Co-Variability of Global SeaWiFS-Chlorophyll and AVHRR-SST

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INTRODUCTION

We used global SeaWiFS and AVHRR imagery from 1997-2003 to determine modes of variability in phytoplankton chlorophyll (Chl) and its relation to SST. Our focus was on the global ocean between 50°S and 50°N and on ca. monthly to interannual time scales.

METHODS

Image Time Series

- Started with 9-km and 8-day SeaWiFS-Chl and AVHRR-SST imagery.
- Averaged on a 0.25º x 0.25º grid and then smoothed using a 1ºx1º median filter.
- Subsampled to a 1ºx1º grid covering the global ocean.
- Log-transformed SeaWiFS imagery but not SST.
- Used a 3-point (24 day) running mean to smooth the time series associated with each pixel.
- Filled in missing points for maximum spatial coverage for EOFs.
- Final x, y, and time cube consisted of 289 and 265 8-day "maps", respectively for Chl and SST.
- Removed the temporal mean of each pixel from each map (Figure 1a).
- Weighted each value using the cosine of latitude (for equal area representation).

Data Analysis

- Singular value decomposition (SVD) to calculate empirical orthogonal functions (EOF).
- Estimated the sampling error of the eigenvalues and estimated that first 5 Chl and SST modes were not degenerate.
- Used the Nino 3.4 definition (Trenberth, 1997) to determine ENSO timing.
- The 1997/1998 El Nino started in May 1997, peaked in November 1997, and ended in April 1998. The transition between El Nino and La Nina occurred between May and June 1998. La Nina started in July 1998, peaked in December 1998, and ended in February 2001.
- A weaker El Nino started in May 2002, peaked in November 2002 and ended in March 2003.

Mean Fields

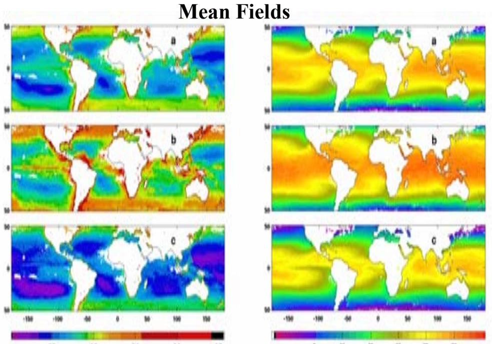


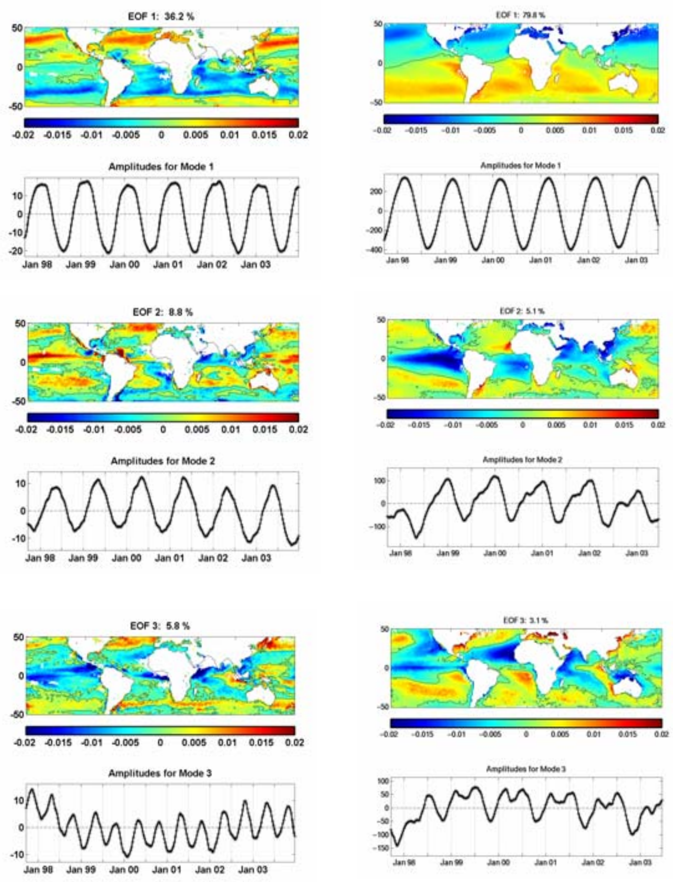
Figure 1. (Left) 1997-2003 SeaWiFS chlorophyll mean (a), maximum (b), and minimum (c) for 50ºS to 50ºN latitudes. Units are $\log_{10}$(chl *a*) + 2 (*i.e.* a log scale but with no negative numbers). (Right) 1997-2003 Pathfinder SST mean (a), maximum (b), and minimum (c). Units are ºC. The color "white" outside of land areas indicates insufficient data for EOF analyses.

