HIGH-RESOLUTION FOSSIL FUEL EMISSIONS ESTIMATES IN SUPPORT OF NACP AND OCO-BASED CO_2 MEASUREMENTS AND ASSIMILATION SYSTEM

Team: Kevin Gurney (Principle Investigator), Scott Denning (CO-PI), Marc Fischer, Dennis Ojima, Gregg Marland, Prasad Kasibhatla

Focus: This Notice of Intent proposes to the NACP and Global Carbon Cycle Modeling and Analyses and topical areas.

Table of Contents

Abstract

A primary goal of the North American Carbon Program and the analysis of planned observations to be made by NASA's Orbiting Carbon Observatory (OCO) measurements, is to use highly resolved spatiotemporal patterns of atmospheric CO_2 to infer regional carbon exchange for the North American and global domain. To quantify that portion of the carbon cycle that is of greatest interest to scientists and policymakers – the *residual* carbon exchange with the land and oceans – the contribution to measured CO_2 due to fossil fuel use and cement manufacturing must be accurately quantified. However, use of the currently available fossil fuel CO_2 emissions estimates within the planned NACP and/or OCO CO_2 measurement and inversion systems will give rise to significant bias, likely defeating the very goal of the expanded CO_2 measurements. In order to achieve unbiased estimates of land and oceanic carbon exchange at resolutions consistent with the temporally and spatially dense North American and space-based CO_2 measurement programs, significant improvement in quantifying fossil fuel CO_2 emissions at smaller space/time scales is essential.

To meet this requirement, we will produce high resolution space and time scale fossil fuel CO_2 emissions estimates using an approach that builds upon the already extensive work performed for US air quality investigations. By incorporating CO_2 emissions factors into a process-based, data-driven, state-of-the-art, air quality emissions model (CONCEPT) we will generate fossil fuel CO and CO_2 emissions at spatial scales of 36 km and timescales of one hour; well within the planned needs of the NACP measurement and inversion work. We propose to quantify spatiotemporally explicit emissions for the United States domain in the current proposed work. The methodologies developed will be extendable to the global domain and hence, support the fossil fuel CO_2 emissions requirements of the OCO CO_2 measurements and inverse-based flux estimates.

Initial evaluation of the modified CONCEPT ("CONCEPT-CO_2") model CO_2 emissions will be made against the top-down inventory CO_2 emissions work by aggregating the high resolution CONCEPT-CO_2 fluxes to monthly time scales and state emissions totals. This will allow for further adjustment of emission factors and process attributes to ensure consistency with the more coarsely resolved but accurate state-level fossil fuel CO_2 emissions estimates.

Emissions estimates will be propagated through a regional atmospheric transport model to predict highly resolved variations in the mixing ratio of CO, which will be evaluated against the MOPITT Earth-observing satellite and *in-situ* observations such as the expanded NACP continuous tower observations and aircraft campaigns.

This work will produce a fossil fuel CO and CO_2 emissions system generating gridded CO and CO_2 fluxes for the United States at a spatial scale of 36 km and a temporal scale of 1 hour. It will have been evaluated against a variety of independent observations including remote-sensing products. It will provide immediate support to the NACP and form the foundation for global extension in direct support of OCO CO_2 measurements and inversion/assimilation research.

I. Technical Plan

A. Background

A.1. Fossil fuel and CO_2 inversions/assimilation

Quantification of carbon sources and sinks as understood from the spatial and temporal patterns of atmospheric CO_2 concentrations have traditionally employed the inverse method (Enting 2002). With the intensification of CO_2 concentration measurements in both space and time planned under NACP and produced by the Orbiting Carbon Observatory (OCO), data assimilation and/or other model-data fusion techniques will be used to estimate carbon exchange at much finer scales than is currently attempted (Wofsy and Harriss,2002). However, for these approaches to be effective, fossil fuel CO_2 emissions must be accurately estimated and removed from the observed CO_2, so that the portion of interest (net biospheric and oceanic exchange) can be isolated and quantified.

In the simplest terms, once the fossil fuel CO_2 emissions are specified in space and time, the fluxes that are estimated in the inversion process - the "residual" fluxes - represent net terrestrial and oceanic sources and sinks of CO_2 such that the sum of the fossil fuel CO_2 and these residual fluxes best match atmospheric CO_2 concentrations observed at particular times and locations.

Consider the Bayesian synthesis inversion used in the TransCom 3 Atmospheric CO_2 Inversion Intercomparison experiment (Gurney et al. 2002; Gurney et al. 2003; Law et al., 2003; Gurney et al., 2004). In this experiment, the fossil fuel emissions are designated as a "background" or "presubtracted" flux. The use of the term "presubtracted" for the fossil fuel flux can best be explained by the following expression denoting the linearly summed components of the atmospheric CO_2 budget.

$$C_{obs} = C_{ff} + C_{ot} + \sum_{i=1}^{N} C_{res} \qquad (1)$$

where C_{obs} represent the observed CO_2 at a particular point in space and time, C_{ff} represents the contribution to the observed CO_2 due to global fossil fuel emissions, C_{ot}, the contribution due to other background fluxes chosen by the investigator, and C_{res}, the contribution of the residual fluxes from the specified N discretized regions (see Gurney et al. 2000). An additional term, the oxidation of CO is considered small and is neglected in this simplified example. This expression is valid for every location in the atmosphere. Rearrangement of this basic budget makes clear the motivation behind the term "presubtracted"; the residual CO_2 can be defined as the difference between the observed CO_2 and the sum of the first two terms on the right-hand side of equation 1. Hence, the background fluxes are subtracted from the observations leaving the residual CO_2 concentration as the observational target of the inversion. For simplicity, we will consider fossil fuel CO_2 as the only background flux.

In practice, the fossil fuel flux can be adjusted in the inversion process in the same way that the discretized residual fluxes are. However, this is typically not performed in atmospheric CO_2 inversions and the fossil fluxes are provided to the inversion with small uncertainty and hence, are fixed at the values provided. There are two reasons for this approach.

First, the fossil fuel CO_2 flux has traditionally been considered well-quantified at the space and time scales estimated in atmospheric inversions performed to date. The second reason relates to the first; the fossil fuel CO_2 fluxes are not considered as scientifically interesting as the residual fluxes because the latter constitute the portion of the global carbon budget that is poorly understood.

The fundamental problem with this line of reasoning comes about if the assumed fossil fuel CO_2 flux is sufficiently different from the true flux, particularly when the spatial and temporal scale of the provided emissions are different from those solved for. Were this to occur, these differences would be aliased into the residual fluxes and constitute a bias to the solution (Kaminski et al., 2001; Engelen et al., 2002).

Currently, the most accurate estimates of spatially and temporally explicit fossil fuel CO_2 are based on country level emissions of fossil fuel CO_2 (Marland and Rotty, 1984; Marland et al., 2003). These, in turn, are derived from United Nations energy statistics. The country emissions are allocated to clusters of grid cells (and sub-clusters for 9 countries) based on a political unit data set outlining nation-states (Lerner et al., 1988). The emissions within these grid cell clusters are allocated according to population density. A number of adjustments are made to account for border issues, land/sea masking, and the maintenance of very small countries. These estimates have been gridded at 1° x 1° and as annual mean values. Recently, fossil fuel CO_2 emissions have been estimated at the monthly timescale and state-level spatial scale for the United States (Blasing et al., 2004a; 2004b). Figure 1 shows the two available fossil fuel CO_2 emissions maps representing the years 1990 and 1995.

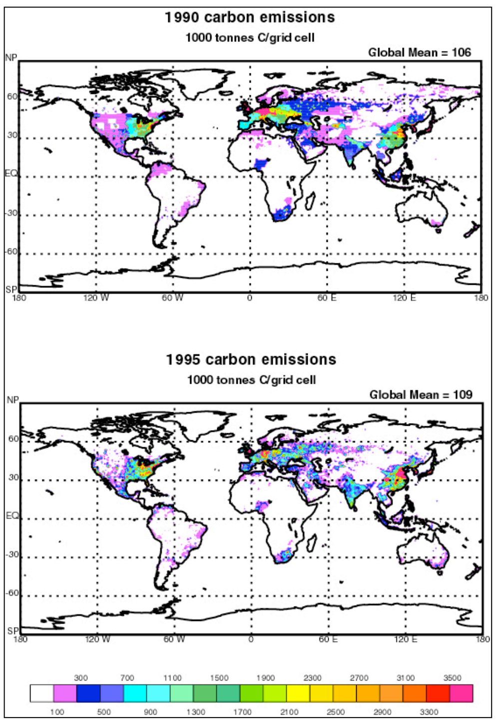

Figure 1. Fossil fuel emissions for a) 1990 and b) 1995. Units are 1000 tonnes C/grid cell and the grid cells are dimensioned 1° x 1°.

A.2.Shortcoming of current fossil fuel CO_2 emissions estimates

Atmospheric CO_2 inverse studies over the last decade have typically estimated residual fluxes at the sub-continental scale and at an annual mean temporal scale. At these space and time-scales, the gridded, population-based, annual mean fossil fuel CO_2 emissions datasets (hereafter referred to as the “top-down” approach) have provided an adequate characterization of the fossil background flux.

