Seasonal and Interannual Variations of CO_2 Fluxes in the Eastern Equatorial Pacific

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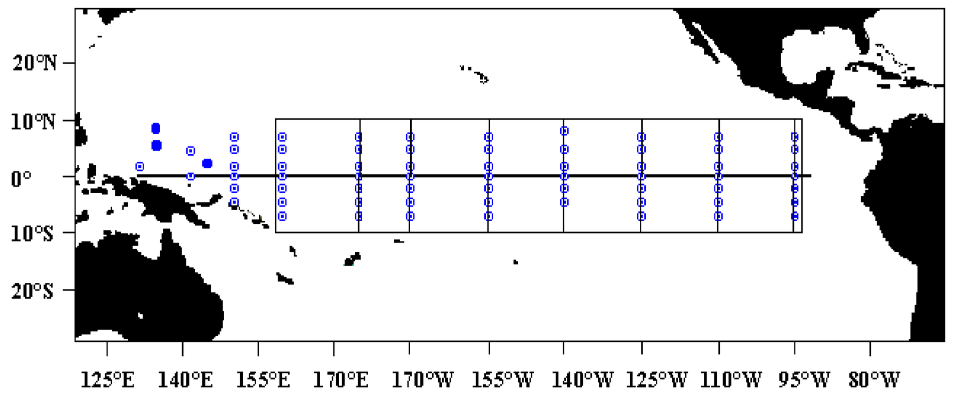
ABSTRACT

In order to utilize satellite temperature data for determining high-resolution variations of CO_2 distributions in the equatorial Pacific, we have developed seasonal and interannual fCO_2-SST relationships from shipboard data. The data were gathered onboard the NOAA ships *Malcolm Baldrige*, *Discoverer*, *Ka'imimoana* and *Ron Brown* from 1992 through 2001 as a companion project to the biannual servicing of the Tropical Atmosphere Ocean (TAO) Array moorings. The cruises included transects of the equatorial Pacific between 95°W and 165°E, and spanned two El Niño events (1992-94 and 1997-98). Data were collected during the equatorial warm season (February through June) and cool season (July through December) of each year making it possible to examine the interannual and seasonal variability of the fCO_2-SST relationship. A linear fit through all of the data yields an inverse correlation between SST and fCO_2, with a root mean square deviation, rmsd, of 26.1 µatm. There is a significant difference between the regression lines for El Niño and non-El Niño data sets. During both non-El Niño and El Niño periods, we observed seasonal differences in the fCO_2-temperature relationship. The regression lines through the warm and cool seasons have lower rmsd values than the composite non-El Niño regression line, and the slopes are significantly different at the 95% confidence level. The slope for the cool season is less negative than the warm season, suggesting higher biological productivity occurred during the cool periods. These relationships have been combined with satellite-based temperature data to provide a composite time-space map of fCO_2 in the central and eastern equatorial Pacific, and with ECMWF winds to provide corresponding fluxes. The mean flux for the 10-year record is 1.5 ± 0.4 mol C m^{-2} yr^{-1} for the region between 5°N to 10°S, and 90°W to165°E.

STUDY REGION



The central and eastern equatorial Pacific exhibits a large amount of spatial and temporal variability in surface water fCO_2 due to El Niño-Southern Oscillation (ENSO)-driven physical and biological changes During non-El Niño periods, easterly trade winds are strong and upwelling of CO_2-enriched water from the Equatorial Undercurrent forms a band of cold water along the surface from the coast of South America to the international dateline.

During El Niño periods, CO_2-enriched cold water reservoir is depressed. This, in combination with a cap of warm water from the western Pacific, acts to decrease fCO_2 levels in the sea surface. Seasonal variability of the equatorial fCO_2 distribution is most significant during non-El Niño periods.

