AMERIFLUX SITE EVALUATION
AND RECOMMENDATIONS FOR NETWORK ENHANCEMENT

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1.0 Executive Summary

The AmeriFlux network is guided by these overriding science questions as described in the AmeriFlux strategic plan (http://public.ornl.gov/ameriflux/AmeriFlux_Strategic_Plan.pdf)
1. What are the magnitudes of carbon storage and the exchanges of energy, CO_2 and water vapor in terrestrial systems? What is the spatial and temporal variability?
2. How is this variability influenced by vegetation type, phenology, changes in land use, management, and disturbance history, and what is the relative effect of these factors?
3. What is the causal link between climate and the exchanges of energy, CO_2 and water vapor for major vegetation types, and how does seasonal and inter-annual climate variability and anomalies influence fluxes?
4. What is the spatial and temporal variation of boundary layer CO_2 concentrations, and how does this vary with topography, climatic zone and vegetation?

Two tiers of flux sites could accomplish our network goals: Tier 1 would be “super sites” for attribution of causes for variation in stocks and fluxes, and for understanding processes (including advection) influencing fluxes. Tier 1 sites would thus need to be well instrumented and staffed with the expertise to conduct full carbon accounting, measure the core variables at appropriate time scales, and participate in coordinated process and synthesis studies. Tier 1 sites would serve as high-quality, long-term anchor points within the network, and would serve as logical sites for experiments. Tier 2 sites would have a more limited scope in observational density and/or time of operation. They could encompass a broader variety of ecosystems than can be observed with Tier 1 sites (e.g. age gradients, species-type diversity in regions), serve as replicates to Tier 1 sites to test experimental hypotheses, or enhance our ability to map the spatial coherence of responses of the atmosphere and ecosystems to climate variability and change. High-quality data and ready access to site data would still be required. As our understanding progresses and new scientific objectives emerge, these definitions and the role of sites will evolve, but we expect that some mixture like this is likely to provide the best opportunities for rapid progress.

We conducted a self-evaluation of the AmeriFlux network to determine areas for improving cohesiveness and quality of the network. Recommended network enhancements for syntheses and regional to continental modeling activities are associated with a consistent suite of measurements at appropriate temporal and spatial scales, calibrations for data quality, and delivery of data to the archive in a timely manner (meteorological, micrometeorological, and biological data). The linkage between CO_2 and water is important to understanding ecosystem response to changes in water availability, and feedbacks to the atmosphere (e.g. biosphere-atmosphere modeling), and this requires enhancement of instrumentation across sites. To understand key processes responding to climate and disturbance, additional enhancements are needed at many sites. A basic level of expectations for network cohesiveness (see AmeriFlux network criteria) may need to be built into agency contingencies for continued funding, and identified in requests for proposals.

In this review, the sites were ranked into three Tiers, where Tiers 1 and 2 generally meet AmeriFlux criteria and objectives, and Tier 3 sites require improvements. The site enhancements carry an additional cost that will need to be addressed by program managers. The SC will contact sites that fall in the third category to discuss how they may improve their situation; if they do not improve significantly within a year, they will be identified as AmeriFlux network affiliates.

An important result from AmeriFlux data is quantification of physiological responses to key environmental drivers. Rigorous examination between the fluxes of CO_2 or H_2O and the environmental drivers is needed to understand the changes in carbon cycling across the landscape and over time. This highlights the critical importance of making high quality measurements of standard meteorological parameters such as temperature and light. For example, in order to demonstrate a 10% increase in light use efficiency at a site both CO_2 flux and light must be measured with the same accuracy.

To minimize data gaps, improve data quality and consistency, and expedite delivery of data to the archive, we recommend that all Tier 1 and 2 sites use a MS-level technician to maintain and calibrate instruments, rather than students. To increase the limited pool of skilled micrometeorologists, and improve data quality at sites that have new people or have limited expertise, we recommend support for a regular 2- week summer intensive workshop on making flux measurements for graduate students, technicians and post-docs.

We recommend improving representativeness of the ecoregions by active sites. This can be accomplished by filling current gaps identified in the current and future ecoregion analyses. Of the currently active sites that have data on the AmeriFlux web site, the average length of time the sites have been running is 2.5 years. As indicated in several publications that have used flux data to test or develop models, long-term data are critical to examine the effects of interannual variation in climate on fluxes, and the magnitude and duration of the effect of disturbances on carbon stocks and fluxes, and energy balance. Because decadal climate anomalies can affect fluxes and there may be a carry-over effect into subsequent years, we suggest at least two decades of data be collected at the high quality sites. The exact number of sites needed for long-term research is an area of research in itself, and depends on the ability of funding agencies to commit to maintaining long-term sites. However, the Tier 1 sites are excellent candidates. All major biomes or ecoregions should be represented in long-term measurements. These long-term sites would also need to measure the full suite of biological and meteorological variables for interpreting fluxes and for modeling.

Data quality recommendations

- Report uncertainty in NEE estimates in publications (High priority, low cost, some effort)
- Develop a general guideline for gap filling procedures to be applied at the central data archive for network use (High priority, low cost, some effort)
- Tier 1 and 2 sites that currently have power limitations should be upgraded with adequate power supply (High priority, high cost)
- Reporting calibration records (metadata) and data quality flags (for each averaging period) in a centralized data repository (i.e., CDIAC) should also be explored to enhance overall network data quality, particularly for Tier 1 activities (High priority, low cost, some effort)
- Data quality flags from instrumentation (i.e., SAT, open- and closed-IRGAs) should be reported from all Tier 1 and 2 sites for each 30-min period. Reporting of calibration records and data quality flags should be mandated (High priority, low cost, some effort)
- Data quality can be improved at all sites by reducing gaps due to instrument malfunction or power failure. We recommend that all Tier 1 and 2 sites have communication systems for daily data access and diagnostics (Low priority, high cost)
- Meteorological data could be acquired at a central location and checked for quality there, such that the data would be near real-time. To do this, we also recommend improved communications from the flux site to a central database (Medium priority, high cost
- Additional sensors that several sites have expressed interest in for their suite of instrumentation include indirect light sensor (model BF3, Delta-T LTD, Cambridge UK), infra-red sensor for canopy temperatures, and web (or automated digital) camera to document seasonal patterns, weather and phenology

Instrumentation:

Aspirated temperature

- Ensure temperature measurements are unbiased and stable with time. High accuracy interchangeable sensor elements should be used along with signal conditioning electronics that will account for variations in cable resistances. Annual (or more frequent as necessary) against a well calibrated transfer standard or measurement in an ice bath to check accuracy is recommended.(High priority, modest cost)
- All sites should use aspirated shields for temperature measurements to reduce temperature errors due to radiation heating. (High priority, modest cost)

Net Radiation

- Upgrade net radiation sensors to 4-component radiation sensors. As existing net radiation sensors fail, at least replace them with more robust sensors that have durable domes, better drying and aspiration to minimize biases due to horizontal wind-speed and problems associated with condensation and frost. (High priority, modest cost)

Photosynthetic Photon Flux Density (PPFD)

- All Tier 1 sites have a second PPFD sensor field deployed and maintained annually by AmeriFlux QA/QC (High priority, low cost)
- All within-site PPFD sensors to be cross-calibrated onsite with PPFD standard that is kept in the lab, and maintain all calibration records in a centralized data repository (High priority, low cost)
- Tier 1 and 2 sites measure direct and diffuse PAR (High priority, low cost)
- Quantum sensors that are prone to long-term drift should be replaced by more robust sensors, however, any network-wide sensor change needs to be accompanied by a period of cross-comparison to ensure that older data can be compared to new data(Medium priority)
- All sites should have upward and downward facing quantum sensors (Medium priority, low cost)

Sonic Anemometry

- SATs that do not produce linear speed of sound response, or provide direct fast-response signal should be phased out and replaced with other SATs at Tier 1 sites (High priority, modest cost)
- Until this can be done for Tier 1 sites, and for the remaining sites, we recommend development of functional relationships (with aspirated T/RH sensors) to account for the non-linearity in the response to sonic temperature and H (High priority)

Profile systems

- All sites (except short canopies) should be upgraded to include profiles of CO_2, H_2O and shielded, aspirated temperature (High priority, high cost)

Scalar density

- AmeriFlux qa/qc lab should be further outfitted to send all Tier 1 and 2 sites (2) CO_2 standards ~ 10 ppm apart in concentration, within the range of ambient concentrations (High priority, modest to high cost)
- All closed-path IRGAs should be temperature and pressure controlled (High priority, modest cost)
- A subset of Tier 1 sites should have both closed- and open-path IRGAs (Medium priority, high cost)
- A subset of both Tier 1 and 2 sites should also make low frequency, high accuracy CO_2 mixing ratio measurements (Medium priority, high cost)

Soil respiration

- Automated continuous measurements of soil respiration, and accompanying spatial representation with portable chambers, plus soil temperature and moisture profiles should be added to Tier 1 sites, and possibly some Tier 2 sites (High priority, high cost)

Water budget components

- Develop a means to automate H_2O calibrations for all IRGAs (High priority)
- All sites improve rainfall measurements by adding rain gauges above-canopy (wind shielded) or in a nearby clearing of sufficient size (High priority)
- Quantify snow depth where applicable (High priority)
- All Tier 1 forested sites quantify throughfall with rain gauges below-canopy (High priority)
- Some Tier 1 forested sites quantify transpiration by measuring sap flow on an appropriate number of trees for scaling to the stand-level (High priority)
- All sites upgrade their soil moisture measurements to define a soil moisture profile to at least rooting depth with sufficient vertical and temporal resolution to observe wetting events and drawdown by plant uptake.(High priority)

2.0 Overview

This evaluation was conducted to improve consistency in the measurements made by the AmeriFlux network, the instrumentation, the quality, breadth and archival of data, and to improve synthesis of results. The goal is to identify areas for improvement.