As the spatial and temporal scales of analysis are reduced, however, a number of shortcomings in these emissions estimates become significant.

1. *Temporal variability:* Fossil fuel CO_2 emissions reflect temporal variations in the use of energy for activities such as heating, transportation, and residential electricity use. These variations occur on a variety of timescales. For example, time-of-day and day-of-week are strong determinants of traffic flow and traffic patterns and hence, motor vehicle CO_2 emissions. Residential heating and cooling have strong diurnal, seasonal and interannual dependence and vary with local weather patterns.

   Recent sensitivity work has explored the impact of fossil fuel seasonality on inverse-derived estimates of carbon exchange (Gurney et al., 2003b). In this work, the global fossil fuel CO_2 emissions created using the top-down approach were altered such that they contained seasonality of varying amplitudes. Furthermore, these amplitudes varied by latitude to reflect the greater heating needs of poleward locations. The new seasonally varying fossil fuel CO_2 emissions were used in a seasonal inversion (following the TransCom 3 inversion protocol) and compared to the control case which contained fossil fuel CO_2 emissions with no seasonal variation. This was performed with 3 transport models that spanned the TransCom 3 intercomparison results.

   Recent data from the United States and Europe indicate that peak to peak amplitudes at approximately 40º N are on the order of 30%. Hence, examination of this case in the suite of seasonal simulations can provide a first estimate of the extent to which nonseasonal fossil fuel CO_2 emissions potentially bias actual residual carbon sources and sinks.

   Figure 2 shows the difference in estimated fluxes for all five of the TransCom 3 northern extratropical land regions when one imposes a seasonal fossil fuel CO_2 flux (the 30% case) versus a nonseasonal fossil fuel CO_2 flux. In many instances, flux differences of up to 0.5 Gt C/year are found. These are biases on the order to 50% due to the use of non-seasonal fossil fuel CO_2 emissions.

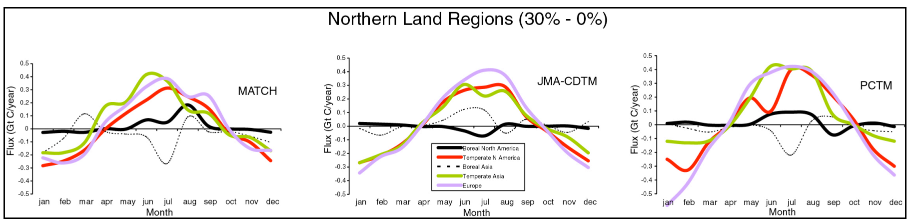

Figure 2. Bias in estimated regional fluxes for each month and each model represented as the difference between the calculations assuming a 30% seasonal variation in fossil fuel CO_2 emissions and the base case with no seasonality (0%). All northern extratropical regions are shown. Change figure title

   The conclusion of this sensitivity test: Using a fossil fuel CO_2 emissions field that does not contain seasonality, when in reality, these emissions have seasonal variation, causes serious bias in the residual flux estimates (the net biosphere and oceanic carbon exchange). This same logic can be applied to any spatial and temporal variability that exists in real-world fossil fuel CO_2 emissions but is not properly accounted for in top-down estimates.

Planning for the NACP includes an expansion and intensification of CO_2 observing systems. Continuous CO_2 measurement will be made at a growing number of locations in North America, resolving hourly timescales. The planned OCO mission will measure surface-weighted CO_2 concentrations covering the globe every two weeks, collecting data at ~1:15 pm local time. In order to fully avail of the CO_2 observational constraint provided by these new measurements, inversion/assimilation techniques must have fossil fuel CO_2 emissions at commensurate temporal scales.

2. *Spatial variability:* Planning for NACP includes the use of mesoscale adjoint inversion and nested assimilation techniques (constrained by remote-sensing imagery, land-use data, and other observations) to quantify carbon sources and sinks. Such fluxes will be resolved at spatial scales reaching 10 km. In order to meet the anticipated flux spatial scales, and avoid the problem associated with spatial representation bias (prescribing spatial variability), accurate fossil fuel CO_2 emissions at commensurate scales is required. Merely downscaling the top-down approach used to generate the fossil fuel CO_2 emissions to smaller scales will not succeed in generating accurate, spatially representative emissions because population is not always an adequate surrogate for fossil fuel CO_2 emissions.

3. *Combustion surrogates:* As described above, the existing top-down approaches for estimating CO_2 emissions at fine spatial scales subdivide large scale totals in proportion to population density. However, fossil fuel combustion often does not scale with population density. A dramatic example is electricity supply/demand in California. One-quarter of the electricity consumed in the state of California is not produced within the state but is imported from generation facilities in neighboring states. Placing the CO_2 emissions associated with this electricity consumption within the state according the population distribution will create spatial offsets of 100s of kilometers. While such offsets are acceptable when inversions are performed at the sub-continental scale, NACP and OCO-based efforts aiming to characterize CO_2 sources and sinks at scales of even hundreds of kilometers will be severely biased by the use of population as a surrogate for fossil fuel CO_2 emissions.

   A further example is the case of vehicle-based emissions. Though much vehicle traffic and their associated emissions covary with population density, large roadways such as interstate highways and urban perimeter traffic corridors often do not. These "line sources" may emit considerable motor vehicle CO_2 (and CO) but do not coincide with high population density.

4. *CO emissions and oxidation:* Current inversions run at timescales of annual or monthly means do not incur substantial error by not explicitly including CO emissions and their subsequent oxidation to CO_2. However, at space and time scales planned for the NACP and OCO measurements and inversion/assimilation, CO emissions and their subsequent oxidation to CO_2 will have to be accurately represented.

The shortcomings in the top-down approach to fossil fuel CO_2 emissions have not seriously impacted atmospheric inversions to date because of the large spatial scales and long time-averaging used in the current work. Very recent inversion studies, however, are attempting to resolve timescales shorter than a year and spatial scales commensurate with transport model gridcells (Roedenbeck et al., 2003). The top-down fossil fuel CO_2 emissions likely generate bias in these studies. Were these same fossil fuel CO_2 emissions used in conjunction with NACP and/or OCO measurements and inversion/assimilation, the biases would be greatly amplified.

Furthermore, extension of the top-down approach to smaller scales will not solve underlying methodological problems associated with the routine mismatch between population density and fossil fuel emissions. Characterizing the temporal signature of fossil fuel CO_2 emissions at the small scale requires emissions that are process-driven and hence, tied to the true time-of-day and day-of-week combustion demands.

It is important to note that the above discussion of the shortcomings of the fossil fuel CO_2 emissions constructed to date is not a criticism of either the methodology or the estimates themselves when placed within the context of what they have been used for. The goal of this discussion is to emphasize the fact that given the direction of top-down carbon exchange estimation (finer space and timescales empowered by highly resolved spatiotemporal CO_2 measurements from *in situ*, aircraft campaigns or remote-sensing efforts), new work is necessary to provide accurate fossil fuel CO_2 emissions estimates at fine scales.

A.3. Air quality emissions modeling

The solution to this critical need is to take a new approach to estimating fossil fuel CO_2 emissions and to focus on reduced space and timescales. We suggest that the most effective way to do this is to take advantage of the long history and development within the air quality and combustion chemistry community on pollutant emissions estimation. Though currently applicable to the United States spatial domain, emissions inventory development and spatiotemporally explicit emissions modeling for use in air quality work has comprehensively quantified emissions of nationally regulated pollutants at spatial scales below 50 km and at hourly time steps.

Because CO_2 is not a nationally regulated pollutant, it has not been included within the framework of air quality emissions estimation. However, because both carbon monoxide (CO) and nitrous oxides (NOx) are regulated, air quality emissions estimation efforts currently capture fossil fuel combustion processes.

The primary objective of this proposal is to include CO_2 in a state-of-the-art air quality emissions modeling system and thereby generate fossil fuel CO_2 emissions that are truly process-based and accurately represented at space and time scales appropriate for use with planned NACP CO_2 measurement and inversion/assimilation carbon exchange system. Currently available monthly and state-based emissions estimates for CO_2 will provide tight constraints on the modeled estimates.

This will be performed for the domain of United States as direct and immediate support to the North American Carbon Program. However, the methodologies developed in this effort can be extended to the globe through a combination of currently available data in the industrial world and simulation to support planned global-scale inverse/assimilation research using the OCO space-based measurement platform.

B. Technical Approach

B.1. The CONCEPT model

The rationale for emissions modeling systems is rooted in the need to estimate, organize, and process emission inventory data for regulatory and scientific analysis and modeling. In the early 1990s the California Air Resources Board (CARB) and the Lake Michigan Air Directors Consortium (LADCO) funded a project to build a new emissions modeling system. This new model, Geocoded Emissions Modeling and Projections (GEMAP), was further developed with the release in 1995 of the EMS-95 (emissions preprocessor system-95). The most recent version of the EMS development is EMS-2003 which includes a number of important developments such as the inclusion of a biogenic emissions model and extensive quality assurance modules.

