The Changing Role of the Ocean and Land in the Global Carbon Balance

Global Ocean Carbon Uptake: Magnitude, Variability and Trends

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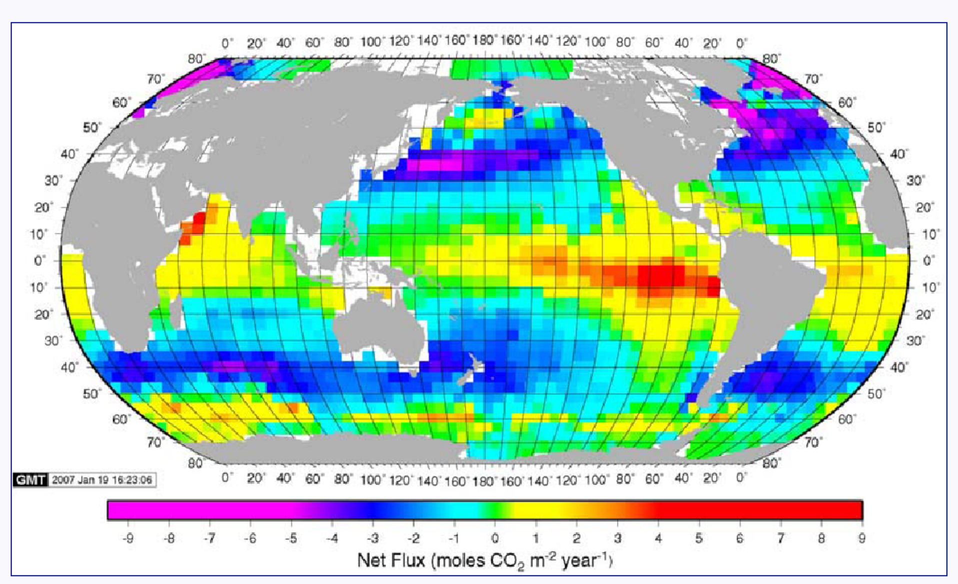
Abstract

As part of the Regional Carbon Cycle Assessment project (RECCAP) the global sea-air carbon dioxide (CO_2) flux and trends over the past two decades are estimated from observations. The net CO_2 flux by the global ocean is estimated at -1.4 Pg C yr^{-1} from a climatology of sea-air partial pressure of CO_2 difference (ΔpCO_2) of Takahashi et al. (2009), based on extensive observations of surface water pCO_2 levels, and a parameterization of gas transfer with wind. The inter-annual variability is estimated to be 0.14 Pg C yr^{-1} from 1990 through 2009 mostly driven by large-scale climate re-organizations. The trend shows a decrease in uptake of 0.1 Pg C $decade^{-1}$ which is attributed to the fact that the empirical method does not implicitly include rising atmospheric CO_2 levels. This is accounted for by applying the output of a "CO_2-only run" to the results that, with this correction, shows good agreement with models. The decadal trends differ regionally with increasing uptake at high latitude caused in equal measure by increasing ΔpCO_2 and wind, and increased outgassing in mid- to low-latitudes.

Magnitude of Global Sea-Air CO_2 Fluxes

The climatological sea-air CO_2 fluxes were determined from the bulk formulation with ΔpCO_2 from Takahashi et al. (2009) and the gas transfer velocity, k from the second moment of the wind, $k_{660} = 0.251 <U^2>$ using the cross-calibrated multiplatform (CCMP) wind product (Atlas et al., 2011) :

$$\text{Sea-air } CO_2 \text{ Flux} = K_0 \times k \times \Delta pCO_2 \quad (1)$$



Net CO_2 flux = -1.4 Pg C yr^{-1} (-0.35 mol C m^{-2} yr^{-1})

This value can be compared with the global estimates based on other observational and modeling approaches as provided in the RECCAP.

Table 1. Comparison of the global sea-air CO_2 fluxes based on different approaches

Product	Period	Net Flux (Pg C yr^{-1})	Uncertainty
pCO_2	1990–2009	-1.4	
Ocean Models	1990–2009	-1.9	0.4
Ocean Inversions	1990–2009	-1.9	0.3
O_2/N_2 derived Estimate	**1990–2000**	-1.3	
Atmospheric Inversions	**1990–2008**	-1.4	0.4

The comparison suggests that the estimate based on sea-air CO_2 fluxes is somewhat lower than models and methods based on global mass balances.

