AXBT data on the flights and Robert Barthelmes and the pilots and crews of VX-20 at Patuxent Naval Air Station for getting us in the air on P-3 774.

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Integrating the Marine Biosphere into Coupled Ocean–Atmosphere Models

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Introduction: Marine phytoplankton are vital to the functioning of Earth's biosphere. Whereas these ubiquitous microscopic organisms account for only ~1% of the Earth's photosynthetic biomass, they contribute to more than half of the global primary production. This fecund productivity forms the foundation for the marine food web and it is the requisite engine of biogeochemical cycling that enables life on Earth to flourish. Phytoplankton thrive precisely where atmospheric and oceanic planetary boundary layers meet. Exchanges of thermal energy and transfers of momentum impact the physical environment with which planktonic organisms must cope. Biological oceanography has thus been largely concerned with identifying how the physics of the ocean–atmosphere system determine microalgal prolificacy via turbulent mixing and the upwelling of deep ocean nutrients in zones of wind-forced hydrodynamic divergence.

Recently, however, numerical modeling studies[1,2] have revitalized a long dormant paradigm in oceanography: phytoplankton and associated organic detritus absorb a significant quantity of the Sun's radiant energy and this additional energy may have a net warming effect on the surface ocean, thereby impacting density gradients. Thus, phytoplankton are not merely passive recipients of the ocean's physical dynamics, they are instead active participants in those dynamics.

Integrated Modeling of the Maritime Battlespace Environment: Motivated by these findings, we have integrated a model of biochemical nitrogen cycling and attendant bio-optical dynamics into NRL's state-of-the-art Coupled Ocean–Atmosphere Mesoscale Prediction System (COAMPS®). This numerical forecasting system includes atmospheric and oceanic components that exchange information regarding transfers of heat and momentum at very high temporal frequency, such that the atmospheric and oceanic density fields develop concomitantly. We use the term "integrate" to emphasize that the surface biota absorb substantial quantities of solar shortwave energy that is accounted for in the modeling system (Fig. 9). Since it is the ocean biology that is driving this additional near-surface retention of thermal energy, we refer to this process as biothermal feedback.

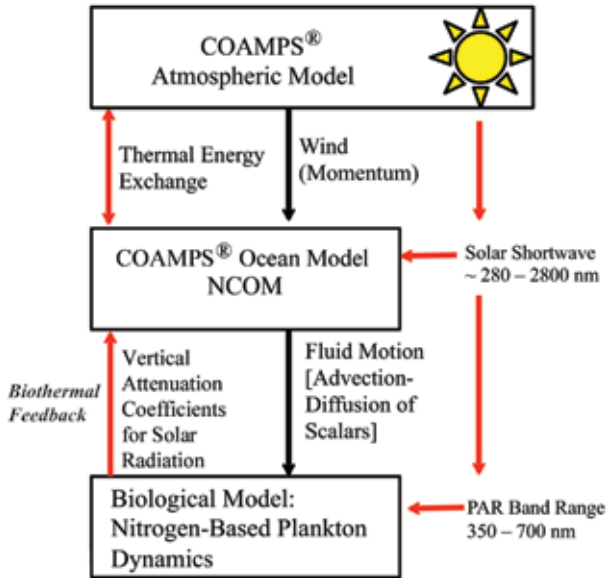

FIGURE 9
Schematic representation of COAMPS is shown with the integrated biological model using the photosynthetically available radiation (PAR) band fraction of the COAMPS solar shortwave and providing the Navy Coastal Ocean Model (NCOM) with the required optical attenuation coefficients.

Indeed, the integrated COAMPS–biology modeling results verify that biothermal feedback may influence the thermal variability of geophysical boundary layer fluids. A simulated phytoplankton bloom develops in northern Monterey Bay (Fig. 10(a)) as a result of coastal upwelling. In contrast to COAMPS simulations wherein no biothermal feedback is represented, the bio-optical properties of phytoplankton provide an additional ~1–2 °C of surface warming to the area (Fig. 10(b)). Elevated sea surface temperatures (SSTs) increase simulated latent heat flux transfers, resulting in a warmer, moister marine atmospheric boundary layer (MABL). The surface warming also increases the upper ocean thermal stratification. Since it is light rather than nitrogen that is most limiting to microalgal growth within this regime, improved vertical stability increases the photosynthetic yield by ~20%. Hence, the simulated thermal and biological fields evolve synergistically in time.

