Terrestrial Biogeochemistry Intercomparison Experiments

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Introduction

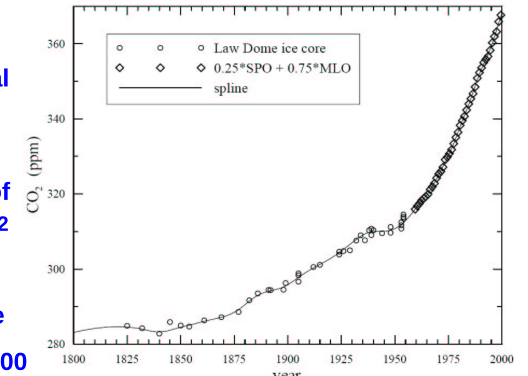
As general circulation models (GCMs) evolve and improve, there is increasing interest in applying them to understand the potential for global climate change. The global carbon cycle is of particular importance since it is thought to have a significant impact on global temperatures. A wide array of carbon models have been coupled to GCMs, and recent work has shown that coupled interactive biogeochemical models can yield useful results for climate change studies (e.g., Friedlingstein et al. 2005). Described here are two such models (CASA' and IBIS, which were previously coupled to GCMs and which have recently been coupled to the Community Climate System Model (CCSM). The CASA' model is presently participating in the C4MIP series of experiments described below. Both CASA' and IBIS, along with a brand new model (called CN) also running in the CCSM3 framework, are part of a more−directed model inter−comparison project specific to CCSM. It is expected that the results of this intercomparison will lead to the deployment of a production terrestrial biogeochemistry capability within the CCSM for use with runs supporting the Intergovernmental Panel on Climate Change Fifth Assessment Report.

C4MIP Experiments

- **Coupled Climate/Carbon Cycle Model Intercomparison Project (C4MIP)** −− an international project sponsored by the International Geosphere−Biosphere Programme − Global Analysis, Integration, and Modelling (IGBP−GAIM) and World Climate Research Programme − Working Group on Coupled Modelling (WCRP−WGCM) to compare coupled model results in two phases:
  - **Phase 1** − controlled experiment using prescribed sea surface temperatures (SSTs), 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 future climate
- Many modeling groups completed Phase 2 experiments, without performing Phase 1 experiments, and contributed results to the IPCC Fourth Assessment Report (Friedlingstein 2005)
- Within the Community Climate System Model (CCSM) framework, two terrestrial biogeochemistry models coupled to the Community Land Model Version 3 (CLM3) are running Phase 1 at T31 resolution (3.75x3.75 degrees)
  - CLM3−CN (Carbon−Nitrogen) model by Thornton
  - CLM3−CASA' (Carnegie and Stanford Approach) model by Fung et al.
- The SciDAC Climate Consortium Project has assisted in implementing, vectorizing, and testing the CASA' model and is carrying out the Phase 1 experiments with this model

C4MIP Phase 1 Protocol

- **C4MIP Protocol** −− at http://www.c4mip.cnrs−gif.fr/protocol.html
- The primary objective is to examine the simulations of the 20th century atmospheric carbon dioxide and the carbon dioxide fluxes at the land surface in the coupled atmosphere−terrestrial biosphere models
- The terrestrial biosphere model must be spun up to
  - Equilibrate to near pre−industrial conditions defined as 1850 CO_2 using repeated cycles of the 1875−1899 SSTs
  - Force the model by two cycles of 1875−1899 SSTs, increasing CO_2 from 1850 to 1899
- The reconstructed carbon dioxide forcing is shown in the figure here



- Transient simulations for 1900−2000 use prescribed land cover (including agricultural change from Ramankutty and Foley), prescribed sea surface temperatures and corresponding sea ice cover (Hadley), prescribed ocean carbon fluxes (from OCMIP), and fossil fuel emissions (Marland et al.)

