WRITTEN TESTIMONY OF
DR. BEVERLY LAW
PROFESSOR, DEPT FOREST ECOSYSTEMS & SOCIETY
SCIENCE CHAIR OF THE AMERIFLUX NETWORK
OREGON STATE UNIVERSITY

HEARING ON
"MONITORING, MEASUREMENT AND VERIFICATION OF GREENHOUSE GAS EMISSIONS II: THE ROLE OF FEDERAL AND ACADEMIC RESEARCH AND MONITORING PROGRAMS"

BEFORE THE
COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

April 22, 2009

Introduction. Good morning Chairman Gordon, Ranking Member Hall, and other Members of the Committee. I am Dr. Beverly Law, Professor of Global Change Forest Science at Oregon State University, and Science Chair of the AmeriFlux network. Thank you for the opportunity to appear before you today to discuss the AmeriFlux network, and the potential to quantify GHG fluxes from natural or managed ecosystems with respect to potential mitigation strategies and advancing carbon cycle science.

Purpose and Status of the AmeriFlux Network. AmeriFlux was initiated in 1996. It currently consists of 90 research sites that measure biology properties, meteorology, and carbon, water vapor and energy exchanges between terrestrial ecosystems and the atmosphere. The sites are in different vegetation types, climatic conditions, and stages of response to natural events and management. Most of the sites are in the lower 48 states, with a few sites in Alaska, Central and S. America (Fig. 1). Similar networks exist on other continents and are loosely coordinated thru FLUXNET (Baldocchi 2008), with over 500 sites from the tropics to high northern latitudes.

The aim of AmeriFlux is to:

- quantify and explain the amounts and variation in carbon storage and the exchanges of carbon dioxide, water vapor and energy at multiple timescales, and
- provide systematic data and analysis that has value for monitoring climate variables and change in terrestrial ecosystem processes in response to climate, land use and management

The AmeriFlux records are now 7-15 years in length and continuation is essential for understanding long-term trends in ecosystem response to climate and management. Support for AmeriFlux is currently provided on a site-by-site basis, and is funded by multiple agencies, with DOE funding about half of the sites. Some long-term, high-quality records are endangered by lack of continued support. Most of the sites are run by academic researchers.

The network plays a major role in the North American Carbon Program (part of the US Climate Change Science Program), where flux data are used to test model assumptions, or to optimize models and apply them spatially. The models also require inputs of remote sensing data on land surface characteristics (Law et al. 2004). Carbon cycle and climate system modelers use the flux data to characterize terrestrial sources and sinks for carbon, effects of climate and land use change on ecosystem fluxes, and effects of ecosystems on climate.

