Influence of the El Niño-La Niña cycle on satellite-derived primary production in the California Current

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[1] Time series of phytoplankton net primary production (NPP) for the California Current were derived using satellite data and the VGPM primary productivity model for a 5-year period (1997–2001) including the 1997–98 El Niño. NPP had a strong annual periodicity correlated with the El Niño-La Niña cycle. The most obvious effects of the El Niño on NPP were 100-300 km off the coast: a reduction by 30% off Southern California but an increase by 40% off Baja California. During its peak El Niño decreased NPP by 10–15% (1.5 Tg C month^{-1}) in the 1000-km band off Southern California but increased by 20–30% off Northern and Southern Baja (4 Tg C month^{-1}). The total annual NPP was lowest during the El Niño years of 1997–1998 and peaked in 2000. Trends of increasing NPP and zooplankton volume were observed off Central and Southern California. *INDEX TERMS:* 4215 Oceanography: General: Climate and interannual variability (3309); 4227 Oceanography: General: Diurnal, seasonal, and annual cycles; 4522 Oceanography: Physical: El Niño; 4516 Oceanography: Physical: Eastern boundary currents; 4855 Oceanography: Biological and Chemical: Plankton. **Citation:** Kahru, M., and B. G. Mitchell, Influence of the El Niño-La Niña cycle on satellite-derived primary production in the California Current, *Geophys. Res. Lett.*, *29*(17), 1846, doi:10.1029/2002GL014963, 2002.

1. Introduction

[2] El Niño events are known to have a strong effect on the ecosystems of the California Current [*Fiedler*, 1984; *McGowan*, 1985; *Chavez*, 1996; *Kahru and Mitchell*, 2000]. However, ecological responses to large-scale changes in physical forcing are not well understood. Satellite remote sensing is a feasible way to sample the high spatial and temporal variability inherent in most oceanic fields over large areas. Several models of phytoplankton net primary production (NPP, g C month^{-1}) have been developed and successfully implemented [e.g., *Behrenfeld et al.*, 2001]. We applied the Behrenfeld-Falkowski Vertically Generalized Production Model (VGPM) [*Behrenfeld and Falkowski*, 1997] to satellite-derived fields of surface chlorophyll a (C_{sat}, mg m^{-3}), incident photosynthetically active radiation (PAR, Einstein m^{-2} Day^{-1}) and sea-surface temperature (SST, °C), and derived a 5-year time series of NPP for the California Current area.

2. Data and Methods

[3] Spatial and temporal distributions were evaluated in alongshore bands of 0–100 km, 100–300 km and 300–1000 km off the coast, divided into 4 zones: Central California, Southern California, Northern and Southern Baja California (Figure 1, Table 1). The study area corresponds to a grid of 3-by-4 sub-areas used in our earlier studies [*Kahru and Mitchell*, 2000, 2001]. For validation we used data from the California Cooperative Fisheries Investigations (CalCOFI) [*Mantyla et al.*, 1995]. The half-day simulated on-deck incubation values were multiplied by 1.81 to obtain full day primary production [*Eppley*, 1992]. Macrozooplankton displacement volumes were also measured by CalCOFI [*Ohman and Smith*, 1995].

[4] The VGPM model was run on monthly composited fields of C_{sat}, PAR and SST with a spatial resolution of ~9 km. C_{sat} was obtained from OCTS (Nov. 1996 to June 1997, reprocessed by NASA) and SeaWiFS (Sept. 1997 to Dec. 2001, version 3) using standard algorithms [*O'Reilly et al.*, 1998]. PAR fields were calculated from SeaWiFS data with the Frouin algorithm http://orca.gsfc.nasa.gov/seawifs/par/doc/seawifs_par_wfigs.pdf]. For the OCTS time period PAR fields were not available and we used the mean monthly PAR fields from SeaWiFS. Interannual variability

