Cleaner water from space

"We will know what's happening, and when it's happening, and can give timely information to local governments for water quality."

Menghua Wang,
Center for Satellite Applications and Research

by Jane Beitler

Travelers from around the world pause at China's Lake Taihu. Tranquility normally prevails along the sculpted limestone cliffs and undulating green hills ringing its placid waters west of Shanghai. But in spring 2007, this picture of Chinese beauty grew ugly when a massive blue-green algal outbreak thickly slimed the lake's surface.

Chinese officials declared the outbreak a major health emergency. The algae, called cyanobacteria, threw off foul odors as well as toxins that can damage human health. Two million nearby residents who drink Lake Taihu's water scrambled to buy bottled water for several weeks. Agricultural runoff and wastewater discharge had overloaded the lake waters with nitrogen; in spring, algae grew explosively in the warm, fertile waters. The most severe of several recent outbreaks, the incident spotlighted the need to better manage Lake Taihu's water quality.

Far away in Maryland, the news of the bloom in China gave oceanographer Menghua Wang an idea. Wang, who specializes in remote sensing of oceans, thought his idea could some day help people who depend on lakes for drinking water. He said, "Water quality is a very big issue affecting people's daily lives." Wang, with help from postdoctoral research associate Wei Shi, had just tested a new method for satellite observations of

Lake Taihu in China is normally tranquil and picturesque; recently, massive algal blooms have spoiled its potability. Researchers hope to use remote sensing to help local officials manage the lake's health. (Courtesy S. J. Photography) stirred-up coastal waters. He was fairly sure he could use it to capture a time series of Lake Taihu's algal bloom. Such space observations of lake conditions could help resource managers prevent and intervene in water quality problems like the Lake Taihu bloom.

Detecting the marine food chain

Wang's plan involved satellite sensors designed to detect phytoplankton, microscopic plants that are the building blocks of the marine food chain, near the ocean surface. A single alga or phytoplankton plant is too small to be seen with the human eye, but like pixels in a photograph, masses of them compose a visible image.

Flying 438 miles (705 kilometers) over the Earth, the NASA Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) and Moderate Resolution Imaging Spectroradiometer (MODIS) measure subtle gradations in visible and near-infrared light reflected up from the oceans, including the signature of green chlorophyll that indicates the presence of phytoplankton. The resulting data, called ocean color, map the abundance and distribution of phytoplankton, giving researchers information about climate conditions that favor this organism, as well as overall ocean health.

In a similar way, the sensors could detect algae that normally exist in a healthy freshwater ecosystem. Unbalanced conditions like those at Lake Taihu can trigger runaway growth, upsetting water quality for both people and fish. Long before detecting an actual massive algal bloom, sensors might spot changes in water clarity, an early clue to problems. Steven Greb, a research hydrologist at the Wisconsin Department of Natural Resources, said, "The usual way to measure clarity is to drive to each lake, put a boat in, and lower a Secchi disk on a line." A Secchi disk, designed for water clarity measurements, is a white disk with a pattern painted on it. As the disk descends, the depth at which the pattern disappears is a measure of the water's transparency.

The technique can be labor intensive and expensive on a large scale. Greb said, "These measurements need to be repeated for several years running to identify changes and trends. We have more than 15,000 lakes in Wisconsin, so it can get expensive. But satellite measurements cost only a few cents per lake."

Greb can use data from another satellite, Landsat, to help assess water quality. But because of its orbit, MODIS can offer more. Greb said, "Landsat passes over any area only every sixteen days. In the Midwest, we have a lot of clouds in the summertime, so there's good chance we'll have cloud cover that sixteenth day that Landsat passes over. Then it's thirty-two days between data, and we don't get a good image that summer. MODIS is going around every day, so the chances are much better of capturing a cloud-free day." While MODIS has the advantage of a more frequent orbit, its resolution is not as fine, so it would be most useful for larger freshwater lakes like Taihu.

Separating air and water

Wang, at the Center for Satellite Applications and Research at the National Environmental Satellite, Data, and Information Service, knew that MODIS and SeaWiFS could obtain high-quality data over the open ocean, but coastlines and inland waters were still a muddle. Wang said, "These areas are very turbid; a lot of sediment causes a problem for remote sensing."