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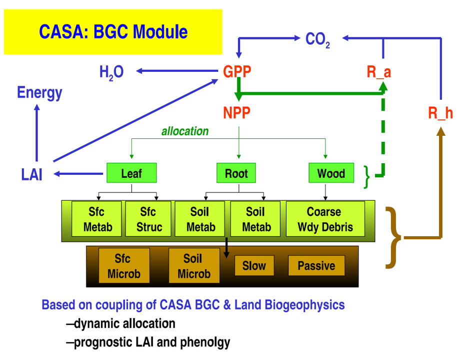
CCSM3 Modifications for Biogeochemistry

- Restore I and F configurations to CCSM3; CSIM vector modifications had disabled thermodynamic ice capabilities (Julie Schramm)
- Add code to CLM3 to support prescribed land cover change using dynamic plant functional types (PFTs) (Mariana Vertenstein)
- Repair soil water deficiencies in CLM3 which significantly reduce net primary production (NPP), particularly in the Amazon (Peter Thornton and others)
- Modify the data atmosphere model (datm) to read hourly atmospheric data generated by CAM from F configuration runs (Brian Kauffman)
- Add code to the ice model (csim) in thermodynamic mode to support data cycling of prescribed ice cover (Forrest Hoffman and Julie Schramm)
- Add code to the data ocean model (docn) to support data cycling of prescribed sea surface temperatures (Forrest Hoffman)
- Complete the integration, vectorization, and testing of CASA' in CLM3 (Forrest Hoffman, Jasmin John, Inez Fung, and Sam Levis)
- Vectorize the CLM3−CN code to support its use on the Cray X1 and Earth Simulator (Forrest Hoffman and Peter Thornton)
- Modify the coupling code used by all component models in CCSM3 to enable exchange of carbon fluxes and other tracers (Mariana Vertenstein, Jeff Lee, and Rob Jacob)
- Modify the CCSM3 scripts to support all these new features (Jeff Lee and Mariana Vertenstein)
- Some of these modifications have since been superceded by implementation of new data models (Brian Kauffman)
- Add code to CAM to read OCMIP ocean fluxes and fossil fuel emissions datasets (Jeff Lee and Mariana Vertenstein)

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.



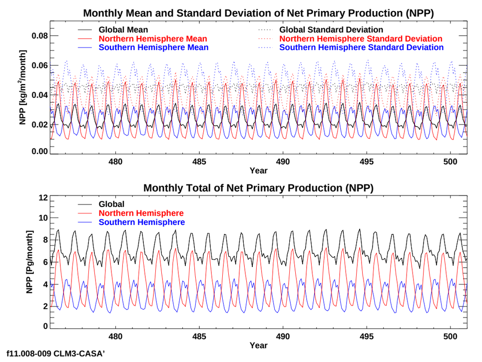
Based on coupling of CASA BGC & Land Biogeophysics
–dynamic allocation
–prognostic LAI and phenolgy

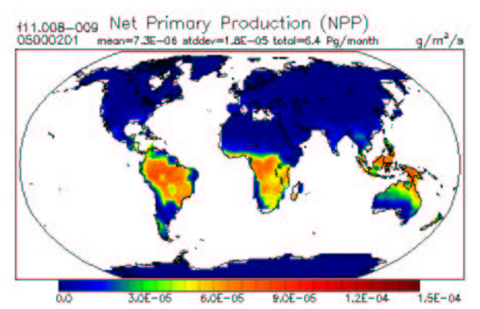
Now coupled into CCSM3, CASA' can provide carbon fluxes from the terrestrial biosphere into the atmosphere. Moreover, the land surface model is forced by atmospheric carbon dioxide concentrations resulting in feedbacks between the land and atmosphere.

CASA' Net Primary Production

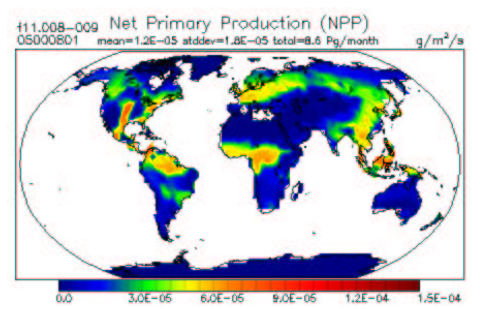
CASA' was spun up with the BGC version of CCSM in the F configuration (i.e., active land and atmosphere) on the Cray X1E at T31 resolution (about 3.75x3.75 degrees). Carbon pools were initialized with spun−up pools from a previous CSIM1.4 simulation. The new pre−industrial spin−up run, forced with Hadley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

