## The Large Scale Biosphere-Atmosphere Experiment in Amazônia, Model Intercomparison Project (LBA-MIP) protocol

LBA-MIP website: http://www.climatemodeling.org/lba-mip/

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(variations from previous version highlighted in yellow)

### 1. Summary

### A. Motivation

The importance of the land-surface dynamics of the Amazon region to the global and regional climates, including water, heat and carbon exchanges between land and atmosphere, has motivated an evaluation of the performance of the land surface models by the LBA community. During the workshop *Integrating eddy flux tower sites, remote sensing, and models to understand Amazonian carbon dynamics*, which was held in Brasilia, Brazil in October 2006 in parallel with the 10$^{th}$ LBA-ECO Science Meeting, a working group was established to plan an LBA Model Intercomparison Project (LBA-MIP). The working group recognizes that by comparing the ecosystem models that simulate terrestrial energy, water and $CO_2$ fluxes with the continuous observations of these quantities over the LBA area will provide understanding on how well the models quantify the land surface process and define any deficiencies in the models and how they can be improved. As such, LBA-MIP will further the goals of the phase III of LBA which is focused on synthesis and analysis.

Similar studies have been conducted in the past. The well known Project for Intercomparison of Land-surface Schemes (PILPS; Pitman et al. 1993, Henderson-Sellers et al. 1993, Henderson-Sellers et al. 1995) led to a distinct improvement in the understanding of the exchanges of water and energy between land surface and atmosphere. More recently, model intercomparison projects with specific objectives have focused on particular climatic conditions (e.g. SNOWMIP-2, PILPS-urban, PILPS semi arid and PILPS C-1). LBA now provides a unique data source for extending process-based understanding of the coupled terrestrial carbon and water cycle in the Amazon. The LBA-MIP initiative has the potential to lead to an improved representation of seasonal-decadal land-atmosphere interactions in tropical climates of global climate simulations.

### B. Objectives.

**The goal** is to gain comparative understanding of ecosystem models that simulate energy, water and $CO_2$ fluxes over the LBA area. **The task** is to subject all the models to the same forcing and experimental protocol, and compare the output. **The protocol** presented below proposes the model intercomparison to be executed in two major steps. The first step is to run models at eight individual LBA tower sites using the most up-to-date available atmospheric forcing and validation data. The second step is will then be to make gridded simulations with the models using the South American LDAS (SALDAS) atmospheric forcing dataset, which is based on the new CPTEC regional reanalysis and surface observations within the LBA region. Initial results from the first phase, generated in advance of LBA-MIP workshops on 24-25 September, 2007 and 2-3 May, 2008, lay ground for more detailed subsequent analysis and simulations suitable for comparison with field data.

## 2. Data protocols

### *2.1 Sites description and driver data availability*

Available sites range across a variety of land classes and soil types as documented in Tables 1A, 1B, 1C, 1D, and 1E. Each group may prescribe additional soil characteristics (rooting depth, depth-to-bedrock, among others) that better suits its model requirements. Therefore the parameters table used for each site and run as well as any other model assumptions should be reported in a separate README file. Therefore, it is required to report the parameters table used for each site and run, as well, as other model assumptions. Crop growth history for the two converted sites (Santarém K77 and FNS) and flooding history at Bananal Island (BAN), are expanded at Tables 1E and 1D, respectively:

**Table 1A. Eddy covariance tower sites providing driver data for LBA-MIP**

| ID | Short Code | Site Name | Longitude [deg] | Latitude [deg] | Local time (from UTC) [hh:mm] | Elev. [m] | Tower Ht [m] | Biome Type | IGBP Link |
|---|---|---|---|---|---|---|---|---|---|
| 1 | BAN | Javaes River - Bananal Island | -50.159111 | -09.824417 | -03:00 | 120 | 40 | Forest-Savanna | 4 |
| 2 | K34 | Manaus Km34 | -60.209297 | -02.609097 | -04:00 | 130 | 50 | Tropical rainforest | 2 |
| 3 | K67 | Santarém Km67 | -54.958889 | -02.856667 | -04:00 | 130 | 63 | Tropical rainforest | 2 |
| 4 | K77 | Santarém Km77 | -54.894357 | -03.019833 | -04:00 | 130 | 18 | Pasture-Agriculture | 12 |
| 5 | K83 | Santarém Km83 | -54.971435 | -03.018029 | -04:00 | 130 | 64 | Selectively logged tropical rainforest | 2 |
| 6 | RJA | Reserva Jarú | -61.930903 | -10.083194 | -04:00 | 191 | 60 | Tropical dry forest | 2 |
| 7 | FNS | Fazenda Nossa Senhora | -62.357222 | -10.761806 | -04:00 | 306 | 8.5 | Pasture | 12 |
| 8 | PDG | Reserva Pe-de-Gigante | -47.649889 | -21.619472 | -03:00 | 690 | 21 | Savanna | 9 |

Principle Investigators and data references for these tower sites are as follows. Please see "Important Note on Data-Use policy," at the end of this section:

- K34: Manzi, A., Nobre, A. (INPA, Brazil) (Araujo et al., 2002)
- K67: Wofsy, S. (Harvard University, USA), Saleska, S. (UofA, USA), Camargo, A. CENA/USP, Brazil). (Hutyra et al., 2007; Saleska et al., 2003)
- K83: Goulden M. (UC Irvine, USA), Miller, S. (SUNY, Albany, USA), da Rocha, H. (USP, Brazil). (da Rocha et al., 2004; Goulden et al., 2004; Miller et al., 2004)
- K77: Fitzjarrald, D. (SUNY, Albany , USA) (Sakai et al., 2003)
- RJA: Manzi, A. (INPA, Brasil), Cardoso, F. (UFR, Brazil.) (Kruijt et al., 2004; von Randow, 2004).
- FNS: Waterloo, M.( Vrije Universiteit Amsterdam, The Netherlands), Manzi, A. (INPA, Brazil) (von Randow, 2004)

| | | |
|---|---|---|
| JAV: | da Rocha, H. (USP, Brazil) (Borma et al., submitted) | |
| PEG: | da Rocha, H. (USP, Brazil) (da Rocha et al., 2002) | |

