Seasonal Chlorophyll/Nitrate Model for Santa Catalina Island

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Abstract

We analyze and model the seasonal phytoplankton bloom and nitrate profile at Santa Catalina Island, California. Previous studies indicate that the seasonal temperature dynamics in the ocean surrounding the island are particularly simple and differs significantly from those found around most other islands of Southern California. We investigate whether the spring bloom corresponds to that deduced from temperature studies. The phytoplankton are inferred from remotely-sensed chlorophyll derived from MODIS Aqua. The nitrate data are from CalCOFI cruises. And, the summer vertical eddy diffusion coefficient is obtained from previous long-term temperature studies in the inner Southern California Bight. We find that a solution of a simple differential equation in time and depth fits the general Santa Catalina data well.

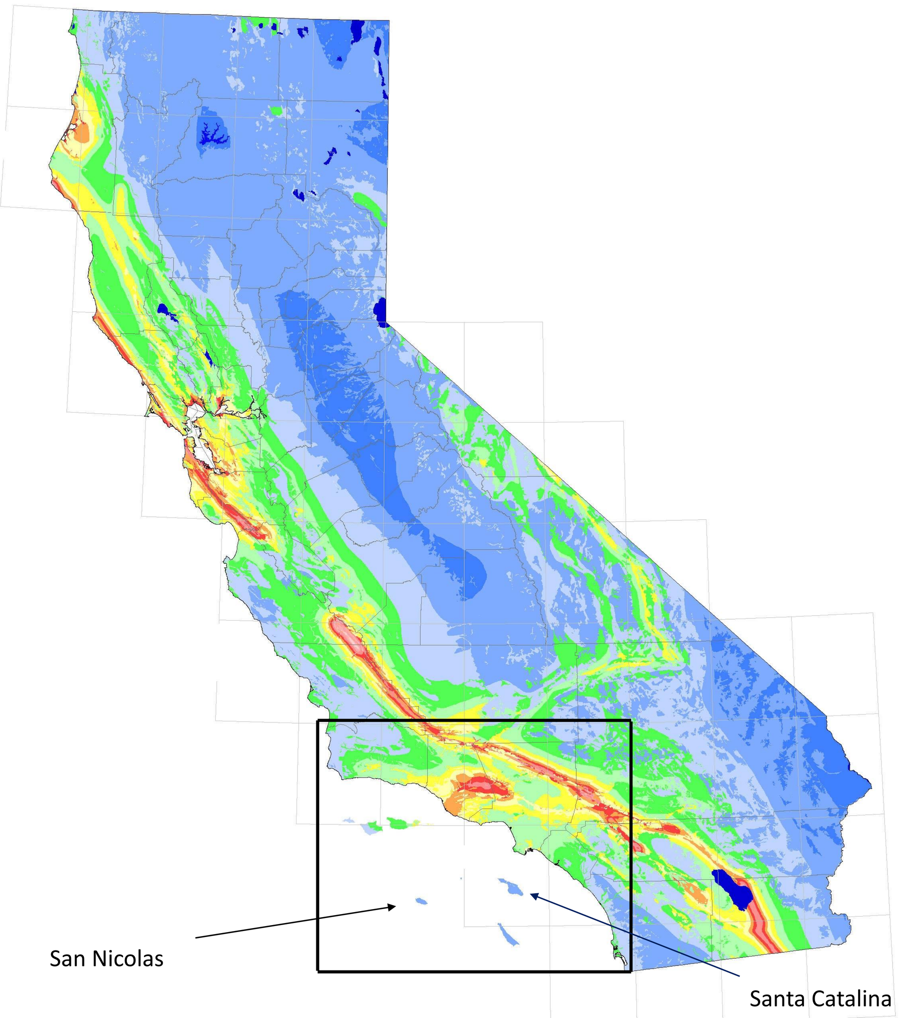

Figure 1. Study area in Southern California Bight

Santa Catalina Island is in the Southern California Bight and is relatively sheltered from the northerly winds that produce the upwelling characteristic of Central and Northern California (Figure 1). Previous work indicated that the temperature dynamics are relatively simple, being controlled by seasonal insolation and mixing with a constant vertical eddy diffusion coefficient during the summer. Hence the ocean surrounding Catalina is a natural laboratory for studying other processes that are controlled by mixing.