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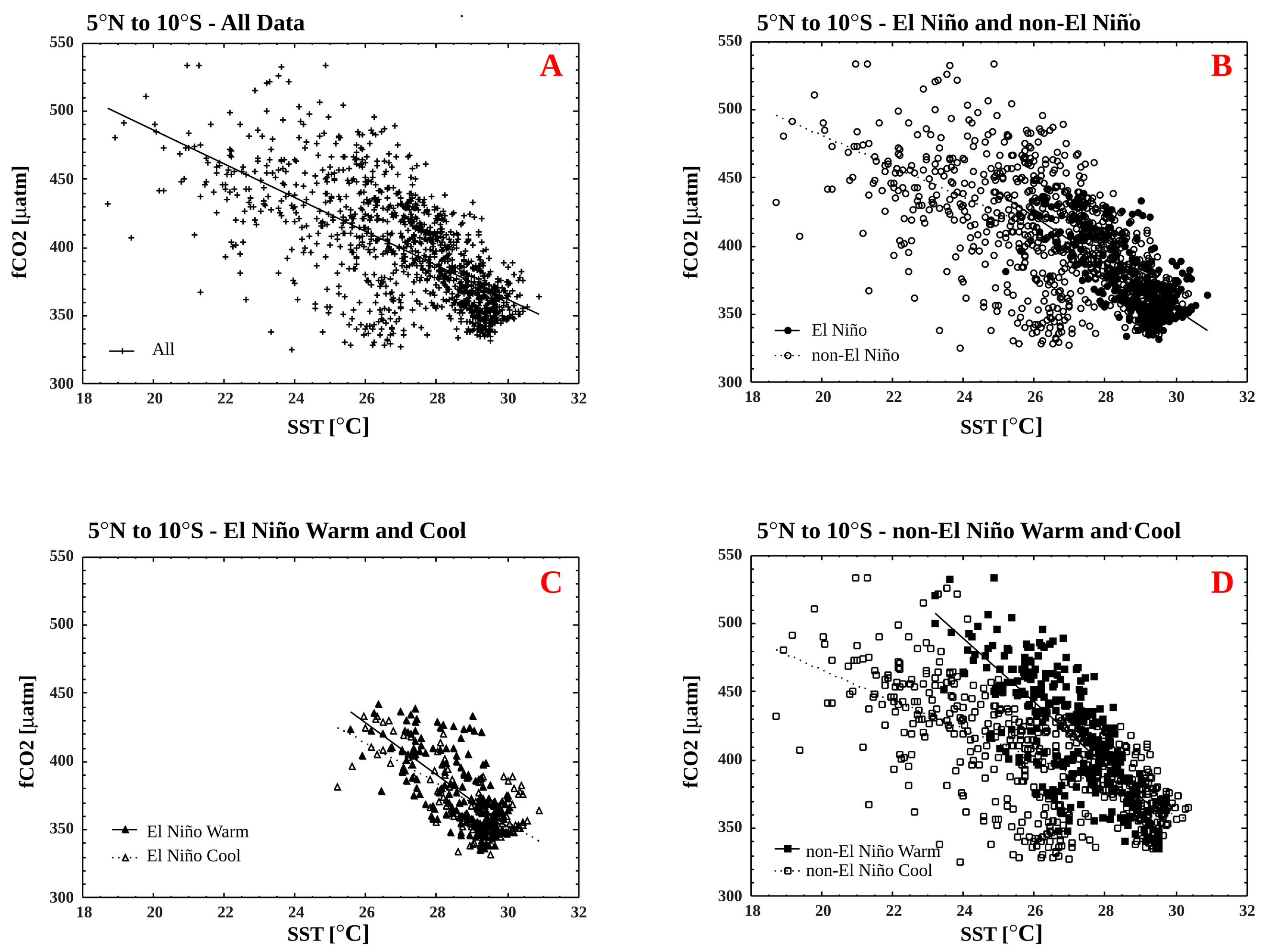
fCO_2-SST RELATIONSHIPS



The data, collected from boreal spring 1992 to July 2001, spanned two El Niño periods (1992-94 and 1997-98), and two La Niñas periods (1995-96 and 1999-2000). The data were also separated into an equatorial warm season (February through June) when the winds were less intense, and a cooler season (July through December) when the winds were strong, making it possible to examine how the fCO_2-SST relationship changed seasonally and interannually. SST and fCO_2 data between 5°N and 10°S were binned into one degree intervals and averaged.

Figure A. A linear fit applied to all data indicates an inverse correlation between SST and fCO_2 with a slope of –12.7 and an rmsd of 26.1 µatm.

Figure B. When data for El Niño and non-El Niño conditions are separated, the slope of the El Niño data sets decreases to –19.4, but the slope for the non-El Niño data sets increases to –10.1. Separating the data into El Niño and non-El Niño periods improves the fits, suggesting that the hydrographic conditions controlling fCO_2 variations during El Niño and non-El Niño periods are significantly different.