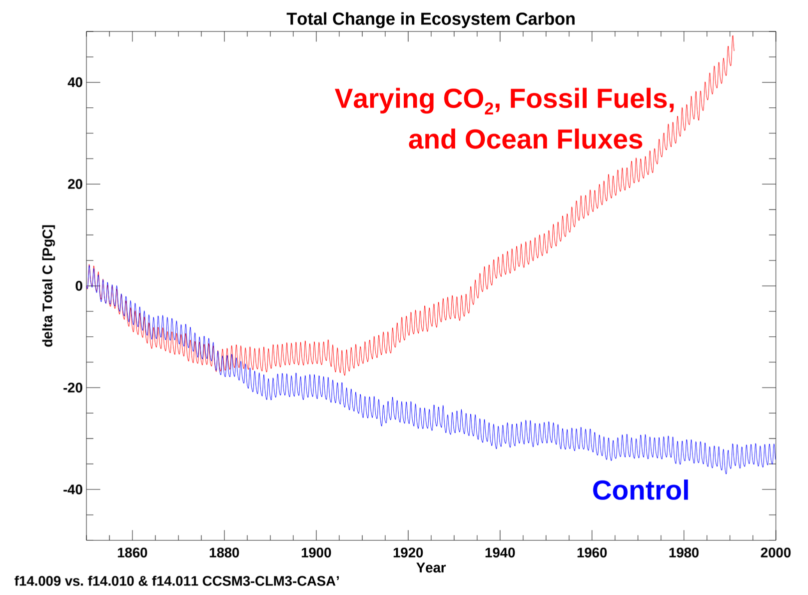
CASA' C4MIP Runs

The following runs using CLM3−CASA' in the BGC version of CCSM3 have been completed on the Cray X1E at ORNL. Landuse Change experiments will require additional software engineering to implement the carbon distribution scheme prescribed by the C4MIP protocol.

Current CLM3-CASA' C4MIP Runs

Case Name	Description	Start Date	End Date	CO_2	Fossil Fuel	Ocean Fluxes	Landuse Change
f11.008	First portion of spin-up	0001-01-01	0066-12-31	Constant	Off	Off	Off
f11.009	Second portion of spin-up	0067-01-01	0500-12-31	Constant	Off	Off	Off
f14.009	Historical Control	1850-01-01	2000-12-31	Constant	Off	Off	Off
f14.010	CO_2 ramping run	1850-01-01	1899-12-31	Varying	Off	Off	Off
f14.011	Transient	1900-01-01	2000-12-31	Varying	On	On	Off
f14.012	Transient	1900-01-01	2000-12-31	Varying	On	Off	Off
f14.013	Transient	1900-01-01	2000-12-31	Varying	Off	On	Off
f14.014	Transient/ Extended ramp	1900-01-01	2000-12-31	Varying	Off	Off	Off

Analysis of these runs has recently begun. However, the model appears to behave as expected as evidenced by the following comparison of the f14.011 transient run against the f14.009 historical control run.



The CO_2 fertilization effect is evident in the transient C4MIP simulation as compared with a historical control run using a fixed CO_2 concentration. The transient used prescribed CO_2 with fossil fuel emissions and the OCMIP ocean carbon fluxes being advected in the atmosphere.

Additional CASA' Posters

A careful analysis of the CLM3−CASA' carbon pool distributions and turnover times was performed during the integration of CASA' into the CLM3 biogeo−physical system. Read more about the spun up carbon pools as well other developments in CLM on the following poster:

SciDAC Land Model Software Engineering
by Forrest Hoffman et al.