Phytoplankton as represented by chlorophyll are measured from the satellite-borne imager Modis Aqua. We downloaded 10 years of the 8-day, 4-km chlorophyll product produced by NASA. The data were averaged over the decade to produce the mean-chlorophyll map shown in Figure 2. Chlorophyll is found to have large values along the coast and especially in the Santa Barbara Channel. Marked on the figure are boxes and profiles signifying regions of emphasis around Santa Catalina as well as San Nicolas Island for contrast.

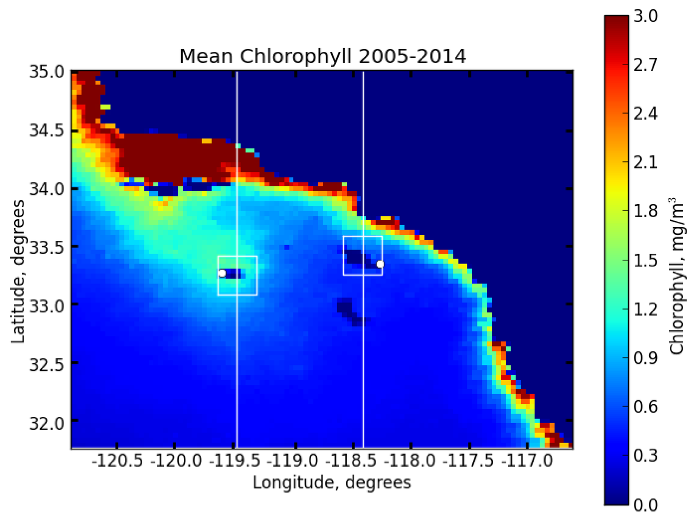

Figure 2. Average chlorophyll value for the decade of study. Locations of latitudinal profiles and averaging areas for Santa Catalina and San Nicolas are shown.

The 8-day day-of-year values were averaged over the decade and values along a latitude profile through Catalina and San Clemente is shown in Figure 3. Chlorophyll has the largest values near the mainland coast, and there is no indication that Catalina has an island mass effect, that is, increased biological activity associated with the presence of the island. A sinusoidal fit to the annual variation is shown in Figure 5, as well as one to similar data corresponding to San Nicolas.

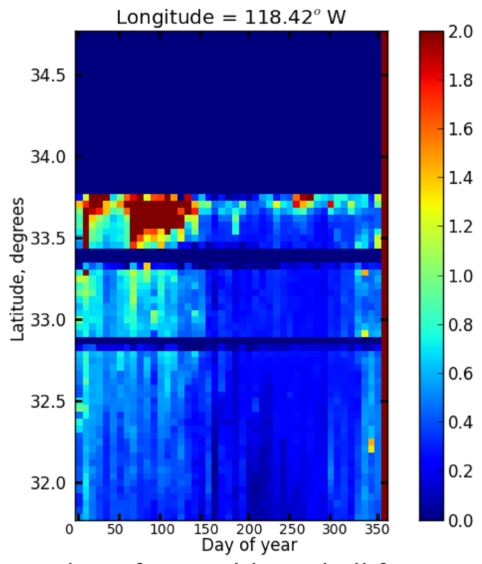

Figure 3. Average day-of-year chlorophyll for S. Catalina profile

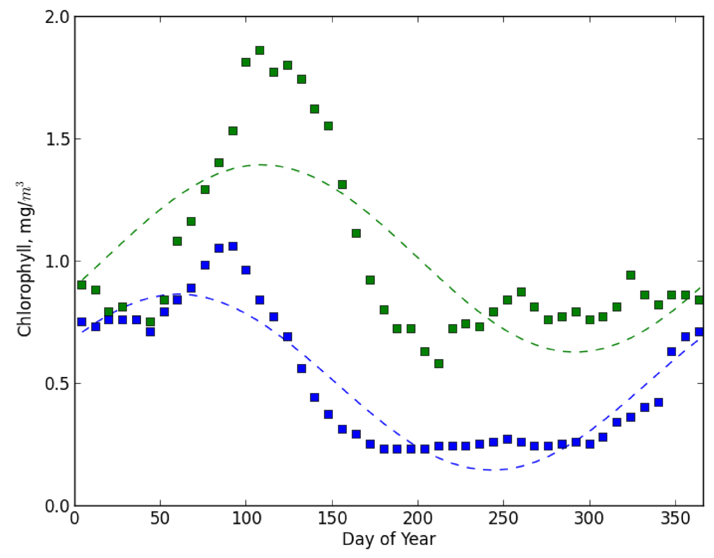

Figure 4. Sinusoidal fit to chlorophyll variation for S. Catalina (blue) and S. Nicolas (green).