The EMS is currently undergoing a fundamental change to a completely open-source environment that will allow for much greater flexibility and user access. This new model is called the Consolidated Community Emissions Processing Tool (CONCEPT). The development of CONCEPT is a collaborative effort between LADCO, Applied Geophysics of Denver Colorado, ENVIRON, of Novato California and ISSRC at the University of California, Riverside. CONCEPT is planned for beta release in June, 2004 with a final operational release expected in January of 2005.

Emissions processing models such as CONCEPT incorporate large amounts of pollutant monitoring data from activities and processes across the United States that emit any of the nationally regulated pollutants (CO, NOx, SOx, particulate matter-10 μm, particulate matter-2.5 μm, volatile organic compounds ozone, lead). This information comes from the National Emissions Inventory (NEI), a national database of air emissions information with input from numerous State and local air agencies, from tribes, and from industry. This database contains information on stationary and mobile sources and can be broken down into three classes of criteria air pollutant sources:

- Point sources – stationary sources of emissions, such as an electric power plant, that can be identified by name and location.

- Area sources – small point sources such as a home or office building, or a diffuse stationary source, such as wildfires or agricultural tilling. These sources do not individually produce sufficient emissions to qualify as point sources.

- Mobile sources – any kind of vehicle or equipment with a gasoline or diesel engine; airplane; or ship.

A number of attributes are associated with each emission record in the NEI. These include items such as the geographic area covered, the time interval represented, population, employment, economic data, collection procedures, etc. Furthermore, the NEI has been compiled roughly every three years since 1985.

In cases where direct emissions estimates are not available, emissions are constructed through the combination of process attributes such as material throughput, emission factors, and pollutant control technologies. All of the emissions are allocated in space and time through geocoding and temporal algorithms. The result is gridded emissions of pollutants for use in photochemical transport models.

The emissions processing model used in this proposal, CONCEPT, is divided into a series of core submodels that parallel the NEI. They are as follows:

- Area source model – provides gridded, hourly, speciated emissions estimates from the area source emissions provided in the NEI. Area source emissions are provided at the county level. Spatial and temporal allocation are performed using a series of surrogates such as population and economic activity.

- Point source model – provides gridded, hourly, speciated emissions estimates from the facility level estimates provided in the NEI. Temporal allocation uses a combination of site-specific monitoring data and process-specific temporal surrogates. Geocoding allows for direct grid cell placement.

- Motor vehicle emissions model – provides gridded, hourly, speciated emissions estimates from motor vehicle combustion. These include emissions from vehicular traffic on roadways, aircraft, trains, shipping, and off-road mobile equipment. Mobile source emissions are dependant upon the ambient temperature, road type, vehicle type and age, miles traveled, etc. This sub model utilizes EPA's MOBILE6 emissions model (EPA, 2001).

- Biogenic emissions model – provides gridded, hourly, speciated emissions derived from vegetation, soils, and lightning. Biogenic emissions are dependant on temperature, solar radiation, and land cover type.

- Nonroad model – provides gridded, hourly, speciated emissions arising from equipment in a variety of general categories such as agriculture, construction, logging, industrial, and recreational equipment.

- Speciation model – splits grouped emissions, such as volatile organic compounds and particulate matter into more defined compounds or groupings.

- Spatial allocation model – prepare spatially resolved values of various geo-spatial features (e.g., railroads, bodies of water, airports) which are then used in the other source submodels such as the area, point, and mobile models.

The CONCEPT model is being constructed using open-source architecture. This means that the code is in the public domain and requires no software licensing to host and run the model.[1] The core of the model is written in postgreSQL database language and runs on the LINUX operating system. Other languages utilized by the model are FORTRAN, PERL (input/output), and GRASS (GIS visualization).

[1] Access to EPAs MOBILE6 motor vehicle emission submodel, included in CONCEPT, will require fortran compiler licensing.

B.2. Deconstruction of the CONCEPT model

The CONCEPT model is currently in the final stages of development. We have contacted the model developers and will have access to the beta version prior to the final release (scheduled for January 2005). We will undergo formal user training with the model. Training is included in the developers formal contract agreement with LADCO and open to interested users.

One of the key developers of CONCEPT (Alpine Geophysics, LLC) is located in Denver, Colorado; within one hour drive of Colorado State University, the location where the CONCEPT CO_2 simulations will be taking place. Alpine Geophysics has indicated a willingness to provide advice and guidance on our work with the CONCEPT model. Furthermore, the open source architecture has spawned a list serve where users and developers will share code, improvements, comments, and advice in an open, publicly accessible format.

The Colorado State University team will identify those processes and activities within the CONCEPT model that contribute to CO_2 emissions. Within these processes and activities, entry points or logical sequences in CONCEPT where CO_2 emissions can be included will be identified. Generation of CO_2 emissions will involve a number of different approaches that will depend upon the level of existing information about emitting processes and activities within CONCEPT and available information regarding combustion characteristics.

B.3. Quantifying CO_2 emissions

Estimates of fossil fuel CO_2 emissions and uncertainties for the identified process and activities in the CONCEPT model will be constructed from a combination of information. This will include fuel use, CO and NOx emissions, and supporting information (e.g., combustion technology) at the greatest level of resolution possible combined with information that Lawrence Berkeley National Laboratory (LBNL) has or will acquire from other sources. LBNL has conducted a number of studies of energy use and CO_2 emissions in these sectors for the U.S. Environmental Protection Agency and the California Energy Commission. LBNL has developed numerous contacts with private and public stakeholders in these sectors in the US, who would be valuable in obtaining new data and its validation.

- For the industrial sector, LBNL will provide CO_2 emissions estimates for major point sources in the cement, steel, petroleum refining, pulp/paper, ammonia, ethylene, and glass industries based on a combination of the data provided by CONCEPT and LBNL-derived estimates using information on technologies by vintage, capacity factors, average capacity utilization, fuel types, heat rates, on-site cogeneration, and CO_2 emissions factors (Worrell et al., 2001). As such, LBNL has information on plant locations, plant types, technologies, energy consumption, commodity production, and on-site cogeneration for a number of these industries. Further research may be required to construct a complete database of plant locations, fuel type, production levels, and CO_2 emissions by major industrial point sources.
- For the electricity sector, LBNL will provide CO_2 emissions estimates for electricity-generation facilities based on a combination of the data provided by CONCEPT and LBNL-derived estimates using information on technologies by vintage, capacity factors,

average capacity utilization, fuel types, heat rates, on-site cogeneration, and CO_2 emissions factors (Marnay et al., 2002).

- For the transportation sector, LBNL will estimate CO_2 emissions factors for use with data on vehicle miles traveled from the EPA MOBIL6 model as provided in CONCEPT. LBNL will apply estimates of vehicle fuel efficiency for different vehicle age, weight, and fuel classes, and assumed operating speeds. Uncertainties will be estimated from uncertainties in estimates of each of these parameters (Wenzel et al., 2000). Estimates for CO_2 emissions factors will be checked against other vehicle pollutant emissions (e.g., CO), and top-down inventory estimates of fuel use in the transportation sector.
- For the buildings sector, data are available for the US for the residential and commercial sector by utility service areas and at the state level for electricity, natural gas, LPG and fuel oil use. In addition, data exist for major metropolitan areas and also at the census division level (Price et al., 1998; 1999). These data will be used to generate CO_2 emissions factors that can be incorporated into CONCEPT to predict spatially resolved CO_2 emission.

B.4. Evaluation of CO and CO_2 emissions estimates

CSU will run the modified CONCEPT ("CONCEPT-CO_2") model forward with the necessary information provided by LBNL to estimate spatially and temporally explicit CO and CO_2 emissions. CSU and LBNL will then compare aggregated CO and CO_2 emission totals to the previously described top-down emissions estimates and sector-specific emissions estimates in the literature (Blasing et al., 2004b, Olivier and Berdowski, 2001; other sector-specific references). The top-down CO_2 estimates for the US domain are available as state totals and as monthly means and have uncertainties of 3-5% (Blasing et al., 2004a; 2004b; Gregg and Andres, 2003; Marland, personal communication, 2004).

The process of comparison will provide insight into potential gaps and/or poor estimation of CO_2-emitting processes within CONCEPT-CO_2. We will attempt to characterize the parameter space that is consistent with the aggregated totals from independent sources. By combining sector-specific and top-down fossil fuel CO_2 emission totals, we expect to be able to narrow the combustion processes and activities giving rise to inventory discrepancies.

