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Three years of ocean data from a bio-optical profiling float

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Three Years of Ocean Data From a Bio-optical Profiling Float

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Ocean color, first measured from space 30 years ago, has provided a revolutionary synoptic view of near-surface fields of phytoplankton pigments. Since 1979, a number of ocean color satellite missions have provided coverage of phytoplankton biomass and other biogeochemical variables on scales of days to years and of kilometers to ocean basin.

Because of the nature of visible light and its interaction with absorbing and scattering materials in the ocean and atmosphere, these measurements are biased toward near-surface waters and are obscured by clouds. As a consequence, ocean color satellites miss significant fractions of phytoplankton biomass, marine primary productivity, and particle flux that occur at depths beyond their sensing range. They also miss phytoplankton blooms and other events that occur during periods of extended cloud cover.

A new approach to mitigating these limitations, based on merging data from in-water autonomous sensing of optical properties with satellite ocean color, has been demonstrated with a pilot project in the Labrador Sea in the North Atlantic Ocean. In-water measurements of chlorophyll *a* fluorescence (a proxy for phytoplankton concentration) and particulate optical scattering (a proxy for particle concentration) were measured on a float that profiles the water column from a 1000-meter depth to the surface, similar to floats used in the global Argo ocean observation program (http://www.argo.ucsd.edu).

A Webb Research Corporation Apex float has been roving the North Atlantic for more than 3 years and has measured 221 profiles of optical and physical (temperature and conductivity) properties, measuring one profile every 5 days (Figure 1; float data can be downloaded from http://misclab.umeoce.maine.edu/research/research03_data.php). The Apex float combines commercially available technology (circa 2004) including a WET Labs miniaturized optical sensor that measures both chlorophyll fluorescence and particle side scattering; a conductivity-temperature-depth (CTD) profiler and a novel auxiliary board to integrate sensors, both from Sea-Bird Electronics, Inc.; and long-lasting lithium batteries. Limitations inherent to the methods (e.g., variable relationships between chlorophyll fluorescence and chlorophyll concentration, and between optical side scattering and backscattering) result in a relative uncertainty of the order of ±50% in chlorophyll and backscattering with a minimal absolute uncertainty of ±0.03 milligrams per cubic meter for chlorophyll and 3×10^{-4} per meter for particulate backscattering. While these uncertainties may seem large, they are much smaller than the observed range in these properties in our study (0–3 milligrams per cubic meter for chlorophyll, $2–20 \times 10^{-3}$ per meter for backscattering).

Averaged over one spatial decorrelation scale (the scale over which concurrent but spatially separated measurements are significantly correlated, here 7.5-kilometer radius) around the Apex float's surfacing location, surface optical properties show good agreement with ocean color–derived optical properties from the Moderate Resolution Imaging Spectroradiometer (MODIS)

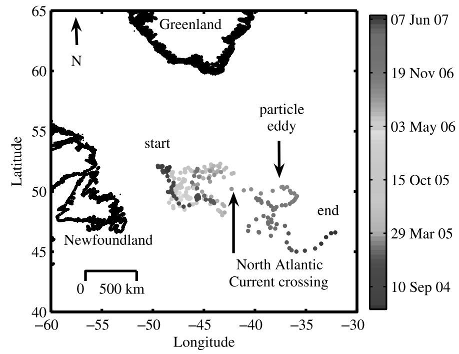

Fig. 1. Trajectory of bio-optical Apex float 0005. Original color image appears at the back of this volume.

