Satellite-derived estimates of interannual variability in recent oceanic CO_2 uptake

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Abstract: The growth rate of atmospheric CO_2 undergoes significant interannual variability, largely due to temporal variability of partitioning of CO_2 between terrestrial biosphere and ocean. In the present paper, as a follow-up to the work by *Lee et al.* [1], we estimated the year-to-year variability in net global air-sea CO_2 fluxes between 1982 and 2003 from observed changes in wind speed and estimated changes in ΔpCO_2. Changes in pCO_{2SW} were inferred from global records of sea surface temperature (SST) anomalies and seasonally varying SST dependence of pCO_{2SW}. The modeled interannual variability of ±0.2 Pg C yr^{-1} (1σ) from the present work is significantly smaller than the values deduced from atmospheric observations of $^{13}CO_2/^{12}CO_2$ in conjunction with different atmospheric transport models, but it is closer to the recent estimates inferred from a 3-D ocean biogeochemical model and atmospheric transport models constrained with extensive observations of atmospheric CO_2.

Keywords: CO_2, interannual variability, oceanic uptake

1. Introduction

Quantifying the year-to-year variability of net air-sea CO_2 fluxes and identifying the mechanisms causing that variability are important for three reasons. First, an accurate estimate of the net air-sea CO_2 flux variability better constrains the interannual variability of land biosphere carbon uptake by inversions of the atmospheric CO_2 data [2]. Second, the large interannual variability of net air-sea CO_2 fluxes inferred from atmospheric studies raises a serious question whether our surface pCO_{2SW} climatology complied from multi-year data sets [3] represents the current oceanic condition. Third, large interannual variability implies corresponding changes in surface ocean biology and physics. Thus, it would provide an independent test for ocean biogeochemical models used to simulate future atmospheric CO_2 concentration [4]. Significant spatial and temporal variability in net air-sea CO_2 flux and lack of long-term time series observations of pCO_{2SW} on a global scale make it difficult to verify large interannual variability in oceanic CO_2 uptake inferred from studies using atmospheric $^{13}CO_2/^{12}CO_2$ data and different inverse methods. Such large variability is in striking contrast to a diagnostic calculation [1]. This was the first effort utilizing oceanic observations of ΔpCO_2 [5] to extrapolate interannual variability in global net air-sea CO_2 flux. The present study considerably supplements the previous work [1] by covering the following issues: (1) Detailed descriptions of the calculation method and modifications made on those used in *Lee et al.* [1]; (2) Extension of analysis covering the 22-year period; (3) Extensive validation of the assumption—that the seasonal pCO_{2SW}-SST relationships can be used to infer interannual variations in net air-sea CO_2 fluxes—by comparing with time-series observations not included in preliminary results of *Lee et al.* [1]; (4) Assessment of random and systematic uncertainties in modeled interannual variability; (5) Investigation of potential factors depressing the interannual variability; and (6) Comparison with outputs from a 3-D global-scale model including components of ocean circulation and biogeochemistry [6] and with inverse modeling results using 20-year atmospheric CO_2 measurements obtained from the global atmospheric sampling network [7].

2. Data analysis and calculation method

The monthly mean CO_2 flux for each latitude 4° × longitude 5° pixel for an individual year other than 1995 was estimated from the improved global climatology of ΔpCO_2 representing 1995, together with global records of monthly mean wind speed and SST anomalies compared to the 1995 climatology in the following manner:

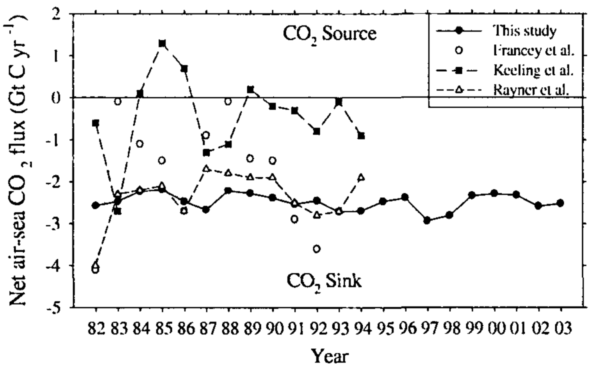
$$F_{ym} = k_{ym}\ K_{O,ym}\ \{[pCO_{2SW\,1995m} + (\partial pCO_{2SW}/\partial SST)_{1995m} \times \Delta SST_{ym-1995m}]\} - pCO_{2AIR\ 1995m} \quad (1)$$

where K_o is the solubility of CO_2, *ym* is the year and month in the time series during the 1982-2003 period, and subscript *1995m* refers to the month in 1995. Net air-sea CO_2 flux (F) can be decomposed into a kinetic (k) and thermodynamic component ($K_o\ \Delta pCO_2$). In the present study we assume that variations in k_{ym} are related to the monthly mean wind speed variations and variations in surface pCO_{2SW} can fully be parameterized by SST variations through seasonal pCO_{2SW}-SST relationships. *Takahashi et al.* [3] produced a global ΔpCO_2 climatology for a single non-El Niño year using approximately 940,000 measurements of surface water pCO_{2SW} and overlying atmospheric pCO_{2AIR} made over the last 40 years since the International Geophysical Year of 1956-1959. Because of measurement sparseness in terms of time and space, the multi-year pCO_{2SW} data were normalized to the reference year 1995, and interpolated in space (4°×5° grid) and time (monthly) using the surface transport field of the Princeton/GFDL General Circulation Model [8]. The assumption in our method is that the

pCO_{2SW}-SST relationship includes a thermodynamic component and an empirical part accounting for pCO_{2SW} changes due to the influence of advection, upwelling and outcropping of water with different levels of CO_2 (transport effect), and photosynthesis and respiration in the surface water (the biological effect).

3. Results

An average of our modeled net air-sea CO_2 fluxes for the period 1982-2003 is -2.22 Pg C yr^{-1} with a variability of ±0.2 Pg C yr^{-1} (1σ). The interannual variability of ±0.2 Pg C yr^{-1} is significantly less than that inferred from an atmospheric carbon and its $\delta^{13}C$ budget method combined with the atmospheric transport models



To evaluate the accuracy of our modeled fluxes, the modeled net air-sea CO_2 fluxes were compared with multi-year observations at time-series stations representing different oceanic regimes. In summary, comparisons with time-series measurements show that there is broad agreement, within about 50%, between our modeled net fluxes and those observed in the equatorial Pacific, BATS, and HOT, but our modeled results appear to underestimate the interannual variability by as much as 50%. This suggests that a single parameterization of pCO_{2SW} with SST may not fully account for the biological effect on pCO_{2SW} such as functional changes in marine ecosystems on seasonal and interannual time scales.

4. Conclusions

The estimated interannual variability for the period between 1982 and 2002 is ±0.2 Gt C yr^{-1} (1σ), which is similar in magnitude to a 3-D ocean model-based estimate [6], but a bit smaller than a recent estimate [7] inferred from extensive atmospheric CO_2 observations. The modeled variability in global net air-sea flux of CO_2 contributes to about a quarter of the atmospheric CO_2 growth rate [9, 10]. Thus, much of interannual changes in atmospheric CO_2 growth rate must be controlled by exchange with the terrestrial biosphere. Determining which regions and processes are responsible for year-to-year variations in CO_2 uptake by ocean and land biosphere is necessary to separate interannual variations from long-term mean fluxes and thus help us to predict future atmospheric CO_2 levels in response to various emission scenarios.

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