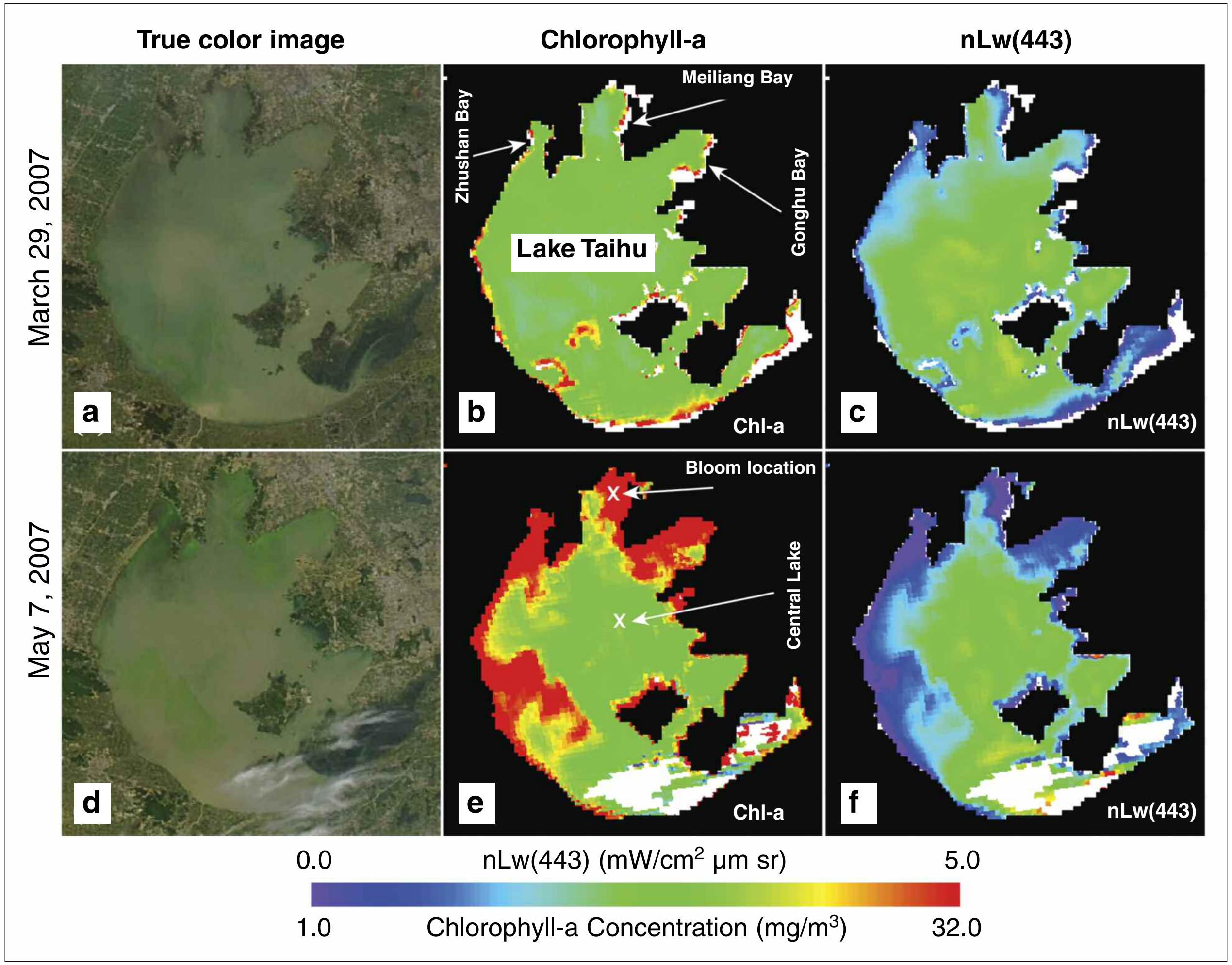
MODIS and SeaWiFS measure solar radiation that is reflected back by both the water and the

A blue-green algal bloom on Lake Taihu, China, recently threatened drinking water supplies. Researchers are studying new methods to detect water quality issues from space. (Courtesy W. Wurtzbaugh)

atmosphere in the near-infrared band. Clear ocean water absorbs almost all of the near-infrared radiation, so the signal of the ocean is quite distinct from the signal of the atmosphere, which reflects much more near-infrared radiation. But sediments in the stirred-up shallower conditions common near coasts and inland also reflect a lot of radiation in the near-infrared band, making it hard to distinguish water from atmosphere.

Wang also knew that MODIS had at least one thing that SeaWiFS did not: a shortwave infrared (SWIR) band, in addition to a near-infrared band. He had recently used this band to refine MODIS ocean color data, sifting out noise in the data from dust and water vapor encountered during radiation's trip up from the ground. Wang said, "Because the signal must travel so high, most of it is from the atmosphere, not from the ocean. The ocean signal is 5 to 10 percent of the data."

Wang thought that SWIR would also be more sensitive to the difference between atmosphere and turbid water, so he proposed to overlay SWIR band data on the near-infrared band data. In 2006, he tried the method along a consistently turbid section of China's eastern coast, near Hangzhou Bay and the Yangtze River estuary, and the ocean to the north of the Yangtze River mouth. Using the new algorithm and MODIS data from 2003, Wang found that he could closely match ground observations from 2003 field campaigns in the area.