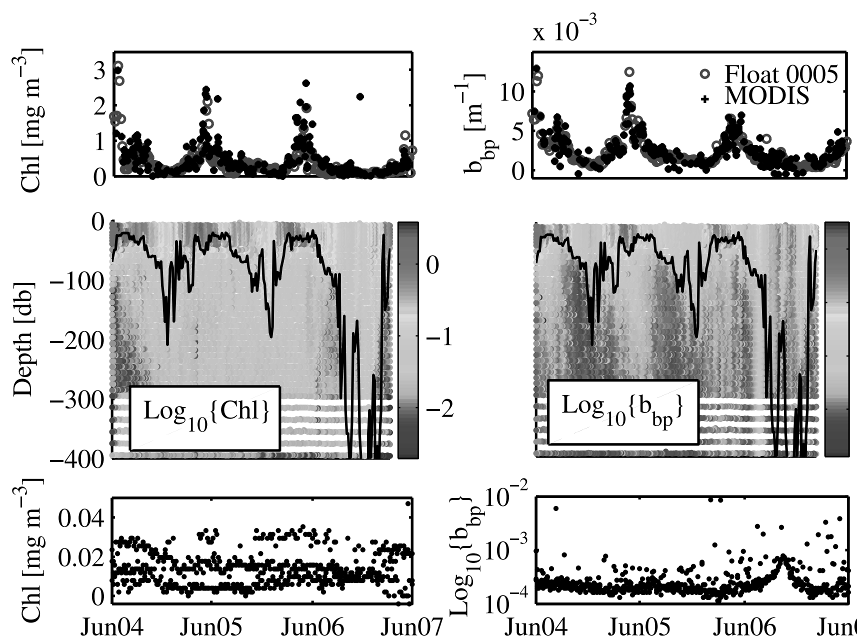

Fig. 2. Time series of (left) chlorophyll concentration and (right) particulate backscattering coefficient. (top panels) Near-surface float and Moderate Resolution Imaging Spectroradiometer Aqua satellite data, (middle panels) midwater column float data, and (bottom panels) float data below 950 meters (note log scale for particle backscattering). For satellite chlorophyll concentration and backscattering coefficient, we use NASA's inversion products OC3 and GSM, respectively (http://oceancolor.gsfc.nasa.gov/DOCS/MSL12/MSl12_prod.html). Original color image appears at the back of this volume.

on board NASA's Aqua satellite (Figure 2, top panels); correlation with chlorophyll (NASA OC3 chlorophyll algorithm, correlation coefficient (R) = 0.88) and backscattering (GSM backscattering algorithm, (R) = 0.9; see http://oceancolor.gsfc.nasa.gov/DOCS/MSL12/MSl12_prod.html for algorithm details) are high. No noticeable trend is observed in the optical measurements below 950 meters (Figure 2, bottom panels). However, a significant elevation of subsurface backscattering at all depths is observed in November 2006 (Figure 2, middle panels), associated with the crossing of a particle-laden anticyclonic eddy observed in altimeter data (not shown). Such subsurface features, although they may have significant biogeochemical implications, cannot be resolved by ocean color observations from space; in the clearest of ocean waters, satellite measurements are limited to depths of only tens of meters.

The success of this Apex float and six other similar floats currently profiling the Pacific Ocean could lead to the design, testing, and implementation of an array of more sophisticated floats to provide critical data on biogeochemical properties, the biomass of key ecosystem variables, and temporal changes in these variables. Profiling floats could revolutionize biogeochemical modeling by providing data that satellites cannot, and for a small cost (total cost of this expandable float's components and telemetry was approximately $25,000).

Given technological advances in sensor technology, we envision the deployment of an array of floats that in addition to phytoplankton and particulate concentration, are capable of measuring parameters constraining nutrients, zooplankton, spectral radiance or irradiance, colored dissolved organic material, and oxygen. Previous biogeochemical investigations with profiling floats included measurements of beam attenuation, irradiance, and oxygen (e.g., *Bishop et al.* [2002], *Mitchell et al.* [2000], and *Riser and Johnson* [2007], respectively).

The International Ocean-Color Coordinating Group recently has assembled a scientific working group to coordinate and recommend future programs and desired protocols associated with bio-optical profiling floats (see http://www.ioccg.org/groups/argo.html). Such multifloat programs would provide data to validate satellite ocean color measurements and derived biogeochemical products. In addition, the depth-resolved, colocated physical and biogeochemical data, in conjunction with ocean color, could initialize and constrain (via assimilation and comparison) nutrient-phytoplankton-zooplankton models, which are the cornerstones of ocean ecosystem modeling.

Acknowledgment

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Alaska's Pavlof Volcano Ends 11-Year Repose

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After an 11-year period of repose, Pavlof volcano on the Alaska Peninsula (Figure 1) began an episode of Strombolian eruption lasting 31 days, from 14 August to 13 September 2007.

The eruption began abruptly on 14 August after a minor increase in seismicity the previous day. Nearly continuous lava fountaining, explosions, and lahars caused by minor disruption of the ice and snow cover on the volcano characterized the eruption. The eruption also produced diffuse ash plumes that reached 5–6 kilometers above sea level, but the plumes were too small and did not extend high enough to affect local or regional air travel. Melting of snow and ice on the upper part of the edifice by hot debris avalanches and lava resulted in numerous lahars that entered the sea and inundated a 2×10^6 square meter area on the volcano's southern slope.

The volcano is a symmetrical, snow- and ice-mantled stratocone, 2518 meters high, located near the Izembek National Wildlife Refuge and 60 kilometers northeast of the city of Cold Bay. Pavlof, the most frequently active volcano in the Aleutian arc and one of the most active volcanoes in North America, has erupted at least 40 times since 1762. These events have been mostly moderate Strombolian eruptions (Volcanic Explosivity Index 2–3) with lava fountaining, spatter-fed lava flows, lahars, and minor ash production. The location of the vent has fluctuated between the north and south sides of the summit, and occasionally activity occurs from multiple summit vents. The location of the summit vent determines which side of the volcano is affected by lava flows and lahars.

