# Protocol for the North American Carbon Project (NACP) Site Model-Data Comparison (MDC), Version 3

## Changes from Version 3:

1) Expanded site list to include Fluxnet Canada towers
2) Completed tables for site description data

## Expected Changes to Version 5:

3) Expanded description of gap-filled weather data
4) Expanded description of products and deliverables
5) A reference list
6) Data table for crop yield and forest inventory data
7) Site MDC Server Information

# 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. Site Data Comparison (MDC) synthesis project will take advantage of strengths in the observational and modeling communities to quantify model performance in the best-studied systems.

## 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. We have identified the most 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 these sites include some of our best measurements of both fluxes and parameters required for high-quality model estimates.

The Site MDC involves a preliminary phase of data coordination, model parameterization, and model execution, followed by a workshop attended by both measurement and modeling groups. The Site MDC will focus on the terrestrial carbon cycle, with special emphasis on reconstruction of recent carbon fluxes and biomass (~1950 to present) ans will not address other aspects of model development, such as radiative transfer, soil hydrology, or snow processes. The Site MDC goal is to arrive at the best possible quantification of measured and modeled carbon water and energy fluxes, and a detailed quantification of the uncertainties associated with both measurements and modeling estimates. The scientific goal is to provide a solid quantitative foundation for estimation of carbon fluxes (sources and sinks) at the scale of individual sites. The Site MDC will provide a quantitative framework that will serve as a strong foundation for subsequent efforts. These results will be an essential ingredient in the interpretation and synthesis of carbon flux estimates at regional and continental scales, and we expect that 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 includes the Site MDC schedule and integrated products (including peer-reviewed publications).

## 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 Site MDC schedule, budget, and products. The core team will organize telecoms, 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 will create a central data repository where participants can download the required inputs and upload model output. The repository will also house all documentation and analysis results. Flux tower observations will remain at the Ameriflux and FluxNet Canada servers. The repository will also include 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. We will incorporate standard security procedures to ensure only Site MDC participants can access the repository.

***Insert server information here***

### 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 will create 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 will 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).

### 2.4. Documentation

Table 2 lists the core documentation required to set up and execute the Site MDC. This list does not include products from 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 technique |
| Model Descriptions | Short, standardized descriptions of each model |

### 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 provide 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

We will compare model output with observations at the eddy flux covariance towers listed in Table 3. These sites represent a broad range of vegetation types and geographic regions to fully test each model's performance under the fullest range of expected conditions across North America. The four letter code will be used as a convenient naming convention for all files related to each site. Start and end times indicate the periods of observations at each site, including observed weather data.

