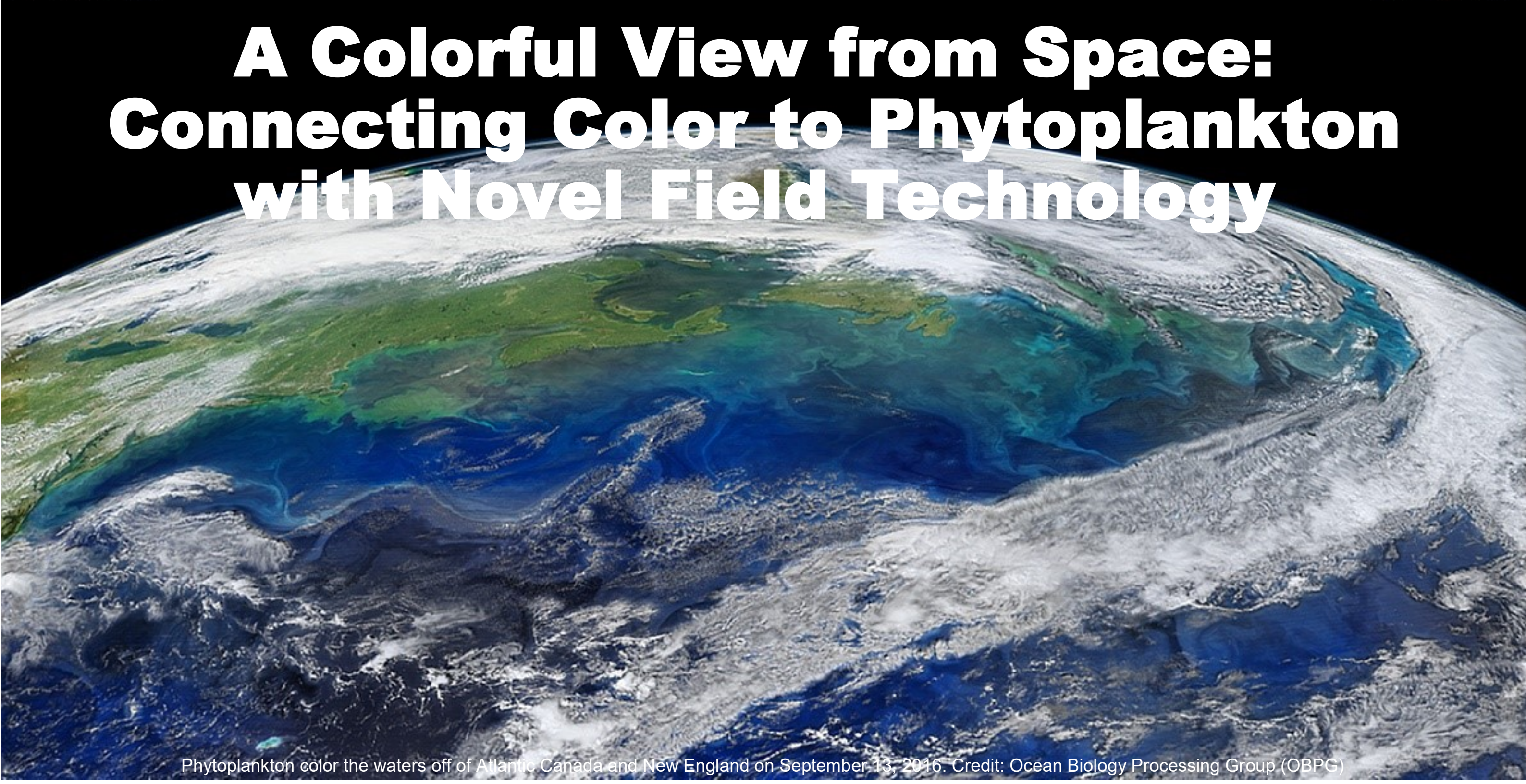
A Colorful View from Space: Connecting Color to Phytoplankton with Novel Field Technology