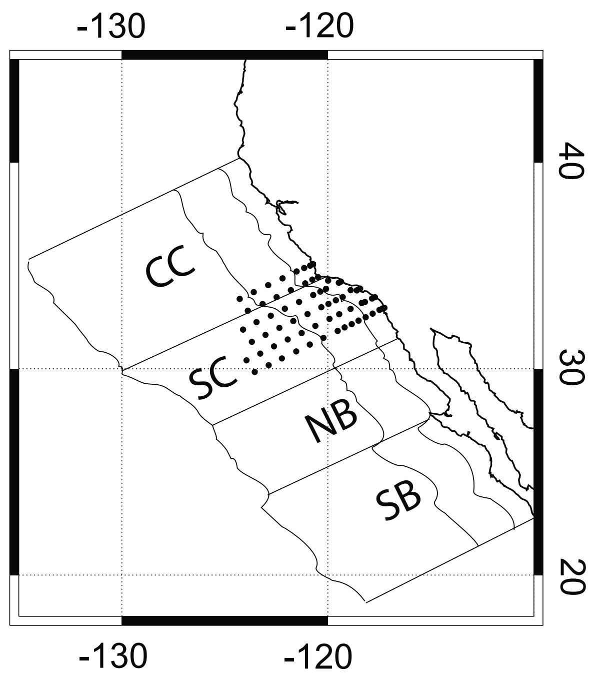

Figure 1. Study area with alongshore bands of 0–100 km, 100–300 km and 300–1000 km subdivided into zones of Central (CC) and Southern California (SC), Northern (NB) and Southern Baja California (SB). The CalCOFI station grid is shown as black dots.

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Table 1. Areas (in 1000 km^2) of the Sub-Areas of Alongshore Bands

	0–100 km	100–300 km	0–1000 km
Central California	61.672	158.504	747.613
Southern California	40.146	97.202	452.664
Northern Baja	40.826	95.511	429.950
Southern Baja	65.474	147.575	689.159

in monthly PAR had only a minor effect on the calculated NPP. SST was derived from the AVHRR Pathfinder daytime products [*Kilpatrick et al.*, 2001] for 1987–2000 and MODIS daytime products for 2001.

[5] As an index of the El Niño-La Niña cycle we used the Northern Oscillation Index (NOI) [*Schwing et al.*, 2002]. The peak of the El Niño period is defined by minima in NOI (filled black areas on Figures 3–6). We refer to the second half of 1997 and first half of 1998 as the El Niño period and the second half of 1998 to 1999 as the La Niña period, therefore annual estimates of NPP were calculated for 12 month periods from July through June.

[6] Monthly NPP in Tg C $month^{-1}$ (Tg = 10^{12} g) for an area was calculated by multiplying each pixel's value by the pixel area and integrating over the whole area. Anomalies were calculated by subtracting the mean annual cycle for each sub-area from the actual monthly values. For each sub-area the mean annual cycle was calculated by fitting a 6th degree polynomial through all the data points. The annual total NPP (Table 2) was calculated as the sum of 12 months. Missing monthly values were replaced with the respective seasonal mean for the area.

3. Results

[7] Rigorous comparison of the satellite-derived time series of NPP with in situ measurements is difficult due to the very different time and space characteristics of these measurements [*Balch and Byrne*, 1994]. We have sufficient in situ data for the 100–300 km band off Southern California (Figure 1). Satellite estimates overestimate ship measurements by ≈40% (Figure 2), which is within expected agreement among in situ and modeling methods.

[8] Possible effects of the El Niño were observed as decreased NPP in Central and Southern California starting from the middle of 1997. These effects are evident in all the alongshore bands (Figures 3–5) but are difficult to quantify due to the gap in satellite data. In the 0–100 km band off Southern California the decrease in NPP disappeared in 1998. Off Southern Baja the effects of the El Niño became evident later: in the middle of 1998, during the typical summer maximum NPP dropped by ≈30%, corresponding to a decrease of 1.5 Tg C $month^{-1}$ (Figure 3). The

Table 2. Estimated Total Annual NPP in Tg C

Distance (km)	0–100	100–300	300–1000	0–1000
1996–1997	90	114	210	413
1997–1998	90	123	231	444
1998–1999	98	131	232	460
1999–2000	108	133	230	471
2000–2001	108	131	236	475