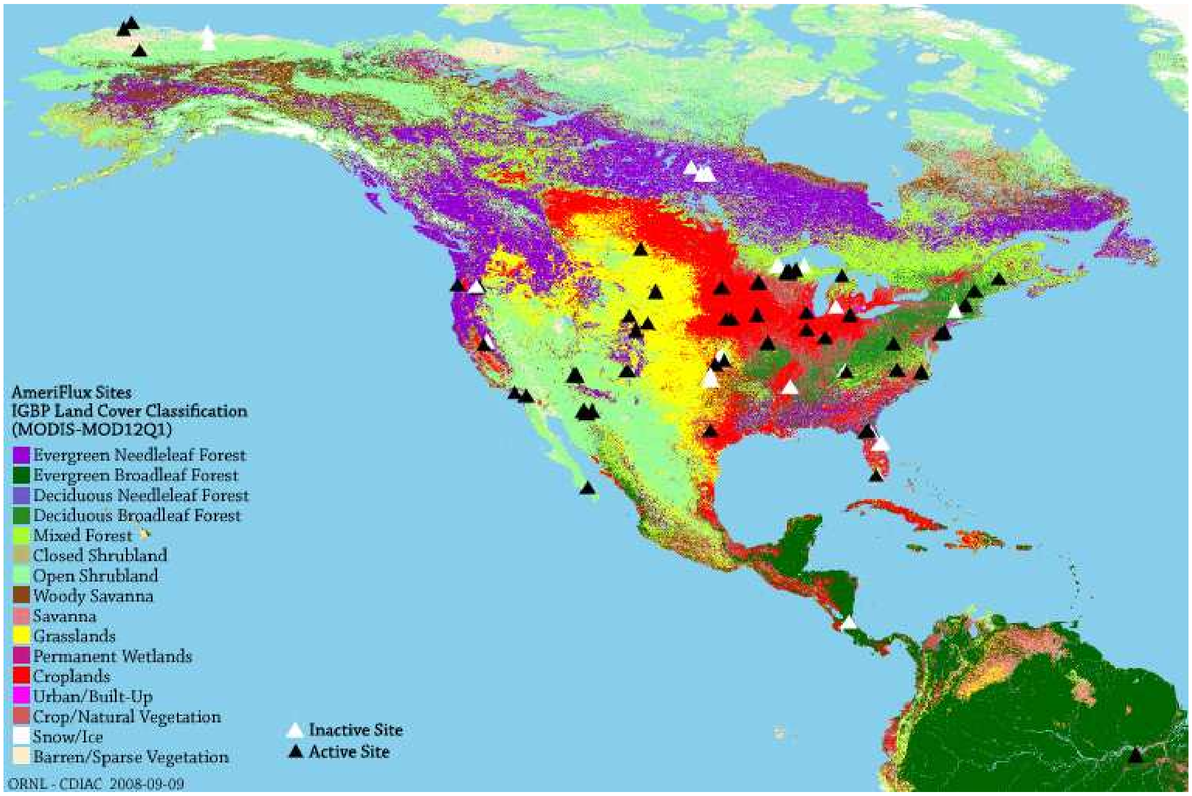

Figure 1. Current status and distribution of AmeriFlux sites

Potential to Improve Understanding of the Carbon Cycle and Accuracy of GHG Inventories. The AmeriFlux network has great potential to improve understanding of the carbon cycle, and land-based contributions to greenhouse gases (GHG). Response of ecosystems to management can be detected by AmeriFlux measurements, which provide direct measurements of net carbon dioxide exchange at the stand-scale that represents the integrated effect of various ecosystem processes. The area coverage of a flux site is the appropriate scale for understanding the effects of climatic events and management activities on terrestrial sources and sinks, such as the outcome of mitigation strategies. For example, the effects of thinning 30% of tree biomass in a forest stand were evaluated using net carbon dioxide exchange measurements in the years before and after the thinning (Misson et al. 2006).

Models optimized with flux data can be used to test scenarios of response to mitigation actions. Mitigation actions cannot be detected by top-down methods that incorporate atmospheric CO_2 concentration observations, but this role can be filled by AmeriFlux, which was designed to be a land-based observation network.

Long-term flux data at individual sites show trends that allow one to identify the relative importance of factors influencing carbon uptake. For example, at Harvard Forest, annual net carbon uptake over 15 years has averaged ~2.5 tons carbon/hectare/year, and has increased at an average rate of ~0.2 tons carbon/hectare/year. The 15 years of data track changes in net carbon uptake driven by long-term increases in tree biomass, successional change in forest composition, and climatic events, processes not well represented in current models (Urbanski et al. 2006). Along with the energy fluxes, the data have proven valuable in evaluating and improving carbon cycle and climate system models, as indicated in many publications and model comparisons.

The potential to improve accuracy of GHG inventories relies on increasing the density of GHG measurements across the continent. A small subset of AmeriFlux sites measure well-calibrated carbon dioxide concentration profiles in an above the vegetation canopy, and more sites could be augmented. These data would improve the density of GHG concentration measurements made by NOAA over the continent so that it might become possible to resolve regional GHG sources and sinks.