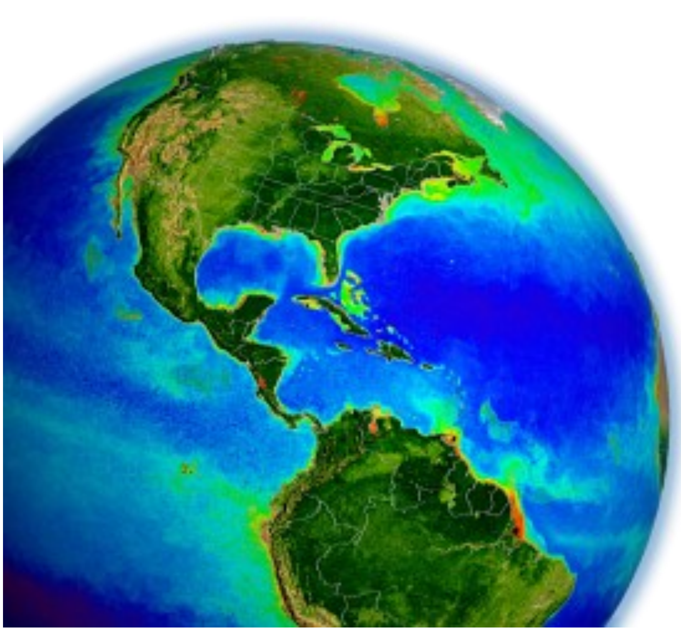
Phytoplankton color the waters off of Atlantic Canada and New England on September 13, 2016. Credit: Ocean Biology Processing Group (OBPG)

An ever-changing patchwork of blues and greens, the sea is a colorful blend of suspended particles and the pigments of phytoplankton. While microscopic in size, these tiny ocean-dwelling plants influence climate and the atmosphere and form the base of the marine food web. Satellite-based ocean color imagery captures the vibrant world of phytoplankton and their relationship with the marine environment. As we enter the human-influenced age, our footprint on the variegated ocean can be seen from land and space as shifting climates, pollution, and excess nutrients cause changes within planktonic communities and impact the surrounding ecosystem. The arrival of new high-resolution field technology opens the door to the next generation of satellite-based sensors which help scientists understand how these organisms are responding to the changing climate and what this means for the health of our oceans.

The color of light that is scattered back out of the sea can be used to derive information about what is in the water column, including the type and abundance of phytoplankton. The detection and tracking of Harmful Algal Blooms (HAB), as well as mapping of ecological boundaries for implementing management approaches for sustainable fisheries, are just two of the many benefits of ocean color imagery. Due to the vast expanse of water covering 70% of the Earth's surface, scientist's efforts to collect data are limited in both time and space. For this reason, satellite-based observations are important in providing a global view of biological activity and monitoring how the hues of the ocean change over time.

As part of the NASA Goddard Space Flight Center, the Ocean Ecology Laboratory Field Group uses information collected at sea to validate data gathered from satellites. Research cruises obtain accurate optical, biological and biogeochemical data. *In situ* radiometers measure ocean color and allow scientists to compare the results to images from space.

Aimee Neeley, a lead research scientist at NASA's Ocean Ecology Laboratory Field Group, explains, "Out in the field, oceanographers typically sample from specific, pre-planned locations called 'Stations.' At these stations, we send instruments into the water column to measure various parameters such as salinity, temperature, and optical signatures at multiple depths, sometimes up to thousands of meters. Because we are limited by ship time, man power and money, we cannot



On September 20, 1997 SeaWiFS collected its first complete day's worth of ocean color data. Ten years later it continues to collect the data that have greatly enhanced our knowledge of the ecology of Earth's oceans. Credit: Ocean Biology Processing Group (OBPG)

The Bering and Chukchi seas was captured by VIIRS on August 30, 2016.
Credit: Ocean Biology Processing Group (OBPG)

sample every single meter of the ocean. So, we rely on the satellites to give us an accurate global picture and use the data collected out in the field to make sure the satellite data matches the field data as much as possible. We call this ground-truthing."

Prof. Joaquim Goes, a biological oceanographer from Columbia University Earth Observatory, researches the effects of climate change on ocean ecosystems. His work extends across the world's ocean basins from the Pacific to the Atlantic and the Indian Ocean. For most of his research, he relies on ocean color images to understand how climate change influences the structure and functioning of plankton ecosystems, driving local- and basin-scale biological oceanographic processes.

In 2005, Goes began studying the effects of the monsoons on phytoplankton within the Arabian Sea, "We noticed that through these ocean color images, that chlorophyll had increased by 3-fold. We went back to try to find out what caused this and connected it to the melting snow caps in the Himalayas region. The snow caps were getting thinner, and their extent was shrinking because of which, the intensity of the monsoons had increased, causing increased upwelling of nutrients required by phytoplankton. From these ocean color images, we predicted that the Arabian Sea would slowly become hypoxic over time, and that's what we have been observing now. It was here that working with the FlowCam© started to interest me."

