Title page

Monitoring and Modeling CO_2 Isotopic Exchange Between the Atmosphere and the Terrestrial Biosphere

NOAA Proposal **GC00 - 280**

Submitted October 14, 1999

Funding period requested: June 1, 2000 - May 31, 2003, 36 months

Total 3-year funds requested:	$ 631,335
Carnegie Institution of Washington:	$ 240,763
Colorado State University:	$ 195,000
University of Utah:	$ 195,572

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Abstract

Monitoring and Modeling CO_2 Isotopic Exchange
Between the Atmosphere and the Terrestrial Biosphere

Joseph Berry, Carnegie Institution of Washington
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The concentration and isotopic composition (^{13}C, ^{18}O) of atmospheric CO_2 are key variables used in top-down analysis of the global carbon cycle. Isotopes in particular play a key role in distinguishing ocean from terrestrial sinks and recent studies indicate that on a regional terrestrial basis it should be possible to partition among landscape elements using isotope analyses. Our study will break new ground as a concerted modeling and measurement program focused on carbon and oxygen isotope exchange by terrestrial ecosystems. The proposed modeling and data acquisition efforts will be conducted primarily at the WLEF tall tower in Park Falls, Wisconsin. The objectives of our proposed work can be summarized as (a) to develop and test a model that can be used to define basis functions for the global inversion of atmospheric measurements of CO_2, $\delta^{13}C$ of CO_2, and $\delta^{18}O$ of CO_2 and (b) to monitor the critical data on the isotopic composition of ecosystem components and on the CO_2 emerging from ecosystems within the WLEF footprint that are essential for interpreting planetary boundary CO_2 observations and also for constraining model predictions. The long-term objectives of the proposed research are the development of coordinated modeling and monitoring efforts to better predict CO_2 dynamics between the biosphere and the atmosphere on regional and continental scales.

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Statement of Work

Introduction

The research proposed here is a collaborative effort with 3 investigators: Joe Berry (Carnegie Institution), Scott Denning (Colorado State University), and Jim Ehleringer (University of Utah).

Our study will break new ground as a concerted modeling and measurement program focused on carbon and oxygen isotope exchange by terrestrial ecosystems. The proposed experiments will be conducted primarily at the WLEF tall tower in Park Falls Wisconsin, and will leverage off of the comprehensive suite of meteorological, ecophysiological, ecological and remote sensing studies also being conducted or proposed at this site. The objective of our proposed work are to:

- Provide a model that can be used to define basis functions for the global inversion of atmospheric measurements of CO_2, $\delta^{13}C$ of CO_2, and $\delta^{18}O$ of CO_2.
- Test the model against observations at WLEF and other sites.
- Develop a robust experimental strategy to expand the scope of these measurements to other continental sites around the world.
- Develop a strategy to estimate tropospheric values of CO_2, and $\delta^{13}C$ and $\delta^{18}O$ of CO_2 from near surface measurements in continental areas (unlike marine sites, continental sites are strongly influenced by local fluxes).

The modeling work will be conducted by Scott Denning of Colorado State University. Joe Berry will setup a system to obtain and analyze the concentration and isotopic composition of air from at least two levels on the WLEF tower and in the canopy of an adjacent forest. Jim Ehleringer of the University of Utah will conduct ecosystem measurements to sample the isotopic composition of key vegetation components of the ecosystems surrounding the tower to provide the data needed to interpret isotopic CO_2 composition. These measurements will be analyzed and integrated with modeling studies at a hierarchy of scales from individual elements (the canopy and soil), complete ecosystems, to regional and continental simulations.

Background and identification of the problem

Isotopes as tracers of regional and global carbon fluxes. The concentration and isotopic composition (^{13}C, ^{18}O) of atmospheric CO_2 are key variables used in the analysis of the global carbon cycle by inversion of atmospheric transport models (Tans et al., 1990, 1993, 1996; Keeling et al., 1995, 1996). Carbon isotopes are used in inverse calculations to distinguish ocean from terrestrial exchange processes (Tans et al., 1993; Keeling et al., 1995, 1996). Peylin (1999) suggests that the oxygen isotopes of CO_2 will be useful to improve geographical resolution of terrestrial sources and sinks and may be used to infer gross primary productivity from inverse calculations. These tracers have tremendous potential to improve our understanding of the carbon cycle. However, two factors have limited the power of this top-down analysis. First, the data from the flask sampling networks is sparse from continental regions. Second, there is a basic lack of complementary data on the kinetic and equilibrium isotope effects on CO_2 exchange between terrestrial ecosystems and the atmosphere. Most ^{13}C inversions have assumed that the terrestrial biosphere has a constant discrimination (e.g., 18 ‰, Ciais et al., 1995) and have used *ad hoc* approaches to estimate the disequilibrium between the biosphere and the atmosphere (Tans et al., 1993). However, carbon isotope discrimination by C_3 plants varies with physiological and meteorological factors (Farquhar et al., 1989; Ehleringer et al., 1993), leading to both spatial and temporal changes on a regional basis. Further, a significant fraction of terrestrial productivity is by species with the C_4 pathway of photosynthesis. These species have a carbon isotope signature similar to the ocean and very different from that of C_3 species. It is estimated that C_4 species account for 16 - 30 % of the total terrestrial photosynthesis (Lloyd and Farquhar 1994; Collatz et al., 1998). Many natural ecosystems contain a mixture of C_3 and C_4 species, and the proportion may vary with season and between seasons with interannual variation in climate. Oxygen isotope discrimination is effected by many of the same factors -- and in addition by isotope fractionation that occurs in the hydrologic cycle (Farquhar et al., 1993). The quality of atmospheric inversions would be improved if data were available to define these variations.

The challenge in developing an integrated multitracer inversion model is to provide appropriate basis functions which capture the variations of the surface fluxes of CO_2, $^{13}CO_2$, and $C^{18}O^{16}O$ in an internally consistent manner. Following Tans et al. (1993), the instantaneous effects of surface carbon fluxes on the isotopic composition of CO_2 are given by:

$$C_a \frac{f\delta_a}{ft} + T(C_a\delta_a) =$$
$$F_{FF}(\delta_{FF} - \delta_a) + F_{BB}(\delta_{BB} - \delta_a) + F_{OA}(\delta_o - \delta_a + \varepsilon_{OA}) + \Delta_{pho}F_{pho} + F_{resp}(\delta_{resp} - \delta_a + \varepsilon_{resp}) \qquad (1)$$

Here *FFF*, *FBB*, *FOA*, *Fpho*, and *Fresp* are the instantaneous fluxes of CO_2 to the atmosphere due to fossil fuel combustion, biomass burning, ocean-atmosphere transfer, terrestrial photosynthesis, and terrestrial respiration, respectively. C_a is the atmospheric concentration of CO_2, and δ is the isotopic ratio associated with the atmosphere and with each carbon flux, defined in the usual way. *T* is the transport operator. ε_{OA} is the kinetic fractionation factor associated with transfer across the air-sea interface and εresp represents isotopic fractionation associated with respiration, if any. Δ_{pho} is the isotopic discrimination associated with terrestrial photosynthesis. Specification of basis functions for a multitracer inversion involves spatial and temporal maps of CO_2 flux, and also specification of each term in equation 1.

The centerpiece of this work is a version of SiB2 (Sellers et al. 1996) that simulates ^{18}O and ^{13}C discrimination by terrestrial ecosystems (Denning, Suits, Still, Berry and Baker, unpublished). This model explicitly simulates the physiological and biophysical mechanisms that effect carbon and oxygen isotope discrimination C_3 and C_4 species as an integral part of simulations of the exchange of energy, water and carbon by the land surface. Figure 1 shows a global map of carbon isotope discrimination by terrestrial ecosystems, integrated for one year and weighted by gross CO_2 assimilation. In this simulation, the model was driven by surface meteorology obtained from an ECMWF reanalysis product. Boundary conditions were provided at 1° x 1° resolution as described by Sellers et al. (1996) with the exception that the relative abundance of C_4 species was specified from a new map based on a climatological index (Collatz et al., 1996) and a new remote sensing product (Still and deFreis, unpublished). In future work, this model will be coupled with a module (constructed by Joerg Kaduk) that explicitly simulates carbon stocks and turnover of biomass and soil organic matter, permitting simulation of isotopic disequilibrium effects, as an internally consistent component of the isotope balance of ecosystems. This model is designed to generate the spatial and temporal maps required for multitracer inversions. However, the parameterization for isotope discrimination are largely based on theoretical arguments and laboratory studies carried out on model systems. The work proposed here will develop the methodology for a complementary set of atmospheric observations at the regional and ecosystem scale that can be used to test, improve and validate the above model.

This model has been coupled to the CSU atmospheric GCM and to a mesoscale atmospheric model, RAMS, permitting simulation of regional and global scale variation in the isotopic composition of CO_2 in the atmosphere at the time step of the atmospheric model. With independent funding, Denning and colleagues are already conducting simulations of surface fluxes and the concentration of CO_2 in the atmosphere as sampled from the WLEF tower. This makes WLEF site an ideal venue to test the model against observations. In addition, these studies can draw on a comprehensive suite of meteorological, ecophysiological and remote sensing studies already in progress or proposed at this site.

WLEF as a site for long-term CO_2 monitoring and CO_2-isotopes model development. The proposed research will focus on the WLEF “tall tower” site and surrounding ecosystems in Wisconsin, where a multi-disciplinary program in carbon cycle research is emerging that spans from canopy to regional scales (Appendix 1). While each of these projects are independent (some funded, others are proposals), interactions and integration among these projects are likely to lead to a substantially better understanding of the controls on regional CO_2 fluxes. The focus of our research will be to link isotopic composition of ecosystem-scale CO_2 fluxes with regional observations from the WLEF tower and planetary boundary layer levels.

The detailed measurements and modeling at the WLEF site will provide a good

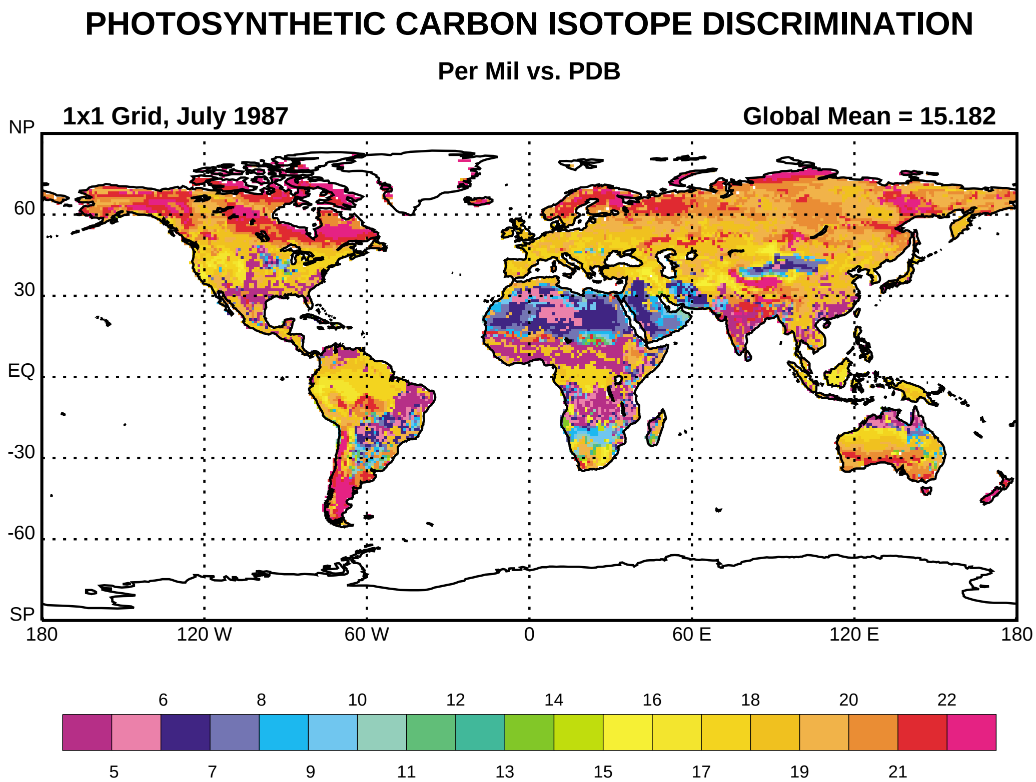

Figure 1. Global estimates of carbon isotope discrimination by ecosystems, integrated for one year and weighted by gross carbon dioxide assimilation. Denning et al. (unpublished).

