Upscaling: Terrestrial ^{13}C Discrimination as a Constraint on Seasonal CO_2 Exchange on Continental and Ocean Basin Scales

The work described here is being summarized in a manuscript in preparation by John Miller (NOAA/CMDL), Scott Denning, Neil Suits, Kevin Gurney, and Joe Berry.

With partial support from this project, we have developed a model of discrimination of stable carbon isotopes by terrestrial photosynthesis, and implemented this algorithm in SiB2.5, including recycling of CO_2 derived from ecosystem respiration through photosynthesis (Suits et al, in review). We have applied this model to investigate an apparent problem in an international intercomparison of global inverse calculations of regional CO_2 exchange (TransCom).

In seasonal inversions of observed CO_2 mixing ratios across 12 transport models Gurney et al (2003) noted that *a posteriori* estimates of seasonal cycles of carbon exchange over the North Atlantic and North Pacific Oceans exhibited much stronger uptake in summer months and weaker uptake in spring relative to the a priori fluxes prescribed from interpolated compilations of in-situ pCO2 measurements reported by Takahashi et al (1999). This shift in the seasonal cycle is allowable under the a priori uncertainty bounds associated with the Takahashi ocean fluxes (but just barely), and significantly improves the seasonality of the simulated CO_2. The result seems suspicious, however, in that the seasonality of air-sea gas exchange in the a posteriori TransCom estimates resembles that of terrestrial photosynthesis and respiration. Typical ocean fluxes are dominated by a spring bloom followed by weak uptake or even outgassing during summer as the surface warms and the mixed layer shallows. We hypothesized that the CO_2 inversion was misattributing terrestrial fluxes as air-sea gas exchange, and tested this hypothesis by comparing the $\delta^{13}C$ of CO_2 to observations.

We calculated $\delta^{13}C$ implied by the TransCom inversion by multiplying the CO_2 response functions by seasonally and regionally varying isotope ratios derived from the multiyear SiB2 simulations performed for this project (Suits et al, in review; see last year's progress report). We treated fossil fuel as having a constant uniform $\delta^{13}C$, and used a constant fractionation of 2 permil for net air-sea gas exchange. Isotopic disequilibrium in the ocean was specified using estimates of $\delta^{13}C$ of ocean DIC from Gruber and Keeling (2001) and one-way fluxes derived from the Takahashi (1999) sea-surface pCO2 climatology. Terrestrial disequilibrium was estimated using pulse-response functions from the CASA ecosystem model (Randerson et al, 1997). We performed this analysis using 12 sets of seasonal transport response functions and fluxes for each of 22 regions at 76 flask stations generated by the TransCom experiment (Gurney et al, 2003).

We found that although the seasonal cycle of CO_2 was quite well simulated for most models, the amplitude of the seasonal cycle of $\delta^{13}C$ was substantially underestimated (Fig CSU-1). This result is consistent with the hypothesis that the a posteriori seasonal fluxes from the TransCom inversion are incorrectly being applied to the oceans (with weak fractionation) rather than to land (with much stronger fractionation). Alternatively, the discrimination simulated by SiB2 for each region and season may have been too weak. We compared simulated discrimination to Keeling plot intercepts in several major biomes (Fig CSU-2), and found general agreement, though the observations are quite sparse in many regions. A tendency for SiB2 fluxes to be too heavy in tropical forests may result

from insufficient recycling of respired CO_2 by canopy photosynthesis, but is unlikely to have much effect on higher latitude $\delta^{13}C$.

We tested the sensitivity of simulated $\delta^{13}C$ to incorrect regional or seasonal simulation of terrestrial discrimination by varying discrimination in all regions by +1.5 and –1.5 ‰. The simulated amplitude was quite insensitive to errors of this magnitude (Fig CSU-3). It is unlikely that the SiB2 discrimination could be systematically wrong by 3 or 4 ‰ that would be required to match the observed seasonality of atmospheric $\delta^{13}C$ in the marine boundary layer given the TransCom estimates of air-sea gas exchange.

