

Popular Summary: Decadal Changes in Global Ocean Chlorophyll
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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-present from SeaWiFS combined with observations from 1979-1986 from 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, using modern advances in atmospheric correction and consistent bio-optical algorithms to advance the CZCS archive to comparable quality with SeaWiFS. We applied blending methodologies, where in situ data observations are incorporated into the CZCS and SeaWiFS data records, to provide improvement of the residuals. 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 in the early-to-mid 1980's and the present, using synoptic satellite observations.

An intercomparison of the global and regional chlorophyll concentrations from these blended satellite observations is important to understand global climate change and the effects on ocean biota. Chlorophyll-containing phytoplankton are responsible for oceanic primary production, which represents the uptake of carbon in the oceans and potentially ultimately from the atmosphere. Previous efforts to estimate global primary production have relied upon CZCS and SeaWiFS estimates of chlorophyll. However, intercomparisons of global primary production are not quantifiable because of the same differences in processing methodologies affecting chlorophyll retrievals. This analysis of decadal change in global chlorophyll concentrations, which are the primary independent variable for primary production estimates, is a first step toward understanding changes in global primary production.

Global seasonal means of ocean chlorophyll decreased from the CZCS record to SeaWiFS, by 8% in winter to 16% in autumn. Chlorophyll in the high latitudes was responsible for most of the decadal change. Conversely, chlorophyll concentrations in the low latitudes increased. The differences and similarities of the two data records provide evidence of how the Earth's climate may be changing and how ocean biota respond. Furthermore, the results have implications for the ocean carbon cycle.

Science Priorities: Decadal Changes in Global Ocean Chlorophyll
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Priority#4 Long-term Climate Variability
Priority#2 Seasonal to Interannual Climate Prediction
Priority#1 Land Cover and Global Productivity

Decadal Changes in Global Ocean Chlorophyll

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Abstract

The global ocean chlorophyll archive produced by the Coastal Zone Color Scanner (CZCS) was revised using compatible algorithms with the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), and both were blended with in situ data. This methodology permitted a quantitative comparison of decadal changes in global ocean chlorophyll from the CZCS (1979-1986) and SeaWiFS (Sep. 1997-Dec. 2000) records. Global seasonal means of ocean chlorophyll decreased over the two observational segments, by 8% in winter to 16% in autumn. Chlorophyll in the high latitudes was responsible for most of the decadal change. Conversely, chlorophyll concentrations in the low latitudes increased. The differences and similarities of the two data records provide evidence of how the Earth's climate may be changing and how ocean biota respond. Furthermore, the results have implications for the ocean carbon cycle.

Introduction

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-present from SeaWiFS combined with observations from 1979-1986 from 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, using modern advances in atmospheric correction and consistent bio-optical algorithms (1,2) to advance the CZCS archive to comparable quality with SeaWiFS. However, even with careful application of modern methodologies, there remain residual errors as a result of assumptions of atmospheric and oceanic optical behavior. We applied blending methodologies (3), where in situ data observations are incorporated into the CZCS and SeaWiFS data records, to provide improvement of the residuals. 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 in the early-to-mid 1980's and the present, using synoptic satellite observations.

An intercomparison of the global and regional chlorophyll concentrations from these blended satellite observations is important to understand global climate change and the effects on ocean biota. Chlorophyll-containing phytoplankton are responsible for oceanic primary production, which represents the uptake of carbon in the oceans and potentially ultimately from the atmosphere. Previous efforts to estimate global primary production have relied upon CZCS (4) and SeaWiFS (5) estimates of chlorophyll. However, intercomparisons of global primary production are not quantifiable because of the same differences in processing methodologies affecting chlorophyll retrievals. This analysis of decadal change in global chlorophyll concentrations, which are the primary independent variable for primary production estimates, is a first step toward understanding changes in global primary production.

Climate Controls on Ocean Chlorophyll

Climate affects ocean chlorophyll by changing the physical environment in which phytoplankton reside. Although temperature affects phytoplankton and zooplankton physiological activity, the primary physical effects on chlorophyll concentrations are related to nutrient and light supply. Increasing ocean temperature can stratify the surface mixed layer more strongly (6, 7) and at shallower depths, reducing the supply of nutrients (8) and inhibiting photosynthesis. This typically has the effect of reducing chlorophyll concentrations. In the local winter, cooler temperatures facilitate convective overturn and increased vertical mixing, which increase the supply of nutrients to the surface mixed layer, where most phytoplankton growth occurs. However, there is a balance between nutrient and light limitation, and if the mixed layer becomes too deep, it may suppress phytoplankton growth by reducing the average light encountered by phytoplankton as they mix in the surface layer (9). Surface wind stresses can modulate the stratification process and affect the depth of the surface mixed layer. Stronger winds supply kinetic energy that tends to destroy the stratification and deepen the mixed layer.

