CARBON-14 CONSTRAINTS ON THE LATITUDINAL DISTRIBUTION OF AIR-SEA GAS EXCHANGE

N. Y. Krakauer[1], J. T. Randerson[2], F. W. Primeau[2]

[1] *Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125; niryk@caltech.edu*
[2] *Earth System Science, University of California, Irvine, CA 92697*

ABSTRACT
The air-sea gas exchange rate is important for modeling and verifying ocean CO_2 uptake, but remains subject to considerable uncertainty. The widely assumed quadratic or cubic dependence of the exchange rate on windspeed together with the latitudinal pattern of mean windspeed implies that exchange is much faster at high compared with low latitudes. This should affect the pattern of ocean uptake of bomb carbon-14 as well as the rate of decline of and latitudinal gradients in atmospheric $\Delta^{14}CO_2$. We evaluate the constraints on the windspeed dependence of the exchange rate offered by available isotopic measurements, discuss the major uncertainties, and suggest observational strategies to reduce these uncertainties.

OCEAN CARBON-14 DISTRIBUTION
To assess the impact of air-sea exchange on ocean uptake, we modeled the transport of bomb carbon-14 into the ocean for different exchange rate patterns using advection-diffusion fields from a coarse-resolution version of the ocean component of the Canadian Centre for Climate Modelling and Analysis Coupled Global Climate Model (CGCM2) driven by climatological forcing. We compared the predicted bomb carbon-14 concentrations with the large observational database developed by the Global Ocean Data Analysis Project (GLODAP) [*Key et al.*, 2004]. To help assess model transport error, we modeled ocean CFC uptake with the same set-up, taking advantage of the fact that CFC uptake is much less dependent than carbon-14 uptake on the air-sea gas exchange parameterization. With the data-model discrepancies for CFCs providing a rough estimate of model uncertainty, we could solve either for the best-fit global relationship between gas exchange and mean windspeed or for the best-fit mean gas exchange rate over each of ~15 ocean regions. Our preliminary results suggest that globally, the air-sea gas exchange rate may be better expressed as a linear than as a quadratic or cubic function of windspeed (Fig. 1). Given the limitations of our model transport, especially at high southern latitudes, the latitudinal mean sir-sea exchange rates deduced from it remain uncertain. Such error could be quantified and probably reduced by intercomparing ocean transport models or by solving for air-sea exchange and transport fields simultaneously in a data-assimilating circulation model.

ATMOSPHERE CARBON-14 DISTRIBUTION
We also looked at the consequences of different gas exchange relationships for $\Delta^{14}C$ of atmospheric CO_2 and compared with tree-ring and atmospheric data. This approach does not require an ocean transport model, as long as the sea-surface $\Delta^{14}C$ distribution is known; its main disadvantages are that data on the atmospheric $\Delta^{14}C$ distribution is sparse, and that the $\Delta^{14}C$ gradients are small and thus hard to measure. We found that the atmospheric $\Delta^{14}C$ gradient between the southern hemisphere tropics and midlatitudes is quite sensitive to the air-sea exchange rate in the Southern Ocean, and hence to its assumed windspeed dependence. Available data support relatively low dependence on windspeed (Fig. 2), consistent with our ocean model results. Ongoing high-precision measurement of atmospheric and ocean radiocarbon can thus provide valuable, independent data on air-sea exchange.

