

Protocol for the North American Carbon Project (NACP) Site-level Interim Synthesis Model-Data Comparison (Site Synthesis), Version 6

October 24, 2008

Changes from Version 5:

- 1) Move all site tables to wiki server
- 2) Updated output variable list
- 3) Updated ancillary data list
- 4) Disturbance history input variables
- 5) MODIS phenology data
- 6) NETCDF tool descriptions

Expected Changes to Version 7:

- 1) Table of crop yield and forest inventory data

Table Of Contents

1.	Introduction.....	3
1.1.	Background.....	3
1.2.	Site Synthesis Objective and Scope.....	3
1.3.	Protocol Objective and Scope.....	4
2.	Site Synthesis Infrastructure.....	6
2.1.	Management Team.....	6
2.2.	Wiki Server.....	6
2.3.	Email Lists.....	6
2.4.	Data and Model Output Fair Use policy.....	7
3.	Data Protocol.....	8
3.1.	Participating Flux Tower Sites.....	8
3.2.	Data from Tower sites.....	8
3.3.	National Inventory Data.....	9
3.4.	Flux Uncertainty.....	10
4.	Model Simulation Protocol.....	11
4.1.	Participating Models.....	11
4.2.	Inputs to Model.....	11
	Gap-filled Observed Weather.....	11
	Phenology.....	12
	Site Specific and Ancillary data.....	13
	Disturbance and Land Use History.....	17
	Initial conditions.....	18
	Simulation Spinup.....	18
4.3.	Outputs from Models.....	18
	Submission Files.....	18
	Model Output Variables.....	19
	NETCDF Tools.....	20
	Model Uncertainty.....	20
	Model Survey.....	21
4.4.	Modelers Checklist.....	21
5.	Intercomparison Methods and Analysis.....	23
	Model Comparison.....	23
	The Residual.....	23
	Multiple Time Scales.....	24
	Data Filtering.....	24
	Mass and Energy Balance.....	25
	Papers.....	25
6.	Schedule.....	26
7.	References.....	27
	Appendix A: Model output Variables.....	29

1. Introduction

1.1. Background

Projections of the terrestrial carbon cycle using multiple coupled carbon-climate models vary from a 10 Gt C yr⁻¹ sink to a 6 Gt C yr⁻¹ source by 2100, introducing uncertainty in projections of future climate [Kicklighter *et al.*, 1999; Cox *et al.*, 2000; Cramer *et al.*, 2001; Friedlingstein *et al.*, 2001, 2006]. These large differences stem primarily from the fact that the terrestrial carbon cycle models vary so widely in basic structure, with each model including different combinations of biological and physical processes [Kicklighter *et al.*, 1999; Cramer *et al.*, 2001; Cox *et al.*, 2000]. Even with similarly constructed models, results differ because of different boundary conditions, initial conditions, and input data. To reduce uncertainty in future climate projections, we must reconcile differences between models in terms of quantified uncertainties. A necessary first step is to assess biases and uncertainties associated with different modeling approaches when using the best available data for model input, boundary conditions, and output evaluation. An important corollary is that the biases and uncertainties in the data sources also be well-characterized. The Site Model Data Comparison (MDC) synthesis project will take advantage of strengths in both the observational and modeling communities to quantify observational uncertainty and model performance.

1.2. Site Synthesis Objective and Scope

The Site Synthesis will address the following science question:

“Are the various measurement and modeling estimates of carbon fluxes consistent with each other - and if not, why?”

Answering this question requires the best available measured and modeled flux estimates, with defensible estimates of measurement and model uncertainty. The Site Synthesis will quantify measurement and modeling uncertainty at the scale of individual sites.

The Site Synthesis project will quantify model and observation uncertainty and bias by comparing simulated surface fluxes and biomass from multiple models to observed values at multiple sites in the AmeriFlux and Fluxnet Canada eddy covariance flux networks. We chose eddy flux towers because the ecological and physical processes at these sites are well understood with detailed observations of surface energy and carbon fluxes, local weather conditions, biomass, and many other important parameters. The Site Synthesis will focus on the terrestrial carbon cycle, with special emphasis on reconstruction of recent carbon fluxes and biomass. The carbon cycle is tightly coupled to the water and energy cycles, so evaluation of model performance will also include comparison with observed latent heat flux, sensible heat flux, soil moisture, soil temperature, and other locally observed quantities.

The Site Synthesis strategy is to collect all model input and output in a central location using standard nomenclature and file format so that multiple analysis teams can simultaneously assess the results. All models will use the same standardized inputs derived from local observations and simulation setup procedures to produce model output optimally consistent with other models and with local observations. All flux tower data

will be filtered and filled using standard procedures, as defined by the AmeriFlux and Fluxnet Canada communities. The AmeriFlux and Fluxnet Canada networks already have centralized data systems using standard formats and nomenclature. The core management team will coordinate the various analysis teams to minimize overlap and maximize results. Each analysis team will focus on different aspects of model performance at time scales ranging from diurnal to inter-annual. The resulting model output and infrastructure will serve as a strong foundation for future efforts.

The Site Synthesis is one of several of a larger NACP project to interim synthesis activities to evaluate and compare models and observations at local and regional scales for the period 2000 - 2005. The Regional and Continental Interim Synthesis compares “bottom up” estimates of North American carbon flux with “top-down” estimates from atmospheric transport inversions. The Mid-Continent Intensive Interim Synthesis will compile, diagnose, and reconcile estimates of carbon fluxes from atmospheric inversions, models, and inventories in the central United States. The Non-CO₂ Greenhouse Gases will examine the spatial and temporal distributions of methane, carbon monoxide, and nitrous oxide over North America. The results from this site level synthesis will provide important constraints to other regional and continental-scale synthesis efforts.

For complete descriptions of the NACP synthesis activities, go to <http://nacp.ornl.gov/mast-dc/>.

1.3. Protocol Objective and Scope

The Site Synthesis Protocol identifies standard model inputs, simulation setup procedures, model outputs, and analysis techniques to ensure a valid and fair comparison of model results against observations. Using standardized input, output, and analysis techniques will minimize setup and analysis time and allow us to accurately gauge model and data uncertainty with minimal error and bias. The Protocol covers procedures, plans, and infrastructure for the Site Synthesis. Protocols for other NACP synthesis projects will appear in separate documents. The protocol covers all information provided to participants and by participants. The protocol lists the Site Synthesis schedule and integrated products (including peer-reviewed publications).

The Protocol will define required site and model specific information in standard terminology, units, and format, but the actual values and the lists of participating sites and models will be stored in tables on the wiki server. Keeping the Protocol up-to-date with the frequent changes to the list of participating sites and models has proven impractical. The tower site and model lists will be maintained separately on the Site Synthesis wiki server (<http://isynth-site.pbwiki.com/>), eliminating the need to frequently update the Protocol.

The basic structure and format of Site Synthesis protocol closely follows the protocol used in the Large-Scale Biosphere - Atmosphere Experiment in Amazonia (LBA) Model Inter-comparison Project (MIP). The Site Synthesis’s emphasis on North America compliments the LBA MIP’s emphasis on South America. We are working closely with the LBA MIP team to take full advantage of their infrastructure, results, and lessons learned. File formats and variable naming conventions for all model input and output closely match those used in the LBA MIP. Our intent is for the participating modeling teams to reuse the programs and infrastructure developed to support the LBA

MIP to minimize the time required to run simulations at the flux tower sites in the Site Synthesis.