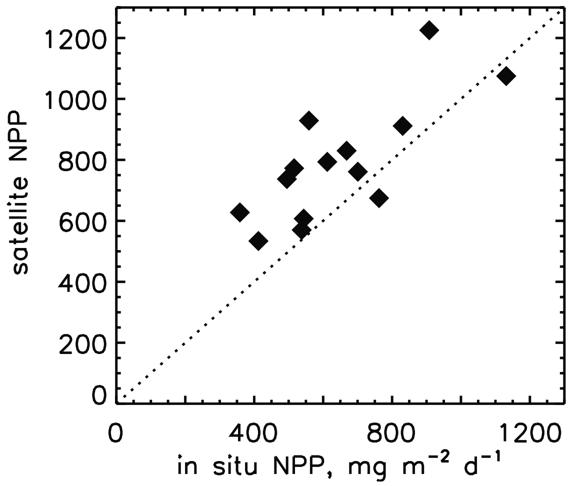

Figure 2. Satellite estimates of NPP versus ship measurements in the 100–300 km band off Southern California with CalCOFI stations. The satellite estimate is the median for the area, the ship measurement is the mean of a few stations in that sub-area during a cruise. Reduced major axis regression: intercept = 183, slope = 1.04, r^2 = 0.59.

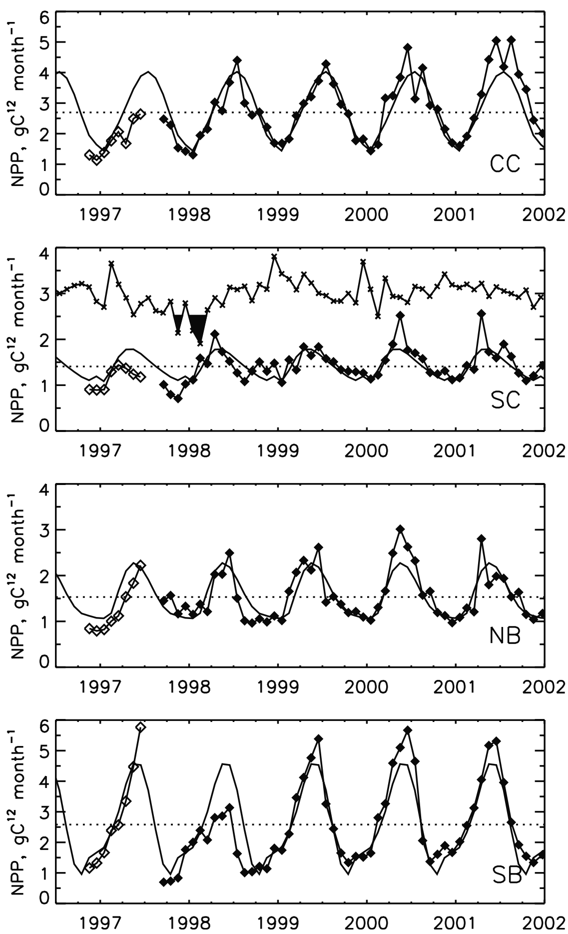

Figure 3. Time series of NPP in 0–100 km band in zones CC, SC, NB, SB calculated with C_{sat} from OCTS (◇) and SeaWiFS (◆) and compared with the mean annual cycle (solid line). The dotted horizontal line is the long-term mean. Minima in the Northern Oscillation Index (×, relative scale) correspond to peaks in the El Niño (filled black areas).