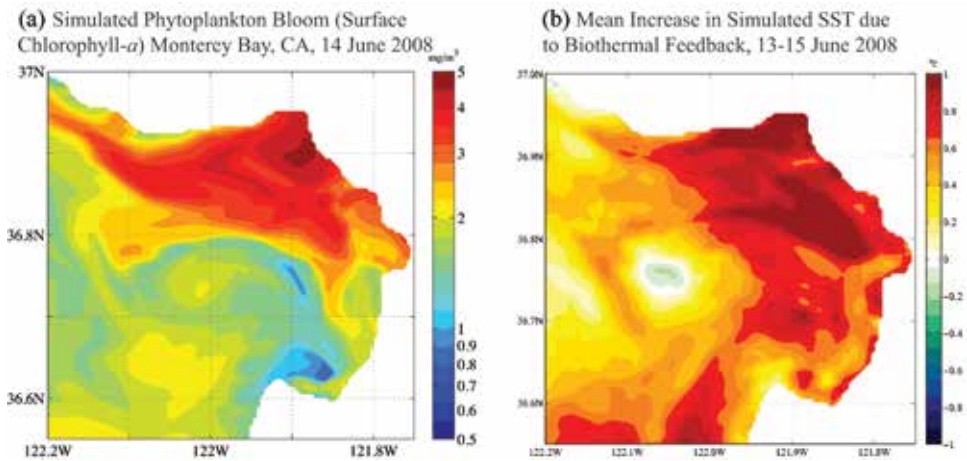

FIGURE 10
(a) The COAMPS simulated phytoplankton bloom in northern Monterey Bay, California, is shown for June 14, 2008; (b) the difference in mean SST between COAMPS with biology and COAMPS without (i.e., no biothermal feedback) is shown.

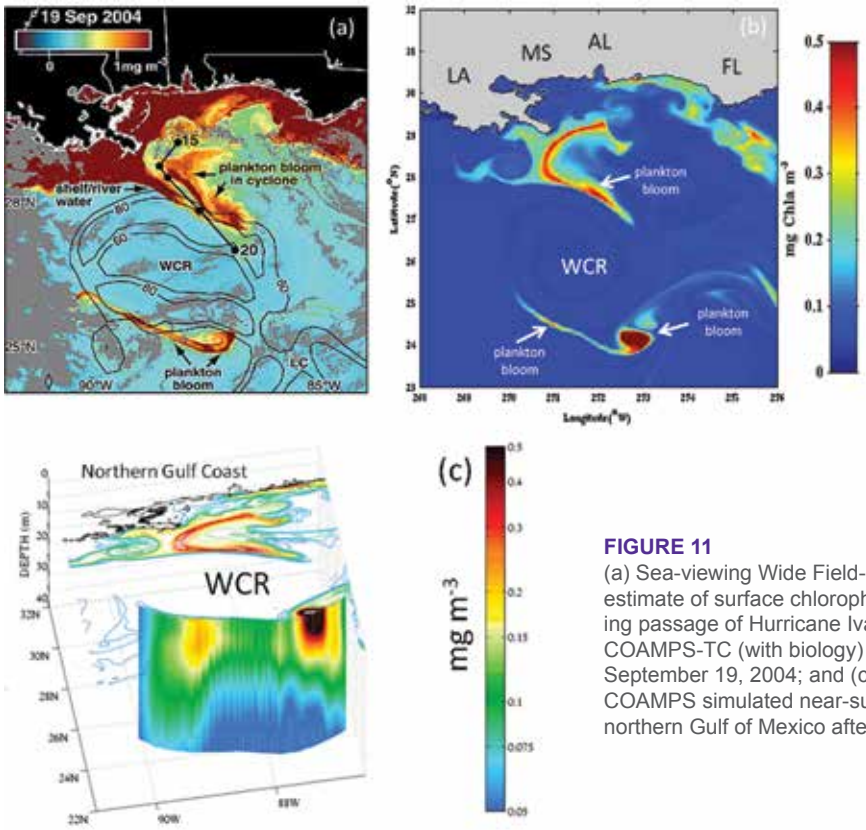

FIGURE 11
(a) Sea-viewing Wide Field-of-View Sensor (SeaWiFS) satellite estimate of surface chlorophyll-a distribution is shown following passage of Hurricane Ivan in the northern Gulf of Mexico; (b) COAMPS-TC (with biology) simulated chlorophyll-a distribution for September 19, 2004; and (c) three-dimensional rendering of the COAMPS simulated near-surface phytoplankton distributions in the northern Gulf of Mexico after the passage of Hurricane Ivan.