Figure C. Further separating the El Niño data into equatorial warm and cool seasons does not show as large a difference in the fCO_2-SST correlation as compared with the non-El Niño condition. This is consistent with persistent relaxed trade winds and reduced upwelling during the entire phase of an El Niño.

Figure D. Separating the non-El Niño data by warm and cool seasons improves the fit. The rmsd value for the non-El Niño warm season fCO_2-SST relationship is 28.8 µatm. For the cool season, the value is 30.2 µatm. Furthermore, the slope for the non-El Niño warm data sets, -23.1, is similar to the slopes for the El Niño data sets, but the slope for the non-El Niño autumn data sets is –10.7, suggesting that seasonal variations of the fits are significant during non-El Niño conditions. Increased biological activity might account for the observed lower fCO_2 values and higher fCO_2–SST slopes in the cool season.

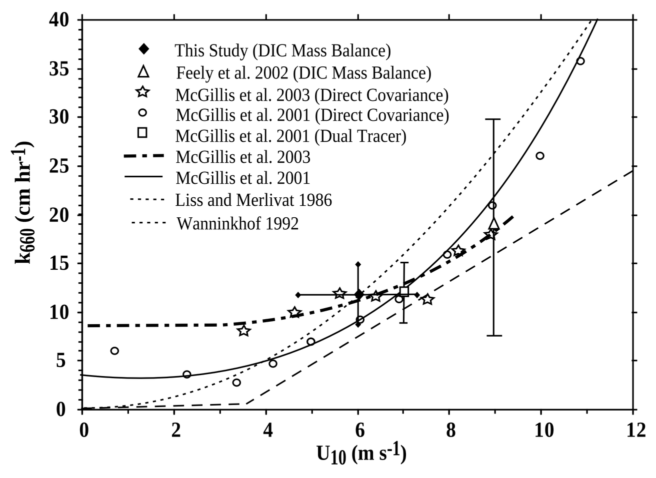
EQUATIONS

fCO_2-SST equations for the equatorial Pacific between 95°W and 165°, 5°N to 10°S.

El Niño Warm Season: $fCO_2\ (\pm 20.3) = -19.0\ (\pm 1.5)T + 923.3\ (\pm 43.6)$; $r^2 = 0.466$
El Niño Cool Season: $fCO_2\ (\pm 16.6) = -14.7\ (\pm 1.2)T + 794.6\ (\pm 33.8)$; $r^2 = 0.532$

Non-El Niño Warm Season: $fCO_2\ (\pm 28.8) = -23.1\ (\pm 1.2)T + 1044.3\ (\pm 33.4)$; $r^2 = 0.550$
Non-El Niño Cool Season: $fCO_2\ (\pm 30.2) = -10.7\ (\pm 0.5)T + 679.9\ (\pm 13.0)$; $r^2 = 0.458$

