Protocol for the North American Carbon Project (NACP) Site Model-Data Comparison (MDC), Version 5

Changes from Version 4:

1) Full preliminary site list, including Fluxnet Canada towers
2) Converted to LaThuile site code convention
3) New tables for site description data
4) Lessons learned from LBA MIP
5) Updated, ALMA compliant input/output variable lists
6) Description of gap-filled weather data
7) Updated working schedule

Expected Changes to Version 6:

1) Final site list, with updated tables
2) Updated schedule
3) List of participating models
4) Crop rotation and land use data for input
5) Table of crop yield and forest inventory data
6) References

1. Introduction

1.1. Background

Multiple modeling efforts are characterizing current carbon sources and sinks in North America. Results from the various modeling efforts differ because they use different approaches (forward vs. inverse), boundary conditions, initial conditions, and input data. One of the most important and difficult challenges facing our community today is synthesizing these results: we must reconcile these inevitable differences in terms of quantitative uncertainties associated with data inputs and model outputs. 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 MDC Objective and Scope

The Site MDC synthesis project will quantify model and observation uncertainty and bias by comparing simulated surface fluxes and biomass to observed values at suitable sites in the AmeriFlux and Fluxnet Canada eddy covariance flux networks. The Site MDC is part of a larger NACP project to answer fundamental science questions associated with a synthesis of multiple modeling and observational estimates of North American carbon cycle dynamics. The Site MDC 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, and defensible estimates of measurement and model uncertainty. We chose eddy flux towers for the analysis 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 MDC will quantify uncertainties associated with both measurements and modeling estimates to provide a solid quantitative foundation for estimating carbon sources and sinks at the scale of individual sites. The Site MDC will develop standardized model input (such as weather and soil texture) to produce model output optimally consistent with other models and with locally observed conditions. The Site MDC 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 MDC will provide a quantitative framework that will serve as a strong foundation for subsequent efforts. Quantified uncertainty will be an essential ingredient in interpretation and synthesis of carbon flux estimates at regional and continental scales. We expect the results from this site level synthesis will provide important constraints to other regional and continental-scale NACP synthesis efforts.

1.3. Protocol Objective and Scope

The Site MDC Protocol identifies standard model inputs, 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 MDC. 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 MDC schedule and integrated products (including peer-reviewed publications).

The basic structure and format of Site MDC protocol closely follows the protocol used in the Large-Scale Biosphere - Atmosphere Experiment in Amazonia (LBA) Model Inter-comparison Project (MIP). The Site MDC'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 MDC.

2. MDC Infrastructure

2.1. MDC Management Team

A core team of individuals will lead and organize the Site MDC (Table 1). The core team will coordinate 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 MDC Core Team

Title	Name	Phone	Email
Lead	Peter Thornton	(303) 497-1727	thornton@ucar.edu
Deputy	Ken Davis	(814) 863-8601	davis@meteo.psu.edu
Deputy	Kevin Schaefer	(303) 492-8869	kevin.schaefer@nsidc.org
Deputy	Daniel Ricciuto		ricciutodm@ornl.gov

2.2. MDC Server

We created an ftp server to serve as a central data repository where participants can download the required inputs and upload model output. The ftp server will also house all documentation and analysis results. Flux tower observations will remain at the Ameriflux and FluxNet Canada servers. The ftp server will also contain some standard software tools to help participants convert these inputs into formats required by their model and convert model output into the standard format for use in model-data comparison. For security reasons, we cannot post the access information to the ftp server here in the protocol. Access information will be given directly to Site MDC participants.

2.3. MDC Email Lists

The Site MDC 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. Documentation

Table 2 lists the core documentation required to set up and execute the Site MDC. This list does not include products of the Site MDC, such as peer-reviewed publications.

Table 2: Site MDC Documentation

Document	Purpose
Prospectus	Defines Site MDC objectives relative to NACP science goals
Protocol	Defines standard model inputs, model outputs, and analysis techniques
Model Survey	Summarizes model characteristics and structure
Model Summaries	Compiled results of individual model surveys
Checker User Guide	User guide for tool to check model output format and content
Filledmet_readme	describes filling techniques for meteorological forcing data

2.5. Data and Model Output Fair Use policy

The Site MDC 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 Site MDC 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 MDC 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 MDC 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. Flux Tower List

Table 3 shows the preliminary list of eddy flux covariance towers in the Site MDC. We will initiate a review process with all participants (including tower PIs and modeling teams) to select the final list of sites from Table 3. These 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. 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. The site codes are a unique identifier for each site and a convenient naming convention for all model input and output files. Start and end times indicate the periods of observations at each site.

