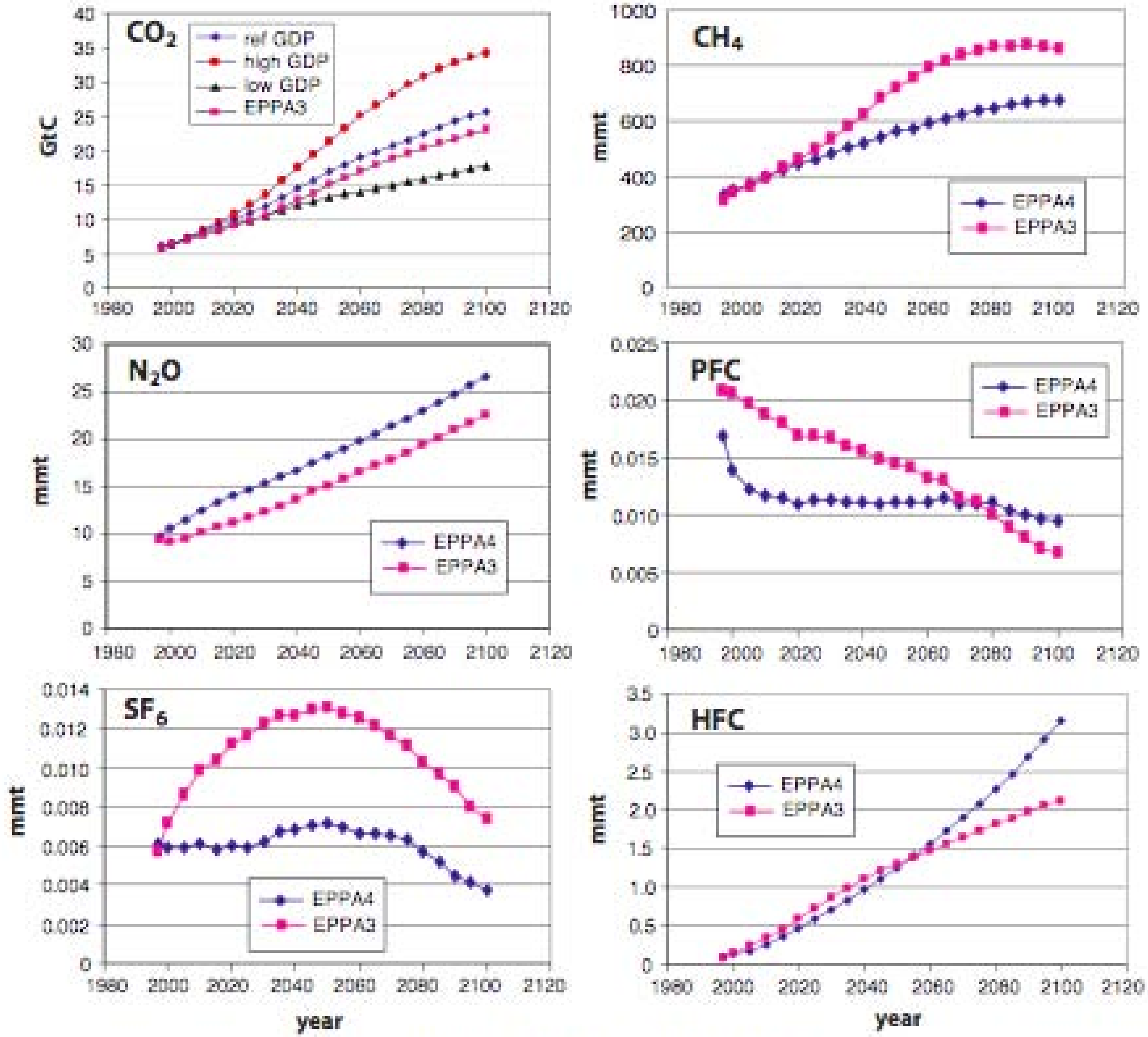


Figure 4. Emissions projections for greenhouse gases.