CALCULATION OF CO_2 FLUX

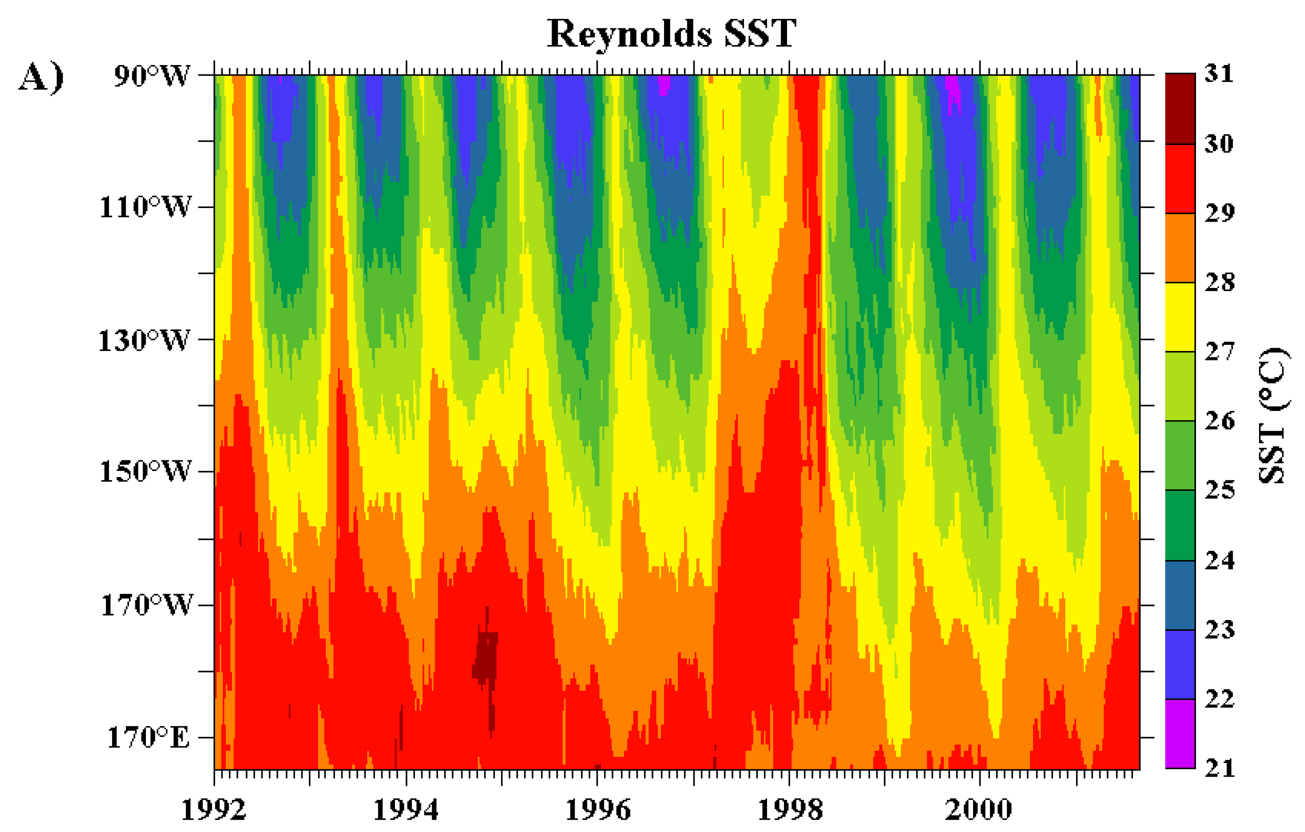


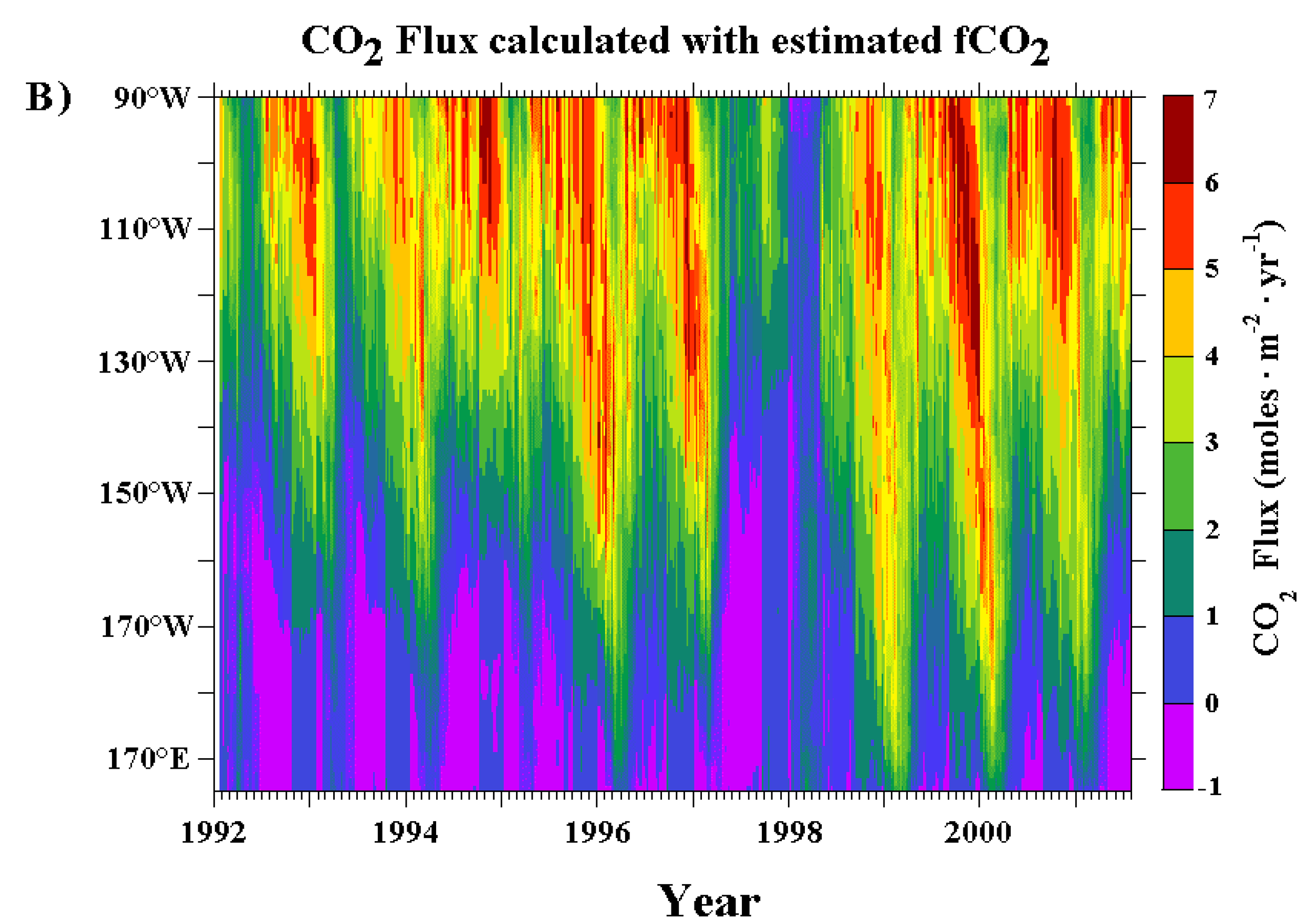
The flux of CO_2 across the air-sea boundary is given by:

$$\text{Flux} = ks\ (fCO_2w - fCO_2a)$$

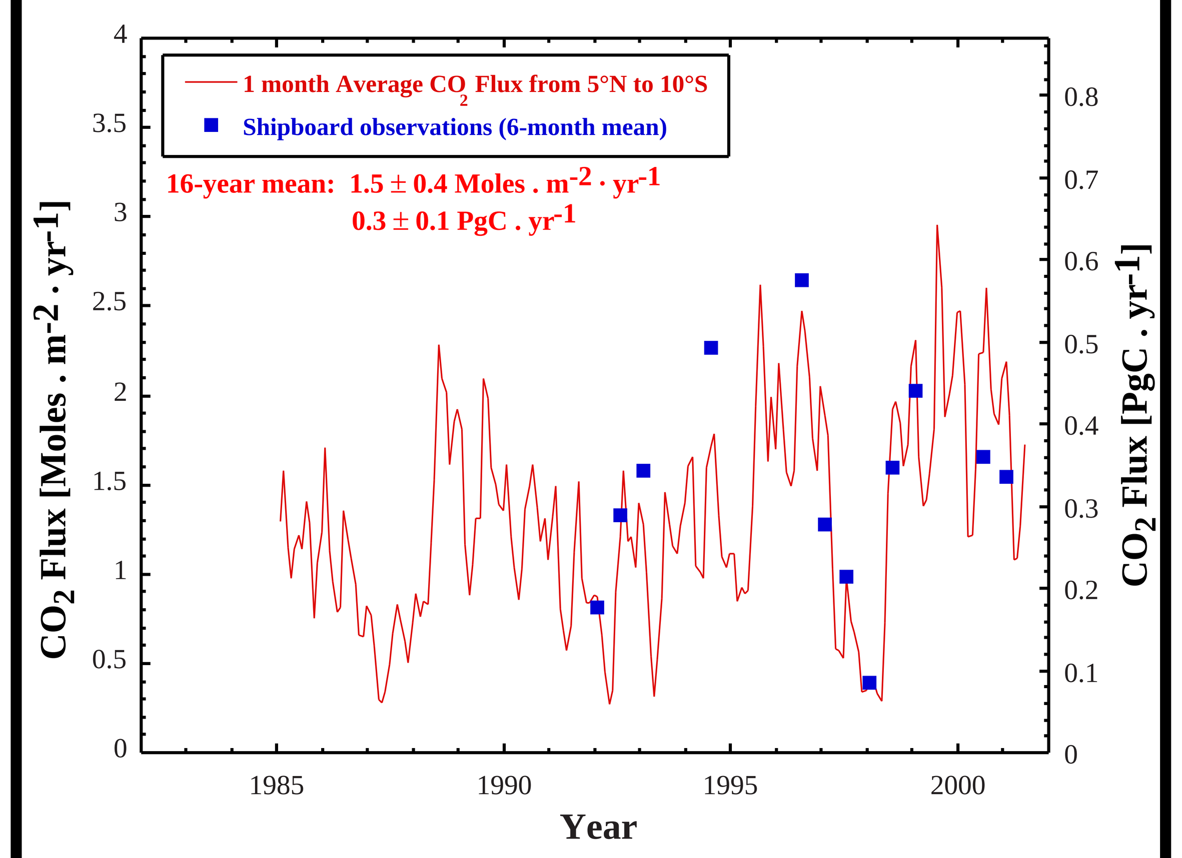
where s is the Henry's law solubility coefficient of the gas, fCO_2w is the fugacity of CO_2 in surface seawater, and fCO_2a is the fugacity of CO_2 in the atmosphere above the interface. The Henry's law coefficient for CO_2 is a function of temperature and salinity, and both fCO_2w and fCO_2a are generally measured with a high degree of precision (± 0.5 µatm) and accuracy (± 2 µatm).