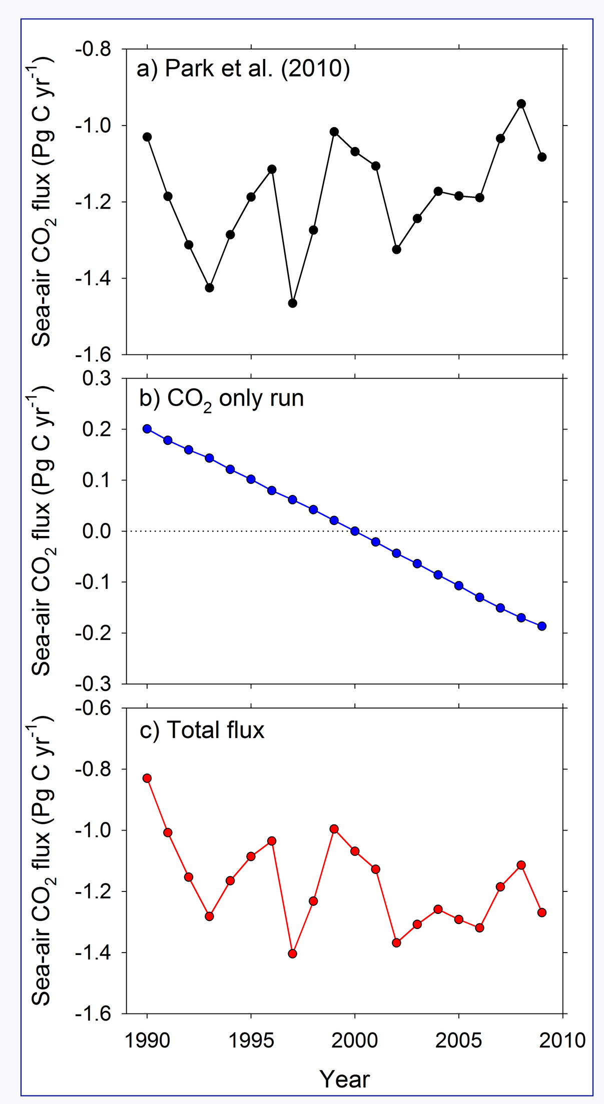
Variability in Global Sea-Air CO_2 Fluxes

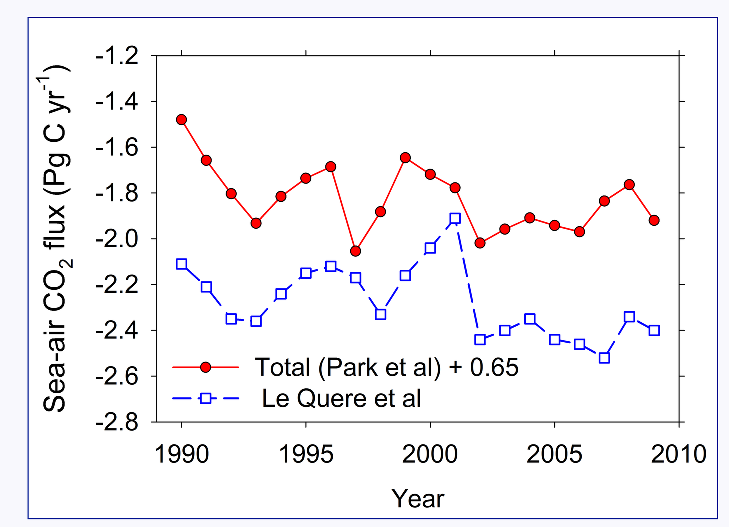
From the climatology the temporal variability in sea-air CO_2 fluxes is determined using sub-annual regionally specific relationships of pCO_2 and SST according to Park et al. (2010):

$$F_{ym} = k_{ym} K_{0\,ym} \{[\Delta pCO_{2\,2000m} + (\delta pCO_{2SW} / \delta SST)_{2000m} \times \Delta SST_{ym-2000m}]\}, \quad (2)$$