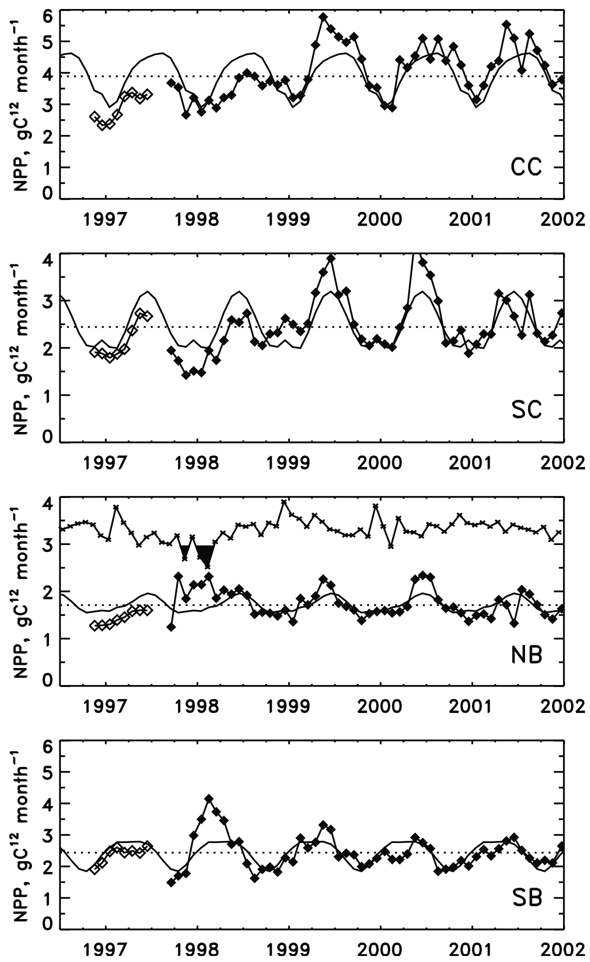

Figure 4. Time series of NPP in 100–300 km band. Symbols as in Figure 3.

termination of the summer NPP maximum about 2 months early caused a 60% negative anomaly in late summer of 1998. In other zones the response to El Niño in the 0–100 km band was not obvious.

[9] The effects of the El Niño on NPP were most evident in the 100–300 km band from the coast. Relative to the mean annual cycle NPP dropped 30% off Southern California but increased by 40% off Southern and Northern Baja during and near the peak of the El Niño (Figure 4).

[10] In the broad 0–1000 km band El Niño resulted in a decrease in NPP off Southern and Central California but in a significant increase off Southern and Northern Baja relative to the 5-year mean (Figure 5). During the whole 1997–1998 period NPP decreased in the 0–1000 km band off Southern California by 10–15% (1.5 Tg C month^{-1}) but increased sharply with the onset of La Niña in late 1998 (Figure 6). Off Southern Baja the annual maximum in NPP shifted from the mid summer to early spring as the increased offshore production more than offset the decreased near-shore production in the first half of 1998. The increase in the 0–1000 km band was 20–30% during the peak of the El Niño and resulted in increased NPP of $\sim$4 Tg C month^{-1} in the Northern and Southern Baja zones combined. The earlier start and termination of the annual NPP maximum caused strong (±30%) fluctuations in the anomalies.

[11] The regular annual cycle in NPP is the dominant feature of these time series while the inter-annual and other effects are usually of smaller magnitude. The seasonal cycle is strongest in the near-shore (0–100 km) and offshore (300–1000 km) bands while the inter-annual variability is strongest in the intermediate 100–300 km band (according to the Lomb normalized periodograms [*Lomb*, 1976]). Within the 0–100 km zone the seasonal cycle is strongest off Central California and Southern Baja California and weakest off Southern California.

[12] A general feature for both 0–100 km and 0–1000 km bands is the increasing trend in NPP (and in C_{sat}) in Central California (Figure 6). In Southern California the increase in NPP resembles a step function. The shift from −10% anomaly to +15% anomaly occurred with the onset of the La Niña in late 1998. The total NPP integrated over the four zones peaked in June, 2000 at 51 Tg C month^{-1} for the 0–1000 km band and at 14.9 Tg C month^{-1} for the 0–100 km band. The total inter-annual minimum was observed in 1996–97 while the maxima were observed in 1999–2000 and 2000–01 (Table 2).

[13] Zooplankton displacement volume was available for portions of the Southern California zone and showed a downturn during the El Niño period and an increase with