The AmeriFlux Steering Committee discussed strategies to build a more cohesive network that meets objectives stated in the AmeriFlux Strategic Plan, the North American Carbon Program (NACP), and the US Carbon Cycle Science Program (US CCSP). The following criteria were developed for evaluation of site performance and membership in the AmeriFlux network:

- Utility and uniqueness to the network - Site is representative of the biome or vegetation type, and helps to fulfill need of adequate coverage of biomes, disturbance classes, and climate.
- Continuous meteorological and micrometeorological measurements year-round
- Follows the instrumentation and calibration guidelines posted on the AmeriFlux web site
- Conducts the core biological, meteorological and micrometeorological measurements outlined on the AmeriFlux web site at appropriate intervals, and provides biological data to the AmeriFlux archive
- Participates in site intercomparison and instrument calibration with AmeriFlux standards and resolves discrepancies
- Submits meteorological and micrometeorological data within 1 year of data collection, following submission guidelines posted on the AmeriFlux web site
- Meets data quality and data archiving standards posted on the web
- Attends annual AmeriFlux meeting
- Demonstrated output – Produces quality publications on key topics in respected professional journals and other outlets
- Network participation - Participates in synthesis activities across sites, demonstrates true availability of site data to others, and participates in the broader array of NACP research.

Additional evaluation criteria for flux sites that provide process-level understanding:

- Focal points for intensive ecological studies on biotic and abiotic controls on the exchanges of CO_2 and water vapor, and changes in carbon stocks
- Conduct full carbon accounting at appropriate temporal and spatial scales (biometric estimate of NEP, carbon stocks in vegetation and soil), and provide uncertainties in these estimates
- Estimate stand structure and phenology with high resolution remote sensing

Additional evaluation criteria for carbon mixing ratios at sites:

- Sites strategically located for quantifying spatial variation in continental CO_2 concentrations
- Potential to be enhanced with instrumentation for methane [CH_4] and carbon monoxide [CO]

AmeriFlux is now requesting flux and meteorology data within one year of data collection (formerly two years). At the AmeriFlux meeting in October 2004, we presented these criteria and asked site investigators to update their information on instrumentation and measurements made at their sites, and to send their data to CDIAC to meet the one-year submission criteria. This communication was followed up with an email in January 2005, which informed the sites that the internal evaluations presented here would be completed in March 2005.

This overall evaluation is based on the updates on i) instrumentation, measurements and data submissions provided to the AmeriFlux archive, ii) interactions between site investigators and the data management group at CDIAC, iii) interactions between site investigators and the AmeriFlux QA/QC lab at Oregon State University, and iv) synthesis activities that were recently conducted by AmeriFlux researchers.

Sites are ranked accordingly: Tier 1 = with the most breadth in measurements, instrumentation and calibration procedures, quality of data, and length of data record, 2 = may have fewer measurements or less than optimal instrumentation, or do not participate regularly in syntheses activities across sites, and 3 = have incomplete data sets, do not respond to queries for data, have substandard instrumentation, inexperienced staff, or do not participate in synthesis activities for a variety of reasons, including poor data sets. As mentioned earlier, two tiers of flux sites could accomplish our network goals: Tier 1 or “super sites” for attribution of causes for variation in stocks and fluxes, and for understanding processes (including advection) influencing fluxes. Tier 1 sites would thus need to be well instrumented and staffed with the expertise to conduct full carbon accounting, measure the core variables at appropriate time scales, and participate in coordinated process and synthesis studies. Tier 1 sites would serve as high-quality, long-term anchor points within the network, and would serve as logical sites for experiments. Tier 2 sites would have a more limited scope in observational density and/or time of operation. They could encompass a broader variety of ecosystems than can be observed with Tier 1 sites (e.g. age gradients), serve as replicates to Tier 1 sites to test experimental hypotheses, or enhance our ability to map the spatial coherence of responses of the atmosphere and ecosystems to climate variability and change. High-quality data and ready access to site data would still be required. As our understanding progresses and new scientific objectives emerge, these definitions and the role of sites will evolve, but we expect that some mixture like this is likely to provide the best opportunities for rapid progress.

3.0 Site instrumentation

Ranking of active sites was based on i) site comparisons made with a portable eddy covariance (EC) system (Appendix A), ii) responsiveness to resolving issues with the roving system comparison, iii) on-site expertise in maintaining instruments and data quality, iv) processing of the 'gold-files' (either open- or closed-path), and v) how data from each site compared to a network-level index (Appendix B). Since the inception of using a portable EC system, we have conducted comparisons with 84% of all research groups, and since the OSU group began conducting comparisons, 55% of research groups have been visited. If a specific site was not visited, the ranking was based on comparisons made at a site operated by the same research group. Because the need for additional micrometeorological instrumentation differs among sites and is based on older (or less robust) instrumentation, overall system design, and the physical structure of the ecosystem, we make recommendations for instrument enhancement at the network-level and list below each recommendation the specific sites that can benefit from instrument upgrades.

It is important to note that changes have occurred in the methodology used in the comparisons since the inception of the first site visit. The first portable EC system was adequate to the network needs at the time of deployment. But as the network matured, we have incorporated a new portable EC system in February 2004 with updated instrumentation, more robust measurements, automated CO_2 calibration, and processing software that is more adaptable to the different needs found from site-to-site. Hence, comparisons made after winter 2004 were broader in scope. An in depth description of the two EC systems can be found in Appendix C. It is also important to note that during each comparison, each site was required to provide processed meteorological, wind, flux data and any appropriate corrections. Not all of the sites provided these key data (for various reasons) and the overall comparisons reflect this, and should be taken into consideration when interpreting the utility of the network index.

3.1 Recommendations for enhanced instrumentation at sites

A. Aspirated temperature. The AmeriFlux network needs to ensure temperature measurements are unbiased and stable with time. There are three primary issues, i) use of a variety of sensors off the shelf without testing them first, and lack of cross calibration, ii) lack of uniform aspirated measurements, and iii) lack of on-site redundancy in air temperature measurements. *Sites should have at least one aspirated shield for temperature measurements located at or about the same height as their sonic anemometer, particularly those sites in arid climates, grasslands, or with open ground. Lastly, temperature accuracy over time should be ensured by comparison to on-site standard temperature measurement traceable to a reference standard or additional roving temperature standards that can be rotated among the network sites annually.* Currently, the temperature sensors that AmeriFlux QA/QC lab uses are sent to sites that specifically request them, and to sites that we have identified as having difficulties making air temperature measurements.

B. Net Radiation. Net radiation measurements have been a problem. Instruments with plastic domes are prone to breakage, and upgrades to include aspiration have not been consistently made. Furthermore, measuring the upward and downward short and long-wave radiation rather than the net radiation provides more insight into the radiation balance of a site. Replacing failed sensors with either a closed-cell net radiation sensor or a 4-component sensor is recommended. All sites should consistently use aspirators and account for any wind-speed corrections in their radiation measurements.

C. Photosynthetic Photon Flux Density (PPFD) and incident radiation. (1) It is common to find lack of agreement with the AmeriFlux QA/QC sensor (Li-190, Li-Cor Inc. Lincoln NE) in the gain (voltage multiplier) or offset, resulting 10-15% lower PPFD estimates. The most common PPFD sensor is the Li-190 series, but one reason for sensors not being maintained is that there is no other means for independent or redundant estimates. Many sites use more than one PPFD sensor, often in a profile or to measure reflectivity. (2) Recent modeling works all suggest that two-leaf (sunlit and shaded) models of canopy photosynthesis are far superior to big-leaf models. To run two-leaf models, separation of direct and diffuse PAR is essential. Although they can be converted from global and diffuse solar radiation, it would involve less error if they are measured directly. Canada Fluxnet has adopted this requirement for all stations. *It is recommended that all Tier 1 and 2 sites measure both total and diffuse PAR. Tier 1 sites should also have a second PPFD sensor field deployed and maintained annually by AmeriFlux QA/QC, all within-site PPFD sensors to be cross-calibrated onsite against a PPFD standard that is kept in the lab (with Li-Cor light source), and maintain all calibration records in a centralized data repository.* Conversion to sensors with better long-term stability is desirable, but needs to be accompanied by an extensive period of sensor overlap to account for any differences between sensors. *We also recommend the addition of downward facing quantum sensors.*

D. Sonic Anemometry. There is no model of sonic anemometer-thermometers (SATs) that is ideal for all situations. Model type should be chosen by the site PI to best suit the site conditions and overall research questions. Close attention should be given to signal processing and conditioning algorithms to ensure that the selected SAT will provide a linear response to temperature and a full representation of the all turbulence information. Comparisons of several anemometers identifies an uncertainty in sensible heat flux (H) estimates by ±10% for any given 30-min averaging period (Loescher *et al*. 2006) due to non-linearities in temperature response. Sites using SAT that have non-linear temperature or smoothing applied by the firmware should check *the relationship (means and variances) between sonic and air temperatures measured with a fire-wire thermocouple across all whole range of observed temperatures for each SAT used, and develop functional relationships to account for the non-linearity and smoothing until the SAT can be replaced or upgraded to eliminate this problem.*

E. Scalar density measurements for CO_2 and H_2O. Precise scalar concentrations are needed to quantify the high frequency turbulent fluctuations of scalar density in making flux measurements, i.e, 5% repeatability (infra-red gas analyzer's gain function, ppm mv-1).. Open-path infra-red gas analyzers (IRGA) provide very good ability to measure high frequency turbulence, but cannot employ automated calibrations for periodic and accurate scalar calibrations. Closed-path sensors can be calibrated automatically but can systematically attenuate high frequency turbulence. Fluxes from both types of IRGAs have to be corrected, WPL and high frequency attenuation, respectively. Once the fluxes are corrected, estimates from both IRGAs agree fairly well over forested systems with large active fluxes. Additional uncertainty becomes apparent in open-path estimates when the flux is close to zero and the WPL term can be one or more orders of magnitude of the flux estimate—which is dependent on accurate measurement of scalar densities. Not all sites currently make precise scalar measurements. Gain functions in either IRGA must also be properly calibrated to achieve the desired repeatability of measurements to estimate EC.