2. Site Synthesis Infrastructure

2.1. Management Team

Table 1 shows the core team of individuals coordinating the Site Synthesis, with Peter Thornton as the lead. The core team will coordinate Site Synthesis activities with all participants and other NACP synthesis projects to define the schedule, budget, and products. The core team will organize telecons, meetings, and email messages as needed to ensure effective communication with all participants and other interested parties.

Table 1: Site Synthesis Core Team

Name	Phone	Email
Peter Thornton	(303) 497-1727	thornton@ucar.edu
Ken Davis	(814) 863-8601	davis@meteo.psu.edu
Kevin Schaefer	(303) 492-8869	kevin.schaefer@nsidc.org
Bob Cook	(865) 574-7319	cookrb@ornl.gov
Daniel Ricciuto	(865) 574-7067	ricciutodm@ornl.gov

2.2. Wiki Server

We created a wiki server as a central data repository where participants can download all required inputs and upload model submission files. The wiki server houses all Site Synthesis documentation, software tools, and analysis results and provides links to other web sites containing information of the Site Synthesis and other NACP synthesis activities. The wiki server also provides links to the primary Site Level Synthesis home page, which contains expanded documentation and presentations. Flux tower observations will remain at the Ameriflux and FluxNet Canada servers. All Site Synthesis participants can access the wiki server with minimal security requirements, such as a password. Site Synthesis participants have the capability to add comments and edit some of the documentation and all participants are automatically notified of any changes to the wiki server. To access the wiki server, go to <http://isynth-site.pbwiki.com/>, where you will be asked to sign up and provide a password.

2.3. Email Lists

The Site Synthesis involves a large number of modelers, observationalists, program managers, and other interested parties widely distributed across North America. To facilitate effective communication, we created participant email lists to disseminate information. As required, we will create smaller email lists consisting of subsets of the full participant list to focus on specific problems or research efforts. We provide means for participants to add or remove their name from emailing lists. We will create a special email list of those participants providing data and model output to ensure quick and effective implementation of our Fair Use Policy (see below).

To join the emailing list, go to http://www.nacarbon.org/cgi-bin/working_groups/wg.pl?synthesis=1 and click on Site-level Interim Synthesis: email lists.

2.4. Data and Model Output Fair Use policy

The Site Synthesis will involve scientists from a large number of independently funded research projects. To ensure the individuals and teams that provide model output and data receive proper credit for their work, we have instituted a Fair Use Policy. The policy applies to all data and model output stored on the wiki server and, by extension, the Ameriflux and Fluxnet Canada servers. The Fair Use Policy is based on the Ameriflux Policy, but expanded to include all Site Synthesis participants:

The data and model output provided on this site are freely available and were furnished by individual scientists who encourage their use. Please kindly inform in writing (or e-mail) the appropriate participating scientist(s) of how you are using the data and of any publication plans. If not yet published, please reference the source of the data or model output as a citation or in the acknowledgments. The scientists who provided the data or model output will tell you if they feel they should be acknowledged or offered participation as authors. We assume that an agreement on such matters will be reached before publishing and/or use of the data for publication. If your work directly competes with an ongoing investigation, the scientists who provided the data or model output may ask that they have the opportunity to submit a manuscript before you submit one that uses their data or model output. When publishing, please acknowledge the agency that supported the research. We kindly request that those publishing papers using AmeriFlux data, Fluxnet Canada data, or Site Synthesis model output supply reprints to the appropriate scientist providing the data or model output, and to the data archive at the Carbon Dioxide Information Analysis Center (CDIAC).

3. Data Protocol

3.1. Participating Flux Tower Sites

The wiki Server includes a list of all participating eddy flux covariance towers in the Site Synthesis, divided into a Priority 1 and a Priority 2 list. The Priority 1 sites represent a broad range of vegetation types and geographic regions to test each model's performance under the fullest range of expected conditions across North America. No more than three Priority 1 sites were chosen to represent each of the major biome types in North America (as defined by the IGBP biome classification described below). The Priority 1 list represents the minimum number of tower sites required to evaluate model performance in North America. The Priority 2 list expands the site selection to include towers required for specialized analyses. For example, to evaluate model performance within a single biome, the modeling teams would run all Priority 1 and Priority 2 towers that fall into that biome class. Each participating site should provide observations as input to models and for comparison with model output, as described below.

For each site we use a unique code taken from the La Thuile synthesis project: CC-XXX, where CC is a two letter country code and XXX is a three letter site code. For those sites that are not participating in the La Thuile synthesis project, we created a new unique code using the La Thuile convention. The site codes are a unique identifier for each site and a convenient naming convention for all model input and output files.

3.2. Data from Tower sites

Table 2 lists the information and observations required for each tower site. The location, biome, and soil texture are required as model inputs. The rest of the observations will be used to compare against model output. Mandatory data are required for each tower and optional data are provided if they are available or applicable, since some observations, such as active layer depth, clearly apply to some towers and not others. We will obtain much of the data in Table 2 directly from the Ameriflux and Fluxnet Canada data sites.

Table 2: Information and Observations for each tower

Data	Description	Units	Positive	Priority
Location	latitude and longitude of tower	deg	East and North	Mandatory
References	published papers describing the site	(-)	na	Mandatory
Biome	doiminant vegetation at tower	(-)	na	Mandatory
Soil Texture	USDA soil type or texture	(%)	na	Mandatory
Data Frequency	time interval between observations	(min)	na	Mandatory
Latent Heat flux	observed latent heat flux	W m ⁻²	Upward	Mandatory
Sensible Heat Flux	observed sensible heat flux	W m ⁻²	Upward	Mandatory
NEE	Net Ecosystem Exchange	□mol c m ⁻² s ⁻¹	Upward	Mandatory
Soil Temperature	soil temperature	C	na	Optional
Soil Temperature Depth	soil temperature measurement depth	m	Downward	Optional
Biomass	any biomass observations	variable	na	Optional
GPP	Gross Primary Productivity	□mol C m ⁻² s ⁻¹	Downward	Optional
Respiration	Total ecosystem respiration	□mol C m ⁻² s ⁻¹	upward	Optional
Soil Respiration	Soil respiration from domes	□mol C m ⁻² s ⁻¹	upward	Optional
Active Layer	active layer depth	m	Downward	Optional

Any processing, filtering, or gap-filling of the observational data should be done using the same techniques and criteria for all flux tower sites. Any modified, deleted, filtered, or filled data values should be identified by a unique flag. For example, a data point removed as an outlier would have a different flag from a data point removed during U* filtering. All flux towers should use standard flag definitions. There should be a separate flag for each major step in the processing to account for the possibility of a data value altered by multiple processing steps. For example, there should be a separate flag indicating the application of a storage flux correction.

Many of the flux towers include separate estimates of Gross primary Productivity (GPP) and total ecosystem respiration (R_t). To separate NEE into GPP and R_t , a statistical respiration model is trained using nighttime fluxes and air temperature, applied to the daytime, and subtracted from the NEE. Such estimates are useful for comparison with modeled GPP and R_t . All towers should use the same technique to estimate GPP and R_t based on unfilled NEE data.

3.3. National Inventory Data

Several national inventory systems in Canada and the United States will provide applicable data for model input or comparison with model output. The Site Synthesis will focus on disturbance history, crop yield and Forest Inventory Analysis (FIA). Table 3 lists the data sources, observed parameters, and points of contact for national inventory data from both the United States and Canada used in the Site Synthesis. Some of the data will be used as standardized inputs to models, which, like the standardized weather data, will minimize potential sources of error in model output. Some will be used to compare with model output to quantify uncertainty. Data providers must also include quantified measures of uncertainty.