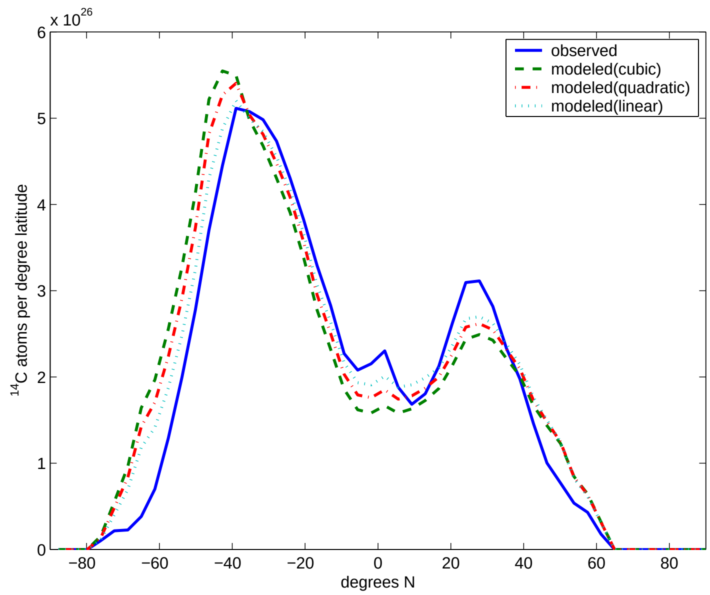

Fig. 1. Distribution of bomb radiocarbon in the ocean by latitude in 1994 from a climatology based on ocean measurements [*Key et al.*, 2004] (solid line) compared with the distribution predicted from our model if we assume either a cubic (dashed line), quadratic (dotted-dashed line), or linear (dotted line) increase of the air-sea gas exchange rate with climatological root-mean-square satellite-derived windspeed. The global mean exchange rate is the same, 21 cm/hr at a Schmidt number of 660 [*Wanninkhof*, 1992], for all three scenarios. As compared with a cubic or quadratic dependence, a linear dependence results in higher predicted inventories in the tropics and lower predicted inventories at high southern latitudes, generally matching the observed distribution more closely. Note that the model consistently overestimates uptake south of 55°S, apparently due to too-strong overturning south of the Subantarctic front.

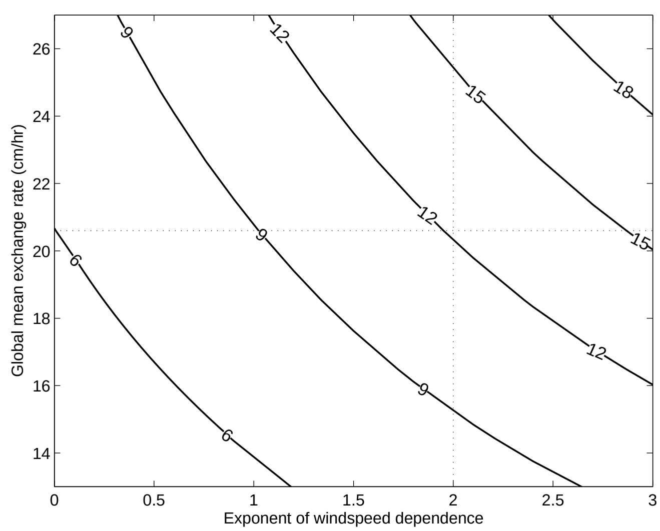

Fig.2. Predicted mid-1990s annual-mean difference $\Delta^{14}C$ of atmospheric CO_2, in per mil, between Llano de Hato, Venezuela (9°N) and Macquarie Island (54°S) for different global mean air-sea gas exchange rates (vertical axis) and exponential dependences of the gas exchange rate on windspeed (horizontal axis; the dotted lines show the widely-used *Wanninkhof* [1992] values for these parameters, with the exchange rate proportional to the squared windspeed). For a given global mean rate, a larger windspeed dependence exponent shifts gas exchange to the windy Southern Ocean, implying more carbon-14 uptake there and thus depressed atmospheric $\Delta^{14}C$ in the southern mid-latitudes compared with the tropics. *Levin and Hesshaimer* [2000] measured a mean gradient of 6±3‰ for 1993-4, suggesting a less than quadratic dependence of gas exchange on windspeed if we assume that the global mean is similar to the *Wanninkhof* [1992] value. The predictions shown are based on a climatology of sea-surface $\Delta^{14}C$ [*Key et al.*, 2004], ^{14}C exchange with the land biosphere calculated from the CASA model [*Thompson and Randerson*, 1999], and fossil fuel emissions from *Andres et al.* [1996], combined with the atmospheric transport model MATCH run with NCEP model winds.

REFERENCES

Andres, R. J., G. Marland, I. Fung, et al. (1996), A 1 degrees x1 degrees distribution of carbon dioxide emissions from fossil fuel consumption and cement manufacture, 1950-1990, *Global Biogeochem. Cycles*, *10*(3), 419-429.

Key, R. M., A. Kozyr, C. L. Sabine, et al. (2004), A global ocean carbon climatology: Results from Global Data Analysis Project (GLODAP), *Global Biogeochem. Cycles*, *18*(4), GB4031.

Levin, I. and V. Hesshaimer (2000), Radiocarbon - A unique tracer of global carbon cycle dynamics, *Radiocarbon*, *42*(1), 69-80.

Thompson, M. V. and J. T. Randerson (1999), Impulse response functions of terrestrial carbon cycle models: method and application, *Glob. Change Biol.*, *5*(4), 371-394.

Wanninkhof, R. (1992), Relationship between wind-speed and gas-exchange over the ocean, *J. Geophys. Res.*, *97*(C5), 7373-7382.