Nitrate data from the California Cooperative Ocean Fisheries Investigation (CalCOFI) for the 10 years also were examined. An example of the data measured during the first 50 days of a calendar year are shown in Figure 5 for the CalCOFI stations closest to Santa Catalina and San Nicolas. The values for specific depths are shown through the year in Figure 6 and the medians are connected via the lines. The near-surface value medians are 0, and deeper values have a seasonal variation.

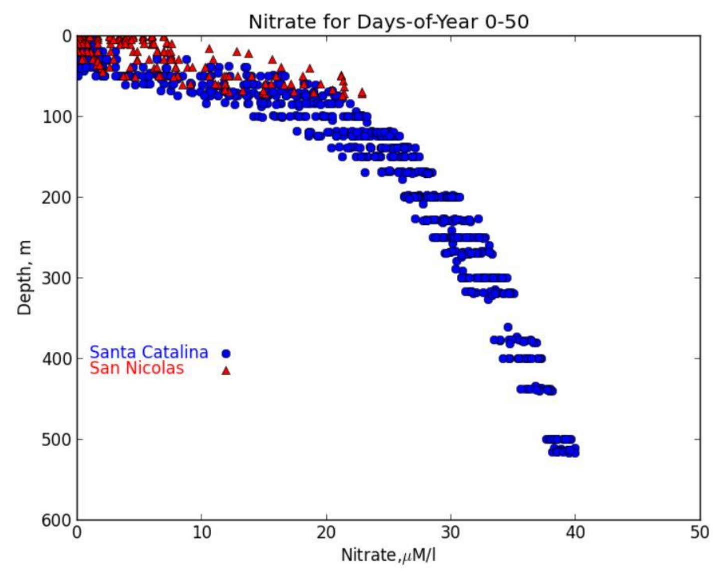

Figure 5. Nitrate vs depth from CalCOFI for measurements made during the first 50 days of the calendar year over the decade.

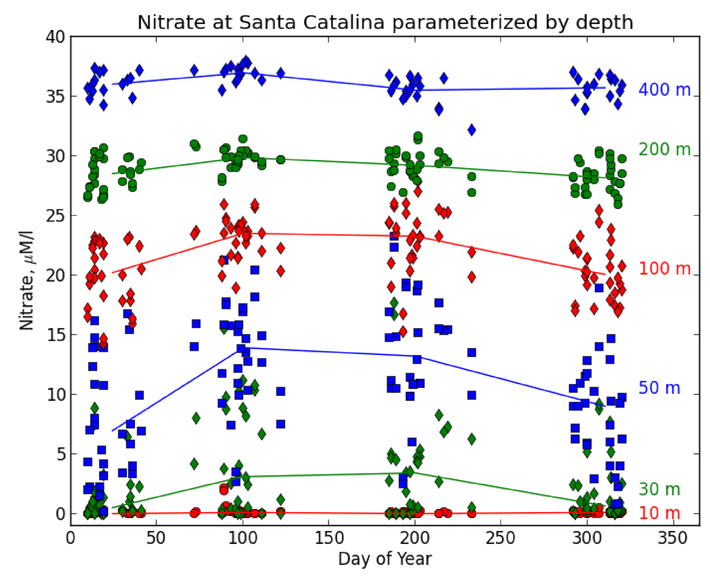

Figure 6. Seasonal variation of nitrate by depth.

The seasonal variations of the data from Santa Catalina, as well as the temperature, temperature gradient and photosynthetically active radiation models are plotted in Figure 7.

