Global autocorrelation scales of the partial pressure of oceanic CO_2

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[1] A global database of approximately 1.7 million observations of the partial pressure of carbon dioxide in surface ocean waters (pCO_2) collected between 1970 and 2003 is used to estimate its spatial autocorrelation structure. The patterns of the lag distance where the autocorrelation exceeds 0.8 is similar to patterns in the spatial distribution of the first baroclinic Rossby radius of deformation indicating that ocean circulation processes play a significant role in determining the spatial variability of pCO_2. Separate calculations for times when the Sun is north and south of the equator revealed no obvious seasonal dependence of the spatial autocorrelation scales. The pCO_2 measurements at Ocean Weather Station (OWS) "P" in the eastern subarctic Pacific (50°N, 145°W) is the only fixed location where an uninterrupted time series of sufficient length exists to calculate a meaningful temporal autocorrelation function for lags greater than a few days. The estimated temporal autocorrelation function at OWS "P" is highly variable. A spectral analysis of the longest four pCO_2 time series indicates a high level of variability occurring over periods from the atmospheric synoptic to the maximum length of the time series, in this case 42 days. It is likely that a relative peak in variability with a period of 3–6 days is related to atmospheric synoptic period variability and ocean mixing events due to wind stirring. However, the short length of available time series makes identifying temporal relationships between pCO_2 and atmospheric or ocean processes problematic.

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1. Introduction

[2] The partial pressure of CO_2 (pCO_2) in seawater is a vapor pressure of CO_2, and hence governs the magnitude of the CO_2 transfer flux across the sea-air interface when multiplied with sea-air gas transfer coefficient. It is a sensitive function of temperature doubling with every 16°C [*Takahashi et al.*, 1993]. It is also a sensitive function of the total concentration of CO_2 (TCO_2) species dissolved in seawater,

$$TCO_2 = [CO_2]_{aqueous} + HCO_3^- + CO_3^{--},$$

that depends on the net biological community production, the rate of upwelling of subsurface waters rich in CO_2, and the air-sea CO_2 flux. The local sensitivity may be expressed in terms of the Revelle factor, $\frac{\partial lnpCO_2}{\partial lnTCO_2}$, which varies from 8 with lower TCO_2 concentrations in tropical waters to 15 with higher concentrations in polar waters. In the surface mixed layer, the effect of warming on pCO_2 is counteracted by lower TCO_2 caused by photosynthetic fixation of CO_2, as often seen during spring bloom periods, and the effect of cooling is counteracted by increasing TCO_2 usually caused by upwelling of subsurface waters rich in respired CO_2. Consider the following example. A parcel of polar ocean water at −1.9°C warmed to an equatorial temperature of 30°C without changes in TCO_2 and other chemicals, increases its pCO_2 by a factor of 4. If the typical nitrate in this water (~35 μmol/kg) is completely utilized by biological growth with the Redfield N/C ratio of 16/106, then the TCO_2 in the same water would decrease from 2150 μmol/kg to 1920 μmol/kg. Thus there is a decrease in pCO_2 by a factor of $(1920/2150)^{10} \approx 33\%$ (using a Revelle factor of 10). This example illustrates that over the global oceans, the effect of change in temperature is roughly compensated by changes in TCO_2, and that the time-space variation in surface seawater pCO_2 is dictated primarily by interactions between the effects of temperature, net biological production, and the deep water upwelling rate. Using climatological mean data, *Takahashi et al.* [2002]

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have observed that in subtropical gyres, seasonal changes in pCO_2 are due primarily to temperature changes, whereas those in subpolar and polar waters are due primarily to TCO_2 changes caused by winter upwelling of subsurface waters and spring plankton blooms in spring. However, finer scale time-space variability of surface water pCO_2 has not been investigated using semi-continuous underway surface water pCO_2 measurements which have been made in increasing numbers during recent years.