Table 3: Eddy Covariance Tower Sites Selected for MDC

Num	Code	Short Name	Full Name	Start	End
1	US-ARM	ARM SGP	OK - ARM Southern Great Plains site-Lamont	2000	2006
2	US-Brw	Barrow	AK - Barrow	1998	2006
3	US-Blo	Blodgett	CA - Blodgett Forest	1997	2004
4	US-Bo1	Bondville	IL - Bondville	1996	2007
5	CA-Ca1	Campbell Mature	British Columbia- Campbell River - Mature Forest Site	1998	2002
6	US-Dk1	Duke open	NC - Duke Forest-open field	2001	2005
7	US-Dk3	Duke pine	NC - Duke Forest - loblolly pine	1998	2005
8	CA-Qfo	Eastern Old Spruce	Quebec Mature Black Spruce Forest Site	2003	2007
9	US-IB2	Fermi Prairie	IL - Fermi Lab- Batavia (Prairie site)	2004	2006
10	US-FPe	Fort Peck	MT - Fort Peck	2000	2007
11	US-Goo	Goodwin Creek	MS - Goodwin Creek	2002	2007
12	CA-Gro	Groundhog	Ontario- Groundhog River-Mat. Boreal Mixed Wood	2003	2007
13	US-Ha1	Harvard	MA - Harvard Forest EMS Tower (HFR1)	1991	2004
14	US-Ho1	Howland main	ME - Howland Forest (main tower)	1996	2004
15	CA-WP1	LaBiche River	Western Peatland- LaBiche-Black Spruce/Larch Fen	2003	2007
16	CA-Let	Lethbridge	Lethbridge	1998	2005
17	US-Los	Lost Creek	WI - Lost Creek	2000	2005
18	US-Ne1	Mead ICM	NE - Mead - irrigated continuous maize site	2001	2005
19	US-Ne3	Mead RMSR	NE - Mead - rainfed maize-soybean rotation site	2001	2005
20	CA-Mer	Mer Bleue	Eastern Peatland- Mer Bleue	1998	2006
21	US-Me4	Metolius old	OR - Metolius-old aged ponderosa pine	1996	2000
22	US-MMS	MMSF	IN - Morgan Monroe State Forest	1999	2005
23	US-NR1	Niwot Ridge	CO - Niwot Ridge Forest (LTER NWT1)	1998	2005
24	CA-Man	NOBS	BOREAS NSA - Old Black Spruce	1994	2004
25	US-Shi	Shidler	OK - Shidler- Oklahoma	1997	2001
26	US-SO2	Sky Oaks Old	CA - Sky Oaks- Old Stand	1997	2006
27	CA-Oas	SSA Old Aspen	Sask.- SSA Old Aspen	1997	2006
28	CA-Obs	SSA Old Black Spruce	Sask.- SSA Old Black Spruce	1999	2006
29	CA-Ojp	SSA Old Jack Pine	Sask.- SSA Old Jack Pine	1999	2006

30	US-Syv	Sylvania	MI - Sylvania Wilderness Area	2001	2006
31	US-Ton	Tonzi	CA - Tonzi Ranch	2001	2006
32	CA-NS1	UCI 1850 burn	UCI-1850 burn site	2001	2005
33	CA-NS2	UCI 1930 burn	UCI-1930 burn site	2001	2005
34	CA-NS3	UCI 1964 burn	UCI-1964 burn site	2001	2005
35	CA-NS4	UCI 1964 burn wet	UCI-1964 burn site wet	2001	2005
36	CA-NS5	UCI 1981 burn	UCI-1981 burn site	2001	2005
37	CA-NS6	UCI 1989 burn	UCI-1989 burn site	2001	2005
38	CA-NS7	UCI 1998 burn	UCI-1998 burn site	2001	2005
39	CA-NS8	UCI 2003 burn	UCI-2003 burn site		
40	US-UMB	UMBS	MI - Univ. of Mich. Biological Station	1999	2004
41	US-Var	Vaira	CA - Vaira Ranch- Ione	2000	2006
42	US-WCr	Willow Creek	WI - Willow Creek	1998	2006
43	US-Wrc	Wind River	WA - Wind River Crane Site	1999	2004
44	US-PFa	WLEF/Park falls	WI - Park Falls/WLEF	1995	2005

3.2. Data from Tower sites

Table 4 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 10 directly from the Ameriflux and Fluxnet Canada data sites, but the PI's will need to check the tables in Section 4 to verify that the site description data is correct.