## Table 1B. Site characterization

| ID | Short | Soil Type | USDA texture classes | Vegetation cover fraction | Canopy height [m] |
|---|---|---|---|---|---|
| 1 | BAN | Loamy sand | 2 | 0.98 | 16 |
| 2 | K34 | clay latosol | 8 | 0.98 | 35 |
| 3 | K67 | clay latosol | 8 | 0.98 | 35 |
| 4 | K77 | clay latosol | 8 | 0 to 0.8 | 0 to 0.6 |
| 5 | K83 | clay latosol | 8 | 0.98 | 35 |
| 6 | RJA | Sandy podsol | 10 | 0.98 | 30 |
| 7 | FNS | Sandy podsol | 10 | 0.85 | 0.2 to 0.5 |
| 8 | PDG | silty sand latosol | 2 | 0.80 | 12 |

## Table 1C. USDA soil texture classes

| Soil No. | Name | Silt (%) | Sand (%) | Clay (%) |
|---|---|---|---|---|
| 1 | Sand | 5 | 92 | 3 |
| 2 | Loamy sand | 12 | 82 | 6 |
| 3 | Sandy loam | 32 | 58 | 10 |
| 4 | Silt loam | 70 | 17 | 13 |
| 5 | Silt | 94 | 3 | 3 |
| 6 | Loam | 39 | 43 | 18 |
| 7 | Sandy clay loam | 15 | 58 | 27 |
| 8 | Sandy clay | 6 | 52 | 42 |
| 9 | Clay loam | 34 | 32 | 34 |
| 10 | Silty clay loam | 56 | 10 | 34 |
| 11 | Silty clay | 47 | 6 | 47 |
| 12 | Clay | 20 | 22 | 58 |

Percentage as mid-point value within each soil texture class (Cosby et al., 1984)

## Table 1D. IGBP biome classification

| No. | Class name |
|---|---|
| 0 | Water |
| 1 | Evergreen Needleleaf Forest |
| 2 | Evergreen Broadleaf Forest |
| 3 | Deciduous Needleleaf Forest |
| 4 | Deciduous Broadleaf Forest |
| 5 | Mixed Forests |
| 6 | Closed Shrublands |
| 7 | Open Shrublands |
| 8 | Woody Savannas |
| 9 | Savannas |
| 10 | Grasslands |
| 11 | Permanent Wetlands |
| 12 | Croplands |
| 13 | Urban and Built-Up |
| 14 | Cropland/Natural Vegetation Mosaic |
| 15 | Snow and Ice |
| 16 | Barren or Sparsely Vegetated |

## Table 1Ea. K77 Crop growth history

| Date | Cover Type K77 (Sakai et al., 2003) |
|---|---|
| Before ~Nov 1990 | Moist tropical forest |
| Jan 2000<br>Sep 2000 (start EC) - Nov 14,2001 | Grassland (pasture) |
| Nov 14, 2001–Feb 24, 2002 | Barren (pasture was burned and plowed) |
| Feb 24, 2002–Jun 13–14, 2002 | Cropland (non-irrigated rice) |
| Jun 13–14, 2002–Jan, 2003 | Barren (after harvest spontaneous re-growth of rice) |

## Table 1Eb. FNS Crop growth history

| Date | Cover Type FNS (von Randow, 2004) |
|---|---|
| Before ~1977 | Tropical dry forest |

| | |
|---|---|
| 1977 | Deforested by fire |
| Since 1991 | Pasture (cattle ranch) |

**Table 1D. BAN flooding schedule***

| Year | Flooding starts | Flooding ends |
|---|---|---|
| 2004 | 02-Feb-2004 ** | 10-Jun-2004 |
| 2005 | 12-Feb-2005 | 06-Jun-2005 |
| 2006 | 12-Dec-2005 | 17-Jun-2006 |

*: Based on soil moisture reaching saturation, approximated dates
**: Missing data

Site-specific driver data are available in ALMA-compliant NetCDF and ASCII formats at the LBA-MIP website: http://www.climatemodeling.org/lba-mip/.

Available data includes:

- general site-specific information (see Table 1, above), in ASCII format only from the LBA-MIP website: ftp://ftp.climatemodeling.org/pub/lba-mip/data/vegsoil.lbamip.txt
- Atmospheric forcing data (see Section 2.2, below)
- MODIS-derived vegetation phenological data (LAI, NDVI, EVI and FPAR), available for those models which cannot simulate fully dynamic vegetation prognostically (see Section 2.3, below).

**Important Note on Data-Use policy**

In accordance with LBA data sharing policy this data is freely available to all LBA researchers (http://www.lbaeco.org/lbaeco/data/data_poldoc.htm; see policy #2). Note, in particular, that policy #7 states that:

*7. Where data are used for modeling or integrating studies, the scientist collecting the data will be credited appropriately, either by co-authorship or by citation. The data collectors should be informed of publication plans well in advance of submission of a paper, given an opportunity to read the manuscript, and be offered co-authorship. In cases where data from other investigators are a minor contribution to a paper, the data should be referenced by a citation. Users of the data will always have to state the source of the data*

Please note that, notwithstanding the availability of this common driver dataset, the LBA data sharing policy still requires any author or presenter of this data to contact and appropriately credit PIs from individual projects that generated the data used. The necessary contact information is given in the Table 1.

