REPORT 2011-2013

Enhancing the precision and accuracy within and among AmeriFlux site measurements

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No Cost Extension

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1.0 GOAL: Build cohesive network of research sites to quantify and understand carbon sources and sinks and the response of terrestrial ecosystems to climate and disturbance.

2.0 OBJECTIVE

The major objective of this project is to contribute to the AmeriFlux network by continuing to build consistency in AmeriFlux measurements by addressing objectives stated in the AmeriFlux strategic plan and self evaluation, the North American Carbon Program, and the US Carbon Cycle Science Program. The project directly contributes to NACP and CCSP goals to establish an integrated, near-real time network of observations to inform climate change science.

3.0 APPROACH

The specific project objectives were i) conduct 10-20 robust site comparisons each year, ii) separate uncertainties associated with site instrumentation and process software through the use of 'Gold-Files', iii) continually enhance and enforce the flux measurement guidelines, iv) develop and disseminate the current suite of roving standards to assist sites in maintaining internal QA/QC protocols, v) report findings to the AmeriFlux Science Chair and Steering Committee, vi) lead and develop synthesis activities across the network, vii) serve as a resource for measurement strategies among the network and other ad hoc, coordinated QA/QC activities, and viii) handle logistics of the annual AmeriFlux Meeting.

In addition, we continued to address four specific recommendations made in the AmeriFlux internal evaluation report 2005 (and supported by the AmeriFlux steering committee and the TCCRP final report, Running *et al.* 2005): i) Provided additional roving temperature standards to each research group for calibrating their systems (High Priority); ii) provided a photosynthetic photon flux density (PPFD) sensor to each research group as a standard that is kept in the site lab, maintained annually by the AmeriFlux QA/QC lab, and maintain all calibration records in a our repository (High Priority); iii) provide all research groups not currently using the World Meteorological Organization-NOAA Global Monitoring division (WMO-GMD, formally CMDL) standards with (2) 'archival' CO2 standards approximately 10 ppm apart in concentration within the range of ambient concentrations, and with an ensemble uncertainty of +/- 0.12 ppm, (High Priority), and iv) explored an appropriate means to automate H2O calibrations for all IRGAs (High Priority).

Our primary activity was comparison of data from the AmeriFlux portable EC system (PECS) and individual AmeriFlux/NACP sites. We prioritized selection of sites we would visit each year by i) existing sites that had not been evaluated for more than three years; ii) sites located in the mid-continental US in support of the NACP mid-continent intensive; iii) recently established sites that were initiated as part of the NACP, iv) sites where more than three years have passed since the last comparison. We made the NACP regional projects a high priority to ensure coherency of flux site data quality within each region and reduce uncertainty in the synthesis of flux and meteorological data within each region.

Our instruments were calibrated in our QA lab between the site visits. We derived our own IRGA polynomials rather than use those provided by LiCor, which helped us to achieve higher accuracy and precision (see Ocheltree 2007 for a detailed description). We encouraged the PIs to provide processed data while the site visit was underway to allow us to perform preliminary analyses. This improved the quality and amount of data we had available for analysis after the site visit.

We communicate directly with individual site PIs through the process of evaluating their data quality, and iterate until we feel they address issues we found with their measurements or data processing. General communication with AmeriFlux investigators is conducted through the AmeriFlux list server, conferences and development of web-based materials for the AmeriFlux web site at Oak Ridge National Lab.

4.0 RESULTS – PROGRAM DEVELOPMENT

Design, development and deployment of new portable eddy covariance system

The portable eddy covariance systems (PECS) were redesigned by C. Hanson in 2008. Changes include improved temperature control, system diagnostics and a remote data link. Performance and reliability of the new PECS are significantly improved over the old system.

In 2010-2011, we installed the new hybrid LI7200 CO_2/H_2O infrared gas analyzer in both roving systems. The enclosed design leads to minimal data loss during precipitation events and icing, and it does not have surface heating issues. The new design also has good frequency response due to small flux attenuation loss in the short intake tube, does not need frequent calibration, has minimal maintenance requirements, and can be used in a very low power configuration. Another important feature is the measurement of CO_2 dry mole fraction. This instrument is well-suited to the design of our roving systems.