Goes and his team needed technology to assist with onboard analysis to make quick and easy measurements of water samples. During one of the cruises to the Arabian Sea, the team operated FlowCam - a particle analysis instrument from Fluid Imaging Technologies using digital imaging to measure particle size and shape of plankton cells - taking discreet samples at each survey location. Measuring some 40 parameters within each image, the plankton community of a sample can be quickly assessed.

The team was able to identify the organism causing the blooms and, within minutes, could see its total contribution to the overall plankton population. "The uses of traditional microscopes would have taken a lot more time - you would have had to get the samples back to the ships laboratory and examine them under the microscope. Microscopy in itself is a time-consuming process and trying to build information of this community structure requires additional effort. Having a FlowCam onboard made it so much easier to tell in almost near-real time, what is in the water and what oceanographic features this community is associated with."

"About two years ago, after one of these Arabian Sea cruises, I was invited on a cruise organized by NOAA. I told Fluid Imaging Technologies that if their FlowCam instrument was operating in a flow-through mode, we wouldn't have to take discrete samples [which misses huge volumes of data between stations] but instead have the FlowCam take samples continuously at very high resolution. I used this new system on a recent cruise off the coast of South Carolina and North Carolina."

This region of the North Atlantic comes under the influence of the Gulf Stream which interacts with the coastal waters of the South and North Carolina, leading to upwelling of deeper, nutrient-rich water. The area is of particular interest to researchers because it is populated with complex physical oceanographic features, such as the formation of meanders, shingles, and filamentous structures, which are formed due to the interaction of the saltier Gulf Stream with fresher coastal waters. During

"The FlowCam opens that avenue for looking at phytoplankton functional types using ocean color data"

Harry Nelson of Fluid Imaging Technologies and Dr. Jeffrey Runge from the Gulf of Maine Institute, using a FlowCam system during the GOMCES 2016 Cruise. Credit: Fluid Imaging Technologies Inc.

the cruise, Goes was able to transect across these complex physical features using the new system and observe changes in the color based on optical instrumentation. For the first time, they could see how changes in the optical properties of seawater were influenced, to a great degree, by the kind of phytoplankton in the water.

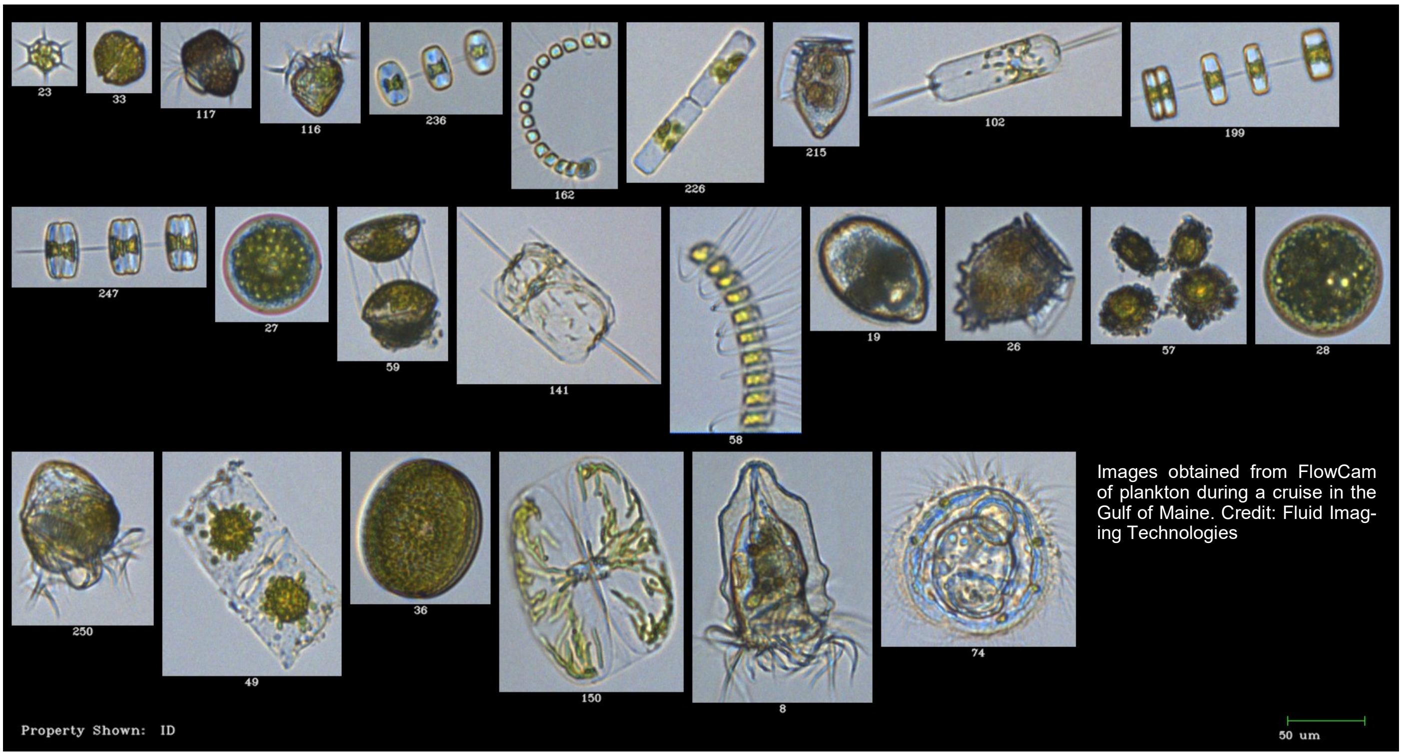
"It wouldn't have been possible to describe these high resolution changes, if it wasn't for the FlowCam operating in this flow-through mode. If we came across some unusual communities of phytoplankton, we could immediately examine whether it was related to a feature in the satellite sea surface temperature or the ocean color images. This also made it easier to infer how different communities influenced the color of the sea. And so, regarding ocean color research, it is really a big step forward. The problem in the past has been that, although you have high-resolution ocean color images, you didn't have enough datasets of phytoplankton to understand how they influenced ocean color properties in the water column. The FlowCam opens that avenue for looking at phytoplankton functional types using ocean color data. And this is one of NASA biggest goals in the next strategic plan."

