CCSM3-IBIS: Initial Testing of a Terrestrial Dynamic Global Ecosystem Model Fully Coupled to CCSM3

Forrest Hoffman[1], Art Mirin[2], Jon Foley[3], Wilfred Post[1], David Erickson[1], Bala Govindasmy[2], Anthony King[1]

Oak Ridge National Laboratory[1]; Lawrence Livermore National Laboratory[2]; University of Wisconsin[3]

Abstract

Terrestrial biogeochemistry models (BGCM), and even in some cases dynamic global terrestrial ecosystem models (DGEM) have been coupled to climate system models. Such coupled models are an important tool for describing the feedback between global biogeochemical dynamics and climate and making improved climate projections under future global change. Often, however, such models are untested. The Integrated Biosphere Simulator (IBIS) has been evaluated in a number of model intercomparisons and model-data intercomparisions in stand-alone mode. Originally developed as a replacement land-surface model for LSX, IBIS was modified in order to be coupled to PCM and C4MIP Phase 2 simulations were completed. The modified IBIS was rewritten to communicate with the CCSM3 Flux Coupler. Here, we present the successful results from this coupled model.

Description of IBIS

IBIS is designed to be a comprehensive model of the terrestrial biosphere. The model represents a wide range of processes including surface physics, canopy physiology, plant phenology, vegetation dynamics and competition, and carbon and nutrient dynamics. The model generates global simulations of surface water balance (soil moisture availablity, runoff), the terrestrial carbon dynamics (photosynthesis, net primary production, net ecosystem exchange, soil carbon, aboveground and belowground litter, and soil CO_2 fluxes), and vegetation structure (biomass, leaf area index, vegetation composition).

Soils: IBIS uses a multi-layer formulation of soil to simulate the diurnal and seasonal variations of heat and moisture in the top 12 meters of the soil. The eight soil layers in IBIS have top-to-bottom thicknesses of 0.10, 0.15, 0.25, 0.50, 1.0, 2.0, 4.0 and 4.0 m, respectively. At any timestep, each layer is described in terms of soil temperature, volumetric water content and ice content. The IBIS soil physics module uses Richard's equation to calculate the time rate of change of liquid soil moisture, and the vertical flux of water is modeled according to Darcy's Law. The water budget of soil is controlled by the rate of infiltration, evaporation of water from the soil surface, the transpiration stream originating from plants, and redistribution of water in the profile.

Energy Balance: The IBIS land surface module, which is based on the LSX, simulates the energy, water, carbon, and momentum balance of the soil-vegetation-atmosphere system. The model represents two vegetation canopies (i.e., trees *versus* shrubs and grasses), eight soil layers, and three layers of snow (when required). IBIS explicitly represents the temperature of the soil (or snow) surface and the vegetation canopies, as well as the temperature and humidity within the canopy air spaces. The radiation balance of the vegetation and the ground, and the diffusive and turbulent fluxes of sensible heat and water vapor, drive changes in temperature and humidity. Solar radiation transfer is simulated following the two-stream approximation, with separate calculations for direct and diffuse radiation in both visible and near-infrared wavelengths.

Description of IBIS (cont.)

SIMULATED RESERVOIRS

Carbon:

- **vegetation**: fine roots, leaves, and wood for upper canopy (trees) and fine roots and leaves for lower canopy (shrubs and grasses)
- **litter**: above and belowground (fine root) separated into 3 distinct pools (decomposable, structural and resistant)
- **SOC**: microbial biomass, protected and unprotected "slow" C pools, and passive C pool

Nitrogen:

- **vegetation**: assumed C:N ratios for fine roots, leaves, wood
- **litter**: above and belowground (fine root) separated into 3 pools (decomposable, structural, and resistant)
- **SON**: microbial biomass, protected and unprotected "slow" pools, and passive pool

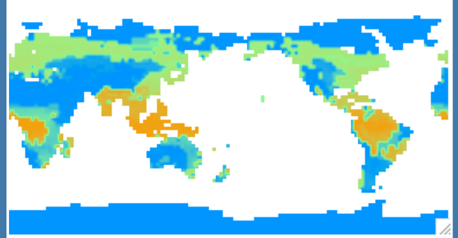
Soil water:

- Physically based model of soil temperature, soil ice and water content in 8 soil layers (0-10, 10-25, 25-50, 50-100, 100-200, 200-400, 400-800, 800-1200 cm)

Results

Simulations for 6 years have been completed on Cheetah a 4.5 TF IBM pSeries System operated by the National Center for Computational Sciences (NCCS) at Oak Ridge National Laboratory.

