Estimating Global Ocean Carbon Trends Using In-situ pCO_2 Observations

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I. ABSTRACT

The oceans' carbon uptake substantially reduces the rate of anthropogenic carbon accumulation in the atmosphere, and thus slows global climate change. Some diagnoses of trends in ocean carbon uptake have suggested a significant weakening in recent years, while others conclude that decadal variability confounds detection of long-term trends. Here, we study trends in observed surface ocean partial pressure of CO_2 (pCO_2) in global gyre-scale biomes, considering decadal to multidecadal timescales between 1981 and 2010. Trends on decadal timescales are of variable magnitudes and are sensitive to the chosen start and end years. As more years are included in the analysis, oceanic pCO_2 trends begin to converge to the trend in atmospheric pCO_2 especially in the northern hemisphere. North of 30ºN, it takes 25 years or more for the influence of decadal-timescale climate variability to be overcome by a long-term trend that is consistent with the accumulation of anthropogenic carbon. In the permanently stratified subtropical gyre of both the north Atlantic and Pacific Oceans, warming has recently become a significant contributor to the observed increase in oceanic pCO_2. This warming, previously attributed to both a multidecadal climate oscillation and anthropogenic climate forcing, is beginning to reduce ocean carbon uptake.

II. DATASETS and BIOMES

Original volunteer observing ship (VOS) observations (Takahashi et al. 2009) have been combined with SURATLANT region data from a VOS line between Iceland and Newfoundland (Corbiere et al., 2007, updated to 2005 by N. Metzl). The compiled dataset has been processed by first regridding the original data onto a 1° x 1° global map, then these data were averaged monthly. Next, coastal influences are eliminated by excluding data with recorded surface salinities of 20 psu or less. Finally, a level of quality control was administered by removing values with observed SST values falling outside of 3sigma deviation from the HAD1SST climatology.

Motivated by an interest in global-scale carbon partitioning, we identify pCO_2 trends across gyre-scale biomes. Biomes were delineated based on three climatological parameters: mixed layer depth (MLD), chlorophyll-a concentration, and SST (Sarmiento et al 2004). Six global biomes are created: Ice regions (**ICE**), seasonally stratified subpolar (**SP-SS**), seasonally stratified subtropical (**ST-SS**), permanently stratified subtropical (**ST-PS**), equatorial (**EQU**), and low latitude upwelling regions (**LLU**).

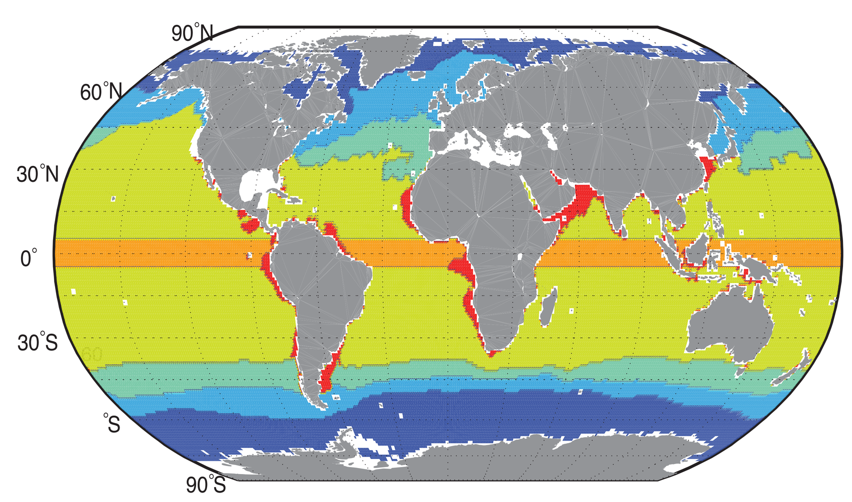


Figure 1: Global Biomes

III. METHODOLOGY

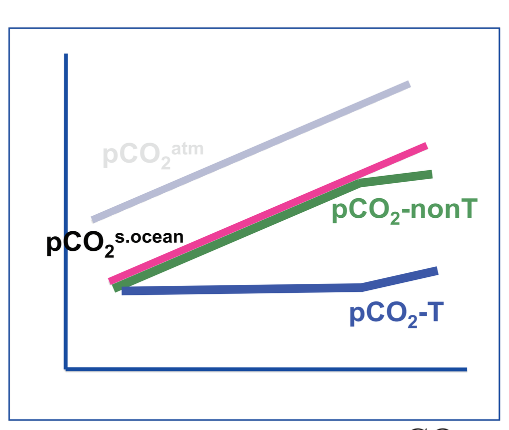


Figure 2: Relationship between pCO_2 trends: showing compensation between pCO_2nonT and pCO_2T components

Trend calculation: Data are regridded to 1° x 1° spatial and monthly temporal resolution. A long-term mean is then removed to eliminate spatial aliasing before averaging to the biomes. A harmonic fit, $y = a + b*t + c*\cos(2\pi t + d)$ captures an annual cycle and linear trend (in µatm/yr) for each biome (McKinley et al 2011). The same analysis method is used on GLOBALVIEW atmospheric monthly means. A comparison of the oceanic and atmospheric pCO_2 trend reveals any change in the flux of carbon dioxide.