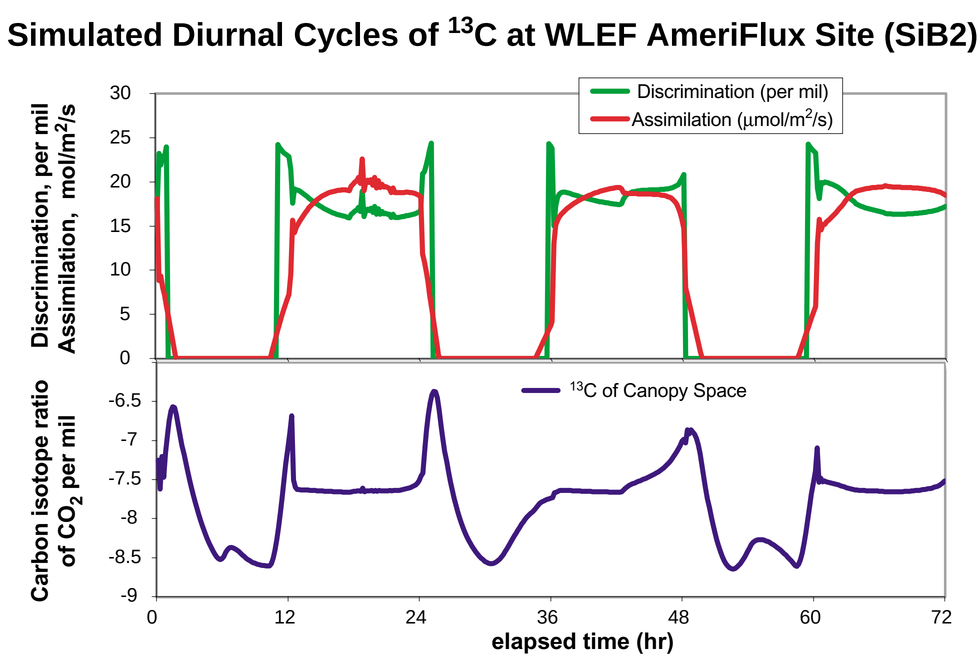

Figure 2. Simulated diurnal cycles of photosynthetic discrimination against 13-C by the forest at WLEF, showing the tight correlation with net assimilation. Denning et al. (unpublished).

basis for designing simpler yet powerful approaches that could be applied in other ecosystems around the world to calibrate and test the ecosystem isotope fractionation model. Such studies will increase confidence in the basis functions produced by the model and provide important new insights into physiological and hydrological processes.

Simulated diurnal cycles of photosynthetic discrimination against ^{13}C by the forest at WLEF are tightly correlated with net assimilation (Figure 2). Enhanced discrimination is simulated in low-light conditions of early morning and late afternoon because of reduced stomatal conductance during these times. Mid-day values are somewhat weaker (heavier photosynthate), reflecting simulation of moderate physiological stress at this site. Diurnal variations in the $\delta^{13}C$ of canopy air (lower panel) reflect the buildup of isotopically light CO_2 in the forest under the nocturnal inversion, with strong turbulent mixing during the day diluting the local influence of the strong isotopic fractionation.

At present, atmospheric flask samples at WLEF are taken from the 400 m level at two-week intervals. Figure 3 summarizes these data (Bakwin, unpublished), which provide important information on synoptic variation in the isotopic composition of CO_2 for this region. Continuous measurements of CO_2 concentration are made at 4 heights on the tower. These data reveal very large variations in CO_2 over the diurnal cycle and with elevation above the ground that are undoubtedly associated with isotopic gradients produced by local CO_2 exchange processes.

Expansion of the existing data stream. We propose to setup automated equipment that will enable us to collect flask samples from at least two levels on the tower and in the canopy of an adjacent forest. These will be conducted every 1.5 h for 24 h to resolve the diurnal variation of concentration in the convective boundary layer (cbl) mixed layer and canopy air space. The repeat frequency will be monthly during the growing season; less frequently in winter, and more frequently during intensive campaigns (e.g., August 2000). Samples for measurement of the $\delta^{18}O$ of atmospheric water vapor from the tower and in the canopy air space will be collected by project personnel when they are on site. These measurement will serve several functions. First, we need data on the isotopic composition of CO_2 and H_2O of the cbl as inputs to run SiB2 driven by observed surface meteorology (not coupled with an atmospheric model). To provide continuous driver data, we plan to develop seasonal calibration functions relating the CO_2 concentration (continuously measured) with the isotopic composition (measured at monthly intervals). Second, these data on isotopic composition of CO_2 and H_2O will provide useful observations to check the validity of simulations with SiB2 in a coupled mode with atmospheric models (CSU-GCM or RAMS). Third, these measurements should provide insight into advective processes. Bakwin (personal communication) has already noted a distinct isotopic signature (co-variation of isotopic ratio with CO_2 concentration) when the wind is from the south. Measurements (to be described below) will characterize the isotopic signature of natural agricultural and urban sources that may influence that observed at the tower. Fourth, we anticipate that these

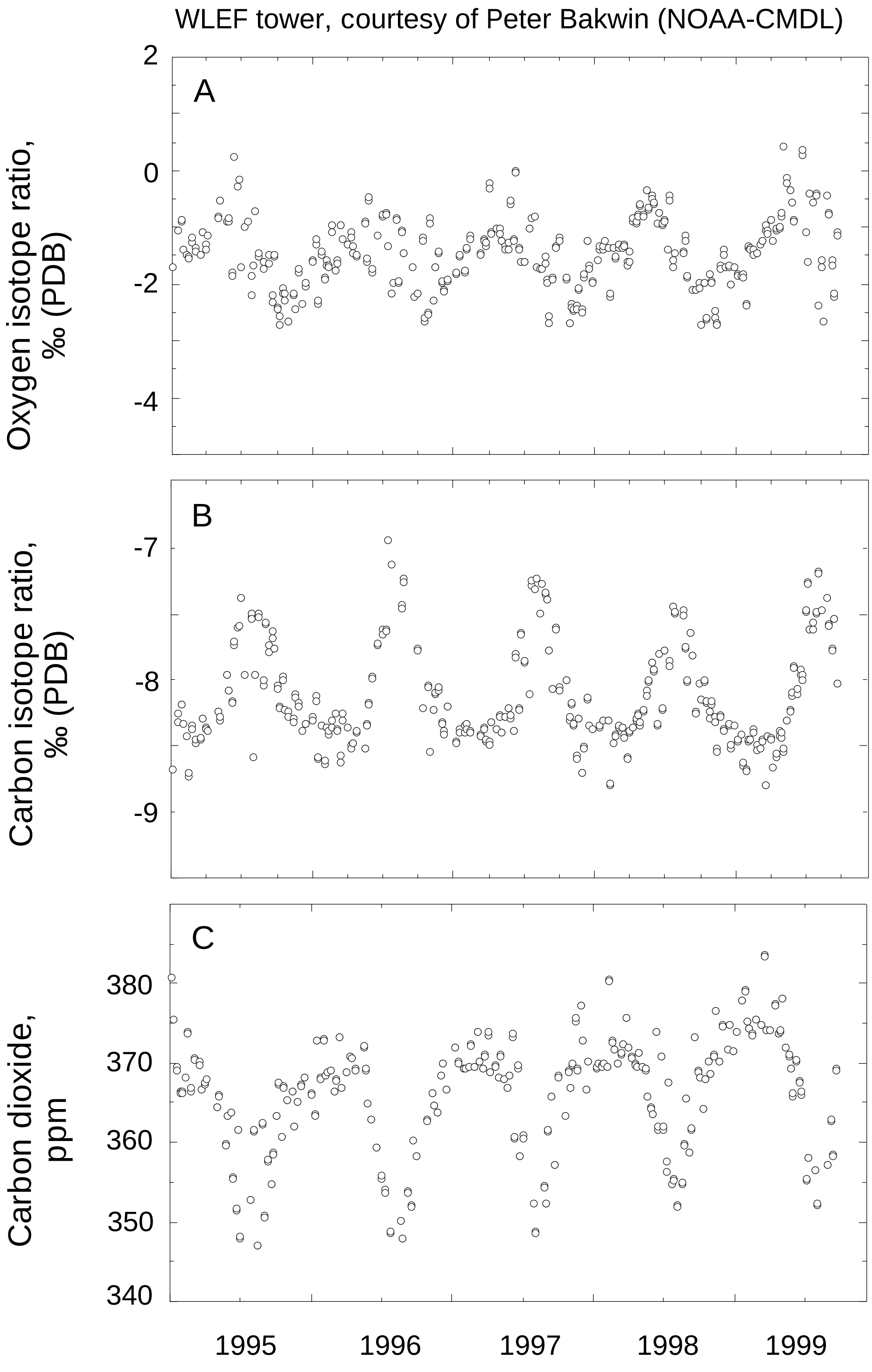

Figure 3. The annual time course of carbon dioxide at the WLEF tall tower in Wisconsin. Data are courtesy of Peter Bakwin (NOAA-CMDL).

Plate A: oxygen isotope ratio of atmospheric CO_2 in ‰ (PDB scale)

Plate B: carbon isotope ratio of atmospheric CO_2 in ‰ (PDB scale)

Plate C: atmospheric CO_2 concentration in ppmV measurement will be useful for development and testing methods for obtaining meaningful estimates of tropospheric concentrations and isotopic composition from surface stations located over the continents. In an independent proposal, Ken Davis proposes a strategy for estimating tropospheric CO_2 from measurements of surface CO_2 concentration and surface CO_2 flux. We suggest that this rationale can be extended to obtain isotopic estimates. If successful, this would provide a strategy to use surface flux measurement sites of the AmeriFlux (and other) networks to extend the density of atmospheric sampling in continental regions.

Complementing these atmospheric observations, we propose to collect a powerful and efficient suite of physiological and ecophysiological measurements to parameterize provide boundary conditions and test the above model. We maintain that these measurements are essential to interpret the proposed atmospheric and modeling work.

Interpreting the carbon isotope signal. Isotopic fractionation of carbon due to photosynthesis involves four steps: diffusion through the laminar leaf boundary layer and stomatal opening, dissolution in interstitial water, diffusion through the mesophyll tissue, and carboxylation reaction. Each step enriches the air in ^{13}C as the plant gets depleted. For C_3 plants, the overall relation is

$$\Delta = a + (b - a)\frac{C_i}{C_a} \qquad (2)$$

where *Ca* and *Ci* are the partial pressure of CO_2 in the atmosphere and at the site of CO_2 fixation in the chloroplast, respectively (calculated every 6 minutes by SiB2), and a = 4.4 ‰ (diffusion fractionation against $^{13}CO_2$) and b =27.5 ‰ (fractionation of C_3 plants during carboxylation) (Farquhar et al., 1989; Ehleringer et al., 1993). For C_4 plants, *Ci* is concentrated by a biochemical mechanism so that b is substantially lower in value. In real life and in the model, *Ci* is subject to change (0.5 - 0.8), being a function of the stomatal conductance and the capacity (inside the stomata) for CO_2 assimilation. One of our goals is to determine if the model correctly predicts Δ. The Δ value for ecosystems integrates all vegetative elements and can be measured directly with great technical difficulty or it can be measured more easily as the $\delta^{13}C$ value of CO_2 released by ecosystems (δ_R).

