# RECOMMENDATIONS ON THE DOE TERRESTRIAL CARBON CYCLE RESEARCH PROGRAM

**Prepared by a Subcommittee of the Biological and Environmental Research Advisory Committee**

**December 2005**

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# Table of Acronyms

| | |
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| ARM | Atmospheric Radiation Measurement |
| BER | Office of Biological and Environmental Research |
| BERAC | Biological and Environmental Research Advisory Committee |
| CCIWG | Carbon Cycle Inter-Agency Working Group |
| CCSM | Community Climate System Model |
| CCSP | Climate Change Science Program |
| CDIAC | Carbon Dioxide Information and Analysis Center |
| CHeaS | Chequamegon Ecosystem-Atmosphere Study |
| CMDL | Climate Monitoring and Diagnostics Laboratory |
| COBRA | $CO_2$ Boundary-layer Regional Airborne |
| DIS | Data Information System |
| DOE | Department of Energy |
| EPA | Environmental Protection Agency |
| FACE | Free Air $CO_2$ Enrichment |
| GPP | Gross Primary Production |
| IPCC | Intergovernmental Panel on Climate Change |
| NACP | North American Carbon Program |
| NASA | National Aeronautics and Space Administration |
| NCAR | National Center for Atmospheric Research |
| NEE | Net Ecosystem Exchange |
| NICCR | National Institute for Climatic Change Research |
| NIGEC | National Institute of Global Environmental Change |
| NOAA | National Oceanographic and Atmospheric Administration |
| NPP | Net Primary Production |
| NSF | National Science Foundation |
| ORCA | Oregon-California |
| ORNL | Oak Ridge National Laboratory |
| SSC | Science Steering Committee |
| TCCRP | Terrestrial Carbon Cycle Research Program |
| TCP | Terrestrial Carbon Processes |
| USDA | United States Department of Agriculture |
| VEMAP | Vegetation-Ecosystem Modeling Project |

# BERAC Subcommittee Recommendations
# DOE Terrestrial Carbon Cycle Research Program
# S. W. Running, Chair

## Introduction

This document is a review of the Department of Energy's Terrestrial Carbon Cycle Research Program (TCCRP) in the Office of Biological and Environmental Research (BER), requested by Dr. Raymond Orbach in a letter to Dr. Keith Hodgson, Chairman of the Department of Energy's (DOE) Biological and Environmental Research Advisory Committee (BERAC) dated April 18, 2005 (Appendix 1). The review was conducted by a Subcommittee (membership listed in Appendix 2) under the auspices of the BERAC. The review consisted of documentation of program goals and current projects disseminated by mail to the subcommittee in September 2005, a 2.5 day review in Washington D.C. on October 4-6, 2005 (Appendix 3), followed by a written summary with recommendations, this document. The Subcommittee was provided with and read abstracts of every project funded by the program in FY 2004-2005, and had electronic copies of all briefing material and presentations given October 4-6 for our deliberations. We also received information from the Climate Change Research Division's Committee of Visitors report on management of BER's TCCRP. The Subcommittee was also provided with both the report on AmeriFlux Site Evaluation and Recommendations for New Enhancements that had been prepared by Beverly Law, Hank Loesher, Tom Boden, William Hargrove, and Forest Hoffman and reviewed by the AmeriFlux Science Steering Group and the Science Implementation Strategy of the North American Carbon Program (NACP).

## Overall Programmatic Considerations

The Subcommittee recognizes DOE as the lead agency for terrestrial carbon science in the U.S. government. While other agencies, notably NSF, USDA, NASA, EPA and NOAA have terrestrial carbon relevant research activities, no other agency has such a clear, specific mandate as DOE to conduct terrestrial carbon research. The overall quality of science reviewed by the Subcommittee was high as a result of commendable efforts by DOE in research solicitation, peer review, and management.

Although individual program elements are operating well, links between projects are weak, inhibiting the integration and modeling that are necessary to meet DOE goals. New effort is required to assure that information from experiments and other field measurements be better integrated and made available to an array of modeling efforts at different spatial and temporal scales. The overarching goal of this DOE science, as stated in the letter of charge to the Subcommittee (Appendix 1), is to "reduce uncertainties about the quantitative role of the terrestrial biosphere as a global sink or source of atmospheric $CO_2$". No matter how good the individual project science, this goal cannot be met without increased emphasis on synthesizing results across projects, incorporating these results in integrated Earth Systems models, and improving the logic for scaling the site level results to continental and global scales. There is a natural reluctance by experimental scientists to rapidly share data before they are fully evaluated and published. This reluctance, however, must be overcome to enable the broader goals of terrestrial carbon science to be achieved. Rapid exchange of ideas and identification of gaps in knowledge require that field scientists share data among sites and with modelers charged with scaling from localized sites to larger geographic units. Success toward this end will require a team effort.

The issues identified above are relevant to all federal agencies in coordinating the U.S. Climate Change Science Program (CCSP) science agenda. However, DOE should clearly lead in integrating terrestrial carbon science, and particularly the Free Air $CO_2$ Enrichment (FACE) and AmeriFlux results, into national carbon cycle research. We acknowledge that some of the most recent DOE application/proposal selections appear to be moving in this direction of increased integration and scaling, but the projects were too new to have results for this review. Recognizing DOE’s leadership role in national carbon cycle science, we recommend initiation of a formally planned data information system (DIS) and an integrated terrestrial carbon modeling program.