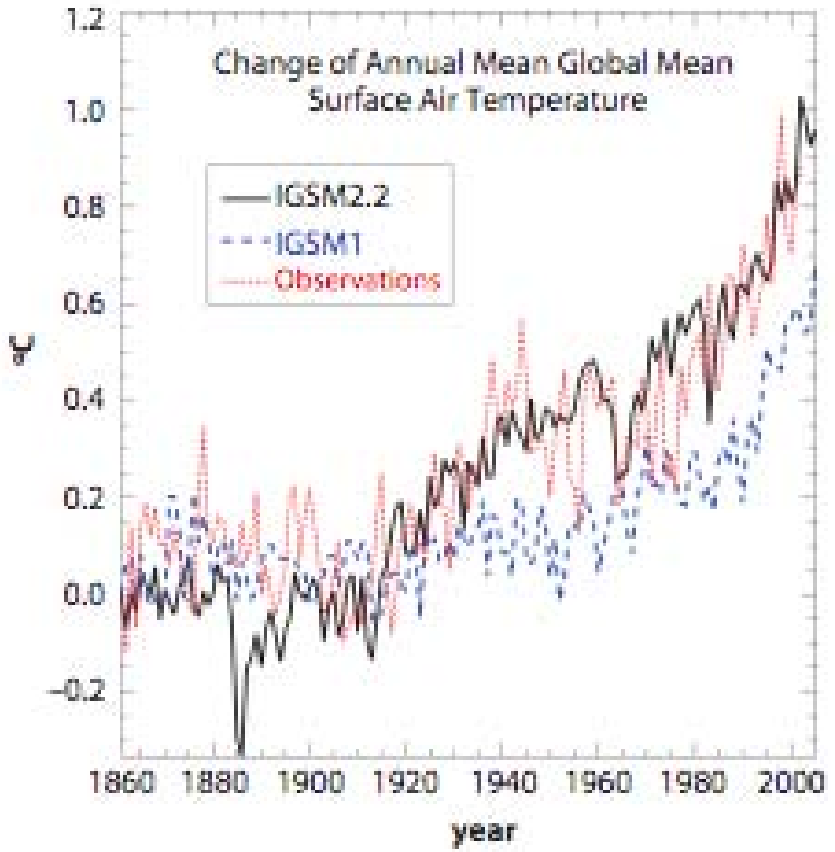


Figure 11. Changes in global mean annual mean surface air temperature in simulations with IGSM1 (dashed blue line) and IGSM2.2 (black line). Observations (dotted red line) are from Jones (2003).

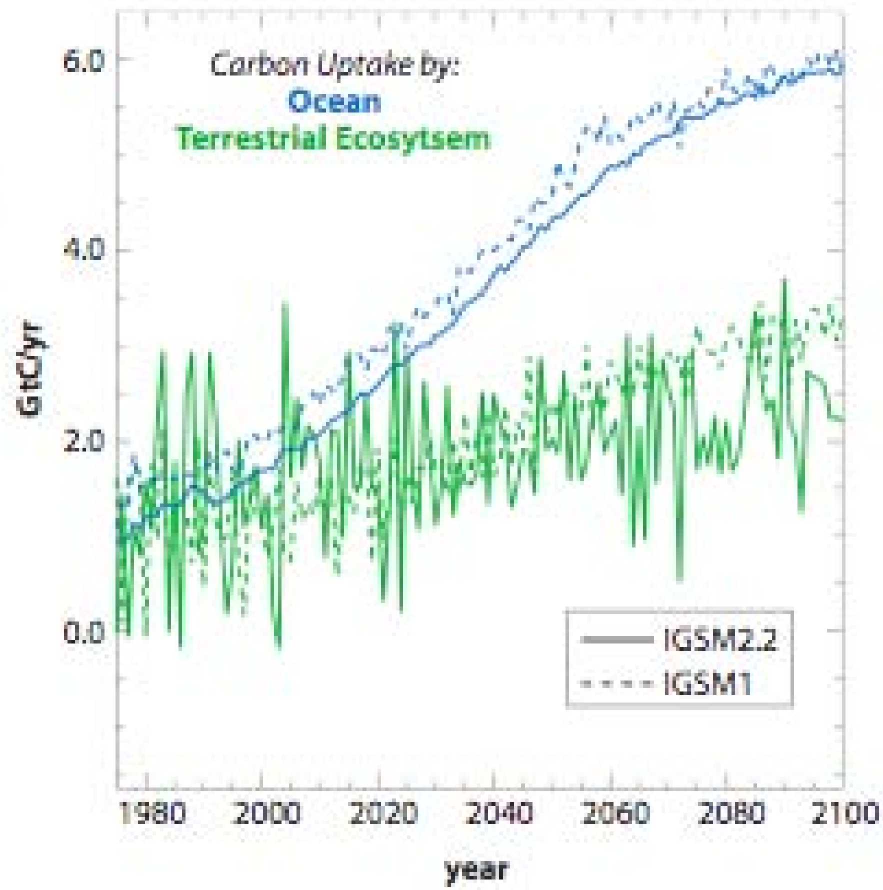


Figure 12. Carbon uptake by ocean (blue) and terrestrial ecosystem (green) in the simulations with the IGSM2.2 (solid lines) and IGSM1 (dashed lines).