While measurements of [CO_2] and isotope ratios are important observations in our efforts to bridge the gap between global inversions and ecosystem-scale CO_2 exchange studies, these are not likely to provide a stringent test of the accuracy of the model. As noted above, the air sampled at the tower is likely to be influenced by several (if not many) ecosystems. Thus, there are too many degrees of freedom to provide a good calibration test. To obtain a more stringent test, we need to focus in on smaller footprints. Our proposed approach makes use of a technique developed by Keeling (1958) to determine the isotope ratio of CO_2 respired from ecosystems at different scales, based on changes in the concentration and isotopic ratio of atmospheric CO_2 within the footprint of interest. Keeling (1958) showed that by plotting the mixing relationship between $\delta^{13}C_{a-i}$ and $1/[CO_2]_{a-i}$ of atmospheric CO_2, a linear relationship was obtained and the intercept of this relationship was the isotope ratio of the respired CO_2 input into the forest canopy.

$$\delta_{a-i} = \frac{[CO_2]_{a-o}}{[CO_2]_{a-i}} \bullet (\delta_{a-o} - \delta_R) + \delta_R \qquad , \qquad (3)$$

where $[CO_2]$ is concentration of CO_2, δ is the stable isotope ratio of CO_2, and the subscripts *a-i* and *a-o* represent the atmosphere inside a canopy and the atmosphere above (outside) the forest, respectively. It can be seen from Eqn 3 that a plot of $1/[CO_2]_{a-i}$ versus δ_{a-i} gives a straight line relationship with a slope, $[CO_2]_{a-o} \cdot (\delta_{a-o} - \delta_R)$, and an intercept, δ_R.

At the ecosystem or forest canopy scale, the intercept (δ_R) represents a spatially integrated measure of the $\delta^{13}C$ of CO_2 respired from both vegetation and soil components (Figure 4). The δ_R values for different forest and grassland ecosystems across North America exhibit significant geographical variation (i.e., not a constant Δ = 18 ‰ or δ_R = -26 ‰), reflecting the inherent meteorological and hydrologic constraints imposed on vegetation by the physical environment. Moreover, there can be significant seasonal variations associated with hydrological changes in forest water balance or with changing C_3/C_4 dynamics in grasslands (Figure 5). The spatial area integrated by the calculation depends on the height at which the air samples are collected, or the footprint of the air sample mast. The calculated intercept also represents a temporal integration, because it includes contributions from different aged carbon pools in plants and soil, that have different turnover times and $\delta^{13}C$ values.

It is possible to use the "Keeling plot" approach to calculate separately the isotope ratio of respired CO_2 at different spatial scales, both above and below that of the forest canopy (Flanagan et al., 1996; Yakir and Wang, 1996; Buchmann et al., 1997a, 1998a, 1998b; Miranda et al., 1997). New analytical approaches make it possible to collect and analyze the $\delta^{13}C$ value of small samples of CO_2 from the free atmosphere (Ehleringer and Cook, 1998). This approach allows the separate calculation of the $\delta^{13}C$ value of CO_2 released from ecosystems (δ_R) or from forest floor respiratory components (δ_{R-soil}), which can then be compared to the isotope ratio of CO_2 respired by the entire forest ecosystem to determine the relative contribution of the aboveground and belowground ecosystem components.

We will use SiB2 to predict the isotopic composition of CO_2 respired by specific ecosystems. Comparison of the prediction to data obtained from measurements will provide a stringent test of the model and its parameterization. Most work indicates that there is no discrimination in respiration (Lin and Ehleringer, 1997). As a result,

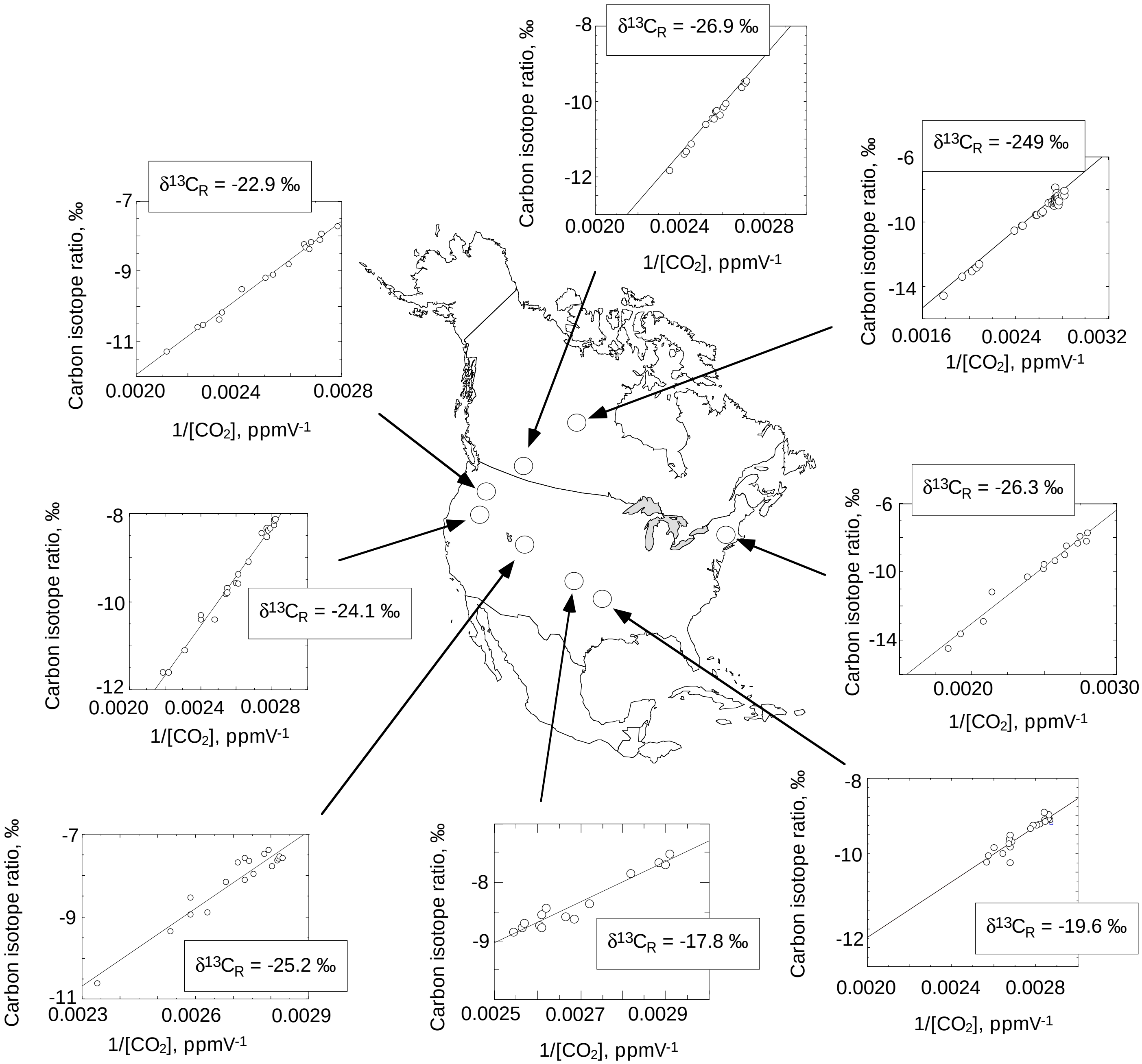

Figure 4. Keeling plots for several major ecosystems across North America that are involved in the AmeriFlux effort. Data represent single point in time sampling. The carbon isotope ratio intercepts shown are the time-dependent values for carbon dioxide e,itted from each of these different land surface components. Data are from Joe Berry (unpublished), Jim Ehleringer (unpublished), and Larry Flanagan (unpublished).

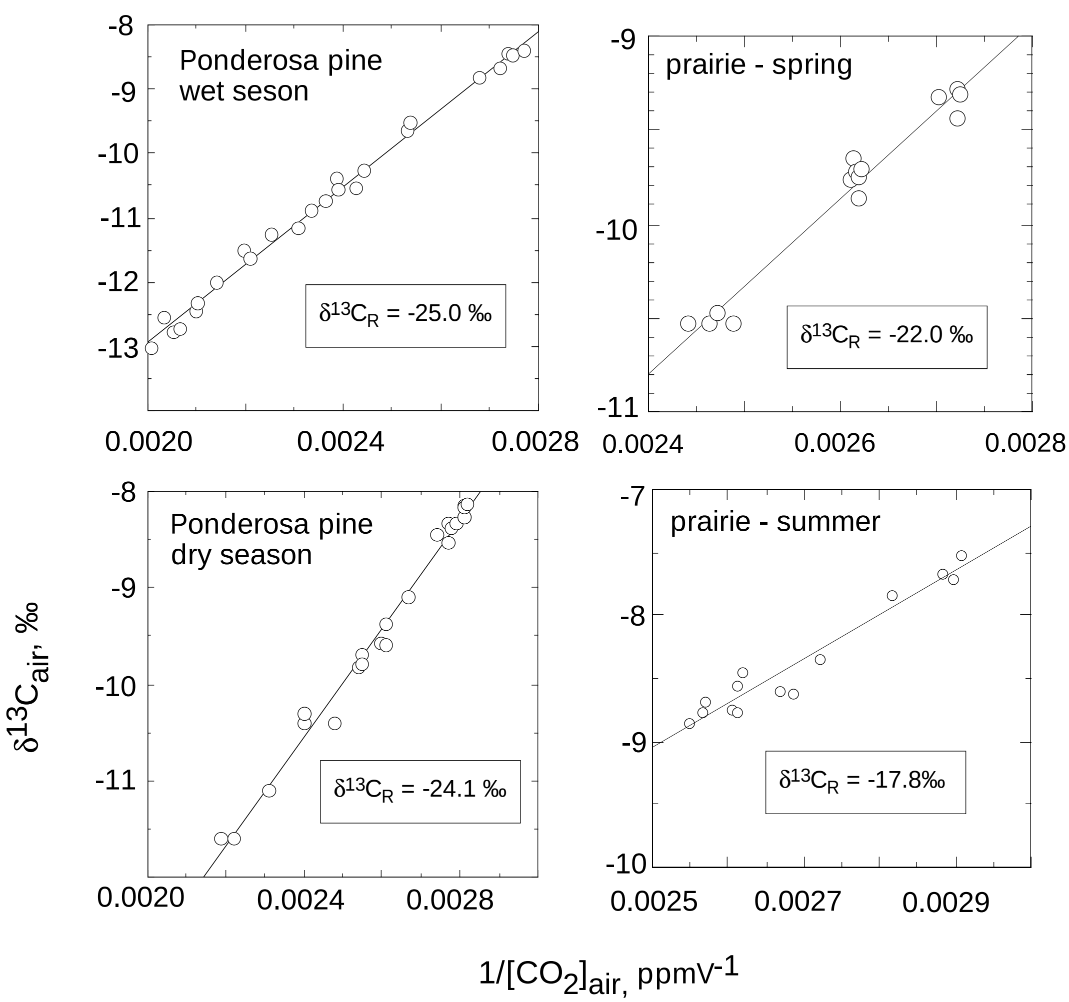

Figure 5. Dynamic changes in the Keeling-plot intercepts in response to (a) seasonal changes in water availability in C3 forests (left) and (b) shifts in C3/C4 activity in a grassland site. Data are from Ehleringer et al. and Berry et al. (unpublished observations).

the integrated isotope effect during photosynthesis will be reflected in the $\delta^{13}C$ value of respiration. If the model simulations and the observations don't match, it may indicate that we may have errors in physiological and biophysical parameters that determine the boundary layer, stomatal, and intracellular conductances or photosynthetic capacity -- all of which affect the steady-state concentration of CO_2 in the chloroplast and discrimination (eqn 2). More detailed studies with leaf chambers or sampling of recent products of photosynthesis would provide more specific insight (see other WLEF projects listed in Appendix 1).

Oxygen isotope discrimination. Ecosystem processes can also have a significant influence on the oxygen isotope ratio of atmospheric CO_2 (Francey and Tans, 1987; Friedli et al., 1987; Farquhar et al., 1993; Flanagan et al., 1997). The isotopic composition of oxygen in atmospheric CO_2 is determined by that of the last water in which the CO_2 was dissolved, as modified by fractionation during both photosynthetic assimilation and diffusion out of soils (Ciais et al, 1997a):

$$C_a \frac{f\delta^{18}{}_a}{ft} = \Delta_{pho} F_{pho} + F_{resp}(\delta^{18}{}_{resp} - \delta^{18}{}_a + \varepsilon_{resp}) \qquad (4)$$

Photosynthetic discrimination is given by

$$\Delta_{pho} = -\varepsilon_d + \frac{C_i}{C_a - C_i} \bullet \left(\delta_L{}^{18} - \delta^{18}{}_a\right) \qquad (5)$$

where ε_d represents kinetic fractionation during diffusion, and δ_L is the isotopic composition of the water in the chloroplasts of the leaves. This water is enriched in ^{18}O relative to that of the source water during evaporation of water transpired by leaves. Simple mechanistic models have been developed that can be used to calculate the isotope ratio of plant leaf water using relative humidity, temperature, and the stable oxygen isotope composition of soil water and atmospheric water vapor (Craig and Gordon, 1965; Flanagan et al., 1991; Roden and Ehleringer, 1999).