Table 3: Inventory Data Sources

Insert table of data sources and contacts here

Those models that can incorporate past land-use into simulated biomass and fluxes will use as input the standardized disturbance histories. Those models that can distinguish different crops will use the crop type history as input. We will compare crop yield and biomass from the FIA to model output.

3.4. Flux Uncertainty

Quantified uncertainty and bias of the flux measurements are essential to the core objectives of the Site Synthesis. To ensure a valid and fair comparison, the methods and techniques to estimate uncertainty and biases should be consistently applied at all participating data providers. Uncertainty falls into two general categories: random and systematic. Random uncertainty represents the irreducible uncertainty in the observations due to instrument precision and the chaotic nature of turbulent flow. *Richardson et al.* [2006] developed equations to estimate uncertainty in carbon flux, sensible heat flux, and latent heat flux. Random uncertainty in biomass observations, such as the allometric observations of wood biomass, should be derived from the literature according to the specifics of the technique used.

Systematic uncertainty represents limits in accuracy due to the physical aspects of tower setup, site layout, and instrumentation design or uncertainty introduced during processing, filtering, and correcting the data. *Papale et al.* [2006] developed techniques quantifying systematic uncertainty for flux data accumulated during data processing. The sources of systematic error often vary from site to site and the Site Synthesis team will work with the data providers, particularly the flux tower community, to ensure consistent estimates of systematic uncertainty. Sources of systematic uncertainty related to physical aspects of the site include

- 1) Representation error (how well the site represents the broader region or the general vegetation type)
- 2) Spatial heterogeneity (the effects of local topography, drainage, and variability in land cover)
- 3) Instrumentation (calibration errors, instrument biases, high frequency losses, etc.)
- 4) Advection
- 5) Energy balance closure

Sources of systematic uncertainty related to data processing include:

- 1) Flux algorithms
- 2) U^* filtering
- 3) Storage correction
- 4) GPP/respiration separation
- 5) Gap filling

4. Model Simulation Protocol

4.1. Participating Models

The wiki server includes a list of all models participating in the Site Synthesis. The list includes a primary point of contact for each modeling team and access to the Model Survey form. All modeling teams should run simulations at all Priority 1 sites and as many Priority 2 sites as possible within available resources. If a particular model is designed to represent only a single biome or vegetation class, such as a crop model, the modeling team should run all applicable Priority 1 and Priority 2 sites of that biome class.

Each modeling team will be provided with standardized gap-filled, locally-observed weather, remotely sensed phenology, land use history, and site description data as model inputs. To ensure consistency, each modeling team should follow standard model setup and spinup procedures. After running simulations, each modeling team should provide to the Site Synthesis specific model output variables in standard netcdf format. The Site Synthesis will provide software tools to help model teams prepare model output for submission.

4.2. Inputs to Model

All models should use standardized inputs provided by the Site Synthesis project derived from local observations. Using standard, observationally-based inputs allow us to isolate uncertainty associated with differences in model structure, rather than uncertainty associated with, for example, input weather. Standardized model input data falls into five categories: weather, phenology, site description data, initial conditions, and land use history. Weather data represents the local weather conditions. Phenology consists of remotely sensed Leaf Area Index (LAI) and absorbed fraction of Photosynthetically Active Radiation (fPAR). Site description data consists of biome type, soil texture, and other site-unique data that does not change with time. Initial conditions represent starting values for slowly changing prognostic variables, such as soil temperature and moisture. Land use history represents site specific record of past disturbances, such as burn history, or changes vegetation, such as crop rotation.

Gap-filled Observed Weather

We will provide gap-filled weather data for each site derived from local observations as shown in Table 4. We use NCDC climate station data when available to fill gaps in tower meteorological data. NCDC climate stations within 50km are available for all sites. About half of these sites had hourly measurements, generally from ASOS sites. The rest were usually coop sites. In addition, DAYMET modeled fine-scale climate data are available for continental US sites through the year 2003. When station data are not available, a 10-day running mean diurnal cycle is used. The filledmet_readme document on the wiki server describes in detail the filling techniques for the individual variables.

Table 4: Gap-filled weather data

Name	Description	Units
Tair	Near surface air temperature	K

Qair	Near surface specific humidity	kg kg ⁻¹
Wind	Near surface module of wind speed	m s ⁻¹
Rainf	Rainfall rate	kg m ⁻² s ⁻¹
Psurf	Surface pressure	Pa
SWdown	Surface Incident shortwave radiation	W m ⁻²
LWdown	Surface incident longwave radiation	W m ⁻²
CO2air	Near surface CO2 concentration	ppmv

The gap-filled weather data will be provided at the native time resolution at each tower. Most towers report time-average observations every 30 minutes, but some towers report every 60 minutes. The native time resolution for each tower is described in the Site Specific and Ancillary Data section below. Separate netcdf files for each site containing the entire time series of gap-filled weather data are available on the wiki server using the following naming convention: CC-XXXforcing.nc.gz, where CC-XXX is the unique site code.

Note that the weather date includes leap year. If your model does not account for leap year (and many do not), the modeling team must remove February 29 in leap years.

For models using an internal time step less than the driver data time step, the model should linearly interpolate between weather data points, except for the down-welling shortwave radiation, where scaling using the cosine of the zenith angle is appropriate. For models using a time step greater than the driver time step, the model should use appropriate time averages or totals of the weather data. For example, a model with a 1-day time step should use 24 hour averages or totals.

Phenology

The Site Synthesis will provide remotely sensed standard phenology data for each site derived from GIMMS version g NDVI dataset [Tucker *et al.*, 2005] and MODIS. We define plant phenology as periodic or seasonal changes in Leaf Area Index (LAI) and absorbed fraction of Photosynthetically Active Radiation (fPAR). Dynamic vegetation models calculate LAI and fPAR internally, but many models use remotely sensed phenology, so we will provide tables of remotely sensed LAI and fPAR as a function of time for each tower site. There are several remotely sensed phenology data sets available, each with different corrections, filtering, spatial coverage, and temporal resolution, etc. We chose GIMMSg and MODIS datasets because they widely used and well understood.

The GIMMS version g NDVI dataset is derived from the AVHRR instrument [Tucker *et al.*, 2005] with 15-day composites at 8 km resolution from 1982-2003. MODIS has 8 day composites with 250 m resolution from 2000 to 2008. For GIMMSg, we extracted the NDVI values for the pixel containing each tower. For MODIS values, we calculated LAI and fPAR area averages of all pixels within 1 km of the tower site.

Neither dataset covers the full time period for all flux tower sites. Both datasets are noisy due to cloud, aerosol, and water vapor contamination, introducing error and uncertainty in the simulated fluxes and biomass. To overcome the time coverage and noise problems, we first constructed 30-day composites of the full time series for both datasets. For the GIMMSg dataset, we then calculated an average seasonal cycle in NDVI and estimated LAI and fPAR values using the methods of *Sellers et al.* [1996b], *Los et al.* [2000], and *Schaefer et al.* [2002, 2005]. We then calculated an average seasonal cycle in NDVI, LAI, and fPAR for each tower site. Each model that uses remotely sensed phenology should repeat the average seasonal cycle for each year.