Potential to define reliable baselines of GHG fluxes from natural or managed ecosystems. The most effective tool to measure the effect of natural events and management at annual timescales is an array of flux sites. The most powerful tool to produce spatial estimate of GHG fluxes from ecosystems is a bottom-up process model that ingests these data. A bottom-up approach starts with measurements where the action is taking place. For example, a regional project uses observations from forest and agricultural inventories, AmeriFlux sites, and Landsat data in a process model to produce estimates of terrestrial carbon stocks and fluxes for every square kilometer (Law et al. 2004, 2006). The model grows forests after disturbances and data compare well with forest biomass from inventories. This type of approach can be applied across the U.S. to track changes in terrestrial sources and sinks at a resolution appropriate for the scale of spatial variability that exists. The output of bottom-up process models could be used in CarbonTracker to improve its estimates of the terrestrial contributions to observed greenhouse gas concentrations.

The potential of the network to define reliable baselines of sources and sinks in the US is high in the near future, but it will require enhancements and a more coordinated effort of the different science communities and agencies. The coordination could be improved through the North American Carbon Program (NACP), part of the Carbon Cycle Science Program.

Internationally, the potential to define baselines of GHG fluxes from natural or managed ecosystems using tower flux measurements is low in the next few years. The distribution of sites is variable, with a sufficient density of sites in Europe and Japan, but no sites in some countries. China and India recently started their own networks. In the past 10 years, the global network of sites has mushroomed from about 100 sites to over 500 flux sites in the regional international networks, so it is possible that the status will change quickly. However, continuity of existing observations remains threatened in some countries, like Canada. In addition, it requires technical expertise both in instrument maintenance and data analysis that isn't likely to be available everywhere.

Additional resources required to develop and sustain a robust carbon monitoring system. This is something that is required; the details are yet to be determined. It would be necessary to enhance the AmeriFlux network, intensify the CO_2 concentration network, enhance the crop and forest inventory programs, ensure continuity of critical remote sensing data, provide more resources for coordinated data management systems for data assimilation, and accelerate analysis of available data for more comprehensive modeling and assessment.

Continuity of the AmeriFlux sites needs to be ensured. Improvements in the AmeriFlux network would require adding new sites in underrepresented biomes, eco-climatic regions, and early stages of forest growth following disturbance events and management/mitigation actions. In 2005, an analysis indicated locations where new towers were needed (Fig. 2 and Hargrove et al. 2003); gaps have since been filled in the SE and SW US. Sites should be enhanced with measurements of methane fluxes, another carbon source from land surfaces. New measurements could include isotopes for distinguishing sources and well-calibrated CO_2 concentration measurements that could augment NOAA's GHG observations. The required resources for a robust monitoring system are the same as if the primary purpose of the network remains focused on carbon cycle research.

More resources are needed for AmeriFlux data management to serve a broad user community. Increased computational resources are needed for data processing and modeling for regional, continental and global scale analysis (e.g. distributed computer clusters, and time on a super computer).

Many of the products needed for integrating AmeriFlux observations with other data and models are provided by individual investigators or programs with other missions, some with significant lags (years) in data availability and others lacking continuity. Additional resources are required for more rapid delivery of upstream data products that are critical to modeling and assessment, such as the State of the Carbon Cycle Report (CCSSP 2007). Examples are Landsat data products, spatially derived weather data, and inventory estimates of biomass and productivity.

