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Effects of Whitecaps on Satellite-Derived Ocean Color

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Final Report

1. Summary of Accomplishments

During the 3.25 years of the project various aspects of satellite ocean-color remote sensing were investigated, including effect of whitecaps on atmospheric correction, validity of aerosol models, and evaluation of ocean-color products. Algorithms to estimate pigment concentration and photo-synthetically active radiation (PAR) were developed, and studies of geophysical phenomena, such as the 1998 Asian Dust event, were performed. The influence of solar radiation absorption by phytoplankton on mixed layer dynamics, ocean circulation, and climate was also investigated. The project's results and findings are described in the articles listed at the end of the report. The main results are summarized below.

1. The spectral optical properties of whitecaps, obtained by interpreting aircraft measurements over the open ocean (NASA AVIRIS and CNES push broom radiometer), appear to be fairly independent of environmental conditions, and in agreement with previous in situ observations (refs. 9 and 21). Consequently, for remote sensing applications, the spectral dependence of whitecap reflectance may be represented accurately by a unique formula. This simplifies greatly the correction of whitecap effects in atmospheric correction algorithms.

2. Whitecaps were found to exert a cooling influence on the planet by increasing surface albedo (ref. 19). The direct, globally averaged radiative forcing due to whitecaps was estimated to lie in the range 0-14 Wm^{-2} with a probable value of 0.03 Wm^{-2}. Though small, this global value is not negligible compared with the forcing due to some greenhouse gases and anthropogenic aerosols since pre-industrial times. Values reach 0.7 Wm^{-2} in the Indian Ocean during summer, indicating a potentially larger importance of whitecaps on regional and seasonal scales. Whitecap effects on surface albedo should be taken into account explicitly in the modeling and analysis of climate change.

3. Multi-layered perceptrons were educated to retrieve phytoplankton pigment concentration from SeaWiFS-derived marine reflectance at 412, 443, 490, 510, and 555 nm (refs. 7 and 14). Learning and testing of the perceptrons was accomplished using synthetic reflectance data, to which was added realistic atmospheric correction and radiometric noise. The perceptrons approximate well the complex, non-linear function between marine reflectance and pigment concentration; they are also able to filter noise efficiently. Compared with standard blue-green ratio algorithms, perceptrons provide much better results. The effect of atmospheric correction errors is reduced by a factor of 4-5.

4. A simple, yet efficient algorithm was developed to estimate PAR at the ocean surface from SeaWiFS data (ref. 13). The algorithm utilizes plane-parallel radiation theory and separates the effects of the clear atmosphere and clouds. PAR is computed as the difference between the 400-700 nm solar energy fluxes incident at the top of the atmosphere (known) and reflected back to space by the atmosphere (derived from

SeaWiFS radiance), taking into account atmospheric absorption. Knowledge of pixel composition is not required, eliminating the need for cloud screening and arbitrary assumptions about sub-pixel cloudiness. For each SeaWiFS pixel, clear or cloudy, a daily PAR estimate is obtained. The unknown diurnal variability of the atmosphere, especially clouds, is neglected. The algorithm results were verified against satellite measurements from ISCCP and in situ measurements from fixed buoys in the equatorial Pacific Ocean and the Georgia Strait, Canada. Agreement between the ISCCP and SeaWiFS estimates was generally good, with root-mean-squared differences of 13.6 (32.6%), 5.7 (13.4%), and 3.6 (8.4%) on daily, weekly, and monthly time scales, and small biases. The comparison with buoy data also showed good agreement, with respective inaccuracies of 6.2 (15.0%), 3.7 (9.1%) , and 3.3 (8.1%) $Em^{-2}d^{-1}$ when data from the two buoys were combined (1387 daily values). The good statistical performance, even on a daily time scale, makes the algorithm suitable for large-scale studies of aquatic photosynthesis. In fact, the algorithm was used in a major study of biospheric primary production during an El Niño/La Niña transition (ref. 18).

5. Numerical experiments were conducted with a general circulation model to investigate the effect of solar radiation absorption by phytoplankton on sea surface temperature (SST). The vertical profile of heating rate was parameterized as a function of phytoplankton pigment concentration, specified in space and time from satellite ocean color imagery. The dynamic model was run without and with phytoplankton radiation forcing (control and anomaly runs, respectively), and the difference between anomaly and control runs yielded the biological effect. Due to phytoplankton the annual amplitude of SST increases by 0.5 to 1 K in most of the oceans, with positive anomalies during summer and negative anomalies during winter (ref. 16). The effect is enhanced in regions of shallow mixed layer (e.g., sub-tropical gyres, Mediterranean Sea). Persistent negative anomalies reaching 2.5 K are obtained in the eastern equatorial Pacific, and are explained by a shoaling of the isotherms toward the equator, anomalous geostrophic currents north and south of the equator, and a strengthening of the equatorial undercurrent (refs. 16 and 17). The SST response to the large pigment concentration increase in the Arabian Sea during fall is dampened by reduced incoming solar radiation (refs. 15 and 16). On a global and annual scale, SST is higher by 0.04 K (0.07 in the Northern Hemisphere and 0.02 K in the Southern Hemisphere). The resulting impact on climate, locally and remotely, is expected to be significant.

6. It was shown that phytoplankton may exert a significant warming influence on the planet, not only by redistributing heat in the upper ocean, but by decreasing surface albedo (ref. 25). Compared with the case of pure seawater, the globally and annually averaged outgoing radiative flux is decreased by a probable value of 0.25 Wm^{-2}. This value corresponds to about 20% of the net radiative forcing by greenhouse gases and anthropogenic aerosols since pre-industrial times, including indirect effects. The relative importance of phytoplankton is greater on regional and seasonal scales, with forcing values reaching -1.5 Wm^{-2} in coastal zones and high latitudes during summer. Spatial and temporal variability of the forcing is however affected by phytoplankton

type, some reflective species increasing the outgoing radiative flux. An increase in phytoplankton abundance associated with enhanced (e.g., artificial) biological pumping of atmospheric carbon dioxide might not decrease global warming as much as expected (due to increased heating of the upper ocean).

2. Publications supported by NASA Grant NAG5-6202

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