Data processing

A previous QA/QC person (2004-2006) used a canned data processing program, EdiRe, but the program was not flexible enough to deal with different data processing needs for robust site comparisons. C. Thomas (Asst. Prof. at OSU) developed Matlab data processing software (TerraFlux_process.m) that is much more flexible and consistent with QA standards in Carbo-Europe. J. Kathilankal subsequently modified the Matlab software in 2009-2010 to include new corrections and options. The program now incorporates corrections for spectral attenuation for line averaging, block averaging and tube attenuation (for closed path IRGA), based on the analytical method of Massman (2000). It also incorporates options for using a constant pressure in flux calculations. The modified program was tested against the gold-file outputs from EdiRe under specific conditions and results indicated differences less than 5 percent. The program is fully tested and is in use for all site comparisons.

Use of Gold-files

Systematic errors between those from instrumentation and software routines can be identified through the comparisons of the AmeriFlux standards and individual sites using the same, independent raw data file, *i.e.*, Gold-file. Gold-file data sets and instructions for both closed-path and open-path IRGAs were updated in 2009 and can be found at http://public.ornl.gov/ameriflux/gold-closed_path.shtml and http://public.ornl.gov/ameriflux/Standards/Open_path_gold_intro_020209.doc. AmeriFlux sites have used the closed-path and open-path 'Gold-files,' respectively (~50 percent of the research groups). Many research groups outside AmeriFlux are also using our Gold-files to standardize their data process procedures (e.g. Japan, Canada, Argentina).

Development of roving standards

Temperature standards. We recalibrate our four temperature standards annually and send them to sites on demand. Our temperature standards have agreed well with observations by NOAA's calibration facility (Oak Ridge, TN); the differences were < 0.1 deg. C. Our temperature standards have visited 12 sites with observed errors ranging from 0 to 3.2 deg C. This has improved quality of air temperature measurements at sites.

Photosynthetic Photon Flux Density (PPFD) and new AmeriFlux PPFD sensors. High quality PPFD measurements are critical for data comparability in synthesis efforts, and for NACP and global modeling activities. PPFD sensors (LiCor 190 series) have been notorious for degradation and drift, and do not calibrate to the ISO Global Clear Sky standard. Other networks do not directly measure PPFD, so it is a critical measurement that AmeriFlux provides to a large scientific community. The DOE-AmeriFlux internal review (Law *et al*. 2004) and the independent TCCRP report (Running *et al.* 2005) recommended improvements to the quality of PPFD measurements. We now use a NIST-traceable standard calibration lamp, K&Z PAR-lite sensor and an established methodology that is more comprehensive than preformed by LiCor and Kipp & Zonen (K&Z). K&Z PAR-lite estimates are 2-4% lower than *true* values, and LiCor estimates are 5-10% below *true* values. Each year we calibrate ~ 40 individual PAR-lite sensors and ship one to each AmeriFlux research group as a standard to keep in the lab for cross-calibration of field sensors. All data from the comparisons and annual calibrations are kept in our data archive to track issues with sensor drift and maintain traceability of measurements. Follow-up correspondence with each research group is ongoing to determine how old calibrations compare with the new in-house standards. We continue to communicate with manufacturers about standardizing PAR calibration because current methods result in unacceptably large discrepancies.

Development of Network-level Secondary CO2 standards. We provide secondary standards to AmeriFlux research groups that do not currently use WMO-GMD primary standards. Improperly calibrated gain functions are one of the primary systematic sources of uncertainty. The AmeriFlux QA/QC lab makes secondary CO2 standards to within ±0.3 ppm (Li-7000 IRGA), and to within ±0.16 ppm (ESP-1000).