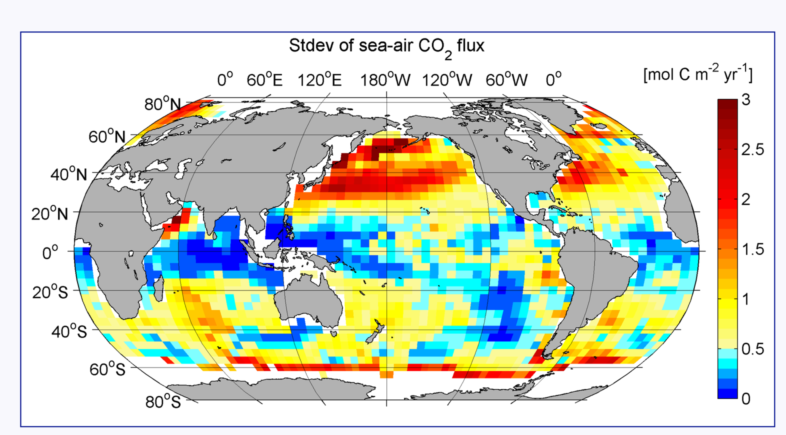
where subscript *ym* is the year (*y*) and the month (*m*) during the study period, and subscript *2000m* refers to the month in 2000. The inter-annual variability is shown in the top panel of the figure below.

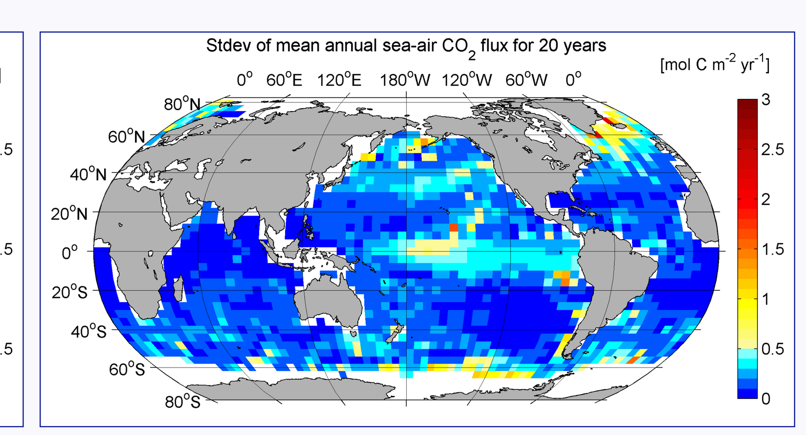
After accounting for the increasing trend due to increasing atmospheric CO_2 levels using the output from a numerical ocean biogeochemistry model (Doney et al., 2009) (center panel) the total flux is estimated that shows reasonable agreement with the variability of ocean models assessed by Le Quéré et al. (2009) (bottom and right panels) albeit with an offset of ≈ 0.6 Pg C yr^{-1} (see Table 1).





The results show appreciable greater seasonal (intra-annual) variability than inter-annual variability with maximum variability centered in different areas.



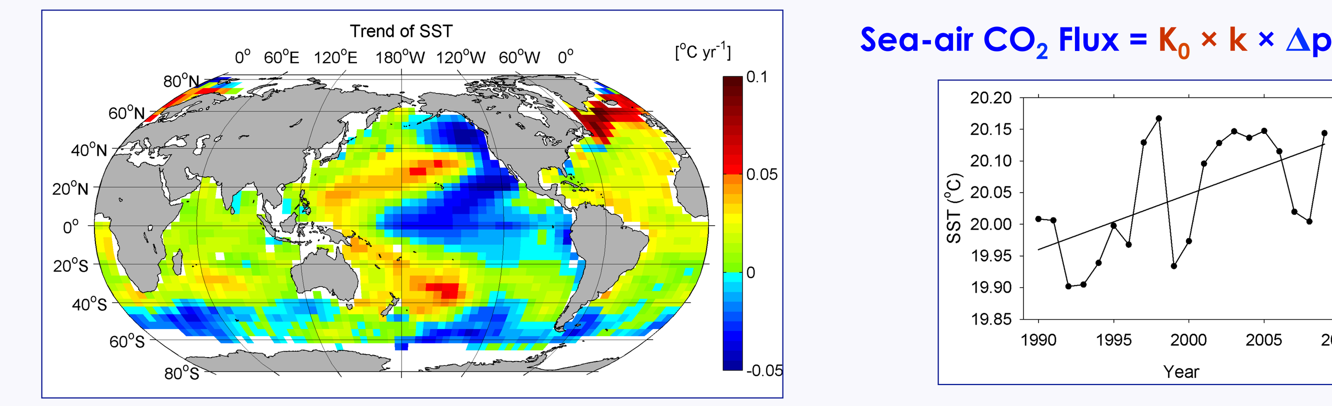


Intra-annual variability
Standard deviation of the 12 monthly fluxes at 4˚ by 5˚ grid as an indicator of intra-annual (seasonal) variability