These results verify that the integrated modeling approach has a direct impact on aspects of environmental forecasting pertinent to U.S. Naval operations. Surface ocean bio-optical properties will impact the performance of electro-optical detection systems used for mine warfare operations. Changing conditions within the MABL will impact other operationally pertinent variables such as humidity, surface visibility, and electromagnetic radiation propagation.

New Research Opportunities: Integrating the marine biosphere into COAMPS also provides for novel research opportunities. For example, COAMPS-Tropical Cyclone (COAMPS-TC[3]) is NRL's integrated

air–ocean–wave modeling system that provides a means to simulate the intense air–sea interactions and the dynamical surface wave–current interactions that are endemic to tropical cyclones. Another consequence of cyclone passage is the disturbance of the upper ocean planktonic ecosystem due to the intense turbulent motions of fluid parcels. Embedding a biological model into COAMPS-TC allows for an examination of these potential bio-optical interactions.

Hurricane Ivan traversed the northern Gulf of Mexico on September 16, 2004, directly perturbing the dynamical mesoscale surface ocean circulation. COAMPS-TC with biology simulates the resulting uplift of deeper water isotherms and the associated introduction of new nutrients into the surface mixed layer. These nutrients stimulated biological productivity that was detected in satellite radiometer data (Fig. 11(a)). The simulated biophysical processes mimic the observations (Fig. 11(b)). Phytoplankton blooms emerge in the centroid of mesoscale cyclones flanking the larger anticyclonic feature (a warm-core ring, WCR). The fidelity of COAMPS-TC to satellite observations provides a unique opportunity to examine the synoptic time evolution of the three-dimensional ocean's integrated biophysical phenomena (Fig. 11(c)).

Summary: Collectively, these results suggest that the continuing development of an Earth systems prediction capability, with applications ranging from operational forecasts for U.S. Naval operations to long-term climate simulations, must consider the synergistic interaction between the Earth's biosphere, atmosphere, and oceans. NRL is uniquely poised to advance numerical modeling of integrated biological-physical systems in ways that improve environmental forecasting tools and expand scientific understanding of complex oceanographic phenomena.

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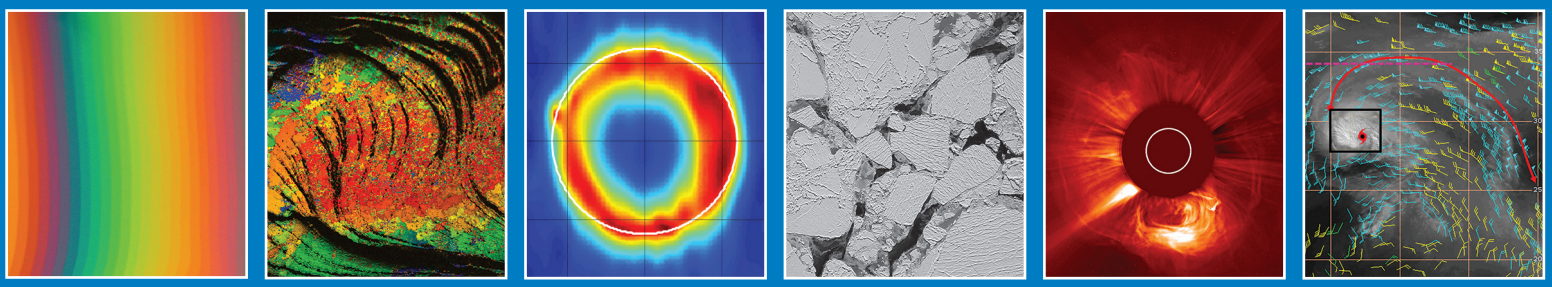

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