### *2.2 Atmospheric Forcing Datasets*

The forcing data are ALMA-compliant, multi-year consistently-filled meteorological observations from selected LBA flux towers (Brasil flux network), including boundary conditions (site location, biome type, soil type and initial data). The data are for periods between 1999 and 2006 *in local time*, the exact time coverage being determined by site-specific data availability (see table below). Forcing datasets include:

a. air temperature
b. specific humidity
c. module of wind speed
d. downward long wave radiation at the surface
e. surface pressure
f. precipitation
g. shortwave downward radiation at the surface
h. $CO_2$ will be set to 375 ppm.

These atmospheric drivers are provided at 1 hour time-step as ALMA-compliant ASCII and NetCDF format files (see http://www.lmd.jussieu.fr/~polcher/ALMA/). Models should use linear interpolation (except for solar radiation, where zenithal angle would be more appropriate) if they are run at shorter than a 1 hour time step. These data are available from the LBA-MIP website http://www.climatemodeling.org/lba-mip/

The drivers will be distributed with leap year; to ensure consistency across models, the *simulations should also be provided with leap day (February 29) excluded.* (make sure it is Feb 29 that is excluded, and not another day. E.g do not exclude December 31.)

**Table 2. Site-specific Availability of continuously filled driver data**

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|
| **1. BAN** | | | | | | | | |
| **2. K34** | | | | | | | | |
| **3. K67** | | | | | | | | |
| **4. K77** | | | | | | | | |
| **5. K83** | | | | | | | | |
| **6. RJA** | | | | | | | | |
| **7. FNS** | | | | | | | | |
| **8. PDG** | | | | | | | | |

### *2.3 (a) Phenological information*

Models with dynamic vegetation (DVMs) should be run in the mode in which they generate their own phenology (e.g., Leaf Area Index, LAI), and the value of LAI should be reported in the outputs (see Table 4F). To facilitate inclusion of those models which cannot prognostically simulate dynamic vegetation structure and phenology, a standard set of monthly LAI values derived by a phenology model (Stöckli et al., in preparation) or MODIS-derived phenological information are provided (Tables 3a-c). It should be recognized that known remote sensing technical and physical uncertainties mean these data may be unreliable. However, to minimize these defects, aggregations of the best quality filtered satellite phenological information were derived for each tower site.

To facilitate comparison between models and to explore the effect of differences between dynamic vegetation model-derived and MODIS-derived vegetation phenologies, DVM's should be run in two modes if possible: i.e. in prognostic mode (in which leaf phenology is simulated) and in forced mode (in which model phenology is forced by the MODIS or phenology-model (Stöckli et al., in preparation) derived). As not all sites allow for constant LAI values (e.g.: PDG or FNS), participants are encouraged to use LAI values in the following priority: modeled LAI (Table 3a), MODIS-derived monthly LAI (Table 3b) then MODIS-derived constant LAI (Table 3c). Please report both the source of the selected LAI, and the actual LAI values used.

**Table 3a. Modeled monthly LAI (Stöckli et al., in preparation)**

| ID | Short | Jan | Feb | Mar | Apr | May | Jun | July | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | BAN | 5.27 | 5.05 | 4.99 | 4.99 | 5.00 | 5.14 | 5.24 | 5.26 | 5.26 | 5.27 | 5.31 | 5.32 |
| 2 | K34 | 6.03 | 5.96 | 5.91 | 5.88 | 5.81 | 5.8 | 5.88 | 5.98 | 6.01 | 6.04 | 6.07 | 6.07 |
| 3 | K67 | 5.77 | 5.71 | 5.67 | 5.62 | 5.63 | 5.63 | 5.70 | 5.80 | 5.82 | 5.82 | 5.82 | 5.81 |
| 4 | K77[1] | 2.04 | 1.28 | 0.72 | 0.81 | 0.91 | 1.24 | 2.59 | 2.85 | 2.76 | 2.32 | 2.10 | 2.54 |
| 5 | K83 | 5.59 | 5.39 | 5.36 | 5.41 | 5.48 | 5.53 | 5.67 | 5.76 | 5.75 | 5.75 | 5.76 | 5.76 |
| 6 | RJA | 5.64 | 5.64 | 5.64 | 5.65 | 5.63 | 5.63 | 5.63 | 5.63 | 5.63 | 5.64 | 5.64 | 5.64 |
| 7 | FNS | 5.56 | 5.60 | 5.63 | 5.61 | 5.46 | 4.74 | 3.77 | 3.15 | 3.34 | 4.13 | 4.95 | 5.43 |
| 8 | PDG | 3.41 | 3.56 | 3.54 | 3.5 | 3.21 | 2.90 | 2.49 | 2.21 | 2.13 | 2.29 | 2.48 | 2.98 |

**Table 3b. MODIS-derived monthly LAI**

| ID | Short | Jan | Feb | Mar | Apr | May | Jun | July | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | BAN | 5.35 | 4.58 | 4.63 | 4.71 | 4.77 | 4.51 | 4.88 | 4.86 | 4.81 | 4.9 | 4.24 | 5.6 |
| 2 | K34 | 5.6 | 4.97 | 5.37 | 4.94 | 4.78 | 4.94 | 5.37 | 5.96 | 6.05 | 5.91 | 5.81 | 5.75 |
| 3 | K67 | 5.08 | 5.43 | 5.58 | 5.19 | 4.93 | 5.33 | 5.22 | 5.56 | 5.15 | 5.55 | 5.5 | 5.73 |
| 4 | K77[1] | 2.04 | 1.28 | 0.72 | 0.81 | 0.91 | 1.24 | 2.59 | 2.85 | 2.76 | 2.32 | 2.10 | 2.54 |
| 5 | K83 | 5.13 | 4.10 | 5.24 | 4.89 | 4.66 | 4.96 | 5.00 | 4.90 | 4.86 | 4.93 | 5.42 | 5.01 |
| 6 | RJA | 5.09 | 5.20 | 4.38 | 5.18 | 4.79 | 4.85 | 4.97 | 5.31 | 5.50 | 5.56 | 5.18 | 5.44 |
| 7 | FNS | 4.81 | 5.70 | 5.23 | 4.64 | 5.15 | 4.62 | 3.38 | 3.27 | 2.10 | 3.82 | 3.98 | 4.82 |
| 8 | PDG | 2.03 | 2.67 | 3.06 | 3.49 | 3.26 | 2.92 | 2.22 | 1.74 | 1.28 | 1.49 | 1.89 | 2.32 |