The same approaches described above for carbon isotope ratios to be measured at the WLEF tower can be used to determine the $\delta^{18}O$ value of CO_2 released during respiration at a range of different spatial scales The measurements of soil respired CO_2 can be compared with analyses of the $\delta^{18}O$ value of soil CO_2 to check the magnitude of the fractionation factor during CO_2 efflux from the soil (Hesterberg and Siegenthaler, 1991; Tans, 1997; Miller et al., 1999). In general, recent measurements of the $\delta^{18}O$ value of respired CO_2 show that CO_2 released from the boreal forest ecosystems is more depleted in ^{18}O than atmospheric CO_2 (Flanagan et al., 1997). This is consistent with soil respired CO_2 being in isotopic equilibrium with a water pool less enriched in ^{18}O than water in leaves of the above ground vegetation. Regional measurements of the $\delta^{18}O$ of respired CO_2, based on samples collected by aircraft flights over the boreal forest, also illustrate that respired CO_2 in northern latitudes is depleted in ^{18}O. Significant spatial and temporal variability among the oxygen isotope ratio of the components of ecosystem respired CO_2 may allow an analysis of their relative importance to ecosystem gas exchange, analogous to what can be accomplished using carbon isotope techniques.

Measurements to test simulations of oxygen isotope discrimination during photosynthesis are more problematic. The atmosphere is mixed much more vigorously during the day when photosynthesis is active and the gradients in [CO_2] and isotope ratio are typically much smaller than occur at night. It will certainly be possible to use chamber measurements, but these have the disadvantage of a small and possibly unrepresentative footprint. Yakir and Wang (1996) were able to measure oxygen isotope discrimination by analysis of gradients established over relatively smooth crop canopies. We think it unlikely that this method will succeed over the rough forest canopies surrounding WLEF. Several groups, including our own are attempting to devise relaxed eddy accumulation procedures suitable for discrimination measurements above forests. We will await a successful result before including this in our suite of measurements.

Environmental water plays a major role in determining the effect of ecosystem processes on the oxygen isotope of CO_2 exchanged by an ecosystem. The hydrologic inputs (precipitation and water vapor) will be measured. Accurately modeling the fractionation of water isotopes in leaves and soil is the primary challenge in modeling the impact of ^{18}O discrimination. A major focus of our ecophysiological work will be to collect samples of leaf and soil water and CO_2 that has exchanged with them for comparison with model simulations. This will be conducted at the ecosystem-scale using the Keeling plot approach and at the chamber scale. Because water moves much more rapidly through an ecosystem than organic carbon, these studies of oxygen exchange will represent much shorter integration times. To obtain a longer term view of environmental water, we will conduct isotopic measurements of organic material. Carbohydrates formed in leaves carry the isotopic signature of leaf water at the time of their synthesis and this is recorded in cellulose (Roden et al., 1999a, 1999b).

Overview of proposed research

This proposal brings together research expertise at different scales to obtain systematic measurements of the concentration and isotopic composition of air at the WLEF tower in Wisconsin and surrounding terrestrial ecosystems and to sample the isotopic composition of key components of these ecosystems to provide the data needed to interpret isotopic CO_2 composition. These measurements will provide information that is needed to provide boundary conditions for and test/improve intermediate and regional models that will allow the dynamic ^{13}C and ^{18}O data from terrestrial studies to be folded into existing inversion models at the continental and global scales. Further, these studies will explore strategies for obtaining data useful for inversion modeling from a continental site that is strongly influenced by local CO_2 exchange.

Our study expands the limited base of ecosystem-level isotope studies already in progress at eddy covariance towers within the AmeriFlux Program. Within the past 1-2 years, periodic canopy-level measurements of the isotopic composition and concentration of CO_2 have been initiated at 2 coniferous sites by Ehleringer (WRCC in Washington and Metolius in Oregon), on C_3 agricultural lands and C_4 prairie by Berry (Ponca City in Oklahoma), and on C_3 grasslands in Alberta by Larry Flanagan.

Our program would also have a strong modeling component. Scott Denning of CSU has played a leading role in development of models of the carbon cycle in global, biosphere atmosphere models. He has an independently funded program that will extend the process and transport models of this integrated modeling system to include the differential exchange of isotopic forms of CO_2. These models provide a framework for scaling that brings leaf and soil-level understanding of CO_2 exchange processes up to canopy, regional and continental scales. This scaling study is based on meteorological theory and is being tested against CO_2 concentration measurements at the WLEF tall tower in Park Falls, WI. Isotopic measurements are not currently conducted at this site and this project would leverage these ongoing studies to test and improve models at various scales.

Modeling will also be used to test strategies for isotopic sampling near the land surface. We are aware that other groups have tried to measure isotope fluxes from forest sites with limited success. We will use modeling to conduct simulated experiments that ask, "what can we expect to observe? and what does it mean?" as we design a strategy for sampling the near surface atmosphere over continental areas. This procedure will also permit us to formulate hypotheses about processes and scaling at meso- and global- scales. Our sampling program described below is designed to test the mesocale models; these models, in turn, will be used to construct basis functions for global-scale inverse calculations. This modeling framework, thus, provides the linkage for our ecosystem studies to inform global scale source/sink calculations.

From regional measurements of CO_2 dynamics collected from the top of the WLEF tower, there is a clear picture that both CO_2 concentration and isotopic composition are changing in response to changes in both anthropogenic emissions and biospheric photosynthesis/respiration (Figure 3). Joe Berry's group will focus on "Keeling plot" analyses based on air flask sampling to understand the isotopic $^{13}C^{18}O^{16}O$ signal emerging from 3 dominant landscape components: upland hardwood forest, low wetland forest, and distant agricultural activities. Jim Ehleringer's group will focus on quantifying the isotopic composition of water sources (vegetation, soil, atmosphere) and associated measures of the isotopic composition of vegetation and soil CO_2 fluxes critical to interpreting the ecosystem-level measurements made by Joe Berry's group. Upland and lowland forests should differ in $C^{18}O^{16}O$, providing strong endmember values for an integrated regional isotopic signal. Similarly, forest and agricultural (corn) ecosystems will differ in their $^{13}CO_2$ values, providing equally strong endmember differences and allowing for clear separation of the CO_2 signal emerging from these contrasting ecosystems.

During critical campaign-mode sampling periods (such as August 2000) when other investigators will be sampling at or near the WLEF tower, we will intensify sampling. Scott Denning's group will focus on developing ecosystem-to-regional carbon flux models constrained by the isotopic data.

Close coordination among the 3 project elements will be ensured by (a) common sharing of data sets immediately after acquisition, even in preliminary form, at our joint FTP sites, (b) joint field efforts, especially during campaigns, (c) joint training of research personnel so that all are familiar with the different techniques and approaches employed in the 3 labs, and (d) semi-annual joint meetings involving the postdoctoral associates and PIs associated with this project.

Statement of work - Carnegie Institution (Joe Berry)

We will set up and install and automated system to collect flask samples from the WLEF tower. A 16-port Valco switching valve in the heart of the system. A flask can be connected to each port. The 16 flasks of a design developed in the Berry lab hold 100 ml of air each and can be sealed with two glass and teflon stopcocks. Both stopcocks are attached to the valve with 1/16 inch stainless steel tubing and Ultra-torr fittings forming a leak tight loop with the stopcocks open. When selected by the valve, dry air can flow through the flask and on to a CO_2 IGRA. When deselected the loop containing the flask is sealed by the valve. Once a sample has been taken the stopcocks on the flask can be closed; exchanged with a fresh flask, and the sample is shipped back to Stanford for analysis. A data logger and laptop computer will be used to control the valve, collect data on the CO_2 concentration, and communicate with the home lab by modem. Using this system, we can schedule a sample sequence from our lab and later interrogate the CO_2 concentration logged for the sample sequence to determine if it was a successful run. Local technical assistance is required only to change the flasks on the system and to ship the flasks. We have constructed a prototype of this system and have tested all aspects of the design except remote control over phone lines. Assuming that we have a reliable phone or cell phone connection to the site, this should be straight forward.

A similar, but portable system will be constructed for ecosystem studies. Depending on the experiment, it can be setup to acquire samples from different heights on a mast or tower for analysis of ecosystem respiration (Keeling-Plots), sampling of eddies during mid day (photosynthesis plus respiration) and sampling of chambers used for respiration or photosynthesis studies. This system will be operated by personnel from the Berry or Ehleringer labs - rather than remotely.

Analysis of the flasks in Berry's lab at the Carnegie Institution will be conducted using a newly developed micro-analysis system comprised of a Finnigan-MAT Delta-S mass spectrometer coupled to a capillary gas chromatograph. A metered sample of air (ca. 1 ml per determination) is withdrawn from the flask; CO_2 is purified form water vapor and air cryogenically, and the CO_2 is introduce as a peak in flowing helium to the gas chromatograph. The separated peaks of CO_2 and N_2O flow through an open split to the inlet of the mass spectrometer. The isotope ratios are determined by integration of the peak using collectors specific for mass 44, 45 and 46. The concentration of CO_2 in the air sample is calculated knowing the quantity of air sampled (by manometry) and the size of the CO_2 peak (integration of mass 44). The unknown sample is alternated with samples of air from a NOAA-CMDL analyzed standard tank. We routinely take 5 samples of each and the $\delta^{18}O$, $\delta^{13}C$, and [CO_2] are calculated by reference to the NOAA standard. Precision of the method is 0.5 ppm CO_2 and 0.05 ‰ for the isotopes. The system has been automated with a Valco switching valve so that 10 flasks can be run in a batch. Each batch requires 8 hours. A technician in the Berry lab will run this system and manage the flasks. The theoretical capacity of our system to process flasks far exceeds the proposed sampling frequency. Some of this excess capacity will be used to process air samples collected by Ehleringer's group, allowing him to focus more on water and organic matter analyses. We will also be able to increase the frequency of sampling during intensive campaigns.

We anticipate that it will be possible to get the tower sampling equipment setup and running within three months of the start of the grant period. These systems will operate continuously for the duration of the grant. A portable system (constructed with independent funding) can be loaned to the project in case the permanent system is not in place by the intensive field campaign planned for August 2000.

Statement of work - University of Utah (Jim Ehleringer)

We will collect ecosystem-level measurements at the 4 site types likely to be influencing regional CO_2 dynamics as sampled by the upper reaches of the WLEF tower with the NOAA-CMDL project headed by Peter Bakwin (recall Figure 3). These first 3 sites influence summertime CO_2 observations, while the last site apparently influences wintertime CO_2 observations:

(a) upland forest ecosystem dominated by hardwood species; an existing AmeriFlux tower site for this ecosystem is nearby and operated by Ken Davis (15 km distant from WLEF tower and within footprint)

(b) lowland wet forest dominated by wetland coniferous species; an existing AmeriFlux tower site for this ecosystem is nearby and operated by Ken Davis (5 km distant from WLEF tower and within footprint)

(c) agricultural ecosystems, almost exclusively corn (we will set up a seasonal 10-m sampling mast; NOAA-CMDL data indicate that these agricultural fields are within the footprint

(d) urban CO_2 generated from petroleum and natural gas sources

These 3 summertime sites contrast in the expected $\delta^{13}C$ and $\delta^{18}O$ values for CO_2 fluxing from those ecosystems. Consider the contrasts likely to imprint distinct isotopic signals on the CO_2 among the 3 different ecosystems. The two forest landscape elements have C_3 photosynthesis, while the agricultural landscape component has C_4 photosynthesis; the C_3/C_4 contrast should result in a $\delta^{13}C$ difference of 10-12 ‰. The 2 forest landscape elements should have fundamentally different water sources during the growing season. Wetland ecosystems are expected to derive a significant fraction of their moisture from water received during the previous winter, while the upland forest will derive a significant fraction of the moisture from summer precipitation. The available IAEA data indicate that these water-source contrasts should result in $\delta^{18}O$ values for CO_2 fluxing from the two forests types that differ by 6-10 ‰. Thus, we have a clear potential to provide field data that will constrain possible interpretations from inverse modeling efforts.

