Coupled Modeling of Terrestrial Ecosystem/ Atmospheric Carbon Cycle Interactions

NOAA-OGP Carbon Modeling Consortium

One of the most promising lines of research contributing to our understanding of the global carbon cycle is the use of atmospheric CO_2 observations to deduce surface fluxes by constrained inversion using a transport model. I can contribute to ongoing CMC inversion research in two key areas: (1) interactions between tracer transport an ecosystem metabolism, and (2) the much tighter constraint on the terrestrial carbon budget that will result from the consideration of additional tracers.

Successful application of the inversion technique requires accurate simulation of atmospheric CO_2 transport both at the resolved scale and in terms of subgrid-scale parameterized motions. A particularly important issue is the representation of terrestrial carbon exchange, which is tightly coupled to the land-surface energy budget and therefore the turbulent and convective transport. This "rectifier" effect may impose spatial structure on the lower tropospheric CO_2 field roughly half as strong as that of anthropogenic emissions (Denning et al, 1995, 1996a, b), even if the terrestrial biosphere is annually balanced with respect to carbon flux. Treatment of this effect in the inversion calculation requires a degree of sophistication in the representation of terrestrial carbon flux, atmospheric turbulence, cumulus convection, and the interactions between them that are not found in the suite of transport models currently used by the CMC.

A long-standing problem with the inversion technique is the difficulty of distinguishing terrestrial and marine fluxes acting in the same latitude band. The preliminary work of Fan and Gloor at CMC shows some skill at distinguishing carbon sinks in the North Atlantic and the boreal forest, but meaningful results will require a significant investment in additional observing sites. Terrestrial and marine fluxes could be better resolved using the existing flask network by adding the additional constraints of stable isotopic composition of CO_2 and atmospheric oxygen to the inversion calculation.

In the short term, improvements in the inversion can be obtained by including $\delta^{13}C$ in the simulation, but this will require representation of isotopic discrimination during photosynthesis and isotopic disequilibrium in soil carbon pools during respiration. These effects can be handled using "off the shelf" products from the literature, but such an approach would fail to capture the potentially crucial linkages to land-surface climate at short time scales. Realistic simulation of these effects will require parameterization of the physiological coupling between stomatal conductance and photosynthesis, and a multi-layer, multi-pool soil carbon model that allows organic material to "age." In addition, these processes should be linked to the atmospheric transport calculation via the surface energy budget and the parameterization of boundary-layer turbulence. I have recently contributed to a new analysis of these processes using SiB2 and CASA (Fung et al, submitted to GBC), and am preparing to implement the on-line calculation in the CSU GCM at a 6-minute time step.

In the longer term, inversion methods may be able to quantify not only regional terrestrial and marine fluxes, but also the relative changes in photosynthesis and respiration at the land surface using the $\delta^{18}O$ ratio of CO_2. Realistic calculation of these fluxes is much more difficult than is the case for ^{13}C, involving isotopic fractionation of both CO_2 and H_2O. oxygen fractionation during CO_2 exchange with land plants depends on interactions among stomatal physiology, photosynthetic biochemistry, boundary-layer turbulence, soil hydrology, and atmospheric water vapor. The isotopic composition of water in precipitation, atmospheric vapor, soil moisture, and plant tissues must be calculated everywhere. This will require a level of detail in the simulated physiology, ecosystem biogeochemistry, and atmospheric hydrology that is not currently available in any global model. I have recently implemented the skeleton of such a calculation in SiB2 (Ciais et al, accepted by JGR), and hope to develop this code further in the next year.

Specific Contributions to CMC Inversion Research:

1) Work with Songmiao Fan and Emanuel Gloor on the design and implementation of an inversion strategy that addresses the problems of the terrestrial carbon balance and the atmospheric "rectifier" effect. To this end, I will immediately provide the results of multiyear global integrations of about 15 tracer scenarios using the CSU GCM, including a fully coupled terrestrial ecosystem calculation using SiB2, as recently published in *Tellus*. In addition, I plan to work closely with CMC scientists on the design of the basis function used to represent fertilization of the terrestrial biota by CO_2 and nitrogen.

2) Work with CMC scientists to evaluate the simulated transport in the GCTM and SKYHI transport models, and to identify and prioritize areas for improvement. This can be done using existing TransCom results, and by performing additional experiments. It will require minimal programming support, which I request from CMC.

3) Develop and implement land-surface ^{13}C fractionation and disequilibrium fluxes in SiB2, and carry out multiyear global integrations of the atmospheric $\delta^{13}C$ ratio of CO_2 in the CSU GCM for a set of basis functions developed jointly with other CMC scientists. The first phase of this work will follow the method used by Fung et al (submitted to GBC). I will provide the results of this calculation to the CMC by the end of 1997. This will require programming support.

4) Develop and implement a new soil biogeochemistry and hydrology model that will replace the one currently used in SiB2. This will greatly improve the "climate" of soil moisture and soil temperature in the model, and will lead to more realistic simulation of soil carbon flux, $\delta^{13}C$, and eventually, $\delta^{18}O$. This will begin in 1997, with a fully interactive $\delta^{13}C$ calculation by 1998. This work will done in collaboration with the Randall EOS-IDS project, requiring considerable programming support and additional funding beyond what the CMC can provide. I am asking the CMC to support part of a technician and half of a graduate student to assist in this work.

5) Begin work on implementing $\delta^{18}O$ calculations in both the next generation SiB and the full 3D GCM, including fractionation during all phase changes of water in clouds, precipitation, groundwater, and plant tissues, and the exchange of ^{18}O between water and CO_2 at the land surface. This is a huge job, and will require major funding beyond that provided by the CMC. I am asking for CMC support to assist in this research.

6) Perform global, fully interactive simulations of atmospheric CO_2, $\delta^{13}C$, $\delta^{18}O$, and O_2/N_2 using the models described above, and use the results to calculate the atmospheric carbon budget by constrained inversion. This will require major support in addition to CMC funds. I expect that this objective can be accomplished by the end of 1999.