**Table 3c. MODIS-derived average LAI**

| ID | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Short | BAN | K34 | K67 | K77[1] | K83 | RJA | FNS | PDG |
| LAI | 4.82 | 5.45 | 5.35 | 1.85 | 4.93 | 5.12 | 4.29 | 2.36 |

[1] *Site history combined to LAI-2000 in-situ measurements at a similar site Santarém Km69 (18 July 2002) (Huete et al., 2007)*

## *2.3 (b) Vegetation structure*

A few of the eddy flux sites also have data on vegetation structure, for example: above-ground live biomass and biomass increment, litterall rates, stocks of coarse wood debris, and soil respiration. We will endeavor to assemble this information for comparison to models in a timely manner.

### *2.4 Initialization and spin-up*

Model physics and biophysics should be initialized as follows:

a) Soil moisture in all layers set to 0.95 of saturation (porosity)
b) Soil temperature in all layers set to the mean of the yearly air temperature
c) Because reliable carbon and nitrogen pools observations are not available, soil carbon, living biomass, etc should be spun up according to the best practices for each model, but the spin up procedure used should be documented.
d) Initial $CO_2$ values will also be assumed as steady-state solution

Spin-up for model physics and biogeochemistry should use one of the following procedures:

a) Replicate the driving dataset to achieve a 10-15 year simulation run
b) Replicating the driver dataset until the mean monthly soil moisture does not deviate by more than 0.1% from the previous year.

### *2.5 Model output*

| Model outputs should be uploaded at the LBA-MIP website: http://www.climatemodeling.org/lba-mip/ |
|---|

The first phase of the LBA-MIP will focus on model simulations at eight individual towers using the meteorological forcing data from the LBA project. Participating models should be able to provide the defined set of variables in the ALMA-compliant format (please see ALMA website http://www.lmd.jussieu.fr/~polcher/ALMA/convention_3.html for units and details). This will allow compatibility among all the models and simplify comparisons. Output should be provided at 1-hour time-step, local time (see Table 1A) in NetCDF for the variables listed below (see appendix for more information on NetCDF data format) The values of state variables should be given at the end of each time-step, fluxes should be averaged values over a time-step, and storage change variables should be accumulated over each time-step.

a. Model states and outputs
    i. *Carbon fluxes*: GPP, NPP, and Re.
    ii. *Energy balance and hydrology*: sensible and latent heat flux, net radiation for short and long wave, and runoff
    iii. Surface soil temperature and soil temperature by layer,
    iv. Soil moisture at the surface and soil moisture by layer
    v. Soil carbon (total, and by pools if possible, including separate litter pool)

vi. Input parameters, re-output at the time resolution to simplify analysis

vii. Parameters table used for soil description at each site and run, as well as other model assumptions should be reported (e.g. rooting depth).

b. Vegetation dynamics (if applicable);

i. vegetation carbon (total, leaves, roots, woods etc. if possible)

ii. Tree mortality, recruitment, and growth (in carbon flux and as annual rates) (broken down by components if possible: total, leaves, roots, wood)

Table 4 shows the list of ALMA variables that each modeling group should return. If a variable is not deliverable, it should be replaced by the value of -999.99 that will represent either undefined or missing value. Please note the desired sign convention for flux directionality is specified in column five of the table. Because it may vary from model to model, reporting by model preference the analysis would complicate the future comparative model analysis.

Model diagnostic variables should comply with the following radiation energy and water conservation equations. Participants are advised to check against these before submitting their results. This will ensure that diagnostics, units and timings of the submitted results are appropriate for the analysis:

Energy balance (residual at all times should be smaller than 1 W m-2):

$$SWnet + LWnet - Qh - Qle - Qg = DelCanh / dt$$

Water balance (residual at all times should be smaller than $1x10^{-6}$ $kg/m^2/s$):

$$Rainf + Snowf - Evap - Qs - Qsb + Qrec = (DelIntercept + DelSrfStor + DelSoilMoist) / dt$$

For the LBA towers neither snow nor ice is separately diagnosed since these states are not likely to occur. If this is a problem for closing the energy and water balance above, please add snow states and fluxes to respective water state and flux variables. If the model needs additional diagnostic radiation, heat and water storage terms (e.g. canopy air space water and heat storage) on the right hand side of the above equations, please add those to the diagnostic output and let us know.

**Table 4A. General energy balance components:**

| Variable | Description | Definition | Units | Positive Dir. (Traditional) | Priority |
|---|---|---|---|---|---|
| SWnet | Net shortwave radiation | Incoming solar radiation less the simulated outgoing shortwave radiation, averaged over a grid cell | $W/m^2$ | Downward | Mandatory |
| LWnet | Net long wave radiation | Incident long wave radiation less the simulated outgoing long wave radiation, averaged over a grid cell | $W/m^2$ | Downward | Mandatory |
| Qle | Latent heat flux | Energy of evaporation, averaged over a grid cell | $W/m^2$ | Upward | Mandatory |
| Qh | Sensible heat flux | Sensible energy, averaged over a grid cell | $W/m^2$ | Upward | Mandatory |
| Qg | Ground heat flux | Heat flux into the ground, averaged over a grid cell | $W/m^2$ | Downward | Mandatory |
| DelCanHeat | Change in canopy heat storage | Change in canopy heat storage | $J/m^2$ | Increase | Mandatory |
| DelSurfHeat | Change in surface heat storage | Change in heat storage over the soil layer and the vegetation for which the energy balance is calculated, accumulated over the sampling time interval. | $J/m^2$ | Increase | Recommended |