[3] In this study, the global distribution of the isotropic spatial autocorrelation structure of available pCO_2 underway measurements is calculated. The approach taken is similar to that of *Murphy et al.* [2001], who investigated pCO_2 autocorrelation structure in the Bering Sea. The motivation is to identify the scales of variability that are resolved in the pCO_2 data, and attempt to relate some of that variability to known physical processes. In addition, time series data available from OWS "P" is similarly analyzed to provide an example of temporal autocorrelation structure and variability. It is hoped that a quantified estimate of autocorrelation scales will be useful to investigators, particularly future data assimilation efforts, for decisions on how best to use the 1.7 million measurements in choosing averaging and subsampling schemes for their work.

5. Summary and Conclusions

[26] A global database containing mainly underway measurements of surface water pCO_2 is used to estimate the spatial autocorrelation structure on a 10° latitude-longitude grid. Since the pCO_2 is a sensitive function of temperature and the total CO_2 concentration in seawater, which depends on biological utilization and upwelling of CO_2-rich subsurface waters, its variability reflects both physical as well as biological processes. The pCO_2 is more densely sampled in space and time in the Northern Hemisphere than the Southern Hemisphere. The longest spatial correlations occur in the equatorial Pacific where the autocorrelations are above 0.8 out to distances between 80–100 km. The other equatorial areas also have relatively long correlation scales compared to other areas of the globe. The North Atlantic subtropical gyre has spatial correlation scales that tend to be about double the correlation scales in the subtropical gyre associated with the Kuroshio. This geographic distribution is similar to the distribution of the values of the first baroclinic Rossby radii of deformation as calculated by *Emery et al.* [1984], indicating that the physical properties of the flow field are a likely contributor to factors controlling the correlation scales. In the Indian Ocean, the correlation scales in the Southern Hemisphere tend to be longer than those in the Northern Hemisphere. A possible explanation for this variability can again be related to the controlling mechanisms of the flow field. An important mode for the southern Indian Ocean variability stems from long annual Rossby waves that are generated on the eastern side of the basin and propagate westward. The northern half of the basin is much more reactive to the strong forcing of the monsoonal flows. The correlation scales tend to be shortest at higher latitudes, again consistent with the scales of the deformation radius, but there is an indication that after an initial steep drop off of the autocorrelation, there is a slowing of the drop off between 0.8 and 0.6 in the northern Atlantic.

[27] An attempt to estimate the temporal correlation structure is made at the only geographic location with relatively long (longer than about 10 days) uninterrupted time series of pCO_2 data at OWS "P" in the eastern North Pacific. Eleven time series were used to calculate the correlation structure with highly variable results. Most of these time series indicated a significant drop in autocorrelation (0.5 and lower) after 1–2 days. Three of the time series contained a more gentle drop off in the temporal correlation, but after 5 days, the correlation was only about 0.5. There was no obvious seasonal dependence in the temporal autocorrelation structure. Indeed, two of the time series that were separated by a single day during the summer of 1978 produced a drastically different autocorrelation structure from each other.

[28] The coherence of the geographic distribution of the spatial autocorrelation structures with physical properties of the flow, such as the internal Rossby radius of deformation, is encouraging. As assimilation models are contemplated for pCO_2, it is necessary to have confidence in an error covariance model for the data being ingested. An autocorrelation function provides a good start, and the fact that some of the global variability can be related to other physical variables gives some hope that any analysis product will be of more use than the ingested data alone. However, the inability to estimate a temporal autocorrelation structure is troubling. Even at OWS "P" where time series data exist, a stable estimate of that correlation structure proved difficult. Long uninterrupted time series measurements at fixed locations, such as those being conducted near the Pacific equator and elsewhere using moored buoy pCO_2 systems by the NOAA group, will help to improve our understanding of temporal variability scale. The estimates of the spatial correlation structure ignored any time change along a particular track, yet those correlations remained high over long distances, which also means over a time period of more than a couple days. Although modeling studies may be useful as a first guess for estimating pCO_2 correlation structure, confident estimates will require more and targeted measurements over the entire globe.