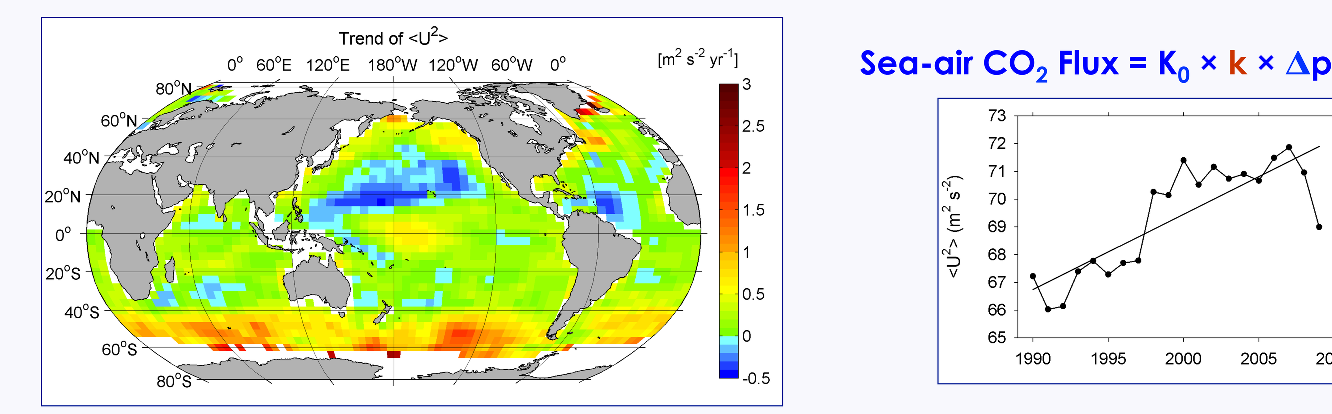
Inter-annual variability
Standard deviation of the 20-year annual mean as an indicator of inter-annual variability

Trends in Global Sea-Air CO_2 Fluxes

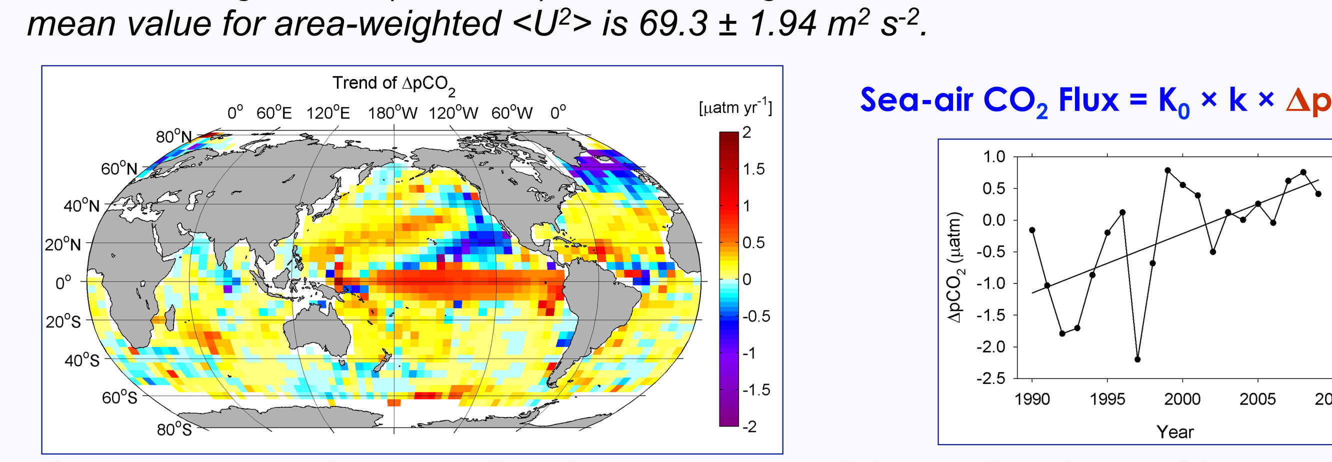
Decadal trends in fluxes can be caused by changes in SST, ΔpCO_2, or changes in k due to wind (see eqn. 1). The three parameters interact such that the net effect is a decrease in ocean CO_2 uptake when not accounting for the impact of increasing atmospheric CO_2 levels.