To achieve the recommended 5% repeatability in high frequency measurements, all sites must adhere to the flux guidelines i.e., temperature and pressure controlled IRGA, frequent and when possible--automated calibrations, use of more than one CO_2 standard, and determine the instrument response within the range of ambient [CO_2]. IRGAs are less responsive (ppm mv^{-1}) at high (ambient, i.e., 360 – 450 ppm) concentrations compared to low [CO_2] concentration, which can affect both the scalar precision and accuracy of estimates. Flux estimates depend only on the accuracy of instrument gain, but the variation in gain across the range of ambient concentration needs to be accounted for, otherwise the diurnal range of ambient concentration can introduce a systematic bias into the flux measurements. The non-linearity of each IRGA is initially determined by manufacturer calibration, but may change over time. The instrument response curve needs to be periodically reassessed. If we wish to determine IRGA responsiveness to within 5% of the CO_2 concentration, sites must use a minimum of 2 CO_2 standards, within the range of ambient [CO_2], and with a 10 ppm difference in concentration. This results in the need for accuracy in the CO_2 standards to be ±0.5 ppm (i.e., 5% of a 10 ppm range = 0.5 ppm). We recommend that all sites use standards that are traceable to primary CMDL-WMO standards. The primary standards are not used directly to calibrate in the field, but are used to calibrate the working standards. Few sites have the primary CMDL-WMO standards (±0.07 ppm) despite their lowered cost. Most other sites do not have traceable, secondary CO_2 standards, which often have ±1-2% accuracy (e.g., at 400±8 ppm). Almost all sites do not have an archival tank that all other secondary gases can be compared to. The AmeriFlux qa/qc lab can make secondary CO_2 standards to within ±0.5 ppm. Maintenance of a full suite of CMDL primary standards and recalibrating working standards against them is a significant effort and expense that may be beyond many sites capabilities. To achieve the network quality goal, *we recommend the AmeriFlux qa/qc lab be further outfitted to prepare a set of (2) secondary CO_2 standards approximately 10 ppm apart in concentration traceable to the WMO-CMDL standards for all Tier 1 and 2 sites that cannot provide them on their own. .*

A subset of Tier 1 sites should have both IRGAs (for redundancy, if nothing else) and an automated calibration system for precision scalar estimates,< 1 ppm CO_2 (which includes temperature and pressure control of the optic bench). Using a Li-7000 IRGA (Li-Cor Inc., Lincoln ME) has less high frequency attenuation associated with the internal flow dynamics compared to the Li-6262 sensor, and the Li-7000 can output data quality flags. *A subset of both Tier 1 and 2 sites should also make low frequency, high accuracy (better than ±0.2 ppm and traceable to the WMO-CMDL standards) estimates to adequately sample regional to sub-continental air masses.*

F. Profile systems. Because any 30-min scalar flux is the sum of both turbulent exchange and the vertical integrated rate of change of the scalar, it is important to have a CO_2 profile system particularly at sites that have a developed canopy > 1 m in height. Li-6262 or li-840 series IRGAs are adequate for profile systems (following the AmeriFlux guidelines). Air temperature profiles also help diagnose potential problems with flux divergence or decoupling of subcanopy fluxes from the measurement above-canopy, particularly at night. Profiles of CO_2, H_2O and aspirated temperature are desired measurements with adequate number of levels to identify and potentially estimate any below- or within canopy dynamics. Temperature sensors can be aspirated by co-locating the inlet for gas sampling. Profile systems are not necessary for short vegetation.

G. Soil respiration. *Automated continuous measurements of soil respiration, and accompanying spatial representation with portable chambers, plus soil temperature and moisture profiles should be added to Tier 1 sites, and possibly some Tier 2 sites.* We have found that automated chamber measurements of soil respiration (hourly) (1) are extremely useful for understanding the contributions of photosynthesis and respiration to NEE, and interannual changes in these contributions with climate, as soil respiration is the major source of respired CO_2; (2) can be used to produce independent estimates of NEP for comparison with tower data; (3) determining the controls on temporal variation in soil CO2 exchanges, and (4) measurements can be used to diagnose nighttime eddy covariance fluxes (respiration). Achieving accuracy to within 20% of a true mean is difficult in a heterogeneous soil environment with a limited number of sensors. Continuous analyzers need to be also supplemented with periodic manual measurements over a spatially extensive area to (1) place the continuous data in a spatial context and (2) to determine an appropriate number of automated chambers needed to temporally and spatially scale soil respiration estimates. Currently, the sites that have automated chambers are using systems they designed and built themselves. Performance checks should be made with known standards. In addition, soil temperature and moisture profiles need to be measured to an adequate depth (e.g. 1 m) to develop respiration models that better represent changes in soil respiration with abiotic variables among different soil and vegetation types. *We recommend that the Tier 1 sites be instrumented with automated soil chamber systems for measuring soil respiration, along with soil temperature and soil moisture profiles (TDR or capacitance probes) to 2 m depth, or as deep as possible.*

H. Water budget components. One key AmeriFlux objective is to explain the processes that control the fluxes of water vapor, and to determine how water vapor flux temporally and spatially affect the exchange of carbon (AmeriFlux Science Plan). Hence, all components of the ecosystem-level water flux are needed not only to achieve this objective, but also for energy balance studies, hydrology modeling, and coupled land-atmosphere models where the energy budget is poorly understood. Currently, few sites have the capability to partition water fluxes below the tower height. AmeriFlux should be first concerned with making quality turbulent exchange and storage flux estimates of water vapor. There are limited means to automate the calibration of water vapor. H_2O calibrations should be done at the same sampling pressures, which can be problematic if dew point generators are used. All sites should be discouraged from using Tedlar bag approach. Options to automate H_2O calibrations include chilled mirror, wet bulb temperature, or calibrated RH (capacitance) sensors. Chilled mirror and wet bulb sensors can be imprecise in very dry environments, capacitance sensors can also be imprecise at Rh > 90%. *All Tier 1 should explore a means to automate precise H_2O calibrations for IRGAs making turbulent measurements and for IRGAs making profile measurements, though the best option may differ among sites depending on specific site conditions.*

Second, AmeriFlux needs to better establish H_2O inputs and to partition below-canopy water fluxes. *We recommend that all sites improve their rainfall measurements by adding an appropriate number of rain gauges. All forested sites should add rain gauges below-canopy for throughfall, and quantify transpiration by measuring sap flow on an appropriate number of trees to temporally and spatially scale to the stand-level, the specific number of which to be determined by site researchers.* This is high priority for some Tier 1 sites. Other water budget components are likely to be too difficult to measure (e.g., stream runoff, soil drainage), though where opportunities to include streamflow or soil-drainage measurements through partnership with other nearby research these should be encouraged.

I. Related recommendations. Several sites, including some in Tier 1 rely on 12 vdc power systems, and have limited power availability through winter or cloudy periods. Some of these recommendations for instrument enhancement require additional power and data acquisition that need to be assessed on a case-by-case basis. W*e recommend upgrading Tier 1 and Tier 2 sites that currently have power limitations to be upgraded with adequate power supply. This is a high priority if we are to reduce uncertainty and data gaps.*

Reporting calibration records (metadata) and data quality flags (for each 30-min period) in a centralized data repository (i.e., CDIAC) should also be explored to enhance overall network data quality, particularly for Tier 1 activities. Currently, each site has developed their own, in-house processing routines and QA/QC procedures. There are no uniform means of assessing and reporting data quality, due in part to different site-specific needs. Once data is submitted to CDIAC, basic data assurance tests are preformed (see below). However, *data quality flags from instrumentation (i.e., SAT, open- and closed-IRGAs) should be reported from all Tier 1 and 2 sites for each 30-min period. Reporting calibration records and data quality flags need to be mandated to work at the network level.*

Data quality can be improved at all sites by reducing gaps due to instrument malfunction or power failure. We recommend that all Tier 1 and Tier 2 sites have communication systems for daily data access and diagnostics. They type of communications system to be determined by the research group based on site constraints and cost efficiency.

Meteorological data could be acquired at a central location and checked for quality there, such that the data would be near real-time. To do this, we recommend improved communications from the flux site to a central database.

Sites that have consistent data quality and maintain site instrumentation all have an MS-level technician, and we recommend this practice be encouraged at all sites. It is not recommended to use graduate students alone to maintain site instrumentation and data quality. There was only one site that was visited where a graduate student had all the skills needed for such a task. Supporting a long term, well-trained MS-level technician not only enhances data quality, but also frees time for graduate, post-doc and PIs to spend on analyses and research activities.

In discussing the new group structure of AmeriFlux with site PIs, there is great interest in further enhancing site activities and gaining additional local support from the respective institutions. This potential change in structure is perceived as a very good opportunity for developing a long-term infrastructure.

It is difficult for many site investigators to find well-trained technicians and post-docs that can make quality flux measurements and analyses across temporal and special scales. *We recommend supporting a 2- week summer intensive workshop on making flux measurements among scales for graduate students, technicians and post-docs*--modeled after J. Ehleringer's summer stable isotope workshops at the University of Utah.

Additional sensors that several sites have expressed interest in placing into their permanent suite of instrumentation include, indirect light sensor, Infra-red sensor for canopy temperatures, and web (or automated digital) camera to document seasonal patterns, weather and phenology.

4.0 Data archive

Gap-filled data. To increase efficiency in network data use and syntheses, gaps in meteorological and micro-met data need to be filled and flagged. Gap-filling is done to create integrals (e.g. monthly, weekly, yearly), and to test models. For example, some models produce daily or monthly estimates of NEE, and modelers would like to determine the level of filling they are willing to accept (e.g. 20%). Thus, gap-filled data need to be flagged for those who work at finer scales and therefore should not use filled data (this will result in comparison of model to model), and integrals need identification of percentage filled. We recommend development of a general guideline for gap filling procedures for network use. Individual stations can submit gap filled data using their own procedure, but beginning in 2006 the central data archive will perform gap filling using a common procedure.

Evaluation and classification of sites into Tiers. The evaluation and classification were determined by the combination of i) the total number of reported variables that are recommended in AmeriFlux core measurement list (http://public.ornl.gov/ameriflux/standards-core.shtml), ii) data quantity, iii) data quality, and iv) site responsiveness in communication and resolving issues that naturally come up with data archiving. *Sites that would like to improve their ranking should follow the posted data submission guidelines, provide the full suite of posted core/desired measurements, and submit data within 1 y of measurement.*

This evaluation was based on data submitted through March 2005. Some sites provided data after the cutoff date. The list of reported variables measured by each site was compared with the list of recommended AmeriFlux core measurements. Tier 1 sites report key additional information (e.g., storage terms, the full suite of radiation terms, Re, GPP, biological data (C stocks, LAI, NPP), and/or redundant measurements). Tier 2 sites report the core AmeriFlux micrometeorology and meteorology measurements routinely, and Tier 3 sites report fewer than ten variables or fail to report carbon fluxes. Data quantity statistics were generated for each site and for each reported variable. These statistics examined the number of measurements reported, the number of data gaps, and the average duration of the gaps (see Appendix 8.0). Gap statistics were then reported for CO_2 flux or net ecosystem exchange. Based on these indices and based on the length and comprehensiveness of the overall data record, a data quantity index was generated. *Sites with record lengths > 6 y were weighed towards a Tier 1 classification, and conversely, sites with < 3 yrs of record length were weighed towards Tier 3 classification. Thus, recently established sites would have a lower ranking for data quantity.*

The assessment of data quality was based on the results of i) CDIAC QA/QC checks, ii) overall data quality, and iii) the utility of data for modeling exercises (e.g., if the site has participated in model evaluation exercises).