Table 3: Eddy Covariance Tower Sites Selected for MDC

| Num | Code | Full Name | Country | State | Start | End | Site Contact | Contact Email | # yrs |
|---|---|---|---|---|---|---|---|---|---|
| 1 | ASGP | ARM Southern Great Plains | USA | OK | 2003 | 2007 | Margaret Torn | mstorn@lbl.gov | 5 |
| 2 | BARR | Barrow- Alaska | USA | AK | 1998 | 2002 | Walter Oechel | oechel@sunstroke.sdsu.edu | 5 |
| 3 | BLOD | Blodgett Forest | USA | CA | 1997 | 2006 | Allen Goldstein | ahg@nature.berkeley.edu | 10 |
| 4 | BOND | Bondville | USA | IL | 1996 | 2007 | Tilden Meyers | tilden.meyers@noaa.gov | 12 |
| 5 | CAMP | Campbell River Mature Douglas-fir | CAN | BC | 1997 | 2007 | Andy Black | andrew.black@ubc.ca | 11 |
| 6 | DUKO | Duke Forest-open field | USA | NC | 1998 | 2005 | Ram Oren | ramoren@duke.edu | 8 |
| 7 | DUKP | Duke Forest - loblolly pine | USA | NC | 2001 | 2005 | Gabriel Katul | gaby@duke.edu | 5 |
| 8 | FERP | Fermi Natl. Accelerator Lab.-Prairie | USA | IL | 2004 | 2007 | Roser Matamala | matamala@anl.gov | 4 |
| 9 | FPEC | Fort Peck | USA | MT | 2000 | 2007 | Tilden Meyers | tilden.meyers@noaa.gov | 8 |
| 10 | GOOD | Goodwin Creek | USA | MS | 2002 | 2006 | Tilden Meyers | tilden.meyers@noaa.gov | 5 |
| 11 | HARM | Harvard Forest EMS Tower (HFR1) | USA | MA | 1991 | 2006 | J. (Bill) Munger | jwm@io.harvard.edu | 16 |
| 12 | HOWM | Howland Forest (main tower) | USA | ME | 1996 | 2004 | David Hollinger | davidh@hypatia.unh.edu | 9 |
| 13 | LETH | Lethbridge | CAN | AB | 1998 | 2005 |  |  | 8 |
| 14 | MERB | Mer Bleue Bog | CAN | ON | 1998 | 2007 | Peter Lafleur | plafleur@trentu.ca | 10 |
| 15 | MICM | Mead - irrigated continuous maize | USA | NE | 2001 | 2005 | Shashi Verma | sverma1@unl.edu | 6 |
| 16 | MMSF | Morgan Monroe State Forest | USA | IN | 1999 | 2005 | Hans Peter Schmid | hschmid@indiana.edu | 7 |
| 17 | MOPP | Metolius-old aged ponderosa pine | USA | OR | 1996 | 2000 | Beverly Law | bev.law@oregonstate.edu | 5 |
| 18 | MRMS | Mead - rainfed maize-soybean rotation | USA | NE | 2001 | 2005 | Shashi Verma | sverma1@unl.edu | 6 |
| 19 | NOBS | Northern Old Black Spruce | CAN | MB | 2001 | 2005 |  |  | 5 |
| 20 | NWT1 | Niwot Ridge Forest (LTER NWT1) | USA | CO | 1998 | 2005 | Russ Monson | russell.monson@colorado.edu | 8 |
| 21 | SHID | Shidler | USA | OK | 1997 | 2000 | Shashi Verma | sverma1@unl.edu | 4 |
| 22 | SKYO | Sky Oaks- Old Stand | USA | CA | 1997 | 2006 | Walter Oechel | oechel@sunstroke.sdsu.edu | 10 |
| 23 | SOAS | Southern Old Aspen | CAN | SK | 1996 | 2007 | Alan Barr | alan.barr@ec.gc.ca | 12 |
| 24 | SOBS | Southern Old Black Spruce | CAN | SK | 1999 | 2007 | Alan Barr | alan.barr@ec.gc.ca | 9 |
| 25 | SOJP | Southern Old Jack Pine | CAN | SK | 1999 | 2007 | Alan Barr | alan.barr@ec.gc.ca | 9 |
| 26 | SYLV | Sylvania Wilderness Area | USA | MI | 2001 | 2006 | Paul Bolstad | pbolstad@umn.edu | 6 |
| 27 | TONZ | Tonzi Ranch | USA | CA | 2001 | 2006 | Dennis Baldocchi | baldocchi@nature.berkeley.edu | 6 |
| 28 | UMBS | Univ. of Mich. Biological Station | USA | MI | 1999 | 2003 | Peter Curtis | curtis.7@osu.edu | 5 |
| 29 | VAIR | Vaira Ranch | USA | CA | 2000 | 2006 | Dennis Baldocchi | baldocchi@nature.berkeley.edu | 7 |
| 30 | WILL | Willow Creek | USA | WI | 1999 | 2006 | Paul Bolstad | pbolstad@umn.edu | 8 |
| 31 | WLEF | Park Falls-WLEF tower | USA | WI | 1996 | 2004 | Arlyn Andrews | arlyn.andrews@noaa.gov | 9 |

## 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. 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 dept | 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.

### 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. Descriptions of the participating models, including references, will appear in a separate document.

Table 6: Models participating in the site MDC

| Model | Full Model Name | Model Contact | Contact email |
|---|---|---|---|
| SiBCASA | Simple Biosphere-Carnegie-Ames-Stanford Approach | Kevin Schaefer | kevin.schaefer@sidc.org |

## 4.2. Inputs to Model

Standardized model inputs ensure comparisons between models represent differences in model structure and comparisons with observations represent the model uncertainty 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) for each site. 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 slowingchanging 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.