Global and Basin Scale Decadal Changes in Blended Ocean Chlorophyll

Blended satellite observations indicate that global ocean chlorophyll has decreased since the CZCS data record (Table 1) in each of the four seasons (10). The decreases range from about 8% in winter, to 16% in autumn. Seasonal temporal patterns between the blended satellite chlorophyll records are similar, indicating a global maximum in summer and a minimum in winter.

However, these global ocean chlorophyll changes are not evenly distributed in the oceans. Most of the global decrease is due to changes in the high latitudes (Fig. 1).

Blended CZCS data are often >20% larger than blended SeaWiFS in the North Pacific, North Atlantic, and Antarctic basins (Fig. 1) (11). The largest differences are often in local autumn and winter, when the potential for primary production is lowest, due to low surface irradiances. The southern mid-ocean basins, South Indian, South Pacific, and South Atlantic, exhibit significant decreases in blended chlorophyll in local autumn and winter, up to 40% in the South Pacific.

These results have major implications for the global carbon cycle, since models suggest greatest sensitivity of ocean-atmosphere carbon flux in these high latitude regions (12, 13). Furthermore, these regions are dominated by diatoms (14, 15, 16), which typically grow and sink faster than other phytoplankton groups, and thus can represent an important carbon transfer mechanism to the deep oceans.

The blended SeaWiFS record, in contrast, exhibits an increase in the low latitude oceanographic basins from the CZCS period (Fig. 1). All 4 of the equatorial basins (North Indian, Equatorial Indian, Equatorial Pacific, Equatorial Atlantic) show major increases for the blended SeaWiFS. The increases often exceed 40%. The only exceptions are winter and autumn in the equatorial Pacific. Here winter exhibits almost no decadal change while autumn indicates a decrease from the blended CZCS.

The observation that the blended satellite chlorophyll records indicate a decadal decrease in the high latitudes and an increase in the low latitudes may have important consequences for the ocean carbon cycle. The high latitudes typically represent a net sink of atmospheric carbon, while the low latitudes represent a source (17). To the extent that phytoplankton population dynamics play a role in the ocean carbon cycle, the results suggest a reduced high latitude carbon sink due to decreased chlorophyll concentrations

and a reduced low latitude carbon source due to increasing chlorophyll. This implication is related to the carbon uptake role played by phytoplankton in photosynthesis, and sequestration to deeper water through sinking and death. However, a balance of effects is not necessarily implied because of differences in the areal change of biomass regionally, and because of differences in regional ecosystem structure and function, which can affect uptake, death, and sinking rates, and thus the cycling of oceanic carbon.

Synoptic Scale Decadal Changes in Blended Ocean Chlorophyll

Synoptic scale observations (100-1000 km) of global ocean chlorophyll trends from the early-to-mid 1980's and the present can provide a detailed understanding of the global and basin scale changes and a basis for estimating the causes. Figs. 2 and 3 depict the synoptic scale blended chlorophyll distributions from 1979-to-mid 1980's (blended CZCS) and the present (blended SeaWiFS). The overall distributions are remarkably similar: the extent, location, and shape of the global ocean mid-ocean gyre regions, the equatorial upwelling regions, and the sub-polar frontal regions exhibit a large degree of commonality between the two decadal time segments. This similarity of global scale patterns was not apparent in the previously available versions of the CZCS (3). Its presence in the re-analyzed data suggests the validity and compatibility of the two archives, and supports the quantitative decadal comparison.

There are indications of major decadal changes in the intercomparisons. Northern high latitude chlorophyll concentrations have diminished since the 1980's (Fig. 2), as previously indicated by the basin-scale analyses (Fig. 1). Chlorophyll in the North Pacific is vastly reduced in summer, as are the central and northern portions of the North

Atlantic. Compensation occurs in the eastern North Atlantic near Great Britain and in the North Sea and affects the summer basin mean.