RESULTS

We used the method of singular value decomposition (SVD) of the 6-year time series to calculate the **amplitude time series**, eigenfunctions (**spatial pattern of each mode**) and corresponding eigenvalues **(% variance explained**). Since we first subtracted the 6-year temporal mean of each pixel (Fig. 1a) from the corresponding pixel value in each of the 8-day maps before our EOF calculations, the spatial patterns of each mode are global maps of the average pixel deviations (with units of log chlorophyll *a* concentration or ºC) from the 6-year temporal mean shown in Fig. 1a. The maps (matrices) are color coded and show both positive and negative deviations. The amplitude time series (shown below each map) is a vector associated with the spatial pattern of each mode. It is dimensionless and shows how the modal spatial pattern evolves with time, *i.e.* all pixels of a given modal spatial pattern change with time according to the single amplitude time series of that mode.

Figure 2. Spatial patterns (50ºS to 50ºN) and amplitude time series for Chl and SST modes 1-3. Chl spatial patterns have units of $\log_{10}$(chl *a*), and SST spatial patterns have units of ºC. Amplitudes are dimensionless. White regions outside of land areas indicate insufficient data for EOF analyses.

CHL MODES | **SST MODES**



Description of EOF Results

Chl Mode 1 accounts for 36.2% of the total variability (from the mean patterns shown in Fig. 1a) in the 289, 8-day map time series. It is dominated by the mean seasonal pattern of comparatively high winter, and low summer, chlorophyll concentrations at mid latitudes in both hemispheres. **Mode 1 SST** accounts for 80% of the variability and shows alternation of seasonal high and low temperatures in both hemispheres.

Chl Mode 2 accounts for 8.8% of the variability. It shows the influence of the spring bloom in the N. Atlantic and N. Pacific and at the high latitudes in the Southern Ocean. It also shows the impact of the Orinoco and Amazon rivers in the Atlantic, as well as seasonality along the Equator, particularly in the Pacific. **SST Mode 2** are modifications of the mean seasonal cycle in both hemispheres.

Chl Mode 3 shows the convolution of two different phenomena: spring/fall peaks (positive anomalies) which are out of phase in the two hemispheres *(i.e.* the NH spring peak coincides with the SH fall peak and visa versa) and the effects of the 1997-98 ENSO. For the latter, negative Chl anomalies in the 1997 and first half of 1998 coincide with higher temperature anomalies **(SST Mode 3**). Also note positive Chl anomalies in the eastern Indian Ocean during 1997-98 coinciding with negative temperature anomalies (upwelling).

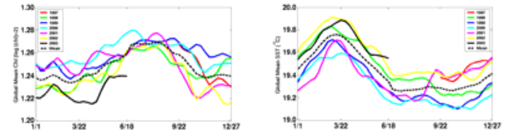


Figure 3. Global mean annual cycles for 1997-2003 (50ºS to 50ºN) for Chl (left) and SST (right).

Discussion. Figure 3 shows the mean 8-day global SeaWiFS chlorophyll concentration and SST, *i.e.* 1 global value for each 8-day interval. The results show the global impact of ENSO in that the *El Nino* periods (e.g. 1998, green lines) have low chlorophyll and high SST and *La Nina* years (e.g. 1999, blue lines) have high chlorophyll and low SST.

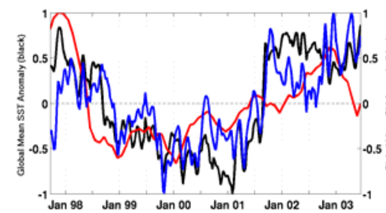


Figure 4. Global 8-day anomaly time series (50ºS to 50ºN) for Chl (in blue, plotted with sign reversed), SST (black), and monthly Nino 3.4 Index (red). All data have been normalized to maximum values.

Discussion. Figure 4 shows the 6-year global anomaly time series of chlorophyll (negative anomaly is actually plotted) and SST. The correlation coefficient between the two series is -0.79. Also shown is the Nino 3.4 index (red line).

CONCLUSIONS

The results from our analyses of the 6-year SeaWiFS time series are similar to those we recently published for the first 4 years of SeaWiFS data (Yoder, J.A. and M.A. Kennelly, *Global Biogeo. Cycles* 17, No. 4, 1112, 2003). Most of the variability (62%) within 8-day composite global chlorophyll images (50°S and 50°N) is contained in the first 6 (of 289 possible) modes.

The two highest Chl modes accounted for 45% of the total variability and were primarily associated with differences between the seasonal phase shifts of maxima and minima of subtropical (~20° to 40° N or S) versus subpolar waters (>45° N or S); and with the spring bloom in subpolar waters.

ENSO effects are prevalent in the imagery that covered the ocean between 50°S and 50°N, *i.e.* inclusive of the tropics but also of the subtropics and extending into subpolar waters. Global Chl and SST anomalies closely track the Nino 3.4 index.