Table 4: 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	$\mu mol\ c\ m^{-2}\ s^{-1}$	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	$\mu mol\ C\ m^{-2}\ s^{-1}$	Downward	Optional
Respiration	Total ecosystem respiration	$\mu mol\ C\ m^{-2}\ s^{-1}$	upward	Optional
Soil Respiration	Soil respiration from domes	$\mu mol\ C\ m^{-2}\ s^{-1}$	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 Sources

Several national inventory systems in Canada and the United States will provide applicable data for model input or comparison with model output. The Site MDC will focus on disturbance history, crop yield and Forest Inventory Analysis (FIA). Table 5 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 MDC. 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 5: 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 MDC. 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 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 MDC 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. Model List

Table 6 lists the models participating in the Site MDC. Participants should also provide a primary point of contact and, if desired, secondary points of contact for each model. Any participant with a question or a request for model out put should contact the appropriate people listed in Table 6.

Table 6: Models participating in the site MDC

Insert model list here

4.2. Model Survey

Each model participant should 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. The survey also includes such static information (does not vary with time) as the number and name of carbon pools, the number and geometry of soil layers, etc. The survey will help interpret differences in model output and will ensure proper matching of model output to observations (matching the correct soil layer to compare with observed soil temperature, for example). The survey form also includes references, documentation, and web pages to allow quick access to greater detail, if required.

The model survey form will appear as a separate document and will be complete before submission of model results.

4.3. Inputs to Model

All models should use standardized inputs provided by the Site MDC 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 slowing 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.

Local Weather

We will provide gap-filled weather data derived from local observations (Table 7). Hourly weather forcing data will be provided in netcdf files using variable nomenclature and units as shown in Table 2. For models using a 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.

Table 7: 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 CO_2 concentration	ppmv

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 ftp server describes in detail the filling techniques for the individual variables.

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.

Phenology

We define plant phenology as periodic or seasonal changes in leafy plant biomass, particularly the Leaf Area Index (LAI) and absorbed fraction of Potosynthetically Active Radiation (fPAR). Dynamic vegetation models calculate LAI and fPAR internally, but many models use remotely sensed phenology. To include such models in the Site MDC, we will provide tables of remotely sensed LAI and fPAR as a function of time for each tower site. To compare model output, all such models should use the same remotely sensed phenology. There are several remotely sensed phenology data sets available, each with different corrections, filtering, spatial coverage, and temporal resolution, etc. For the Site MDC, the remotely sensed phenology dataset must cover the full time period of all chosen tower sites (1991-2007) and must have a resolution consistent with the flux tower footprint (~km).

We chose the GIMMS version g NDVI dataset derived from the AVHRR instrument [*Tucker et al*., 2005] because it covers the full observational period with 15-day composites at 8 km resolution. We selected 30-day (monthly) composite NDVI values for the pixel containing the eddy covariance flux tower for the entire period of record (1982-2003). 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*., [2001], *Schaefer et al*. [2002], and *Schaefer et al*. [2005]. The phenology data is provided in ascii files using variable nomenclature and units as shown in Table 8. The naming convention for the phenology files is CC-XXX_phenology, where CC is the two letter country code and XXX is the three letter site code from Table 3. Model participants should describe any modifications they made to the phenology data when they submit model output.

Table 8: Phenology Variables

Name	Description	Units
LAI	Leaf Area Index	m2 m^{-2}
fPAR	absorbed fraction of Potosynthetically Active Radiation	kg kg^{-1}
NDVI	Normalized Difference Vegetation Index	-

Site Description data

Site description data covers any input variable or parameter that varies from site-to-site, but does not vary with time: location, soil texture, and biome type (Table 9). Soil texture defines the soil thermal and hydraulic characteristics. We will add to Table 9 USDA soil classes used by some models. If available, we used locally observed sand and clay fractions at the tower site and determined the appropriate soil texture class from the USDA soil texture triangle. If only soil texture class is available, we assumed the sand and clay fraction corresponding to the centroid of the class on the USDA soil texture triangle. At this time, we extracted all in Table 9sand and clay fractions from the International Global Biosphere Program (IGBP) global maps of soil texture.