The ‘responsiveness’ criteria reflect the level of communication and willingness to resolve naturally occurring issues between CDIAC (and the AmeriFlux QA/QC lab) and site investigators and technicians. Submitting data without prompting is a first step towards establishing a good working relationship with CDIAC. Reasons for unresponsiveness vary. Overall, most investigators were responsive to data questions and requests.

5.0 Network-wide synthesis accomplishments

The following three synthesis activities were fairly recent and network-wide, allowing all active sites to participate. Although there have been more limited syntheses conducted (e.g. model evaluation at evergreen forest sites, fluxes in deciduous forests), they are not included so as to avoid bias towards particular site characteristics in this evaluation. Therefore, this is just a sample of syntheses that have been conducted.

Soil respiration synthesis. The most recent network-wide synthesis was on soil respiration. All of the AmeriFlux sites were invited to participate in the synthesis, where the goal was to investigate trends in response to temperature and moisture, and to develop and test various models of soil respiration. The extent of the analysis was limited by the breadth and frequency of various measurements, thus *we recommend better coordination of frequency and breadth of soil flux and ancillary measurements, and experimentation on controls on soil fluxes at a subset of sites in different biomes (Tier 1).*

This activity took ~2 years to complete (started in 2003). Twenty AmeriFlux sites and about 18 CarboEurope sites participated in the synthesis. Some sites did not have adequate data, and others simply didn’t respond to the invitation to participate. This research is now published in a special issue on soil respiration that includes 12 additional papers from the flux community (Biogeochemistry vol 73(1); Hibbard, Law, and Ryan, guest editors; Hibbard, K.A., *et al*. 2005). The workshop and special issue were supported by NIGEC (Verma) and DOE AmeriFlux funding (Dahlman). Most groups that contributed to this synthesis activity had sufficient breadth of data and longevity of measurements, and willingness to participate in syntheses across sites. Only seven of the AmeriFlux sites had their biological data posted on the web, and 30% of the participating sites had partial data sets that limited their participation in the analysis.

MODIS validation activity. The MODIS validation activity, lead by the S. Running lab, requested near real-time meteorological data, daily and annual GPP from flux data, and summer maximum LAI and fPAR. The purpose was to evaluate regional patterns and temporal dynamics of satellite remote sensing estimates of seasonal and annual GPP from MODIS using more limited information from a greater number of sites within various biomes and climate regimes. The effort was aimed at determining if there is a systematic bias in MODIS production estimates relative to network observation-based GPP estimates, and if such a bias originates from the MODIS input data (DAO climatology, MODIS fPAR, PAR). The paper resulting from this activity is in press (Heinsch et al. 2005. IEEE Geoscience and Remote Sensing Letters). Fifteen sites had enough quality data to participate in the activity, and three of them had limited datasets that resulted in only partial participation

Fluxnet synthesis on environmental controls on fluxes. In a previous analysis across Fluxnet sites, conducted in 2000-2001, we examined the relations between environmental variables and NEP, GPP, and water vapor exchange, and examined water-use efficiency by biome. Among 37 sites in different biomes, an average of 83% of the total amount of carbon taken up by the terrestrial systems in photosynthesis was respired back to the atmosphere. Evergreen coniferous forests were more water-use efficient – they took up more carbon per unit of water loss than other biomes, and three of the biomes had lower but similar efficiencies (grasslands, deciduous broadleaf forests, and crops). Mean annual temperature and site water balance explained much of the variation in annual GPP. AmeriFlux and CarboEurope investigators received the 2004 Norbert-Gerbier Mumm International Award from the World Meteorological Organization for this paper. 19 flux sites had sufficient data to contribute to the publication (Law *et al*. 2001. Environmental controls over carbon dioxide and water vapor exchange of terrestrial vegetation.

Agric. For. Meteorol. 113:97-120). Four of the sites participated in only some of the analyses because they had limited data (primarily missing flux data that exceeded 25% of the year). It is also recognized that several of the participating sites are not currently active, and many new sites were initiated during or after this analysis and could not participate. However, this and the soil flux paper indicate the sites that consistently have value in terms of longevity and breadth of data available for across-site syntheses, and willingness to participate in syntheses.

6.0 Temporal representation.

Of the currently active sites that have data on the AmeriFlux web site, the average length of time the sites have been running is 2.5 years, while about 20% have been running for 5-10 years. As indicated in several publications that have used flux data to test or develop models, long-term data are critical for examining the effects of interannual variation in climate on fluxes, and the magnitude and duration of the effect of disturbances on carbon stocks and fluxes, and energy balance. *Because decadal climate anomalies can affect fluxes and there may be a carry-over effect into subsequent years, we suggest that at least two decades of data would be extremely useful for separating the effects of climate and disturbance on stocks and fluxes. The exact number of sites needed for long-term research is an area of research in itself, and depends on the ability of funding agencies to commit to maintaining long-term sites. However, the Tier 1 sites are excellent candidates. The major biomes or ecoregions should be represented in long-term measurements. These long-term sites would also need to measure the full suite of biological and meteorological variables for diagnosing fluxes and for modeling. Logically, it would include the sites that have a good track record for breadth, responsiveness, and data quality.*

7.0 Spatial representation.

A new analysis was made to evaluate the spatial representativeness of existing AmeriFlux sites across larger scales (e.g. biomes, ecoregions), and to identify any under-represented ecosystem types in the current network. The analysis accounts for the need to have cluster sites along gradients of climate/disturbance/vegetation type in major ecoregions. A brief description of the methodology used here can be found in Appendix D. It is our first effort at characterizing existing sites and their representativeness, and research on the topic is still underway.

As of July 2004, the AmeriFlux network contained 69 active tower locations, in contrast to 59 tower sites analyzed by Hargrove *et al.* (2003). Changes in the number of tower sites continue. In Figure 1, flux environments in darker ecoregions are poorly represented by the current AmeriFlux network. There is strong similarity between the AmeriFlux representativeness depicted in Figure 1 and the original data shown in Hargrove *et al.* (2003). Even though the two datasets (maps) were generally similar, it is encouraging that our methodology is likely sound because each analysis utilized different initial parameterizations. These representativeness maps indicate that the AmeriFlux network has adequate coverage to predict large-scale patterns of flux, regardless of which statistical ecoregions were selected for the basis of the analysis. It is important to note that these results have never been tested by evaluation of the fluxes, and should be the topic of future research. In addition, we might consider an area weighting scheme if it is determined that smaller, unique flux ecoregions are less important to sample than larger regions.

As in the preliminary analysis, the Pacific Northwest, the Sierra Nevada Mountains, and the Sonoran desert region were shown to be under-represented (black in color). The Pacific Northwest is known to be an intersection of multiple abiotic gradients, and is probably difficult to adequately represent all the ecosystem types with the current number of towers. Lakes, rivers, and swamps were shown to be under-represented, e.g., the coastline of the Great Lakes. Classification of under-represented ecoregions was probably due to them containing atypical or complex ecosystem types, making them difficult to sample adequately. It is interesting to note that all of these under-represented regions were located around the geographic periphery of the continental United States, suggesting it is easier to capture the representation of the more spatially consistent continental interior, but much more difficult to achieve adequate representation in a mosaic of spatially complex ecosystems along the coastal margins. This analysis directly contributes towards the management decisions needed to make improvements (by adding additional towers) to the AmeriFlux network in a directed fashion.

The two maps show important differences as well, particularly in Texas and Florida. A substantial gain in representation has been achieved in Texas, ostensibly due the addition of new towers. The general decrease in representativeness in Florida was probably due to the improvement in specifying flux-specific ecoregions used in the new analysis, which suggested under-representation in the Everglades and much of central Florida. Because this new analysis included information about anthropogenic disturbances (including agriculture), the areas of intensive agriculture including parts of Ohio, Indiana, Illinois, Missouri, eastern Kansas, the Mississippi valley, and western Texas changed from being well-represented in the preliminary analysis to marginally-represented (grey in color) in the updated analysis.

This is only the first of a series of analysis products for AmeriFlux that will be produced (in FY2005). Ultimately, a series of nine AmeriFlux representativeness maps will be produced like the one presented here. The sequence of maps will add seasonality and other contributing affects to the representativeness of the AmeriFlux network. In FY2006, we will make suggestions for optimizing the locations for additional flux towers, and provide information about the importance and uniqueness of each existing tower in the AmeriFlux network.