## RECOMMENDATIONS IN SPECIFIC AREAS

### FACE

Elevated $CO_2$ experiments supported by DOE represent to the public the most concrete evidence of how fossil fuel emissions will directly influence an array of managed and natural ecosystems. The experiments are designed to consider interactions among species as well as processes that control the acquisition, allocation, turnover, and release of carbon back into the atmosphere. The results of these experiments have been widely reported in prestigious journals and in newspapers and magazines. In this sense, DOE's investment in this area of terrestrial carbon cycling has been amply rewarded. The cadre of scientists involved in the DOE FACE experiments has acquired talents that represent a national and international resource. We depend on this cadre to mentor new investigators, to encourage exchange of information, and to share their enthusiasm and insights. Only with their assistance, will the long-term objectives of the carbon cycling program be achieved.

The DOE FACE program does not appear to have a scientific steering committee that sets strategic directions for the collective FACE research. Each site appears to have been initiated, and operates individually. At this juncture with the FACE experiments now 7-9 years old, two major questions arise: how long should a current site remain operational, and where might new sites best be established? While long-term continuity of some FACE sites is clearly warranted, DOE should periodically evaluate when a site has reached a point of diminishing scientific returns. This Subcommittee did not review in detail each FACE site, so will not make recommendations of sites that should potentially be closed, but we think that not all DOE FACE sites are permanently valuable. In some cases, the height growth of trees in current facilities makes it logistically difficult to continue $CO_2$ enrichment experiments; in other cases, where interannual variation has been found to be small, additional measurements may not yield new information commensurate with the investment. The substantial DOE FACE investment might then yield more valuable information if moved to a site where no information now exists, and uncertainty about potential ecological responses is high.

**Recommendations:**

1. ***We recommend that a review be undertaken of existing scientific information and the potential for new findings at each DOE FACE installation. The review should be similar to the self-assessment undertaken by the AmeriFlux Science Steering Committee.***
2. ***Following the review, we suggest potentially phasing out support for some current sites and the transfer of investment to new areas not currently sampled (e.g., drought-prone forests, peat bogs, areas that are N-deficient or that receive limited atmospheric N deposition, climatic zones that are highly variable).***
3. ***We recommend that periodic (e.g., 3 years) self-evaluations of the DOE-funded FACE sites be scheduled and that these include a report on which of the previous recommendations have been implemented. This evaluation should be***

***used to set priorities for locating future FACE sites and decommissioning existing sites.***

4. ***We recommend that funding be provided to establish and maintain a database for data collected at all the DOE FACE sites.***
5. ***We recommend the establishment of a Science Steering Committee (SSC) led by a FACE Scientific Director. This SSC should include representatives from each DOE FACE site as well as representatives from the modeling community, the data management community, and fields related to the major cross-cutting, multiple site subjects pertinent to the FACE . The SSC should meet regularly and organize an annual meeting for all FACE scientists.***

Data collected by automated instruments at short time intervals accumulate terabytes of information very rapidly. Developing a protocol to catch errors, fill in missing data, and circulate the distilled results in a common format has proved to be a task beyond the resources of any individual site. As a result, it is difficult for scientists within the DOE FACE program, let alone those not directly involved, to attain well documented, synthesized data sets to conduct cross-comparisons and to scale the implications of the research to larger areas and longer periods (i.e., decades). These data may include hourly net ecosystem exchange (NEE), daily gross primary production (GPP), monthly net primary production (NPP), and final annual NEE and NPP for example. Additional supplementary data acquired less frequently is also required in a common format. These include measurements of seasonal variation in leaf area by vegetation class, soil water status, mortality, litter production and turnover.

We advise there be a major emphasis on data assimilation and distribution, first to evaluate the accumulated state of knowledge, and secondly, to use modeling to predict changes in the state of systems that can be tested at future dates using existing FACE facilities and potentially at future locations**.**

**Metrics:**

1. **Establishment of a SSC and completion of a review of existing DOE FACE research detailing present achievements and future priorities.**
2. **Use of the review procedure to produce a set of recommendations concerning which DOE FACE sites should be maintained, phased out and where new one(s) should be established.**
3. **Establishment of a national database designed and established to house data collected at DOE FACE installations. Design should be in close consultation with data suppliers and end-users.**

## AMERIFLUX

AmeriFlux is a network of eddy covariance flux towers located primarily within the U.S., but also includes sites in Latin America and Canada. The goal of the network is to enhance understanding of the terrestrial carbon cycle and its interaction with the atmosphere at time scales ranging from days to decades. Overall, the AmeriFlux research network is making a key contribution to the development of the scientific concepts and tools required to implement a carbon monitoring system for North America.