As a further step in evaluation of the analyzed emissions, we will perform a numerical simulation of an annual cycle of meteorology and the mixing ratio of atmospheric CO driven by our CO emissions estimates. This simulation will be performed using the CSU Regional Atmospheric Modeling System (RAMS), and results will be compared in detail to in-situ and remotely-sensed variations of observed CO. The Regional Atmospheric Modeling System (RAMS) is a mesoscale meteorological (non-hydrostatic) model and contains time-dependent equations for velocity, non-dimensional pressure perturbation, ice-liquid water potential temperature (Pielke et al, 1992), total water mixing ratio, and cloud microphysics. Vapor mixing ratio and potential temperature are diagnostic. A significant feature of the model is the incorporation of a telescoping nested-grid capability, which enables the simulation of phenomena involving a wide range of spatial scales. A second-order-in-space advection scheme is employed. The turbulence closure scheme of Deardorff (1980) is used, which employs a prognostic sub-grid turbulent kinetic energy. The two-stream radiation scheme developed by Harrington (1997) is used. At regional scales for

denning 4/6/04 12:42 PM
Deleted: the

denning 4/6/04 12:41 PM
Deleted: surface fluxes will

denning 4/6/04 12:42 PM
Deleted: be

denning 4/6/04 12:43 PM
Deleted: transported through the atmosphere using the RAMS transport model.

which individual convective elements (clouds) cannot be resolved, we use convective parameterizations (Grell, 1993; Freitas et al, 2000) that compute precipitation rates, atmospheric heating and moistening, and mass and tracer fluxes (including updraft and downdraft velocities) by unresolved cloud processes. In the RAMS simulations, CO production and oxidation will be simulated using prescribed OH and CH_4 fields and simple first order reaction kinetics following Gerbig et al., 2003b.

denning 4/6/04 12:47 PM
Deleted: RAMS is a general purpose atmospheric simulation modeling system consisting of equations of motion, heat, moisture, and continuity in a terrain-following coordinate system (Pielke *et al*. 1992). The model has flexible vertical and horizontal resolution and a large range of options that permit the selection of processes to be included (such as cloud physics, radiative transfer, subgrid diffusion, and convective parameterization). Two-way interactive grid nesting allows for a wide range of motion scales to be modeled simultaneously and interactively.

The period covered by the simulation will likely be 2005, by which time many new in-situ CO observing stations are expected to be collecting data. Lateral boundary conditions for meteorological variables will be specified from the NASA Goddard EOS Data Assimilation System (GEOS-DAS) on a 1ºx1.25º grid with 55 levels, and will be interpolated on isentropic surfaces to nudge an outer RAMS grid of resolution 100 km that covers all of North America and extends well out over the Atlantic and Pacific Oceans. The outermost three grid columns will be nudged to the global analysis with a three-hour relaxation time. We will run a nested mesoscale grid (Δx=20 km) over the continental USA and adjacent portions of Canada, Mexico, and the oceans, and evaluate the coupled simulation by comparing model quantities with observations within this finer domain. Evaluations will include comparisons of simulated station temperature, humidity, precipitation and winds to local observations; storm events to precipitation radar data; upper air winds to radiosondes and wind profilers; and simulated PBL depth to soundings, ceilometers, and profilers. Preliminary tests of the coupled modeling system suggest that the proposed simulation experiment would take about 10 days to perform on a single CPU of a state-of-the-art Linux workstation.

The resulting simulated atmospheric CO concentrations from the RAMS model will be compared to observed CO values. However, because observed CO measurements contain a portion attributable to biogenic emissions, which are not explicitly simulated in the CONCEPT model, we will isolate the fossil fuel component by examining spatial CO gradients across large urban airsheds. The use of spatial gradients across urban airsheds minimizes the biogenic versus the fossil fuel CO contribution. This further relaxes the need for knowledge of lateral boundary conditions from long range transport of CO.[2]

These simulated CO gradients will be compared to surface CO concentration gradients from The Measurement of Pollution in the Troposphere (MOPITT) instrument on board the NASA EOS Terra satellite. Explicit consideration of the MOPITT averaging kernals will be undertaken by resampling the RAMS model output to the MOPITT standard vertical pressure grid (6 layers plus the surface) and transforming this resampled output using the MOPITT averaging kernel. Spatial gradients in the lowest 3 layers of the MOPITT retrieval across large urbanized regions will provide a valuable comparison for the CONCEPT-CO_2/RAMS simulated CO.

There is the possibility of including another remote-sensing device: avoiding fire events through the use of remotely-sensed fire incidence.

A second form of evaluation will isolate the fossil fuel CO component from measured CO concentrations by comparing specific CO concentration "events" from the expanded *in situ* continuous CO monitoring planned for the NACP. Under certain meteorological conditions

[2] Lateral boundary conditions for CO will be constructed following the procedure asopted in Gerbig et al., 2003a.

driven by synoptic scale transport phenomena, continuous monitoring sites will be under direct influence of urban areas. The collection of large short-term increases in CO concentrations can be directly compared to the simulated temporal gradients simulated by the RAMS transport model forced by CONCEPT emissions. Bakwin or Potosnak reference is probably useful here. Again, further filtering of fire could be done with remote sensing imagery.

B.5. NACP intensives and extension to the global domain

The effort proposed here can be naturally extended for use in the recently announced Mid-continent NACP intensive campaign.[3] In the Mid-continent intensive proposal, fossil fuel CO_2 emissions at fine spatial and temporal scales were deemed an essential element in deconvolving the many contributions to the intensively measured CO_2 signal.

Because the CONCEPT-CO_2 model will contain all emitting activities as either geocoded point sources or spatially-resolved area and mobile sources within the intensive domain, CONCEPT-CO_2 is well-suited to meet the needs of the intensive. If needed, additional downscaling of the area and mobile sources in CONCEPT could be made to generate spatial scales smaller than the current 36 km resolution. Furthermore, because the CONCEPT model contains fuel throughput and a number of combustion attributes that contribute to time-specific fossil fuel CO_2 emissions, fuel use data specific to the domain of the intensive could be gathered and included in CONCEPT-CO_2 to generate accurate time-specific fossil fuel CO and CO_2 emissions. The goal would be to generate fossil fuel CO_2 emissions that are valid for short-term measurement campaigns within the intensive domain.

The development of the CONCEPT-CO_2 model contained within this proposed research can be extended to the global domain with further development. The most difficult task associated with extension beyond the US domain is the requirement for pollutant monitoring data and/or fuel use data that is specific to geocoded sources. In the US, this is routinely provided by the United States Environmental Protection Agency.

However, much of the industrial world (e.g., Europe, Australia, and Japan) engage in detailed pollutant monitoring for regulatory purposes (references). Because nearly every country in the industrial world has agreed to lower their CO_2 emissions, direct CO_2 monitoring data is often collected (reference).

The most effective pathway to global extension of the CONCEPT approach, therefore, is to generate cooperative collaborations that can provide access to information such as point source locations, fuel use, and the area/mobile source attributes necessary to drive the CONCEPT-CO_2 emissions algorithms outside the US domain. Cooperation of this sort with the major industrial countries would currently capture roughly 60% of the global CO_2 emissions. In many cases, direct CO_2 monitoring data may be available.

In the less-developed world, population density is much more closely correlated with actual CO_2 emissions because energy production and consumption is based on smaller disaggregated

[3] Because additional development would very likely be necessary, extension of CONCEPT-CO_2 would be performed through a proposal to the intensives proposal request.

technologies and energy transport is less common (reference). Therefore, the current top-down fossil fuel CO_2 emissions approach would prove adequate until similar data becomes available in the less developed world. A critical exception to this argument is the rapid ongoing industrialization in China.

The extension of the CONCEPT-CO_2 approach to the global domain would meet the need of the OCO CO_2 assimilation system for accurate, process-driven fossil fuel CO_2 fluxes at spatial scales determined by transport model gridcells.

C. Summary of Objectives

The technical objectives for this proposal can be summarized as follows:

1) **Acquire state-of-the-art air quality emissions model ("CONCEPT") and identify methodologies to include fossil fuel CO_2 emissions.** This model uses the National Emissions Inventory (NEI) as input and produces multi-species emissions at spatial scales of 36 km and timescales of one hour for use in photochemical transport models. The model will be deconstructed in order to identify the underlying logic and attributes used to construct trace gas emissions.

2) **Apply CO_2 emissions factors to all fossil fuel combustion activities.** For many emitting activities, fuel-based energy use is the metric used to account for trace gas emissions. For others, measured emissions combined with process characteristics generate pollutant emissions. Emission factors that convert fossil fuel combustion sources into CO_2 exist for a wide variety of combustion technologies and environmental conditions. Where pollutant emissions are built from observations, relationships to CO emissions and process characteristics will be used to determine CO_2 emissions.

3) **GenerateCO and CO_2 emissions at aggregated spatial and temporal scales and compare to existing emissions inventories. Adjust emission factors as necessary.** This will require complete forward simulations. Comparison will be made to the most reliable aggregate level (state totals at monthly means). Monte Carlo simulation or parameter space sensitivity will be used to adjust emission factors.

4) **Run emissions forward in transport model and compare to remotely sensed and *in situ* CO measurements.** We plan on using the RAMS model forced with CO emissions from the CONCEPT-CO_2 model to generate simulated CO concentrations. Simulated surface gradients across large urban airsheds will be compared to MOPITT CO concentrations. Simulated temporal gradients associated with downwind urban airflow will be compared to continuous *in situ* CO monitoring at tower and flask locations within the US.

D. Scientific Significance

Fossil fuel CO_2 emissions explicit at space and time scales commensurate with planned NACP and OCO CO_2 measurement and inversion/assimilation system is absolutely essential to avoid biased estimates of carbon sources and sinks. Creation of an accurate, process-driven CO_2

emissions model will fulfill a critical need in the application of highly resolved NACP and/or OCO-based CO_2 measurements to the problem of carbon source/sink identification. This will be immediately available for the NACP spatial domain with potential future extension to the global domain in support of space-based CO_2 measurement (e.g., OCO). The product will be a publicly available US fossil fuel CO_2 emissions field for immediate use in assimilation/inverse work, forward modeling and carbon management efforts.