On the other hand, shifting 2 GtC of summertime uptake from the northern oceans to the temperate continents resulted in a much improved simulation of the amplitude of atmospheric $\delta^{13}C$ (Fig CSU-4). This shift is well within the a priori uncertainty assigned to the TransCom seasonal fluxes over the continents, and does not markedly degrade the simulation of atmospheric CO_2. We conclude that the inversion of CO_2 alone misattributes terrestrial seasonality (and net annual flux) to the northern oceans, and that the additional constraint on land-ocean partition afforded by $\delta^{13}C$ leads to more accurate characterization of the carbon cycle.

A remaining puzzle is that after adjusting the fluxes to better match the seasonal observations, the simulated north-south gradient of $\delta^{13}C$ in the annual mean is not strong enough. We can simultaneously match the seasonal amplitude and annual mean gradient only by both (1) shifting some of the ocean flux seasonality back onto the continents, as outlined above; and (2) substantially increasing the isotopic disequilibrium fluxes from the northern land. The amount of increased disequilibrium required varies strongly among transport models, from values that seem realistic to values that seem too large. It may be, therefore, that comparing simulated and observed $\delta^{13}C$ in carbon cycle inversions can tell us not only about errors in the seasonal fluxes, but also about errors in the transport models used in the calculation.

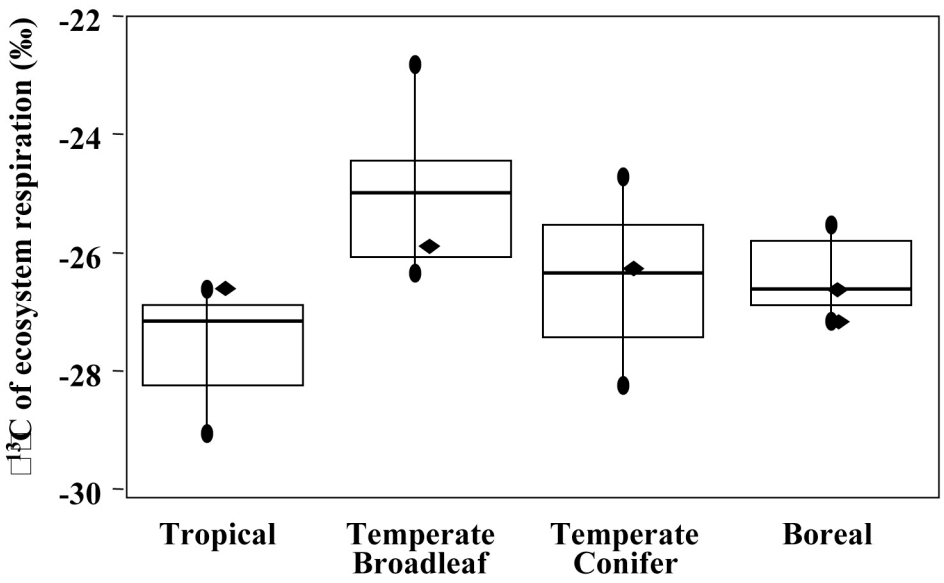

Fig CSU-2: comparison between simulated and observed $\delta^{13}C$ of ecosystem respiration for four forest biome types. Observations are from the BASIN network (see figure 7 in Pataki et al., 2002). The boxes enclose 50% of the observed data population. The center line shows the median value. Error bars show the upper/lower quartile + 1.5 times the interquartile distance. Sample sizes range from 6-17 for the boreal forests and temperate broadleaf forests, respectively. The diamonds are mean $\delta^{13}C$ values for C3 plants from comparable biomes calculated in the 11-year simulation. SiB2's broadleaf evergreen is compared to data from tropical forests; broadleaf deciduous is compared to temperate broadleaf; broadleaf and needleleaf is compared to temperate conifer; and needleleaf and needleleaf deciduous are compared to boreal. The sample sizes range from approximately 300 to 2000. The standard deviations are all lower than 0.02‰. In general, simulated $\delta^{13}C$ values are close to observed values although there is slightly less variability in simulated values than in observations. In particular, simulated $\delta^{13}C$ values in the tropics are heavy relative to observations. In contrast, simulated $\delta^{13}C$ values in broadleaf deciduous are relatively light compared to observations in temperate broadleaf.