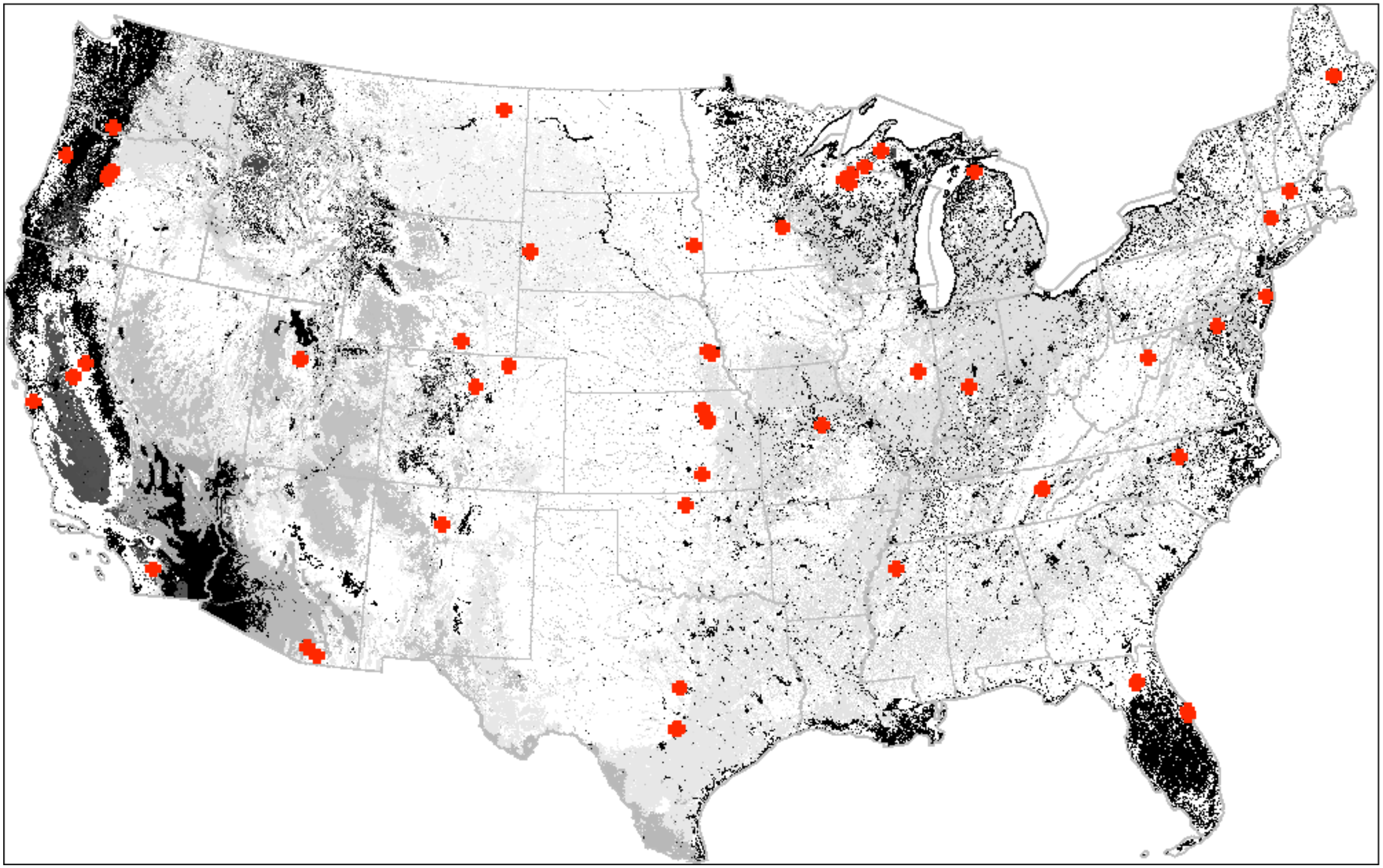

Figure 1. The spatial representativeness of this existing AmeriFlux tower sites calculated using an updated set of criteria (see Appendix D). White, shades of grey and black correspond to well-, marginal, and under-represented ecoregions by the current network, respectively.

8.0 References

Curtis, P.S., Hanson, P.J., Bolstad, P., Barford, C., Randolph, J.C., Schmid, H.P., Wilson, K.B. 2002. Biometric and eddy-covariance based estimates of annual carbon storage in five eastern North American deciduous forests. *Agric. For. Meteorol.* 113: 3-19.

Hargrove, WW, Hoffman FM 2004. A flux atlas for representativeness and statistical extrapolation of the AmeriFlux network. ORNL Technical Memorandum ORNL/TM-2004/112. Available at http://geobabble.ornl.gov/flux-ecoregions/

Hargrove, WW, Hoffman FM, Law BE 2003. New analysis reveals representativeness of the AmeriFlux network. *Eos* 84(48):529-535.

Heinsch, F.A., M. Zhao, S.W. Running, J.S. Kimball, R.R. Nemani, K.J. Davis, P.V. Bolstad, B.D. Cook, A.R. Desai, D.M. Ricciuto, B.E. Law, W.C. Oechel, H. Kwon, H. Luo, S.C. Wofsy, A.L. Dunn, J.W. Munger, D.D. Baldocchi, L. Xu, D.Y. Hollinger, A.D. Richardson, P.S. Stoy, M.B.S. Siqueira, R.K. Monson, S.P. Burns, L.B. Flanagan. 2005. Evaluation of Remote Sensing Based Terrestrial Production from MODIS Using AmeriFlux Eddy Tower Flux Network Observations. IEEE Geoscience and Remote Sensing Letters. In press.

Hibbard KA, Law BE, Reichstien M, *et al*. 2005. An analysis of soil respiration across northern hemisphere temperate ecosystems. *Biogeochemistry*. In press.

Law BE, Falge E, Gu L, Baldocchi DD, Bakwin P, Berigier P, Davis KJ, Dolman AJ, Falk M, Fuentes JD, Goldstein AH, Granier A, Grelle A, Hollinger DY, Janssens IA, Jarvis P, Jensen N-O., Katul G, Malhi Y, Matteucci G, Meyers T, Monson RK, Munger JW, Oechel W, Olson R, Pilegaard K, Paw U KT, Thorgeirsson H, Valentini R, Verma S, Vesala T, Wilson K, Wofsy S 2001. Environmental controls over carbon dioxide and water vapor exchange of terrestrial vegetation. *Agric. For. Meteorol.* 113:97-120.

Loescher HW, Ocheltree T, Tanner B, Swiatek E, Dano B, Wong J, Zimmerman G, Campbell J, Stock C, Jacobsen L, Shiga Y, Kollas J, Liburdy J, Law BE 2005. Comparison of temperature and wind statistics in contrasting environments among different sonic anemometer-thermometers. *Agric. For. Meteorol.* 133: 119-139.

Ocheltree T, Loescher HW 2006. Design of the AmeriFlux portable eddy-covariance system and uncertainty analysis of CO_2 measurements. *J. Ocean. Atmos. Tech.*, in review.

Niyogi D, Chang H-I, Saxena VK, Holt T, Alapaty K, Booker F, Chen F, Davis KJ, Holben B, Matsui T, Meyers T, Oechel WC, Pielke RA, Wells R, Wilson K, Xue Y 2004. Direct oberservations of the effects of aerosol loading on net ecosystem CO2 exchanges over different landscapes. *Geophys. Res. Lett.,* 31:doi.10.1029/2004GL020915

9.0 Appendix A.

Air temperature, horizontal wind speed, carbon flux, sensible and latent heat flux, net radiation, PPFD, and scalar concentrations were measured for each site comparison. Within site regression analyses are fine for individual site comparisons, but regressions are often not parallel to a 1:1 line, with differing and significant offsets. Performance at one site may be very different for positive and negative fluxes. Because environmental conditions vary among sites during the comparisons, we wanted to conduct a fair assessment that wasn't dependent on conditions during the comparison. In hopes of assessing site performance in a fair and objective way, the percent difference between measurements made with site instrumentation and the portable EC system were calculated with a fixed value. For example, Audubon Ranch the carbon flux may only be +/- 5 μmol m^{-2} s^{-1} with a maximum H is 500 W m^{-2}, but the comparison at Duke the carbon flux was +/- 25 μmol m^{-2} s^{-1} and maximum H was 100 W m^{-2}. Here, the percentage difference was calculated with H at 250 W m^{-2}, F_C at 10 μmol m^{-2} s^{-1} efflux, and at -20 μmol m^{-2} s^{-1} uptake for all sites. The figures below depict the distribution of the percent difference for each of the variables among all sites. The table tallies how each site faired for each of the variables, and each site's overall index (average percent difference).

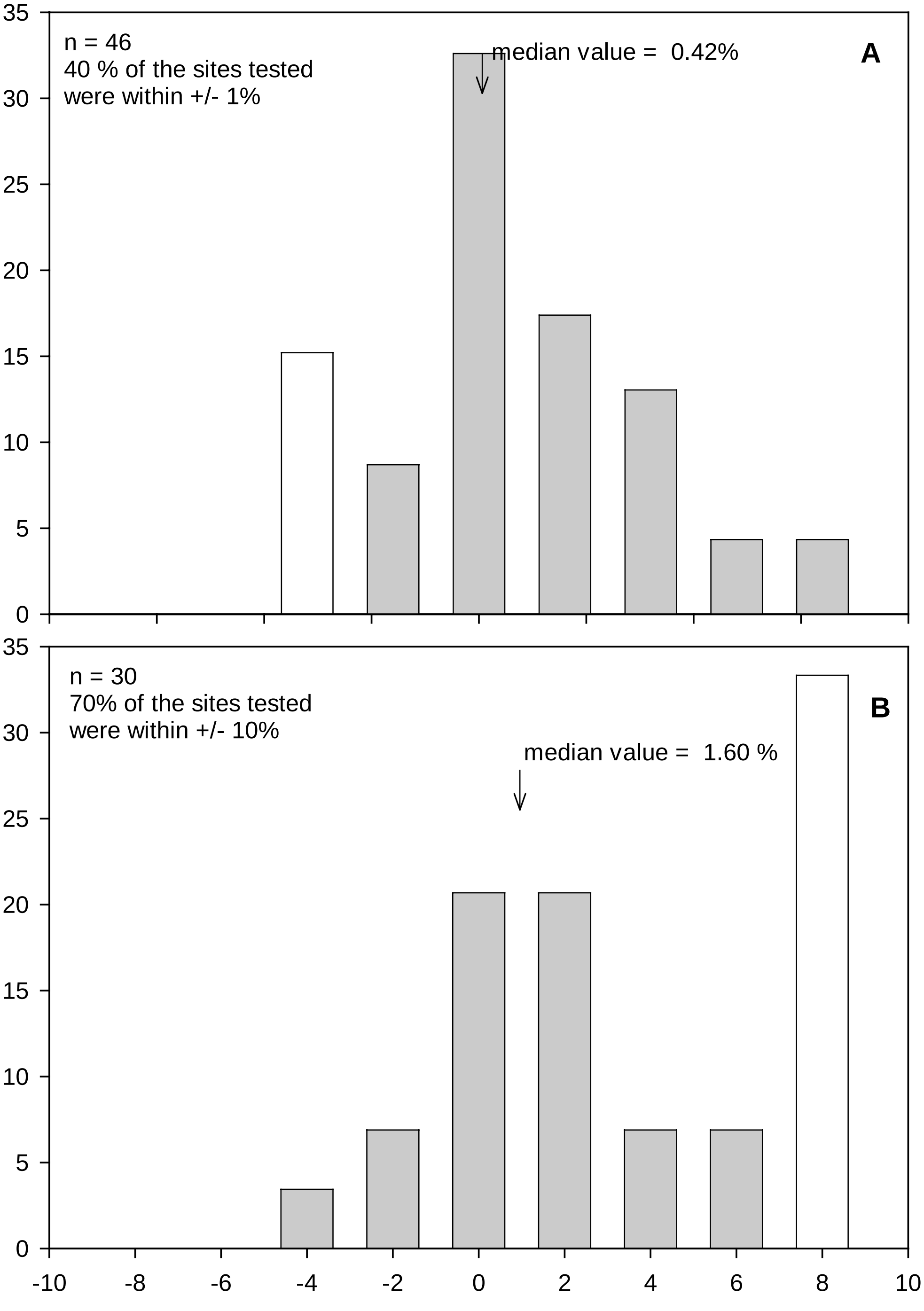

Figure 1A. Maximum percent deviation of A) air temperature at 25 ºC, and B) horizontal wind speed at 2 m s^{-1}, measured among AmeriFlux site instrumentation and the portable eddy-covariance system. Open-bars indicate calibration error from site instrumentation and have been resolved after the comparison. The skewness in graph A is, in part, due to lack of aspiration.