The NOAA-CMDL data in Figure 3 indicate during the winter there are likely to CO_2 sources; the lighter $\delta^{13}C$ signal may represent a light fossil fuel source, such a natural gas. The inclusion of a wintertime CO_2 measurement will capitalize on the known $\delta^{13}C$ and $\delta^{18}O$ differences CO_2 emitted from fuel sources (e.g., natural gas) and native vegetation. The sampling will occur in conjunction with tower facilities available in a nearby city (most likely Rhinelander).

To characterize the isotopic composition of hydrologic components, at each of the 3 ecosystems we will measure (a) the $\delta^{18}O$ of precipitation (by major event), (b) the $\delta^{18}O$ of atmospheric water vapor (above and within canopy), and (c) the $\delta^{18}O$ of stem source water. From these measures, we can model the $\delta^{18}O$ of leaf water (Flanagan et al., 1991; Roden and Ehleringer, 1999). We will test these model predictions against field observations of the $\delta^{18}O$ of leaf water, in order to better predict $C^{18}O^{16}O$ values leaving ecosystems.

The $\delta^{18}O$ of ecosystem CO_2 will reflect input from both vegetative ($\delta^{18}O_{lw}$) and soils ($\delta^{18}O_{sw}$) components. We will measure $\delta^{18}O_{sw}$ using a sealed cuvette approach (Flanagan et al., 1999; Miller et al., 1999). These component data can then be compared with ecosystem-scale measures from the Keeling-analysis flask collections and scaled using eddy covariance flux data available for each of the sites.

Intensive field sampling will occur 5 times between spring and late fall, including any intensive campaigns planned for WLEF (such as the August 2000 campaign). At other times, we will hire a graduate student part-time from the University of Minnesota to assist in precipitation sampling and biweekly sampling of $\delta^{18}O_{lw}$, $\delta^{18}O_{sw}$, and $\delta^{18}O_{wv}$.

The isotope ratio of water from leaves ($\delta^{18}O_{lw}$), soils ($\delta^{18}O_{sw}$), and atmospheric water vapor ($\delta^{18}O_{wv}$) will be determined by equilibration of water with CO_2 followed by measurement of the isotope ratio using a delta S isotope ratio mass spectrometer (Precision is ± 0.2 ‰). Water vapor will be sampled by drawing air from different heights through a dry-ice slurry and freezing the water vapor in a trap (Flanagan et al., 1993). Leaf and soil waters will be sampled at midday. All water samples will be sealed in glass vials for transport back to the laboratory.

Soil CO_2 efflux from these ecosystems will complement existing whole ecosystem eddy covariance CO_2 flux measures. These data will be collected with a Licor Photosynthesis System (LI-6200) and a modified soil cuvette, operating in a closed-loop mode. We will use a plexiglass cuvette which covers 0.37 m^2 soil surface in place of the standard Licor soil-respiration chamber in order to (i) increase the sample area, (ii) reduce heterogeneity associated with patchy root distributions, and (iii) reduce chamber-edge effects. The chamber will have a total volume of ~100 L.

A precise estimate of the isotope ratio of soil respiration ($\delta^{13}C_{R\text{-soil}}$) is essential for partitioning $\delta^{13}C_R$ into above- and below-ground components. We will use the Keeling-type approach combining cuvette and gas analyses to calculate $\delta^{13}C_{R\text{-soil}}$ and $\delta^{18}O_{R\text{-soil}}$ (Flanagan et al., 1999).

Sun-lit leaves will be collected and dried and ground to a homogeneous mixture for measurement of $\delta^{13}C_p$ and $\delta^{18}O_p$. A 2-mg subsample will be combusted to produce CO_2 using an elemental analyzer coupled to a delta S isotope ratio mass spectrometer in the SIRFER facility for $\delta^{13}C_p$ analyses (Ehleringer, 1991) and a pyrolysis of cellulose used for $\delta^{18}O_p$ analyses (Sauer et al., 1998).

Statement of work - Colorado State University (Scott Denning)

We will work closely with the other investigators to refine the existing parameterization of stable isotope exchanges in SiB2 according to the data collected in the field. These data are particularly valuable because the existing algorithms are based on theoretical considerations and are largely unconstrained by macroscopic data. The isotopic model is already coupled to both CSU RAMS and the CSU GCM, and allows us to predict stable isotopic exchange and resulting $\delta^{13}C$ and $\delta^{18}O$ ratios in atmospheric CO_2 at multiple spatial scales. Simulations can be performed as "case studies" by prescribing observed weather and wind fields at a station or across a region; or as a fully coupled "forecast" in which the biophysics, isotope geochemistry, weather, and atmospheric transport interact and influence one another.

The improved model will be tested against atmospheric data at each field site by comparing simulated and observed time series of $\delta^{13}C$ and $\delta^{18}O$, forcing the model with observed weather. At the WLEF tower site, a richer suite of observations is available (multiple observing heights up to the mid-CBL; component fluxes in upland hardwood and lowland spruce forest, soil and snow physical data, etc). Here we will simulate the spatial and temporal variations of the isotopic tracers for intensive observing periods using the coupled SiB2-RAMS system, with a set of nested grids. The outer grid will be about 1000 km across, with a horizontal grid spacing of 64 km, with weather at lateral boundaries forced from operational products and tracer boundary conditions forced from the output of a global simulation with the CSU GCM. Two-way interactive nested grids will be run with spacing of 16, 4, 1, and 0.25 km within this outer grid. The innermost grid will resolve vegetation heterogeneity in the tall tower footprint and the vertical variations measured on the tower. Biophysical properties of the vegetation will be specified from remotely sensed data products (NDVI and subpixel mixtures of woody and herbaceous vegetation derived from 1 km AVHRR by Defries et al. (1999) for the outer grids, and 30 m LandSat Thematic Mapper imagery for the innermost grid). These simulations will be compared against tower data and also against flasks collected further aloft during the August 2000 intensive observing campaign by John Birks' team using balloon and kite soundings, Ron Dobosy's team using the LongEZ aircraft, and Steve Wofsy's COBRA team up to 10 km. These campaigns will allow us to evaluate the fully coupled modeling system at multiple spatial scales.

The results of the high-resolution coupled RAMS-SiB2 simulations will include realistic fully populated grids of CO_2, $\delta^{13}C$, and $\delta^{18}O$ over the upper Midwest, which we will use to test methods for regional extrapolation from surface measurements over the land surface. These tests will include an evaluation of the feasibility of estimating mid-CBL isotopic ratios using the "virtual tall tower" concept pioneered by Ken Davis, in which AmeriFlux data may be used to correct for local offsets to concentrations due to strong surface fluxes and turbulence to obtain regionally-representative "background" values appropriate for use in inversions. In addition, we will test the feasibility of routine aircraft soundings for stable isotopic composition of CO_2 by subsampling our simulated atmosphere with "virtual aircraft." This will include a careful assessment of spatial and temporal variability of the isotopic tracers in the model and the representativeness of these ratios as measured by the various sampling systems.

After conducting the intensive regional simulations and comparing to the data collected in the intensive observing period, we will extend the simulations to the scale of the entire continental USA using the mesoscale model in "climate" mode (ClimRAMS) on a 50 km grid. Weather on the lateral boundaries will be specified from NCEP reanalysis products. We will prescribe trace gas boundary conditions from a global simulation with the CSU GCM (Denning et al., 1996, 1999). The global fluxes that control these trace gas boundary conditions will be optimized through synthesis inversion to ensure consistentency with the NOAA flask network. The ClimRAMS simulation will then produce fully populated 3-dimensional fields of the trace gases on the 50 km grid which we will archive hourly for one year. These "pseudodata" will be consistent with the field measurements of isotopic exchange processes, with the actual weather, with the state of the vegetation as measured from space, and with the NOAA flask measurements at the global scale.

We will investigate the feasibility of performing mesoscale inversions on these pseudodata, by assuming various configurations of atmospheric sampling networks that might be deployed in the future using aircraft, surface measurements, tall towers, or micrometeorological extrapolation ("virtual tall towers"). We will subsample the large pseudodata volume at this hypothetical network and try to recover the regional fluxes that produced it in the model. Unlike inversions of real data, we will know the flux distribution exactly, so we will be able to rigorously evaluate these inversions and quantify the error in the results depending on the configuration of the hypothetical observing network. These studies will be essential for the design of continental observing systems in the future, and we will explore the ways in which stable isotopic tracers might add value to such a network.

Finally, we will use the results of the local, regional, and continental experiments described above to develop isotopic basis functions for global inverse models which include realistic variations of coupled CO_2, $\delta^{13}C$, and $\delta^{18}O$ exchanges in both space and time. These basis functions should allow inverse calculations to distinguish much more reliably between ocean and terrestrial uptake at similar latitudes (using $\delta^{13}C$). In addition, the use of spatially and temporally varying distributions of $\delta^{18}O$ exchanges will allow global inversions that recover distributions of gross photosynthesis and respiration, rather than simply the net flux (Peylin, 1999). This will allow inverse modeling to move beyond simple diagnosis of flux maps toward a better understanding of the processes responsible for the sources and sinks, which is necessary if we are to predict changes in the carbon cycle in the future.

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Recent Publications Most Closely Related Or Significant To Project:

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Woodrow, I. E., J. T. Ball, and J. A. Berry. 1990. Control of photosynthetic carbon dioxide fixation by the boundary layer, stomata and ribulose 1,5-biphosphate carboxylase/oxygenase. *Plant Cell Environ.* **13**:339-347.

Collatz, G. J., J. T. Ball, C. Grivet, and J. A. Berry. 1991. Physiological and environmental regulation of stomatal conductance, photosynthesis and transpiration: a model that includes a laminar boundary layer. *Agricultural and Forest Meteorology* **54**:107-136.

Berry, J. A. 1992. Biosphere, atmosphere, ocean interactions: a plant physiologist's perspective, *In:* P. G. Falkowski and A. D. Woodhead (eds.), *Primary Productivity and Biogeochemical Cycles in the Sea*, pp. 441-454. Plenum Press, New York.

Cardon, Z., and J. A. Berry. 1992. Effects of O_2 and CO_2 concentration on the steady-state fluorescence yield of single guard cell pairs in intact leaf discs of *Tradescantia albiflora*: evidence for Rubisco-mediated CO_2 fixation and photorespiration in guard cells. *Plant Physiol.* **99**:1238-1244.

Collatz, G. J., M. Ribas-Carbo, and J. A. Berry. 1992. Coupled photosynthesis-stomatal conductance model for leaves of C_4 plants. *Aust. J. Plant Physiol.* **19**:519-538.

Mott, K. A., Z. G. Cardon, and J. A. Berry. 1992. Asymmetric patchy stomatal closure for the two surfaces of *Xanthium strumarium* L. leaves at low humidity. *Plant Cell Environ.* **16**:25-34.

Sellers, P. J., J. A. Berry, G. J. Collatz, C. B. Field, and F. G. Hall. 1992. Canopy reflectance, photosynthesis and transpiration. III. A reanalysis using improved leaf models and a new canopy integration scheme. *Remote Sensing of Environment* **42**:187-216.

Guy, R. D., M. L. Fogel, and J. A. Berry. 1993. Photosynthetic fractionation of stable isotopes of oxygen and carbon. *Plant Physiol.* **101**:37-47.

Tans, P. P., J. A. Berry, and R. F. Keeling. 1993. Oceanic $^{13}C/^{12}C$ observations: a new window on ocean CO_2 uptake. *Global Biogeochemical Cycles* **7**:353-368.

Cardon, Z. G., J. A. Berry, and I. E. Woodrow. 1994. Dependence of the extent and direction of average stomatal response in *Zea mays* L. and *Phaseolus vulgaris* L. on the frequency of fluctuations in environmental stimuli. *Plant Physiol.* **105**:1007-1013.

Ciais, P., P. P. Tans, J. W. C. White, M. Trolier, R. J. Francey, J. A. Berry, D. R. Randall, P. J. Sellers, J. G. Collatz, and D. S. Schimel. 1995. Partitioning of ocean and land uptake of CO_2 as inferred by ^{13}C measurements from the NOAA climate monitoring and diagnostics laboratory global air sampling network. *J. Geophys. Res.* **100**:5051-5070.