E. References

Andres, R.J., Marland, G., Fungi, I., & Matthews, E. Distribution of carbon dioxide emissions from fossil fuel consumption and cement manufacture, 1950-1990. *Global Biogeochem. Cycles* **10**, 419-429 (1996).

Blasing, T.J., C.T. Broniak, and G. Marland,. The annual cycle of fossil–fuel carbon dioxide emissions in the USA. Manuscript submitted to *Tellus*, 2004a.

Blasing, T.J., C.T. Broniak, and G. Marland,. State-by-state carbon emissions from fossil-fuel use in the United States, 1960-2000, manuscript submitted, 2004b.

Brenkert, A.L. Carbon dioxide emission estimates from fossil-fuel burning, hydraulic cement production, and gas flaring for 1995 on a one degree grid cell basis, (http://cdiac.esd.ornl.gov/ndps/ndp058a.html), 1998.

Engelen, R.J., A. Scott Denning, K.R. Gurney, and TransCom 3 modelers. On Error Estimation in Atmospheric CO_2 Inversions, *Journal of Geophysical Research*, **107** (D22), 4635, 2002.

Enting, I. 2002. *Inverse Problems in Atmospheric Constituent Transport*. Cambridge University Press: Cambridge, U.K.

Environmental Protection Agency. Users guide to MOBILE6: Mobile source emissions factor model, draft. EPA420-D-01-002a, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, February, 2001.

Gerbig, C., J.C. Lin, S.C. Wofsy, B.C. Daube, A.E. Andrews, B.B. Stephens, P.S. Bakwin, and C.A. Grainger. Toward constraining regional-scale fluxes of CO_2 with atmospheric observations over a continent: 1. Observed spatial variability from airborne platforms, *J. Geophys. Res.*, **108** (D24), 4756, doi:10.1029/2003JD003018, 2003a.

Gerbig, C., J.C. Lin, S.C. Wofsy, B.C. Daube, A.E. Andrews, B.B. Stephens, P.S. Bakwin, and C.A. Grainger. Toward constraining regional-scale fluxes of CO_2 with atmopsheric observations over a continent: 2. Analysis of COBRA data using a receptor-opriented framework, *J. Geophys. Res.*, **108** (D24), 4757, doi:10.1029/2003JD003770, 2003b.

Gregg, J.S. and R.J. Andres. A method for improving temporal and spatial resolution of carbon dioxide emissions, EOS Trans. AGU, **84** (46), Fall Meet. Suppl., Abstract B42A9-36, 2003

Gurney, K., R. Law, P. Rayner, and A.S. Denning, TransCom 3 Experimental Protocol, Department of Atmospheric Science, Colorado State University, USA, Paper No. 707, http://transcom.colostate.edu/TransCom_3/transcom_3.html, 2000.

Gurney, K.R., R.M. Law, A.S. Denning, P.J. Rayner, D. Baker, P. Bousquet, L. Bruhwiler, Y.H. Chen, P. Ciais, S. Fan, I.Y. Fung, M. Gloor, M. Heimann, K. Higuchi, J. John, T. Maki, S. Maksyutov, P. Peylin, M. Prather, B.C. Pak, J. Sarmiento, S. Taguchi, T. Takahashi, C.W. Yuen, Towards robust regional estimates of CO_2 sources and sinks using atmospheric transport models, *Nature,* **415**, 626-630, 2002.

Gurney, K.R., R.M. Law, A.S. Denning, P.J. Rayner, D. Baker, P. Bousquet, L. Bruhwiler, Y.H. Chen, P. Ciais, S. Fan, I.Y. Fung, M. Gloor, M. Heimann, K. Higuchi, J. John, T. Kowalczyk, E. Maki, S. Maksyutov, K. Masarie, P. Peylin, M. Prather, B.C. Pak, J. Randerson, J. Sarmiento, S. Taguchi, T. Takahashi, C.W. Yuen, Transcom 3 CO_2 Inversion Intercomparison: 1. Annual mean control results and sensitivity to transport and prior flux information, *Tellus*, **55B,** 555-579, 2003.

Gurney, K.R., R.M. Law, A.S. Denning, P.J. Rayner, B. Pak, and the TransCom 3 L2 modelers, Transcom 3 Inversion Intercomparison: Control results for the estimation of seasonal carbon sources and sinks, accepted to ***Global Biogeochemical Cycles,***18**,** GB1010, doi:10.1029/2003GB002111, 2004.

Gurney, K.R., Chen, Y-H., Maki, T., Kawa, R., Andrews, A., and Zhu, Z., Sensitivity of inverted carbon sources and sinks from seasonal and interannual varying fossil fuel emissions. EOS Trans. AGU, **84** (47), Fall Meet. Suppl., Abstract A51H-08, 2003b.

Kaminski, T., Rayner P.J., Heimann M. & Enting I.G. On aggregation errors in atmospheric transport inversions. *J. Geophys. Res.*, **106**, 4703-4715, 2001.

Law, R., Y.H. Chen, K.R. Gurney, P. Rayner, A.S. Denning, and TransCom 3 modelers. TransCom3 CO_2 inversion intercomparison: 2. Sensitivity of annual mean results to data choices, *Tellus*, **55B** (2), 512-521, 2003.

Lerner, J. Matthews, E. and Fung, I. Methane emissions from animals: A global high-resolution database, *Global Biogeochemical Cycles*, **2**, 139-156, 1988.

Marland, G., T.A. Boden, and R. J. Andres. 2003. Global, Regional, and National Fossil Fuel CO_2 Emissions. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

Marland G. and Rotty R.M. Carbon dioxide emissions from fossil fuels: a procedure for estimation and results for 1950-1982, *Tellus*, **36B**, 232-261, 1984.

Marnay, C., Fisher, D., Murtishaw, S., Phadke, A., Price, L., and Sathaye, J., 2002. *Estimating Carbon Dioxide Emissions Factors for the California Electric Power Sector*. Berkeley, CA. Lawrence Berkeley National Laboratory (LBNL-49945).

Olivier, J.G.J. and J.J.M. Berdowski (2001) Global emissions sources and sinks. In: Berdowski, J., Guicherit, R. and B.J. Heij (eds.) *The Climate System*, pp. 33-78. A.A. Balkema Publishers/Swets & Zeitlinger Publishers, Lisse, The Netherlands. ISBN 90 5809 255 0.

Pielke

Price, L., Michaelis, L., Worrell, E., and Khrushch, M., 1998. “Sectoral Trends and Driving Forces of Global Energy Use and Greenhouse Gas Emissions,” Mitigation and Adaptation Strategies for Global Change, 3:263-319, 1998.

Price, L., Worrell, E., and Khrushch, M., 1999. Sector Trends and Driving Forces of Global Energy Use and Greenhouse Gas Emissions: Focus in Industry and Buildings. Berkeley, CA. Lawrence Berkeley National Laboratory (LBNL-43746).

Rödenbeck, C. S. Houweling, M. Gloor, and M. Heimann. CO_2 flux history 1982-2001 inferred from atmospheric data using a global inversion of atmospheric transport, *Atmos. Chem. Phys. Discuss.,* **3**, 2575-2659, 2003b.

Wenzel, Tom, Brett Singer, and Robert Slott, 2000. "Some issues in the statistical analysis of vehicle emissions." *Journal of Transportation and Statistics*, 3:2, 1-14.

Wofsy, S.C. and R.C. Harriss, 2002: *The North American Carbon Program* (NACP)_. Report of the NACP Committee of the U.S. Interagency Carbon Cycle Science Program. Washington, DC: US Global Change Research Program.

Worrell, E., Price, L, Martin, N., Hendricks, C., and Ozawa Meida, L., 2001. “Carbon Dioxide Emissions from the Global Cement Industry,” *Annual Review of Energy and Environment* **26**: 303-29 (LBNL-49097).

II. Management Plan

1st year – familiarize and deconstruct CONCEPT model. Me and student. End of 1st year will begin work with LBNL. They will begin emission factor characterization. 2nd year – build in emissions factors and reassemble. Forward simulations – comparison to existing enventories, factor adjustment. 3rd year – forward with transport and chemistry, compare to MOPITT and *in situ* CO.

III. Cost Plan
Jillian will supply. Total: ~$250,000/year

IV. Current and Pending Funding

Pending funding: CO-PI on proposal to NASA NRA-04-OES-01 with Lisa Dilling (Principal investigator). Title: “Usable Science: Connecting the NACP to Useful Application in Multiple Scales of Carbon Management and Governance”.

