The Future of Climate Modeling at GFDL

The Earth System Model

NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), http://www.gfdl.noaa.gov, has been constructing the next generation Earth System Model (ESM), http://www.gfdl.noaa.gov/~jpd/esmdt.html, to advance our understanding of how the Earth's biogeochemical cycles, including human actions, interact with the climate system. Like GFDL's current models, this simulation tool is based on an atmospheric circulation model coupled with an oceanic circulation model, with representations of land and sea ice dynamics. These models have been a large collaborative effort for GFDL scientists to construct a set of mathematical equations for fluid flow devised by climate modelers to study weather, climate, and potential changes, both natural and anthropogenic. The mathematical equations require large super computers to calculate and produce the model's results, http://www.oar.noaa.gov/climate/t_modeling.html.

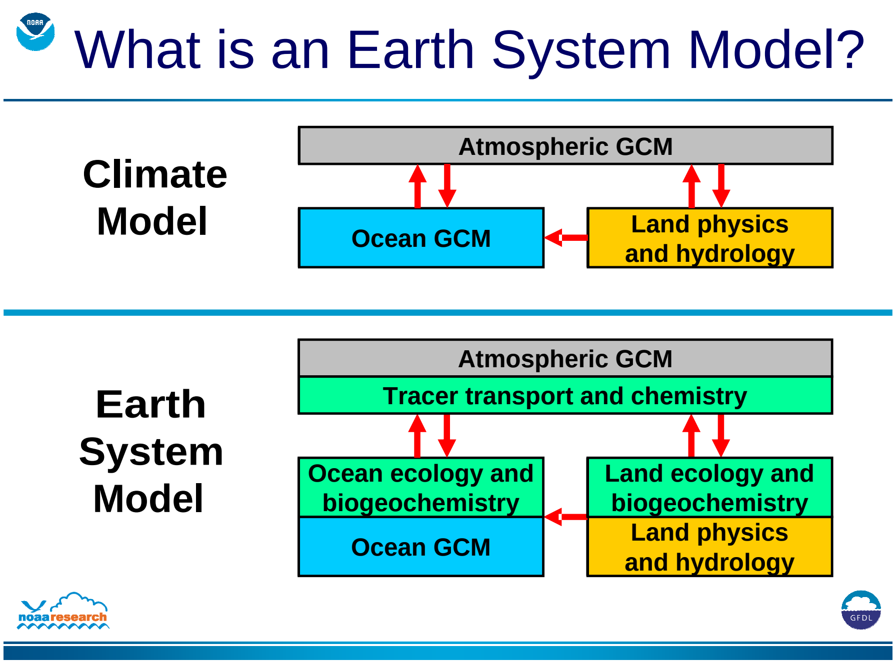

Figure 1. Basic structure of GFDL's Earth System Model

The atmospheric component includes physical features such as aerosols (both natural and anthropogenic), cloud physics, and precipitation. The land component includes precipitation and evaporation, streams, lakes, rivers, and runoff. The oceanic component includes features such as free surface, to capture wave processes; water fluxes, or flow; currents; sea ice dynamics; and a state-of-the-art representation of ocean mixing.

Carbon is the basic building block of ecosystems and undergoes extensive ocean chemistry. An ESM adds, to all of these processes, the interactive carbon cycles, and associated chemical and ecological tracers, which determine nutrients, plant biomass and productivity. Chemical tracers also keep track of reactions as they move along in the water or air. For example, a cloud would be a tracer of air movement because a cloud is easily visible. The ESM also captures numerous types of emissions, variations of land surface albedo due to both natural vegetation changes and land use history, including agriculture and forestry, and aerosol chemistry. Adding these different components to the ESM represents a major step towards simulating the Earth's ecological systems.