Scientists strive to increase observations across both time and space beyond what is currently possible. In order to link environmental drivers to plankton species composition and ecosystem function, efforts are being made to understand spectral variations in the light field to develop algorithms which identify phytoplankton groups using ocean color.

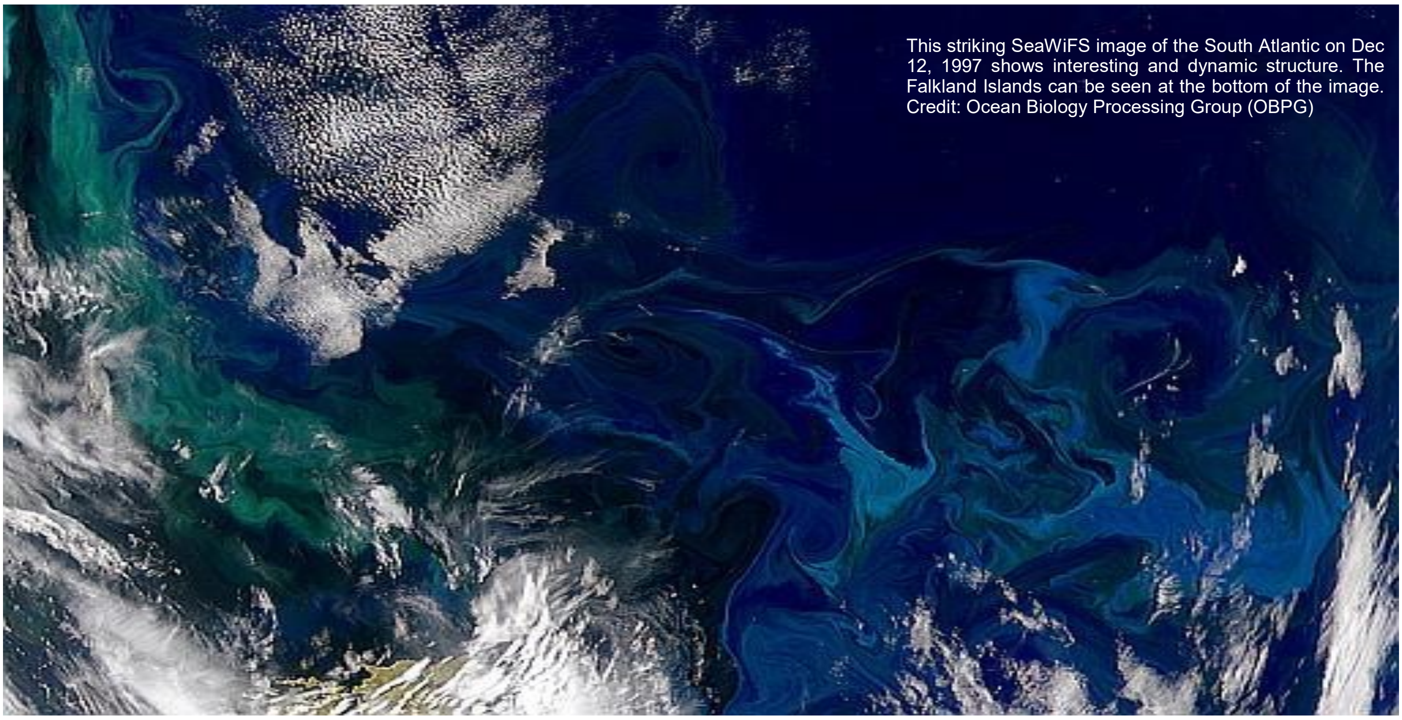
As part of this endeavor, NASA is looking to launch the next generation of hyperspectral ocean color sensors for satellites. Hyperspectral imaging can capture the spectrum for each pixel in an image, with the purpose of finding objects, identifying materials, or detecting processes. The next NASA satellite mission, PACE (Plankton, Aerosols, Cloud, ocean Ecosystems), aims to deliver the most comprehensive look at global ocean color measurements in NASA's history. Unlike its predecessors, this satellite will be able to make hyperspectral measurements beyond which the human eye could naturally see.