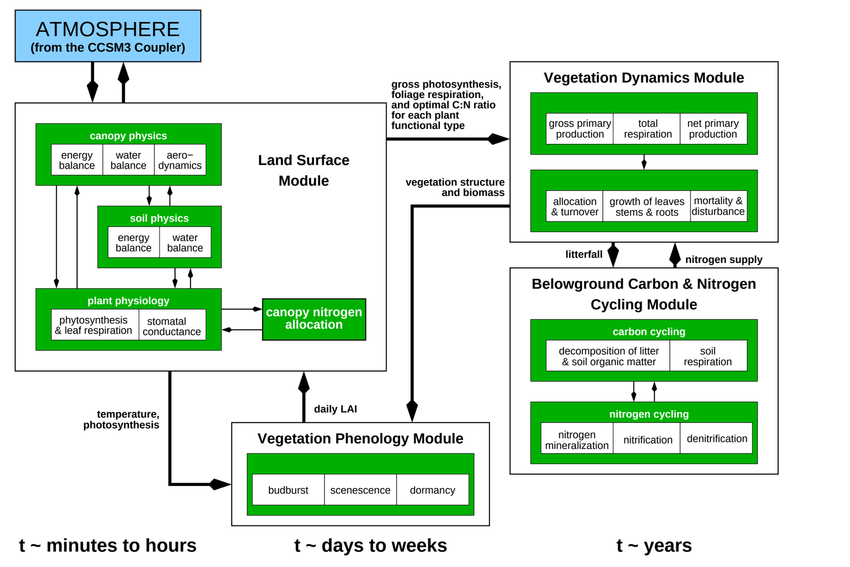
CLM3−CASA' was used in conjunction with the finite volume atmosphere at 2x2.5 degree resolution in a short fully coupled experimental simulation often referred to as the SciDAC Deliverable Run. Read more about this simulation on the following poster:

A Coupled Biogeochemistry Physical Climate System
by the DOE SciDAC Team

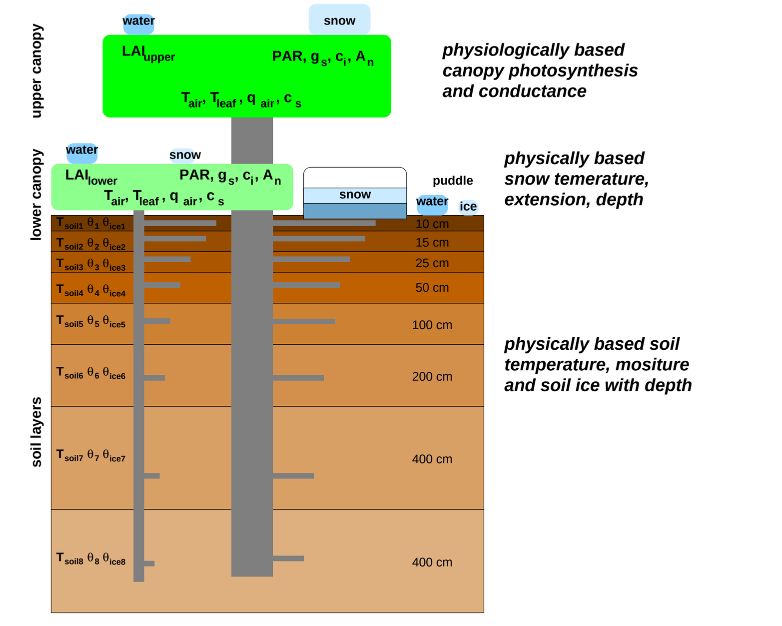
CLM3−CASA' is also presently being used for the CCSM Carbon−Land Model Intercomparison Project on the Climate End Station at the Leadership Computing Facility (LCF) at ORNL. Read more about these intercomparison experiments on the next panel.

Integrated Biosphere Simulator (IBIS)

- The Integrated Biosphere Simulator (IBIS) from Jon Foley's group at the University of Wisconsin, Madison, was coupled to the Parallel Climate Transitional Model (PCTM) and used for C4MIP Phase 2 and related climate change experiments (Thompson et al., Bala et al.)
- IBIS was recently coupled to the CCSM3 as a replacement land model by Art Mirin at Lawrence Livermore National Laboratory
- IBIS represents surface physics, canopy physiology and plant phenology with a two−level canopy, vegetation dynamics and competition, and carbon and nutrient dynamics.
- Hence it is of interest to DOE carbon cycle modelers, plant physiologists, researchers studying carbon sequestration, and carbon management decision−makers