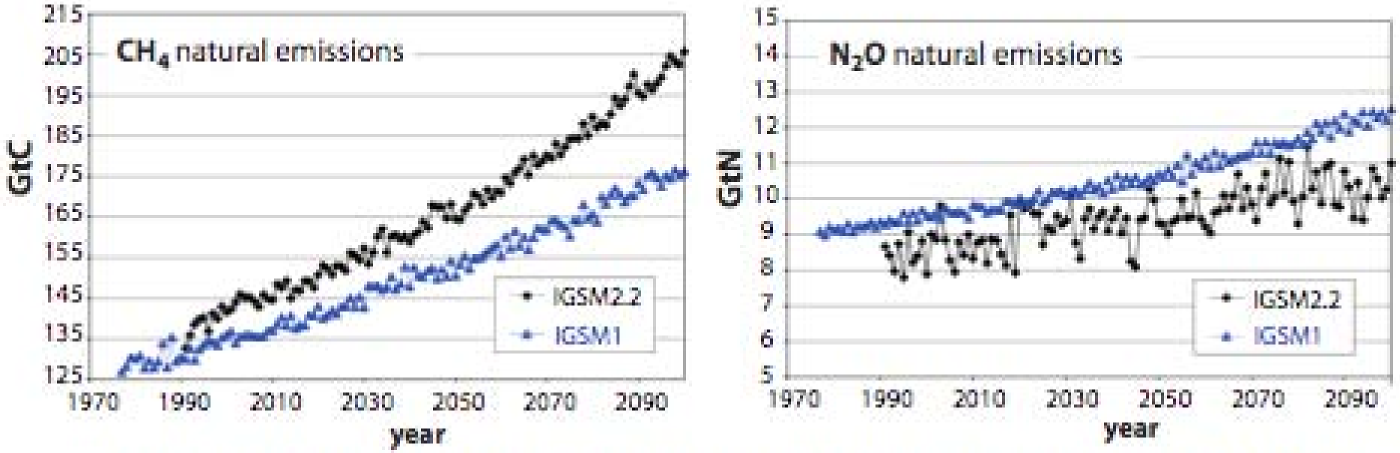


Figure 13. Natural emissions of CH_4 and N_2O in the simulations with the IGSM1 and IGSM2.2.