In the subarctic North Pacific and North Atlantic, the timing of the spring bloom is also changed: the spring bloom peaks one month earlier in the present decade (May) than in the 1980's (June, Fig. 4) (18). The spring bloom is also not as large as in the 1980's. In a coupled general circulation/biogeochemical/radiative model tracking the SeaWiFS record, it was found that warmer ocean temperatures produced accelerated mixed layer shoaling, and an earlier spring bloom (19). Analysis of sea surface temperature (SST) data (20) for the North Atlantic indicates that the recent decade exhibits substantial warming relative to the 1980's: 0.6°C in spring and 0.8°C in summer. Levitus et al. (21) observed a warming of about 0.4°C in the top 300 m in the extended North Atlantic basin (equator to pole) from the 1980's to 1997. The North Pacific did not indicate a similar SST warming in spring but mean spring surface wind stresses (22) decreased about 8%, which could contribute to accelerated mixed layer shoaling and stratification. In summer the North Pacific SST's were warmer by about 0.4°C . These results correspond with increased 300-m volume mean ocean temperatures from the 1980's to 1997, where an increase of about 0.3°C occurred in the extended North Pacific basin (equator to pole) (21).

Changes are maximum in autumn and winter in the subarctic Northern Hemisphere basins. The large concentrations observed during these seasons in both the blended CZCS and SeaWiFS may be the result of resuspension of deep nutrients (see 23, 24) that can support increased chlorophyll, and possibly also the presence of resuspended chlorophyll. Both the North Atlantic and Pacific indicate colder SST's in the 1980's in

autumn, about 0.66° and 0.20°C, respectively. These decreases in chlorophyll will have relatively small influence on carbon uptake however, because reduced light limits photosynthesis during this season in these regions.

These decadal patterns in chlorophyll and SST may be related to the North Atlantic Oscillation (NAO) (25) and Pacific Decadal Oscillation (PDO) (26). The phasing of each climatic event has changed from the early 1980's to the present decade. The CZCS observations occurred in a period of positive NAO (27), while most of the SeaWiFS record here was in negative phase, although there is an indication of a recent switch back to positive phase. Positive NAO produces strong winter winds and decreased temperatures (27) which can produce increased deep convective mixing and nutrient supply to support increased autumn and winter chlorophyll concentrations, which is consistent with the findings here. Interestingly, the extreme northeastern portion of the North Atlantic, in the North Sea and near Great Britain, exhibit positive temperature anomalies in positive NAO (27, 28), and thus colder ocean temperatures recently. This corresponds to the increasing chlorophyll observed in this region in the blended satellite analysis (Fig. 2).

Similarly, the PDO changed to positive phase in 1977 (26), which produced colder winter SST's in the central and western North Pacific (26, 29), again potentially supporting convection and nutrient supply to support increased chlorophyll concentrations in winter, as observed here. Reversed phase in 1997-1999 led to warmer SST's in the central and western North Pacific, colder eastern SST's, and increased coastal chlorophyll (30). These NAO and PDO events may also be responsible for the earlier spring blooms observed in these basins by requiring less surface heating to shoal a

shallower winter mixed layer enough to support a bloom. Reduction of the bloom amplitude may be the result of decreased nutrient availability from shallow mixing and convection in the previous winter.

Decadal results in the mid-Northern Hemisphere basins generally indicate little change, although there are exceptions. In the autumn North Central Pacific and North Central Atlantic, there appears to have occurred a reduction since the 1980's, and summer in the North Central Atlantic, where an increase has occurred. The reductions derive mostly from the northern portions of the two basins between 30-40° N, where the sub-polar front appears to have receded northward recently. Some of this may be due to reduced convection and mixing and shallower mixed layer depths associated with warmer temperatures recently, again implicating NAO and PDO. Warmer ocean temperatures are in fact indicated in the autumn SST record, with increases of nearly 0.4°C in both basins.

Like their Northern Hemisphere counterparts, the Southern Hemisphere basins generally indicate substantially decreased surface chlorophyll concentrations from the 1980's to the present (Fig. 1). The differences are also substantial, often > 20%. Again like the Northern Hemisphere, the largest decreases occur in spring and summer, when light levels are reduced, thus minimizing the potential effect on carbon uptake through photosynthesis. Furthermore, spring and summer sampling south of -40° latitude by the CZCS was sparse, so these results should be viewed with caution.

The Antarctic and South Indian basins indicate large decreases from the 1980's to the present in autumn and winter. In the Antarctic in autumn, the decreases are due to vastly smaller chlorophyll concentrations in the Indian Ocean sector, especially between 30° and 60° E longitude and 90 to 140°E, in the Drake Passage, and in the central portion of the

Atlantic sector. These large increases are partially offset by increases south of New Zealand and between 60-90°E in the central Indian sector, but the net effect is a reduction of >20%. A more modest decrease of about 9% occurs in winter, based mostly on the Drake Passage, the southeastern portion of the Pacific sector, the Ross Sea, and along the edge of the Antarctic continent.