Decomposition of pCO_2***:*** Variation in pCO_2 is decomposed, using empirical equations (Takahashi et al 1993), into the isochemical variation that is driven solely by temperature change (pCO_2-T) and the remaining variability (pCO_2-nonT) that is driven by the combined effects of variability in SSS, ALK and DIC. These two components compensate for one another to collectively make up the pCO_2 trend (Figure 2).

IV. ARE BIOME-SCALE pCO_2 TRENDS REPRESENTATIVE?

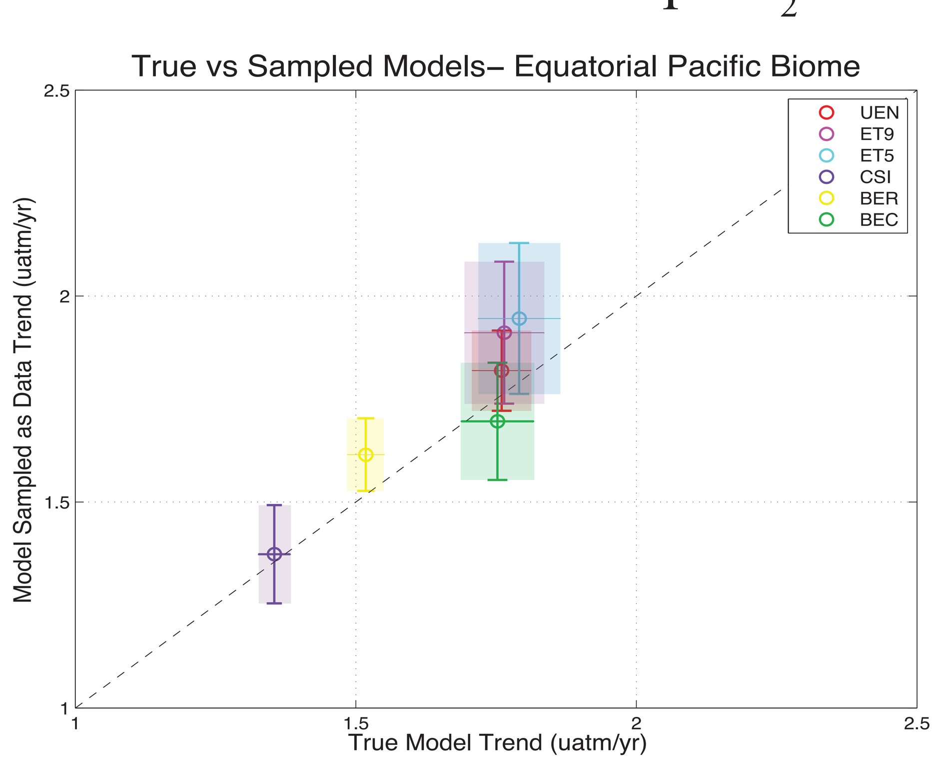


Figure 3: Comparison of RECCAP model's true and sampled trends for years 1990-2009. Colored boxes are 1σ uncertainty regions.

To address this issue, we use a collection of numerical models, compiled as part of the RECCAP project. We subsample the models as the data, at monthly resolution, and calculate trends as outlined above. We compare the sampled trends to results of trend estimates calculated using all model points. This test for 1990-2009 is presented in Figure 3 for the equatorial pacific biome. We find that the 1σ uncertainty ranges of the sampled and full model overlap for all 6 models tested, indicating that they are statistically indistinguishable. We conclude that trend estimates are representative and that our methodology for calculating biome-scale trends is robust given available sampling.