In February and March of 2001, the Ocean-atmosphere Global Carbon Cycle Program of NOAA and NSF jointly sponsored a gas exchange experiment (GasEx-2001) onboard the NOAA ship Ron Brown in the equatorial Pacific, beginning at approximately 3°S, 125°W. The expedition was devoted to developing a better understanding of the processes controlling gas transfer and improving algorithms with environmental forcing. Several approaches were employed during the expedition to directly determine the gas transfer velocity including eddy covariance and the vertical gradient methods (McGillis et al., in preparation). These data on short time scles were verified with an ocean carbon mass balance (Sabine et al., submitted). Based on a local Schmidt number of 482.5 for the study region, the k_{660} from the GasEx-2001 study is 11.8 ± 3.1 cm hr^{-1} for a mean wind speed of 6 m s^{-1}. These results agree well with the gas transfer velocity estimates based on eddy correlation measurements made on the same cruise (McGillis et al., in preparation), as seen in the figure above.





CO_2 FLUXES



The satellite based estimates of fCO_2 can be combined with the European Centre for Medium Range Weather Forecasts (ECMWF) winds and the McGillis (2003) wind speed-gas exchange relationship to provide an estimate of the CO_2 flux variability. The figure to the left displays estimated CO_2 flux for the period 1992 through 2001.

The figure above shows the monthly mean and integrated flux (solid line) for the region from 90°W to 165°E and from 5°N to 10°S, an area spanning an area of approximately 18 x 106 km^2. Also shown are the 6-month average fluxes based on the shipboard observations (solid squares). The results show good agreement between these estimates.

There is about a factor of 5 difference in the regional efflux of CO_2 between the strong El Niño events of 1986-87 and 1997-98 (0.10 – 0.26 Pg C yr^{-1}) and the La Niña events of 1996 and 1999-2000 (0.40 – 0.75 Pg C yr^{-1}).

The mean flux for the 10-year record represented in the figure to the left is 1.5 ± 0.4 mol C m^{-2} yr^{-1} for an area that covers approximately half of the Pacific equatorial belt. Estimates of the annual efflux of CO_2 from the entire Pacific equatorial belt average about 0.8 Pg C yr^{-1} during non-El Niño conditions and about 0.3 Pg C yr^{-1} during El Niño conditions. These estimates are in good agreement with recent modeling results and earlier observations-based estimates.

CONCLUSIONS

Our results indicate that there is a strong upwelled-driven inverse fCO_2-SST relationship in the central and eastern equatorial Pacific. Four equations are used to define the interannual and seasonal fCO_2-SST relationships in this region; two for El Niño warm and cool conditions and two for non-El Niño warm and cool conditions. These relationships have been successfully utilized with satellite SST data to obtain highly resolved fCO_2 distributions and CO_2 fluxes in the region between 5°N and 10°S and from 90°W to 165°E. As our ability to measure additional parameters from satellites improves so will our ability to use the satellite-based data to estimate CO_2 fluxes with greater accuracy. Nevertheless, these initial estimates suggest significant seasonal and interannual variations of the CO_2 flux from the equatorial Pacific. In this region the variability in interannual fluxes is dominated by changes in fCO_2.

REFERENCES

Sabine, C.L., R.A. Feely, G.C. Johnson, P.G. Strutton, M.F. Lamb, and K.E. McTaggart. Carbon Chemistry of the water column during GasEx-2001. J. Geophys. Res. [Submitted], 2003.