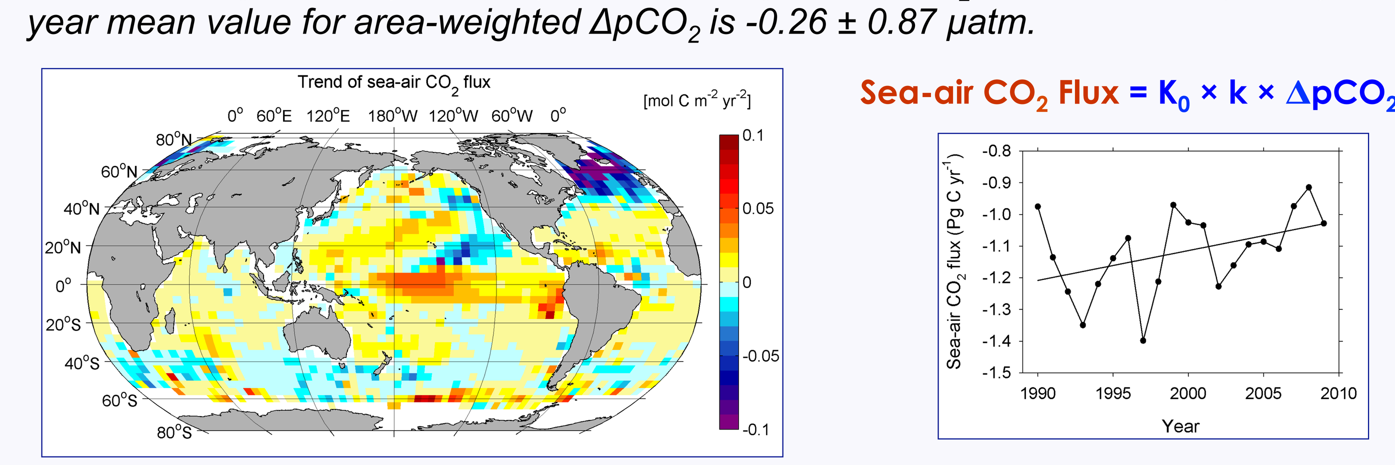
The SST data are obtained from the NCEP Optimal Interpolated SST product (http://www.cdc.noaa.gov/data/gridded/data.noaa.oisst.v2.html), re-gridded onto a 4˚ by 5˚ grid. The linear regression (solid line) for area-weighted SST is 0.009 ± 0.003 ˚C yr^{-1}. The 20-year mean value for area-weighted SST is 20.04 ± 0.09 ˚C.



The linear regression (solid line) for area-weighted $<U^2>$ is 0.27 ± 0.04 m^2 s^{-2}. The 20-year mean value for area-weighted $<U^2>$ is 69.3 ± 1.94 m^2 s^{-2}.



The linear regression (solid line) for area-weighted ΔpCO_2 is 0.09 ± 0.03 µatm yr^{-1}. The 20-year mean value for area-weighted ΔpCO_2 is -0.26 ± 0.87 µatm.



The linear regression (solid line) for the flux is 0.009 ± 0.005 Pg C yr^{-1}. The 20-year mean value for the flux is -1.18 ± 0.14 Pg C.

Conclusions

- Measurement based global sea-air CO_2 fluxes are lower than ocean model and ocean inversion based estimates but in agreement with atmospheric estimates.
- Seasonal variability in sea-air CO_2 fluxes is greater than interannual variability.
- The inter-annual variability of sea-air fluxes determined by an empirical approach is similar to model derived estimates.
- Over the past two decades wind speeds have increased and the ΔpCO_2 has decreased, not accounting for the atmospheric CO_2 increases, suggesting a decreased oceanic CO_2 uptake.

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