V. Resumes

Kevin Robert Gurney

Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523
Ph: (970) 491-0604
e-mail: keving@atmos.colostate.edu

EDUCATION

Ph..D. 2004 – Ecology, Colorado State University
M.P.P 1996 – University of California, Berkeley
S.M. 1990 – Massachussetts Institute of Technology
B.A. 1986 – University of California, Berkeley

PROFESSIONAL EXPERIENCE

Research Scientist, Department of Atmospheric Science, Colorado State University, July 1998 – present

Staff Research Associate, Bren School of Env. Science and Management, University of California, Santa Barbara, Apr 1997 – June 1998

Senior Scientist, Institute for Energy and Environmental Research, September 1992 – January 1997

Research Associate, Atmospheric and Environmental Research, Inc., February 1992 – September 1992

Research Associate, Tellus Institute, February 1990 - October 1991

Research Assistant, National Oceanic and Atmospheric Administration, Summer 1988

Research Intern, Environmental Sciences Division, Lawrence Livermore National Laboratory, Nov 1986 - Sept 1987

Student Assistant, Atmospheric Aerosol Research Group, Lawrence Berkeley National Laboratory, Feb 1985-Oct 1986

PEER-REVIEWED PUBLICATIONS

1) Gurney, K.R., A.D.A Hansen, and H. Rosen, "Methane and Carbon Dioxide Increases in the Urban Boundary Layer: Inferences from Whole Column Infrared Absorbance Measurements" *Geophysical Research Letters*, **15**, 32, 1988.
2) Gurney, K.R. "National Greenhouse Accounting," *Nature*, **353**, 23, 1991.
3) Gurney, K.R. "Evidence for increasing ultraviolet irradiance at Point Barrow, Alaska," *Geophysical Research Letters*, **25** (6), 903-906, March 15, 1998.
4) Denning, A.S. M. Holzer, K.R. Gurney, M. Heimann, R.M. Law, P.J. Rayner, I.Y. Fung, S. Fan, S. Taguchi, P. Friedlingstein, Y. Balkanski, M. Maiss, and I. Levin, "Three-dimensional transport and concentration of SF_6: A model intercomparison study (Transcom 2)," *Tellus*, **51B**, 266-297, 1999.
5) Engelen, R.J., A.S. Denning, K.R. Gurney, and G.L. Stephens, "Global observations of the carbon budget: I. Expected satellite capabilities in the EOS and NPOESS eras," *Journal of Geophysical Research*, **106** (D17), 20055-20068, 2001
6) Gurney, K.R., R.M. Law, A.S Denning, P.J. Rayner, D. Baker, P. Bousquet, L. Bruhwiler, Y.H. Chen, P. Ciais, S. Fan, I.Y. Fung, M. Gloor, M. Heimann, K. Higuchi, J. John, T. Maki, S. Maksyutov, K. Masarie, P. Peylin, M. Prather, B.C. Pak, J. Randerson, J. Sarmiento, S. Taguchi, T. Takahashi, C.W. Yuen, "Towards robust regional estimates of CO_2 sources and sinks using atmospheric transport models," *Nature,* **415**, 626-630, February 7, 2002.
7) Engelen, R.J., A. Scott Denning, K.R. Gurney, and TransCom 3 modelers, "On Error Estimation in Atmospheric CO_2 Inversions," *Journal of Geophysical Research*, **107** (D22), 4635, 2002.
8) Gurney, K.R., R.M. Law, A.S Denning, P.J. Rayner, D. Baker, P. Bousquet, L. Bruhwiler, Y.H. Chen, P. Ciais, S. Fan, I.Y. Fung, M. Gloor, M. Heimann, K. Higuchi, J. John, E. Kowalczyki, T. Maki, S. Maksyutov, P. Peylin, M. Prather, B.C. Pak, J. Sarmiento, S. Taguchi, T. Takahashi, C.W. Yuen, "Transcom 3 CO_2 Inversion Intercomparison: 1. Annual mean control results and sensitivity to transport and prior flux information," *Tellus*, **55B**, 555-579, 2003.
9) Law, R., Y.H. Chen, K.R. Gurney, P. Rayner, A.S. Denning, and TransCom 3 modelers, "TransCom3 CO_2 inversion intercomparison: 2. Sensitivity of annual mean results to data choices," *Tellus*, **55B** (2), 512-521, 2003.
10) Maksytuov, S., T. Machida, H. Mukai, P. Patra, T. Nakazawa, G. Inoue, and TransCom 3 modelers, "Effect of recent observations on Asian CO_2 flux estimates with transport model inversions," *Tellus*, **55B**, 522-529, 2003.

11) Patra, P.K., S. Maksyutov, and TransCom 3 modelers, "Optimal network design for improved CO_2 source inversion," submitted to *Tellus*, **55B**, 498-511, 2003.
12) Dilling, L., S. Doney, J. Edmonds, K. R. Gurney, R. Harriss, D. Schimel, B. Stephens, and G. Stokes, "The role of carbon cycle observations and knowledge in carbon management," *Annu. Rev. Environ. Resour.*, **28**, 521-558, 2003.
13) Gurney, K.R., R.M. Law, A.S. Denning, P.J. Rayner, B. Pak, and the TransCom 3 L2 modelers, "Transcom 3 Inversion Intercomparison: Control results for the estimation of seasonal carbon sources and sinks," *Global Biogeochemical Cycles,* **18**, GB1010, doi:10.1029/2003GB002111, 2004.
14) Gurney, K.R. "Towards robust regional estimates of carbon sources and sinks using atmospheric transport models - the TransCom 3 Experiment," World Resource Review, *submitted*.
15) Gurney, K.R., Y.H.Chen, "Seasonal and interannually varying fossil fuel emissions: impact on atmospheric CO_2 inversions," 2004, *in preparation*.
16) Baker, D. R.M . Law, K.R. Gurney, A.S. Denning, P.J. Rayner, and TransCom 3 modelers, "Interannually varying sources and sinks of CO_2: Results from the TransCom 3 intercomparison," 2004, *in preparation*.

BOOKS

Makhijani A. and K. R. Gurney, "Mending the Ozone Hole: Science, Technology and Policy," MIT Press, 1995.

OTHER PUBLICATIONS

1) Bernow, S., M. Breslow, M. Becker, K.R. Gurney, D. Marron, D. Singh, and J. Stutz, "Incorporating Environmental and Economic Goals into Nevada's Energy Planning Process" Tellus Institute, 89-209, July 30, 1990.
2) Bernow, S., M. Becker, B. Biewald, K.R. Gurney, R. Hornby, D. Marron, R. Rosen, and D. Singh, "Environmental Impacts of Long Island's Energy Choices: The Environmental Benefits of Demand-Side Management", Tellus Institute, September, 1990.
3) Bernow, S., K.R. Gurney, and G. Prince, "Regional Biomass Strategies and Their Potential to Mitigate the Accumulation of Greenhouse Gases in the Atmosphere", Presented to the CONEG/NRBP Meeting, Burlington, VT. June 10, 1991.
4) Makhijani, A., K. Gurney and A. Makhijani, "Saving Our Skins: The Causes and Consequences of Ozone Layer Depletion and Policies for its Restoration and Protection", IEER, February 19, 1992.
5) Ko, M.K.W., N.D. Sze, D.T. Chang, G.I. Molnar, and K.R. Gurney, "Estimates of the Lifetimes and Global Warming Potentials of Chemical Compounds", AER, Inc., March 1992.
6) Ko, M.K.W., D.T. Chang, N.D. Sze and K.R. Gurney, "A Preliminary Compilation of Industrial Halocarbon Production Data", AER, Inc., May 1992.
7) Makhijani, A., and K.R. Gurney, "Petition Under the Clean Air Act to the Administrator of the Environmental Protection Agency for Reclassification of HCFC-22, HCFC-141b, and HCFC-142b as Class I Compounds, and Other Matters Related to the Protection of the Ozone Layer", Submitted to the Administrator of the EPA, April 14, 1992.
8) Chang, D.T., K.R. Gurney, M.K. W. Ko, C.E. Kolb, D.D. Nelson, Jr., J.M. Rodriguez, and D.K. Weisenstein, "Chemicals in the Atmosphere, Part II: Workbook", AER, Inc., August, 1992.
9) Franke, B., K.R. Gurney, A. Makhijani and M. Hoenig, "Uranium Doses to Workers at The Feed Materials Production Center -- Six Case Studies", IEER, December 23, 1992.
10) Franke, B., and K.R. Gurney, "Dose Calculations for Selected Residents Near the Cotter Mill, Canon City, Colorado", IEER, February 24, 1993.
11) Denning, A.S., P.J. Rayner, R.M. Law, and K.R. Gurney, "Atmospheric Tracer Transport Model Intercomparison Project (TransCom)," IGBP/GAIM Report Series, Report #4, edited by Dork Sahagian, 1998.
12) Gurney K.R. and J. Neff, "Carbon Sequestration Potential in Canada, Russia, and the United States Under Article 3.4 of the Kyoto Protocol," World Wildlife Fund, June 2000.
13) Gurney, K.R., R. Law, P. Rayner, and S. Denning, "TransCom 3 Experimental Protocol," Department of Atmospheric Science, Colorado State University, paper no. 707, July 2000.
14) Gurney, K.R. 2003. Book review of Fay and Golomb, *Energy and the Environment*, *EOS*, **84** (17), 2003.