"For the first time, FlowCam technology allows us to achieve high-resolution maps of phytoplankton that can be related to satellite data in more meaningful ways than possible before."

Neeley explains, "PACE is a mission that will include the first satellite ocean color instrument to combine high-resolution global coverage with an extended spectral range to the ultraviolet wavelengths. The ocean color instrument is also being designed at hyperspectral resolution, making the PACE mission truly unique. The advantage of this finer spectral resolution will be large amounts of information in the visible spectrum from which we'll be able to detect different phytoplankton groups that were not previously distinguishable in ocean



Images obtained from FlowCam of plankton during a cruise in the Gulf of Maine. Credit: Fluid Imaging Technologies



This striking SeaWiFS image of the South Atlantic on Dec 12, 1997 shows interesting and dynamic structure. The Falkland Islands can be seen at the bottom of the image. Credit: Ocean Biology Processing Group (OBPG)

“Advancing this ground-truthing technology is vital to the advancement of satellite technology.”

color imagery. Many applications are expected from PACE, such as the improvement of HAB detection and forecasting as well as mapping of ecological boundaries, such as upwelling regions and eddies that can influence the entire food chain from the phytoplankton, the base of the food chain, up to the fish and whales."

Another NASA satellite, the GEOstationary Coastal and Air Pollution Events (GEO-CAPE), will be launched after PACE in 2020. GEO-CAPE is a dual stationary satellite which will be able to make repeated daily measurements off the east and west coast of the USA, covering the coastal waters of Canada as well as down south to the Amazon River, north of Brazil. When a phenomenon occurs in the ocean, such as an algal bloom, scientists can target the satellite to observe that particular location. This is one of the advantages of a dual stationary satellite over polar orbiting satellites which can be exceptionally useful when monitoring the health of coastal ecosystems. Korea is the only other country which currently has this system for ocean color.

The satellite, Geostationary Ocean Color Imager (GOCI), has been in operation for just over five years monitoring sediments, water types, and blooms. It is also used for fisheries and building structures along the coast which are influenced by sediment. Goes has recently returned from a cruise off the coast of Korea, "We wanted to look at their satellite data for ocean color and mapping phytoplankton groups. Korea's GOCI satellite does not have the hyperspectral capability, but we wanted to see if the specifications of the satellite meet with those of the GEO-CAPE satellite that NASA is planning to launch. Working in those waters are particularly complex: they have a lot of water coming via the Taiwan current and the Yellow Sea. The Yangtze River also influences the entire area. When you see something as complex as that, you also see changes in the optical properties and variations in the phytoplankton types, so that's why I decided to take the FlowCam. I can't tell you how useful it was.”

Using the new system, Goes was able to construct a high-resolution picture of phytoplankton on the fly while another FlowCam took discreet samples. During the time and distance it took to travel between stations, the team was able to observe previously unseen features, aggregations of HABs, and different phytoplankton groups that was not possible in the discrete mode traditionally used by the researchers.

"We managed to collect a lot of optical data on this cruise, along with other scientists from NASA, obtaining measurements continuously. For the first time, FlowCam technology allows us to achieve high-resolution maps of phytoplankton that can be related to satellite data in more meaningful ways than possible before. Advancing this ground-truthing technology is vital to the advancement of satellite technology. With this capability that NASA is trying to put up on one of its satellites, the important thing is to have the right amount of data to make the transition from ocean color to phytoplankton functional types. FlowCam has tremendous potential, and that is why I think in the near future, we will see the role of FlowCam and other automated imaging systems expanding significantly.” concludes Goes.

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