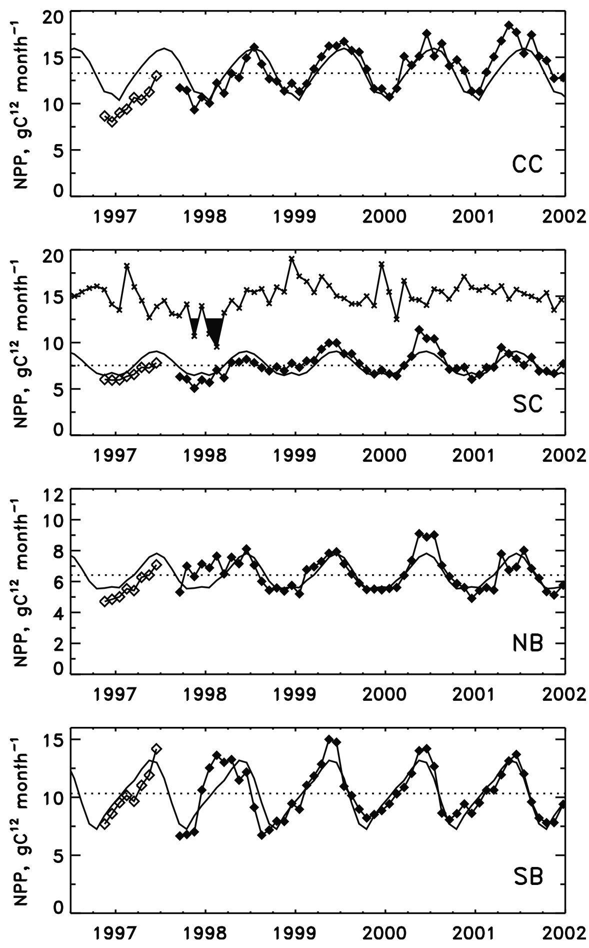

Figure 5. Time series of NPP in 0–1000 km band. Symbols as in Figure 3.

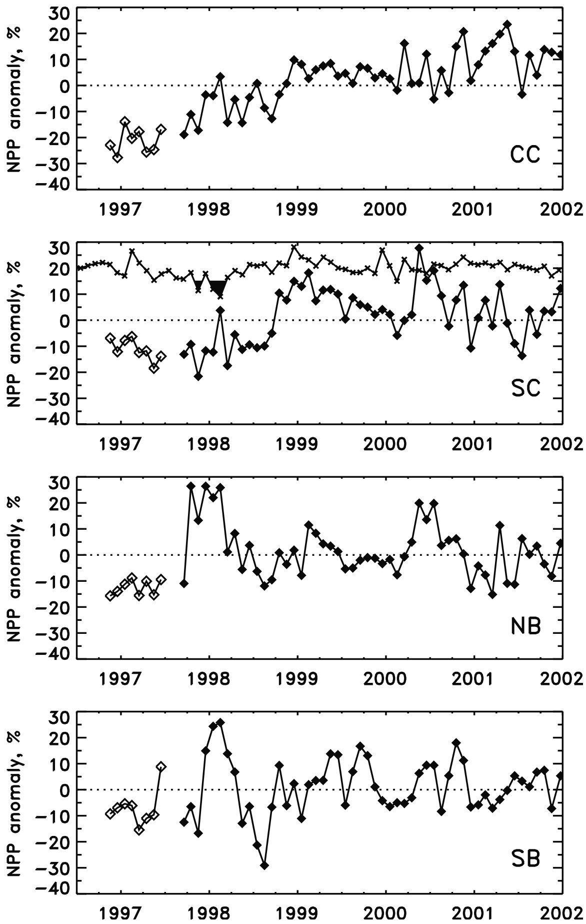

Figure 6. Anomalies of NPP in 0–1000 km band in zones CC, SC, NB, SB relative to the mean annual cycle. Symbols as in Figure 3.

the onset of the La Niña. The increasing trend is significant for the 5-year period.

4. Conclusions

[14] In our previous paper [*Kahru and Mitchell*, 2000] we showed that in addition to the well-known [*Fiedler*, 1984; *Strub et al.*, 1990; *Thomas et al.*, 1994] reduction in upwelling and high-chlorophyll surface waters, El Niño events in the California Current are associated with increased surface chlorophyll off Baja California. We hypothesized that these offshore blooms in warm stratified waters were caused by nitrogen-fixing cyanobacteria.

[15] We have quantified the seasonal and inter-annual changes in NPP in relation to the 1997–98 El Niño and the subsequent La Niña. Increased primary production in the 0–1000 km band off Northern and Southern Baja during the peak of the El Niño caused a positive NPP anomaly of 25–30% or 4.5 Tg C for the two zones combined. This phenomenon shifted the annual NPP maximum from mid summer to early spring and caused a negative anomaly in late summer as the maximum in NPP terminated 2 months early. Off Southern California the 10–15% negative anomaly during the 1997–98 El Niño period turned into a 10–20% positive anomaly with the onset of La Niña in late 1998 and increased NPP by ~1 Tg C month^{-1}.

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