PROFESSIONAL AND HONORARY SOCIETIES

American Geophysical Union since 1990

Sigma Xi since 2000

Marc L. Fischer
Atmospheric Sciences Program, MS 51-208
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
1 Cyclotron Rd. Berkeley, CA 94720
Phone: 510-486-5539
FAX: 510-486-6658
mlfischer@lbl.gov

Education
Ph.D. 1991 - Physics, University of California at Berkeley
M.S. 1982 - Physics, University of Illinois at Urbana-Champaign
B.S. 1981 - Physics, Massachusetts Institute of Technology

RESEARCH POSITIONS
Staff Scientist, Lawrence Berkeley National Laboratory, 1998-present.
Assistant Researcher, University of California, Berkeley, 1995-1997.
Postdoctoral Fellow**,** Lawrence Berkeley National Laboratory, 1993-1995.
Postdoctoral Fellow, University of California, Berkeley, 1991-1993.
Graduate Research Assistant, University of California, Berkeley, 1986 - 1991.

GRANTS
Public Interest Research Program, California Energy Commission, 2003-2005.
DOE-Atmospheric Radiation Program, 2000-2002, 2003-2005.
Laboratory Director Long-Term Development, LBNL, 1997-1998.
NASA Graduate Student Research Fellow, 1987-1990
Berkeley University Fellow, 1983

RESEARCH INTERESTS
Green House Gas Monitoring: Principal Investigator. Design of Atmospheric Monitoring Strategies for Green House Gases in California.
Atmosphere-ecosystem carbon exchange: Co-Investigator. Implementation of Carbon Cycle Measurements at the DOE ARM Southern Great Plains Site.
Indoor Air Quality: Collaborator. Measurements and modeling of factors controlling indoor PM2.5 of outdoor origin.

Selected Publications
1) Billesbach, D.P., M.L. Fischer, J.A. Berry and M.S. Torn. 2003. A highly portable, rapidly deployable system for eddy covariance measurements of CO2 fluxes. Journal of Oceanic and Atmospheric Technology (in press).
2) Dunne, J.A., Saleska, S.R., Fischer, M.L., and J. Harte. 2004. Integrating Experimental and Gradient Methods in Ecological Climate Change Research. Ecology (Concepts and Synthesis) (in press).
3) Lunden, M.M., Revzan, K.L., Fischer, M.L., Thatcher, T.L., Littlejohn, D., Hering, S.V. and N.J. Brown. 2003. The Transformation of Outdoor Ammonium Nitrate Aerosols in the Indoor Environment. Atmospheric Environment, 37, 5633-5644.
4) Fischer, M.L., Littlejohn, D., Lunden, M.M., and N. J. Brown. 2002. Automated Measurements Ammonia and Nitric Acid Vapors in Indoor and Outdoor Air. Environmental Science and Technology, 37, 2114-2119.
5) Saleska, S.R., M.R. Shaw, M.L. Fischer, J.A. Dunne, C.B. Still, M. Holman, and J. Harte. 2002. Large transient Decline and Predicted Long-term Recovery of Soil Carbon under Climate Warming, Global Change Biology, 16, 1055.
6) Torn, M.S., A. Lapenis, A. Timofeev, M. Fischer, I. Babikov, J. Harden. 2002. Soil Carbon Cycling in the Russian Steppe: Radiocarbon Analysis of Modern and Historic Russian Soils. Global Change Biology, 8, 1-14.

7) Fischer, M. L., Price, P. N., Thatcher, T. L., Schwalbe, C. A., Craig, M. J., Wood, E. E., Sextro, R. G., and A. J. Gadgil. 2001. Rapid Measurements and Mapping of Tracer Gas Concentrations in a Large Indoor Space. Atmospheric Environment, 35, 2837-2844.
8) Price, P. N., M. L. Fischer, R. G. Sextro, and A. J. Gadgil. 2001. Algorithm for rapid tomography of gas concentrations. Atmospheric Environment, 35, 2827-2835.
9) Harte, J., S. McCarthy, K. Taylor, A. Kinzig, M. L. Fischer. 1998. Estimating Species-Area Relationships from Plot to Landscape Scale Using Species Spatial-Turnover Data. OIKOS, 86, 45-54.
10) Conrad, M. E., P. F. Daley, M. L. Fischer, B. B. Buchanan, T. Leighton, M. Kashgarian. 1997. Carbon Isotope Evidence for Intrinsic Bioremediation af Petroleum Hydrocarbons, Environmental Science & Technology, 31, 1463.
11) Fischer, M.L., A. J. Bentley, K. A. Dunkin, A. T. Hodgson, W. W. Nazaroff, R. G. Sextro, and J. M. Daisey. 1996. Factors Affecting Indoor Air Concentrations of Volatile Organic Compounds at a Site of Subsurface Gasoline Contamination", Environmental Science & Technology, 30, 2948.
12) Bock, J., M. L. Fischer, A. E. Lange, and M. K. Parikh. 1995. Emissivity Measurements of Reflective Surfaces at Near-Millimeter Wavelengths, Applied Optics, 34,4812.
13) Fischer, M.L., A. Clapp, M. Devlin, J.O. Gundersen, A.E. Lange, P.M. Lubin, P.R. Meinhold, P.L. Richards, and G.F. Smoot. 1995. Measurements of the Millimeter-wave Spectrum of Interstellar Dust Emission, Astrophys.J., 444, 226.
14) Fischer, M.L., and A.E. Lange. 1993. Confusion Limits to the Measurement of the Sunyaev-Zel'dovich Effect in Clusters of Galaxies at Millimeter Wavelengths, Astrophys. J. , 419, 433.
15) Fischer, M.L., D.C. Alsop, E.S. Cheng, A.C. Clapp, D.A. Cottingham, J.O. Gundersen, T.C. Koch, E. Kreysa, P.R. Meinhold, A.E. Lange, P.M. Lubin, P.L. Richards, and G.F. Smoot. 1992. A Bolometric Millimeter-Wave System for Observations of Anisotropy in the Cosmic Microwave Background Radiation on Medium Angular Scales, Astrophysical Journal, 330, 242.
16) Alsop, D.C., E.S. Cheng, A.C. Clapp, D.A. Cottingham, M.L. Fischer, J.O. Gundersen, E. Kreysa, A.E. Lange, P.M. Lubin, P.R. Meinhold, P.L. Richards, and G.F. Smoot. 1992. A Search for Anisotropy in the Cosmic Background Radiation on Intermediate Angular Scales, Astrophysical Journal, 395, 317.

SELECTED PROFESSIONAL ACTIVITIES
Reviewer: The Astrophysical Journal, Environmental Science & Technology, The Journal of Atmospheric Environment, The Journal of Remote Sensing, US NSF, US DOE, US EPA

PROFESSIONAL AFFILIATIONS
American Geophysical Union
American Physical Society
Ecological Society of America

A. Scott Denning

Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523-1371

(970)491-6936 denning@atmos.colostate.edu FAX 491-8449

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:

2003– : *Associate Professor*, Department of Atmospheric Science, Colorado State University
Atmosphere-biosphere interactions. Global carbon cycle. Land-surface climate.

1998–03 : *Assistant Professor*, Department of Atmospheric Science, Colorado State University

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 $\mathbf{d}^{18}$O in atmospheric CO_2. Part 1: Surface fluxes. *Journal of Geophysical Research,* **102**, 5857-5872.

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 SF_6: 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.

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.

Gurney, K.R., R. M. Law, A. S. Denning, P. J. Rayner, D. Baker, P. Bousquet, L. Bruhwiler, Y.-H. Chen, P. Ciais, S. Fan, I.Y. Fung, M. Gloor, M. Heimann, K. Higuchi, J. John, T. Maki, S. Maksyutov, K. Masarie, P. Peylin, M. Prather, B.C. Pak, J. Randerson, J. Sarmiento, S. Taguchi, T. Takahashi and C.-W. Yuen, 2001: Towards robust regional estimates of CO_2 sources and sinks using atmospheric transport models. *Nature*, **415**, 626-630, Feb. 2002.

Engelen, R.J., A.S. Denning, K.R. Gurney and G.L. Stephens. Global observations of the carbon budget: I, 2001. Expected satellite capabilities in the EOS and NPOESS eras. *Journal of Geophysical Research*, **106,** (D17), 20055-20068.

Schaefer, K., A.S. Denning, N. Suits, Jorg Kaduc, I. Baker, S. Los, and L. Prihodko, 2002: The effect of climate on inter-annual variability of terrestrial CO2 fluxes. *Global Biogeochemical Cycles,* **16**, 1102, doi:10.1029/2002GB001928.

Baker, I.T., A.S. Denning, N. Hanan, L. Prihodko, P.-L. Vidale, K. Davis and P. Bakwin, 2003: Simulated and observed fluxes of sensible and latent heat and CO_2 at the WLEF-TV Tower using SiB2.5. *Global Change Biology,* **9**, 1262-1277.

Denning, A.S., M. Nicholls, L. Prihodko, I. Baker, P.-L. Vidale, K. Davis and P. Bakwin, 2003: Simulated and observed variations in atmospheric CO_2 over a Wisconsin forest. *Global Change Biology*, **9**, 1241-1250.

Nicholls, M.E., A.S. Denning, L. Prihodko, 2003: A multiple-scale simulation of variations in atmospheric carbon dioxide using a coupled biosphere -atmospheric model, *Journal of Geophysical Research*, in press.