Note: These outputs are intended to capture energy budget components sufficient to ensure that the energy balance is satisfied: SWnet + LWnet - Qh - Qle - Qg = DelCanh /dt

**Table 4B. General water balance components:**

| Variable | Description | Definition | Units | Positive Dir. (Traditional) | Priority |
|---|---|---|---|---|---|
| Rainf | Rainfall rate | Average of the total rainfall over a time step and grid cell. | $kg/m^2/s$ | Downward | Mandatory |
| Evap | Total Evapotranspiration | Sum of all evaporation sources, averaged over a grid cell | $kg/m^2/s$ | Upward | Mandatory |
| Qs | Surface runoff | Runoff from the land surface and/or subsurface stormflow | $kg/m^2/s$ | Out of gridcell | Mandatory |
| Qrec | Recharge | Recharge from river to the flood plain | $kg/m^2/s$ | Into gridcell | Optional |
| Qsb | Subsurface runoff | Gravity drainage and/or slow response lateral flow. Ground water recharge will have the opposite sign. | $kg/m^2/s$ | Out of gridcell | Mandatory |
| Qt | Total runoff | Qsb + Qs (allows water-budget closure for models that don't separate into Qs & Qsb) | $kg/m^2/s$ | Out of gridcell | Mandatory |
| DelSoilMoist | Change in soil moisture | Change in the simulated vertically integrated soil water volume, averaged over a grid cell, accumulated over the sampling time interval. | $kg/m^2$ | Increase | Mandatory |
| DelSurfStor | Change in Surface Water Storage | Change in vertically integrated liquid water storage, other than soil, snow or interception (lake, depression and river channel etc.), accumulated over the sampling time interval. | $kg/m^2$ | Increase | Recommended |
| DelIntercept | Change in interception storage | Change in the total liquid water storage in the canopy, accumulated over the sampling time interval. | $kg/m^2$ | Increase | Recommended |

Note: These outputs are intended to capture water budget components sufficient to ensure that the water balance is satisfied: Rainf - Evap - Qs - Qsb + Qrec = (DelIntercept + DelSrfStor + DelSoilMoist) /dt

## Table 4C. Surface state variables:

| Variable | Description | Definition | Units | Positive Dir. (Traditional) | Priority |
|---|---|---|---|---|---|
| VegT | Vegetation Canopy Temperature | Vegetation temperature, averaged over all vegetation types | K | - | Mandatory |
| BaresoilT | Temperature of bare soil | Surface bare soil temperature | K | - | Mandatory |
| AvgSurfT | Average surface temperature | Average of all vegetation, bare soil and snow skin temperatures | K | - | Mandatory |
| Albedo | Surface Albedo | Grid cell average albedo for all wavelengths. | - | - | Mandatory |
| SurfStor | Surface Water Storage | Total liquid water storage, other than soil, snow or interception storage (i.e. lakes, river channel or depression storage). | $kg/m^2$ | - | Mandatory |

## Table 4D. Subsurface State Variables

| Variable | Description | Definition | Units | Positive Dir. (Traditional) | Priority |
|---|---|---|---|---|---|
| ZSOI | Soil layer depth | Midpoint depth of each soil layer | m | - | Mandatory |
| DZSOI | Soil layer thickness | Thickness of each soil layer | m | - | Mandatory |
| SoilMoist | Average layer soil moisture | Soil water content in each user-defined soil layer (3D variable). Includes the liquid, vapor and solid phases of water in the soil. | $kg/m^3$ | - | Mandatory |
| SoilTemp | Average layer soil temperature | Average soil temperature in each user-defined soil layer (3D variable) | K | - | Recommended |
| SoilWet | Total Soil Wetness | Vertically integrated soil moisture divided by maximum allowable soil moisture above wilting point. | - | - | Mandatory |

## Table 4E. Evaporation components:

| Variable | Description | Definition | Units | Positive Dir. (Traditional) | Priority |
|---|---|---|---|---|---|
| ECanop | Interception evaporation | Evaporation from canopy interception, averaged over all vegetation types within a grid cell. | $kg/m^2/s$ | Upward | Recommended |
| TVeg | Vegetation transpiration | Transpiration from canopy, averaged over all vegetation types within a grid cell. | $kg/m^2/s$ | Upward | Mandatory |
| ESoil | Bare soil evaporation | Evaporation from bare soil. | $kg/m^2/s$ | Upward | Mandatory |
| EWater | Open water evaporation | Evaporation from surface water storage. | $kg/m^2/s$ | Upward | Recommended |
| RootMoist | Root zone soil moisture | Total simulated soil moisture available for evapotranspiration. | $kg/m^2$ | - | Mandatory |
| CanopInt | Total canopy water storage | Total canopy interception, averaged over all vegetation types within a grid cell. | $kg/m^2$ | - | Recommended |

**Table 4F. Carbon Budget:**

| Variable | Description | Definition | Units | Positive Dir. (Traditional) | Priority |
|---|---|---|---|---|---|
| GPP | Gross Primary Production | Gross carbon assimilation via photosynthesis | $KgC/m^2/s$ | Downward (production is positive) | Mandatory |
| NPP | Net Primary Production | Net carbon assimilation by vegetation | $KgC/m^2/s$ | Downward (production is positive) | Mandatory |
| NEE | Net Ecosystem Exchange | Sum of all carbon fluxes exchanged between the surface and the atmosphere | $KgC/m^2/s$ | Upward (flux to atmosphere is positive) | Mandatory |
| AutoResp | Autotrophic Respiration | Autotrophic respiration includes maintenance respiration and growth respiration | $KgC/m^2/s$ | Upward | Recommended |
| HeteroResp | Heterotrophic Respiration | Total flux from decomposition of organic matter | $KgC/m^2/s$ | Upward | Recommended |
| ANPP | Aboveground Net Primary Production | Component comparable to measurements | $KgC/m^2/s$ | Downward (production is positive) | Recommended |
| BgResp | Belowground Respiration | Auto- and heterotrophic respiration belowground | $KgC/m^2/s$ | Upward | Recommended |
| LitterFall | Leaf litterfall | Not including reproductive or fine wood litter | $KgC/m^2/s$ | Downward (litterfall is positive) | Recommended |
| TotSoilCarb | Total Soil Carbon | Total soil and litter carbon content integrated over the entire soil profile | $KgC/m^2$ | - | Recommended |
| TotLivBiom | Total Living Biomass | Total carbon content of the living biomass | $KgC/m^2$ | - | Recommended |
| AWBiom | Aboveground wood | aboveground live wood biomass | $KgC/m^2$ | Downward (production is positive) | Recommended |
| LAI | Leaf Area Index | | $m^2 m^{-2}$ | | Required* |