There are currently 115 active sites run by 50 different research teams. Twenty-six of the teams run multiple sites, usually along gradients of disturbance, climate, or vegetation. The DOE-Terrestrial Carbon Processes (TCP) Program provides funding to many, but not all of the AmeriFlux sites. The network is led by a Science Chair, Professor Beverly Law of Oregon State University. The Science Chair is supported by (1) a SSC, (2) a quality-control/quality-assurance team that has visited 47 percent of the network sites with a portable instrument package to verify measurement quality, and (3) a data manager. Network participants use standard "gold files" taken under ideal measurement conditions to validate their data processing protocols. Climate Monitoring and Diagnostics Laboratory (CMDL) traceable gas standards are sent to ~16 sites per year to calibrate local gas tanks for high precision $CO_2$ concentration measurements. The DIS for AmeriFlux is located at the Carbon Dioxide Information and Analysis Center (CDIAC) within the Oak Ridge National Laboratory (ORNL). The current archive holds 310 site-years of data from 72 sites and 50 site-years of ancillary data. Forty percent of the sites submitted data to the DIS in 2004. The average duration of measurement for an AmeriFlux site is currently 2.5 years and 20 percent of the active sites (~30 sites) have been running for 5 to 10 years. In contrast to the initial *ad hoc* site selection, the network has more recently conducted two rigorous ecoregion analyses to determine the degree to which the existing sites are representative of the dominant vegetation types in the U.S. and to prioritize locations for new sites.

The Science Chair is responsible for leading and facilitating network synthesis activities, but only 25 percent of the U.S. sites have so far contributed data to these analyses. AmeriFlux data have been used to develop and test models that simulate climate response for different stages of ecosystem development following disturbance, for model-data fusion activities aimed at regional and continental scale assessments of carbon budgets, for testing remote sensing algorithms, and for conducting syntheses on environmental controls of the component fluxes (photosynthesis, aboveground autotrophic respiration, and soil respiration). Uncertainties in the various models are being defined and reduced using data from the AmeriFlux network.

Key investigators in the network conducted a self-evaluation in 2005 and produced a high-quality summary document. The evaluation identified three tiers of sites, the first tier having the highest quality and most comprehensive data sets, tier two having satisfactory quality but less comprehensive data, and a third tier, which comprised 17 percent of the 46 sites evaluated, had incomplete data, inexperienced staff, provided no response to data inquiries, or had sub-standard instrumentation. The recommendations in the self-evaluation are comprehensive and include criteria for filling critical gaps in the vegetation types being measured; suggest implementing the full set of core measurements at more sites; improving site instrumentation and data quality; measuring carbon stocks at more sites; increasing the number of strategically located sites for high-precision $CO_2$ concentration measurements; conducting a 2-week intensive training course for those people who are relatively new to eddy covariance measurements; hiring of M.Sc.-level research assistants to assure data quality; and improving data management at each site and the DIS.

We find that the overall quality of the science produced by AmeriFlux is excellent and that the network is making major advancements in terrestrial carbon cycle science. The length of the data records at the longer running sites is now approaching the level required to measure decadal climate signals and events, such as drought, where the perturbation to the system may have a multi-year lag. The Science Chair is highly competent and motivated and has been active in interacting with policymakers, the media, and congressional committees. The network has a common database that is designed for use by the modeling community, although there are still some significant data management issues. Providing readily useable AmeriFlux data to the modeling community is essential for accomplishing the goals of DOE and NACP for carbon cycle science. While the network has made efforts to standardize measurement and data processing protocols, the diversity of funding sources and investigators involved has made this a challenge. The AmeriFlux research program has placed much of its focus so far on the response of the carbon cycle to short-term variations in environmental forcing (i.e., carbon “weather”) at the site level. Attaining DOE’s objectives, however, require that greater efforts be made to link these short-time scale processes to processes that operate at decadal and multi-decadal scales.

**Recommendations:**

We identified the following weaknesses and make suggestions for improvement.

1. ***The DIS is not well structured for use by modelers, file structures are inconsistent between sites, and data formats are difficult to use. Anecdotal evidence suggests that many data users bypass the data system altogether and contact the site principal investigators directly.***

2. ***We recommend that DOE support a “re-analysis product” of the archived data to produce standardized products for easy use by the modeling community, including higher level products such as annual sums. The reanalysis effort will require close collaboration with the modeling community to adequately understand their needs. Assuring that the DIS always has the most recent data versions requires that site investigators commit to sending any recalculated or corrected data sets to the DIS at the same time the data is posted on other web sites.***

3. ***The timeliness of data submission has been relatively poor for many sites, e.g., only 40 percent of the sites have submitted their 2004 data and consequently only a small number of sites have been included in network syntheses. One reason for this problem appears to be that not all of the agencies supporting AmeriFlux research require that data be fully processed and submitted in a timely manner. We recommend that the Carbon Cycle Inter-Agency Working Group (CCIWG) requires that all research announcements include a clear statement of the obligation of the researchers to provide high-quality data to the AmeriFlux data information system and that the funding agencies require that an adequate data management budget and data management plan be included in all applications/proposals for AmeriFlux-related work. We also recommend that AmeriFlux enforce the requirement for timely submission of high-quality data by deselection of sites when necessary.***

4. ***The identification of Tier 1 sites selected for long-term, multi-decade flux measurements needs to be conducted. We recommend that DOE make a commitment to long-term support of selected Tier 1 sites similar to that made to atmospheric concentration sampling sites such as Mauna Loa.***

5. ***We recommend that at least 25 percent of the Tier 2 sites be decommissioned after 3 to 5 years and that DOE encourage the movement of these towers to other high priority areas through a Request for Applications/Proposals designed for this specific purpose. Cluster sites should be encouraged since they are a powerful means of scaling in time and space. Tier 3 sites should be given the opportunity to improve their performance with the understanding that funding will be withdrawn if standards for tier 2 sites are not met within one year .***