Name: **Dennis Shoji Ojima**
Natural Resource Ecology Laboratory, Colorado State University, Ft. Collins, CO 80523
Phone: (303) 491-1976, E-mail: dennis@nrel.colostate.edu

Academic Training:

Pomona College	Botany	B.A.	1975
University of Florida	Plant Ecology	M.Ag.	1978
Colorado State University	Ecosystem Science	Ph.D.	1987

Professional Experience:

1996-	Sr. Research Scientist	Natural Resource Ecology Laboratory, CSU
1993-1996	Research Scientist	Natural Resource Ecology Laboratory, CSU
1992-	Assistant Professor	Rangeland Ecosystem Science Dept., CSU
1990-1991	Visiting Scientist	Office for Interdisciplinary Earth Studies, UCAR
1988-1990	Programme Officer	International Geosphere-Biosphere Programme

Synergistic Activities: International Global Atmospheric-Biospheric Chemistry (IGAC) Program Steering Committee Member on Activity 7.2: Trace-Gas Fluxes in Mid-Latitude Terrestrial Ecosystems, 1990-2000

Covenor of the Central Great Plains Regional Assessment, 1997-2001

Aldo Leopold Leadership Fellow, 1999 - Present

Co-Chairperson of the IGBP Science Planning Committee for the Global Land Project (2001-present)

Recent Research (Selected Funded Projects):

Using Multi-sensor Data to Model Factors Limiting Carbon Balance in Global Grasslands (NASA) (PI). Funded: 1/1/91-5/2001

Vegetation Ecosystem Modeling and Analysis Project (VEMAP- Phase I and II), (USDA-FS and NASA) (PI). Funded: 11/93-5/2000.

Integrated Assessment of Climate and Land Use Changes in the Central U.S. (NSF) (PI). Funded: 10/1/95-9/30/98

Regional Great Plains Assessment (Univ. Chi./Agronne/DOE) (PI). Funded: 7/31/98-6/30/01.

An Integrated Assessment of the Effects of Climate Change on Rocky Mountain National Park and its Gateway Community. (EPA) (CO-PI). Funded: 7/1/99-6/30/02.

Integrated Research Challenges: Biological Controls of Terrestrial Carbon Fluxes (NSF). Funded: 9/1/99-8/31/03.

Land Use/Management Change and Trace Gas Emissions in East Asia (Asian Pacific Network). Funded: 4/00-3/02.

Land-use Change in Temperate East Asia: Land Cover Changes Impacts on Carbon Fluxes and Land Productivity (NASA). Funded: 8/01-7/04.

Five Relevant Publications:

Ojima, D.S., D.S. Schimel, W.J. Parton, and C. Owensby. 1994. Long- and short-term effects of fire on N cycling in tallgrass prairie. Biogeochemistry 24:67-84.

VEMAP, et al. J. Borchers, J. Chaney, H. Fisher, S. Fox, A. Haxeltine, A. Janetos, D. Kicklighter, T. Kittel, A.D. McGuire, B. McKeown, J.M. Melillo, R. Neilson, R. Nemani, D. Ojima, T. Painter, Y. Pan, W. Parton, L. Pierce, L. Pitelka, C. Prentice, B. Risso, N. Rosenbloom, S. Running, D. Schimel, S. Sitch, T. Smith and I. Woodward. 1995. Vegetation/ecosystem modeling and analysis project (VEMAP): assessing biogeography and biogeochemistry models in a regional study of terrestrial ecosystem responses to climate change and CO_2 doubling. Global Biogeochemical Cycles 9:407-437.

Walko, R.L., L.E. Band, J. Baron, T.G.F. Kittel, R. Lammers, T.J. Lee, D.S. Ojima, R.A. Pielke, C. Taylor, C. Tague, C.J. Tremback, and P.L. Vidale. 2000. Coupled atmospher-biophysics-hydrology models for environmental modelling. J. Appl. Meteor. 39: 931-944.

Schimel, D.S., J.M. Melillo, H. Tian, A.D. McGuire, D. Kicklighter, T. Kittel, N. Rosenbloom, S. Running, P. Thornton, D. Ojima, W. Parton, R. Kelly, M. Sykes, R. Neilson, Brian Rizzo, and L. Pitelka. 2000. Contribution of increasing CO2 and climate to carbon storage by ecosystems in the United States. Science 287: (5460) 2004-2006.

Lu, Lixin, R.A. Pielke, Sr., G.E. Liston, W.J. Parton, D.S. Ojima, and M.D. Hartman. 2001. Implementation of a two-way interactive atmospheric and ecological model and its application to the central United States. Journal of Climate 14: 900-919.

Five Other Publications:

Ojima, D.S., T.G.F. Kittel, T. Rosswall, and B.H. Walker. 1991. Considerations for studying global change effects on terrestrial ecosystems. Ecological Applications 1:316-325.

Ojima, D.S. (ed.) 1992. Earth System Modeling. Proceedings from the 1990 Global Change Institute on Earth System Modeling. Snowmass, Colorado, 16-27 July 1990. UCAR/OIES. Global Change Institute Vol 3. 488 pp.

Ojima, D.S., W.J. Parton, D.S. Schimel, J.M.O. Scurlock and T.G.F. Kittel. 1993. Modeling the effects of climatic and CO_2 changes on grassland storage of soil C. Water, Air and Soil Pollution 70:643-657.

Harden, J. W., J.M. Sharpe, W.J. Parton, D.S. Ojima, T.L. Fries, T.G. Huntington, and S.M. Dabney. 1999. Dynamic replacement and loss of soil carbon on eroding cropland. Global Biogeochemical Cycles 13(4):885-901.

Ojima, D., L. Garcia, E. Elgaali, K. Miller, T.G.F. Kittel, and J. Lackett. 1999. Potential Climate Change Impacts on Water Resources in the Great Plains. Journal of the American Water Resources Association 35(6):1443-1454.

Graduate and Undergraduate Advisors and Advisees: J.J. Ewel, USDA, Honolulu, HI; A.E. Lugo, Intl. Inst. of Tropical Forestry, Rio Piedras, Puerto Rico; W.J. Parton, CSU; D.S. Schimel, NCAR; C.V. Cole, CSU; G. Innis, Retired; J.K. Detling, CSU; R. Martin, Colo U; X. Xiangming, U. of New Hampshire; L. Stretch, USDA; M. Walsh, Natl Academy of Sciences, N. Barger, CSU.

Collaborators (out of a list of 150)[4]

Conflict of Interest: Archer, S., Texas A & M; Asner, G., Colorado University; Baron, J., NREL, CSU; Braswell, Jr., B.H., Univ. New Hampshire; Cole, C.V., NREL, CSU; Coughenour, M.B., NREL, CSU; Frolking, S., Univ. New Hampshire; McGuire, A.D., Univ. of Alaska; McKeown, R., NREL, CSU; Melillo, J.M., Marine Biological Laboratory; Mosier, A.R., USDA/ARS; Neilson, R.P., USDA/Oregon State; Parton, W.J., NREL, CSU; Paustian, K., NREL, CSU; Pielke, R.A., Sr., Atmospheric Sciences, CSU; Running, S.W., Univ. of Montana; Schimel, D.S., National Center for Atmospheric Research, Boulder, CO; Scurlock, J.M.O., Oak Ridge Laboratories; Wessman, C.A., Colorado University.

Graduate and Undergraduate Advisors and Advisees: J.J. Ewel, USDA, Honolulu, HI; A.E. Lugo, International Institute of Tropical Forestry, Rio Piedras, Puerto Rico; W.J. Parton, NREL, CSU; D.S. Schimel, NCAR; C.V. Cole, NREL, CSU; G. Innis, Retired; J.K. Detling, Biology, CSU; Robin Martin, Colorado University; Xiao Xiangming, Univ. of New Hampshire; Laura Stretch, USDA; Meg Walsh, National Academy of Sciences, Nichole Barger, NREL, CSU.

VI. Letters of Support

Dear Dr. Gurney,

I write to express considerable interest and support in your effort to describe fossil-fuel-based CO_2 emissions at finer spatial and temporal scales. We now have manuscripts submitted that describe US emissions on both a monthly time scale and a state-by-state spatial scale, but these are the finest scales at which there are real data on fuel use from which to estimate CO_2 emissions. To go to finer scales is going to require proxy data and modeling efforts and I will be delighted to participate in such an effort, share our data, and share our experiences and insights. Our data sets should provide a firm foundation from which to derive estimates at finer spatial and temporal scales and I think that we can generate some very useful data sets that will include rigorous estimates of uncertainty.

Sincerely,

Gregg Marland
Distinguished Staff Scientist
Oak Ridge National Laboratory
Oak Ridge, TN 37830

Phone 865-241-4850
e-mail marlandgh@ornl.gov

letter from Prasad

The weaknesses:
1) Only US domain (Canada and Mexico?) not the world which is needed ultimately for OCO.
2) The temporal structure may not have the specificity of a particular date. It will very likely be able to simulate average day of the week, week of the year behaviour but will not likely be able to isolate a particular day of a particular week of a particular year. This makes it difficult to use in very specific CO_2 measurement campaigns which are very much tied to real days when measurements occurred.