Each modeling team should choose either the GIMMSg or the MODIS phenology for all sites. For consistency, we prefer that the modeling teams do not use GIMMSg at some sites and MODIS at others. The phenology data is provided in separate ascii files for each site using variable nomenclature and units as shown in Table 5. The naming convention for the phenology files is CC-XXX_GIMMS or CC-XXX_MODIS, where CC-XXX is the unique site code. Model participants should describe any modifications they made to the phenology data when they submit model output.

Table 5: Phenology Variables

Name	Description	Units
LAI	Leaf Area Index	m ² m ⁻²
fPAR	absorbed fraction of Photosynthetically Active Radiation	kg kg ⁻¹
NDVI	Normalized Difference Vegetation Index	-

Site Specific and Ancillary data

The Site Synthesis will provide standard site specific and ancillary data for each site. Site specific and ancillary data covers any model input variable or parameter that varies from site-to-site, but does not vary with time. This includes site location, soil texture, biophysical parameters, and initial values of some prognostic variables. Most models use biome specific lookup tables to define internal biological characteristics, parameters, and constants. Many extract soil texture, initial values, and other inputs from generic global or regional maps. Using lookup tables and maps is, of course, necessary when running global or regional simulations, but introduces uncertainty in point simulations, where the generic values may not match actual conditions at the site.

Table 6 defines the site specific and ancillary data parameters selected from the AmeriFlux Biological Data template for use as input to models or as parameters normally chosen from a lookup table or map. All models should use the specified priority 1 inputs for site location, soil texture, and biome type. Each modeling team should identify those parameters in Table 6 that can be used by their model and substitute them for the generic values obtained from lookup tables or maps.

The site specific data also includes the required time step for model output (Obs_Delta_time). The models must produce time average output that matches the time averaging period of the observations, which varies between each tower. Most towers report time averages every 30 minutes, but some report every 60 minutes.

The site specific data also includes the closest IGBP biome type for each site. The biome classification scheme used to select parameters from lookup tables varies from model to model, so the model participants must match the observed vegetation characteristics at each tower to the most suitable biome classification used by their model. To help match locally observed vegetation with a model's biome class, we identified the closest vegetation type in the IGBP biome classification system, which, with minor variations, is widely in the modeling community (Table 7). The provided IGBP classification is meant as a guide: model participants must match the observed biome type to the classification system used by their model.

Table 6: Site specific Data for Each Tower

Variable	Description	Units	ABT	Time varying	Priority
Latitude	latitude of site	deg	No	No	1
Longitude	longitude of site	deg	No	No	1
Obs_Delta_Time	Time averaging period of observations	min	No	No	1
Biome_Type	IGBP biome classification	-	No	No	1
SAND_PERC	Soil percent sand	%	Yes	No	1
CLAY_PERC	Soil percent clay	%	Yes	No	1
SILT_PERC	Soil percent silt	%	Yes	No	1
AG_BIOMASS_CF	Aboveground biomass: crop foliage	gC/m2	Yes	No	2
AG_BIOMASS_CH	Aboveground biomass: crop harvest	gC/m2	Yes	No	2
AG_BIOMASS_NWT	Aboveground biomass: non- woody plants	gC/m2	Yes	No	2
AG_BIOMASS_SF	Aboveground biomass: shrub foliage	gC/m2	Yes	No	2
AG_BIOMASS_SW	Aboveground biomass: shrub wood	gC/m2	Yes	No	2
AG_BIOMASS_TF	Aboveground biomass: tree foliage	gC/m2	Yes	No	2
AG_BIOMASS_TW	Aboveground biomass: tree wood	gC/m2	Yes	No	2
ASA	Mean stand age	year	Yes	No	2
BUDBK_SPP<n>	Species for budbreak date	-	Yes	Yes	2
BUDBK<n>_DATE	Budbreak date	DOY/YYYY	Yes	Yes	2
CR_BIOMASS	Coarse root biomass	gC/m2	Yes	No	2
CROOT_N	Coarse root nitrogen	gN/100g dry weight	No	No	2

	concentration				
CROP_RESID	Crop residue	gC/m2	Yes	No	2
CWD	Coarse woody debris	gC/m2	Yes	No	2
FOL_N_SPP<n>	Species for foliar nitrogen concentration	-	Yes	No	2
FOL_N<n>	Foliar nitrogen concentration	gC/100g foliar mass	Yes	No	2
FR_BIOMASS	Fine root biomass	gC/m2	Yes	No	2
FROOT_N	Fine root nitrogen concentration	gN/100g dry weight	No	No	2
FWD	Fine woody debris	gC/m2	Yes	No	2
HEIGHTC	Mean canopy height	m	Yes	No	2
LAI<n>	Leaf Area Index	m2/m2	Yes	Yes	2
LAI<n>_DATE	LAI measurement date	DOY/YYYY	Yes	Yes	2
LEAF_LONG	Leaf longevity for evergreens	year	No	No	2
LEAF_WIDTH	Leaf width, narrowest dimension	m	No	No	2
LEAFFULL_SPP<n>	Species for maximum leaf expansion	-	Yes	Yes	2
LEAFFULL<n>_DATE	Maximum leaf expansion date	DOY/YYYY	Yes	Yes	2
LEAFOFF_SPP<n>	Species for total leaf-off	-	Yes	Yes	2
LEAFOFF<n>_DATE	Total leaf-off date	DOY/YYYY	Yes	Yes	2
LEAFSEN_SPP<n>	Species for leaf senescence	-	Yes	Yes	2
LEAFSEN<n>_DATE	Leaf senescence date	DOY/YYYY	Yes	Yes	2
LIT_C	Litter carbon concentration	gC/100g litter	Yes	No	2
LIT_MASS<n>	Litter mass	gC/m2	Yes	No	2
LIT_N	Litter nitrogen concentration	gN/100g litter	Yes	No	2
LMA_BOT	Leaf mass per unit area at the bottom of canopy	gC/m2 leaf area	No	No	2
LMA_SPP<n>	Species for LMA measurement	-	Yes	No	2
LMA_TOP	Leaf mass per unit area at the top of the canopy	gC/m2 leaf area	No	No	2
LMA<n>	Leaf mass per unit leaf area	gC/m2 leaf area	Yes	No	2

MSA	Maximum stand age	year	Yes	No	2
SNAG	Mass of standing dead trees	gC/m ²	Yes	No	2
SOIL_C	Soil carbon content	kg/m ²	Yes	No	2
SOIL_DEPTH	Soil depth	m	Yes	No	2
SOIL_N	Soil nitrogen content	kg/m ²	Yes	No	2
SOIL_WATER_CAP	Soil water holding capacity	mm	Yes	No	2
SPP_O<n>	Overstory dominant species	-	Yes	No	2
SPP_O<n>_PERC	Overstory dominant species percent	%	Yes	No	2
SPP_U<n>	Understory dominant species	-	Yes	No	2
SPP_U<n>_PERC	Understory dominant species percent	%	Yes	No	2
WOOD_N_SPP<n>	Species for wood nitrogen concentration	-	Yes	No	2
WOOD_N<n>	Wood nitrogen concentration	gN/100g dry weight	Yes	No	2

Table 7: IGBP biome types

Number	Code	Name
0	Wat	Water
1	ENF	Evergreen Needleleaf Forest
2	EBF	Evergreen Broadleaf Forest
3	DNF	Deciduous Needleleaf Forest
4	DBF	Deciduous Broadleaf Forest
5	MF	Mixed Forests
6	CSH	Closed Shrublands
7	OSH	Open Shrublands
8	WSA	Woody Savannas
9	SAV	Savannas
10	GRA	Grasslands
11	WET	Permanent Wetlands
12	CRO	Croplands
13	URB	Urban and Built-Up
14	CNV	Cropland/Natural Vegetation Mosaic
15	SNO	Snow and Ice
16	BAR	Barren or Sparsely Vegetated

Disturbance and Land Use History

The Site Synthesis will provide an observed disturbance and land use history for each site extracted from the AmeriFlux Biological Data template. Table 8 lists types of disturbances recorded at each tower site and Table 9 lists the parameters that describe each disturbance event. Disturbance histories for each site will be provided in separate excel files on the wiki server using the following naming convention: CC-XXX_dist, where CC-XXX is the site code. Those models that can account for disturbance and land use history should run two simulations: one with disturbance history and one steady state simulation without disturbance history.