HO vapor calibration

Similar to CO2 measurements, differences in network wide H2O measurements show a large range (+/- 15 %) and in latent heat show a strong non-Gaussian distribution, suggesting significant differences in IRGA gain functions (*i.e.*, unaccounted for sensor drift). Eddy covariance estimates of latent heat are subject to calibration error and unaccounted for sources of error due to sensor drift. Real-time, automated, *in situ* water vapor calibrations are difficult to make because water vapor cannot be delivered to the IRGA under negative pressure, or at the same flow rates as when sampling. We developed a statistical method using a chilled mirror and averaged ambient H2O measurements to provide daily corrections to IRGA gain functions (Loescher, H.W., Hanson, C.V., Ocheltree, T.W., 2009). Similar methods using chilled mirrors are currently used at some sites. For our site comparisons we have decided to perform frequent manual calibrations using LI-610's that are calibrated against our NIST traceable chilled mirror in the QA/QC lab. This choice was made due to the short and intensive nature of our site visits which allow frequent calibrations and to minimize the cost and complexity of deploying accurate chilled mirrors as part of the PECS.

Maintain and update flux measurement and SOP guidelines

We developed flux measurement guidelines (2005) that meet precision and accuracy requirements of network science objectives. The guidelines include tower placement, eddy covariance flux estimates, profile systems, data acquisition and processing, and calibration procedures. In 2009 the guidelines were updated on the AmeriFlux web site (http://public.ornl.gov/ameriflux/measurement_standards_020209.doc). We also updated the standard operating procedures (SOPs) for calibration of temperature sensors and IRGAs. The new SOPs, 'Calibration of PAR sensors' and 'Secondary CO2 standard mixing and calibration' were also added to the web in 2009 (http://public.ornl.gov/ameriflux/sop.shtml). In 2012 S. Chan thoroughly updated, documented and provided up references for the processing steps and corrections we use and posted them to the AmeriFlux website.

Coordination of QA/QC activities

To enhance the data quality for both meteorological and scalar measurements across the network, we: i) enforce measurement guidelines and use of Gold-file, ii) provide our roving standards of PT100 temperature sensor and CO2 standards to site for in-house comparisons, iii) stress importance of aspirating temperature measurements, and iv) analyze data and present results of a quick comparison at each visited site, and iterate with PIs to correct problems. We continue this approach to address measurement issues with PPFD sensors, incident and net radiation sensors, anemometers and IRGAs. We coordinate activities throughout the network to enhance communication and quality assurance. These activities evolve and now include archive of site visit documents and photos at CDIAC (Oak Ridge National Lab).

4.1 RESULTS

Accomplishments FY2012 – 2013 (no-cost extension period)

A total of nine AmeriFlux site intercomparisons were conducted during the 2012 field season with reports submitted to PI's. One additional gold file comparison was conducted for Dr. Jeffrey Geddes in the Department of Chemistry, University of Toronto. We successfully published the network level error analyses paper that was in prep during the last report and presented the study as a poster at the DOE TES PI meeting in April, 2012. The results were also presented in a poster at Asia flux, 2013 in Korea by the new LBNL team. The specific findings of the error analysis are described in Schmidt et al. (2013) and in detail below. At the 2012 DOE-TES meeting we also presented a second poster outlining the current QA/QC activities.

At the end of 2012, we began the transition of AmeriFlux Network Management from OSU to Lawrence Berkeley National Lab, and moving the QA/QC program to LBNL. To help ensure the ongoing success of the project, the OSU team actively participated in the transition of the QA/QC lab. The OSU team helped design the next generation of portable eddy covariance reference systems for use during the 2013 field season. In April of 2013, we participated in an intercomparison of the new and old systems at Dennis Baldocchi's Sherman Island flux site to make sure we established a good benchmark of the new systems and to complete a current intercomparison of the site. The intercomparison was very successful in general and a detailed report from the LBNL team should be forthcoming. We trained and advised the new QA/QC team on site visits and reports. Chad Hanson from OSU conducted 2 site intercomparisons (Willow Creek, WI, and Rosemount, MN) during the 2013 field season to help maximize the number of sites visited in the first year of the LBNL QA/QC program.

