The Carbon-Land Model Intercomparison Project (C-LAMP)

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The **Carbon-Land Model Intercomparison Project (C-LAMP)** began as a **CCSM Biogeochemistry Working Group** project to assess model capabilities in the coupled climate system and to explore processes important for inclusion in the CCSM4 Earth System Model for use in the IPCC Fifth Assessment Report (AR5).

Unlike traditional MIPs, C-LAMP was designed to confront models with best-available observational datasets, develop metrics for evaluation of biosphere models, and build a general-purpose BGC diagnostics package for model evaluation.
C-LAMP is a Biogeochemistry Subproject of the **Computational Climate Science End Station** (Warren Washington, PI), a U.S. Dept. of Energy INCITE Project.

Models were initially run on the Cray X1E vector supercomputer in ORNL’s **National Center for Computational Sciences (NCCS)**. 

**Cray X1E (phoenix)**

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

**DECOMMISSIONED September 30, 2008**
Present Jaguar: 250 TFlop/s
New Jaguar: Second Fastest in the World at 1.059 PFlop/s
C-LAMP Protocol Overview

- **Experiment 1**: Models forced with an improved NCEP/NCAR reanalysis climate data set (Qian, *et al.* 2006) to examine the influence of climate variability, prescribed atmospheric CO$_2$, and land cover change on terrestrial carbon fluxes during the 20th century (specifically 1948–2004).

- **Experiment 2**: Models coupled with an active atmosphere (CAM3), prescribed atmospheric CO$_2$, prescribed sea surface temperatures and ocean carbon fluxes to examine the effect of a coupled biosphere-atmosphere for carbon fluxes and climate during the 20th century.

- **CCSM3.1** partially coupled ("I" & "F" configurations) run at T42 resolution ($\sim 2.8^\circ \times 2.8^\circ$), spectral Eulerian dycore, $1^\circ \times 0.27^\circ$–$0.53^\circ$ ocean & sea ice data models (T42gx1v3).


At the October 2006 C4MIP Workshop at the UK Met Office in Exeter, there was strong interest in Experiment 1 and validation experiments using Fluxnet observations.

At the Marie Curie/iLEAPS Workshop in Hyères, a number of modeling groups expressed interest in consistent model validation and model-data comparisons for their coupled biosphere models, but best-available observations from ground and satellite measurements are difficult to manipulate.

C-LAMP is sharing forcing and observational datasets, and model results are available through the Earth System Grid (ESG), just like for CMIP3 (the IPCC AR4 model results).
### Offline Forcing with NCEP/NCAR Reanalysis

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Description</th>
<th>Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Spin Up</td>
<td>$\sim$4,000 y</td>
</tr>
<tr>
<td>1.2</td>
<td>Control</td>
<td>1798–2004</td>
</tr>
<tr>
<td>1.3</td>
<td>Varying climate</td>
<td>1948–2004</td>
</tr>
<tr>
<td>1.4</td>
<td>Varying climate, CO$_2$, and N deposition</td>
<td>1798–2004</td>
</tr>
<tr>
<td>1.5</td>
<td>Varying climate, CO$_2$, N deposition and land use</td>
<td>1798–2004</td>
</tr>
<tr>
<td>1.6</td>
<td>Free Air CO$_2$ Enrichment (FACE) Control</td>
<td>1997–2100</td>
</tr>
<tr>
<td>1.7</td>
<td>Free Air CO$_2$ Enrichment (FACE) Transient</td>
<td>1997–2100</td>
</tr>
</tbody>
</table>

