One of the more uncertain parameters in the model is the temperature coefficient for heterotrophic bacterial growth. As noted, reported $Q_{10}$ values for heterotrophic bacterial growth range between 2 and 4 [Hobbie and Cole, 1984; White et al., 1991]. By assuming the temperature coefficient for autotrophs and heterotrophic bacteria to be identical, we effectively assigned the heterotrophic bacteria a $Q_{10}$ of 1.9. In order to explore the implication of other possibilities, we reran the model with $Q_{10}$ of 4 for the heterotrophic bacteria, with the assumed $A_{9}$ at 0°C the same as in the standard model. The ef values and other system properties at 28°C (the most extreme case) were virtually identical at high production rates with this change. The principal change occurred at low production rates, where ef ratios were higher than in the standard model by 0.05-0.10.

Plate 1. Annual average of ratios calculated from the EP model. Net photosynthesis was estimated on a monthly basis as described in the text using data collected by the SeaWiFS satellite from October 1997 to September 1998.

Plate 2. Annual average ef ratios calculated using the TE model. Sea surface temperature (SST) fields were derived from monthly AVHRR global data as described in the text.
6. Implications for Global Change

It is hoped that the results presented here will be of use to those modeling the larger scale impacts of climate change on the productivity of the oceans. On the basis of the results in Figure 2, warming the surface waters of the ocean would be expected to decrease ef ratios in the more productive parts of the ocean and particularly in the temperature range 10-20°C. In relatively warm oligotrophic regions, ef ratios might actually increase, but under any conditions the ef ratios in such regions would be low, i.e., 0.10-0.15. An important concern is that warming of surface waters would restrict vertical circulation and reduce allochthonous nutrient inputs. Such a change might shift some systems across the transition from high to low ef ratio modes and dramatically reduce the export of organic carbon to the interior of the ocean.
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