Table 9: Site Data for Each Tower

n	Code	Lat (deg)	Long (deg)	Sand (%)	Clay (%)	Biome
1	US-ARM	36.6050	-97.4884	37.0330	23.3759	CRO
2	US-Brw	71.3225	-156.6260	45.4100	11.0720	WET
3	US-Blo	38.8952	-120.6330	50.4270	25.0132	ENF
4	US-Bo1	40.0061	-88.2919	28.9060	31.2320	CRO
5	CA-Ca1	49.8672	-125.3340	57.2853	12.6397	ENF
6	US-Dk1	35.9712	-79.0934	54.4318	21.6226	GRA
7	US-Dk3	35.9782	-79.0942	54.4318	21.6226	MF
8	CA-Qfo	49.6925	-74.3421	52.6339	16.6626	ENF
9	US-IB2	41.8406	-88.2410	29.3889	31.0765	GRA
10	US-FPe	48.3079	-105.1010	47.4538	21.0254	GRA
11	US-Goo	34.2500	-89.9700	45.2300	27.5369	GRA
12	CA-Gro	48.2167	-82.1556	60.4317	10.9146	MF
13	US-Ha1	42.5378	-72.1715	53.4717	8.9774	DBF
14	US-Ho1	45.2041	-68.7403	50.3488	15.9005	ENF
15	CA-WP1	54.9538	-112.4670	32.4374	31.1263	MF
16	CA-Let	49.7093	-112.9400	46.3194	21.7292	GRA
17	US-Los	46.0827	-89.9792	46.5589	16.4289	CSH
18	US-Ne1	41.1651	-96.4766	30.7017	31.6827	CRO
19	US-Ne3	41.1797	-96.4397	30.7017	31.6827	CRO
20	CA-Mer	45.4094	-75.5186	34.1178	27.9233	OSH
21	US-Me4	44.4992	-121.6220	44.1185	20.8463	ENF
22	US-MMS	39.3231	-86.4131	42.3608	25.1048	DBF
23	US-NR1	40.0329	-105.5460	43.1259	21.4260	ENF
24	CA-Man	55.8796	-98.4808	26.7412	41.9534	ENF

25	US-Shi	36.9333	-96.6833	40.4081	26.9595	GRA
26	US-SO2	33.3739	-116.6230	43.9442	21.3065	WSA
27	CA-Oas	53.6289	-106.1980	32.8814	26.6199	DBF
28	CA-Obs	53.9872	-105.1180	30.9857	27.7471	ENF
29	CA-Ojp	53.9163	-104.6920	32.9215	27.7024	ENF
30	US-Syv	46.2420	-89.3477	46.5589	16.4289	MF
31	US-Ton	38.4316	-120.9660	50.4270	25.0132	WSA
32	CA-NS1	55.8792	-98.4839	26.7412	41.9534	ENF
33	CA-NS2	55.9058	-98.5247	26.7412	41.9534	ENF
34	CA-NS3	55.9117	-98.3822	26.7412	41.9534	ENF
35	CA-NS4	55.9117	-98.3822	26.7412	41.9534	ENF
36	CA-NS5	55.8631	-98.4850	26.7412	41.9534	ENF
37	CA-NS6	55.9167	-98.9644	26.7412	41.9534	OSH
38	CA-NS7	56.6358	-99.9483	34.0610	37.1910	OSH
39	CA-NS8	55.8981	-98.2161	26.7412	41.9534	ENF
40	US-UMB	45.5598	-84.7138	55.0094	8.8893	DBF
41	US-Var	38.4133	-120.9507	50.4270	25.0132	GRA
42	US-WCr	45.8059	-90.0799	42.5168	20.1670	DBF
43	US-Wrc	45.8205	-121.9520	44.8315	19.8470	ENF
44	US-PFa	45.9459	-90.2723	42.5168	20.1670	MF

Most models define physical and biological parameters and constants using look-up tables based on biome type. Biome classification systems vary 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 10).