**Coupled Land-Atmosphere Forcing with Hadley SSTs**

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Description</th>
<th>Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Spin Up</td>
<td>$\sim$2,600 y</td>
</tr>
<tr>
<td>2.2</td>
<td>Control</td>
<td>1800–2004</td>
</tr>
<tr>
<td>2.3</td>
<td>Varying climate</td>
<td>1800–2004</td>
</tr>
<tr>
<td>2.4</td>
<td>Varying climate, CO$_2$, and N deposition</td>
<td>1800–2004</td>
</tr>
<tr>
<td>2.5</td>
<td>Varying climate, CO$_2$, N deposition and land use</td>
<td>1800–2004</td>
</tr>
<tr>
<td>2.6</td>
<td>Varying climate, CO$_2$, N deposition, seasonal FFE</td>
<td>1800–2004</td>
</tr>
</tbody>
</table>

All but the land use experiments were run with CCSM3.1 using CLM3-CASA’ and CLM3-CN biogeochemistry models yielding $>16,000$ y and $\sim50$ TB.
## C-LAMP Common Model Output

While all models participating in the Carbon Land Model intercomparison Project (C-LAMP) will output their own "native" fields, a common set of fields is needed to facilitate head-to-head comparison of the models to each other and to available observational datasets. Model results transmitted to the Earth System Grid for redistribution to the community will use common field names, netCDF long names, CF Standard Names and units. Contained below is a table of the common output fields required for the C-LAMP and consistent with the metadata conventions used for CMIP3, formerly called the IPCC 4\textsuperscript{th} Assessment Model Output database. Corrections and suggestions are solicited on this information. Software is available for rewriting model output into netCDF files following the Climate and Forecast (CF) Metadata Convention.


**Atmospheric forcing**

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Long Name and CF Standard Name</th>
<th>Units</th>
<th>Comment</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>husf</td>
<td>Specific humidity at atmospheric forcing height</td>
<td>kg kg(^{-1})</td>
<td>Rainfall includes all liquid types (rain, large-scale, convective, etc.)</td>
<td>MHM, MHS, MM</td>
</tr>
<tr>
<td>prra</td>
<td>Rainfall precipitation flux</td>
<td>kg m(^{-2}) s(^{-1})</td>
<td></td>
<td>MHM, MHS, MM</td>
</tr>
<tr>
<td>prsn</td>
<td>Snowfall precipitation flux</td>
<td>kg m(^{-2}) s(^{-1})</td>
<td>Snowfall includes all frozen types (snow, hail, ice, etc.)</td>
<td>MHM, MHS, MM</td>
</tr>
</tbody>
</table>

**Biogeochemistry**

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Long Name and CF Standard Name</th>
<th>Units</th>
<th>Comment</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>agbc(^*)</td>
<td>Above-ground biomass carbon</td>
<td>kg m(^{-2})</td>
<td>Total carbon content in above-ground live and dead carbon pool(s)</td>
<td>MM</td>
</tr>
<tr>
<td>agibc(^*)</td>
<td>Above-ground live biomass carbon</td>
<td>kg m(^{-2})</td>
<td>Total carbon content in above-ground live carbon pool(s)</td>
<td>MM</td>
</tr>
<tr>
<td>agnpp</td>
<td>Above-ground net primary production</td>
<td>kg m(^{-2}) s(^{-1})</td>
<td>Component of net primary production attributable to above-ground live biomass</td>
<td>MM</td>
</tr>
<tr>
<td>ar</td>
<td>Autotrophic respiration</td>
<td>kg m(^{-2}) s(^{-1})</td>
<td>Sum of maintenance respiration and growth respiration of vegetation</td>
<td>MHM, MHS, MM</td>
</tr>
<tr>
<td>bco</td>
<td>Biogenic carbon monoxide flux</td>
<td>kg m(^{-2}) s(^{-1})</td>
<td>Total biogenic carbon monoxide flux out of biosphere</td>
<td>MM</td>
</tr>
</tbody>
</table>

Done
An evolving draft document on metrics for model evaluation is available at http://www.climatemodeling.org/c-lamp/

Each model is scored with respect to its performance on various output fields compared with best-available observational datasets.

