SciDAC Land Model Software Engineering

Forrest M. Hoffman and Pat Worley, Oak Ridge National Laboratory
Inez Fung and Jasmin John, Lawrence Berkeley National Laboratory and University of California at Berkeley
Gordon Bonan, Sam Levis, Keith Oleson, Peter Thornton, and Mariana Vertenstein, National Center for Atmospheric Research

Introduction

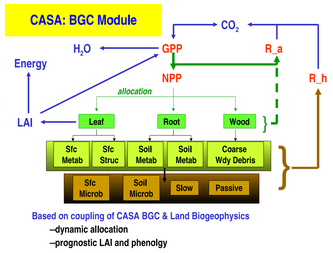
Over the last five years, the SciDAC Climate Consortium Project has contributed to software engineering and model development of the Community Land Model (CLM) within the Community Climate System Model (CCSM). Early software engineering activities included implementation of cache−friendly blocking structures (called "clumps") resulting in better performance and improved load balancing, MxN transposition between land surface "clumps" and atmospheric physics "chunks" speeding up communications between the two models, and vectorization of the CLM for use on the Earth Simulator in Japan and the Cray X1 at ORNL.

Recent efforts include vectorization of the CN (Carbon−Nitrogen) biogeochemistry model within the Community Land Model Version 3 (CLM3); implementation, testing, and spin up of the CASA' biogeochemistry model within CLM3; and regular maintenance of vectorizable code in the model. The results of the CASA' implementation as well as on−going work on a Prognostic Canopy Air Space algorithm are described here.

The CASA' Biogeochemistry Module

The Carnegie/Ames/Stanford Approach (CASA) biogeochemical model, previously modified for use in global climate simulations (Randerson et al. 1997) and coupled to LSM1 in the Climate System Model Version 1.4 (CSIM1.4) Fung et al., 2005), was adapted to CLM3 biogeophysics for use in CCSM3.

Now called CASA', this module computes net primary production (NPP) from CLM's gross primary productivity (GPP) and allocates carbon among three live pools: leaf, root, and wood. These pools feed nine dead pools which include litter, coarse woody debris and various soil pools with different turnover times. CASA' calculates heterotrophic respiration and net ecosystem exchange as well as prognostic phenology and leaf area index (LAI), providing water and energy feedbacks to the atmosphere.

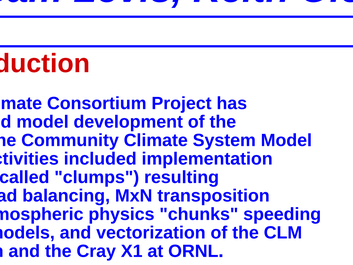


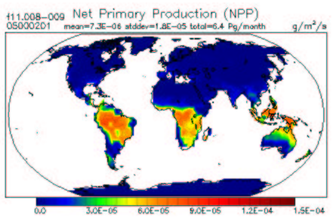
Now coupled into CCSM3, CASA' can provide carbon fluxes from the terrestrial biosphere into the atmosphere. Moreover, the land surface model is forced by atmospheric carbon dioxide concentrations resulting in feedbacks between the land and atmosphere.

CASA' Net Primary Production

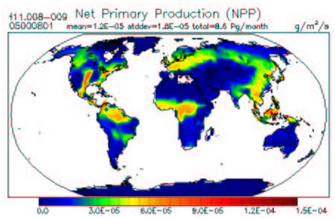
CASA' was spun up with the BGC version of CCSM in the F configuration (i.e., active land and atmosphere) on the Cray X1E at T31 resolution (about 3.75x3.75 degrees). Carbon pools were initialized with spun−up pools from a previous CSIM1.4 simulation. The new pre−industrial spin−up run, forced with Hadley sea surface temperatures, extended out beyond 500 years.

The net primary production (NPP) has the correct seasonal cycle and distribution by hemisphere.