In autumn and winter the South Atlantic shows the opposite pattern as the rest of the Southern Hemisphere basins in the growing season – it indicates a very large increase in chlorophyll in the recent decade (Fig. 3). The increases are nearly 20% in the winter and > 30% in autumn (Fig. 1). They are nearly entirely due to vastly larger chlorophyll concentrations along the South Atlantic sub-polar front and the Patagonian shelf (Figs. 2, 3). While elevated chlorophyll is clearly apparent in both time segments, SeaWiFS indicates expansive enhancement and also more coherent spatial structure. This spatial coherence is probably due to the routine sampling of SeaWiFS in contrast to the CZCS. There is also an indication of gyre contraction in the recent decade, as the southwest portion of the gyre has elevated chlorophyll in the SeaWiFS record, along with some additional increases in the northeastern portion offshore of Namibia.

The plume on the Patagonian shelf and extending eastward has 41% larger chlorophyll concentrations in autumn in the recent decade. Local observations in the plume indicate 23% stronger winds than in the 1980's, deriving from a more northerly and easterly direction, i.e., directly from the land/shelf. SST's are 0.17°C colder. This evidence suggests that winds have increased in the SeaWiFS record and changed direction, which is driving upwelling and producing elevated chlorophyll concentrations that extend nearly across the South Atlantic.

The New Zealand/Tasmania/Tasman Sea region indicates large changes in the decade between CZCS observations and SeaWiFS. In autumn and winter, chlorophyll concentrations in these regions indicate substantial increases (Fig. 3). However, spring and summer indicate major reduction (Fig. 2). It is this region that is most responsible for the spring and summer basin-wide reductions observed. Data in the recent decade follow a more normal local spring bloom pattern while the 1980's indicate a reverse pattern. This area was sampled systematically by the CZCS, so sampling alias is not as much a problem as in other parts of the hemisphere in spring and summer. Summer decreases in chlorophyll from the 1980's to the present are about 29%, and are associated with a rise in SST of nearly 0.5°C in this region. This, along with less vigorous mean summer wind stresses (-19%) helps to explain the spring and summer reductions in chlorophyll by reducing mixing and re-supply of nutrients. In autumn a 54% increase in chlorophyll here was also associated with more vigorous wind stresses (+16%) and a negligible warming ($+0.05^{\circ}\text{C}$) that tends to run counter to expectations. Possibly the increased winds produce mixed layer deepening and enhance nutrient entrainment to support phytoplankton growth.

The global tropics represent an overall increase in chlorophyll concentrations from the 1980's to the present. This is especially true for the spring and summer seasons. The North and equatorial Indian Oceans indicate increases in equatorial upwelling zone concentrations, disappearance of a small gyre region, enhancement of chlorophyll on the eastern side near Indonesia, and a vast expansion of chlorophyll in the Arabian Sea and the Somalian coast during the southwest monsoon. Spring increases exceed 40% in each basin, and summer increases are 43% and 22% in the North and equatorial Indian oceans,

respectively. Winter differences, which represent a transition from the northeast monsoon to the intermonsoon, are considerably less than the other seasons.

The changes in the equatorial Pacific are mostly related to the relative over-representation of the 1997-1998 El Niño Southern Oscillation (ENSO) events in the data records. Although each observational time segment contained an equal number of El Niño and La Niña events (1 each), the duration of the total record (3.5 years and 7.5 years, for SeaWiFS and CZCS, respectively) changes their influence on the seasonal mean. Also, the La Niña event in the SeaWiFS record lasted 2.5 years, compared to nearly 2 years for the CZCS, and was much stronger in intensity. In fact, the 3 years of summer season data for the SeaWiFS record are composed entirely of La Niña conditions. Thus it is not surprising that substantial differences exist between the two observational segments, due to the relative importance of these events. The apparent increase along the equator in summer in the SeaWiFS record directly reflects the over-representation of La Niña (Fig. 2). Similarly, apparent decreases in autumn and winter are due to the relative importance of the 1997-1998 El Niño in the SeaWiFS record.