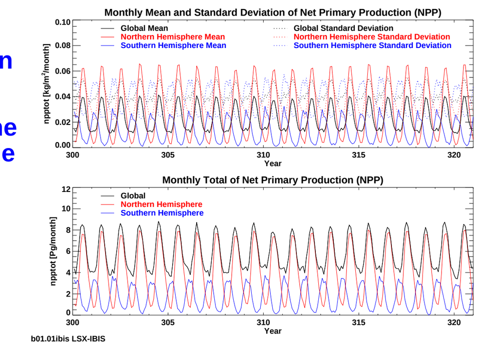
IBIS consists of hierarchically organized, interacting model components operating with different time steps forced by an atmosphere model.

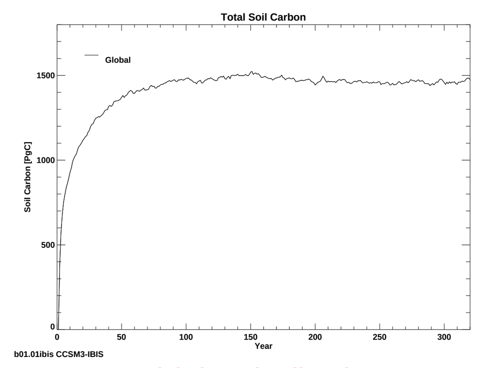


The IBIS land surface contains two layers of overlapping vegetation and eight soil layers. The model simulates photosynthesis, growth and maintenance respiration, and soil biogeochemistry.

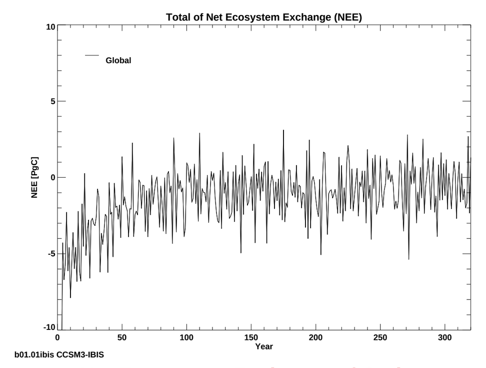
IBIS Spin Up Run

- A spin up run of IBIS running within the fully coupled CCSM3 has been performed at ORNL using the spectral atmospheric dynamical core at T42 (2.5x2.5 degree) resolution
- The land surface was forced with a constant carbon dioxide concentration of 355 ppm
- Soil carbon was started at zero, but the run used an accelerated spin−up mode
- NPP has the correct seasonal cycle and distribution, and it is ~72 Pg/year
- Spin up is out over 350 years and appears to be reaching equilibrium





Global Total Soil Carbon



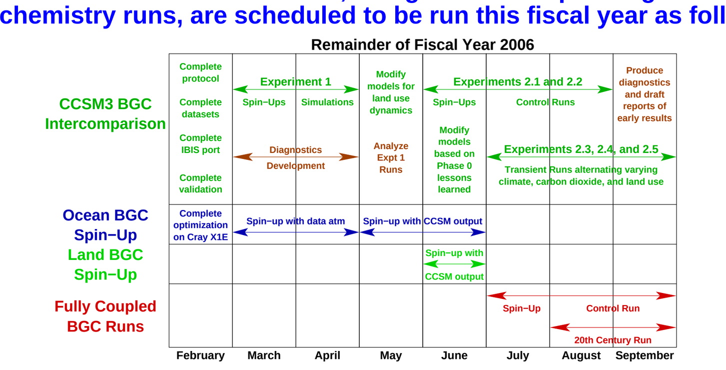
Net Ecosystem Exchange of Carbon

CCSM Carbon Land Model Intercomparison Project (C−LAMP)