To ensure the LBNL calibration facilities are up and running quickly and capable of the highest precision and accuracy, Chad designed and built a new calibration gas blending facility at LBNL that is in the final testing and validation stages. OSU has continued to perform PAR and secondary CO_2 standard preparation for distribution to the network.

2013 Publication Findings

In Schmidt et al. 2012, we presented the relative instrumental errors from the AmeriFlux QA/QC site intercomparisons of 84 site visits (2002 – 2012). Relative errors, including random and systematic instrumental errors, are presented for meteorological and radiation variables, gas concentrations, and the turbulent fluxes. The lowest relative errors (< 2%) were found for the meteorological parameters while the largest relative errors were found for latent heat and CO_2 fluxes. The mean relative instrumental error for CO_2 flux averaged -8.2% (underestimation by the tower instruments). Sensible and latent heat fluxes exhibited mean errors of -1.7% and -5.2%, respectively. Deviation around the mean was largest for the turbulent fluxes, approaching 20%. Because the data collected during QA/QC site visits are used to identify and correct errors, our results represent a conservative estimate of instrumental errors in the AmeriFlux database. Overall, the presented results confirm the high quality of the network data and demonstrate the value of the intercomparisons as data source for the research community.

During the 2011 field season, we visited the Coweeta AmeriFlux site in NC, which had recently acquired the new EC 155 gas analyzer system from Campbell Scientific. The data from our site visit was used as part of an assessment of spectral properties, elimination of density corrections by computing fluxes from mixing ratios and wet weather performance of the new short inlet closed path IRGAS at the site and the competing LI-COR sensors in in our reference system. The results of this study were published in November of 2013 (Novick et al., 2013).

Site Visits- Executive Summary

Site report summaries contain sensitive information and a description of the site visits during the 2012 and 2013 field season was submitted separately to the program manager.

4.11 Network Level Assessment

A total of 5 sites were visited during the 2011 field season, one completed in 2012 at the time of this report, with 9 planned for the 2012 season. S. Chan joined the group in August of 2011 and completed his training in fall 2011. A few PIs have not provided their data from the site visit in a timely manner. A typical comparison of the roving system with site measurements includes the fluxes, scalar concentrations and meteorology. More extensive analysis is conducted if QA/QC issues are found in the preliminary analysis that takes place during the site visit. Regression analysis is used for the comparisons and to deduce site performance. Because instrumentation varies from site to site, percentage differences are calculated from a fixed value for each variable. The statistics presented here represent 83 site visits from 2002 through 2011 and are part of a paper in preparation analyzing network level uncertainty (see publications below).

Air temperature: The mean relative error among sites averages 0.24 deg C.

Horizontal wind speed: The mean relative error of wind velocity estimates observed for all the sites is 0.79 +/- 6.83 percent.

PAR. The mean error of PAR observed across all sites is -3.39 +/- 14.05 percent, which is significant in terms of the light compensation point for photosynthesis.

Net Radiation (R_n). The mean relative error of net radiation estimates across AmeriFlux sites is -3.68 +/- 8.23 percent

Scalar density measurements. The mean relative error of the network CO2 measurements is -0.37 +/- 3.18 percent, making the differences in gain function among sensors a real and identifiable source of systematic error. The SD for water vapor density estimates across the network is 2.25 +/- 9.51 percent.

Latent and sensible heat fluxes. The mean relative error for sensible heat is -1.27 +/- 10.27 percent and -4.90 +/- 16.87 percent for latent heat flux.

Carbon fluxes and friction velocity.
The mean relative error for FC is -6.75 +/- 17.63 percent while friction velocity is -3.84 +/- 7.82 percent. Calibration issues continue to be detected and include problems associated with the actual IRGA polynomials, field calibration techniques, accuracy and precision of secondary standards, and infrequent field calibrations. The AmeriFlux QA/QC lab is addressing these issues, as noted earlier.