Examples include:

- net primary production (NPP) from EMDI and MODIS
- leaf area index (LAI) using MODIS spatial distribution and phase
- CO$_2$ seasonal cycle (NOAA/Globalview flask sites, after running fluxes through an atmospheric transport model for Experiment 1)
- regional carbon stocks (Saatchi et al., 2006; Batjes, 2006)
- carbon and energy fluxes (Fluxnet sites)
- transient dynamics ($\beta$ factor, etc.)

More diagnostic or metric ideas? Please contribute them!
### C-LAMP Score Sheet for Biogeochemical Model Evaluation

<table>
<thead>
<tr>
<th>Metric</th>
<th>Metric components</th>
<th>Observations &amp; comparison protocol</th>
<th>Model CASA</th>
<th>Model CN</th>
<th>Score (points) Possible</th>
<th>CASA</th>
<th>CN</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAI MODIS Phase</td>
<td>global map</td>
<td>global map</td>
<td>global map</td>
<td>global map</td>
<td>6.00</td>
<td>5.11</td>
<td>4.24</td>
</tr>
<tr>
<td>MODIS Maximum</td>
<td>global map</td>
<td>global map</td>
<td>global map</td>
<td>global map</td>
<td>5.00</td>
<td>4.60</td>
<td>4.26</td>
</tr>
<tr>
<td>MODIS Mean</td>
<td>land class obs</td>
<td>model vs obs table</td>
<td>model vs obs</td>
<td>model vs obs</td>
<td>4.00</td>
<td>3.75</td>
<td>3.53</td>
</tr>
<tr>
<td>NPP EMDI NPP observations</td>
<td>Class A table</td>
<td>table scatter plot</td>
<td>table scatter plot</td>
<td>table scatter plot</td>
<td>1.00</td>
<td>0.68</td>
<td>0.73</td>
</tr>
<tr>
<td>Correlation with MODIS</td>
<td>Class A histogram</td>
<td>Class A histogram</td>
<td>Class A histogram</td>
<td>Class A histogram</td>
<td>2.00</td>
<td>1.50</td>
<td>1.74</td>
</tr>
<tr>
<td>Correlation with MODIS-zonal mean</td>
<td>zonal mean obs</td>
<td>zonal mean model vs obs</td>
<td>zonal mean model vs obs</td>
<td>zonal mean model vs obs</td>
<td>2.00</td>
<td>1.64</td>
<td>1.44</td>
</tr>
</tbody>
</table>

- **CO₂ Seasonal Cycle**
  - Comparison with Globelview phase and amplitude
    - 60°N–90°N
    - 30°N–60°N
    - 0°N–30°N

- **Energy and C Fluxes from Fluxnet**
  - Net radiation
  - Latent heat
  - Sensible heat

- **Energy and C Fluxes from Ameriflux**
  - NEE
  - Shortwave incoming
  - Latent heat
  - Sensible heat
  - GPP
  - ER

- **Aboveground live biomass in South America**
  - obs amazon
  - model amazon
  - amazon map

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The Carbon-Land Model Intercomparison Project (C-LAMP)
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Comparisons with field observations include net primary production (NPP) from the Ecosystem Model-Data Intercomparison (EMDI). Measurements were performed in different ways, at different times, and by different groups for a limited number of field sites. Shown here are comparisons of NPP with EMDI Class A observations (Figures a and b) and Class B observations (Figures c and d).

Data provided by NASA Distributed Active Archive Center (DAAC) at ORNL

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The Carbon-Land Model Intercomparison Project (C-LAMP)
Comparisons with satellite “modeled observations” must be made carefully because of high uncertainty.

This comparison with MODIS leaf area index (LAI) focuses on the month of maximum LAI (phase), a measurement with less uncertainty than the “observed” LAI values.

C-LAMP accounts for this uncertainty by weighting scores accordingly.

CLM-CASA’ scored 5.1/6.0 while CLM-CN scored 4.2/6.0 for this metric.
MODIS net primary production (NPP) “observations” have higher uncertainty.

