model. The GPs achieves this by switching from a 443/550 to a 520/550 band ratio, thereby avoiding the relatively lower and noisier 443/555 ratios when C exceeds ~1.5 μg L^{-1}. The GPs algorithm follows the well-known shift of the maximum of Rrs spectra toward higher wavelengths with increasing C. The strategy behind the GPs is sound and insightful, but the switching between power equations leads to the artifacts described above.

With this in mind, a strategy was devised to maximize model precision over the entire chlorophyll concentration range. The functional form of this algorithm, named ocean chlorophyll 4 (OC4), is a modified cubic polynomial relating a band ratio to C (Table 7). The significant departure from previous band ratio algorithms is that the band ratio is determined by whichever ratio, Rrs443/Rrs555, or Rrs490/Rrs555, or Rrs510/Rrs555, is greatest. Thus the OC4 maximum band ratio (MBR) model uses three-band ratios but only a single set of coefficients in a single MCP equation. Similar MBR models for three-band combinations are shown in Table 7.

After tuning to the SeaBAM data set, the OC4 model yields an R^2 of 0.932 and RMS of 0.156 (Figure 5, Table 8). Of the three-band ratios considered, Rrs443/Rrs555 was maximal from lowest C to values of ~0.3 μg L^{-1}; Rrs490/Rrs555 generally dominated between 0.3 and ~1.5 μg L^{-1}; and Rrs510/Rrs555 dominated when C exceeded ~1.5 μg L^{-1} (Figure 7 (top)). Note that the ranges of dominant band ratios overlap by ~10–30%, so there is a smooth transition from Rrs443/Rrs555 to Rrs490/Rrs555 to Rrs510/Rrs555 with decreasing band ratio (Figure 7 (bottom)). This overlap is a desirable property because it implies that discontinuities in frequency distributions of C estimated with OC4 are unlikely.

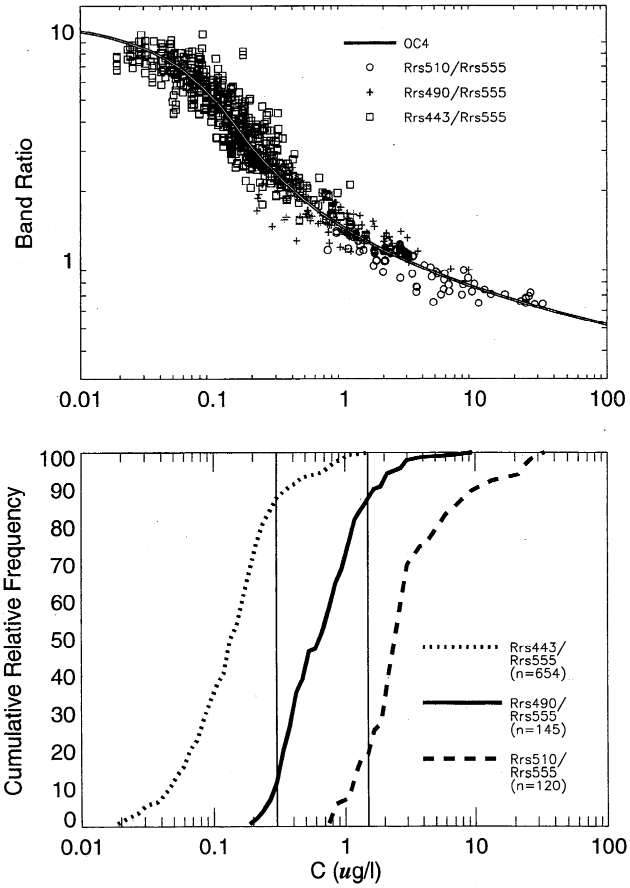

Figure 7. Ocean chlorophyll 4 algorithm. (top) In situ band ratio versus C. OC4 model is represented by curved line. The in situ data are represented by symbols indicating dominant band ratio. (bottom) Cumulative relative frequency distribution of maximum band ratios showing regions of dominance overlap between Rrs443 and Rrs490 and between Rrs490 and Rrs510 (vertical lines at 0.3 and 1.5 μg L^{-1}, respectively).

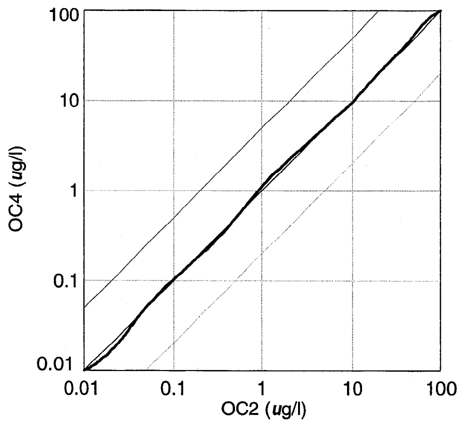

Figure 8. Comparisons between OC4 and OC2. Quantile-quantile plot using simulated radiance ratios with random noise added.

Possible discontinuities in the OC4 model were investigated by subjecting OC4 to a large, continuously varying population of simulated radiance ratios with random noise added. To simulate all band ratios involved in the OC4 model, a MCP equation was derived for each (Table 7), similar to the OC2 model. By inverting these equations it was then possible to generate values for all radiance ratios for any given chlorophyll concentration. Random noise was introduced as a function of C concentration and wavelength [*André and Morel*, 1991] so that several realistic band ratio combinations could be generated at each C concentration. OC2 served as a reference since it does not generate any discontinuities for C between 0.001 and 100 μg L^{-1}. If discontinuities were present, we would expect them to appear near C values of 0.3 μg L^{-1} and 1.5 μg L^{-1}, the general regions where dominant band ratios shift (Figure 7 (bottom)). The q-q comparison shown in Figure 8 indicates that no discontinuities were observed. While further tests are needed, these results indicate that discontinuities do not result from maximum band ratio models such as OC4 when ample overlap exists between adjacent dominant band ratios, as is the case for the SeaWiFS bands.

This maximum band ratio model is a new approach in empirical ocean color algorithms. It has the potential advantage of maintaining the highest possible satellite sensor signal:noise reflectance ratio over a broad range of C concentrations. This aspect is important for passive ocean color sensors aboard satellites since normalized water-leaving radiances retrieved for the 443 nm band, after atmospheric correction, may be quite low or below the sensor detection threshold in chlorophyll-rich coastal water or offshore phytoplankton blooms [*Gordon*, 1987]. The MBR model may also be a useful approach with sensors having many radiance bands (e.g., MODIS or hyperspectral data). MBR models such as OC4 might also be useful to define operationally three ocean realms with respect to trophic status: oligotrophic (<0.3 μg L^{-1}), mesotrophic (0.3–1.5 μg L^{-1}), and eutrophic (>1.5 μg L^{-1}), depending on