Spring and summer chlorophyll concentrations in the equatorial Atlantic represent the largest decadal changes in the global comparison (Fig. 1). The summer increase (57%) is due to vastly enhanced chlorophyll along the equator in the upwelling zone (Fig. 2). Additional contributions are from the Congo, Amazon, and Niger River outflows. Extreme summer rainfall in 1999 produced flooding in the Niger River basin (30), which contributes to the seasonal basin mean. High chlorophyll is observed in the Gulf of Guinea in the recent record that does not appear in the blended CZCS. The Congo River is largely responsible for the increases in chlorophyll in this basin for the autumn and

winter seasons, as well. Part of this is due to a major flood that occurred in the Congo drainage basin in winter 2000 (31). It is important to note that these tropical rainforest rivers primarily contribute chromophoric dissolved organic matter (CDOM) to the oceans, rather than chlorophyll, but the satellite ocean color algorithms cannot distinguish them. There were no in situ observations of the river plumes to allow the blended analysis to correct this error. The increased equatorial chlorophyll in the central portion of the basin was not accompanied by anomalously low SST's (19), as would be expected if it was enhanced upwelling. In fact, the basin exhibits strongly warmer SST's than the 1980's, ranging from 0.28° in autumn to 0.48°C in spring. Other than the enhanced summer equatorial upwelling and the riverine discharges, the equatorial Atlantic chlorophyll patterns are generally similar between the two data records.

Summary

A revision of the CZCS ocean chlorophyll archive using compatible atmospheric correction and bio-optical algorithms with the modern generation ocean color sensor SeaWiFS, permits, for the first time, a quantitative comparison of the decadal trends in global ocean chlorophyll from 1979- mid-1986, when the CZCS sensor was active, to the present (Sep. 1997-Dec. 2000), observed by SeaWiFS. Blending of both archives with available coincident in situ data improves the residuals of each and provides further compatibility. The analysis of the two chlorophyll records indicates large similarity in the global spatial distributions and seasonal variability. This includes the extent and spatial structure of the mid-ocean gyres, the equatorial upwelling regions, and the bloom-recede dynamics of the high latitudes. There are also many decadal changes indicated in

the analysis of the archives. Generally, chlorophyll concentrations in the high latitudes appear to have decreased from the CZCS record (1979-1980's) to the present. Conversely, chlorophyll in the low latitudes appears to have increased. Mid-ocean gyres exhibit limited changes, however, expansion of the North Central Pacific gyre and contraction of the South Atlantic gyre is apparent. These results may indicate facets of climate change, some of which may be related to regional oscillation behavior such as the NAO, PDO, and ENSO. Some of the decadal changes can be attributed to observed changes in SST or meteorological forcing, but some cannot. The overall spatial and seasonal similarity of the two data records strongly suggests that the changes are in fact due to natural variability, although some residual effects due to CZCS sensor design and sampling may still exist. 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 the ocean biota respond.

The results also have potential implications for our understanding of ocean carbon cycling. To the extent that phytoplankton population dynamics modulate the ocean carbon cycle, the results suggest a reduction in the high latitude carbon sink due to decreased chlorophyll concentrations since the 1980's and a reduction in the low latitude carbon source due to increasing chlorophyll.

References and Notes

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2. Our methods for improving CZCS data take advantage of recent advances in atmospheric correction and bio-optical relationships (*1*). This includes revised CZCS

calibration (32), and common methods for navigation modification (33), Rayleigh scattering (34), water-leaving radiance estimation at near infrared bands (35), aerosol scattering (36), spectral foam correction (37, 38) and blending with in situ data (3). Aerosol type is determined from the clear water radiance technique (39) and extrapolated to high chlorophyll areas using the Successive Correction Method (40), a standard meteorological methodology. The bio-optical algorithm is a three-band maximum band ratio method (41) similar to the four-band maximum band ratio method used for SeaWiFS (41), and derived from the same in situ data set. There remain two exceptions to the processing: 1) SeaWiFS corrects for shadowing effects due to waves, and 2) SeaWiFS provides a correction to sun glint outside a masking area where the glint is heaviest. The shadowing effects are only important at very large solar zenith angles ($> 65^\circ$) (42), and in this analysis only CZCS data with angles less than this limit are utilized. Second, independent analyses of SeaWiFS data without applying the sun glint correction method have indicated no effect at the space and time scales used here.

SeaWiFS chlorophyll data were obtained from the NASA/Goddard Space Flight Center (GSFC)-Distributed Active Archive Center (DAAC) using version 3 algorithm and processing methodologies (43). CZCS data were processed using new algorithms from Level-1A uncalibrated radiance data, also from the GSFC-DAAC. Both data sets were averaged to produce seasonal means at 1 deg. x 1 deg. spatial resolution.