6. ***We recommend greater collaboration with the soil carbon processes group, particularly in regards to estimating residence times of soil carbon at the main flux sites and surrounding landscape. We also recommend an expansion of the modeling efforts that use AmeriFlux data to extrapolate the carbon cycle in space and time. Thus, priority should be given to future research applications/proposals which explicitly include collaboration between measurement and modeling communities.***

7. ***The impact of the network on the training of the next generation of scientists was not clear. We recommend that AmeriFlux management keep a record of the employment of the graduate students and postdoctoral fellows who have conducted their research within the network and including this in periodic progress reports as a means of demonstrating one of the long-term impacts of the network on carbon cycle science.***

8. ***We recommend that periodic (e.g., 3 years) self-evaluations of the DOE-funded AmeriFlux sites, such as that conducted in June 2005 be scheduled and that these include a report on which of the previous recommendations have been***

***implemented. This evaluation should be used to set priorities for locating future AmeriFlux sites and decommissioning existing sites.***

**Metrics:**

1. **Improved design of AmeriFlux database developed in consultation with key data suppliers and users.**
2. **A specific requirement for submission of all data from active sites within 12 months of the end of each calendar year.**
3. **Revision of the list of active sites to reflect performance in #2.**
4. **A set of key data-reanalysis products developed in a form suitable for regional, continental and global climate models.**
5. **A set of recommendations from the AmeriFlux Scientific Steering Committee as to which sites to phase out and an ecoregion analysis developed to locate prospective sites.**
6. **A list of Tier 3 sites developed for which future funding is contingent on improving measurement standards and timely reporting of data.**
7. **A list of researchers trained by the AmeriFlux network and current employment developed.**
8. **A research plan developed that links AmeriFlux measurement activities to the regional-continental scale modeling efforts at annual to decadal time scales.**

**SOIL CARBON**

An over-arching goal of TCP and other DOE carbon cycle programs is to anticipate the fate of terrestrial carbon, which requires an understanding of processes that dictate Net Ecosystem Production over not just years, but over decades. As soils are the largest reservoir for carbon entering the terrestrial system over such timescales, it is appropriate that DOE and TCP have a program focused on soil carbon and the complex, interactive mechanisms that control its fate.

DOE's Soil Carbon program currently includes five research projects, but significant soil carbon research is also funded by the National Institute of Global Environmental Change (NIGEC) - now called National Institute for Climatic Change Research (NICCR), FACE, and AmeriFlux programs. Several recent results are found to be provocative: First, as demonstrated by Paul Hanson and others at ORNL, carbon entering mineral soil layers is derived almost exclusively from roots whereas carbon entering organic litter layers is derived from leaf litter plus roots. Secondly, partitioning of carbon flux into heterotrophic vs. autotrophic contributions will enable the science community to assess components contributing to net carbon exchange from gas-based data of FACE and AmeriFlux. Also, Eric Davidson and Susan Trumbore (NIGEC, Harvard forest) demonstrated a high sensitivity of soil respiration to drought, which can invoke a transient sink of $CO_2$. Techniques developed with the use of natural abundance $^{14}C$ and stable isotope $^{12}C$ and $^{13}C$ studies have now been used in a number of DOE studies to gain an understanding of soil carbon turnover. For example NIGEC studies such as by Eric Davidson and Susan Trumbore, Robert Jackson, Jeff Chanton, and Todd Dawson; AmeriFlux studies such as by Jim Ehleringer and Margaret Torn employed stable and/or radiogenic isotopes of carbon to these key questions of carbon utilization and fate.

Despite this notable progress toward understanding soil carbon turnover, the need for understanding the fate of carbon across North America is not being met by the existing programs and structure. In most cases, results were either site specific or were linked to processes that are not currently quantified at regional scales. The need exists to develop an integrated database of turnover time across climate and bioregions and thereby to provide a constraint on terrestrial carbon models for the processes and fate of belowground carbon.

We discussed a number of options and approaches that might facilitate a broader understanding of soil carbon and its role in $CO_2$ budgets. To set the stage for further advancement, we recommend holding an international workshop regarding the use of carbon isotopes and new organic chemical analysis techniques to measure, model, and understand soil carbon turnover. We see a particular need for soil carbon process research that is spatially scaleable, i.e., incorporates variables that are measurable at continental scales. How do turnover times respond to temperature in a variety of environments and soil types? Which key response variables are most important for extrapolating turnover to future scenarios of climate and environmental changes, N deposition, sedimentation, fire history, vegetation change? Resulting from such a workshop, a solicitation for applications/proposals should then be formed in which methods and modeling approaches be developed for a regional understanding of soil carbon turnover and its fate in North America. Applications/proposals could be developed in collaboration with FACE and AmeriFlux sites or could invoke environmental gradients (of climate, vegetation or landscape for example) that challenge our state of knowledge.