- An intercomparison of terrestrial biogeochemistry models running in the CCSM3 framework is being organized by the CCSM Biogeochemistry Working Group (BGCWG)
- The objectives are to compare model capabilities and effects in the coupled climate system and to understand processes important for inclusion in the coupled model for simulations supporting the IPCC Fifth Assessment Report
- Current terrestrial models running within the CCSM framework are
  - **CLM3−CASA'** − Carnegie/Ames/Stanford Approach model previously run in CSM1.4 for C4MIP Phase 2 (Fung et al.)
  - **CLM3−CN** − coupled carbon and nitrogen cycles based on the BIOME−BGC model (Thornton)
  - **LSX−IBIS** − Integrated Biosphere Simulator from U. Wisconsin previously run in the Parallel Climate Transitional Model (PCTM) for C4MIP Phase 2 (Thompson, Foley, Mirin, Post, Erickson)
- The experimental protocol is being developed by Inez Fung, Jim Randerson, and Peter Thornton with input from all members of the CCSM BGCWG
- The protocol involves a series of simulations at T42_gx1v3 resolution that borrows from but improves upon the C4MIP Phase 1 protocol
  - **Experiment 1** − "offline" biosphere model runs (CCSM I configuration) forced with new NCEP/NCAR Reanalysis datasets (A. Dai et al.)
    - Spin−up
    - Control run (1798−2004)
    - Climate varying run (1948−2004)
    - Climate and carbon dioxide varying with nitrogen deposition (1798−2004)
    - Climate and carbon dioxide varying with nitrogen deposition and landuse
  - **Experiment 2** − coupled land−atmosphere model runs (CCSM F configuration) with prescribed SSTs, sea ice and carbon dioxide
    - Spin−up
    - Control run (1800−2004)
    - Climate varying run (1800−2004)
    - Climate and carbon dioxide varying with nitrogen deposition (1800−2004)
    - Climate and carbon dioxide varying with nitrogen deposition and landuse
- Complete protocol, metrics, and output approach are described and available for comment at http://climate.ornl.gov/bgcmip/

Climate End−Station at the Leadership Computing Facility (LCF)

- The C−LAMP experiments will be run through the Climate End−Station (Dr. Warren Washington, PI) at the Leadership Computing Facility (LCF) located at ORNL
- Experiments 1 and 2 outlined above, along with corresponding ocean biogeochemistry runs, are scheduled to be run this fiscal year as follows:



- All of these runs will be performed on the Cray X1E at the LCF

Cray X1E

- 256 interleaved "dual−core" SMP nodes
- 4 Multi−Streaming Processors (MSPs) per node
- 4 Single Streaming Processors (SSPs) per MSP
- Two 32−stage, 64−bit wide vector units running at 1.13 GHz and one 2−way superscalar unit running at 400 MHz per SSP
- 2 MB E−cache per MSP
- 8 GB of memory per interleaved node (partitioned)

1024 processors (MSPs), 2048 GB of memory, and 18.08 TFlop/s peak

Common Output Fields for Intercomparison

atmospheric forcing

Common Field Name	Long Name	Units	Subgrid	Type	Object(s)	Statistics
SPEC_HUM	atmospheric specific humidity	1	gridcell	state	humidity	MA, MH
RAIN	rainfall rate	$m\ s^{-1}$	gridcell	flux	rain	MA, MH
SNOW	snowfall rate	$m\ s^{-1}$	gridcell	flux	snow	MA, MH

biogeochemistry

Common Field Name	Long Name	Units	Subgrid	Type	Object(s)	Statistics
AR	autotrophic respiration	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	vegetation	MA, MH
CWDC	coarse woody debris C	$kg\ m^{-2}$	gridcell	state	carbon	MA
CWDC_LOSS	CWD C loss	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	carbon	MA
FROOTC	fine root C	$kg\ m^{-2}$	gridcell	state	carbon	MA
FROOTC_ALLOC	fine root C allocation	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	carbon	MA, MH
FROOTC_LOSS	fine root C loss	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	carbon	MA
GPP	gross primary production	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	carbon	MA, MH
HR	heterotrophic respiration	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	carbon	MA
LEAFC	leaf C	$kg\ m^{-2}$	gridcell	state	carbon	MA
LEAFC_ALLOC	leaf C allocation	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	carbon	MA, MH
LEAFC_LOSS	leaf C loss	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	carbon	MA
LITTERC	total litter C (excluding CWDC)	$kg\ m^{-2}$	gridcell	state	carbon	MA
LITTERC_LOSS	litter C loss	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	carbon	MA
N_MINERAL	gross rate of N mineralization	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	nitrogen	MA
NEE	net ecosystem exchange (GPP, Re, and fire)	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	carbon	MA, MH
NEP	net ecosystem production (GPP and Re)	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	carbon	MA, MH
SOILC	total soil organic matter C (excluding CWDC and LITTERC)	$kg\ m^{-2}$	gridcell	state	carbon	MA
SOILC_LOSS	total soil organic matter C (excluding CWDC and LITTERC) loss	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	carbon	MA
WOODC	wood C	$kg\ m^{-2}$	gridcell	state	carbon	MA
WOODC_ALLOC	wood C allocation	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	carbon	MA, MH
WOODC_LOSS	wood C loss	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	carbon	MA