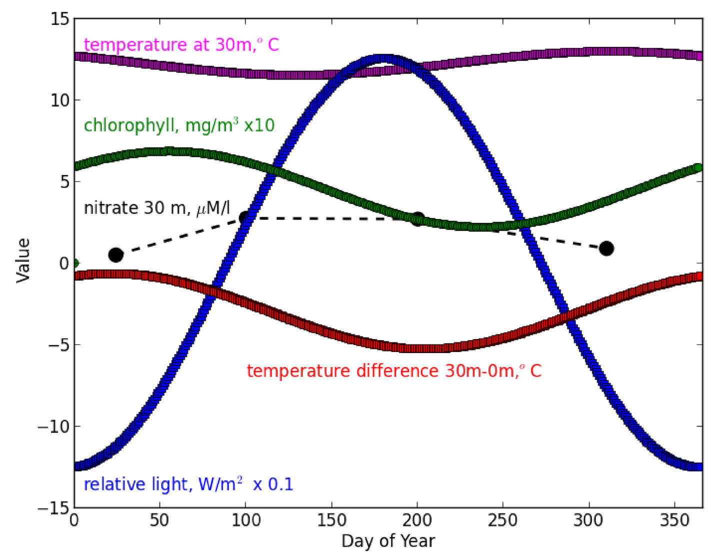

Figure 7. Seasonal variation of key parameters.

Inspection of Figure 7 indicates that the chlorophyll is in phase with stratification, implying the it is controlled by vertical eddy diffusion. A differential equation is constructed relating the diffusion of nitrate (N) with a sink produced by nitrate uptake by phytoplankton (P). The phytoplankton are represented by chlorophyll. In the equation below, κ is the diffusion coefficient, α is the conversion from chlorophyll to nitrate, μ is optimal growth rate and β is mortality. H describes the reduction in optimum growth due to nitrate limitation.

$$\frac{\partial N}{\partial t} - k(t)\frac{\partial^2 N}{\partial z^2} = -\alpha(\mu H(N) - \beta)P(t)$$

$$H(N) = \frac{N}{K_N + N}$$

α = 420 μM Nitrate/mg Chl
μ = 2/day
β = 1/day
K_N = 0.25 μM/l

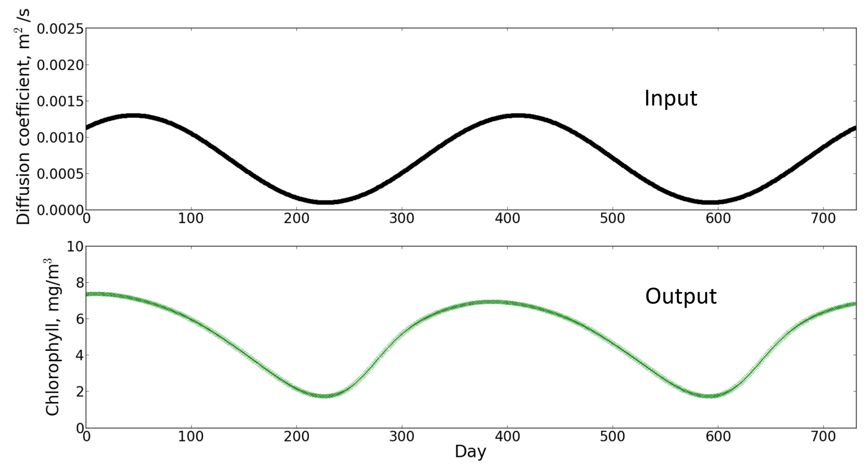

Figure 8. Input variation in the diffusion coefficient (top) and the resulting variation in chlorophyll (bottom).

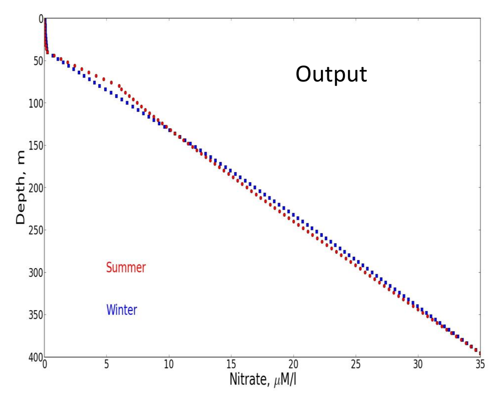

Figure 9. Solution for the seasonal variation in nitrate.

Using the seasonal variation in diffusion coefficient shown, the seasonal variation in chlorophyll and nitrate is obtained via numerical solution of the differential equation. The results are in the qualitative agreement with the observations.

Summary

Remotely-sensed chlorophyll and in situ measured nitrate and temperature are related via a diffusion equation. The diffusion coefficient is season dependent, being set to the measured value during the summer and a larger value to represent the mixing produced during winter storms. The solution agrees qualitatively with the measurements. In contrast to most of the California coast the ocean surrounding Santa Catalina behaves according to the classic description of phytoplankton spring blooms for temperate seas.