Decadal changes in global ocean chlorophyll

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[1] The global ocean chlorophyll archive produced by the CZCS was revised using compatible algorithms with SeaWiFS. Both archives were then blended with in situ data to reduce residual errors. This methodology permitted a quantitative comparison of decadal changes in global ocean chlorophyll from the CZCS (1979–1986) and SeaWiFS (1997–2000) records. Global spatial distributions and seasonal variability of ocean chlorophyll were similar, but global means decreased over the two observational segments. Major changes were observed regionally: chlorophyll concentrations decreased in the northern high latitudes while chlorophyll in the low latitudes increased. Mid-ocean gyres exhibited limited changes. The overall spatial and seasonal similarity of the two data records suggests that the changes are due to natural variability. These results provide evidence of how the Earth's climate may be changing and how ocean biota respond. *INDEX TERMS:* 1620 Global Change: Climate dynamics (3309); 4805 Oceanography: Biological and Chemical: Biogeochemical cycles (1615); 4215 Oceanography: General: Climate and interannual variability (3309); 1635 Global Change: Oceans (4203); 4275 Oceanography: General: Remote sensing and electromagnetic processes (0689)

1. Introduction

[2] The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) has produced the first multi-year time series of global ocean chlorophyll observations since the demise of the Coastal Zone Color Scanner (CZCS) in 1986. Global observations from 1997–2000 by SeaWiFS combined with observations from 1979–1986 by the CZCS should in principle provide an opportunity to observe decadal changes in global ocean chlorophyll. However, incompatibilities between algorithms have so far precluded quantitative analysis. We have developed and applied compatible processing methods for the CZCS [*Gregg et al.*, 2002], using recent advances in atmospheric correction and consistent bio-optical algorithms to enhance the CZCS archive to comparable quality with SeaWiFS. Even with careful application of modern methodologies, there remain residual errors deriving from assumptions of atmospheric and oceanic optical behavior. We applied blending methodologies [*Gregg and Conkright*, 2001], where in situ data observations are merged with the satellite data, to reduce residual errors. These re-analyzed, blended data records provide maximum compatibility and permit, for the first time, a quantitative analysis of the changes in global ocean chlorophyll from the early-to-mid 1980's to the present.

2. Methods

[3] Reanalyzed CZCS chlorophyll data (Jan 1979–Jun 1986) [*Gregg et al.*, 2002] and Version 3 SeaWiFS data (Sep 1997–Dec 2000) were averaged to produce seasonal means at 1° spatial resolution, and were then blended with in situ chlorophyll data [*Gregg and Conkright*, 2001]. In statistical analyses of these data sets, we excluded comparisons in the North Pacific, North Atlantic, and Antarctic basins poleward of 40° in local autumn and winter, because of sparse sampling by the CZCS. These were the only places and times when the lower density sampling of the CZCS was important in the comparison. Basin and global means were areally-weighted for both satellite data sets and only co-located observations were used, to further minimize problems associated with low sampling density by the CZCS. Coastal observations (where bottom depth $\leq$200 m) were excluded from the analysis.

[4] Sea surface temperature (SST) and surface mean wind stress data were obtained from the NOAA/National Center for Environmental Prediction (NCEP) Reanalysis Project. The data were averaged over the two observational segments corresponding to the CZCS and SeaWiFS. Only data co-located with the ocean color data were used in the means.

3. Global and Basin Scale Decadal Changes in Blended Ocean Chlorophyll

[5] Blended satellite/in situ observations indicated that global ocean chlorophyll has decreased since the CZCS data record (Table 1). The decreases ranged from about 9% in autumn (Oct–Dec) to nearly 11% in summer (Jul–Sep). No significant change was observed in winter (Jan–Mar) or spring (Apr–Jun). Seasonal temporal patterns between the blended satellite chlorophyll records were similar, indicating a global maximum in spring/summer and a minimum in winter/autumn. The annual mean global change was −6.1% from the early 1980's to the present.

[6] Much of the global decrease was due to changes in the high latitudes (Figure 1). Blended SeaWiFS data were more than 10% lower than blended CZCS in the North Pacific and Atlantic basins in summer (Figure 1). The southern mid-ocean basins, South Indian, South Pacific, and South Atlantic, all exhibited significant decreases in blended chlorophyll in spring and summer, to nearly 28% in the South Pacific.