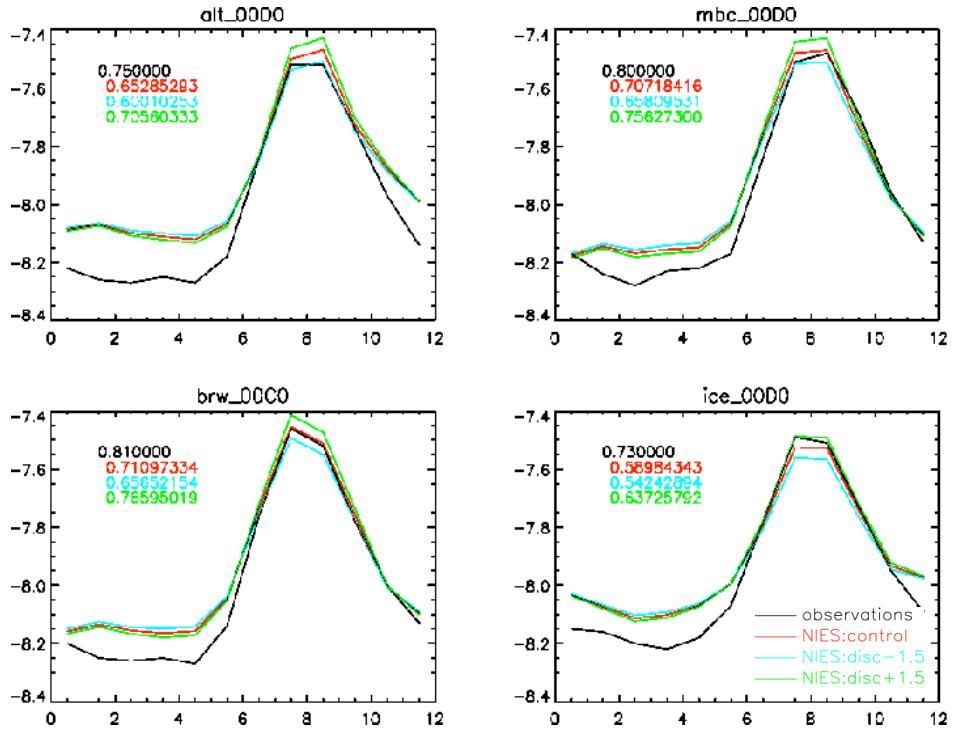

Fig CSU-3: Sensitivity of simulated seasonal cycle of atmospheric $\delta^{13}C$ at 4 high-latitude CMDL flask stations to terrestrial discrimination. Amplitudes are indicated by text numerals in colors indicated by the legend.