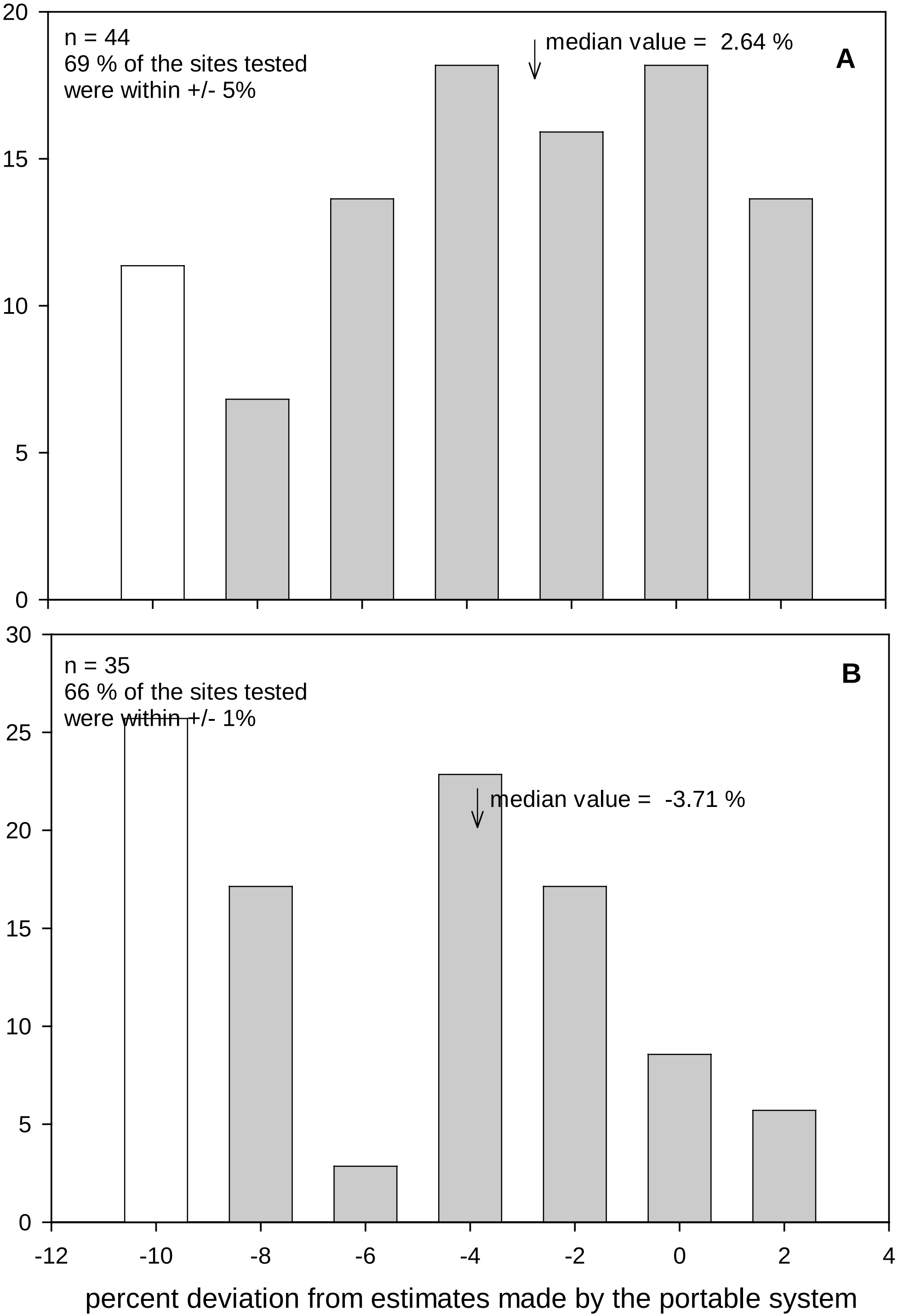

Figure 2A. Maximum percent deviation of A) net radiation at 600 W m^{-2}, and B) PPFD at 1800 $\mu mol\ m^{-2}\ s^{-1}$, measured among AmeriFlux site instrumentation and the portable eddy-covariance system. Open-bars indicate calibration error from site instrumentation and have been resolved after the comparison.

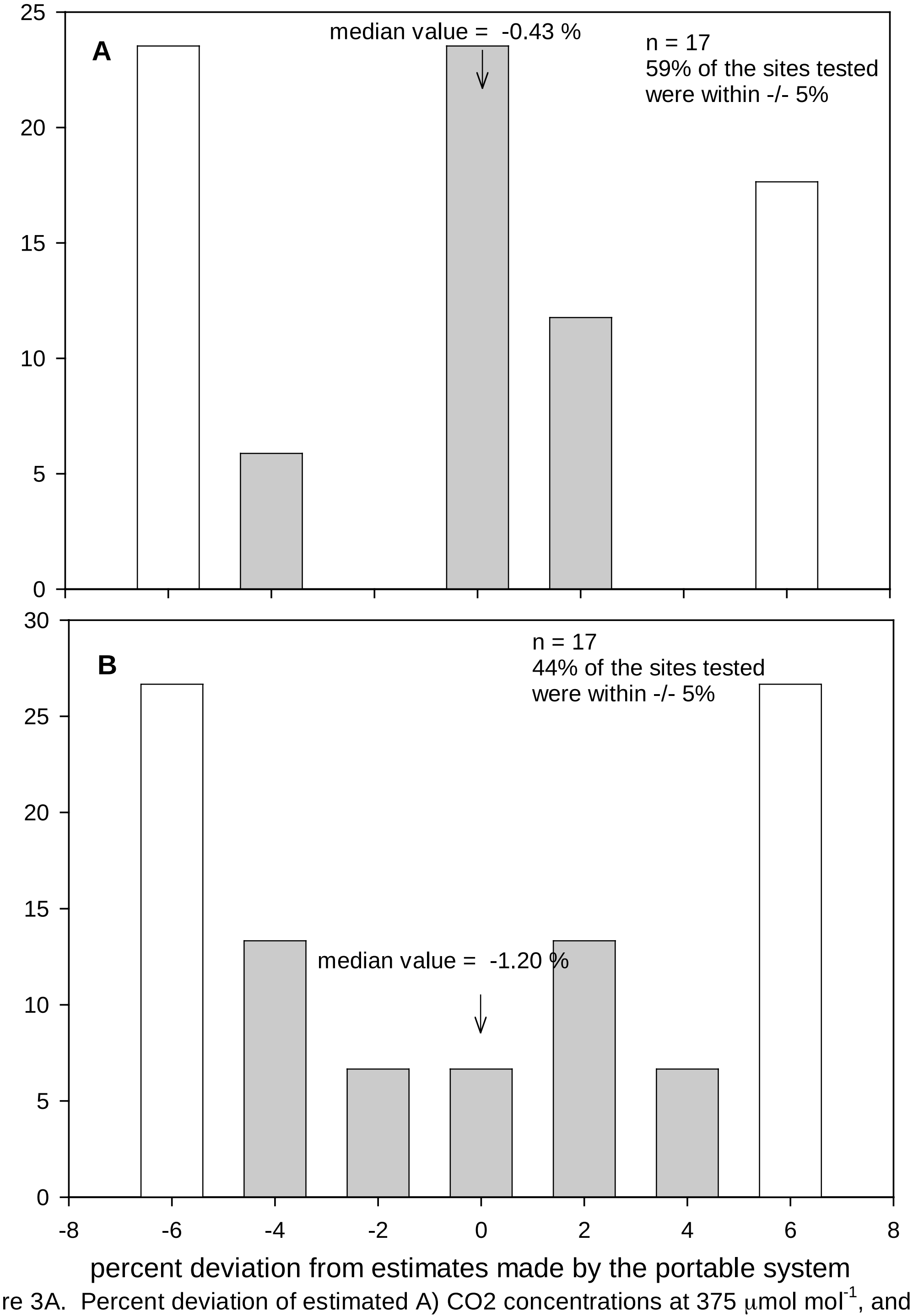

Figure 3A. Percent deviation of estimated A) CO2 concentrations at 375 μmol mol^{-1}, and B) water vapor at 20 mmol mol^{-1}, as determined through comparisons among AmeriFlux site instrumentation and the portable eddy-covariance system. Open-bars indicate calibration error from site instrumentation and have been resolved after the comparison.

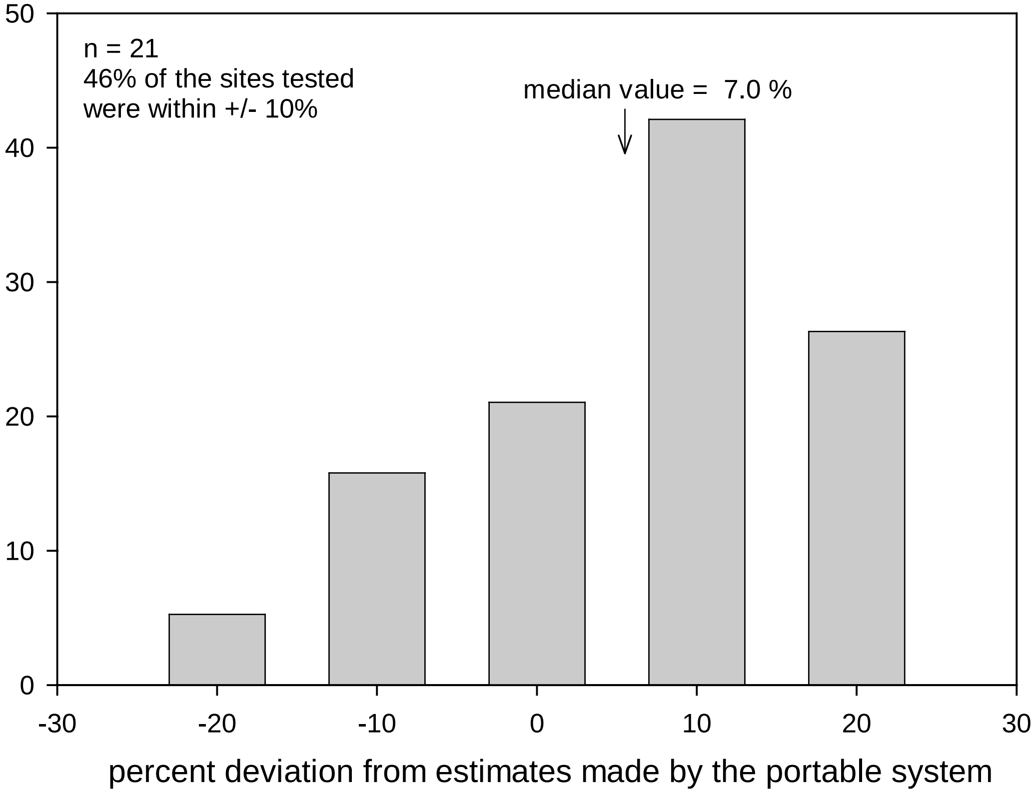

Figure 4A. Maximum percent deviation of u* at 0.6 m s^{-1} as determined through comparisons among AmeriFlux sites instrumentation and the new portable eddy-covariance system.