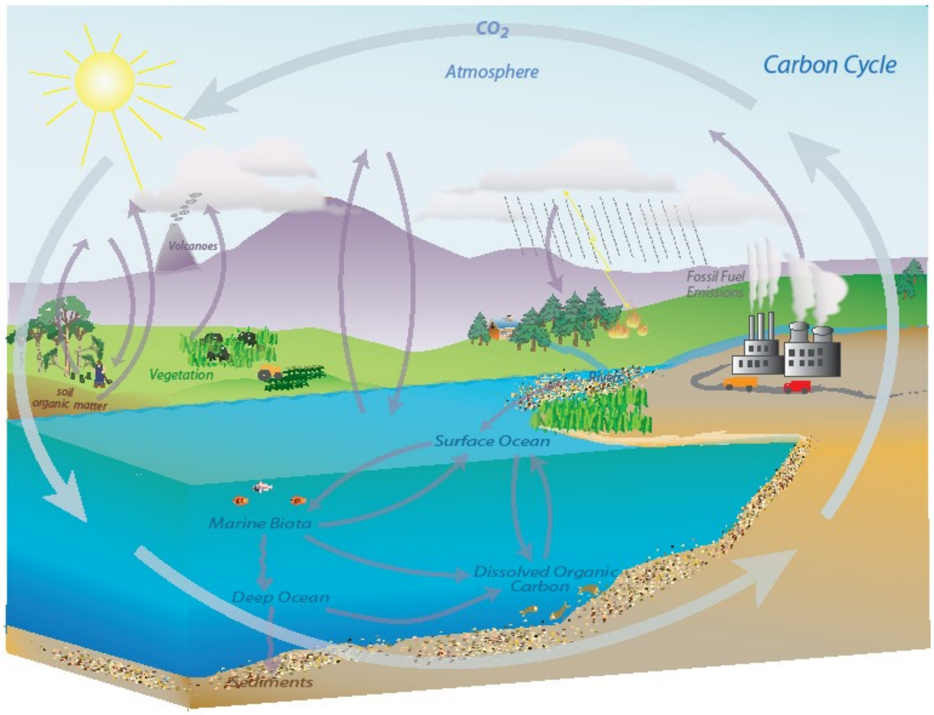

Figure 2. Global Carbon Cycle

In the absence of these complex components, most current models simplify biogeochemical processes, such as the carbon cycle, making future predictions less certain; models that simulate carbon in a realistic manner would have many additional applications. The present goal for the ESM modelers is to simulate change in land and ocean interactions with atmospheric carbon dioxide. Our vision of global modeling is an integrated ESM, projecting not only climate variability on seasonal to centennial timescales, but also biogeochemical and ecosystem cycling and biospheric feedbacks on the climate system. It will allow us to study coastal ocean ecosystems and is an important step toward ecological prediction. This is a comprehensive effort, requiring incorporation of climate dynamics, ecological processes and human activity. GFDL has made great strides in developing and applying predictive models of climate - the physics backbone of the ESM. For the recent set of Intergovernmental Panel on Climate Change (IPCC) studies, GFDL's climate models were ranked among the world's best. These models have been successful in representing the observed dynamics of El Nino and drying in the African Sahel, and providing good seasonal predictive skill.

GFDL's current ESM development efforts are focused on the inclusion of interactive carbon cycling in the GFDL climate model. This will allow us to simulate changes and biospheric feedbacks associated with terrestrial ecology, atmospheric greenhouse gas, and ocean biogeochemistry responses to fossil fuel emissions and land use change. In partnership with Princeton University and the University of New Hampshire, the lab has developed a global land biogeochemistry and ecology model that includes dynamic vegetation and a representation of changing land use practices such as management of crops, pasture, and secondary forests. Current efforts are focused on evaluation of biophysical and biogeochemical feedbacks and improvements in the hydrological model. Additionally, a nitrogen cycle model is being developed to track effects of nutrient limitation on plant photosynthesis and organic matter reformation of minerals in soils.

