MARINE ECOLOGY, BIOGEOCHEMISTRY AND ATMOSPHERIC CO_2 SIGNATURE FROM A 43-YEAR REANALYSIS IN A GLOBAL ICE/OCEAN BIOGEOCHEMICAL GENERAL CIRCULATION MODEL

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ABSTRACT

We have developed a multiple element (C, N, P, Si, Ca, Fe) biogeochemical model of marine ecology that includes small, large and diazotrophic phytoplankton as well as explicit ballast-driven sinking and remineralization of detrital organic matter and cycling of dissolved organic matter. Phytoplankton growth is described through a new formulation including co-limitation by N, P, Si, Fe and light to reproduce broad observational trends. Phytoplankton grazing is described through different power laws in the closure terms for small and large phytoplankton to reproduce observed augmentation of large phytoplankton with increasing production. Detritus production is assumed to be a temperature dependent fraction of small and large phytoplankton. This model has been imbedded in a 1-degree; global ice/ocean general circulation model (MOM4) forced by a 43-year atmospheric reanalysis forcing from the Common Ocean Reference Experiments (CORE) program to quantify the relationship between food web structure, biogeochemical cycles and the atmospheric CO_2 signature on inter-annual timescales. Novel aspects in the model structure are described, the impact of the formulation of ecosystem structure on biogeochemical cycling are discussed, and results of the atmospheric reanalysis forcing experiment presented. Of particular interest are the dynamical roles played by equatorial ENSO variability and polar sea ice dynamics on air-sea CO_2 fluxes.

MODEL DESCRIPTION

The physical model is a moderate resolution global ocean general circulation model as part of the current Modular Ocean Model Version 4 development effort at the NOAA Geophysical Fluid Dynamics Laboratory. The ocean model rests under a mixed-boundary coupler with and ice model and active estimation of outgoing fluxes. Incoming fluxes of wind stress, freshwater flux, shortwave and longwave radiation are prescribed as boundary conditions from the ECMWF and NCAR Ocean Model Intercomparison Project (OMIP) reanalysis efforts. The model has a 1-degree horizontal resolution globally with enhanced meridional resolution near the equator and a tri-polar grid. There are 50 vertical layers with 10 m resolution in the upper 200 m. It is a C-grid, z-coordinate model with the KPP mixed-layer diffusivity scheme, Bryan-Lewis deeper vertical mixing, neutral physics (re-orientation of diffusivities along isopycnal surfaces) and Gent-McWilliams isopycnal thickness diffusion.

The biogeochemical model tracks multiple elements (C, N, P, Si, Ca, Fe) and includes small, large and diazotrophic phytoplankton as well as explicit ballast-driven sinking and remineralization of detrital organic matter and cycling of dissolved organic matter. The growth of phytoplankton is described through a new formulation of co-limitation by N, P, Si, Fe and light with variable Chl:N ratios. Most notably, the Fe:N ratio is allowed to modulate the Chl:N ratio via the Fe:N ratio of phytoplankton, consistent with observations. The Si:N uptake ratio in diatoms is modulated by nutrient limitation while $CaCO_3$

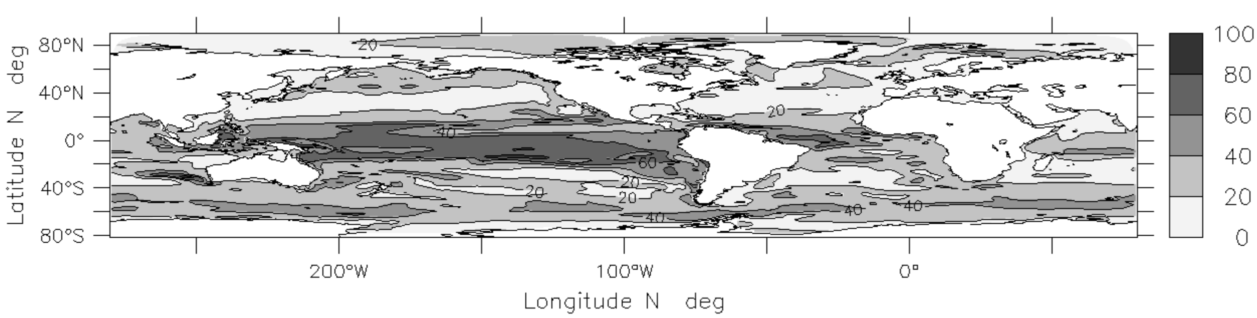
production is assumed to be a constant fraction of small phytoplankton production. The grazing of small and diazotrophic phytoplankton is proportional to their concentration to the 2nd power – consistent with an instantaneous steady state with an implicit grazer population – while grazing of large phytoplankton is proportional to their concentration to the 4/3rd power – consistent with a moderate imbalance with an implicit grazer population. Sinking detritus production is a temperature dependent fraction of small (plus diazotrophic) and large phytoplankton grazing, with one temperature dependence, but different maximal detritus-production-efficiencies. Dissolved Fe adsorbs onto sinking organic particles. Sinking organic material is protected from remineralization by silica and $CaCO_3$ mineral.

RESULTS : MODEL-DATA COMPARISON

Comparison of surface nutrients between the World Ocean Atlas 2001 and the model suggests that the model is reproducing large scale geographical variability in surface nutrients, though many areas for improvement exist. Model Equatorial and North Polar nitrate and phosphate are artificially high, suggesting too little production in these regions. Silicate has a high lobe along the Chilean coast and artificially low values on the equator. Comparison of model surface chlorophyll (Chl) with estimates from the SeaWIFS satellite suggests that the model captures some features of geographical and seasonal variability, but misses others. The general features of low Chl in oligotrophic regions and high Chl in shelf regions and eastern boundary currents are well-represented. The model gives a ribbon of high Chl in the tropical North Pacific that is not observed. The North Atlantic bloom begins and disappears too early. Observed Southern Ocean high Chl. values banding 40S are not captured in the model while those in the Equatorial and Northern Subpolar Pacific are too high. The model reproduces thermocline oxygen distributions extremely well as required to simulate the extent of thermocline anoxia. Modeled air-Sea CO_2 flux patterns compares very well with the Takahashi maps, being dominated by out-gassing in the Equatorial Pacific and in-gassing in the North Atlantic. The primary discrepancy is in the southern ocean, for which the model has a great deal of out-gassing.

DISCUSSION: INTER-ANNUAL VARIABILITY

While the ocean carbon system needs to be equilibrated with pre-industrial conditions and allowed to undergo increases given observed atmospheric forcing, early results of inter-annual variability by forcing the model with NCAR/NCEP re-analysis winds and freshwater fluxes suggest that variability in sea-air CO_2 fluxes is dominated by the inter-annual timescales in the equatorial Pacific, but were elsewhere dominated by seasonal timescales. Globally integrated however, variability in these fluxes was found to be mild relative to terrestrial fluxes. This is due in part to the perpetual outgassing inferred for the Equatorial Pacific upwelling region, and to our key result that the intermittently ice-covered regions do not degas significant levels of CO_2 as phytoplankton growth was able to consume excess CO_2 accumulated over-winter under the ice before it was able to escape. The model results suggest, however, that water column denitrification may be subject to significant modes of variability on these timescales. This variability was due a combination of variability in the volume of anoxic waters and the variability of sinking fluxes into those waters.



Map of the percent of sea-air CO_2 flux variability attributable to inter-annual timescales in the model.