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11. We follow the conventions of the National Oceanographic Data Center (NODC) (44) in defining the 12 major oceanographic basins: equatorial basins are between -10° and 10° latitude, the Antarctic is defined as south of -50° , and the North Pacific and North Atlantic are $> 40^{\circ}$. The other basins fall within these limits.
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Table 1. Global ocean chlorophyll concentrations (mg m^{-3}) from the blended CZCS record (1979-1986) and the modern blended SeaWiFS record (1997-2000), and the percent change (SeaWiFS-CZCS).

	Winter (Jan.-Mar.)		Spring (Apr.-Jun.)		Summer (Jul.-Sep.)		Autumn (Oct.-Dec.)	
CZCS	0.332	± 0.556	0.378	± 0.727	0.403	± 0.709	0.388	± 0.675
SeaWiFS	0.306	± 0.537	0.344	± 0.808	0.370	± 0.938	0.326	± 0.630
% difference	-7.8		-9.0		-8.2		-16.0	

Fig. 1. Seasonal differences between blended SeaWiFS and blended CZCS chlorophyll in the 12 major oceanographic basins. Differences are expressed as blended SeaWiFS-blended CZCS). Generally, blended CZCS exceeds blended SeaWiFS in the high latitudes, while blended SeaWiFS exceeds blended CZCS in the low latitudes. These trends appear to hold seasonally. The basin scale decadal changes from CZCS to SeaWiFS are often large ($>30\%$).

Fig. 2. Summer (Jul-Sep) chlorophyll distributions for the blended SeaWiFS era (1997-2000), the blended CZCS era (1979-mid-1986), and the difference. Units are mg m^{-3} .

Fig. 3. Autumn (Oct-Dec) chlorophyll distributions for the blended SeaWiFS era (1997-2000), the blended CZCS era (1979-mid-1986), and the difference. Units are mg m^{-3} .

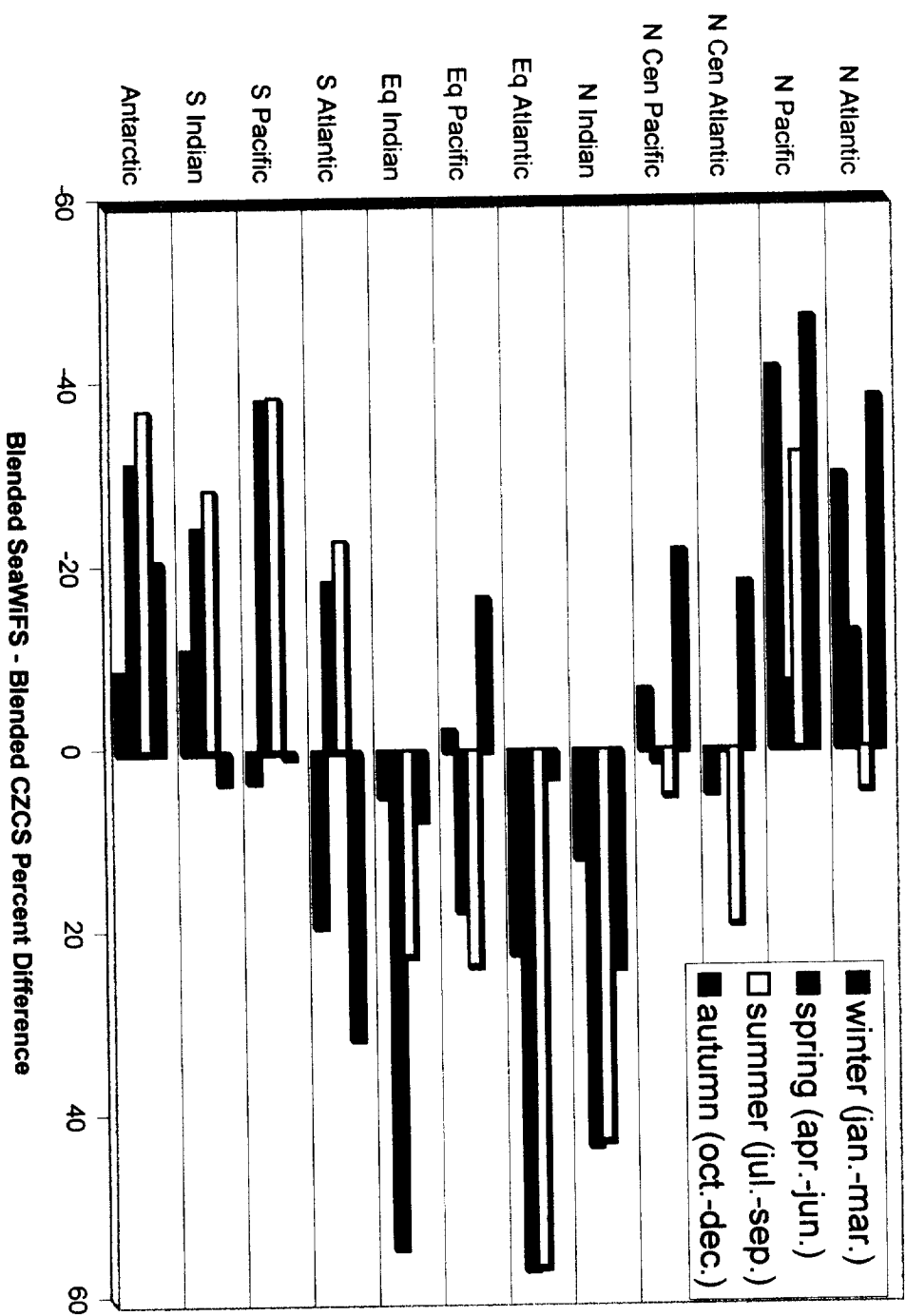
Fig. 4. Monthly mean blended chlorophyll concentrations for the CZCS (solid squares) and SeaWiFS (solid diamonds). Top: North Atlantic. Bottom: North Pacific.