Table 10: 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

In Table 9 we recognize that the IGBP biome class does not always match the observed vegetation, a typical problem for most biome classification systems. For example, the US-Brw (Barrow) site is a wetland, while some models have a separate tundra class. Some models combine croplands with grasslands, some separate out croplands, and others can distinguish between different crop types. We attempted to correct incorrect biome types plucked from the IGBP map of vegetation classes. For example, plucking the US-NR1 (Niwot Ridge) biome type from a 1°x1° map of IGBP biome classes give grassland when in fact, the site is a needleleaf forest.

Table 9 is meant as a guide: model participants must match the observed biome type to the classification system used by their model. The Site MDC hopes to quantify how strongly mismatches between actual vegetation and the model's assumed biome class influences simulated fluxes and biomass. To help, model participants should supply the biome classes used in their model and the assumed biome class for each tower.

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.

Land Use Data

Those models that can incorporate land use history into their simulated biomass and fluxes should use the standardized disturbance or crop-use histories described in Table 11. This data is not available or applicable for all sites. Participants should use whatever land use history they deem appropriate for those sites without a standard disturbance or crop type history.

Table 11: Inventory data available at each site

insert data availability matrix

4.4. 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 MDC 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.

4.5. Outputs from Models

All model participants should provide model output in netcdf format using standard variable names and units as listed in Table 12. Each file will contain one year of output following a standard file naming convention: CC-XXX_MMMRR_YYYY.nc, where CC is the country code, XXX is the site code, MMM is the model code, RR is the run number, and YYYY is year. The country and site codes are listed in Table 3 and the model codes in Table 6. The run code allows multiple simulations from one model (e.g., RR=01 for steady state and RR=02 for disturbance simulations. Teams with only one simulation should use RR=01.

netcdf is a widely used, binary, self-descriptive file format independent of platform with a supporting library of standard read/write routines. We will provide sample fortran routines to create standard output files for model teams that do not use netcdf. To ensure all model submission files have exactly the same format and content, we will also provide a checker program that will read the submission files and check for proper variable names, units, and long-term energy and water balance.

Table 12 lists the required output variables from each model, selected to allow direct comparison with local observations at each site. 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.

Variable names, definitions, and units adhere to the ALMA standard. We did not include those ALMA defined variables clearly designed to test mass and energy balance. We added several new variables not currently in the ALMA (indicated by ALMA column) standard in order to compare with local observations, such as AbvGrndWood.

The units for all carbon related variables are kg pure carbon. If your model estimates kg CO_2 or kg biomass, please convert to kg pure carbon.

Table 12 also includes time-dependant input weather and phenology variables to check consistency, energy balance, and mass balance. 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 NDVI derived values.

Table 12: Model Output

Variable	Description	Definition	Units	Positive	ALMA	Alma Category
AbvGrndWood	Above ground woody biomass	Total above ground wood biomass	Kg/m2	-	No	Carbon Budget
AutoResp	Autotrophic Respiration	Autotrophic respiration includes maintenance respiration and growth respiration	Kg/m2/s2	Upward	Yes	Carbon Budget
CarbPools	Size of each carbon pools	Size of each carbon pool	Kg/m2	-	No	Carbon Budget
CO2CAS	Canopy Air Space CO2 concentration	Canopy Air Space CO2 concentration	ppmv	-	No	Carbon Budget
CropYeild	Annual Crop yield	Annual yeild of perrenial crops	Kg/m2	-	No	Carbon Budget
GPP	Gross Primary Production	Net assimilation of carbon by the vegetation	Kg/m2/s2	Downward	Yes	Carbon Budget
HeteroResp	Heterotrophic Respiration	Total flux from decomposition of organic matter	Kg/m2/s2	Upward	Yes	Carbon Budget
NEE	Net Ecosystem Exchange	Sum of all carbon fluxes exchanged between the surface and the atmosphere	Kg/m2/s2	Upward	Yes	Carbon Budget
NPP	Net Primary Production	Carbon assimilation by photosynthesis	Kg/m2/s2	Downward	Yes	Carbon Budget
TotalResp	Total ecosystem respiration	Total ecosystem respiration (AutoResp+HeteroResp)	Kg/m2/s2	Upward	No	Carbon Budget
TotLivBiom	Total Living Biomass	Total carbon content of the living biomass (leaves+roots+wood)	Kg/m2	-	Yes	Carbon Budget
TotSoilCarb	Total Soil Carbon	Total soil and litter carbon content integrated over the enire soil profile	Kg/m2	-	Yes	Carbon Budget