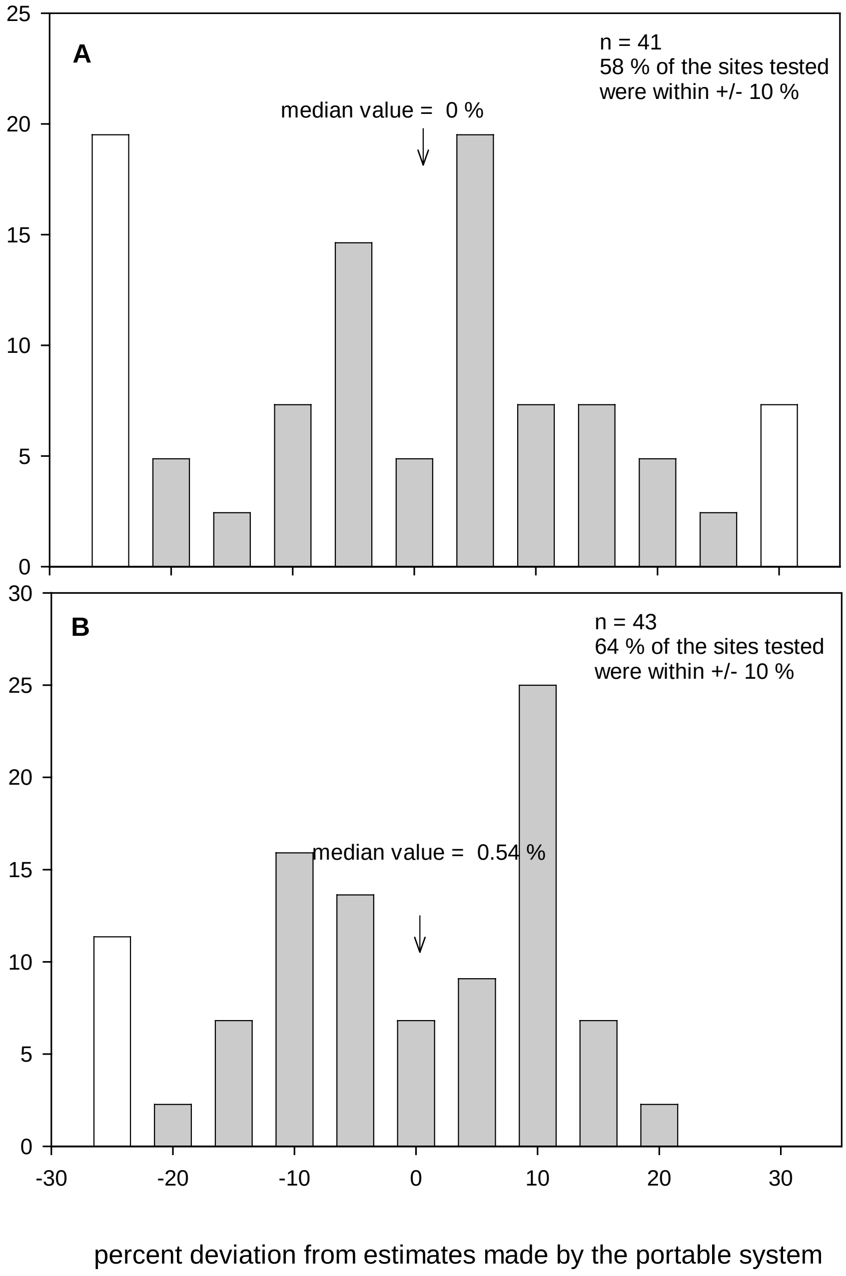

Figure 5A. Maximum percent deviation from energy flux estimates from the portable eddy covariance system among AmeriFlux sites, A) are λE calculated at 500 W m^{-2}, and B) are H calculated at 250 W m^{-2}. Open-bars indicate calibration error from site instrumentation and have been resolved after the comparison.

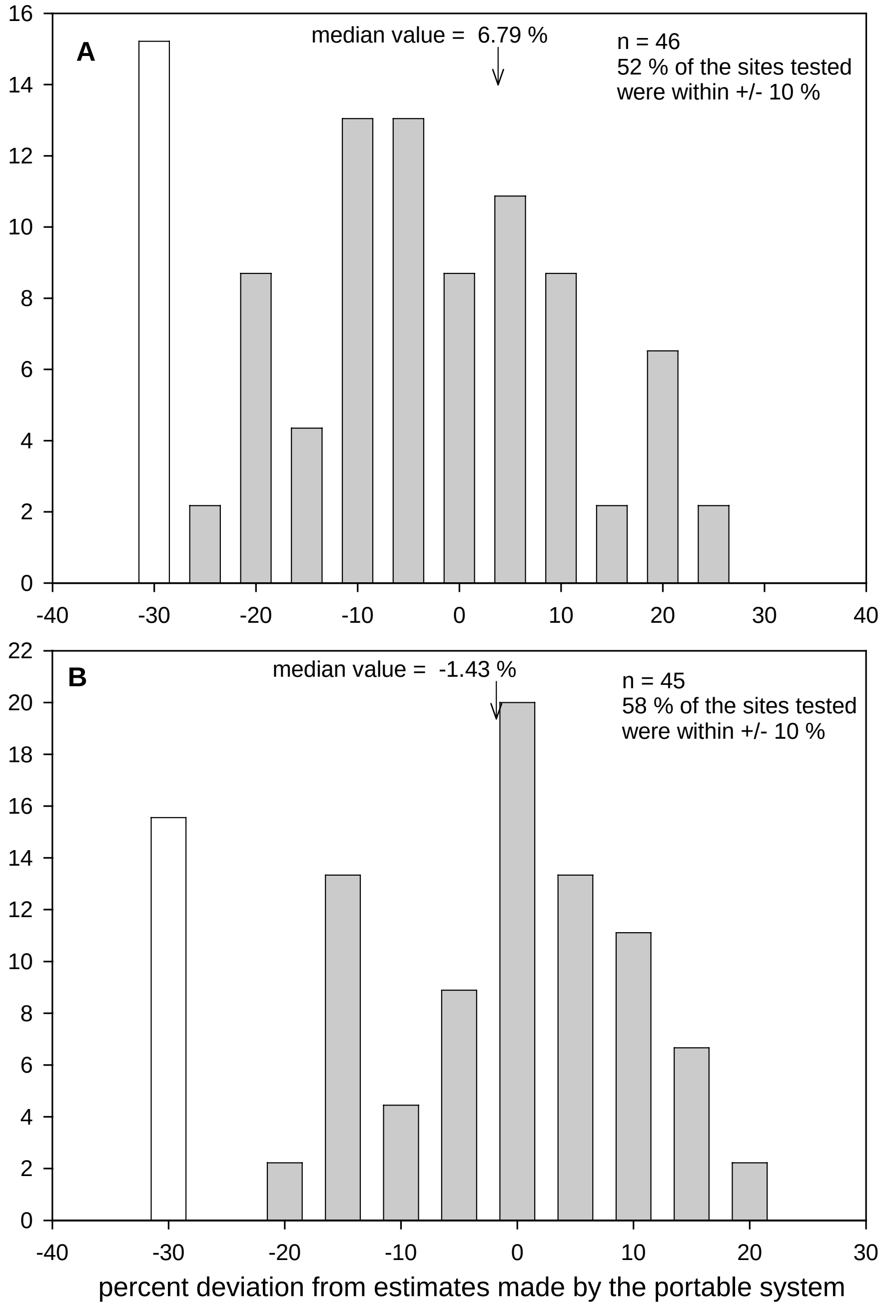

Figure 6A. Maximum percent deviation from carbon flux estimates from the portable eddy covariance system among AmeriFlux sites, where A) are calculated at 10 μmol m^{-2} s^{-1} efflux, and B) calculated at -20 μmol m^{-2} s^{-1} uptake.

10.0 Appendix B

Brief description of the two portable EC systems.

Hardware. Overall (low) frequency response of the older, original portable EC system introduces an uncertainty not desirable for a standard EC system. This was due, in part, by the resonance time in the cell, i.e., low flow rates, (~ 6.5 lpm), long sensor separation, and CO_2 and H_2O channels operating at ~ 9 and 7 hz, respectively. Assessment of data quality was also not available (i.e., spikes definition, zero drift, and quality flags from IRGA and ATI-sonic). The (lack?) of frequency response becomes apparent in comparisons with the open-path IRGAs that operate at ≥ 10 hz with little or no sensor separation. Separate (and dedicated) DAQ systems are needed for the IRGA, ATI-sonic and meteorological data collection. Other hardware limitations include; multiple power supplies, SAT is susceptible to transportation damage, and the overall design was not waterproof and did not lend itself to mounting on towers decreasing sensor separation (i.e., tube length).

Software. Reliable once configured for specific site conditions. But for quick analyses sometimes was cumbersome. For example, determining cross-correlations and lagtimes with confidence can take days. Moreover the software lacks the (quick) adaptability to incorporate new instrumentation and additional analyses.