Randall, D. A., P. J. Sellers, J. A. Berry, D. A. Dazlich, C. Zhang, G. J. Collatz, A. S. Denning, S. O. Los, C. B. Field, I. Fung, C. O. Justice, and C. J. Tucker. 1995. A revised land surface parameterization (SiB2) for atmospheric GCMs. Part 3: The greening of the CSU GCM. *J. of Climate* **9:**738-763.

Sellers, P. J., L. Bounoua, G. J. Collatz, D. A. Randall, D. A. Dazlich, S. Los, J. A. Berry, I. Fung, C. J. Tucker, C. B. Field, and T. G. Jenson. 1996. A comparison of the radiative and physiological effects of doubled CO_2 on the global climate. *Science* **271:**1402-1406.

Sellers, P. J., D. A. Randall, C. J. Collatz, J. A. Berry, C. B. Field, D. A. Dazlich, C. Zhang, and G. D. Colello. 1996. A revised surface parameterization (SiB2) for atmospheric GCMs. Part 1: Model formulation. *J. Climate* **9:**676-705.

Denning, A. S., G. J. Collatz, C. Zhang, D. A. Randall, J. A. Berry, P. J. Sellers, G. D. Colello and D. A. Dazlich. 1996. Simulations of terrestrial carbon metabolism and atmospheric CO_2 in a general circulation model. Part 1: Surface carbon fluxes. *Tellus* **48B**:521-542.

Ciais, P., A. S. Denning, P. P. Tans, J. A. Berry, D. A. Randall, G. J. Collatz, P. J. Sellers, J. W. C. White, P. Monfray, and M. Heimann. 1997. A three-dimensional synthesis study of ^{18}O in atmospheric CO_2. 1. Surface fluxes. *J. Geophysical Res.* **102**:5857-5872.

Ciais, P., P. P. Tans, A. S. Denning, R. J. Francey, M. Trolier, H. A. J. Meijer, J. W. D. White, J. A. Berry, D. A. Randall, G. J. Collatz, P. J. Sellers, P. Monfray, and M. Heimann. 1997. A three-dimensional synthesis study of ^{18}O in atmospheric CO_2. 2. Simulations with the TM2 transport model. *J. Geophysical Res.* **102**:5873-5883.

Colello, G. D., C. Grivet, P. J. Sellers, and J. A. Berry. 1998. Modeling of energy, water, and CO_2 flux in a temperate grassland ecosystem with SiB2. 1998. *J. Atmospheric Sciences* 55:1141-1169.

Berry, J.A., P.J. Sellers, D.A. Randall, G.J. Collatz, G.D. Colello, S. Denning, and C. Grivet 1997 SiB2, a model for simulation of biological processes within a climate model, In P. van Gardingen, G. Foody, and P. Curran, (ed.), *SEB Seminar Series 63 Scaling-up, From cell to Landscape.* pp. 347-369 Cambridge University Press, Cambridge.

Sellers, P.J., R.E. Dickinson, D.A. Randall, A.K. Betts, F.G. Hall, J.A. Berry, G.J. Collatz, A.S. Denning, H.A. Mooney, C.A. Nobre, N. Sato, C.B. Field and A. Henderson-Sellers. 1997 Modeling the exchanges of energy, water, and carbon between continents and the atmosphere, *Science* 275:502-509

Fung, I.Y., C.B. Field, J.A. Berry, M.V. Thompson, J.T. Randerson, C.M. Malmstrom, P.M. Vitousek, G.J. Collatz, P.J. Sellers, D.A. Randall, A.S. Denning, F. Badeck and J. John. 1997 Carbon 13 exchanges between the atmosphere and biosphere. *Global Biogeochem. Cycles* 11: 507-533.

Collatz, G.J., J.A. Berry and J.S. Clark. 1998. Effects of climate and atmospheric CO_2 pressure on the global distribution of C_4 grasses: present, past, and future. *Oecologia*,114: 441-454.

Peylin, P., P. Ciais, A.S. Denning, P. Tans, J.A. Berry and J.W.C. White. 1999. A 3-dimensional study of the $\delta^{18}O$ in atmospheric CO_2: Contribution of different land ecosystems. *Tellus* 51B: 642-667.

A. Scott Denning

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Education:

B.A., Geological Sciences, 1984. University of Maine, Orono, Maine. Highest Honors.
M.S., Atmospheric Science, 1993. Colorado State University, Ft. Collins, Colo.
Ph.D. Atmospheric Science, 1994. Colorado State University, Ft. Collins, Colo.

Professional Experience:

1998– : Assistant Professor, Department of Atmospheric Science, Colorado State University
Atmosphere-biosphere interactions. Global carbon cycle. Land-surface climate.

1996–98 : Assistant Professor, Donald Bren School of Environmental Science and Management, University of California, Santa Barbara.

1994–96: Postdoctoral Research Associate, Department of Atmospheric Science, Colorado State University, Fort Collins, CO. David A. Randall, supervisor. (NASA supported).

Global-scale atmosphere-biosphere interactions using a general circulation model.
1990–1994: Graduate Research Assistant, Department of Atmospheric Science, Colorado State University, Fort Collins, CO. David A. Randall, supervisor. (NASA supported).

Synthesis inversion of the global carbon budget using a general circulation model.
1986–90: Research Associate, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO. Jill S. Baron, supervisor. (NPS supported).

Biogeochemical and hydrologic dynamics of an alpine-subalpine watershed.
1985–86: Wellsite Geochemist, GEO Inc., Denver, CO.

Gas chromatographic and lithologic analyses in support of oil exploration objectives.
1980–85: Research Assistant, Department of Geological Sciences, University of Maine.

Paleolimnologic Investigation and Reconstruction of Lake Acidification.

Selected Publications:

Denning, A. S., I. Y. Fung, and D. A. Randall, 1995: Latitudinal gradient of atmospheric CO_2 due to seasonal exchange with land biota. Nature, 376, 240-243.

Denning, A. S., J. G. Collatz, C. Zhang, D. A. Randall, J. A. Berry, P. J. Sellers, G. D. Colello, and D. A. Dazlich, 1996. Simulations of terrestrial carbon metabolism and atmospheric CO_2 in a general circulation model. Part 1: Surface carbon fluxes. Tellus, 48B, 521-542.

Denning, A. S., D. A. Randall, G. J. Collatz, and P. J. Sellers, 1996. Simulations of terrestrial carbon metabolism and atmospheric CO_2 in a general circulation model. Part 2: Spatial and temporal variations of atmospheric CO_2. Tellus, 48B, 543-567.

Law, R. M., P. J. Rayner, A. S. Denning, D. Erickson, M. Heimann, S. C. Piper, M. Ramonet, S. Taguchi, J. A. Taylor, C. M. Trudinger, and I. G. Watterson, 1996. Variations in modelled atmospheric transport of carbon dioxide and the consequences for CO_2 inversions. Global Biogeochemical Cycles, 10, 783-796.

Sellers, P. J., R. E. Dickinson, D. A. Randall, A. K. Betts, F. G. Hall, J. A. Berry, C. J. Collatz, A. S. Denning, H. A. Mooney, C. A. Nobre, and N. Sato, 1997. Modeling the exchanges of energy, water, and carbon between the continents and the atmosphere. Science, 275, 502-509.

Ciais, P., A. S. Denning, P. P. Tans, J. A. Berry, D. A. Randall, G. J. Collatz, P. J. Sellers, J. W. C. White, M. Trolier, H. J. Meijer, R. J. Francey, P. Monfray, and M. Heimann, 1997: A three-dimensional synthesis study of $\delta^{18}O$ in atmospheric CO_2. Part 1: Surface fluxes. Journal of Geophysical Research, 102, 5857-5872.

Ciais, P., P. P. Tans, A. S. Denning, R. J. Francey, M. Trolier, H. J. Meijer, J. W. C. White, J. A. Berry, D. A. Randall, G. J. Collatz, P. J. Sellers, P. Monfray, and M. Heimann, 1997: A three-dimensional synthesis study of $\delta^{18}O$ in atmospheric CO_2. Part 2: Simulations with the TM2 transport model. Journal of Geophysical Research, 102, 5873-5883.

Fung, I., C. B. Field, J. A. Berry, M. V. Thompson, J. T. Randerson, C. M. Malmstrom, P. M. Vitousek, G. J. Collatz, P. J. Sellers, D. A. Randall, A. S. Denning, F. Badeck, and J. John, 1997. Carbon-13 exchanges between the atmosphere and biosphere. Global Biogeochemical Cycles, 11, 507-534.

Berry, J. A., G. J. Collatz, A. S. Denning, G. D. Colello, W. Fu, C. Grivet, P. J. Sellers, and D. A. Randall, 1997: SiB2, a model for simulation of biological processes within a climate model. In: P. van Gardingen, G. Moody, and P. Curran. (Eds.), Scaling Up, Society for Experimental Biology, Cambridge University Press, 347-370.

Pielke, R. A., R. Avissar, M. Raupach, H. Dolman, X. Zeng, and S. Denning, 1998. Interactions between the atmosphere and terrestrial ecosystems: influence on weather and climate. Global Change Biology, 4, 101-115.

Denning, A. S., M. Holzer, K. R. Gurney, M. Heimann, R. M. Law, P. J. Rayner, I. Y. Fung, S.-M. Fan, S. Taguchi, P. Friedlingstein, Y. Balkanski, J. Taylor, M. Maiss, and I. Levin, 1999. Three-dimensional transport and concentration of SF6: A model intercomparison study (TransCom 2). Tellus, 51B, 266-297.

Denning, A. S., T. Takahashi and P. Friedlingstein, 1999. Can a strong atmospheric CO_2 rectifier effect be reconciled with a "reasonable" carbon budget? Tellus, 51B, 249-253.

Peylin, P., P. Ciais, A. S. Denning, P. P. Tans, J. A. Berry, and J. W. C. White. A three-dimensional study of $\delta^{18}O$ in atmospheric CO_2: Contribution of different land ecosystems. Tellus, 51B, 642-667.

Potosnak, M. J., S. C. Wofsy, A. S. Denning, T. J. Conway, and D. H. Barnes, 1999. Influence of biotic exchange and combustion sources on atmospheric CO_2 concentrations in New England from observations at a forest flux tower. Journal of Geophysical Research, 104, 9561-9569.

Budget and Budget Justifications

Budget Justification for University of Utah

Salaries and benefits. Funds are requested to for a 0.75 FTE postdoctoral associate ($30,000/yr base salary) and a 0.25 FTE graduate student ($18,000/yr base salary). The postdoctoral associate will oversee all aspects of field sample collection and stable isotope ratio analyses for the Utah portion of the project. The PI (Ehleringer) and the postdoctoral associate will provide the linkages between the data collection at the Carnegie Institution and modeling efforts at Colorado State University through frequent communications and semi-annual inter-university project meetings. The graduate student funds will be used to hire local assistance from the University of Minnesota (Ken Davis or Paul Bolstad labs). Fringe benefits are estimated at 20% for the postdoctoral associate and at 9% for the graduate student. Annual salary increases are projected to be 3% annually.

Travel. Funds are requested to cover the cost of travel to the field sites (travel, per diem, and lodging) 4 times per year and to cover the expenses for the PI and postdoctoral associate to attend semi-annual meetings associated with the project.

Materials and Supplies. Funds are requested to cover the costs of lab and field supplies associated with the collection of stable isotope samples (air, water, and organic samples). Funds are also requested to cover the shipping costs for samples collected by the graduate student and sent back to Utah for processing.

Stable isotope analyses. Funds are requested to analyze 1,050 samples for their isotope ratios. All users of the SIRFER facility must pay a minimum break even cost for analysis. If we do all of the work, we pay $8/sample, which covers the cost of expendables and equipment repair/maintenance.

Telephone. Funds are requested to cover long-distance costs associated with communications among Pis and with communication with WLEF personnel and the graduate student at Minnesota.

Xeroxing. Funds are requested to cover the costs of duplication needs associated with the project.