4.12 New instrument tests

During 2011 we conducted an intercomparison between the new Campbell Scientific EC 155 and 150 open and closed path IRGAS and the LI-COR 7500 and 7200 open and closed path IRGAs. Analyses of the results are ongoing in cooperation with manufacturers. We also participated in the publication of a paper titled "Fast mixing ratio computations of CO2 and H2O eddy covariance fluxes from an enclosed gas analyzer" and presented the same in a poster at the 2011 AmeriFlux/NACP meeting.

4.13 Other achievements

We collaborated with flux sensor manufacturers including Picarro (San Mateo, CA), LI-COR (Lincoln, NE), and Campbell scientific (Logan, UT) to help develop and identify application appropriate technologies for the flux community.

We gave two posters "Overview of AmeriFlux QA/QC Lab Activities" and "Empirical Assessment of Uncertainties in the AmeriFlux Network" on QA/QC progress at the DOE TES PI's meeting in Washington D.C in April 2012. The Second poster was a summary of a paper in preparation which will be submitted in the next month.

Site visit map

We continue to use the electronic site comparison map that became available in March 2008 to plan our field visits (http://bwc.berkeley.edu/Amflux/MapsComp/). This map was developed by LBNL in conjunction with our lab, and it has been immensely useful.

5.0. PERSONNEL

PI. Beverly Law- Responsible for overseeing the QA/QC activities, including identifying areas for improvement, and communicating input from the AmeriFlux steering committee to the QA group.

Post-doc, Andres Schmidt- started working September, 2009, QA post-doc responsible for site visits and reporting.

Post-doc, Stephen Chan –started working August 2011, QA post-doc responsible for site visits and reporting through February 2013.

Lab Manager, Chad Hanson- M.S. degree. Facilitates intercomparisons. Duties include all laboratory calibrations, QA/QC and maintenance for portable EC instrumentation; document the calibration traceability from PECS instrumentation, shipping and receiving of roving instrumentation and gas samples, and assisting the processing of raw flux data. He and the two post-docs conduct synthesis research that enhances our understanding of uncertainty in network-level flux estimates.

6.0 FACILITIES AND EQUIPMENT

Lab space is provided by the College of Forestry, Department of Forest Science, Oregon State University, Corvallis, Oregon. Field space to test and calibrate instrumentation is provided by the Crop and Soils Department, Hyslop Field Research Lab, Corvallis, OR. In addition to the equipment listed in Table 1, the AmeriFlux QAQC lab utilizes (2) li-6262 IRGAs (Li-Cor, Lincoln, NE), (2) CNR 1 net radiometer. (Kipp and Zonen, Delft, Netherlands), (2) PAR LITE quantum sensor, (2) CR-5000 data loggers (Campbell Scientific, Logan UT), (2) CR-23x dataloggers (Campbell Scientific, Logan UT), (2) li-610 dew point generator, (1) digital multitester (Keithley Instruments Inc., Cleveland OH), (1) Polystat precision water bath (Cole Parmer, Vernon Hills, IL), (1) D2 chilled mirror sensor and Optica monitor (General Eastern, Bussum Germany), (1) gallium cell standard (NIST, Gaithersburg, MD), secondary gas standards (Scott Specialty Gases, Wakefield, MA), in-house fabricated automated gas calibration unit used for secondary tanks and for IRGAs.

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Empirical assessment of uncertainties in the AmeriFlux network. Schmidt, A , C. Hanson, W. S. Chan, B. E. Law.. DOE-TES PI meeting, Washington D.C., 2012.

Overview of AmeriFlux QA/QC lab activities. C. Hanson, Schmidt, A ,W. S. Chan, B. E. Law. DOE-TES PI meeting, Washington D.C., 2012.

2011 Posters

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Networks (used high quality long-term data of 56 sites from the AmeriFlux network; associated paper was published in Agric. For. Meteorol., 2011).

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