Before-and-after satellite images captured a fast-moving algal bloom at Lake Taihu, China. Images (a) and (d) are true-color, similar to what the human eye would see. Images (b) and (e), processed with the shortwave infrared (SWIR) method, show the dramatic change in levels of chlorophyll (yellow and red), indicating the presence of algae. Images (c) and (f) compare the radiation before and after the bloom in the blue range to help accurately detect chlorophyll. (Courtesy M. Wang, from Aqua MODIS)

A fast-moving bloom

Encouraged by his success with measurements in turbid coastal waters in 2006, Wang saw the 2007 bloom at Lake Taihu as a chance to prove the method in turbid fresh waters. Wang obtained archived MODIS data for March through May 2007 for the Lake Taihu area from NASA's Level 1 Atmosphere Archive and Distribution System Web site. MODIS data were ideal for capturing the fast-spreading bloom, providing time-continuous coverage at a high resolution of up to 0.25 kilometers (0.15 miles).

The new algorithm worked. Wang said, "We looked at the MODIS data and sure enough, we could pick up the signal of where the bloom was happening." Applying the SWIR method, Wang studied Meiliang Bay, one of the main water sources for Wuxi, a city on the Lake Taihu shore. A series of MODIS images on cloud-free days captured the algal bloom as it started the first week of April, peaked around May 7, and then tapered off in early June.

Wang sees a key role for near-real-time space observations of lake water in the Taihu area and in other regions trying to manage increasingly pressured water resources. Wang said, "An image series like this will be very useful for local officials in the management of water quality. We will know what's happening, and when it's happening, and can give timely information to local governments for water quality."

Satellites for drinking water?

After the bloom, cleanup crews removed 6,000 tons of blue algae and 1 million cubic meters (1.3 million cubic yards) of silt from the lake, and after some weeks, restored its potability for local residents. The cleanup resolved only the latest crisis. Agriculture, city sewage, and manufacturing in the area continue to increase, overloading the lake with nutrients. Local officials must work to lower emissions and better treat sewage, while also finding substitutes for nitrogen and phosphorus-rich fertilizers, pesticides, and detergents. Continuous observations from space could help gauge the success of such measures, and in the shorter term enable officials to warn residents well before an algal bloom fouls their drinking water.

While the quarter-kilometer (0.2-mile) view of MODIS may be too coarse to capture data on smaller lakes in his region, Greb thinks that work like Wang's underscores the possibilities for future sensors. Greb said, "Many of us in the water quality community want a sensor on the next generation of Earth observing satellites that is tuned for measuring inland and coastal water quality." Banding with like-minded researchers as members of the international Group on Earth Observations (GEO), Wang and Greb helped craft a series of recommendations to this end.

Wang continues his work with existing satellite data, refining and testing the SWIR algorithm. He is inspired by the possibility of making a difference to people who depend on freshwater lakes like Taihu. He said, "I would like to see if someone can use this method for monitoring, or apply it to other regions. We need to learn if this is a useful tool to do not only science, but also to have an effect on people's daily lives."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2008/2008_algae.html.

References

Wang, M. 2007. Remote sensing of the ocean contributions from ultraviolet to near-infrared using the shortwave infrared bands: simulations. *Applied Optics* 46(9): 1535-1547.

Wang, M., J. Tang, and W. Shi. 2007. MODIS-derived ocean color products along the China east coastal region. *Geophysical Research Letters* 34, L06611, doi:10.1029/2006GL028599.

Wang, M., and W. Shi. 2008. Satellite-observed algae blooms in China's Lake Taihu. *Eos, Transactions, American Geophysical Union* 89: 22, 201-202.

For more information

NASA Level 1 Atmosphere Archive and Distribution System
http://laadsweb.nascom.nasa.gov

Center for Satellite Applications and Research
http://www.star.nesdis.noaa.gov/star

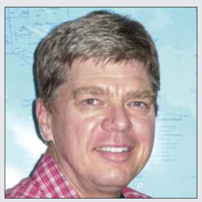
Group on Earth Observations
http://www.earthobservations.org

Wisconsin Department of Natural Resources
http://www.dnr.state.wi.us

About the remote sensing data used

Satellite	Aqua
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data sets used	MYD02QKM–Level 1B Calibrated Radiances–250 km MYD02HKM–Level 1B Calibrated Radiances–500 km
Resolution	0.25 kilometer and 0.5 kilometer
Parameter	Radiances
Data center	NASA Level 1 Atmosphere Archive and Distribution System

About the scientists



Steven Greb is a research hydrologist for the Wisconsin Department of Natural Resources. His interests include new technologies for surface water monitoring and modeling, use of remote sensing tools for water quality measurements, and the influence of process hydrology mechanisms on water quality. He also is the point of contact for the Group on Earth Observations water quality work task. (Photograph courtesy S. Greb)

Menghua Wang is an oceanographer at the Center for Satellite Applications and Research at the National Environmental Satellite, Data, and Information Service in Camp Springs, Maryland. His research interests include radiative transfer modeling; ocean color remote sensing; ocean and aerosol optical and microphysical properties; and development of techniques. NASA and the National Oceanic and Atmospheric Administration supported his Lake Taihu study.