V. ATLANTIC TRENDS ACROSS VARYING TIMESCALES

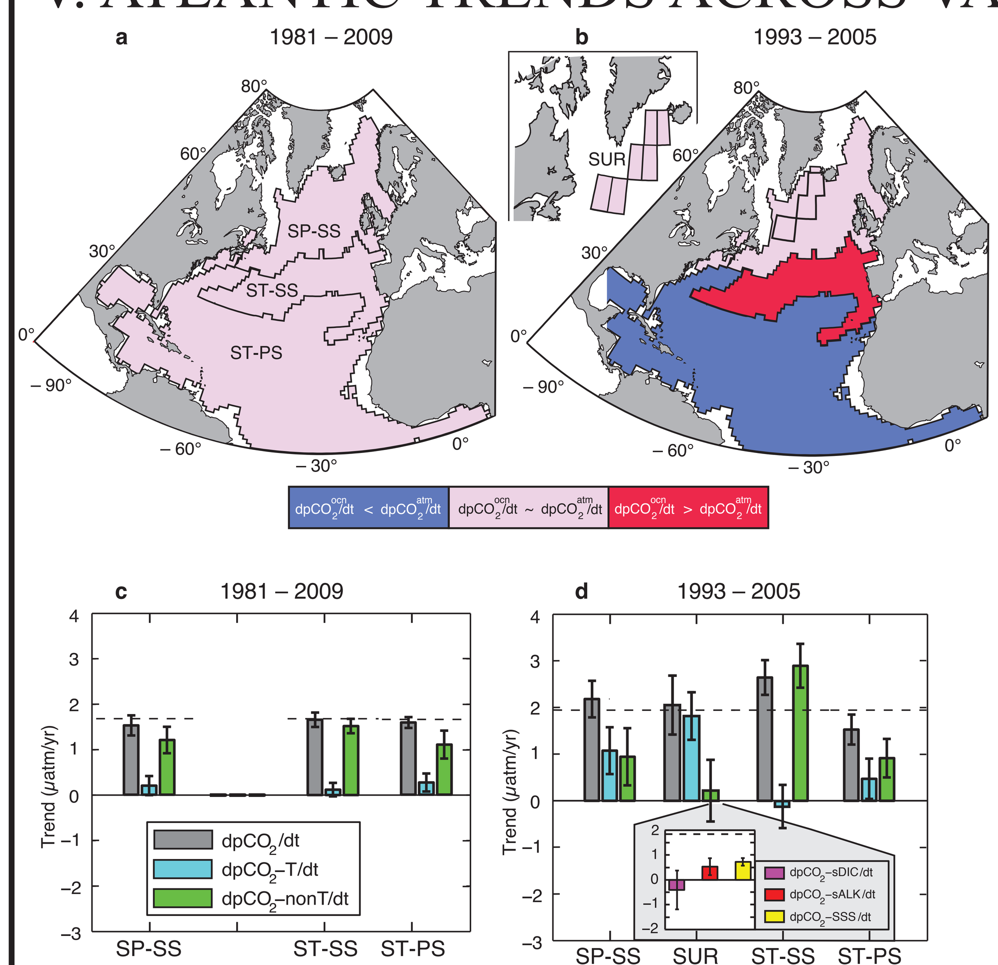


Figure 4: Trends in $pCO_2^{s.ocean}$ (a) 1981-2009 and (b) 1993-2005 compared to the trend in pCO_2^{atm}. Blue areas indicate $pCO_2^{s.ocean}$ trends less than pCO_2^{atm}, pink indicates indistinguishable from the atmosphere, and red depicts regions of $pCO_2^{s.ocean}$ trend greater than pCO_2^{atm}. In (c) and (d) these trends are shown in the gray bar, with pCO_2^{atm} trend in dash; pCO_2-T (blue) and pCO_2-nonT (green) are also shown.

- In North Atlantic SP-SS, we find significant sensitivity to the precise selection of years in timeseries less than 25 years. After about 25 years, the trend in $pCO_2^{s.ocean}$ generally tracks the atmosphere, and there is less influence of pCO_2-T, which suggests a waning influence of short-term climate variability.
- In NA ST-PS, warming (pCO_2-T) impacts almost all trends with endyears 2006-2009. With $pCO_2^{s.ocean}$ tracking the atmosphere, a trend in pCO_2-T greater than zero means a pCO_2-nonT trend less than the atmosphere (e.g. Figure 4d). This indicates a negative feedback on the carbon sink - i.e. that climate warming is damping carbon uptake.