Comparison with MODIS NPP focuses on correlation of spatial patterns.

CLM-CASA’ scored 1.6/2.0 while CLM-CN scored 1.4/2.0.
• Estimates of carbon stocks are very difficult to obtain.

• This comparison with estimates of aboveground live biomass in the Amazon by Saatchi et al. (2006) shows that both models are too high by about a factor of 2.

• Using a score based on normalized cell-by-cell differences, CLM-CASA’ scored 5.3/10.0 while CLM-CN scored 5.0/10.0.
Comparisons with AmeriFlux eddy correlation CO₂ flux tower sites include net ecosystem exchange (NEE), gross primary production (GPP), respiration, shortwave incoming radiation, and latent and sensible heat.

Shown here is a comparison of CLM-CASA’ results with the Morgan Monroe L4 time series data.

All AmeriFlux data are stored and distributed by ORNL’s Carbon Dioxide Information Analysis Center (CDIAC).
Additional field measurement comparisons include the Free Air CO$_2$ Enrichment (FACE) results, including the ORNL site.

The Norby *et al.* (2005) synthesis of four FACE site observations suggested “response of forest NPP to elevated [CO$_2$] is highly conserved across a broad range of productivity, with a stimulation at the median of 23 ± 2%.”

A C-LAMP experiment was added to test this result by increasing [CO$_2$] to 550 ppmv in 1997.
But! Norby is now reporting reduced NPP enhancement at the ORNL FACE site due probably to N limitation!
### C-LAMP Score Sheet for CLM3-CASA’ and CLM3-CN

<table>
<thead>
<tr>
<th>Metric</th>
<th>Metric components</th>
<th>Uncertainty of obs.</th>
<th>Scaling mismatch</th>
<th>Total score</th>
<th>Sub-score</th>
<th>CASA’</th>
<th>CN</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAI</td>
<td>Matching MODIS observations</td>
<td></td>
<td></td>
<td>15.0</td>
<td></td>
<td>13.5</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>• Phase (assessed using the month of maximum LAI)</td>
<td>Low</td>
<td>Low</td>
<td>6.0</td>
<td></td>
<td>5.1</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>• Maximum (derived separately for major biome classes)</td>
<td>Moderate</td>
<td>Low</td>
<td>5.0</td>
<td></td>
<td>4.6</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>• Mean (derived separately for major biome classes)</td>
<td>Moderate</td>
<td>Low</td>
<td>4.0</td>
<td></td>
<td>3.8</td>
<td>3.5</td>
</tr>
<tr>
<td>NPP</td>
<td>Comparisons with field observations and satellite products</td>
<td></td>
<td></td>
<td>10.0</td>
<td></td>
<td>8.0</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>• Matching EMDI Net Primary Production observations</td>
<td>High</td>
<td>High</td>
<td>2.0</td>
<td></td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>• EMDI comparison, normalized by precipitation</td>
<td>Moderate</td>