January: 6.4 Pg/month

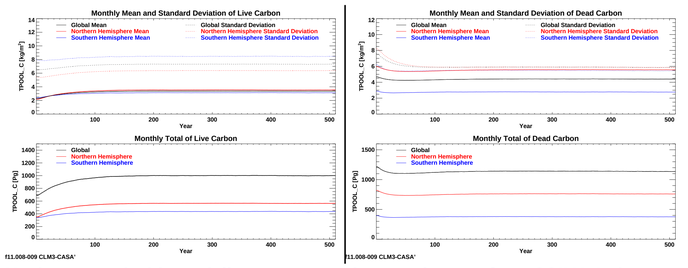


July: 8.6 Pg/month

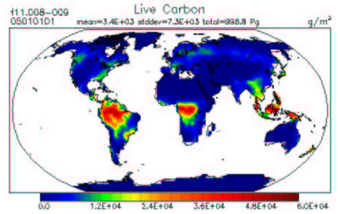
Office of Science
U.S. DEPARTMENT OF ENERGY

Berkeley
University of California

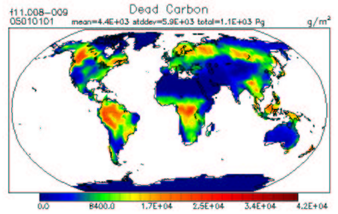
CASA' Carbon Pools



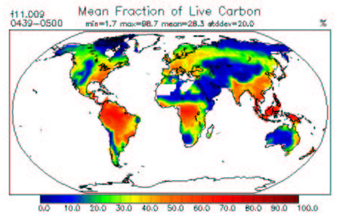
Having started with partially spun−up carbon pool states from CSIM1.4, the CASA' carbon pools equilbrated in CCSM3 within about 300 years.



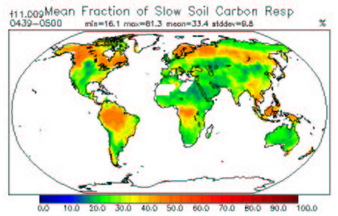
Live Carbon: ~1000 Pg



Dead Carbon: ~1100 Pg

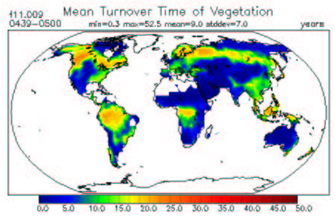


Mean Fraction of Live Carbon: 28.3%



Long Fraction of Respiration: 33.4%

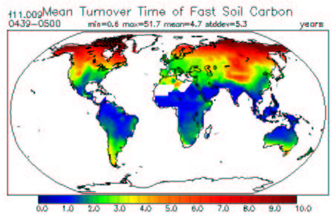
CASA' Carbon Turnover Times

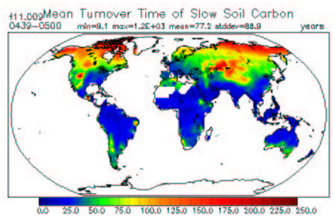


Mean Vegetation Turnover Time is 9 years

Woody Vegetation Turnover Time is 20−30 years

Mean Turnover Time of the Six Fast Soil Carbon Pools combined is 4.7 years





Mean Turnover Time of the Three Slow Soil Carbon Pools combined is 77.2 years

CASA' running within CLM3 adds very little computational expense to the model (<10%), maintains reasonable terrestrial carbon budgets, and does not negatively impact the model biophysics. CLM3−CASA' has been run in CAM−standalone mode and in CCSM partially and fully coupled.