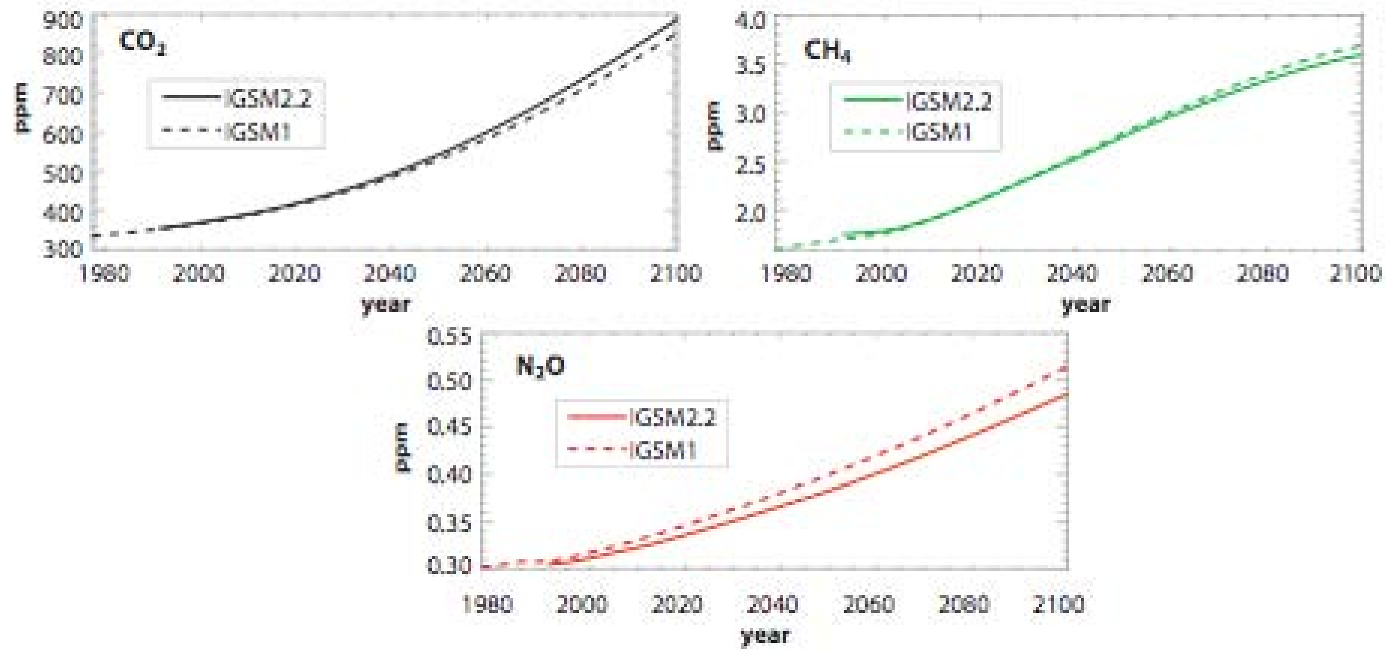


Figure 14. Atmospheric concentrations of CO_2 (black), CH_4 (green) and N_2O (red) in the simulations with the IGSM2.2 (solid lines) and IGSM1 (dashed lines).

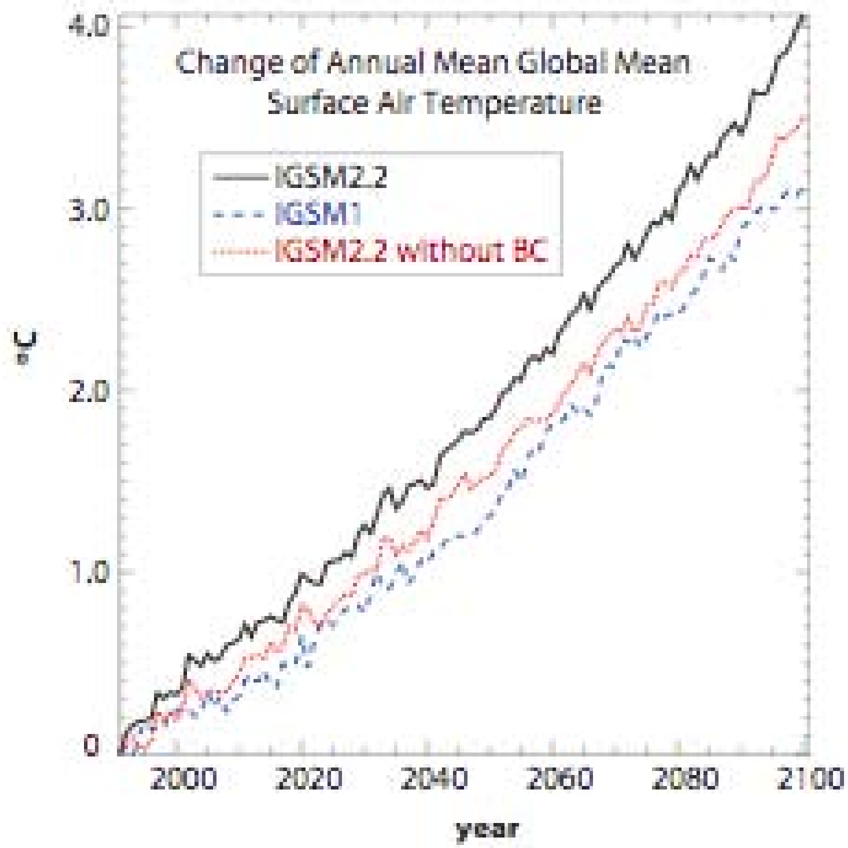


Figure 17. Changes in global mean annual mean surface air temperature in simulations with IGSM1(dashed blue line), IGSM2.2 (solid black line), and IGSM2.2 without including the radiative effect of black carbon (dotted red line).