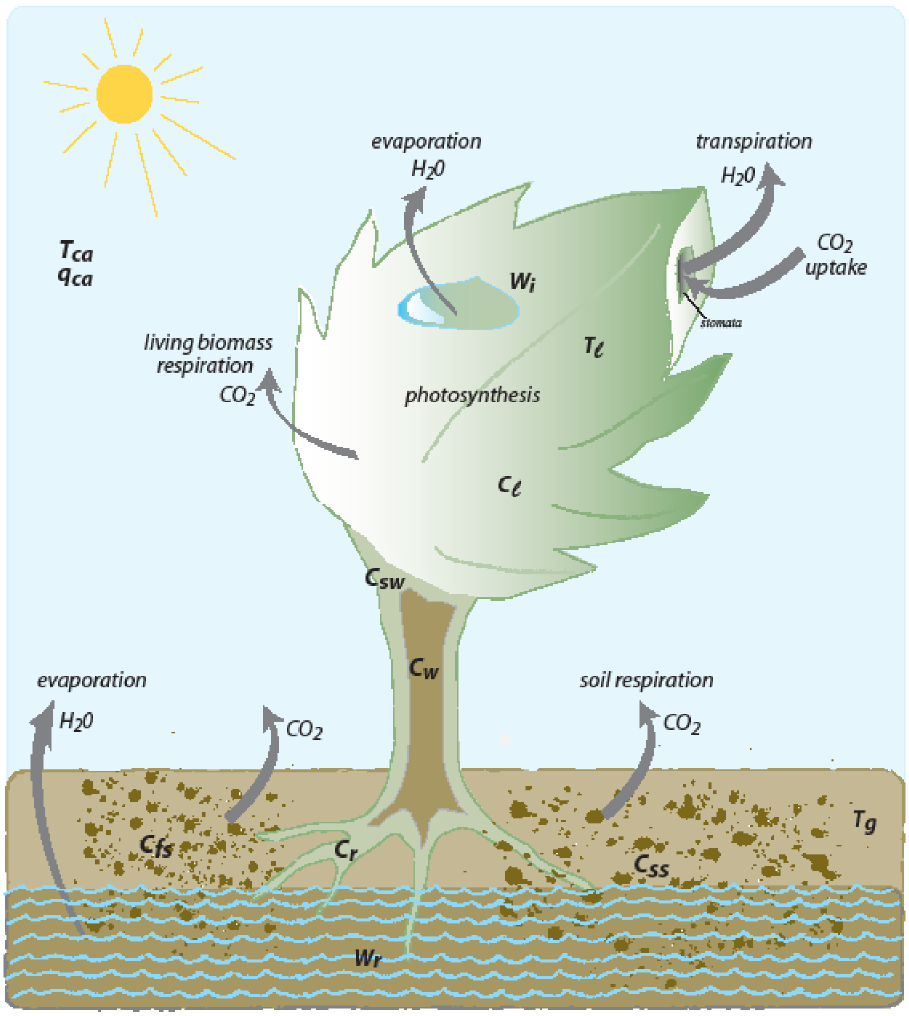

Figure 3. Global land biogeochemistry and ecology model used in GFDL's Earth System Model

In parallel to land model development efforts, GFDL has developed a new model of oceanic ecosystems and biogeochemical cycles. This state-of-the art model considers 22 tracers including three phytoplankton groups, animal and bacteria biomass (organisms that survive on carbon for growth and development), two forms of dissolved organic matter, and dissolved inorganic species for carbon, nitrogen, iron, calcium carbonate, and oxygen cycling. The model includes such processes as gas exchange, atmospheric deposition, scavenging, nitrogen gas fixation, and transforming active nitrogen into inactive nitrogen gas. Current efforts are focused on model tuning of river inputs, ocean acidification, calcium carbonate cycling, and sediment processes.

Beyond carbon, simulating complex nitrogen biogeochemistry - with its vast human influence - is a critical challenge. Building upon our success of the integration of climate and carbon cycle models, we plan to fully integrate nitrogen cycling into the atmosphere, land, river, and coastal components and apply this model to study problems of global and regional environmental change. One of the most important goals of NOAA's ESM is to model coastal ecological systems, since this is where most human activity occurs in the ocean, such as fishing, recreation, and marine research. A broad array of new efforts will be directed towards a detailed understanding of global and local physical, biogeochemical, and ecological processes as they relate to the coast, including productivity and water quality issues such as hypoxia and harmful algal bloom events.

Based on GFDL's expertise in climate modeling, our efforts to include realistic Earth mechanisms and processes represent an initial stride towards modeling the Earth as a system. Fine tuning the ESM will enable better predictions of how the land and ocean biosphere will respond to atmospheric carbon dioxide admissions and thus, the degree of greenhouse warming. The ESM will also enable better understanding of the climate change impacts to the biosphere and pollution affects. These efforts are propelling GFDL to new frontiers of climate science.

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