Table 8: Types of Disturbances

Disturbance	Comments
grassland/grazed	
grassland/ungrazed	
harvest	DIST<n>_QUAL indicates if left on the field and is either on field or removed
thinning	DIST<n>_QUAL indicate the % of thinning
FWD removal	If not by underburning
underburn	Underburn
planted	Planted
fertilized	DIST<n>_QUAL field contains the amount in Kg/hectare
Irrigated	
natural regeneration	
natural regeneration filled	natural regeneration, supplemented with planted trees
wildfire	DIST<n>_QUAL indicates the wildfire severity and is one of high, moderate or low
crop type	
no-till	DIST<n>_QUAL indicates the type of no till
till	
crop residue management	DIST<n>_QUAL indicates the % left on field
windthrow	DIST<n>_QUAL indicates the % left on field
insects and pathogens	
woody encroachment	

Table 9: Disturbance Parameters

Variable	Description
DIST<n>	Site disturbance history code
DIST<n>_QUAL	Site disturbance code qualifier
DIST<n>_DATE	Date of site disturbance in mm/dd/yyyy format
DIST<n>_DATE_QUAL	Date of site disturbance qualifier

Initial conditions

Assumed initial values of slowly changing prognostic variables strongly influence simulated surface fluxes, particularly the initial values for soil temperature, soil moisture, and carbon pools. Soil temperatures, canopy temperatures, and canopy air space temperatures should be initialized to the overall, long-term average air temperature as defined by the gap-filled weather data. Soil moisture at all soil levels should be initialized to 95% of saturation. Because we want to examine differences in simulated biomass, we will not prescribe initial values for carbon, nitrogen, or phosphorus pools. Participants should initialize the biogeochemical pools as best suited for their model and provide descriptions of the initialization techniques.

Simulation Spinup

We assume steady state conditions for all model output. To achieve steady state, participants should repeat the supplied weather driver data until the slow response prognostic variable reach steady state. Slow response prognostic variables include soil temperature, soil moisture, and some carbon pools (primarily wood and slow soil pools). Steady state for soil moisture occurs when the seasonal cycle of monthly average values for each layer varies less than 1% between consecutive years. Steady state for the carbon cycle occurs when growth balances decay and the annual NEE~0 when averaged over the last five years of the spinup. We assume steady state for soil temperature occurs when the soil moisture reaches steady state.

The Site Synthesis hopes to quantify the effects of the assumed steady state initial condition on the simulated carbon fluxes and biomass. Many models assume steady state or near steady state conditions to initialize their carbon pools. While useful and easy, using the steady state assumption precludes the model from simulating long-term carbon sources and sinks. However, some models can incorporate observed land use disturbance history, stand age, or locally observed biomass to initialize the carbon pools, thus allowing simulated carbon sources and sinks. We encourage participants who use such models to run two sets of simulations, one assuming steady state and another with actual land use history.

4.3. Outputs from Models

Submission Files

All model participants should provide submission files in netcdf format using standard variable names and units as listed in Appendix A. netcdf is a widely used, binary, self-descriptive file format independent of platform with a supporting library of standard read/write routines. In the following paragraphs, we refer to the standard format files provided from the modeling teams to the Site Synthesis as the “submission” files and the uniquely formatted files from each model as “model output” files.

Each submission file should contain one year of model output using the following standard naming convention: CC-XXX_MODEL_RR_YYYY.nc, where CC is the country code, XXX is the site code, MODEL is the model name, RR is the run number,

and YYYY is year. The run number allows a single modeling team to submit more than one simulation using the same model. The different simulations may represent multiple internal model configurations, one at steady state and another including disturbances, for example. RR=01 should represent the baseline simulation at steady state. Teams submitting only one simulation should use RR=01.

Model Output Variables

Appendix A lists the required variables in the submission files, selected to allow direct comparison with local observations at each site. The variables are grouped into general categories such as biomass and carbon flux. Variable names, definitions, and units adhere to the ALMA standard. We did not include ALMA variables designed to test mass and energy balance. We added new variables not currently in the ALMA standard in order to compare with local observations. Not all variables are measured at all sites, but we felt a customized variable list for each site was impractical and too confusing. Some variables are not measured at any site, but are useful in diagnosing model behavior. If your model does not calculate a particular variable, insert the standard missing value of -999.

Appendix A specifies the expected units, sign convention, and variable type for each variable. Appendix A also specifies the variable type (real or integer) and expected dimension of each variable in the submission files. Nearly all variables have only one dimension: time. Several of the variables have a second dimension: nsoil (number soil layers), nsnowmax (number snow layers), and npool (number carbon pools). Each variable is assigned a unique alphanumeric code that is used by the alma_var program (described below) to match model output variables to ALMA compliant submission file variables.

Appendix A includes time-dependant input weather and phenology variables. If your model does not use a particular input weather variable, insert the standard missing value of -999. If your model predicts plant phenology (i.e., a dynamic vegetation model), insert your predicted LAI and fPAR rather than the values supplied by the Site Synthesis.

All times in the submission files must be in Greenwich Mean Time rather than local time at each tower. Times in the submission files correspond to the start and the end of the time averaging period of the observations. Models should save time averages that correspond to the observed fluxes at each site. The time averaging periods start at 0:00 GMT on January 1 of each year. If your model updates a particular variable only once per day, such as prognostic LAI, or once per month, simply repeat the value at the same time interval as the other variables. The time averaging periods for the observed fluxes differs from site to site. Most sites report time averages every 30 minutes, but some sites report time averages every 60 minutes (see Site Specific and Ancillary data above).

Submission files must include February 29 in leap years. Some models account for leap years and others do not. If your model does not account for leap years, duplicate February 28 values for February 29 in leap years (do not add a day at the end of the year).

The units for all carbon related variables are kg pure carbon. If your model estimates kg CO₂ or kg biomass, please convert to kg pure carbon.

NETCDF Tools

The Site Synthesis will provide some software tools to read and write netcdf files. The ALMA_var program reads in model output files and writes out submission files in the proper format. The ALMA_check program reads submission files and checks them for proper format and content. The netcdf_utilities contains various generic netcdf read subroutines. These tools will simplify and shorten the time required to create and verify the submission files.

ALMA_var is a Fortran 90 program that reads output files from a model and creates the standard submission files with all variables as defined above. The user matches model output variables to ALMA compliant submission variables using the variable code defined in Appendix A. Each team will have to modify ALMA_var in the appropriate location to properly read model output files and link model output variables to the ALMA variables. As an alternative, a modeling team can choose to extract the appropriate netcdf write routines from ALMA_var and insert them directly into their model.