<td>Moderate</td>
<td>4.0</td>
<td></td>
<td>3.0</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>• Correlation with MODIS ($r^2$)</td>
<td>High</td>
<td>Low</td>
<td>2.0</td>
<td></td>
<td>1.6</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>• Latitudinal profile comparison with MODIS ($r^2$)</td>
<td>High</td>
<td>Low</td>
<td>2.0</td>
<td></td>
<td>1.9</td>
<td>1.8</td>
</tr>
<tr>
<td>CO₂ annual cycle</td>
<td>Matching phase and amplitude at Globalview flash sites</td>
<td></td>
<td></td>
<td>15.0</td>
<td></td>
<td>10.4</td>
<td>7.7</td>
</tr>
<tr>
<td></td>
<td>• 60°–90°N</td>
<td>Low</td>
<td>Low</td>
<td>6.0</td>
<td></td>
<td>4.1</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>• 30°–60°N</td>
<td>Low</td>
<td>Low</td>
<td>6.0</td>
<td></td>
<td>4.2</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>• 0°–30°N</td>
<td>Moderate</td>
<td>Low</td>
<td>3.0</td>
<td></td>
<td>2.1</td>
<td>1.7</td>
</tr>
<tr>
<td>Energy &amp; CO₂ fluxes</td>
<td>Matching eddy covariance monthly mean observations</td>
<td></td>
<td></td>
<td>30.0</td>
<td></td>
<td>17.2</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td>• Net ecosystem exchange</td>
<td>Low</td>
<td>High</td>
<td>6.0</td>
<td></td>
<td>2.5</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>• Gross primary production</td>
<td>Moderate</td>
<td>Moderate</td>
<td>6.0</td>
<td></td>
<td>3.4</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>• Latent heat</td>
<td>Low</td>
<td>Moderate</td>
<td>9.0</td>
<td></td>
<td>6.4</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>• Sensible heat</td>
<td>Low</td>
<td>Moderate</td>
<td>9.0</td>
<td></td>
<td>4.9</td>
<td>4.6</td>
</tr>
<tr>
<td>Transient dynamics</td>
<td>Evaluating model processes that regulate carbon exchange on decadal to century timescales</td>
<td></td>
<td></td>
<td>30.0</td>
<td></td>
<td>16.8</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>• Aboveground live biomass within the Amazon Basin</td>
<td>Moderate</td>
<td>Moderate</td>
<td>10.0</td>
<td></td>
<td>5.3</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>• Sensitivity of NPP to elevated levels of CO₂: comparison to temperate forest FACE sites</td>
<td>Low</td>
<td>Moderate</td>
<td>10.0</td>
<td></td>
<td>7.9</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>• Interannual variability of global carbon fluxes: comparison with TRANSCOM</td>
<td>High</td>
<td>Low</td>
<td>5.0</td>
<td></td>
<td>3.6</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>• Regional and global fire emissions: comparison to GFEDv2</td>
<td>High</td>
<td>Low</td>
<td>5.0</td>
<td></td>
<td>0.0</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td></td>
<td>100.0</td>
<td></td>
<td>65.9</td>
<td>58.3</td>
</tr>
</tbody>
</table>