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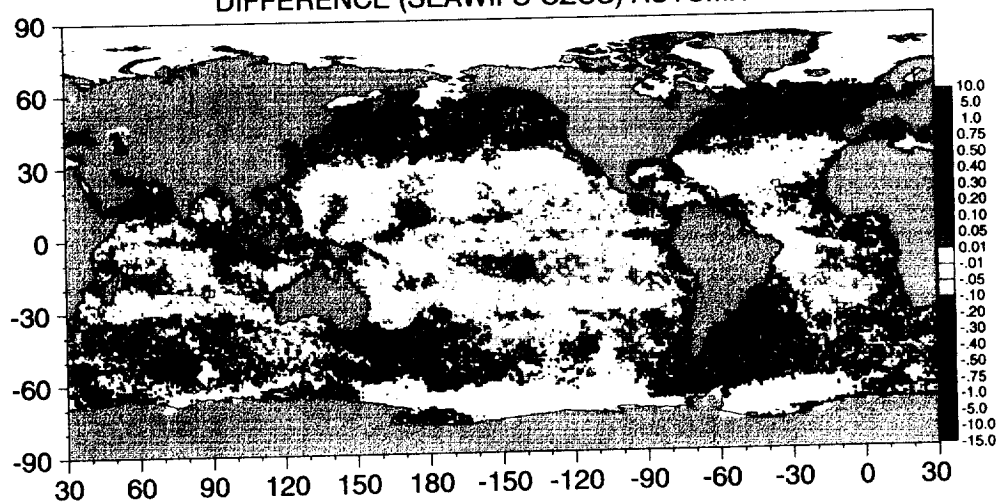
SEAWIFS BLENDED CHLOROPHYLL AUTUMN