energy

Common Field Name	Long Name	Units	Subgrid	Type	Object(s)	Statistics
GROUND	heat flux into soil	$W\ m^{-2}$	gridcell	state	surface	MA, MH
LATENT	latent heat flux	$W\ m^{-2}$	gridcell	state	surface	MA, MH
SENSIBLE	sensible heat flux	$W\ m^{-2}$	gridcell	state	surface	MA, MH
SENSIBLE_GND	sensible heat flux from ground	$W\ m^{-2}$	gridcell	state	surface	MA, MH
SENSIBLE_VEG	sensible heat flux from vegetation	$W\ m^{-2}$	gridcell	state	surface	MA, MH

humidity

Common Field Name	Long Name	Units	Subgrid	Type	Object(s)	Statistics
REL_HUM	relative humidity at 2m	1	gridcell	state	air	MA, MH
SPEC_HUM	specific humidity at 2m	1	gridcell	state	air	MA, MH

hydrology

Common Field Name	Long Name	Units	Subgrid	Type	Object(s)	Statistics
BTRAN	transpiration beta factor	1	gridcell	state	vegetation	MA, MH
CANOPY_EVAP	canopy evaporation	$m\ s^{-1}$	gridcell	flux	vegetation	MA, MH
DRAINAGE	subsurface drainage	$m\ s^{-1}$	gridcell	flux	soil	MA, MH
ET	evapotranspiration	$m\ s^{-1}$	gridcell	flux	surface	MA, MH
INTERCEPTION	canopy interception	$m\ s^{-1}$	gridcell	flux	vegetation	MA, MH
RUNOFF	surface runoff	$m\ s^{-1}$	gridcell	flux	surface	MA, MH
SNOW_DEPTH	snow depth	m	gridcell	state	snow	MA, MH
SOIL_EVAP	soil evaporation	$m\ s^{-1}$	gridcell	flux	soil	MA, MH
SOIL_ICE	soil ice in each soil layer	$kg\ m^{-2}$	gridcell	state	soil	MA, MH
SOIL_LIQUID	soil liquid water in each soil layer	$kg\ m^{-2}$	gridcell	state	soil	MA, MH
SOIL_PSI	soil water potential in each soil layer	Pa	gridcell	state	soil	MA, MH
SOIL_WATER	volumetric soil water	$m^3\ m^{-3}$	gridcell	state	soil	MA, MH
TRANSPIRATION	transpiration	$m\ s^{-1}$	gridcell	flux	vegetation	MA, MH