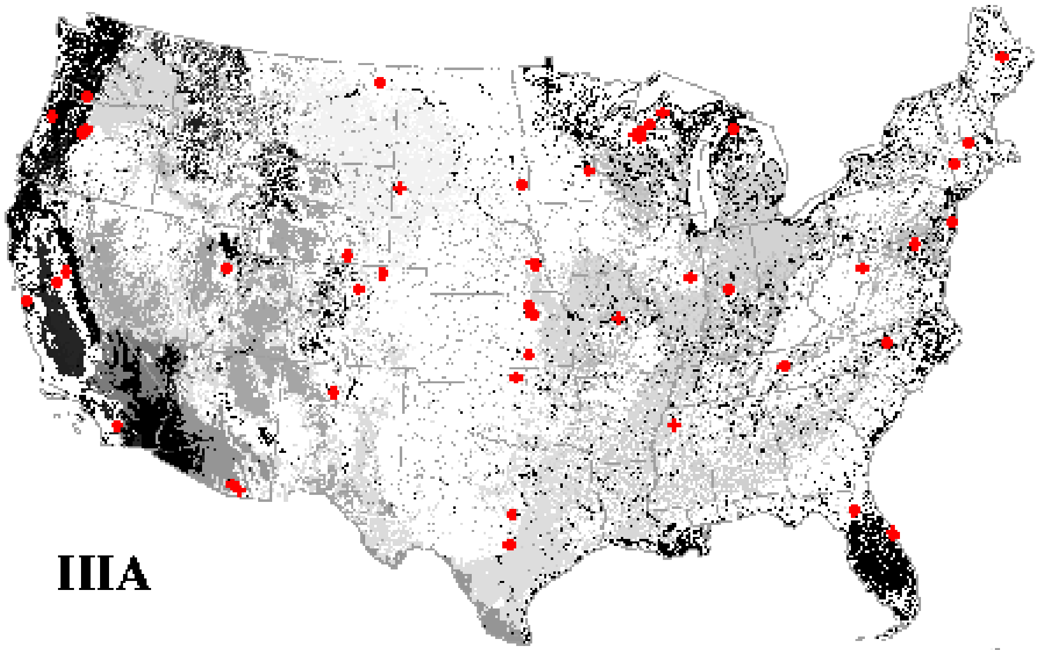

Figure 2. Representativeness of AmeriFlux sites of major biomes and climate zones in 2005. The black areas show the Pacific Northwest, Sierra Nevada Mountains, and Sonoran desert region were poorly represented by the AmeriFlux towers in 2005. Since then, sites were added in the SE and SW US. (http://www.esd.ornl.gov/research/terrestrial_ecology/carbon_flux_ecoregions.shtml).

Relationship between academic community involved in carbon cycle research and regional to continental mapping of fluxes of GHG, and the federal agencies supporting this work. There are existing mechanisms for communication between the academic community and the federal agencies supporting the work. The academic community involved in NACP projects is using the range of observation networks and models to produce maps of fluxes of GHG. The observation and modeling communities are represented on the steering groups. The Science Steering Groups of the NACP and Carbon Cycle Science Program meet a couple of times a year with the program managers in the Interagency Working Group. This has proved to be an effective way for scientists to discuss current gaps in observations or knowledge, and future research needs. The challenge is in responding to these needs in a timely manner.

Mechanism for Coordinating Efforts with Other Nations to Better Understand Carbon and GHG. A mechanism for coordinating observation networks among nations could build on the NACP and the Integrated Carbon Observation System (ICOS), a new European Research Infrastructure for quantifying and understanding the greenhouse balance of the European continent and of adjacent regions. ICOS aims to build a network of standardized, long-term, high precision integrated monitoring of (1) atmospheric greenhouse gas concentrations to quantify the fossil fuel component; (2) ecosystem fluxes of carbon dioxide, water vapor and energy and ecosystem variables (http://icos-infrastructure.ipsl.jussieu.fr/). The ICOS infrastructure would integrate terrestrial and atmospheric observations at various sites into a single, coherent, highly precise database, which would allow a regional top-down assessment of fluxes from atmospheric data, and a bottom-up assessment from ecosystem measurements and fossil fuel inventories. This is similar to aspirations of the US North American Carbon Program (NACP).

One of the activities of the North American Carbon Program is ongoing coordination with Canada and Mexico on carbon observations and modeling. Here, the framework and science plan are under development, but again, there aren't enough resources for a high degree of coordination. Additional support necessary to ensure that data collected by different nations are comparable includes institutional support for coordination of observation systems, interchange of standards, and development of curated, active data management systems for data assimilation.

