Recent trends in global ocean chlorophyll

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[1] A 6-year time series of remotely-sensed global ocean chlorophyll was evaluated using linear regression analysis to assess recent trends. Global ocean chlorophyll has increased 4.1% ($P < 0.05$). Most of the increase has occurred in coastal regions, defined as bottom depth < 200 m, where an increase of 10.4% was observed. The main contributors to the increase were the Patagonian Shelf, Bering Sea, and the eastern Pacific, southwest African, and Somalian coasts. Although the global open ocean exhibited no significant change, 4 of the 5 mid-ocean gyres (Atlantic and Pacific) showed declines in chlorophyll over the 6 years. In all but the North Atlantic gyre, these were associated with significant increases in sea surface temperature in at least one season. These results suggest that changes are occurring in the biology of the global oceans. **Citation:** Gregg, W. W., N. W. Casey, and C. R. McClain (2005), Recent trends in global ocean chlorophyll, *Geophys. Res. Lett.*, *32*, L03606, doi:10.1029/2004GL021808.

1. Introduction

[2] The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) mission has provided the first continuous, long-term observations of global ocean chlorophyll from space. This rigorously calibrated and validated data set spans >6 years beginning in 1997. Using SeaWiFS chlorophyll observations, the responses of ocean biology to seasonal, regional, and interannual events have been observed comprehensively for the first time. In this paper we use the SeaWiFS record to evaluate the question: Are there current trends in global ocean chlorophyll?

2. Methods

[3] SeaWiFS Level-3 Version 4 monthly 9-km data were obtained from the NASA Goddard Earth Sciences Distributed Active Archive Center and interpolated to 25-km resolution. Inland seas and isolated bays and inlets were masked out. Although SeaWiFS began taking data in Sep 1997, we only used data from the period 1998–2003 because these represented complete annual records from the SeaWiFS lifetime. Trends were assessed by 1) subtracting monthly climatological mean values from each month to remove the background (producing monthly anomalies), 2) averaging the 12 monthly anomalies of each year to remove the seasonal signal (producing annual mean anomalies), 3) computing best-fit linear trends using regression analysis, and 4) assessing statistical significance of the trends [*Zar*, 1976]. A statistically significant trend was one that exceeded the 95% confidence level. Trends in chlorophyll are reported as percent, computed from the linear trend, with the chlorophyll value at the y-intercept representing the starting point. We recognize that this methodology increases our chances of Type-II errors (not detecting a trend when one exists), but it is our preference to err in this direction rather than in the direction of a Type-I error (falsely detecting a trend when one does not exist).

[4] Monthly climate data fields were obtained for the 1998–2003 period. Sea surface temperature (SST; NOAA/NASA Advanced Very High Resolution Radiometer [AVHRR] Oceans Pathfinder Project) was obtained at 4-km spatial resolution and interpolated to 25-km to match the SeaWiFS resolution used in the analysis. Daytime and nighttime data were equally weighted. Other climate data fields were only available at lower spatial resolution, and were interpolated to 1-degree, monthly resolution. These included scalar wind stress and net short-wave radiation (NOAA National Center for Environmental Prediction).

[5] Trends in ocean chlorophyll were evaluated globally, and were subdivided into coastal regions (bottom depth < 200 m) and open ocean. We also computed trends on a point-by-point basis to try to understand where changes were occurring. Based on a significance value of 95% ($P < 0.05$) we derived a global map of trends (Figure 1). All clusters of pixels with significant trends were isolated as regions of interest, and the data were then averaged within the region. For oceanic gyre regions, we chose areas where the climatological chlorophyll over the six years was ≤ 0.1 mg m^{-3}. A minor exception was the South Atlantic gyre region, where southerly pixels outside the 0.1 mg m^{-3} limit were included. The maximum value was 0.29 mg m^{-3}. Only regions for which significant trends were observed are identified in Figure 1. These regions are intended to be biogeographically coherent at the same time grouping similarly trended points. Seasonal analyses were performed in a similar manner as the annual analyses described above, with seasons corresponding with the Northern Hemisphere convention:

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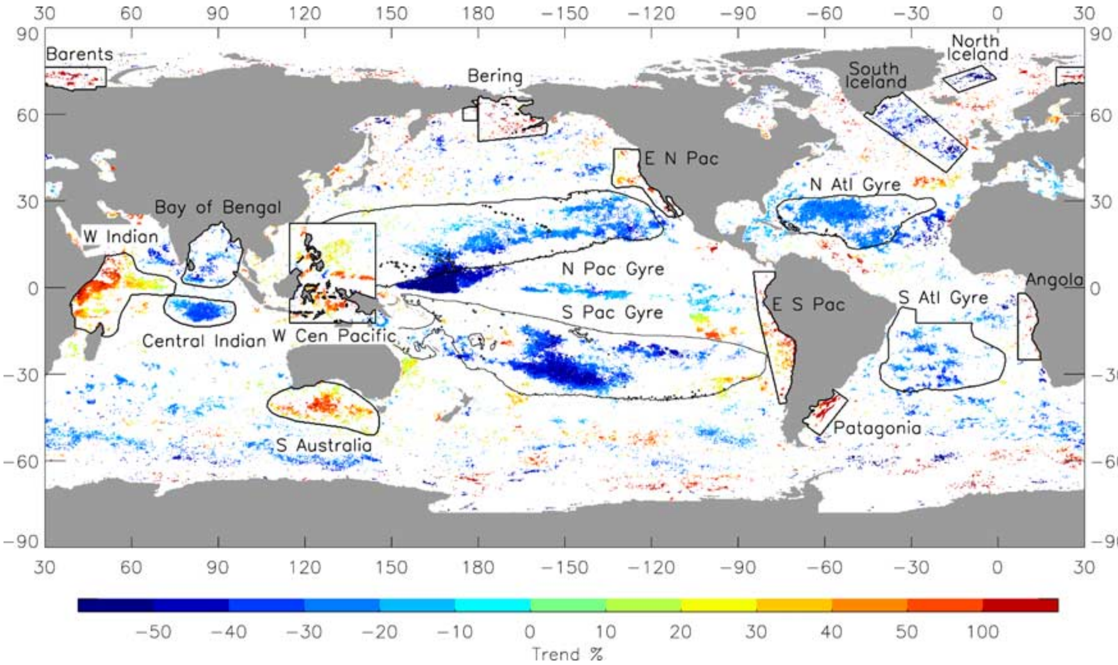

Figure 1. Regions defined by coherent distribution of 25-km grid points where chlorophyll concentrations indicated a significant trend (P < 0.05) over the 6-year data record of SeaWiFS. Only regions where significance was found within the region as a whole are shown here.

winter (Jan–Mar), spring (Apr–Jun), summer (Jul–Sep), and autumn (Oct–Dec).

3. Results and Discussion

3.1. Global Trends

[6] Global ocean chlorophyll increased 4.13% from 1998 to 2003 (P < 0.05; Table 1). When subdivided into coastal and open oceans, only the coastal regions indicated a significant trend (Table 1). The coastal trend was large and positive (10.4%).

[7] To estimate the effects of El Niño-Southern Oscillation (ENSO) events on the longer-term detection of trends, we eliminated all chlorophyll data in the Pacific equatorial upwelling region (10°N and S) plus moderately high chlorophyll (>0.45 mg m^{-3}, determined using the SeaWiFS 6-year climatology) along the eastern coasts of the Pacific, extending to 40°N and S. The global trends showed negligible change (global trend = 4.11%), as did the open ocean and coastal trends (open ocean = 0.6%, coastal = 10.6%). Therefore, we believe that the global trends observed here were not influenced by the timing and magnitude of ENSO events.

Table 1. Global Trends in Ocean Chlorophyll 1998–2003[a]

Region	N	Slope	Intercept	Error	Trend	Significance
Global	560247	0.00261	−0.007	±0.002	+4.13%	P < 0.05
Coastal	51979	0.03687	−0.092	±0.033	+10.35%	P < 0.05
Open Ocean	530579	0.00040	−0.001	±0.003	+0.90%	NS

[a]NS indicates not statistically significant at the 95% confidence level. N is the maximum number of values in a given year, error represents the standard error of the estimate, and trend is reported as percent change over 6 years.

4. Concluding Remarks

[18] The 6-year time series of global ocean chlorophyll from SeaWiFS is insufficient to unambiguously characterize long-term trends. It is also difficult to relate the trends to climate decadal oscillatory behavior, such as the North Atlantic Oscillation and Pacific Decadal Oscillation, among others. However, it is sufficiently long to minimize the influence of ENSO events. This analysis is intended to serve as a benchmark for current trends in chlorophyll data.

[19] *Gregg and Conkright* [2002] recorded a decline in global open ocean chlorophyll from the historical record (1979–1986) to the present (1997–2000 in their analysis). The present analysis suggests that further declines in open ocean chlorophyll are not occurring. However, the observed increase in chlorophyll in coastal regions is a very important result from the present study. *Bakun and Weeks* [2004] have suggested a warming Earth can enhance coastal upwelling. Conflicting relationships between the increases and SST in the Bering Sea and Patagonian shelf, two of the largest changes, are difficult to reconcile, but the possibility of anthropogenic influences on these and other coastal areas cannot be ignored. This study is not intended to explain all of the open ocean and coastal trends, but rather, to document the current trends and suggest climatic relationships when possible. More concrete evidence of the trends and their causes will require a longer term time series and more focused analyses in specific regions.