CCSM3-IBIS Biomass Distribution



Results (cont.)

Carbon Fluxes:

Biomass pools were initialized from previous PCM-IBIS equilibrium runs and appear to be near equilibrium when coupled to CCSM3.

Figure 1. Soil carbon and nitrogen are initialized at small amounts and as a result NEE starts high but rapidly declines toward 0 as soil C pools increase. The soil pools increase rapidly due to an accelerated decomposition scheme employed during spinup (see *Figure 3*).

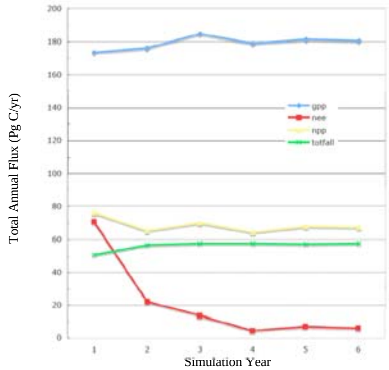
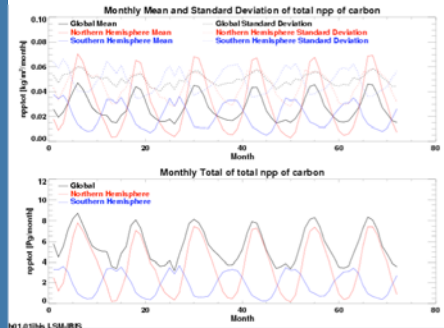


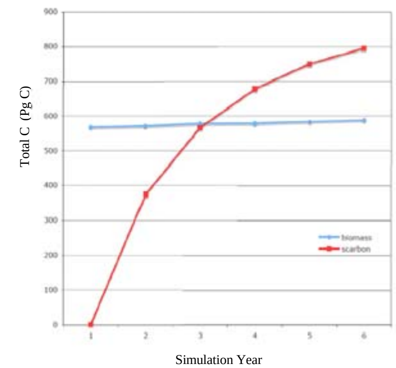
Figure 2. Annual variation of NPP in LSX-IBIS shows larger amplitude than in CLM-CASA'. Comparison of NEE with Globalview observations will be a useful evaluation.



Results (cont.)

Carbon Pools:

Figure 3. Initial biomass pools are near equilibrium. Soil pools start near zero and increase rapidly due to an accelerated decomposition scheme employed during model spinup.



Next Steps

- Completion and evaluation of terrestrial carbon spinup and evaluation with continental and global data on river discharge, NPP, vegetation structure, root biomass, soil carbon, litter carbon, and CO_2 flux.
  - Equilibrate to near pre-industrial conditions defined as 1850 CO2 using repeated cycles of the 1875-1899 SSTs
  - Force the model by two cycles of 1875-1999 SSTs, increasing CO_2 from 1850 to 1999
- Complete simulations for Coupled Climate/Carbon Cycle Model Intercomparison Project (C4MIP)
  - Phase 1 - controlled experiment using prescribed sea surface temperatures (SSTs) and CO_2 uptake, sea ice cover, land cover change, ocean carbon fluxes, and fossil fuel emissions with active atmosphere and land surface models exchanging carbon over the 20th century (1900-2000)
  - Phase 2 - fully coupled model experiments for the future (2000 to 2100) with a CO_2 emission scenario and interactive ocean carbon cycle (POP2).

Future

IBIS is a mature DGEM that could serve as an additional comparison for CCSM. Land surface physics, transpiration and photosynthesis could be made compatible with CLM within the constraints of other IBIS processes (allocation, phenology, nutrients, etc.)