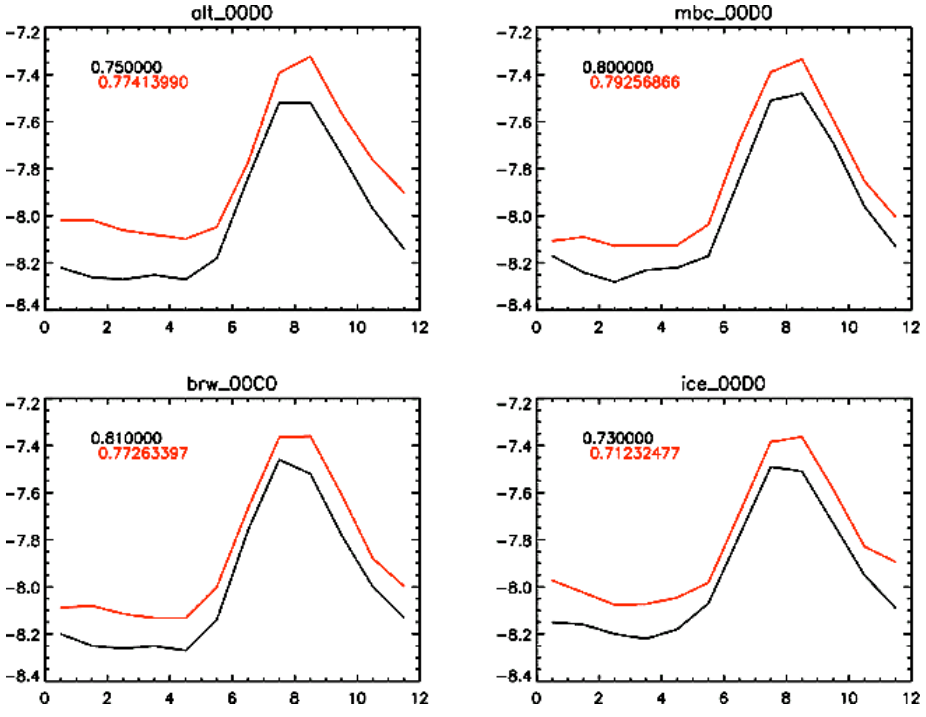

Fig CSU-4: Simulated seasonal cycle of atmospheric $\delta^{13}C$ at 4 high-latitude CMDL flask stations after shifting 2 GtC/yr of summertime uptake from the northern oceans to the northern continents. The absolute numbers are shifted by an arbitrary "offset" that reflects the fossil fuel trend, and should be ignored.

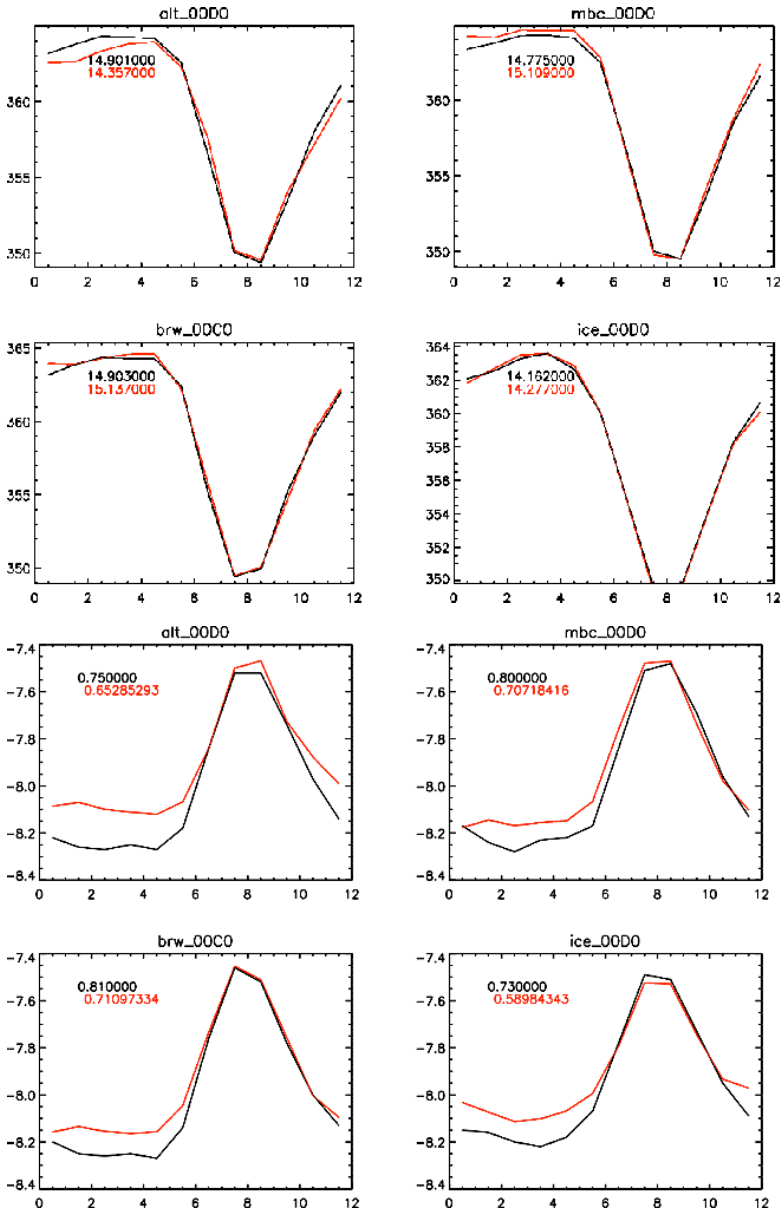

Fig CSU-1: Simulated (red) and observed (black) seasonal variations of CO_2 (top 4 panels) and $\delta^{13}C$ (bottom 4 panels) at 4 CMDL flask stations in high northern latitudes. The stations are: Alert, Mould Bay Canada, Point Barrow, and Iceland. Numbers on the plots list the observed (black) and simulated (red) seasonal amplitudes.