Table 1. Global ocean chlorophyll concentrations (mg m^{-}) and standard deviations from the blended CZCS record (1979–1986) and the modern blended SeaWiFS record (1997–2000), and the percent change (SeaWiFS-CZCS). *An asterisk indicates statistical significance at P < 0.05.

	Winter (Jan–Mar)	Spring (Apr–Jun)	Summer (Jul–Sep)	Autumn (Oct–Dec)
CZCS	0.232±0.359	0.250±0.402	0.288±0.431	0.242±0.412
SeaWiFS	0.225±0.309	0.245±0.375	0.257±0.347	0.221±0.296
% difference	−2.8	−2.1	−10.7*	−8.6*

compatibility. The analysis of the two chlorophyll records indicated large similarity in the global spatial distributions and seasonal variability. This included the extent and spatial structure of the mid-ocean gyres, the equatorial upwelling regions, and the bloom-recede dynamics of the high latitudes. There were also many decadal changes indicated in the analysis of the archives. Global chlorophyll concentrations indicated a decrease from the CZCS record to the present, of about −6%. Larger reductions occurred in the northern high latitudes. Conversely, chlorophyll in the low latitudes increased. Mid-ocean gyres exhibited limited changes. These results may indicate facets of climate change, some of which may be related to regional oscillation behavior such as the PDO and ENSO. Some of the decadal changes can be attributed to observed changes in SST or meteorological forcing, but some cannot. We believe that this reanalysis of the CZCS and SeaWiFS archives enables identification of some aspects of decadal change, and provides a marker of how the Earth's climate may be changing and how ocean biota respond.

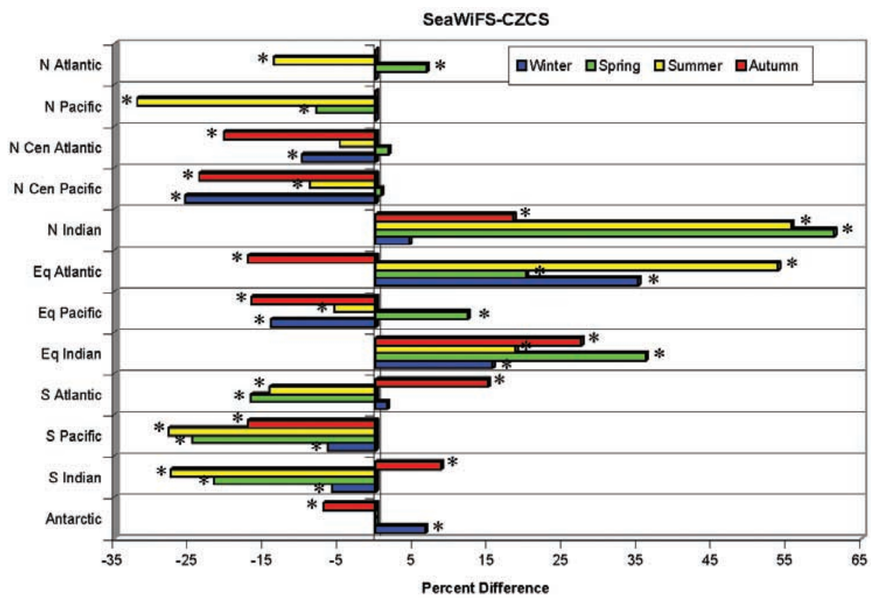

Figure 1. Seasonal differences between blended SeaWiFS and blended CZCS chlorophyll in the 12 major oceanographic basins [*Gregg et al.*, 2002]. Equatorial basins are between −10° and 10° latitude, the North Pacific and North Atlantic are north of 40°, and Antarctic is south of −40°. The other basins fall within these limits. Differences are expressed as blended SeaWiFS-blended CZCS. An asterisk indicates the difference is statistically significant at P < 0.05.

[7] The low latitude oceanographic basins, in contrast, generally exhibited an increase in chlorophyll from the CZCS period (Figure 1). Three of these basins (North Indian, Equatorial Indian, Equatorial Atlantic) showed major increases for the blended SeaWiFS. An exception was the equatorial Pacific in winter, summer, and autumn.

5. Summary

[17] The CZCS global ocean chlorophyll archive was reanalyzed using compatible atmospheric correction and bio-optical algorithms with SeaWiFS. This permitted, for the first time, a quantitative comparison of the decadal trends in global ocean chlorophyll from 1979- mid-1986 to the present (Sep 1997–Dec 2000). Blending of both archives with available coincident in situ data improved the residual errors of each data record and provided further