### 4.2.1. 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 |
|---|---|---|
| T_air | air temperature | K |
| SH | specific humidity | kg $kg^{-1}$ |
| Wind | module of wind speed | m $s^{-1}$ |
| LW_down | downward long wave radiation at the surface | W $m^{-2}$ |
| Press | surface pressure | mb |
| Precip | precipitation | mm $s^{-1}$ |
| SW_down | shortwave downward radiation at the surface | W $m^{-2}$ |

***Insert gap-filling description here***

### 4.2.2. 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 [ref] because it covers the full observational period with 15-day composites at 8 km resolution. We will select 15-day composite NDVI values for the pixel containing the eddy covariance flux tower and estimate LAI and fPAR values using the methods of [ref]. The phenology data will be provided in netcdf files using variable nomenclature and units as shown in Table 8. 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 | - |

### 4.2.3. Site Description data

Site description data covers any input variable or parameter that varies from site-to-site, but does not vary with time, such as location, soil texture, and biome type. Table 9 lists the location and soil texture for each tower. Soil texture defines the soil thermal and hydraulic characteristics. Some models use soil texture class (defined by the USDA soil texture triangle) and some use sand and clay fraction, so we provided both. The source column refers to how we obtained soil texture data. 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 (source = obs_text). 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 (source = obs_class). If neither is available, we extracted sand and clay fractions from the International Global Biosphere Program (IGBP) global maps of soil texture and determined soil texture class from the USDA triangle. Model participants should identify whether they calculated soil characteristics from a lookup table of soil texture classes or from sand and clay fractions.

Table 9: Site Data for Each Tower

| Num | Code | Latitude (deg) | Longitude (deg) | USDA Class | sand (%) | clay (%) | Source |
|---|---|---|---|---|---|---|---|
| 1 | ASGP | 36.6050000 | -97.4884000 | loam | 37.033 | 23.376 | IGBP |
| 2 | BARR | 71.3225250 | -156.6258806 | loam | 45.410 | 11.072 | IGBP |
| 3 | BLOD | 38.8952500 | -120.6327500 | sandy clay loam | 50.427 | 25.013 | IGBP |
| 4 | BOND | 40.0061000 | -88.2918667 | clay loam | 28.906 | 31.232 | IGBP |
| 5 | CAMP | 49.8672500 | -125.3336000 | sandy loam | 57.285 | 12.640 | IGBP |
| 6 | DUKO | 35.9712024 | -79.0933759 | sandy clay loam | 54.432 | 21.623 | IGBP |
| 7 | DUKP | 35.9781659 | -79.0941956 | sandy clay loam | 54.432 | 21.623 | IGBP |
| 8 | FERP | 41.8406167 | -88.2410333 | | | | |
| 9 | FPEC | 48.3078833 | -105.1005333 | loam | 47.454 | 21.025 | IGBP |
| 10 | GOOD | 34.2500000 | -89.9700000 | loam | 45.230 | 27.537 | IGBP |
| 11 | HARM | 42.5377556 | -72.1714778 | sandy loam | 53.472 | 8.977 | IGBP |
| 12 | HOWM | 45.2040700 | -68.7402778 | loam | 50.349 | 15.901 | IGBP |
| 13 | LETH | 49.709278 | -112.940167 | loam | 46.319 | 21.729 | IGBP |
| 14 | MERB | 45.4160000 | -75.5170000 | | | | |
| 15 | MICM | 41.1650560 | -96.4766380 | clay loam | 30.702 | 31.683 | IGBP |
| 16 | MMSF | 39.3231500 | -86.4131390 | loam | 42.361 | 25.105 | IGBP |
| 17 | MOPP | 44.4991662 | -121.6223688 | | | | |
| 18 | MRMS | 41.1796670 | -96.4396460 | | | | |
| 19 | NOBS | 55.879620 | -98.480810 | clay | 26.741 | 41.953 | IGBP |
| 20 | NWT1 | 40.0328778 | -105.5464028 | loam | 43.126 | 21.426 | IGBP |
| 21 | SHID | 36.9333333 | -96.6833333 | | | | |
| 22 | SKYO | 33.3738889 | -116.6228889 | loam | 43.944 | 21.307 | IGBP |
| 23 | SOAS | 53.6288900 | -106.1977900 | | | | |
| 24 | SOBS | 53.9871700 | -105.1177900 | | | | |
| 25 | SOJP | 53.9163400 | -104.6920300 | | | | |
| 26 | SYLV | 46.2420170 | -89.3476500 | loam | 46.559 | 16.429 | IGBP |
| 27 | TONZ | 38.4316000 | -120.9659833 | sandy clay loam | 50.427 | 25.013 | IGBP |
| 28 | UMBS | 45.5598400 | -84.7138200 | sandy loam | 55.009 | 8.889 | IGBP |
| 29 | VAIR | 38.4066667 | -120.9507333 | sandy clay loam | 50.427 | 25.013 | IGBP |
| 30 | WILL | 45.8059267 | -90.0798592 | loam | 42.517 | 20.167 | IGBP |
| 31 | WLEF | 45.9458778 | -90.2723042 | loam | 42.517 | 20.167 | IGBP |

Most models define physical and biological parameters and constants using lookup 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 (Tables 10 and 11).