**Recommendations:**

*We identified three specific tasks for accomplishing these goals*

1. ***We recommend that DOE design a solicitation to study controls of soil carbon turnover explicitly at landscape to global scales.***
2. ***We recommend that DOE develop a strategic but generalized database that will enable regional parameterization of soil carbon turnover. Such a database should include turnover times, both organic litter and mineral soil layers, and should include a variety of environmental gradients, end members, ongoing research sites, and areas under-represented by existing studies.***
3. ***We recommend that DOE support the development of a national model that, together with the database for soil carbon turnover and associated environmental controls, establishes a dynamic, testable model for the fate of belowground carbon at continental scales.***

DOE has an opportunity to capitalize on key findings of DOE soil carbon research. The soil carbon process science being discovered needs now to explore generalizing concepts that will allow continental scaling to reach the goals of the NACP. This opportunity could be realized by (a) providing more uniform management of soil carbon research, (b) playing a leadership role in the soils community in quantifying soil carbon turnover over broad landscape to NACP scales, (c) prioritizing critical measurements of soil carbon turnover enabled by the current program, and implement them in a regional strategy and, (d) reserving part of the soil program for more exploratory research in this scientific frontier for innovative methods and approaches.

**Metrics:**

1. **Host an international workshop on soil carbon processes. Goals for the workshop should include identification of areas or 'hot spots' where turnover times are unknown or are particularly slow or fast and contribute a disproportionate control on atmospheric $CO_2$ composition; and those areas where turnover times are most likely to change.**

2. **Design and implement a national database of soil carbon turnover times. Turnover times are derived from a number of approaches and need to be categorized according to accuracy, uncertainty, and applicability for spatial or temporal extrapolation. A suite of parameters needs to be identified for reporting turnover times.**

3. **Development of a modeling approach for spatial and temporal extrapolation of soil C turnover times to a variety of temporal and spatial scales. This**

**requires sophisticated models and tests of models that include both dynamic and static landscape properties.**

## FOSSIL FUEL EMISSIONS

Improvements in the space/time details of fossil fuel emissions are an essential part of NACP and CCSP goals. The current projects by Gregg Marland and colleagues at ORNL building a state level, monthly $CO_2$ emission database for integrated carbon modeling are very important. The seasonal and even diurnal estimates of $CO_2$ emissions even down to a 36x36km cell are an impressive improvement in the emission database over just a few years ago. This is critical activity that we support, and see no need for any new recommendations.

**Recommendations:**

**None**

**Metric:**

**Delivery of the national fossil fuel inventory resolving temporal trends to monthly or better and spatial scales to county levels or better.**

## REGIONAL SCALING/AIRCRAFT

DOE supports several integrated regional studies that include aircraft components. These studies include contributions to the $CO_2$ Boundary-layer Regional Airborne (COBRA) program, which has conducted flight experiments at continental and subcontinental scales to quantify fluxes using innovative model-data fusion techniques, the Sky-Arrow aircraft used locally around flux towers, and a variety of measurement approaches centered on the DOE Atmospheric Radiation Measurement (ARM) site in Oklahoma. The COBRA studies began with a strong methodological focus and have moved on to develop a focused approach for estimating regional fluxes and for expressing regional fluxes in terms of climate dependant parameters. The ARM site has focused mainly as a testbed for cutting-edge methods including boundary layer gradient methods, airborne eddy fluxes and coupled concentration-isotope approaches. The Sky-Arrow activity aims to understand fluxtower footprints on a more localized scale. These programs have been in a discovery and methodological stage, but are beginning to move into a more question-oriented stage of research. A logical scaling from local Sky Arrow flights to regional ARM flights to subcontinental COBRA flights may provide a coordination that could enhance scaling studies.

A coherent question-oriented strategy should drive the regional and airborne programs. Aircraft-based flux and concentration measurements provide a critical scaling step between intensive sites and continental-global budgets and need to be strategically integrated with regional modeling and the rest of the DOE program. Current aircraft programs provide information on methodology and snapshots of carbon fluxes and, with the COBRA approach, possibly information on the climate sensitivity of fluxes. CCSP, NACP, and DOE goals require eventual regional integration to time scales of interannual and longer.

As noted above, lack of direct links to longer time scales is a program-wide deficiency that applies to regional experiments as well. Can regional "snapshots" provide a constraint on models that address long time scales? Can any aspects of longterm climate sensitivity be estimated from appropriate airborne studies? These questions need to be addressed at a strategic level and considerably more discussion of this topic promoted. Approaches in both the COBRA and ARM programs provide hints as to how this may be accomplished. Also, the ARM site as a long-term program and facility could be an ideal site to pick a small number of airborne approaches and implement them on a routine basis for several years to observe regional exchange over seasonal to interannual time scales. The ARM site could serve as a testbed for linking scaling in space and time.

### Recommendations

1. ***We recommend regular, possibly monthly, deployment of aircraft flux measurements over key sites to build a strategy for temporal continuity of this data, and to quantify the seasonal cycle of carbon fluxes.***