- For the multidecadal timeframe (1981-2009, Figure 4a,c), the $pCO_2^{s.ocean}$ trend is indistinguishable from the atmospheric trend in all three biomes. Chemical change (pCO_2-nonT) dominates the signal in all biomes, although in the subtropical gyre (ST-PS), warming (pCO_2-T) is partially driving the total trend.
- For the decadal timeframe (1993-2005, Figure 4b,d), each biome has a distinct trend in $pCO_2^{s.ocean}$ in comparison to pCO_2^{atm}. Warming in SP-SS and increased carbon accumulation in ST-SS is consistent with observed physical variability in these regions.
- The SURATLANT / SP-SS comparison for 1993-2005 indicates less carbon accumulation in SUR than in SP-SS, and suggests changing DIC/ALK ratios. Clearly, biome trends do not preclude different trends at smaller scales.

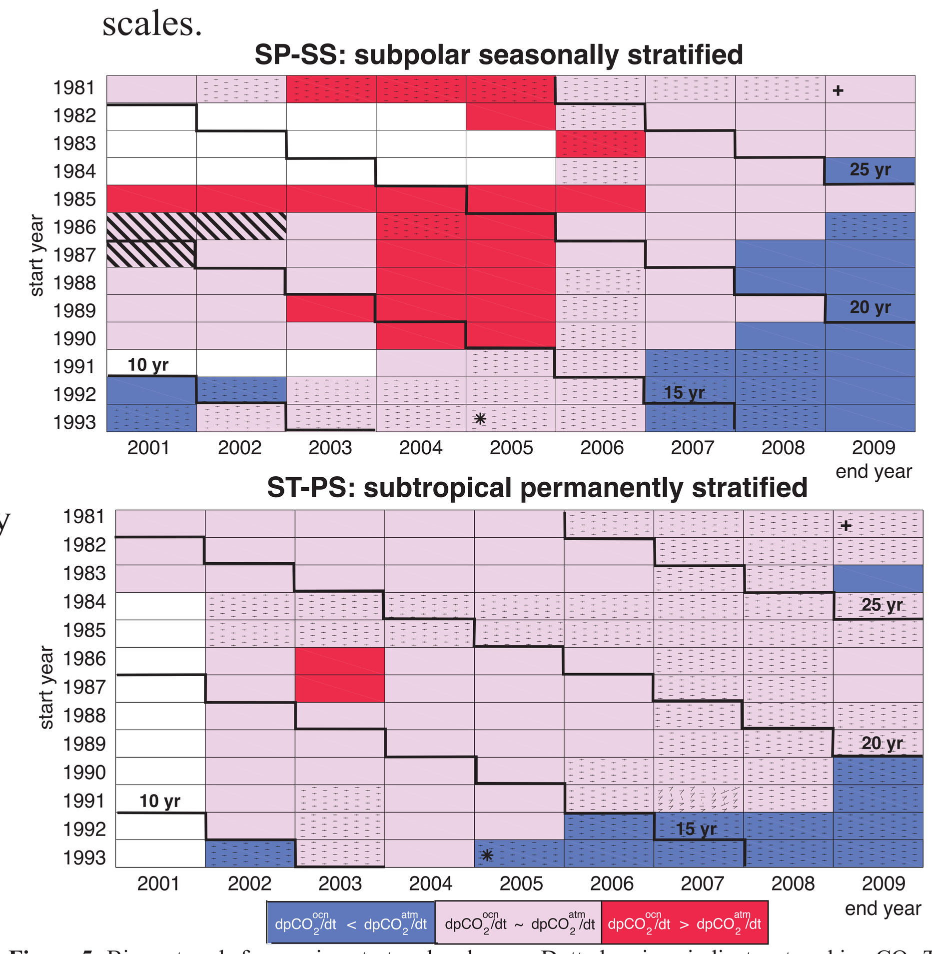
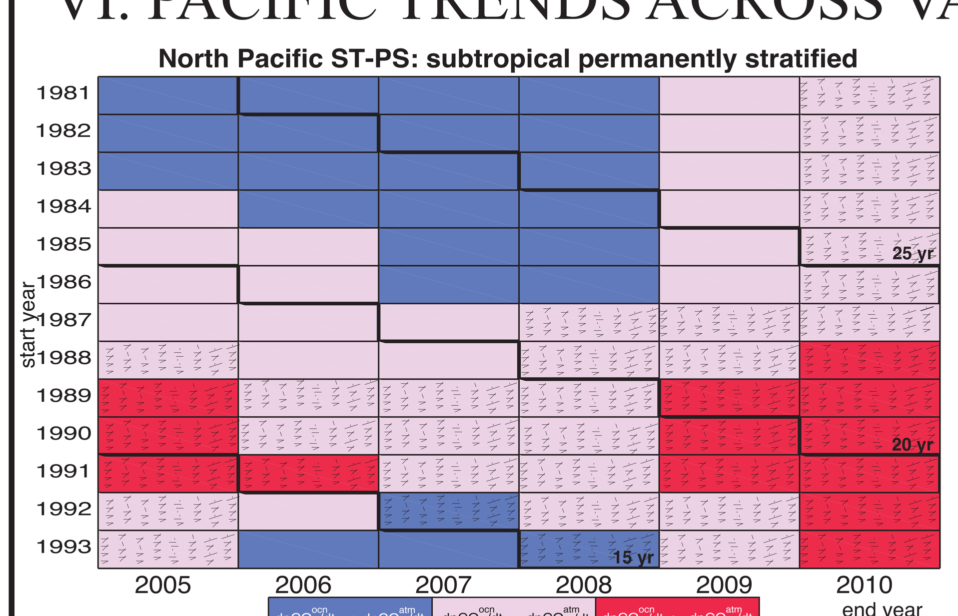