CASA' Applications

CLM3−CASA' was used in conjunction with the finite volume atmosphere at 2x2.5 degree resolution in a short fully coupled experimental simulation often referred to as the SciDAC Deliverable Run. Read more about this simulation on the following poster:

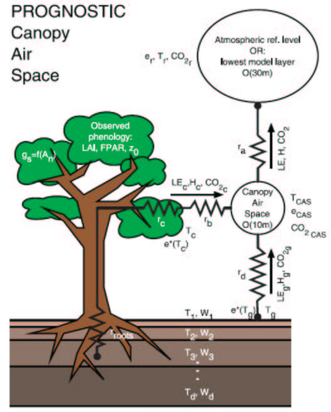
A Coupled Biogeochemistry Physical Climate System
by the DOE SciDAC Team

CLM3−CASA' is presently being used for terrestrial biogeochemistry model intercomparison experiments on the Climate End Station at the Leadership Computing Facility (LCF) at ORNL. Read more about these intercomparison experiments on the following poster:

Terrestrial Biogeochemistry Intercomparison Experiments
by Forrest Hoffman et al. and the CCSM Biogeochemistry Working Group

CLM4 with Prognostic Canopy Air Space

- CLM3 presently solves near−surface state equations for prognostic temperature and humidity using an iterative method (Oleson et al. 2004)
- Proposed for CLM4 is an analytical method of solving the same set of equations employing an explicit coefficient/implicit temperature scheme of Kalnay & Kanamitsu (1988)
- This new scheme includes a Prognostic Canopy Air Space (PCAS) with the capacity to store heat, moisture, and carbon dioxide similar to that in the SiB2.5 model (Baker et al. 2003, Vidale and Stöckli 2005)
- It allows for treatment of canopy storage fluxes observed in flux tower measurements and will simplify future implementation of water isotope tracer capabilities in the model
- The new algorithm will reduce large sections of existing code and is expected to yield the same or better performance on most computer architectures



$$\begin{bmatrix} C^1_{T_s} & 0 & C^1_{(T_v)_1} & C^1_{(T_v)_2} & C^1_{(T_v)_3} & C^1_{T_g} \\ 0 & C^2_{q_s} & C^2_{(T_v)_1} & C^2_{(T_v)_2} & C^2_{(T_v)_3} & C^2_{T_g} \\ C^3_{T_s} & C^3_{q_s} & C^3_{(T_v)_1} & 0 & 0 & C^3_{T_g} \\ C^4_{T_s} & C^4_{q_s} & 0 & C^4_{(T_v)_2} & 0 & C^4_{T_g} \\ C^5_{T_s} & C^5_{q_s} & 0 & 0 & C^5_{(T_v)_3} & C^5_{T_g} \\ C^6_{T_s} & C^6_{q_s} & C^6_{(T_v)_1} & C^6_{(T_v)_2} & C^6_{(T_v)_3} & C^6_{T_g} \end{bmatrix} \times \begin{bmatrix} \Delta T_s \\ \Delta q_s \\ \Delta(T_v)_1 \\ \Delta(T_v)_2 \\ \Delta(T_v)_3 \\ \Delta T_g \end{bmatrix} = \begin{bmatrix} F_{T_s} \\ F_{q_s} \\ F_{(T_v)_1} \\ F_{(T_v)_2} \\ F_{(T_v)_3} \\ F_{T_g} \end{bmatrix}$$

canopy air space — plant functional types 1, 2, & 3 — top soil/ snow layer

$$A \cdot x = B$$

- Formulated as a system of linear equations, the biogeophysical solution core produces temperature and moisture quantities for the next time step using a standard LAPACK matrix solver (DGESV) that performs LU decomposition
- The snow/soil layer profile will still be predicted using a tridiagonal solver
- Algorithms are now being tested at NCAR and ORNL

Other Land Model Developments

Development of the Community Land Model remains very active with projects taking place at various laboratories and universities. Some of the other current developments include a fine mesh implementation, giving CLM its own high resolution grid (separate from that of the atmosphere), an improved hydrological parameterization yielding more realistic soil moisture, and integration of the Dynamic Global Vegetation Model (DGVM) with CN & CASA' biogeochemistry models.

ACKNOWLEDGEMENTS
This research used resources of the National Center for Computational Sciences at Oak Ridge National Laboratory which is supported by the Office of Science of the U.S. Department of Enegy under Contract No. DE−AC05−00OR22725.