The ALMA_check program reads submission files and checks for proper format, variable names, units, leap year, and time resolution. With so many models at so many sites, the analysis teams will have a very difficult time resolving format and unit problems after you submit the files. We strongly encourage the modeling teams to use the ALMA_check program to verify format before uploading the submission files.

Both ALMA_var and ALMA_check will be available for download from the wiki server as tar files. Each tar file includes a user's guide, the main program, required input files, and a generic set of utility subroutines that read netcdf files. Both programs include an option to create netcdf files compatible with the LBA MIP, for those modeling teams participating in both projects. To run ALMA_var and ALMA_check, each team will have to install the Fortran 90 netcdf library on their computer. Contact Kevin Schaefer if you encounter problems or find previously undetected bugs in the code.

Please do not delete your simulations after uploading your submission files. Even with the ALMA_var and ALMA_check tools, mistakes may occur that would require you to re-process the submission files. We cannot anticipate what we will see during comparison with observations and we may ask for additional diagnostics, which are easy to extract from an old run, but difficult to recreate from scratch.

Model Uncertainty

Quantified uncertainty and bias of simulated fluxes and biomass are essential to the core objectives of the Site Synthesis. Model uncertainty falls into four broad categories: structural, input, parameter, and initial condition uncertainty. Structural uncertainty refers to missing physical processes or errors in the mathematical representation of processes. Parameter uncertainty refers to errors in various physical and biological parameters and constants that do not vary with time. Input uncertainty refers to errors in all time-dependent model drivers, particularly weather. Initial condition uncertainty refers to errors in the assumed initial values for various prognostic variables, such as soil temperature and biomass.

We will employ a two-step strategy in quantifying model uncertainty: 1) gather already complete and available uncertainty analyses, and 2) focused sensitivity analyses on the dominant sources of model uncertainty. Monte Carlo simulations (the best technique for estimating model uncertainty) and sensitivity analyses for all participating models is too time consuming to complete within the timeframe of the Site Synthesis. Fortunately, many model development groups have already performed uncertainty analyses on their models. By gathering these analyses, we can identify the dominant 5-10 sources of error. We will then run a focused sensitivity analysis for this subset of parameters and inputs at selected sites. This two step strategy will give us quantified uncertainty for the dominant sources of error, avoiding the difficulty and expense of quantifying all sources of error.

Model Survey

Each model team must fill out the Model Survey form, which uses standard nomenclature to summarize basic model structure, such as the type of photosynthesis model, soil model snow model, or radiative transfer model. This information will help analysis teams interpret differences between model output and observations and between models. The survey includes references, documentation, and web pages to allow quick access to greater detail, if required. The survey also includes static information that does not vary with time, such as the number and name of carbon pools, the number and geometry of soil layers, etc. The analysis teams will use this information to read multidimensional variables in the required model output to ensure proper matching of model output to observations (matching the correct soil layer to compare with observed soil temperature, for example). The same survey form is used for both the Site Synthesis and the NACP Regional Synthesis, so the modeling teams participating in both synthesis activities only need fill out the survey once.

To fill out the survey form, go to <http://daac.ornl.gov/SURVEY8/survey.shtml> or to the wiki server (<http://isynt-site.pbwiki.com/>) and click on participating models.

4.4. Modelers Checklist

To help the modeling teams collect and organize all the model input and output, we put together a checklist shown in Table 10.

Table 10: Modelers Checklist

Item	Filename	Number of files
Gap Filled Weather (input)	CC-XXXforcing.nc.gz	1 per site
GIMMSg Phenology (input)	CC-XXX_GIMMS	1 per site
MODIS Phenology (input)	CC-XXX_MODIS	1 per site
Site Specific/Ancillary data (input)	Site_Ancillary_data	1
Disturbance history (input)	CC-XXX_dist	1 per site
ALMA_var and ALMA_check	alma_var, alma_check, netcdf_utilities	3
Submission files	CC-XXX_MODEL_RR_YYYY.nc	1 per year per site
Model Uncertainty	variable	variable

Model Survey

on-line interactive

na

5. Intercomparison Methods and Analysis

Our basic analysis strategy is to evaluate the simplest statistical measures of model performance first, such as bias and root mean square error, and then move on to more sophisticated analyses. We anticipate multiple teams of researchers, each focusing on a different aspect of model performance, to simultaneously compare model output to observations. The Site Synthesis Management Team will informally coordinate the efforts of the various analysis teams. Here we define common variables, techniques, and assumptions to ensure we can integrate and compare the results of the various analysis teams.

Model Comparison

To identify fundamental modes of model behavior, the analysis team will compare the mean annual cycle based on monthly averages for all simulations at all towers. Such a summary of model behavior of the mean annual cycle, without direct comparison with data, is useful for identifying basic patterns and regimes of model behavior. This will also help identify “problem simulations” where some error occurred during setup, allowing the modeling team to correct the error and submit a new simulation.

The Residual

We will base our model-data comparison on the statistics of the residual, δ_n ,

$$(1) \delta_n = M_n - O_n,$$

where n is the time index, M_n is the model value, and O_n is the observed value. A positive δ_n indicates the model value is greater than observed. We will calculate the raw residuals on the native time resolution of the observations without gap-filling. Model output will be matched exactly with valid observed data and model output without a corresponding observation will be ignored.

Various statistical quantities derived from δ_n measure different aspects of model performance. For example, the residual mean, δ_{ave} , quantifies bias between the model and the observations, with a positive value indicating the model, on average, is higher than observed. The number of residual statistical quantities increases with shorter time scales. For the overall time scale, we will calculate one δ_{ave} for the entire time series:

$$(2) \delta_{ave} = \frac{1}{N_{Tot}} \sum_{n=1}^{N_{Tot}} \delta_n,$$

where N_{Tot} is the total number of points in the observed time series. For the seasonal time scale, we will calculate δ_{ave} for each month:

$$(3) \delta_{avei} = \frac{1}{N_i} \sum_{n=1}^{N_i} \delta_{ni},$$

where N_i is the total number of residual for the i^{th} month. For diurnal time scales, we will calculate δ_{ave} for each hour of the day and for each month.

The residual standard deviation or root mean square error, δ_{std} , measures how closely the model follows the observed variability:

$$(4) \delta_{std}^2 = \frac{1}{N} \sum_{i=1}^N (\delta_i - \delta_{ave})^2$$

The chi-squared statistic, X , indicates how well the model matches the observations relative to observational uncertainty.

$$(5) X^2 = \frac{1}{N} \sum_{i=1}^N \frac{\delta_i^2}{E^2},$$

where E is the combined model and observation uncertainty. A $X < 1$ indicates the model over matches or over-fits the observations while $X > 1$ indicates the model does not match the observations well enough. A X of one indicates the model matches the observations within the uncertainty, which is the optimal target for any model.

Multiple Time Scales

We evaluate model performance on four time scales: overall, seasonal, synoptic, and diurnal. The residual statistics at each time scale measures how well the models reproduce observed variability at each time scale. The overall statistics measure model performance for the entire time series, the seasonal statistics measure how well the model captures the observed seasonal cycle, etc. Because of missing observed flux data and the potential for introducing bias during filtering of the data (see below), we do not feel we can properly evaluate long-term sources and sinks.

The exact techniques for constructing time averages from the flux data are not clear at this time. The LBA MIP analysis team is performing sensitivity studies to see how estimated model performance might change depending on the exact technique or minimum coverage threshold used to construct the time average. We will wait and see the results of these studies before choosing a specific technique to construct time averages from the observations. Whatever technique is chosen will be applied in the same manner to all towers and model output.