Indirect Costs. Under a special agreement with Utah's Office of Sponsored Projects, we have been able to obtain an indirect cost rate of 20% MTDC for this project, which is identical to the CSU agreement between NOAA and the Cooperative Institute for Research in the Atmosphere at Colorado State University.

Budget Justification for Colorado State University

Salaries. A total of $121,044 is requested for salaries. One month of salary support per year (at $6,722/month) is requested for the Principal Investigator (Denning) for the coordination and planning of the research activities. Four and a half months of salary support per year (at $2,967/month) are requested for a Research Associate (Neil Suits), for Year 1 and 4 months/year for the rest of the period of performance. One month of salary support per year (at $4,067/month) is requested for a Research Associate (Marek Uliasz). He will be involved in analyzing the research results and producing model runs. 1 month of salary support per year (at $3,542/month) is requested for a scientific and systems programmer (John Kleist). He will procure and set up the computer system and software requested (see details below), analyze data for the study area, and administer the computer systems required to conduct the research. One half of a month of salary support per year (at $2,233/month) is requested for a Research Coordinator (Connie Uliasz). She will produce scientific graphics and be responsible for Web development and for logistical duties associated with communication and collaboration. A graduate student researcher (Ni Zhang) will work half time on this project and be supported for the other half through other work. Consistent with CSU practice, she will be promoted one grade per year if sufficient progress toward the graduate degree is achieved.

Benefits. A total of $17,578 is requested for fringe benefits. Fringe benefits are billed by CSU in the amount of 17.8% of salary for professional employees and 3.6% for the Graduate Research Assistant. Many of these figures are adjusted in later years to reflect cost projections of the University.

Travel. A total of $9,364 is requested to support domestic travel related to this project. This includes 1 trip each per year (at $1,500 per trip) for Scott Denning and Neil Suits to travel for collaborative meetings, inflated at 4% a year.

Materials and Supplies. We request $395 in Years 1 and 3 to cover the costs of data cartridges for the storage of research results, inflated at 4% per year, for a total of $822.

Tuition. Funds are requested ($1,347) for one semester per year of in-state tuition for the graduate research associate, inflated at 4% per year.

Equipment. We request a total of $5,621 for equipment. This includes the purchase of a desktop computer for the graduate student in Year 1 and disks for the server computer in Year 2.

Other Direct Costs. The data analysis and visualization associated with this work will require a substantial investment in commercial software and computer services, primarily in the beginning of the project. A total of $3,632 over the three years is requested to cover workstation maintenance and software agreements, hardware repairs, technical support and use of Department and University computers. We request $600 per year (inflating 4% annually) to cover direct costs of communication with other members of the project and NOAA collaborators. This includes long-distance telephone charges, fax, and FedEx charges.

Indirect Costs. Under a cooperative agreement between NOAA and the Cooperative Institute for Research in the Atmosphere at Colorado State University, indirect costs are billed at 20% of modified direct costs. Indirect costs for this work are $10,192 in Year 1, $10,080 in Year 2, and $10,591 in Year 3, for a total of $30,863. Indirect costs are not charged on tuition or equipment.

Budget Justification for the Carnegie Institution of Washington

Direct Labor. Funds are requested for a 0.75 FTE technician. This individual will be responsible for operation and maintains of the mass spectrometer, management of field acquisition of samples, shipping receiving and organizing flasks, and managing data. Fringe benefits are calculated at 28.5%, and the salary is project to increase at 4% per year.

Equipment. Funds are requested in the first year to construct an automated sampling system to be installed at the WLEF tower and a portable sampling system to be use at remote sites. A total of $27K is requested. This will be used to purchase 3 Valco valves with microprocessor actuators; flasks (120 @ $100/each) for $12K; 2 Campbell Scientific data loggers $2.4K; 2, 486 laptop computers $1K; 2 CO_2 analyzers, $6K; pumps, $0.8K.

Materials and Supplies. Funds requested in this category will be used to purchase expendable supplies and maintenance for the mass spectrometer, for supplies needed in running the sampling systems and for shipping of the flasks between WLEF and my lab at Stanford CA. Also included in this category are funds to contract with a person in the WLEF area to assist in collecting samples. The individual will come to the site to recharge the automated sampling system and would be responsible for shipping and receiving flasks. I estimate that this will require 8 hr per month @ $20/hr or $2K .

Domestic Travel. Funds are requested to attend research coordination meetings with our group and others working at the WLEF site. We also plan 5 trips to the WLEF tower site per year. These are required to setup and maintain the auto sampling system and to conduct field sampling.

PROPOSED BUDGET

Institution: Carnegie Institution of Washington

Principal Investigator: Joseph A. Berry

Project Title: Monitoring and Modeling CO2 Isotopic Exchange Between the Atmosphere and the Terrestrial Biosphere

	Notes	year 1	year 2	year 3	Summary 3 years
1. Direct Labor					
Technician	0.75 FTE	$ 26,250	$ 27,300	$ 28,392	$ 81,942
Total Salaries		$ 26,250	$ 27,300	$ 28,392	$ 81,942
Fringe Benefits	28.5%	$ 7,481	$ 7,780	$ 8,091	$ 23,352
Total Salaries and Benefits		$ 33,731	$ 35,080	$ 36,483	$ 105,294
2. Other Direct Costs					
a. Subcontracts		$ -	$ -	$ -	$ -
c. Equipment					
Automated samplers	see remarks	$ 27,000			$ 27,000
d. Supplies					
Materials and Supplies	see remarks	$ 5,000	$ 5,000	$ 5,000	$ 15,000
e. Travel					
Domestic	see remarks	$ 5,000	$ 5,000	$ 5,000	$ 15,000
Total Other Direct Costs		$ 37,000	$ 10,000	$ 10,000	$ 57,000
Total Direct Costs		$ 70,731	$ 45,080	$ 46,483	$ 162,294
3. Indirect Costs	58% TMDC	$ 25,363	$ 26,146	$ 26,960	$ 78,469
4. Other Applicable Costs					
5. SUBTOTAL		$ 96,094	$ 71,226	$ 73,443	$ 240,763
6. Proposed Cost Sharing					
7. Carryover Funds					
8. TOTAL ESTIMATED COST		$ 96,094	$ 71,226	$ 73,443	$ 240,763

Proposed budget

Institution: Colorado State University
Principal Investigator: A. Scott Denning
Project title: Measurement and modeling CO2 isotopic exchange between the atmosphere and the terrestrial biosphere

Sponsor Contribution	Year 1	Year 2	Year 3	Total
PERSONNEL SALARIES				
Academic Faculty:	$6,722	$6,991	$7,271	$20,984
Fringe Rate	$1,197	$1,265	$1,352	$3,814
Administrative Professional:	$23,192	$22,577	$23,481	$69,250
Fringe Rate	$4,128	$4,086	$4,367	$12,581
State Classified:	$0	$0	$0	$0
Fringe Rate	$0	$0	$0	$0
Post-Doctorates:	$0	$0	$0	$0
Fringe Rate	$0	$0	$0	$0
Non-Student Hourly:	$0	$0	$0	$0
Fringe Rate	$0	$0	$0	$0
Student Hourly:	$0	$0	$0	$0
Fringe Rate	$0	$0	$0	$0
GRA's:	$9,870	$10,265	$10,675	$30,810
Fringe Rate	$355	$380	$448	$1,183
TOTAL SALARY:	$39,784	$39,833	$41,427	$121,044
TOTAL FRINGE:	$5,680	$5,731	$6,167	$17,578
TOTAL PERSONNEL:	**$45,464**	**$45,564**	**$47,594**	**$138,622**
DOMESTIC TRAVEL:	**$3,000**	**$3,120**	**$3,244**	**$9,364**
INTERNATIONAL TRAVEL:	**$0**	**$0**	**$0**	**$0**
MATERIALS AND SUPPLIES	**$395**	**$0**	**$427**	**$822**
OTHER DIRECT COSTS				
In-State Tuition:	$1,347	$1,401	$1,455	$4,203
Out-State Tuition:	$0	$0	$0	$0
Publications:	$0	$0	$0	$0
Participant Stipends:	$0	$0	$0	$0
Participant Allowances:	$0	$0	$0	$0
Participant Travel:	$0	$0	$0	$0
Equipment Use Fees:	$500	$520	$541	$1,561
Animal Care:	$0	$0	$0	$0
Consultants:	$0	$0	$0	$0
Other:	$1,600	$1,196	$1,148	$3,944
TOTAL OTHER DIRECT:	**$3,447**	**$3,117**	**$3,144**	**$9,708**
SUBCONTRACTS:	**$0**	**$0**	**$0**	**$0**
EQUIPMENT:	**$2,502**	**$3,119**	**$0**	**$5,621**
TOTAL DIRECT COSTS:	**$54,808**	**$54,920**	**$54,409**	**$164,137**
INDIRECT COSTS:	**$10,192**	**$10,080**	**$10,591**	**$30,863**
TOTAL:	**$65,000**	**$65,000**	**$65,000**	**$195,000**

Proposed NOAA Budget

Institution: University of Utah
P.I.: James Ehleringer
Project Title: Monitoring and modeling CO_2 isotopic exchange between the atmosphere and terrestrial biosphere

	year 1	year 2	year 3	total
Principal investigator				
James Ehleringer	$ -	$ -	$ -	$ -
Graduate student - 0.25 FTE	$ 4,500	4,635	$ 4,774	$ 13,909
benefits	$ 405	$ 417	$ 430	$ 1,252
Postdoctoral associate - 0.75 FTE	$ 22,500	23,175	$ 23,870	$ 69,545
benefits	$ 4,500	$ 4,635	$ 4,774	$ 13,909
Supplies and expendables	$ 3,600	3,708	$ 3,819	$ 11,127
Domestic travel	$ 8,100	8,343	$ 8,593	$ 25,036
Other direct costs				
Stable isotope ratio analyses	$ 8,400	$ 8,400	$ 8,400	$ 25,200
Telephone	$ 720	742	$ 764	$ 2,225
Xeroxing	$ 250	258	$ 265	$ 773
Total direct costs	$ 52,975	$ 54,312	$ 55,690	$ 162,977
Indirect costs: (20% as per VP Koehn 10/11/99)	10,595	10,862	11,138	$ 32,595
Total funds requested	$ 63,570	$ 65,175	$ 66,828	$ 195,572

Current and pending support

Current Support for Jim Ehleringer (Principal Investigator)

NASA	Carbon and Oxygen Isotope Ratio CO_2 Flux Analyses at the Soil, Canopy, and Landscape Scales (NASA-LBA) J. Ehleringer and L. Flanagan (co-PIs)	7/98 - 2/01	$233K / yr
NASA	Continued Support of the GCTE Focus 1 Office	8/98 - 7/01	$147K / yr
EPA	Nitrogen Deposition and UV Stressor Impacts in Canyonlands National Park As Affected By Climatic Pulse Events (Utah portion) J. Belnap, M. Caldwell, R.D. Evans, R. Sanford Jr. (co-PIs)	10/98- 9/00	$41K / yr
NSF	Sensitivity to change in aridland ecosystems (SCALE) J.R. Ehleringer and R.D. Evans (co-PIs)	8/98 - 7/01	$310K / yr
	Exploring the Utility of Stable Isotopes for Sourcing Drugs	7/99 - 6/00	$221K / yr
DOE	WESTGEC, Stable isotope analyses at the Wind River Canopy Crane Facility	7/98-6/00	$80K / yr
	Exploring the Utility of Stable Isotopes for Sourcing Explosives	11/98 - 10/99	$112K / yr
USDA	Isotopic Analyses of Ecosystem Respiration and Photosynthetic Discrimination along the OTTER Transect, J. Ehleringer and B. Bond (co-PIs)	10/99 - 9/02	$128K / yr
NSF	Using natural variation is isotopic composition of forest CO_2 to study ecosystem-atmosphere carbon exchange J. Ehleringer and R. Monson (co-PIs)	10/99 - 9/01	$88K / yr
Packard	Atmospheric CO_2 controls over animal evolution and extinction, T. Cerling, D. Dearing, J. Harris (co-PIs)	7/99 - 6/04	$240K / yr

Pending Support for Jim Ehleringer (Principal Investigator)

