INT. J. REMOTE SENSING, 2003, VOL. 24, NO. 5, 969–991

Comparison of global chlorophyll climatologies: *In situ*, CZCS, Blended *in situ*-CZCS and SeaWiFS

M. E. CONKRIGHT

Ocean Climate Laboratory, NOAA/National Oceanographic Data Center, E/OC5, Silver Spring, Maryland, 20910–3282, USA;
e-mail: mconkright@nodc.noaa.gov

W. W. GREGG

Laboratory for Hydrospheric Processes, NASA/Goddard Space Flight Center, Code 971, Greenbelt, Maryland, 20771, USA; email: gregg@cabin.gsfc.nasa.gov

(*Received 18 April 2001; in final form 9 October 2001*)

Abstract. Chlorophyll climatologies derived from historical *in situ* data, Coastal Zone Color Scanner data (CZCS) and SeaWiFS (Version 3) data were inter-compared to evaluate their strengths and weaknesses in representing chlorophyll distributions in the global ocean. A fourth dataset, produced by blending *in situ* data with CZCS data was compared to the other three. Systematic biases were associated with each of these datasets. *In situ* and CZCS data appeared to underestimate chlorophyll since the blended analysis produced generally elevated values. The underestimate by *in situ* data is related to problems mostly in the analysis of the data. CZCS underestimates are related to calibration and algorithm problems. The SeaWiFS data for the open ocean appears to be valid since its within 10% of the blended climatology for all seasons except winter. In the coastal ocean, SeaWiFS may overestimate chlorophyll with values 30–77% higher than the next closest climatology. Blending of *in situ* and satellite may produce the best climatology. This method takes advantage of the higher quality of *in situ* data, and the spatial variability of satellite sensor data. The blended method may be of greatest use for SeaWiFS in coastal areas, where the algorithm problems are greatest.

1. Introduction

What is the distribution of chlorophyll in the surface ocean? The concentration of chlorophyll *a*, (hereafter chlorophyll), the dominant photosynthetic pigment in phytoplankton, is widely used as a proxy for phytoplankton abundance and biomass (Strickland 1965). Accurate chlorophyll data are critical for determining the magnitude and variability of global ocean primary production, the effect of biological processes on carbon dioxide drawdown in surface waters and for improving our understanding of phytoplankton dynamics in the oceans.

There are three comprehensive global chlorophyll climatologies generally available: an *in situ* archive from 1957–1998 maintained by the National Oceanographic Data Center/ Ocean Climate Laboratory (NODC/OCL), the Coastal Zone Color Scanner (CZCS) dataset spanning the time period 1978–1986 and the Sea-Viewing Wide Field-of-view Sensor (SeaWiFS) dataset dating from 1997 to the present. The latter two datasets are maintained by the NASA/Goddard Space Flight Center (GSFC) Distributed Active Archive Center (DAAC). Conventional *in situ* chlorophyll methods (e.g. ships, buoys) typically provide high quality, accurate data but are limited in time and space due to the expense of sea operations and the large areal extent of the ocean. The CZCS provided repeat, albeit irregular, observations of global chlorophyll distributions (Feldman *et al.* 1989). After an 11 year gap, the SeaWiFS sensor was launched in 1997 and has provided routine estimates of global

International Journal of Remote Sensing
ISSN 0143-1161 print/ISSN 1366-5901 online
http://www.tandf.co.uk/journals
DOI: 10.1080/01431160110115573

chlorophyll distributions (McClain *et al*. 1998). Satellite ocean colour data, while providing incomparably high frequency temporal and spatial data, are subject to cloud obscuration and contamination by excessive sun glint and are generally considered inferior in quality compared to *in situ* data. A fourth dataset, produced by combining *in situ* data with CZCS data using the blended analysis of Reynolds (1988) has been developed for the CZCS era in an attempt to ameliorate some of the adverse effects of satellite sensor data while preserving its spatial variability (Gregg and Conkright 2001). The Ocean Color and Temperature Scanner (OCTS) data are not included here because of its short lifespan (9 months, from November 1996 to June 1997) nor are the Moderate Resolution Imaging Spectrometer (MODIS) data (launched December 1999).

This article compares seasonal surface chlorophyll climatologies derived from all available satellite ocean colour data (CZCS and SeaWiFS), *in situ* data (Conkright *et al*. 1998a), and the blended *in situ* and CZCS dataset (Gregg and Conkright 2001). Although these climatologies are based on different methods and cover different time periods, it is important to compare them. Accurate measurements of chlorophyll concentrations are crucial for global primary production models (Antoine *et al*. 1996, Behrenfield and Falkowski 1997, Iverson *et al*. 2000) which utilize chlorophyll as a primary independent variable. Accurate estimates can improve our knowledge of fluxes of CO_2 into and out of the oceans (e.g. Chavez *et al*. 1999). Ocean biogeochemical models use these various datasets to validate their results (Oschlies, 2000, Gregg 2001, Moore and Doney 2001). An evaluation of the problems associated with each data source, will yield greater understanding of the modeling results.

5. Conclusions

Currently, three sources of data are available for understanding the large scale seasonal distributions of chlorophyll in the surface ocean: historical *in situ* data (1955–1998), CZCS (1978–1986) and SeaWiFS (1997–2001). Additionally, blended CZCS and *in situ* data were compared. A comparison of chlorophyll distributions using these climatologies show that general seasonal and spatial patterns are in agreement: (1) high chlorophyll at high latitudes and coasts, low chlorophyll in mid-ocean gyres; (2) higher chlorophyll in the Northern Hemisphere compared to the Southern Hemisphere; and (3) higher chlorophyll in the Atlantic than in the Pacific Ocean. Major disagreements are observed in the magnitudes of chlorophyll concentrations for different regions and seasons. For most regions and seasons, SeaWiFS chlorophyll is highest, *in situ* chlorophyll is lowest; blended chlorophyll is intermediate between CZCS and SeaWiFS.

We are left with the question of which dataset best represents the surface distribution of chlorophyll. *In situ* and CZCS appear to underestimate chlorophyll as shown by the results of the blended analysis which increases the global and regional means. *In situ* data are limited by poor spatial resolution, and the method used to extrapolate into unsampled areas, appears to bias the analysis toward low values. CZCS data are impacted by calibration and algorithm problems which leads to an underestimate. Blended CZCS/*in situ* and SeaWiFS data appear to be reasonable representations of climatological global chlorophyll in the open ocean. Differences between these last two climatologies are $<10\%$ in every season except winter, when SeaWiFS was higher by 25%. Although SeaWiFS chlorophyll is always higher than the other datasets in the open ocean, the relatively small differences could be due to natural variability. SeaWiFS may overestimate coastal chlorophyll, with values 30%–77% higher than the next closest climatology. Blending of *in situ* and satellite sensor data, originally applied to correct biases in the satellite sensor data, may produce the best climatology. This method takes advantage of the higher quality of *in situ* data, and the spatial variability of satellite sensor data. It is only hindered by the sparseness of *in situ* chlorophyll data, and by the quality of satellite sensor data where no *in situ* observations are available. In the case of extreme *in situ* data sparseness, the blended set reverts to the satellite fields and thus acquires all of the biases associated with the satellite sensor data. The blended method may be of greatest use for SeaWiFS in coastal areas, where the algorithm problems are greatest and the *in situ* sampling frequency is also greatest.