CZCS BLENDED CHLOROPHYLL AUTUMN



DIFFERENCE (SEAWIFS-CZCS) AUTUMN



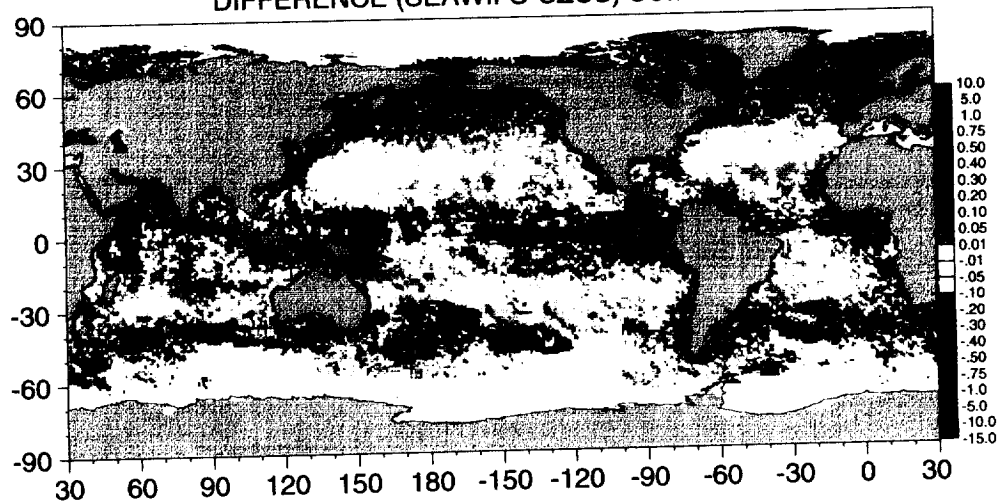
SEAWIFS BLENDED CHLOROPHYLL SUMMER



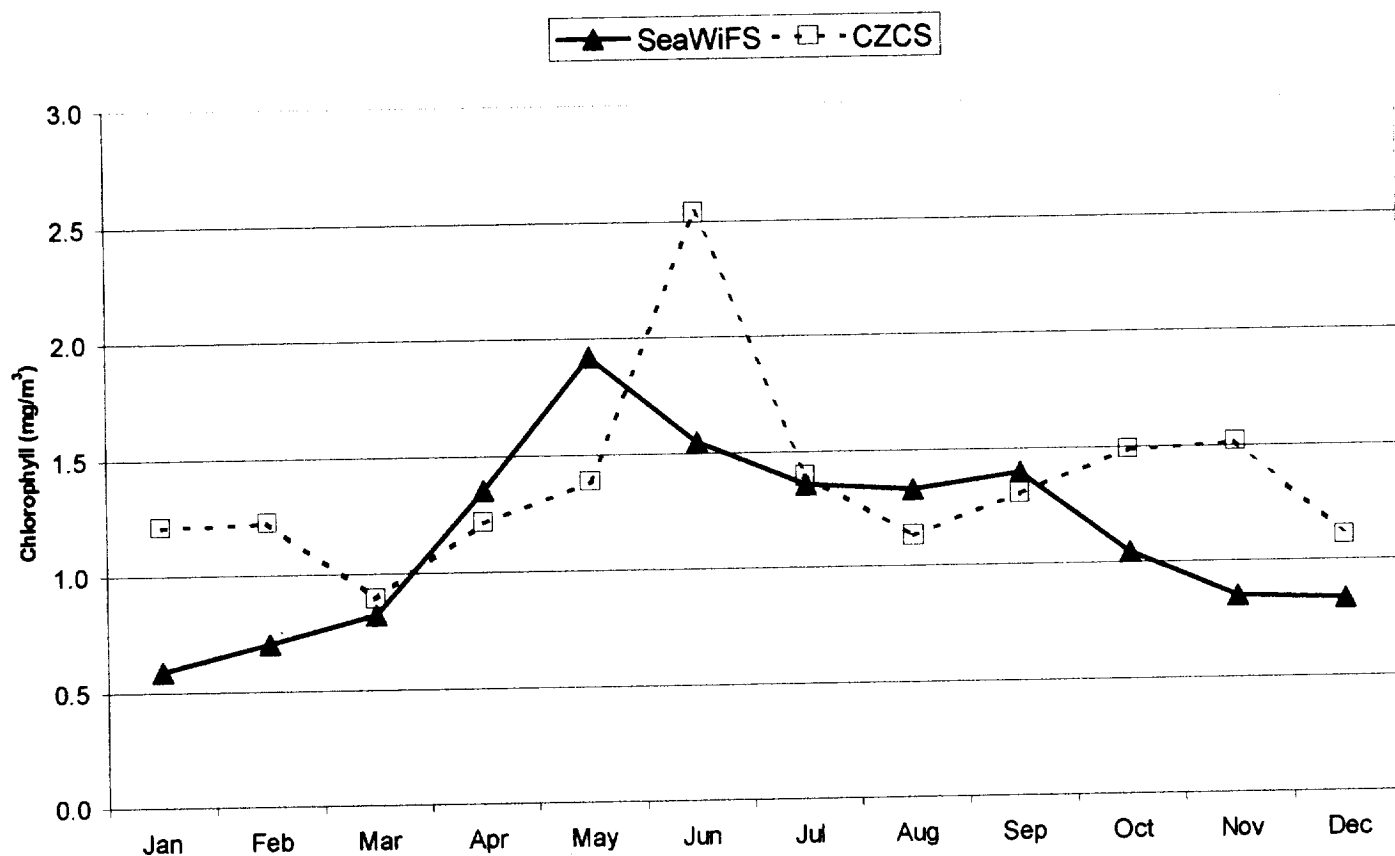
CZCS BLENDED CHLOROPHYLL SUMMER



DIFFERENCE (SEAWIFS-CZCS) SUMMER



North Atlantic



North Pacific