* Required if your model uses LAI
Note: units should be in mass of carbon (not mass of $CO_2$ or organic matter)

### 2.6. Checklist and diagnostics for submission

A diagnostic tool is available online (http://www.climatemodeling.org/lba-mip/tools) so that each modeling group can systematically check the simulations, as represented in NetCDF format, for correct format and internal consistency. In particular, the diagnostic tool will ensure that the checklist (**Table 5**, below) applies.

**Table 5: Checklist for submission**

| Issue | Desired Procedure |
|---|---|
| Timestamp correct | Driver data are in Local time; output should also be in local time. (See **Table 1A** for time offset of each site relative to UTC) |
| Leap days excluded | On leap years, leap day (Feb. 29) should be excluded in the model outputs.. |
| Variable Names correct | Make sure column names of output variables are compliant with the protocol |
| Variable sign conventions correct | The output specification table (Table 4) indicates the sign conventions for each variable. |
| Additional variables added | Incorporate additional carbon-cycle variables (if relevant to model) into output (Table 4F). |
| Convert to NetCDF | To ensure consistency and uniformity of access to simulation data, all output should be in NetCDF format (see appendix A of this protocol). |
| Run output diagnostic tool | Provided, with instructions, on the LBA-MIP website (http://www.climatemodeling.org/lba-mip/) |
| Upload runs | Upload runs to the LBA-MIP website (http://www.climatemodeling.org/lba-mip/upload_instructions.html) |
| | |

## 3. Intercomparison Methods and Analysis

The models compared will be divided in two categories, i.e. models that simulate carbon (C) and models that do not simulate carbon (NC). Models that simulate carbon may also participate in the simulations for group NC with their carbon component disabled. Models that simulate carbon will further be divided into fully dynamic vegetation models (which prognostically simulate vegetation phenology) and those that require phenological driving data.

The evaluation will include comparison between the model output and measured fluxes and state variables, at the different sites, namely:

a. Latent heat flux
b. Sensible heat flux
c. Ground heat flux
d. Carbon flux (NEE – Net Ecosystem Exchange)
e. Soil moisture
f. Soil temperature
g. Net short wave radiation
h. Net long wave radiation

The proposed evaluation will also be performed at different time-scales:

a. Daily mean
b. Monthly mean
c. Annual mean
d. Seasonal (dry and wet seasons analyzed separately)
e. Hourly
f. Diurnal cycle (amplitude and phase)
g. Daytime and nighttime carbon

***Sensitivity analysis***

A minimal standard set of sensitivity analyses are recommended for all model participants, with focus on sensitivity to precipitation and to vegetation phenology: In the case of *phenology*, in addition to runs in which MODIS phenology is used, a sensitivity run in which models use their own default phenology prescription (i.e.: model calculated or from lookup tables). The following relevant driving data are available:

- Vegetation and Soil Characteristics
- ALMA NetCDF forcing data
- ASCII forcing data
- Plots of driver variables
- Annual and monthly mean LAI fields

## 4. Files and datasets name conventions

The file naming will follow the PILPS convention:

[modelname].[simulationcode].[sitename].lbamip.nc

where:

- [modelname] is the name of the model used;
- [simulationcode] is the convention used to identify the experiment: “c” or “nc” for carbon or non carbon, respectively, followed by the experiment number;
- [sitename] is the name of the site, for example, “ban” or “fns” or “k83” or “k77” or etc.
- file extension ‘.nc’ indicates the NetCDF format.

For example, the file “sib.nc1.k83.lbamip.nc” includes all the output for the first experiment using the sib model, without carbon at the K83 site. Files with additional information such as set of parameters used at a specific experiment or initial states should follow similar convention, respectively, e.g.:

[modelname].[simulationcode].[sitename].lbamip.par
[modelname].[simulationcode].[sitename].lbamip.ini

## 5. Participant Models Registration

A list of participating modeling groups is being maintained and the latest available version is given below. Groups that have not yet registered their model should provide the following information:

a. A short model description including model structure
b. A description of land surface that can be represented (topography? Land cover (plant functional types? Or biomes?, rooting depth, soil texture etc.) Although some parameters will be provided (i.e. vegetation cover, LAI, height of canopy, etc.) for LBA-MIP, the default set of parameters for the given soil and vegetation types for each site should be reported.
c. A description of the external forcing required (not calculated by the model) such as time variant and time invariant parameters, atmospheric forcing, etc.
d. Description of the “default” parameters used based on the different towers characteristics and, if any calibration is used, description of the calibration procedure and parameters affected.
e. Groups may upload models source code if desired.