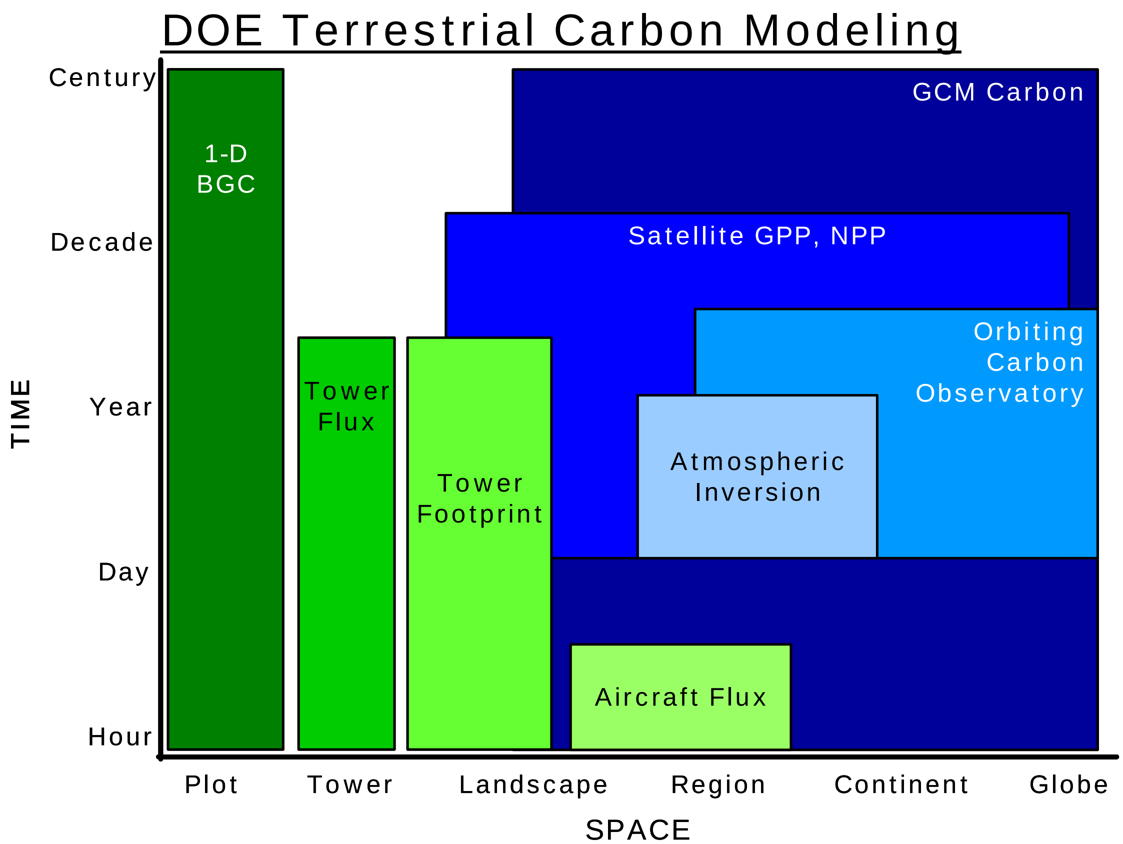
2. ***We recommend a strategic scaling logic be developed for integrating airborne studies with continental-global carbon balance models.***

**Metric:**

**Scientific logic developed for how aircraft measurements can be used to scale from short-term measurements at regional scales to long term estimates of the regional and national carbon budget**.

## MULTI-SCALE MODELING AND INTEGRATION

Overall, DOE Terrestrial carbon modeling is on what one might call an undirected evolutionary path towards the kind of integrated model analysis that will fulfill NACP and DOE goals. The figure below shows the range of time and space domains covered by current DOE Terrestrial Carbon Modeling. Evolution on its own can take a long time to reach any given objective. We suggest that DOE consider an “intelligent design” approach selecting, tasking and funding a specific modeling team for the purposes of building a National Terrestrial Carbon model. Recalling how difficult the Vegetation-Ecosystem Modeling Project (VEMAP) was a decade ago, and the order of magnitude additional complexity involved here, we see no way that following a passive evolutionary activity will result in a successful carbon model for DOE or the nation. Also, we see no other agency that would logically take responsibility for a National Terrestrial Carbon model. DOE already supports modeling in most necessary components of a National Terrestrial Carbon model, with the possible exception of remote sensing driven modeling, but would need to better integrate with that community.




Many DOE and CCSP science goals require an integrated understanding of carbon cycle-climate feedbacks. DOE contributes substantial resources to the National Center for Atmospheric Research (NCAR) Community Climate Modeling program in the Community Climate System Model (CCSM) Land and Biogeochemistry working groups. Within CCSM, there is discussion of “entrepreneurial” and “common path” science. Entrepreneurial science is the way new ideas are developed and tested for injection into large scale efforts. Common path science supports community activities, and assessments such as the Intergovernmental Panel on Climate Change (IPCC). The DOE-supported work on flux observations, soil processes and detailed mechanistic controls over $CO_2$ responses needs to become part of common path science as this work can greatly increase the credibility of coupled carbon climate models. While the DOE should support creative entrepreneurial modeling, there is a need for new process insights to enter the CCSM common path. Rather than injecting new insights from observational and experimental studies, DOE has added a third land-carbon model to the CCSM, but one whose process representations owe little or nothing to the DOE field programs, and whose emphasis on dynamic vegetation addressed time scales not really addressed in FACE or AmeriFlux. This is an overall benefit to the program but with limited resources, effort that could have gone to critical evaluation and improvement of processes, or implementation of the DOE modeling group's own detailed model components in a global framework goes elsewhere.

The global carbon modeling at ORNL does not seem fully integrated with other DOE supported modeling efforts. For example, the DOE assimilation effort developed a new model, so parameters estimated with that system cannot be directly transferred to a DOE prognostic carbon model framework (although process knowledge can flow indirectly). What should DOE's role be? Carbon data assimilation models require critical coordination with large forcing datasets, and are a substantial software engineering challenge that DOE can support. The ORNL assimilation effort is excellent science, and badly needed, but it has been developed entrepreneurially and likewise needs to enter a "common path" for the AmeriFlux network. Supporting Lianhong Gu and Mac Post, and integrating their work better with AmeriFlux could produce a "reanalysis" of the network in terms of component fluxes and rate controls that would be a great complement to the data and statistical products of the data. Before this could be achieved or accepted, the team would have to be expanded, ideally by increased support for the ORNL group and also support for key colleagues to work with them.