Fdepth	Frozen soil depth	Depth from surface to the first zero degree isotherm. Above this isotherm T < 0o, and below this line T > 0o.	m	Downward	Yes	Cold Season
SnowDepth	Depth of snow layer	Depth of each layer of snow is a 3D variable for multi-layer snow schemes and the total snow depth for simpler models.	m	-	Yes	Cold Season
SnowFrac	Snow covered fraction	Grid cell snow covered fraction	-	-	Yes	Cold Season
Tdepth	Depth to soil thaw	Depth from surface to the zero degree isotherm. Above this isotherm T > 0o, and below this line T < 0o.	m	Downward	Yes	Cold Season
CO2air	Near surface CO2 concentration	The partial pressure of CO2 concentration at the atmospheric reference level (3D variable).	ppmv	-	Yes	Driver
LWdown	Surface incident longwave radiation	Incident longwave radiation averaged over the time step of the forcing data	W/m2	downward	Yes	Driver
PSurf	Surface pressure	Pressure measured at the surface	Pa	-	Yes	Driver
Qair	Near surface specific humidity	Specific humidity measured at reference levels near the surface (3D variable)	kg/kg	-	Yes	Driver
Rainf	Rainfall rate	Average total rainfall over a time step of the forcing data.	kg/m2s	downward	Yes	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	Yes	Driver

Tair	Near surface air temperature	Temperature measured at reference levels near the surface (3D variable)	K	-	Yes	Driver
Wind	Near surface module of the wind	Wind speed measured at a reference levels near the surface (3D variable).	m/s	-	Yes	Driver
LWnet	Net longwave radiation	Incident longwave radiation less the simulated outgoing longwave radiation, averaged over a grid cell	W/m2	Downward	Yes	Energy Balance
Qg	Ground heat flux	Heat flux into the ground, averaged over a grid cell	W/m2	Downward	Yes	Energy Balance
Qh	Sensible heat flux	Sensible energy, averaged over a grid cell	W/m2	Upward	Yes	Energy Balance
Qle	Latent heat flux	Energy of evaporation, averaged over a grid cell	W/m2	Upward	Yes	Energy Balance
SWnet	Net shortwave radiation	Incoming solar radiation less the simulated outgoing shortwave radiation, averaged over a grid cell	W/m2	Downward	Yes	Energy Balance
RootMoist	Root zone soil moisture	Total simulated soil moisture available for evapotranspiration.	kg/m2	-	Yes	Evaporation
TVeg	Vegetation transpiration	Transpiration from canopy, averaged over all vegetation types within a grid cell.	kg/m2s	Upward	Yes	Evaporation
WaterTableD	Water table depth	Depth of the water table if it is considered by the land-surface scheme.	m	-	Yes	Other Hydrologic

fPAR	Absorbed fraction incoming PAR	absorbed fraction incoming photosyntetically active radiation	-	-	No	Phenology
LAI	Leaf Area Index	Leaf Area index	m2/m2	-	No	Phenology
SMFrozFrac	Average layer fraction of frozen moisture	Fraction of soil moisture mass in the solid phase in each user-defined soil layer (3D variable)	-	-	Yes	Subsurface State
SMLiqFrac	Average layer fraction of liquid moisture	Fraction of soil moisture mass in the liquid phase in each user-defined soil layer (3D variable)	-	-	Yes	Subsurface State
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/m2	-	Yes	Subsurface State
SoilTemp	Average layer soil temperature	Average soil temperature in each user-defined soil layer (3D variable)	K	-	Yes	Subsurface State
SoilWet	Total Soil Wetness	Vertically integrated soil moisture divided by maximum allowable soil moisture above wilting point.	-	-	Yes	Subsurface State
Albedo	Surface Albedo	Grid cell average albedo for all wavelengths.	-	-	Yes	Surface State
SnowT	Snow Surface Temperature	Temperature of the snow surface as it interacts with the atmosphere, averaged over a grid cell.	K	-	Yes	Surface State