## 6. LBA- MIP Timeframe and Deadlines

| | |
|---|---|
| June 8, 2007: | Driver datasets at individual tower sites made available (downloadable at: http://www.climatemodeling.org/lba-mip/ |
| Jun 8–Jul 10, 2007: | Initial simulation runs conducted |
| July 15, 2007: | Target for preliminary model outputs made available by participants |
| Jul 15–Sep 10, 2008: | Analysis and intercomparison of initial model outputs |
| Sep 24-25, 2007: | Workshop meeting to present/discuss the LBA/MIP preliminary results – Hotel Fiesta, Salvador, Brazil (just prior to the LBA-ECO 11th Science Team Meeting) |
| Dec 12, 2007: | Meeting at AGU, San Francisco, USA |
| Jan 2008: | Release updated drivers |
| April 1, 2008 | Submission of updated MIP runs |
| May 2-3, 2008: | LBA-MIP Workshop<br>University of Maryland Inn and Conference Center,<br>3501 University Boulevard East,<br>Adelphi, MD, USA |
| **November 05, 2008** | **Re-submission of MIP results with errors corrected** |
| **Nov. 17-21, 2008** | **LBA-MIP session at LBA Meeting, Manaus, Brazil** |

## Appendix A. Notes on using NetCDF file formatting convention for model runs

Please note the following requirements for a NetCDF file to pass the test:

1. Four dimensions, 'x', 'y', 'z', and 'time'. They must be spelled correctly.
2. Time series of length 70080.
3. ALL variables must be must be reported as 4-D (x,y,z,time) variables.
4. All mandatory variables must be reported. (Note four new required variables, ZSOI, DZSOI, Qt, LAI)

Please supply additional variables as needed. Re-reporting of model variables that correspond to driver data variables also helps us verify that you used the correct driver data.