The COBRA and ARM aircraft projects, and other regional studies (e.g., but not limited to Chequamegon Ecosystem-Atmosphere Study (CHeaS), Oregon-California (ORCA) could contribute key data for scaling studies. Full carbon budgets for North America as called for by NACP will require much more coordination of field, aircraft and satellite observations with advanced scaling logic and strategic integration via modeling. This type of work is in its infancy, but coordination of the DOE ORNL assimilation with the type of scaling work being done by Steven Wofsy and others is a logical path to begin following.

**Recommendation:**

***We recommend that DOE consider forming a Terrestrial Carbon Modeling Team whose task would be to develop a National Terrestrial Carbon modeling program (supporting one, several or a family of connected models) that would fulfill the stated agency goals. The style of this might be similar to the organization of the NCAR Community Climate Modeling, with both internally funded scientists and opportunity for external contributions. Immediate modeling goals have been clearly outlined in the***

***NACP Science and Implementation plans. We see no way the NACP goals can be reached without a specifically designated team for coordination of the necessary carbon modeling components. This activity should be closely coordinated with the DOE experimental activities (soil C, FACE and AmeriFlux) on the one hand, and with coupled carbon climate modeling on the other hand.***

**Metrics:**

1. **Formation of a Terrestrial Carbon Modeling Team with the objective of modeling the expected long-term changes in the terrestrial carbon stocks of North America as outlined in the NACP Science and Implementation plans.**
2. **Develop and implement a model to integrate data from the spatial and temporal scales identified in the above figure**.

## NATIONAL INSTITUTE FOR CLIMATIC CHANGE RESEARCH (NICCR) REGIONAL COORDINATION

This subcommittee finds the replacement of the old NIGEC project management to the new competitively selected NICCR, a regionally focused organization, to be scientifically stronger, programmatically more logical and fiscally more efficient. Since the new NICCR organization is just beginning, it is too early to measure new successes.

**Recommendation:**

***We recommend that the NICCR regional organization be used to coordinate Tier 2 and 3 level AmeriFlux sites. NICCR could identify regional bioclimatic and land use gradients where new FACE experiments should be initiated, and allow an improved strategy for prioritizing new site selection for NACP, AmeriFlux and soil carbon studies, and for regular re-deployment of these sites.***

## Cross-cutting metrics

Across these topical areas, we saw a recurring need for better coordination and synthesis of the research, most of which was excellent in terms of individual quality. We suggest the following metrics to help improve research coordination.

1. **Evaluate research sites according to the quality of data generated and submitted in timely fashion to central databanks. Identify the degree to which insights from those data help address the DOE carbon cycle goal over the next decade: to "reduce uncertainties in the quantitative role of the terrestrial biosphere as a global sink or source of atmospheric $CO_2$ ".**
2. **Evaluate individuals and projects in regard to their contributions to synthetic activities according to the extent that:**
    a. **quality data are provided in a timely manner and common format to a central databank.**
    b. **their research helps bridge spatial scales from individual sites to the North American continent.**
    c. **their research allows predictions to be extended from annual to decadal time scales.**
3. **Evaluate leadership role of participants in synthesis and modeling efforts that result in more cohesive research within DOE and in collaboration with other government agencies.**
4. **Encourage greater visibility and integration of all program elements by requesting investigators to condense their key findings into 3-5 PowerPoint Slides accompanying annual reports that can be posted on a central programmatic website open to the scientific community.**

APPENDIX 1 - Charge Letter

**Department of Energy**
Office of Science
Washington, DC 20585

APR 1 8 2005

**Office of the Director**

Dr. Keith Hodgson
Stanford Synchrotron Radiation Laboratory
Department of Chemistry
Stanford University
Stanford, California 94305

Dear Dr. Hodgson:

I am charging the Biological and Environmental Research Advisory Committee (BERAC) to undertake a review of the Office of Biological and Environmental Research's (BER) terrestrial carbon cycle research program. The review is to include an evaluation of the carbon cycle research funded through not only the core program, but also through the National Institute for Global Environmental Change (NIGEC). The BERAC review should address the following questions:

1. In what ways will the currently configured program contribute to the long term goal of BER's Climate Change Research to deliver improved climate data and models for policy makers to determine a safe level of greenhouse gases in the earth's atmosphere? Is the program on track to do so, and are any changes recommended to better enable the program to make important contributions toward that long term goal? In addition, the subcommittee of BERAC that conducts the review is asked to comment on draft performance metrics for use in tracking progress of the program toward the goal. The draft metrics will be provided to the subcommittee when it meets.
2. In what ways will the currently configured program help reduce uncertainties about the quantitative role of the terrestrial biosphere as a global sink or source of atmospheric $CO_2$ and how much the terrestrial biosphere might amplify or dampen the increase in atmospheric $CO_2$ as a result of changes in climate and/or the direct effect of elevated atmospheric $CO_2$ levels on plants, for example?
3. Is the current focus of BER's terrestrial carbon cycle research, which is targeted on addressing the North American Carbon Program (NACP) goals, an appropriate near-term priority given the uncertainties about future atmospheric concentrations of $CO_2$, and whether and by how much terrestrial sources and sinks of carbon will change in the future? Over the longer term, should BER consider making any changes in its terrestrial carbon cycle research program to address carbon cycle issues and questions besides those included in the NACP, and if so, what changes should be considered?
4. Does the current program have an appropriate balance of experimental and process studies, field observations, and modeling studies to both identify and provide an understanding of the environmental factors regulating the net exchange of $CO_2$ between the terrestrial ecosystems and the atmosphere and improve our ability to accurately predict changes and variation in the net exchange at scales ranging from the ecosystem to regional to continental? Are results from observational studies, such as the AmeriFlux network, used effectively in carbon cycle modeling studies? Is