SWE	Snow Water Equivalent	Total water mass of the snowpack (liquid or frozen), averaged over a grid cell. 3D variable for multi-layer snow schemes.	kg/m2	-	Yes	Surface State
VegT	Vegetation Canopy Temperature	Vegetation temperature, averaged over all vegetation types	K	-	Yes	Surface State
Evap	Total Evapotranspiration	Sum of all evaporation sources, averaged over a grid cell	kg/m2s	Upward	Yes	Water Balance
Qs	Surface runoff	Runoff from the landsurface and/or subsurface stormflow	kg/m2s	Out of gridcell	Yes	Water Balance
Qsb	Subsurface runoff	Gravity drainage and/or slow response lateral flow. Ground water recharge will have the opposite sign.	kg/m2s	Out of gridcell	Yes	Water Balance

All model output should be in Greenwich Mean Time rather than local time at each tower. Model participants should save time averages that correspond to the observed fluxes at each site. For most towers, this is every 30 minutes, but some towers have fluxes every hour (Table 13). In output files, the time of day corresponds to the end of the time period (30 minutes corresponds to a time average from 0:00 to 0:30 GMT). New days start at 0:00 GMT (midnight) and are indicated by 0:00 rather than 24:00. 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.

Table 13: Output Frequency for each tower

n	Code	Frequency (min)	Obs per day
1	US-ARM	30	48
2	US-Brw	30	48
3	US-Blo	30	48
4	US-Bo1	30	48
5	CA-Ca1	30	48
6	US-Dk1	30	48
7	US-Dk3	30	48
8	CA-Qfo	TBD	TBD
9	US-IB2	30	48
10	US-FPe	30	48

11	US-Goo	30	48
12	CA-Gro	TBD	TBD
13	US-Ha1	60	24
14	US-Ho1	30	48
15	CA-WP1	TBD	TBD
16	CA-Let	30	48
17	US-Los	30	48
18	US-Ne1	60	24
19	US-Ne3	60	24
20	CA-Mer	TBD	TBD
21	US-Me4	30	48
22	US-MMS	60	24
23	US-NR1	30	48
24	CA-Man	30	48
25	US-Shi	30	48
26	US-SO2	30	48
27	CA-Oas	TBD	TBD
28	CA-Obs	TBD	TBD
29	CA-Ojp	TBD	TBD
30	US-Syv	30	48
31	US-Ton	30	48
32	CA-NS1	30	48
33	CA-NS2	30	48
34	CA-NS3	30	48
35	CA-NS4	30	48
36	CA-NS5	30	48
37	CA-NS6	30	48
38	CA-NS7	30	48
39	CA-NS8	30	48
40	US-UMB	60	24
41	US-Var	30	48
42	US-WCr	30	48
43	US-Wrc	30	48
44	US-PFa	60	24

Model output 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.

Please do not delete your simulations after submitting your output 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.

4.6. Model Uncertainty

Quantified uncertainty and bias of simulated fluxes and biomass are essential to the core objectives of the Site MDC. Model uncertainty falls unto 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 MDC. 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.

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 MDC 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 Summary

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,

$$\textbf{(1)}\quad \delta_n = M_n - O_n \,,$$

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:

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

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:

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

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:

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

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

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

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

MDC. 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 MDC 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

$$\textbf{(6)} \quad \begin{array}{c} \overline{SW} + \overline{LW} - \overline{LH} - \overline{SH} \le \delta_{energy} \\ \overline{P} - \overline{LH} - \overline{Runoff} \le \delta_{water} \end{array} \;,$$

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 denergy and dwater are minimum criteria for balance. The overbars represent time averages over the entire simulation period. We will use the values for denergy and dwater developed for the LBA MIP, which are balance to with 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 14 shows the current projected schedule for the Site MDCI. Submission procedures for model output, data, and tools are described above under “MDC Server.” The dates for the individual milestones ensure that we have suitable results to support the Site MDC workshop and NACP all scientist meeting. The timing of the Site MDC 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 MDC 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 14: NACP Site MDC Schedule

Event	Date
Final Site Selection	July 15, 2008
Final Protocol Update	July 21, 2008
Start Model Runs	July 21, 2008
Model Runs Due	September 1, 2008
Workshop	October 1, 2008
Start papers for special issue	November 1, 2008
Present results at NACP All-Scientist meeting	February 1, 2009
Submit papers for JGR special issue	May 1, 2009

7. References