Explosive bursts that have occurred during several historical eruptions (including those in 1906, 1950, 1973, 1975, 1980, 1981, 1983, and 1986) have produced ash plumes reaching altitudes of up to 15 kilometers and fallout up to 1 centimeter thick on nearby communities. The volcano's high frequency of eruptions, often with rapid onset, and the possibility of ash plumes entering the airspace of planes traveling North Pacific air routes (200–300 aircraft fly those routes daily, as well as regional aircraft serving local communities) make Pavlof particularly hazardous to aviation.

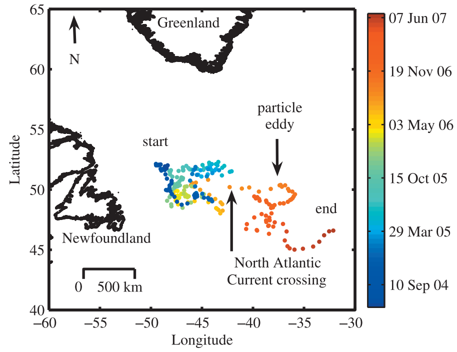
Pavlof has been seismically monitored since 1973, and much of the information about the volcano's eruptions since then has been interpreted from seismic data supplemented with satellite and visual observations and with intermittent field studies from 1986 to 2007. Here we provide an overview of Pavlof's most recent eruption and report observations made during visits to the volcano in August and September 2007.

Description of 2007 Activity

Throughout the summer of 2007, occasional clear views of Pavlof indicated nothing unusual. The volcano was seismically quiet in early August, and occasional small earthquakes (magnitude of 1 or less) at that time were within the range of normal background activity for Pavlof. On 14 August, the rate of small, low-frequency earthquakes increased to two to seven events per 10 minutes, whereas the day before there had been no noticeable difference in seismicity relative to background levels. The change in seismic activity prompted the Alaska Volcano Observatory (AVO) to raise the volcano alert level and color code to Advisory/Yellow on 14 August, although clear satellite views of the summit that morning indicated nothing unusual was occurring.

During the night of 14–15 August, a strong thermal anomaly was detected in advanced very high resolution radiometer (AVHRR) satellite imagery, accompanied by an increasing number of low-frequency earthquakes and tremor bursts observed on the five seismic stations that surround Pavlof. Individual discrete earthquakes and bursts of tremor lasting about 1 minute were common on 14–15 August. By midday on 15 August, AVO had received from people in the area reports of incandescent blocks on the eastern-southeastern flank of the volcano seen the night before and of a diffuse ash plume extending 3 kilometers southwest from the summit.

The change in seismicity, eyewitness reports, and a distinct thermal anomaly in the summit area left little doubt that the volcano had begun its first eruption of the 21st century. On 15 August, AVO again raised its alert level and color code, this time to Watch/Orange, where it remained until 20 September. While at this level of alert, in



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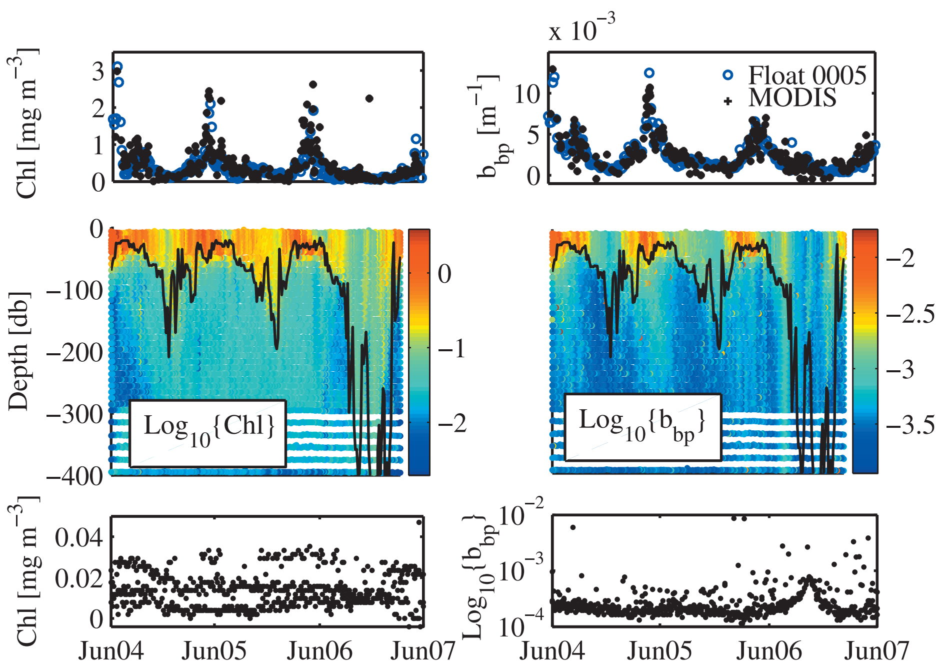

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