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The Carbon-Land Model Intercomparison Project (C-LAMP)
Collaboration with SciDAC Visualization and Analytics Center for Enabling Technologies (VACET)

- C-LAMP and other model results are being used by members of VACET at the National Center for Computational Sciences (NCCS) to explore high performance visualization techniques.
C-LAMP model results and MODIS satellite data are being used by Jian Huang’s group at the University of Tennessee, Knoxville (UTK) applying novel statistical methods to the analysis of very large climate data sets.
Earth System Grid (ESG) Node at ORNL for C-LAMP

Welcome
Welcome to the CCES C-LAMP data portal. If you are new to this site, please review the help pages:
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Browsing and Downloading Data
Downloading from FTP

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Search Dataset metadata for:

Search

Example: mri, ccmes

Advanced Search

Browse Dataset Catalogs
CISM Carbon Land Model Intercomparison Project (C-LAMP)

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Done
Biases and Weaknesses Exposed by the C-LAMP Analysis

- Both models had a low LAI bias in boreal and arctic regions. This bias was partially eliminated by a new hydrology model capturing freeze-thaw dynamics.
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- Both models had a 1–3 month delay in the timing of maximum LAI. This bias was reduced in CLM3-CN where it was most significant.

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¹ The Carbon-Land Model Intercomparison Project (C-LAMP)
Biases and Weaknesses Exposed by the C-LAMP Analysis

- Both models had a low LAI bias in boreal and arctic regions. This bias was partially eliminated by a new hydrology model capturing freeze-thaw dynamics.
- Both models had a 1–3 month delay in the timing of maximum LAI. This bias was reduced in CLM3-CN where it was most significant.
- Both models overestimate woody biomass in the Amazon Basin. Carbon comparisons with Malhi et al. (in press) suggest too much allocation to wood. Allocation in CLM3-CN was adjusted to reduce this bias.
Biases and Weaknesses Exposed by the C-LAMP Analysis

- Both models had a low LAI bias in boreal and arctic regions. This bias was partially eliminated by a new hydrology model capturing freeze-thaw dynamics.
- Both models had a 1–3 month delay in the timing of maximum LAI. This bias was reduced in CLM3-CN where it was most significant.
- Both models overestimate woody biomass in the Amazon Basin. Carbon comparisons with Malhi et al. (in press) suggest too much allocation to wood. Allocation in CLM3-CN was adjusted to reduce this bias.
- The models differed by a factor of two in annual carbon sinks. Both results are compatible with atmospheric budgets given other uncertainties.
Both models underestimated the amplitude of the seasonal cycle of CO$_2$ in the northern hemisphere. Adjustment of the $Q_{10}$ for heterotrophic respiration from 2.0 to 1.5 in CLM3-CASA′ reduces this bias. Adoption of the same $Q_{10}$ formulation, in place of Lloyd & Taylor, reduces this bias in CLM3-CN. The $Q_{10}$ for maintenance respiration in CLM3-CN was also reduced from 2.0 to 1.5.
Both models underestimated the amplitude of the seasonal cycle of CO$_2$ in the northern hemisphere. Adjustment of the $Q_{10}$ for heterotrophic respiration from 2.0 to 1.5 in CLM3-CASA reduces this bias. Adoption of the same $Q_{10}$ formulation, in place of Lloyd & Taylor, reduces this bias in CLM3-CN. The $Q_{10}$ for maintenance respiration in CLM3-CN was also reduced from 2.0 to 1.5.

CLM3-CN seasonal cycle was out of phase with observations. A new day-length control on photosynthesis mechanism mitigates this bias in CLM3-CN.

Systematic assessment of terrestrial biogeochemistry in coupled climate–carbon models

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Abstract

With representation of the global carbon cycle becoming increasingly complex in climate models, it is important to develop ways to quantitatively evaluate model performance against in situ and remote sensing observations. Here we present a systematic framework, the Carbon-LAnd Model Intercomparison Project (C-LAMP), for assessing terrestrial biogeochemistry models coupled to climate models using observations that span a wide range of temporal and spatial scales. As an example of the use of such a comparison, we compare two complete land surface biogeochemistry models that...
Recent Progress

- C-LAMP drove the development of model improvements in the terrestrial biogeochemistry models for the Community Land Model version 4 (CLM4).
- Subsequent C-LAMP analyses of six model configurations using CLM3.6 (a pre-release version of CLM4) with CASA' and CN demonstrated better performance by CN.
- Therefore, the CLM4 release will include CN. That configuration will probably be called CLM4-BGC.
- CLM4-BGC will be part of the Community Climate System Model version 4 (CCSM4), which may be called the Community Earth System Model (CESM). This model will be used for IPCC AR5 simulations.
- The physical models for CCSM4 are expected to be finalized before the end of 2009, and the full ESM configuration will follow within six months.
We believe that C-LAMP should serve as a prototype for a wider international benchmarking activity, as we have discussed at this meeting.

Needed are

1. a well-crafted protocol that exercises model capabilities for simulating energy, water, and biogeochemical cycles;
2. model output data and metadata standards to simplify subsequent analyses;
3. best-available forcing data sets; and
4. best-available observational data sets and diagnostics.

Follow-on discussions should be held at iLEAPS in Melbourne in August and ICDC8 in Jena in September.

We could finalize the protocol, output standards, and relationship to AR5 simulations at a meeting in Spring 2010 at Irvine, California or Oak Ridge, Tennessee.
Thank you!

Questions?

More Discussion?

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