Data Filtering

The observations may require some filtering to remove questionable values. For flux data, this includes U^* (friction velocity) and energy closure filtering. The eddy covariance technique works only when the air flow around the tower is turbulent. Removing fluxes when the U^* falls below a minimum threshold eliminates data taken under low turbulence conditions. The energy associated with the observed fluxes does not balance, indicating potential biases in one or more fluxes. An energy closure filter eliminates those days where the energy imbalance exceeds a threshold value.

The exact techniques for data filtering are not clear at this time. The LBA MIP analysis team is performing studies to see how estimated model performance might change with various filtering thresholds and techniques. We will wait to see these sensitivity analyses from the LBA MIP before determine the best approach for the Site

Synthesis. Whatever technique is chosen will be applied in the same manner to all towers and model output.

Mass and Energy Balance

The checker program will perform a basic “sanity check” on long-term mass and energy conservation, but the Site Synthesis will not check for balance at each time step. Differing model structures makes inclusion of all possible terms to calculate balance in the required model output impractical. We assume the modeling teams have already verified mass and energy balance as part of normal model validation. The checker program will verify that

$$(6) \quad \begin{aligned} \overline{SW} + \overline{LW} - \overline{LH} - \overline{SH} &\leq \delta_{energy} \\ \overline{P} - \overline{LH} - \overline{Runoff} &\leq \delta_{water} \end{aligned},$$

where SW and LW are absorbed shortwave and longwave energy, LH and SH are latent and sensible heat fluxes, P is precipitation, $Runoff$ is surface and below ground runoff, and δ_{energy} and δ_{water} are minimum criteria for balance. The overbars represent time averages over the entire simulation period. We will use the values for δ_{energy} and δ_{water} developed for the LBA MIP, which are balance to within about 10-20%.

Papers

We expect to produce a series of papers broken down primarily by time scale. We hope to write one or two high profile papers and a special issue in as-yet-determined journals with the following focused articles:

- 1) “Big picture” paper with overview and summary of results
- 2) Diurnal time scale: sensible, latent heat, and carbon flux
- 3) Mean annual cycle time scale: sensible, latent heat, and carbon flux
- 4) Inter-annual time scale: sensible, latent heat, and carbon flux
- 5) Multiple papers focusing on specific issues, such as light use efficiency, biomass, soil temperature, snow properties, etc.

6. Schedule

Table 11 shows the current projected schedule for the Site Synthesis. The dates for the individual milestones ensure that we have suitable results to support the Site Synthesis workshop and NACP all scientist meeting. The timing of the Site Synthesis workshop is set to coincide roughly with workshops sponsored by the other NACP synthesis projects. We will update this schedule after final site selection.

The model participants must submit preliminary or test simulation results prior to the due date of the final simulation results to allow time for the Site Synthesis staff to check for format errors and correct output units. At the same time, the model participants can compare against observations using the preliminary analysis tools. Participants then have sufficient time before the final due dates to correct any format problems or perform any model improvements prior to the final due date.

Table 11: NACP Site Synthesis Schedule

Event	Date
Final Site Selection	Nov 3, 2008
Final Protocol Update	Nov 3, 2008
Start Model Runs	Nov 3, 2008
Model Runs Due	Dec 3, 2008
AGU Mini-workshop	Dec 16, 2008
Full Workshop	Jan 7-9, 2009
Present results at NACP All-Scientist meeting	Feb 17-20, 2009
Submit papers for JGR special issue	May 1, 2009

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Appendix A: Model output Variables

Code	Category	Variable	Description	Definition	Units	Positive	type	nDim	Dim1	Dim2
B1	Biomass	AbvGrndWood	Above ground woody biomass	Total above ground wood biomass	Kg/m2	na	real	1	time	na
B2	Biomass	CarbPools	Size of each carbon pool	Carbon mass of each carbon pool	Kg/m2	na	real	2	npool	time
B3	Biomass	CASCO2	Canopy Air Space CO2 concentration	Canopy Air Space CO2 concentration	ppmv	na	real	1	time	na
B4	Biomass	CropYeild	Annual Crop yeild	Annual yeild of perennial crops	Kg/m2	na	real	1	time	na
B5	Biomass	TotLivBiom	Total Living Biomass	Total carbon content of the living biomass (leaves+roots+wood+seeds)	Kg/m2	na	real	1	time	na
B6	Biomass	TotSoilCarb	Total Soil Carbon	Total soil and litter carbon content integrated over the entire soil profile	Kg/m2	na	real	1	time	na
C1	Carbon Flux	AutoResp	Autotrophic Respiration	Total respiration due to plant maintenance and growth	Kg/m2/s2	Into Atm.	real	1	time	na
C2	Carbon Flux	GPP	Gross Primary Production	Photosynthetic assimilation rate of carbon by the vegetation	Kg/m2/s	Into Grnd.	real	1	time	na
C3	Carbon Flux	HeteroResp	Heterotrophic Respiration	Total respiration from decomposition of organic matter	Kg/m2/s	Into Atm.	real	1	time	na
C4	Carbon Flux	NEE	Net Ecosystem Exchange	Total ecosystem respiration minus Gross Primary Productivity (TotalResp-GPP) or Heterotrophic respiration minus Net Primary Productivity (HeteroResp-NPP)	Kg/m2/s	Into Atm.	real	1	time	na
C5	Carbon Flux	NPP	Net Primary Production	Carbon assimilation by photosynthesis after growth and maintenance (GPP-AutoResp)	Kg/m2/s	Into Grnd.	real	1	time	na
C6	Carbon Flux	TotalResp	Total ecosystem respiration	Total ecosystem respiration (AutoResp+HeteroResp)	Kg/m2/s	Into Atm.	real	1	time	na

Code	Category	Variable	Description	Definition	Units	Positive	type	nDim	Dim1	Dim2
D1	Driver	CO2air	Near surface CO2 concentration	The partial pressure of CO2 concentration at the atmospheric reference level (3D variable).	ppmv	na	real	1	time	na
D2	Driver	LWdown	Surface incident longwave radiation	Incident longwave radiation averaged over the time step of the forcing data	W/m2	downward	real	1	time	na
D3	Driver	PSurf	Surface pressure	Pressure measured at the surface	Pa	na	real	1	time	na
D4	Driver	Qair	Near surface specific humidity	Specific humidity measured at reference levels near the surface (3D variable)	kg/kg	na	real	1	time	na
D5	Driver	Rainf	Rainfall rate	Average total rainfall over a time step of the forcing data.	kg/m2s	downward	real	1	time	na
D6	Driver	SWdown	Surface incident shortwave radiation	Incident radiation in the shortwave part of the spectrum averaged over the time step of the forcing data	W/m2	downward	real	1	time	na
D7	Driver	Tair	Near surface air temperature	Temperature measured at reference levels near the surface (3D variable)	K	na	real	1	time	na
D8	Driver	Wind	Near surface module of the wind	Wind speed measured at a reference levels near the surface (3D variable).	m/s	na	real	1	time	na
E1	Energy Flux	Evap	Total Evapotranspiration	Sum of all evaporation sources, averaged over a grid cell	kg/m2s	Up	real	1	time	na
E2	Energy Flux	LWnet	Net longwave radiation	Incident longwave radiation minus the simulated outgoing longwave radiation, averaged over a grid cell	W/m2	Down	real	1	time	na
E3	Energy Flux	Qg	Ground heat flux	Heat flux into the ground, averaged over a grid cell	W/m2	Down	real	1	time	na
E4	Energy Flux	Qh	Sensible heat flux	Sensible heat flux, averaged over a grid cell	W/m2	Up	real	1	time	na