TSWG	Stable Isotopes for Sourcing Explosives	11/99 - 10/01	$229K / yr
NOAA	Monitoring and Modeling CO_2 Isotopic Exchange Between the Atmosphere and the Terrestrial Biosphere J. Ehleringer, J. Berry, S. Denning (co-PIs)	06/00 - 05/03	$64K / yr

Current and Pending Support: Joseph A. Berry

NAME (List PI/PD #1 first)	SUPPORTING AGENCY AND AGENCY NUMBER	TOTAL $ AMOUNT	EFFECTIVE AND EXPIRATION DATES	% OF TIME COMMITTED	TITLE OF PROJECT
	Current:				
JA Berry CB Field	NASA EOS NAS531731	$970k	1/1/91 - 12/31/99	15	Biosphere/Atmosphere interactions
JA Berry CB Field	DOE-NIGEC	$75k	7/1/99 - 6/30/00	5	Effects of increased CO_2 on ecosystem water balance: Experimental and modeling studies
JA Berry O Bj rkman CB Field	Mellon Foundation	$590k	4/1/96 - 12/31/00	5	Program in global ecosystem function
JA Berry Shashi Verma (Subcontract)	DOE-NIGEC LWT6212308543	$43k	7/1/99-6/30/00	5	Net exchange of carbon dioxide in grassland and agricultural ecosystems in the ARM-CART region: Modeling and year-round Measurements.
JA Berry Shashi Verma (Subcontract)	DOE-NIGEC LWT6212308502	$40k	1/1/96 — 6/30/00	5	Measurement and Modeling of net exchange of carbon dioxide in grassland and agricultural ecosystems in the ARM/CART region
JA Berry	NSF (TECO) DEB 9814976	$243k	9/1/98 — 9/30/00	10	Studies of Radon and CO_2 Exchange by the Land Surface and their Transport in the Surface Layer and Planetary Boundary Layer
JA Berry	CIW	$10k	7/1/99-6/30/00		Independent Research
JA Berry E Walter-Shay (Subcontract)	NASA SHAEA6231817703	$46k	3/1/98-2/28/01	5	Characterization and Improvement of EOS land products using measurements at Ameriflux grasslands and wheat sites in the ARM-CART Region
	Pending:				
JA Berry (Subcontract)	NASA EOS/GMAP	$150k	3/1/00 — 2/28/03	5	Improved Parameterization of Land-Surface Processes Using EOS Data Products (Subcontract with Colo. State -- PI Scott Denning)
JA Berry CB Field Subcontract	NASA EOS/IDS	$300k	3/1/00 — 2/28/03	5	Biosphere/Atmosphere interactions (Subcontract with UC Berkeley — PI I. Fung)

JA Berry CB Field Subcontract	NASA EOS/New Data Products	$300k	3/1/00 — 2/28/03	5	Incorporating new EOS data products into models to improve estimates of biogeochemical processes (Subcontract with UC Davis — PI S. Ustin)
JA Berry	NOAA GC00 280	$240k	4/1/00 - 3/31/03	10	Monitoring and Modeling CO_2 Isotopic Exchange Between the Atmosphere and the Terrestrial Biosphere

Current and Pending Support

See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: A. Scott Denning

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: X Current Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title:
The Earth System Science Workbench: A Scalable Infrastructure of ESIPs
Contract No. KK8023

Source of Support: Univ. of California, Santa Barbara/NASA

Total Award Amount: $55,267 Total Award Period Covered: 03/01/1998-01/31/2001

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. .5 Cal: .5 Acad: 0 Sumr: 0

Support: X Current Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title:
NASA EOS-IDS Atmosphere-Biosphere Interactions
Contract No. NAS5-31730, Amend 14

Source of Support: NASA

Total Award Amount: $118,000 Total Award Period Covered: 06/01/1998-04/30/2000

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. .5 Cal: .5 Acad: 0 Sumr: 0

Support: X Current Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title: Spatial Integration of Regional Carbon Balance in Amazonia
Grant No. NCC5-284

Source of Support: NASA

Total Award Amount: $294,173 Total Award Period Covered: 07/01/1998-12/31/1999

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 1 Cal: 0 Acad: 0 Sumr: 1

Support: X Current Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title:
Regional and Global Estimation of Terrestrial CO2 Exchange from NIGEC
Flux Data, Contract No. TUL-066-98/99

Source of Support: NIGEC

Total Award Amount: $97,734 Total Award Period Covered: 07/01/1998-12/31/1999

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 1.25 Cal: 1.25 Acad: 0 Sumr: 0

Support: X Current Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title:
Regional Forest-ABL Coupling: Influence on CO2 and Climate
Contract No. M4166262101 AMEND A001

Source of Support: Univ. of Minn./DOE

Total Award Amount: $76,956 Total Award Period Covered: 07/01/1998-12/31/1999

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. .5 Cal: .5 Acad: 0 Sumr: 0

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this propos...

Investigator: A. Scott Denning

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: X Current Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title:

Sources and Sinks of Anthropogenic CO2: Integrated Assessment using Biogeochemical Modeling and Inversion of Atmospheric Tracer Transport, Grant No. ATM-9896261

Source of Support: NSF

Total Award Amount: $244,000 Total Award Period Covered: 07/01/1998 - 09/30/2000

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 2 Cal: 0 Acad: 1 Sumr: 1

Support: X Current Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title:

The Effects of Remotely-Sensed Data on Modeled Land Surface Atmosphere Interactions; Consequences for Global Carbon Balance Research, Grant No. NGT5-30182

Source of Support: NASA

Total Award Amount: $22,000 Total Award Period Covered: 09/01/1999-08/31/2000

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 0 Cal: .0 Acad: 0 Sumr: 0

Support: X Current Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title: Linking Biogeochemistry and Atmospheric Transport in the NCAR GCM Contract No. ATM-9906658

Source of Support: NSF

Total Award Amount: $24,943 Total Award Period Covered: 05/01/1999-04/30/2000

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 0.2 Cal: 0.2 Acad: 0 Sumr: 0

Support: X Current Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title:

Atmospheric CO2 Inversion Intercomparison Project (TransCom 3)
Contract No. NA67RJ0152 AMEND 21 (NOAA) and OCE-9900310 (NSF)

Source of Support: NSF/NOAA

Total Award Amount: $230,576 Total Award Period Covered: 04/23/1999-06/30/2002

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 1.5 Cal: 1.5 Acad: 0 Sumr: 0

Support: Current X Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title:

Regional and Global Estimation of Terrestrial CO2 Exchange from NIGEC Flux Data

Source of Support: NIGEC

Total Award Amount: $101,746 Total Award Period Covered: 07/01/1999-06/30/2000

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 1.5 Cal: 1.5 Acad: 0 Sumr: 0

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this propos...l

Investigator: A. Scott Denning

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: Current Pending X Submission Planned in Near Future *Transfer of Support

Project/Proposal Title: Spatial Integration of Regional Carbon Balance in Amazonia

Source of Support: NASA

Total Award Amount: $354,320 Total Award Period Covered: 01/01/2000-12/31/2000

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 2 Cal: 2 Acad: 0 Sumr: 0

Support: Current X Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title: Application of EOS Data for Coupled Simulation of Land-Surface Biophysics, Biogeochemistry, and Hydrology

Source of Support: NASA

Total Award Amount: $600,000 Total Award Period Covered: 03/01/2000-02/28/2003

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 0 Cal: 0 Acad: 0 Sumr: 0

Support: Current X Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title: Biosphere-Atmosphere Interactions

Source of Support: UC Berkeley

Total Award Amount: $151,293 Total Award Period Covered: 03/01/2000-02/28/2003

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 1 Cal: 1 Acad: 0 Sumr: 0

Support: Current X Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title: Incorporating new EOS Data Products into Models to Improve Estimates of Biogeochemical Processes

Source of Support: UC Davis

Total Award Amount: $73,360 Total Award Period Covered: 03/01/2000-02/28/2003

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 0.2 Cal: 0.2 Acad: 0 Sumr: 0

Support: Current Pending X Submission Planned in Near Future *Transfer of Support

Project/Proposal Title: Monitoring and Modeling Isotopic Exchange Between the Atmosphere and the Terrestrial Biosphere

Source of Support: NOAA

Total Award Amount: $168,000 Total Award Period Covered: 03/01/2000-02/28/2003

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 0 Cal: 0 Acad: 0 Sumr: 0

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this propo...l

Investigator: A. Scott Denning

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: Current Pending X Submission Planned in Near Future *Transfer of Support

Project/Proposal Title: Regional Integration of Carbon Exchange Using Ameriflux Data and Atmospheric Modeling

Source of Support: DOE

Total Award Amount: $300,000 Total Award Period Covered: 07/01/2000-06/30/2001

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 1.0 Cal: 1.0 Acad: 0 Sumr: 0

Support: Current X Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title: Regional Forest-ABL Coupling: Influence on CO2 and Climate

Source of Support: JPL/DOE

Total Award Amount: $41,301 Total Award Period Covered: 10/01/1999-08/31/2000

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 0.2 Cal: 0.2 Acad: Sumr:

Support: Current Pending X Submission Planned in Near Future *Transfer of Support

Project/Proposal Title: A Virtual Tall Tower Network of Understanding Continental Sources and Sinks of CO2.

Source of Support: NOAA

Total Award Amount: $100,000 Total Award Period Covered: 03/01/2000-02/28/2002

Location of Project: Colorado State University

Person-Months Per Year Committed to the Project. 1.0 Cal: 1.0 Acad: Sumr:

Support: Current Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: Current Pending Submission Planned in Near Future *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Appendix 1. Scaling and Integration Studies Using AmeriFlux and Related Data

Theme	*PI (Institution)*	*Funding*	*Site(s)*	*Activity*
Ecosystem-scale Measurements and Modeling	Vince Gutschick (NMSU)	NIGEC South-Central	WLEF	Leaf-canopy-landscape measurements and modeling
	Paul Bolstad (UMn)	NIGEC Midwest	WLEF, nearby upland and wetland flux towers	Ecosystem process measurements and modeling: "end-member" leaf-canopy-landscape
	Ned Patton (UMn)	NIGEC South-Central	Several	Large eddy simulation of flux footprints and surface-layer flux-gradient relationships
	Jim Ehleringer (Utah)	NOAA OGP GCC	WLEF, nearby upland and wetland flux towers	Characterization of stable isotopic exchange associated with fluxes
	Jiquan Chen (Michigan Tech)	NIGEC Midwest	N. Wisconsin	Mobile flux towers in 10 landscapes over 3 years
Larger-Scale Atmospheric Measurements for Scaling	Peter Bakwin (NOAA/UColo)	NIGEC Midwest	WLEF	Multi-level continuous measurement of scalars and fluxes in surface and mixed layers
	Ken Davis (UMn)	DoE (TECO), NSF	WLEF, Walker Branch	PBL Soundings with Radar and Lidar
	John Birks (UColo)	NIGEC Great Plains	WLEF, Ponca City	Soundings in and above CBL with kite and balloon borne sensors
	Steve Wofsy (Harvard)	COBRA: NSF, NOAA, DOE	WLEF, Harvard Forest, Oak Ridge, regional	Aircraft campaigns with continuous multitracer vertical profiles and horizontal transects
	Ron Dobosy (NOAA)	NOAA OGP GCC	WLEF	Spatial variation of ecosystem fluxes (LongEZ flux aircraft)
	Ken Davis (UMn)	NSF Career Development NOAA OGP GCC NIGEC South Central	Severa l	"Virtual tall towers" using high-precision CO_2 and CBL scaling
Remote Sensing Studies for Scaling	Stith T. Gower (Wisc)	NASA EOS Cal-Val	WLEF and others	Local to regional scaling of land-cover with multi-scale imagery
	Lara Prihodko (CSU)	NASA ESS Fellowship	WLEF	Local to regional scaling of land-cover with multi-scale imagery
Modeling Studies of Regional Fluxes	Dennis Ojima (CSU)	NSF Bio IRC	Continental USA	Coupled modeling of ecosystem succession, BGC, and ecophys with 20-year assimilated weather and CO_2
	Scott Mackay (Wisc)	NASA LSHP	N. Wisconsin	Remote sensing/GIS, historical data analysis, and SVAT modeling
	Scott Denning (CSU)	NIGEC South Central	WLEF, ARM-CART, USA, World	Coupled SVAT-tracer models, remote sensing, and inverse modeling