Within the frameworks of NACP/ICOS, a mechanism for coordinating tower flux work with other nations is the scientific bodies FAO Global Terrestrial Observing System – Terrestrial Carbon (GTOS-TCO) and FLUXNET. These frameworks exist, but there isn't enough support for a high degree of coordination. GTOS is supported by the Food & Agricultural Organization, and the role of GTOS-TCO is to organize and coordinate reliable data and information on carbon, linking the scientific community with potential end users. One important recent product is the guidelines for terrestrial carbon measurements and global standardization of protocols for submitting data to a database for international comparisons (Law et al. 2008).

The FLUXNET project is a "network of regional flux networks," serving a synthesis coordination role rather than primary data collection. The intent is to stimulate regional and global analysis of observations from tower flux sites. It is operated from the U.S., and has functioned intermittently depending on grants (http://www.fluxnet.ornl.gov/fluxnet/index.cfm). Through FLUXNET, we produced a global database using the data standardization protocols we developed for AmeriFlux (and published in the GTOS document, Law et al. 2008). However, the Fluxnet database is currently static and no one is responsible for continually updating it. To continue these developments and building international continuity in methods and databases, it would make sense for the community to have FLUXNET regularly funded. Along with guidelines for instrumentation and calibration we provide on the AmeriFlux web site, we have the templates for international coordination; they just need to be implemented.

Summary. The AmeriFlux network of 90 sites has great potential to improve understanding of the carbon cycle, and land-based contributions to GHG. AmeriFlux provides direct measurements of net carbon dioxide exchange at the stand-scale that represents the integrated effect of various ecosystem processes. The area coverage of a tower is the appropriate scale for understanding the effects of climatic events and management activities, such as the outcome of mitigation strategies.

The network plays a major role in the North American Carbon Program, where modeling approaches use the flux data to test model processes, or to optimize the models and apply them spatially with inputs of weather data and remote sensing data on land surface characteristics (e.g. Landsat products, MODIS; Goward et al. 2008). Carbon cycle and climate system modelers use flux data to characterize terrestrial sources and sinks for carbon, responses of carbon and energy fluxes to climate and land use change, and resulting radiative forcing feedbacks to climate.

The potential of the network to define reliable baselines of sources and sinks in the US is high in the near future, but it will take enhancements and a more coordinated effort of the science communities and federal agencies. Critical to this effort is timely availability of upstream observations and data products that are used in terrestrial models to map fluxes. The coordination could be improved through the North American Carbon Program.

Internationally, the potential to define baselines of GHG fluxes from natural or managed ecosystems using tower flux measurements is low in the next few years. The distribution of sites is variable, with a sufficient density of sites in many developed countries, but no sites in some countries. It also requires technical expertise both in instrument maintenance and data analysis that isn't likely to be available everywhere. Continuity of existing observations remains threatened in countries like Canada.

Additional resources will be required to develop and sustain a robust carbon monitoring system. It would be necessary to enhance the AmeriFlux network, intensify the GHG observation network, improve terrestrial inventories, ensure continuity of remote sensing data, develop coordinated data management, and accelerate analysis of available data for more comprehensive modeling and assessment.

Additional resources are needed to ensure continuity of the AmeriFlux sites. Required resources would fill gaps in coverage by existing AmeriFlux sites, particularly in underrepresented regions and biomes, and in different stages of forest growth such as following management/mitigation actions. The sites should be enhanced with additional measurements to include methane fluxes (another GHG), isotopes for distinguishing sources, and well-calibrated CO_2 concentration measurements. NOAA CO_2 concentration measurements and CarbonTracker would benefit from addition of well-calibrated CO_2 concentration measurements on more of the AmeriFlux towers. More resources are needed for AmeriFlux data management, data processing and modeling for regional to global scale analysis (e.g. distributed computer clusters, and access to super computers). The required resources for a robust monitoring system are the same as if the primary purpose of the network remains focused on carbon cycle research.