Code	Category	Variable	Description	Definition	Units	Positive	type	nDim	Dim1	Dim2
E5	Energy Flux	Qle	Latent heat flux	Latent heat flux out of canopy top, averaged over grid cell	W/m2	Up	real	1	time	na
E6	Energy Flux	SWnet	Net shortwave radiation	Incoming solar radiation minus the simulated outgoing shortwave radiation, averaged over a grid cell	W/m2	Down	real	1	time	na
E7	Energy Flux	TVeg	Vegetation transpiration	Total transpiration from canopy, averaged over all vegetation types within a grid cell.	kg/m2s	Up	real	1	time	na
I1	Isotope	I3CarbPools	I3C fraction of each carbon pool	I3C fraction of each carbon pool	per mil	na	real	2	npool	time
I2	Isotope	CAS13CO2	Canopy Air Space I3CO2 concentration	Canopy Air Space I3CO2 concentration	ppmv	na	real	1	time	na
I3	Isotope	CAS180OCAS	Canopy Air Space C180O concentration	Canopy Air Space C180O concentration	ppmv	na	real	1	time	na
I4	Isotope	deI13CTotalResp	I3C fraction total ecosystem respiration	I3C fraction total ecosystem respiration	per mil	na	real	1	time	na
I5	Isotope	deI180TotalResp	I8O fraction total ecosystem respiration	(AutoResp+HeteroResp) I8O fraction total ecosystem respiration	per mil	na	real	1	time	na
I6	Isotope	LeafMoist18O	Leaf water I8O concentration	(AutoResp+HeteroResp) Leaf water I8O concentration	kg/m3	na	real	1	time	na
I7	Isotope	SoilMoist18O	Soil water I8O	Soil water I8O per soil layer	kg/m2	na	real	2	nsoil	time
P1	Phenology	fPAR	Absorbed fraction of PAR	absorbed fraction of incident photosynthetically active radiation	-	na	real	1	time	na
P2	Phenology	LAI	Leaf Area Index	Leaf Area index	m2/m2	na	real	1	time	na
S1	Snow	nsnow	Number snow layers	Total number of snow layers as a function of time; zero for no snow conditions	-	Up	integer	1	time	na
S2	Snow	SnowDepth	Total snow depth	Total snow depth from soil surface to top of snow pack	m	na	real	1	time	na

Code	Category	Variable	Description	Definition	Units	Positive	type	nDim	Dim1	Dim2
S3	Snow	Snowdz	Thickness of each snow layer	Thickness of each snow layer; bottom layer is layer 1	m	na	real	2	nsnowmax	time
S4	Snow	SnowFrac	Snow covered fraction	Grid cell snow covered fraction	-	na	real	1	time	na
S5	Snow	SnowT	Snow Surface Temperature	Temperature of the snow surface as it interacts with the atmosphere, averaged over a grid cell.	K	na	real	1	time	na
S6	Snow	SnowTdz	Temperature of each snow layer	Temperature of each snow layer; bottom layer is layer 1	K	na	real	2	nsnowmax	time
S7	Snow	SWE	Snow Water Equivalent	Total water mass of snow pack (liquid plus frozen)	kg/m2	na	real	1	time	na
S8	Snow	SWEdz	Snow Water Equivalent of each snow layer	Total water mass of each snow layer (liquid plus frozen); bottom layer is layer 1	kg/m2	na	real	2	nsnowmax	time
SM1	Soil Moisture	Qs	Surface runoff	Runoff from the landsurface and/or subsurface stormflow	kg/m2s	Out gridcell	real	1	time	na
SM2	Soil Moisture	Qsb	Subsurface runoff	Gravity drainage and/or slow response lateral flow. Ground water recharge will have the opposite sign.	kg/m2s	Out gridcell	real	1	time	na
SM3	Soil Moisture	RootMoist	Root zone soil moisture	Total simulated soil moisture available for evapotranspiration.	kg/m2	na	real	1	time	na
SM4	Soil Moisture	SMFrozFrac	Layer fraction of frozen moisture	Fraction of soil moisture mass in the solid phase in each soil layer	-	na	real	2	nsoil	time
SM5	Soil Moisture	SMLiqFrac	Layer fraction of liquid moisture	Fraction of soil moisture mass in the liquid phase in each soil layer	-	na	real	2	nsoil	time
SM6	Soil Moisture	SoilMoist	Layer soil moisture	Soil water content in each soil layer; includes the liquid, vapor and solid phases of water	kg/m2	na	real	2	nsoil	time

Code	Category	Variable	Description	Definition	Units	Positive	type	nDim	Dim1	Dim2
SM7	Soil Moisture	SoilMoistFrac	Layer fraction of saturation	Fraction of saturation in each soil layer (fraction of filled pore space); includes the liquid, vapor and solid phases of water	-	na	real	2	nsoil	time
SM8	Soil Moisture	SoilWet	Total Soil Wetness	Vertically integrated soil moisture divided by maximum allowable soil moisture above wilting point.	-	na	real	1	time	na
SM9	Soil Moisture	WaterTableD	Water table depth	Depth of the water table if it is considered by the land-surface scheme.	m	na	real	1	time	na
ST1	Soil Temperature	Fdepth	Frozen soil depth	Depth from surface to the first zero deg C isotherm. Above this isotherm T < 0 deg C, and below this line T > 0 deg C.	m	Downward	real	1	time	na
ST2	Soil Temperature	SoilTemp	Average layer soil temperature	Soil temperature in each soil layer	K	na	real	2	nsoil	time
ST3	Soil Temperature	Tdepth	Active Layer depth	Depth from surface to first zero deg C isotherm. Above this isotherm T > 0 deg C, and below this isotherm T < 0 deg C.	m	Downward	real	1	time	na
T1	Temperature	CAST	Canopy air space temperature	Canopy air space temperature	K	na	real	1	time	na
T2	Temperature	VegT	Vegetation Canopy Temperature	Vegetation temperature, averaged over all vegetation types	K	na	real	1	time	na
Ti1	Time	dom	day-of-month, start of time per.	day-of-month, start of time per.	day	na	integer	1	time	na
Ti2	Time	month	month, start of time period	month, start of time period	month	na	integer	1	time	na
Ti3	Time	start_doy	day-of-year, start of time per.	day-of-year at start of time averaging period	day	na	real	1	time	na

Code	Category	Variable	Description	Definition	Units	Positive	type	nDim	Dim1	Dim2
Ti4	Time	start_hr	hour of day, start of time per.	hour of day at start of time averaging period	hour	na	real	1	time	na
Ti5	Time	start_sec	second since Jan 1, start per.	seconds since Jan 1 of year at the start of the time averaging period	sec	na	integer	1	time	na
Ti6	Time	stop_doy	day-of-year, stop of time per.	day-of-year at stop of time averaging period	day	na	real	1	time	na
Ti7	Time	stop_hr	hour of day, stop of time per.	hour of day at stop of time averaging period	hour	na	real	1	time	na
Ti8	Time	stop_sec	second since Jan 1, stop per.	seconds since Jan 1 of year at the stop of the time averaging period	sec	na	integer	1	time	na
Ti9	Time	year	year, start of time period	year, start of time period	year	na	integer	1	time	na