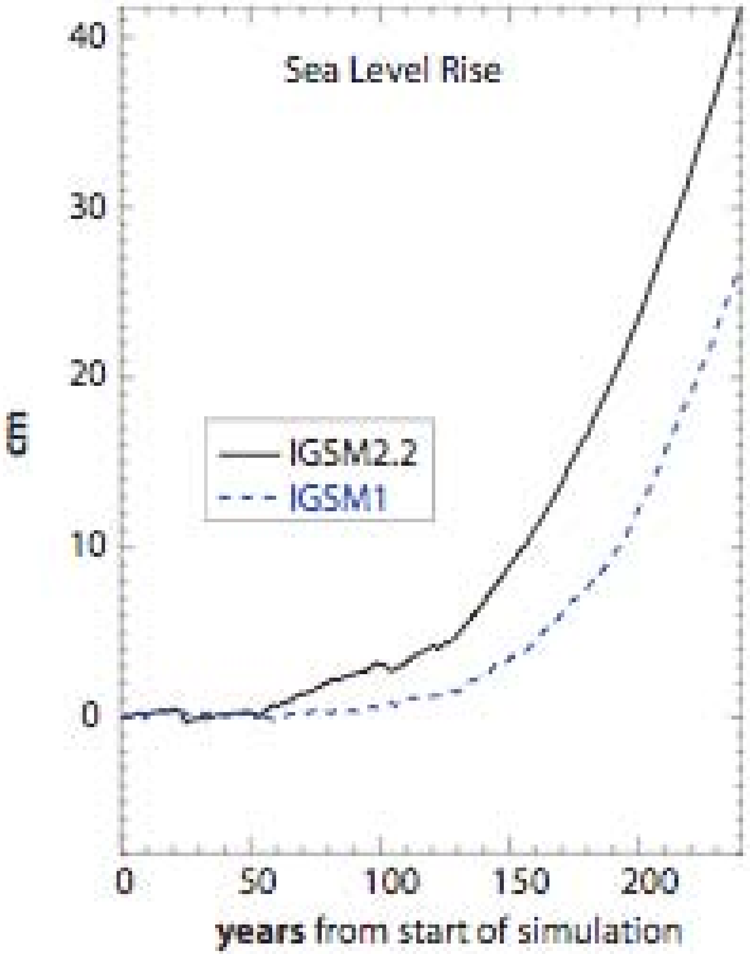


Figure 18. Sea level rise due to thermal expansion in simulations with IGSM1 (dashed blue) and IGSM2.2 (solid line).

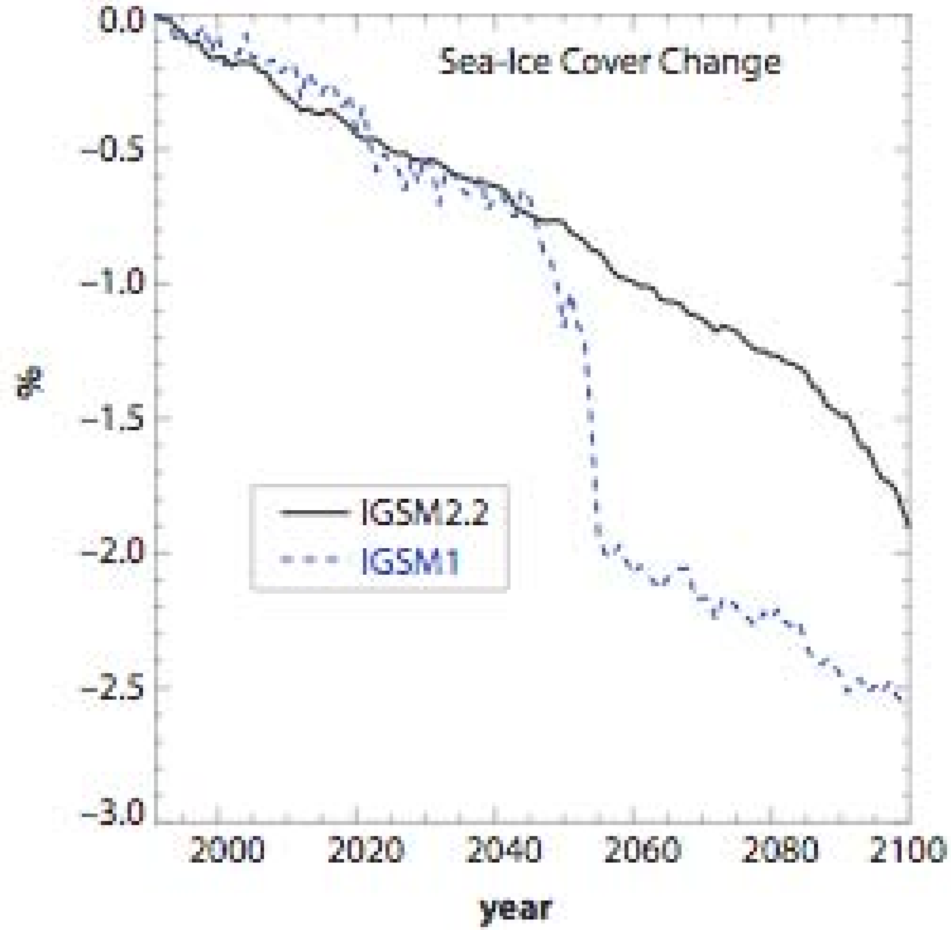


Figure 19. Sea-ice cover change (from 1990) in simulations with IGSM1 (dashed blue line) and IGSM2.2 (solid black line).