Table 10: Tower Biome Types

| Num | Code | Observed Biome Type | IGBP Num | IGBP Class |
|---|---|---|---|---|
| 1 | ASGP | Croplands (winter wheat) | 12 | Croplands |
| 2 | BARR | Tundra | 10 | Grasslands |
| 3 | BLOD | Evergreen Needleleaf Forest | 1 | Evergreen Needleleaf Forest |
| 4 | BOND | Croplands (maize-soybean rotation) | 12 | Croplands |
| 5 | CAMP | Evergreen Needleleaf Forest | 1 | Evergreen Needleleaf Forest |
| 6 | DUKO | Mixed Forest | 5 | Mixed Forests |
| 7 | DUKP | Evergreen Needleleaf Forest | 1 | Evergreen Needleleaf Forest |
| 8 | FERP | Grasslands | 10 | Grasslands |
| 9 | FPEC | Grasslands | 10 | Grasslands |
| 10 | GOOD | Grasslands | 10 | Grasslands |
| 11 | HARM | Mixed Forest | 5 | Mixed Forests |
| 12 | HOWM | Mixed Forest | 5 | Mixed Forests |
| 13 | LETH | Grasslands | 10 | Grasslands |
| 14 | MERB | Wetland | 11 | Permanent Wetlands |
| 15 | MICM | Croplands (maize) | 12 | Croplands |
| 16 | MMSF | Deciduous Broadleaf Forest | 4 | Deciduous Broadleaf Forest |
| 17 | MOPP | Evergreen Needleleaf Forest | 1 | Evergreen Needleleaf Forest |
| 18 | MRMS | Croplands (maize-soybean rotation) | 12 | Croplands |
| 19 | NOBS | Boreal Forest | 1 | Evergreen Needleleaf Forest |
| 20 | NWT1 | Evergreen Needleleaf Forest | 1 | Evergreen Needleleaf Forest |
| 21 | SHID | Grasslands | 10 | Grasslands |
| 22 | SKYO | Closed shrublands | 6 | Closed Shrublands |
| 23 | SOAS | Aspen Forest | 5 | Mixed Forests |
| 24 | SOBS | Evergreen Needleleaf Forest | 1 | Evergreen Needleleaf Forest |
| 25 | SOJP | Evergreen Needleleaf Forest | 1 | Evergreen Needleleaf Forest |
| 26 | SYLV | Mixed Forest | 5 | Mixed Forests |
| 27 | TONZ | Woody Savannas | 8 | Woody Savannas |
| 28 | UMBS | Mixed Forest | 5 | Mixed Forests |
| 29 | VAIR | Woody Savannas | 8 | Woody Savannas |
| 30 | WILL | Deciduous Broadleaf Forest | 4 | Deciduous Broadleaf Forest |
| 31 | WLEF | Mixed Forest | 5 | Mixed Forests |

Table 11: IGBP biome types

| Number | Class name |
|---|---|
| 0 | Water |
| 1 | Evergreen Needleleaf Forest |
| 2 | Evergreen Broadleaf Forest |
| 3 | Deciduous Needleleaf Forest |
| 4 | Deciduous Broadleaf Forest |
| 5 | Mixed Forests |
| 6 | Closed Shrublands |
| 7 | Open Shrublands |
| 8 | Woody Savannas |
| 9 | Savannas |
| 10 | Grasslands |
| 11 | Permanent Wetlands |
| 12 | Croplands |
| 13 | Urban and Built-Up |
| 14 | Cropland/Natural Vegetation Mosaic |
| 15 | Snow and Ice |
| 16 | Barren or Sparsely Vegetated |

In Table 10 we see that the IGBP biome class does not always match the observed vegetation, a typical problem for most biome classification systems. For example, in Table 10, the BARR (Barrow) site is grassland, 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. Plucking biome type from a map of vegetation classes can lead to incorrect results as well. For example, plucking the NWT1 (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 10 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.