Figure 5: Biome trends for varying start and end years. Dotted regions indicate a trend in pCO_2-T that is greater than zero. The shortest timeseries (9 years) in the bottom left; the longest timeseries (29 years) in the top right. White regions are those where the model tests do not verify at the 1σ level.

VI. PACIFIC TRENDS ACROSS VARYING TIMESCALES



- In the equatorial region of the Pacific Ocean the $pCO_2^{s.ocean}$ trend has been consistently less than the atmosphere.
- El Nino conditions were more common during the early years of our analysis, and La Nina during the later years. This was a critical physical change.
- Enhanced upwelling of low-anthropogenic waters during La Nina conditions is a plausible mechanism to have damped $pCO_2^{s.ocean}$ trends.
- Despite these La Nina conditions, pCO_2-T has driven a positive trend in pCO_2, suggesting an influence of climate warming.

- In the North Pacific ST-PS significant sensitivity to the precise selection of years exists for all timescales. Only for the few longest timescales (29-30 years), do $pCO_2^{s.ocean}$ trends consistently track the atmospheric trend. More years of data are needed to determine if this is robust.
- Warming has influenced the North Pacific ST-PS, especially for trends with start years in the 1990s or ending in 2010. More data are needed to determine if this effect is an increasing one.

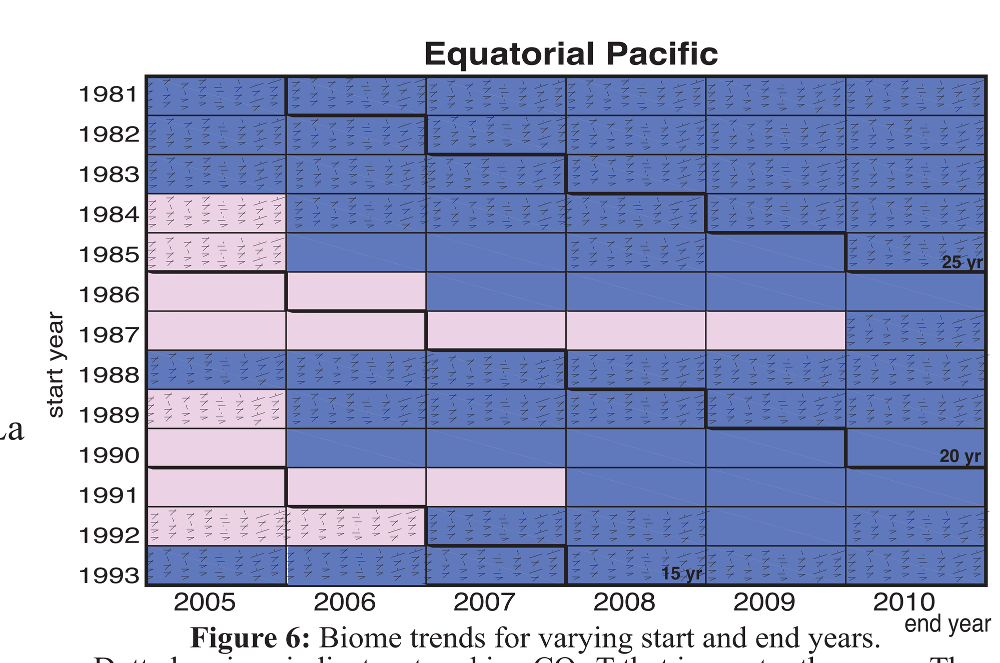


Figure 6: Biome trends for varying start and end years. Dotted regions indicate a trend in pCO_2-T that is greater than zero. The shortest timeseries is 1993-2005 (13 years) in the bottom left; the longest timeseries is 1981-2010 (30 years) in the top right.

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