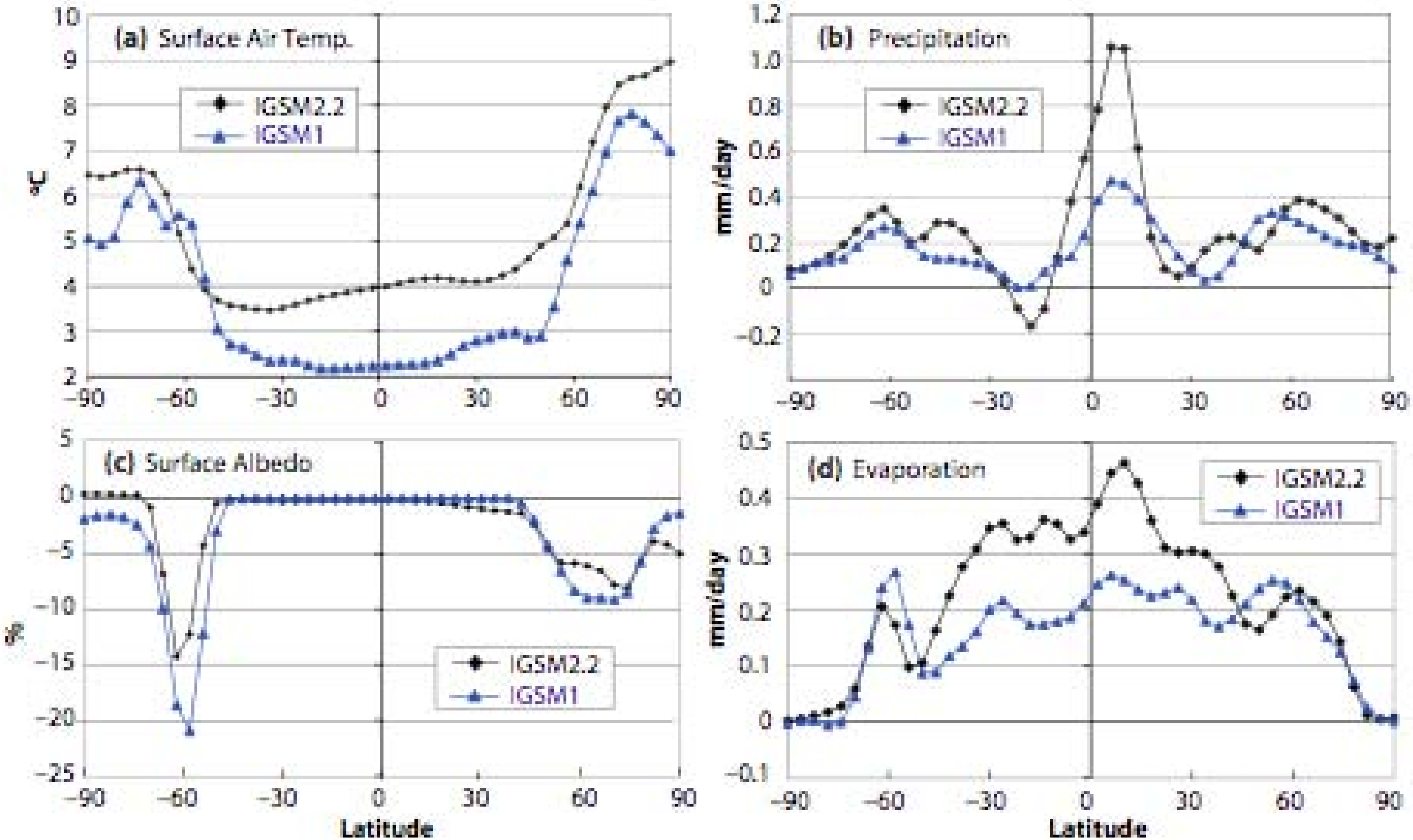


Figure 20. Changes in zonally averaged (a) surface air temperature, (b) precipitation, (c) surface albedo, and (d) evaporation. Difference between decadal means 2091-2100 and 1981-1990.