### 4.2.4. 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.

### 4.2.5. 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 12. As indicated in Table X, 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 12: Inventory data available at each site

***insert data availability matrix***

## 4.3. Simulation Spinup

We would like to compare all the model output for steady state conditions. 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.

## 4.4. Outputs from Models

All potential model participants should provide model output and general information as described in Table 13. The description, references, and input list are provided only once in a suitable word processor format. This includes a short model overview (1-2 paragraphs) with a brief description, basic structure, web pages, and associated references. Participants should also provide a primary point of contact and, if desired, secondary points of contact for each model. Lastly, we recognize that the required inputs for each model differ, so the participants should provide a list of those standardized inputs actually used by their model.

Each model should save a core set of mandatory variables and a secondary set of recommended variables. Mandatory variables focus on the carbon fluxes and biomass while the secondary variables focus on the model representation of system components important to the carbon cycle (such as soil moisture and temperature).

Participants should convert their output to standard units and netcdf file format as shown in Table 13. The participant should convert all model output to Greenwhich Mean Time. 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 15). Some observations are intermittent, such as biomass, so the models will output “snapshot” or instantaneous values at a particular time consistent with the observation time.

Table 13: Model Output

| Variable | Description | Definition | Units | Positive | Priority |
|---|---|---|---|---|---|
| Description | Model Description | 1-2 paragraph model description | na | na | Mandatory |
| References | References | published papers describing model | na | na | Mandatory |
| Inputs | Input List | list of standard inputs actually used | na | na | Mandatory |
| NEE | Net Ecosystem Exchange | Net carbon sxchange with surface (TotResp - GPP) | Kg/m2/s2 | Upward | Mandatory |
| SenseHeat | sensible heat flux | upward turbulent heat flux out of canopy top | W/m2 | Upward | Mandatory |
| LatentHeat | latent heat flux | water vapor transport (evaporation + transpiration) out of canopy top | W/m2 | Upward | Mandatory |
| GPP | Gross Primary Production | Photosynthetic uptake of carbon by vegetation | Kg/m2/s2 | Downward | Mandatory |
| NPP | Net Primary Production | Net carbon assimilation by photosynthesis (GPP - AutoResp) | Kg/m2/s2 | Downward | Mandatory |
| TotResp | Total respiration | total respired carbon (autotrophic + heterotrophic) | Kg/m2/s2 | Upward | Mandatory |
| AutoResp | Autotrophic Respiration | Maintenance respiration and growth respiration | Kg/m2/s2 | Upward | Recommended |
| HeteroResp | Heterotrophic Respiration | Total flux from decomposition of organic matter | Kg/m2/s2 | Upward | Recommended |
| Wood | wood biomass | total wood biomass | Kg/m2 | na | Recommended |
| TotLivBiom | Total Living Biomass | Total carbon content of the living biomass (wood + leaf + root) | Kg/m2 | na | Recommended |
| TotSoilCarb | Total Soil Carbon | Total soil and litter carbon content integrated over the entire soil | Kg/m2 | na | Recommended |
| Litter | surface litter | total surface litter carbon, including coarse woody debris | Kg/m2 | na | Recommended |

Table 14: Output Frequency for each tower

***Insert table 14 here***

### 4.5. 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

An essential component of the MDC is a quantified measure of model performance when compared to observations. The basic strategy is for multiple teams of researchers, each focusing on a different aspect of model performance, to simultaneously compare model output to observations. 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. Here we define common variables, techniques, and assumptions to ensure we can integrate and compare the results of the various analysis teams.

We will base our model-data comparison on the statistics of the residual, $\delta_n$,

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

where $n$ is the time index, $M_n$ is the model value, and $O_n$ is the observed value. A positive $\delta_n$ 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. Some types of analyses may require gap-filled flux observations, such as frequency domain or wavelet analyses. The Core Team will post the raw residuals on the server for use by all analysis teams.

Various statistical quantities derived from $\delta_n$ measure different aspects of model performance. For example, the residual mean, $\delta_{ave}$, 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 $\delta_{ave}$ 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 $\delta_{ave}$ 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 $\delta_{ave}$ for each hour of the day and for each month.

The residual standard deviation, $\delta_{std}$, 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.

## 6. Schedule

Synthesis Protocol send to participants

Prospectus to NACP for Funding

Observational and model input data sent to MAST-DC

Model output sent to MAST-DC

Analysis of model-data comparison

MDC Workshop

Write papers for special issue

Submit papers for JGR special issue

Present results at NACP All-Scientist meeting

## 7. References