there sufficient interaction and collaboration between the modeling and process studies funded by the program to ensure that information and data from process studies and observations are being collected and used to improve carbon cycle models, and model results are used to help define the kinds of information needed from process and observational studies to test and improve carbon cycle models? What changes, if any, are recommended to enhance use of such data to improve our ability to understand and reliably predict the effects on the terrestrial carbon cycle of, for example, future potential environmental changes, such as climatic change and increasing atmospheric $CO_2$ levels?

5. Are the AmeriFlux sites funded by BER effectively operating as an integrated network? What changes in AmeriFlux, if any, are recommended to demonstrate and enhance its added value as an integrated network of flux measurement sites? Is AmeriFlux providing data and information that will be helpful in resolving uncertainties about the role of terrestrial ecosystems in the global carbon cycle? Is the current distribution of sites in the network representative of dominant vegetation types in the conterminous US? If additional sites were necessary to achieve representative coverage, what would be an appropriate strategy or rationale for site selection? Are the AmeriFlux quality control standards and protocols for both site operations and data quality assurance appropriate, and are all sites adequately and consistently complying with the AmeriFlux guidelines? What changes, if any, in AmeriFlux quality control standards and protocols and their implementation are necessary to help ensure that the DOE component of AmeriFlux is an effective network using comparable methods and providing comparable data and results across all DOE-funded sites?
6. Are the Free-Air $CO_2$ Enrichment (FACE) Experiments funded by BER providing important and useful process information for understanding and interpreting the direct effects of elevated $CO_2$ on terrestrial plants, communities, and ecosystems? How useful are results from these studies for assessing the potential response of terrestrial ecosystems to future increases in atmospheric $CO_2$ levels, especially the effect of elevated $CO_2$ on carbon cycle processes and the capacity of terrestrial ecosystems to sequester carbon from the atmosphere at the elevated levels? What changes in the FACE experiments, if any, are recommended to improve their value and relevance?

I recommend that Dr. Knute Nadelhoffer from the University of Michigan be asked to chair a subcommittee of BERAC to undertake this review. Dr. Nadelhoffer is an expert on terrestrial carbon cycling. If possible, I would like the subcommittee to give at least a preliminary report of its findings and recommendations at the fall, 2005 meeting of the BERAC which is tentatively scheduled to be held in November of this year.

Sincerely,

Raymond L. Orbach

Raymond L. Orbach
Director
Office of Science

APPENDIX 2 – Subcommittee Members

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APPENDIX 3 - Agenda for Carbon Cycle Review, October 4, 5 and 6, 2005

**Tuesday, October 4-Randolph Room**

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| 7:00PM | Committee arrives for an organizational dinner |

**Wednesday, October 5-Jackson Room**

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| 8:00 – 8:30 | Introduce Review Panel, discuss objectives and response to charge<br>S. Running |
| 8:30 – 9:00 | Carbon Cycle Program in context of Climate Change Research<br>J. Elwood |
| 9:00 – 10:00 | Overview of Terrestrial Carbon Cycle Research<br>Implementation in context of Inter-Agency carbon cycle research (CCSP and CCIWG)<br>R. Dahlman |
| 30 min Break | |
| 10:30 – 11:30 | Experimental Research<br>R. Norby |
| 11:30 – 12:30 | AmeriFlux Research<br>B. Law & S. Wofsy |
| 12:30 – 1:15 | Lunch Buffet |
| 1:15 – 1:45 | Regional Analysis (Focus)<br>COBRA – S. Wofsy<br>ARM – M. Torn |
| 1:45 – 2:15 | Soil Carbon<br>M. Torn |
| 2:15 – 3:15 | Modeling and Synthesis<br>M. Post |
| 30 min Break | |
| 3:45 – 4:15 | NIGEC Carbon Cycle Research<br>J. Amthor |
| 4:15 – 4:45 | Research contributions to the CCSP Carbon Cycle Program<br>W. Emanuel |

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|---|---|
| 4:45 - 5:15 | Strategic Discussion<br>R. Dahlman, Program Scientists and Review Committee |
| 5:15 – 5:45 | Requests by committee for additional information<br>S. Running |
| 7:00 PM | Committee Dinner-Jackson Room |

**Thursday, Oct 6-Jackson Room**

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| 8:00 – 2:00 | Review Panel in Executive Session, with lunch |
| 2:00 – 3:00 | Debrief<br>Review Panel, R. Dahlman & J. Elwood |
| 3:00 – 4:00 | Committee discussion of final written report |

4:00PM Adjourn