There are existing mechanisms for communication between the academic community and the federal agencies supporting the work. The observation and modeling communities are represented on the steering committees of the Carbon Cycle Science Program and NACP, and meet regularly with the Interagency Working Group of the federal agencies to identify gaps and needs. The challenge is meeting those needs in a timely manner.

Mechanisms for international coordination of infrastructure and analysis could build on the NACP and the new European infrastructure called the International Carbon Observation System (ICOS). FLUXNET, a 'network of regional flux networks', and the FAO Global Terrestrial Observing System would operate within this framework. Additional support necessary to ensure that data collected by different nations are comparable includes institutional support for coordination of observation systems, interchange of standards, and development of high quality data management systems.

In summary, the tools and communication mechanisms exist for monitoring, measuring and understanding GHG sources and sinks. Each of the agencies has been working on their piece of the puzzle. Now what is required is a high level of commitment and coordination to build an integrated national system. For successful implementation, the observation networks, analysis teams, and data management need to be enhanced in the near term to develop and sustain a robust carbon monitoring system.

Citations

Baldocchi, D.D. 2008. ‘Breathing’ of the Terrestrial Biosphere: Lessons Learned from a Global Network of Carbon Dioxide Flux Measurement Systems. *Australian Journal of Botany* 56:1-26.

CCSP. 2007. *The First State of the Carbon Cycle Report (SOCCR): The North American Carbon Budget and Implications for the Global Carbon Cycle.* Anthony W. King, Lisa Dilling, Gregory P. Zimmerman, David M. Fairman, Richard A. Houghton, Gregg Marland, Adam Z. Rose, and Thomas J. Wilbanks, editors, 2007. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

Goward, S.N., J.G. Masek, W. Cohen, G. Moisen, G.J. Collatz, S. Healey, R.A. Houghton, C. Huang, R. Kennedy, B.E. Law, S. Powell, D. Turner, M. Wulder. 2008. Forest Disturbance and North American Carbon Flux. *EOS Transactions* 11:105-106.

Hargrove, W.W., F.M. Hoffman, B.E. Law. 2003. New Analysis Reveals Representativeness of AmeriFlux Network. *EOS Transactions* 84:529.

Law, B.E., T. Arkebauer, J.L. Campbell, J. Chen, M. Schwartz, O. Sun, C. van Ingen, S. Verma. 2008. Terrestrial Carbon Observations: Protocols for Vegetation Sampling and Data Submission. Report 55, Global Terrestrial Observing System. FAO, Rome. 87 pp.

Law, B.E., D. Turner, J. Campbell, O.J. Sun, S. Van Tuyl, W.D. Ritts, W.B. Cohen. 2004. Disturbance and climate effects on carbon stocks and fluxes across western Oregon USA. Global Change Biology 10:1429-1444.

Law, B.E., D. Turner, M. Lefsky, J. Campbell, M. Guzy, O. Sun, S. Van Tuyl, W. Cohen. 2006. Carbon fluxes across regions: Observational constraints at multiple scales. In J. Wu, B. Jones, H. Li, O. Loucks, eds. Scaling and Uncertainty Analysis in Ecology: Methods and Applications. Springer, USA. Pages 167-190.

Misson, L., J. Tang, M. Xu, M. McKay, A.H. Goldstein. 2005. Influences of recovery from clear-cut, climate variability, and thinning on the carbon balance of a young ponderosa pine plantation. *Agricultural and Forest Meteorology* 130:207-222.

Urbanski, S., C. Barford, S. Wofsy, C. Kucharik, E. Pyle, J. Budney, K. McKain, D. Fitzjarrald, M. Czikowsky, J. W. Munger 2007. Factors Controlling CO_2 Exchange on timescales from hourly to decadal at Harvard Forest. *Journal of Geophysical Research* 112: G02020, doi:10.1029/2006JG000293.