From October 2003-February 2004, we designed and tested two new portable eddy covariance (EC) systems that incorporate both open- and closed-path infra-red analyzers (Li-7500, -7000, respectively), CNR-1 4-way net radiometer, Eppley PSP pyranometer, new aspirated shields, consolidating the data acquisition system to a single logger (CS-5000), and various other instrumentation that assist with the comparison. Changes include, mounting of the portable EC system on the tower to minimize tubing length for the closed-path, radiation shielding on the instrument box, and temperature, pressure, and flow controls on the closed-path sensor (more specific are described below). We have currently developing a simple, compact means to automate the CO_2 calibrations for the closed-path sensor (Ocheltree and Loescher, 2006). This system can be transferable to other sites wishing to assure high precision measurements of CO_2.

11.0 Appendix C.

Data Processing Performed by the AmeriFlux Data Archive at the Carbon Dioxide Information Analysis Center (CDIAC)

CDIAC receives data from individual AmeriFlux sites in several ways including submission by AmeriFlux investigators through e-mail, on mailed storage media, or by direct deposit to a File Transfer Protocol (FTP) server at CDIAC. CDIAC also obtains data from AmeriFlux sites using mirroring technologies where the AmeriFlux investigator posts data at their host institution and programming scripts written by CDIAC execute on a regular weekly schedule to download any new or revised files. The content and format of AmeriFlux data files received by CDIAC differ markedly. When data from an AmeriFlux site are received they are posted immediately on the CDIAC FTP server in their native file format. Old files are removed from the public server but are kept for permanent archival. All files are backed up on a routine basis and stored in two separate physical locations at Oak Ridge National Laboratory (ORNL).

The first simple check performed by the AmeriFlux data management team is to evaluate the basic condition of the data file (i.e., Can the data file be read? Does the file have a header or companion documentation file clearly stating the content of the file? Was the file(s) transferred completely? Does the file contain anomalous characters, blank lines, or truncated lines?) Once the basic condition of the files has been evaluated SAS codes are written to read all data and create working SAS data sets. During the writing of these codes, submitted data are translated and converted into common AmeriFlux-prescribed naming conventions, units, and reporting times. These working SAS data sets are then used to evaluate the quality and consistency of the submitted data and for comparison with data from other AmeriFlux sites.

After SAS working data sets are created standard threshold checks are performed for all submitted variables. Values outside expected ranges (Table 1D) are identified and confirmed in the original file(s). Results are summarized in a Web-compatible report (i.e., HTML file) generated using SAS Output Delivery Software (ODS) capabilities. In cases where obvious errors are identified values are immediately set to missing, with the changes documented in the SAS code, and new SAS working data sets created. The threshold checks code is then run a second time and the results of both runs are summarized.

The graphics phase of AmeriFlux data QA/QC at CDIAC produces time series plots for every variable over the entire period of record. Daytime and nighttime plots are also generated for a subset of variables using radiation data to differentiate between night and day. Property-property plots are generated (e.g., PAR versus global solar radiation) to confirm expected relationships. Histograms are generated to help assess sensible and latent heat fluxes and net ecosystem exchange estimates. All plots and histograms are reviewed with suspect values or for interesting trends to be evaluated further.

Another facet of the AmeriFlux data processing at CDIAC is to evaluate the length and continuity of the submitted data record. SAS codes have been written to identify and characterize gaps in AmeriFlux records for each variable. The codes identify the number of gaps for each variable and the average duration of each gap. Plots are then generated for each site which identify periods of data availability and gaps for key measurements (Figure 1D).

After completion of these steps, CDIAC then consults with the contributing investigator to resolve any data issues. CDIAC does not change any values, other than the obvious errors mentioned above, without the permission of the contributing investigator. Once all data issues are resolved, with changes documented in the SAS codes, the final SAS data sets and gap plots are created and incorporated into the AmeriFlux Web-based Data Viewing and Retrieval System (http://public.ornl.gov/ameriflux/data-access-select.shtml). This system serves as the primary mechanism to deliver quality-assured data with uniform naming conventions, units, and reporting times for the AmeriFlux network.

Table 1C. First-order range values used by the AmeriFlux Data Archive to evaluate AmeriFlux data.

Variable Definition and Name	Units	Lower/Upper Threshold
CO_2 flux (Fc)	umol/m2/s	-100/100
Sensible heat flux (H)	W/m2	-150/700
Latent heat flux (LE)	W/m2	-150/700
Water vapor flux (E)	mmol/m2/s	-10/15
Net radiation (Rn)	W/m2	-200/900
Relative humidity (RH)	%	10/100
Air temperature (Ta)	degrees C	-50/50
CO_2 storage in canopy (Sc)	umol/m2/s	-50/50
Global radiation (Rg)	W/m2	0/1200
Incoming shortwave radiation (Rgs)	W/m2	0/1200
Incoming longwave radiation (Rgl)	W/m2	200/300
Photosynthetically active radiation (PAR)	umol/m2/s	0/2200
Wind speed (WS)	m/s	0/40
Wind direction (WD)	degrees	0/360
Precipitation (PREC)	mm	0/20
Barometric pressure (PRESS)	kPa	600/1100
Soil CO_2 flux (SFc)	umol/m2/s	0/20
Soil heat flux (FG)	W/m2	-50/50
Soil temperature (Ts)	degrees C	-50/50
Soil moisture (SWC)	% by volume	0/60
CO_2 concentration profile (CO_2)	umol/mol	300/700
Friction velocity (UST)	m/s	0/20

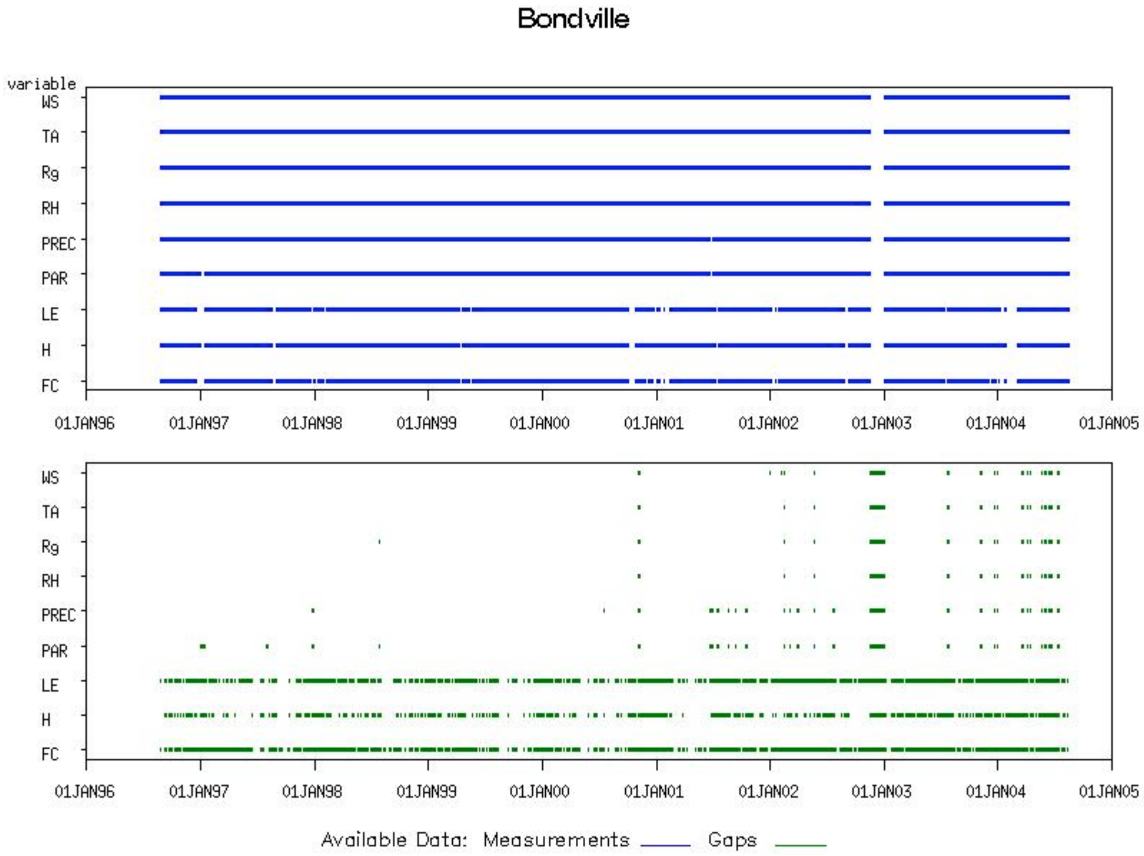

Figure 1C. A sample plot showing periods of data availability and gaps for key measurements from a specific site, in this case, Bondville IL.

12.0 Appendix D.

Brief description of the methodology used to determine spatial representativeness.
This new analysis (Hargrove *et al.* 2003) gauged how well the existing 59 active (AmeriFlux) tower locations sampled the different environmental regions present within the continental United States. Representativeness was calculated by determining how different each ecoregion in the continent was from the ecoregion containing the most similar AmeriFlux tower site. Because an earlier study was based on a general set of quantitative ecoregions produced statistically from a set of 25 maps of environmental conditions at 1 km2 resolution, was considered to be only a preliminary index of the representativeness of ecosystem type in the AmeriFlux network. Here, an updated analysis was made, based on a set of custom quantitative ecoregions constructed from flux-relevant characteristics.

Characteristics of nine alternative flux-ecoregions were created specifically for the purpose of analyzing representativeness of the AmeriFlux network (Hargrove and Hoffman 2004). Determined from 30 national 1 km2 maps, the nine flux-ecoregions were grouped based on the progressive inclusion of (1) abiotic (climatic and edaphic) factors only, (2) abiotic factors plus information on extant vegetation (remotely sensed from MODIS), and (3) abiotic factors plus extant vegetation plus derived indicators of ecosystem productivity (MODIS GNP and respiration). Thus, Tier 1 with only abiotic factors contributing towards the interpretation of flux-ecoregions reflect potential plant types, while Tier 2 and 3 flux ecoregions include information about natural and anthropogenic disturbance, which include the effects of urbanization and agriculture. Tier 3 data, while more sophisticated and inclusive, utilize a greater proportion of derived data, which in turn, contribute towards more uncertainty.

Data from each group was analyzed by season. Frost-free periods were identified for every 1 km2 cell in the conterminous United States and assumed to define the growing season (and by difference, frost periods were identified and assumed that no growth occurred during these periods). Each flux-relevant characteristic was then integrated over the different seasons and analyzes were conducted based on a) both growing and non-growing season, b) growing season only, and c) non-growing season only. Each of the nine alternative flux-ecoregions was created by statistically delineating the 90 most different ecosystem characteristics for the ecoregion of interest. For these initial analyses, the set of 3a flux ecoregions was selected with nine replicates.