radiation

Common Field Name	Long Name	Units	Subgrid	Type	Object(s)	Statistics
ALL_SKY_ALBEDO	surface all-sky albedo	1	gridcell	flux	surface	MA, MH
BLACK_SKY_ALBEDO	surface black-sky albedo	1	gridcell	flux	surface	MA, MH
IRDOWN	downward infrared radiation	$W\ m^{-2}$	gridcell	flux	air	MA, MH
IRUP	upward infrared radiation	$W\ m^{-2}$	gridcell	flux	air	MA, MH
LAI	total one-sided leaf area index	$m^2\ m^{-2}$	gridcell	state	vegetation	MA, MH
LAISHA	shaded projected leaf area index	1	gridcell	state	vegetation	MA, MH
LAISUN	sunlit projected leaf area index	1	gridcell	state	vegetation	MA, MH
NETIR	net infrared radiation	$W\ m^{-2}$	gridcell	flux	air	MA, MH
NETRAD	net radiation	$W\ m^{-2}$	gridcell	flux	air	MA, MH
REFLECT	total reflected solar radiation	$W\ m^{-2}$	gridcell	flux	air	MA, MH
SNOW_FRACTION	snow fraction	1	gridcell	state	snow	MA, MH
SOLAR	total incident solar radiation	$W\ m^{-2}$	gridcell	flux	air	MA, MH
SOLAR_ABG	solar radiation absorbed by ground	$W\ m^{-2}$	gridcell	flux	air	MA, MH
SOLAR_ABV	solar radiation absorbed by vegetation	$W\ m^{-2}$	gridcell	flux	air	MA, MH

temperature

Common Field Name	Long Name	Units	Subgrid	Type	Object(s)	Statistics
DEGREE_DAYS	accumulated degree days	K	gridcell	state	air	MA
TREFMNAV	daily minimum of average 2m air temperature	K	gridcell	state	air	MA, MH
TREFMXAV	daily maximum of average 2m air temperature	K	gridcell	state	air	MA, MH
TSA2M	2m air temperature	K	gridcell	state	air	MA, MH
TSOIL	soil temperature by soil layer	K	gridcell	state	soil	MA, MH
TVEG	vegetation temperature	K	gridcell	state	vegetation	MA, MH

vegetation phenology

Common Field Name	Long Name	Units	Subgrid	Type	Object(s)	Statistics
ELAI	exposed one-sided leaf area index	$m^2\ m^{-2}$	gridcell	flux	vegetation	MA
ESAI	exposed one-sided stem area index	$m^2\ m^{-2}$	gridcell	flux	vegetation	MA

vegetation physiology

Common Field Name	Long Name	Units	Subgrid	Type	Object(s)	Statistics
PHOTOSYNTHESIS	photosynthesis	$kg\ m^{-2}\ s^{-1}$	gridcell	flux	vegetation	MA, MH
RSSHA	shaded leaf stomatal resistance	$s\ m^{-1}$	gridcell	state	vegetation	MA, MH
RSSUN	sunlit leaf stomatal resistance	$s\ m^{-1}$	gridcell	state	vegetation	MA, MH

MA = Monthly averages
MH = Means and standard deviations by hour of day output monthly

These output fields will be extracted or derived from each of the three models and will serve as the basis for intercomparison of both model results and observational datasets.

C−LAMP Output and Diagnostics

- Special attention is being given to the development of intercomparison metrics and diagnostics relevant to the carbon cycle
- Seasonal and diurnal cycles will be analyzed and compared with observational datasets from AmeriFlux/Fluxnet towers, MODIS/satellites, and GlobalView
- Model output and post−processing data will be rewritten using PCMDI's Computer Model Output Rewriter (CMOR)
- Model output and post−processing data will be made available to the wider science community by PCMDI via the Earth System Grid (ESG) for further analysis
- Data will be available via FTP, HTTP, and OpenDAP for interactive analysis
- Analysis products and Taylor diagrams (using Climate Data Analysis Tools (CDAT)) will be produced −− See also the poster:

Diagnosis and Intercomparison of Climate Models with Interactive Biogeochemistry
by Curtis Covey, Inez Fung, Yun (Helen) He, Forrest Hoffman, and Jasmin John

C−LAMP Current Status and Plans

- Spin−up runs for Experiment 1 are currently running on the Cray X1E
- It is anticipated that most of Experiment 1 will be complete before the CCSM Annual Workshop in June 2006
- An additional ESG server is being acquired to provide these model results to interested researchers around the time of the Workshop
- Watch the website for updates, status information, and links to data

For More Information

Visit the C−LAMP Website: http://climate.ornl.gov/bgcmip/

Contact: Forrest Hoffman (forrest@climate.ornl.gov)

Visit the CCSM Biogeochemistry Working Group Website: http://www.ccsm.ucar.edu/working_groups/Biogeo/

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