The below is a sample NetCDF output (ncdump –h) showing all of the required dimensions, variables, and attributes that must be included. **All dimensions and variables must be spelled correctly**!

```
dimensions:
        x = 1 ;
        y = 1 ;
        z = 10 ;
        time = 70080 ;
variables:
        double lon(x) ;
                lon:long_name = "longitude" ;
                lon:units = "unitless" ;
        double lat(y) ;
                lat:long_name = "latitude" ;
                lat:units = "unitless" ;
        float ZSOI(x, y, z, time) ;
                ZSOI:long_name = "soil depth" ;
                ZSOI:units = "m" ;
        float DZSOI(x, y, z, time) ;
                DZSOI:long_name = "soil thickness" ;
                DZSOI:units = "m" ;
        double time(time) ;
                time:long_name = "time" ;
                time:units = "days since 1485-01-01 00:00:00 -04:00" ;
                time:calendar = "noleap" ;
                time:bounds = "time_bounds" ;
        float TBOT(x, y, z, time) ;
                TBOT:long_name = "atmospheric air temperature (compare to forcing
data)" ;
                TBOT:units = "K" ;
```

```
	float QBOT(x, y, z, time) ;
		QBOT:long_name = "atmospheric specific humidity (compare to forcing data)" ;
		QBOT:units = "kg/kg" ;
	float WIND(x, y, z, time) ;
		WIND:long_name = "atmospheric wind velocity magnitude (compare to forcing data)" ;
		WIND:units = "m/s" ;
	float FSDS(x, y, z, time) ;
		FSDS:long_name = "atmospheric incident solar radiation (compare to forcing data)" ;
		FSDS:units = "watt/m^2" ;
	float FLDS(x, y, z, time) ;
		FLDS:long_name = "atmospheric longwave radiation (compare to forcing data)" ;
		FLDS:units = "watt/m^2" ;
	float SWnet(x, y, z, time) ;
		SWnet:units = "W/m2" ;
		SWnet:long_name = "Net shortwave radiation" ;
		SWnet:missing_value = -999.99 ;
	float LWnet(x, y, z, time) ;
		LWnet:units = "W/m2" ;
		LWnet:long_name = "Net longwave radiation" ;
		LWnet:missing_value = -999.99 ;
	float Qle(x, y, z, time) ;
		Qle:units = "W/m2" ;
		Qle:long_name = "Latent heat flux" ;
		Qle:missing_value = -999.99 ;
	float Qh(x, y, z, time) ;
		Qh:units = "W/m2" ;
		Qh:long_name = "Sensible heat flux" ;
		Qh:missing_value = -999.99 ;
	float Qg(x, y, z, time) ;
		Qg:units = "W/m2" ;
		Qg:long_name = "Ground heat flux" ;
		Qg:missing_value = -999.99 ;
	float DelCanHeat(x, y, z, time) ;
		DelCanHeat:units = "J/m2" ;
		DelCanHeat:long_name = "Change in canopy heat storage" ;
		DelCanHeat:missing_value = -999.99 ;
	float DelSurfHeat(x, y, z, time) ;
		DelSurfHeat:units = "J/m2" ;
		DelSurfHeat:long_name = "Change in surface heat storage" ;
		DelSurfHeat:missing_value = -999.99 ;
	float Rainf(x, y, z, time) ;
		Rainf:units = "kg/m2/s" ;
```

```
            Rainf:long_name = "Rainfall rate" ;
            Rainf:missing_value = -999.99 ;
      float Evap(x, y, z, time) ;
            Evap:units = "kg/m2/s" ;
            Evap:long_name = "Total evapotranspiration" ;
            Evap:missing_value = -999.99 ;
      float Qs(x, y, z, time) ;
            Qs:units = "kg/m2/s" ;
            Qs:long_name = "Surface runoff" ;
            Qs:missing_value = -999.99 ;
      float Qrec(x, y, z, time) ;
            Qrec:units = "kg/m2/s" ;
            Qrec:long_name = "Recharge" ;
            Qrec:missing_value = -999.99 ;
      float Qsb(x, y, z, time) ;
            Qsb:units = "kg/m2/s" ;
            Qsb:long_name = "Subsurface runoff" ;
            Qsb:missing_value = -999.99 ;
      float DelSoilMoist(x, y, z, time) ;
            DelSoilMoist:units = "kg/m2" ;
            DelSoilMoist:long_name = "Change in soil moisture" ;
            DelSoilMoist:missing_value = -999.99 ;
      float DelSurfStor(x, y, z, time) ;
            DelSurfStor:units = "kg/m2" ;
            DelSurfStor:long_name = "Change in surface water storage" ;
            DelSurfStor:missing_value = -999.99 ;
      float DelIntercept(x, y, z, time) ;
            DelIntercept:units = "kg/m2" ;
            DelIntercept:long_name = "Change in interception storage" ;
            DelIntercept:missing_value = -999.99 ;
      float VegT(x, y, z, time) ;
            VegT:units = "K" ;
            VegT:long_name = "Vegetation canopy temperature" ;
            VegT:missing_value = -999.99 ;
      float BaresoilT(x, y, z, time) ;
            BaresoilT:units = "K" ;
            BaresoilT:long_name = "Temperature of bare soil" ;
            BaresoilT:missing_value = -999.99 ;
      float AvgSurfT(x, y, z, time) ;
            AvgSurfT:units = "K" ;
            AvgSurfT:long_name = "Average surface temperature" ;
            AvgSurfT:missing_value = -999.99 ;
      float Albedo(x, y, z, time) ;
            Albedo:units = "proportion" ;
            Albedo:long_name = "Surface albedo (direct)" ;
            Albedo:missing_value = -999.99 ;
```

```
    float SurfStor(x, y, z, time) ;
        SurfStor:units = "kg/m2" ;
        SurfStor:long_name = "Surface water storage" ;
        SurfStor:missing_value = -999.99 ;
    float SoilMoist(x, y, z, time) ;
        SoilMoist:units = "kg/m2" ;
        SoilMoist:long_name = "Average layer soil moisture" ;
        SoilMoist:missing_value = -999.99 ;
    float SoilTemp(x, y, z, time) ;
        SoilTemp:units = "K" ;
        SoilTemp:long_name = "Average layer soil temperature" ;
        SoilTemp:missing_value = -999.99 ;
    float SoilWet(x, y, z, time) ;
        SoilWet:units = "unitless" ;
        SoilWet:long_name = "Total soil wetness" ;
        SoilWet:missing_value = -999.99 ;
    float ECanop(x, y, z, time) ;
        ECanop:units = "kg/m2/s" ;
        ECanop:long_name = "Interception evaporation" ;
        ECanop:missing_value = -999.99 ;
    float TVeg(x, y, z, time) ;
        TVeg:units = "kg/m2/s" ;
        TVeg:long_name = "Vegetation transpiration" ;
        TVeg:missing_value = -999.99 ;
    float ESoil(x, y, z, time) ;
        ESoil:units = "kg/m2/s" ;
        ESoil:long_name = "Bare soil evaporation" ;
        ESoil:missing_value = -999.99 ;
    float EWater(x, y, z, time) ;
        EWater:units = "kg/m2/s" ;
        EWater:long_name = "Open water evaporation" ;
        EWater:missing_value = -999.99 ;
    float RootMoist(x, y, z, time) ;
        RootMoist:units = "kg/m2" ;
        RootMoist:long_name = "Root zone soil moisture" ;
        RootMoist:missing_value = -999.99 ;
    float CanopInt(x, y, z, time) ;
        CanopInt:units = "kg/m2" ;
        CanopInt:long_name = "Total canopy water storage" ;
        CanopInt:missing_value = -999.99 ;
    float GPP(x, y, z, time) ;
        GPP:units = "kgC/m2/s" ;
        GPP:long_name = "Gross primary production" ;
        GPP:missing_value = -999.99 ;
    float NEE(x, y, z, time) ;
        NEE:units = "kgC/m2/s" ;
```

```
        NEE:long_name = "Net ecosystem exchange" ;
        NEE:missing_value = -999.99 ;
    float AutoResp(x, y, z, time) ;
        AutoResp:units = "kgC/m2/s" ;
        AutoResp:long_name = "Autotrophic respiration" ;
        AutoResp:missing_value = -999.99 ;
    float NPP(x, y, z, time) ;
        NPP:units = "kgC/m2/s" ;
        NPP:long_name = "Net primary production" ;
        NPP:missing_value = -999.99 ;
    float HeteroResp(x, y, z, time) ;
        HeteroResp:units = "kgC/m2/s" ;
        HeteroResp:long_name = "Heterotrophic respiration" ;
        HeteroResp:missing_value = -999.99 ;
    float ANPP(x, y, z, time) ;
        ANPP:units = "kgC/m2/s" ;
        ANPP:long_name = "Aboveground Net Primary Production" ;
        ANPP:missing_value = -999.99 ;
    float BgResp(x, y, z, time) ;
        BgResp:units = "kgC/m2/s" ;
        BgResp:long_name = "Belowground Respiration" ;
        BgResp:missing_value = -999.99 ;
    float LitterFall(x, y, z, time) ;
        LitterFall:units = "kgC/m2/s" ;
        LitterFall:long_name = "Leaf Litterfall" ;
        LitterFall:missing_value = -999.99 ;
    float TotSoilCarb(x, y, z, time) ;
        TotSoilCarb:units = "kgC/m2" ;
        TotSoilCarb:long_name = "Total soil carbon" ;
        TotSoilCarb:missing_value = -999.99 ;
    float TotLivBiom(x, y, z, time) ;
        TotLivBiom:units = "kgC/m2" ;
        TotLivBiom:long_name = "Total living biomass" ;
        TotLivBiom:missing_value = -999.99 ;
    float AWBiom(x, y, z, time) ;
        AWBiom:units = "kgC/m2" ;
        AWBiom:long_name = "Aboveground Wood" ;
        AWBiom:missing_value = -999.99 ;
    float LAI(x, y, z, time) ;
        LAI:units = "m2/m2" ;
        LAI:long_name = "Total projected leaf area index" ;
        LAI:missing_value = -999.99 ;

// global attributes:
        :title = "K34 c1 simulation in My Model for 2002 - 2005" ;
        :source = "My University" ;
```

:history = "Created on Thu Apr 24 19:20:54 2008" ;

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