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the ultraviolet (UV) light can get blocked by solids, said Cotruvo. He hoped the sensor will be fully developed within 5 years and engineered to detect other valuable rare earths as well.

From Waste to Revenue

Currently, the U.S. Department of Energy (DOE) is funding more than 30 projects to source rare earth elements from coal mining and its waste. Coal ash, refuse rock, young lignite coal, sludge, and acid mine drainage are treasure troves of rare earth elements, but the technology needed to extract the valuable materials has yet to hit the commercial market.

Acid mine drainage forms from the outflow of water from subsurface mines. Sulfur-bearing minerals in the rock turn water flowing by it acidic. In turn, the acidic water leaches heavy metals (including rare earths) from the rock. The highly corrosive water threatens aquatic life and water supplies.

Forty hard-rock mines in the United States produce 17–27 billion gallons of polluted water annually.

Forty hard-rock mines in the United States produce 17–27 billion gallons of polluted water annually, according to the environmental nonprofit Earthworks in 2013.

But converting the waste into revenue has become a priority of DOE and NETL. In a report to the U.S. Congress in 2017, the groups said that two coal and coal ash areas in the United States could supply millions of tonnes of rare earth elements, which is well above the domestic demand of 100,000 tonnes annually.

In recent years, China has produced and supplied an average of 90% of global rare earth elements, according to the U.S. Geological Survey. In 2019, the country threatened to curb supply during trade tensions with the Trump administration.

By **Jenessa Duncombe** (@jrdscience), Staff Writer

Satellites Allow Scientists to Dive into Milky Seas

For centuries, sailors have reported sightings of large patches of glowing oceans, stretching like snowfields from horizon to horizon. The ephemeral phenomenon, incidents of which can grow larger than some states, has long evaded close examination by scientists. But now, thanks to a little assistance from space, researchers may finally be able to dive into these milky seas.

Milky seas are associated with bioluminescence, light created by living organisms using biochemical triggers. Most well-known examples of bioluminescence are short-lived flashes, like those emitted by fireflies. But milky seas last for days or even weeks, a steady glow of light in the dark ocean visible only on moonless nights. Scientists suspect tiny, bioluminescent bacteria are responsible, but because glimpses of milky seas are so fleeting, researchers have had virtually no opportunity to examine the phenomenon directly.

Hunting for milky seas from space in near-real time may change that. Researchers using two NOAA satellites—the Suomi National Polar-orbiting Partnership (NPP) and the Joint Polar Satellite System (JPSS)—have developed the ability to quickly identify milky seas, opening the possibility of study before the glow disappears.

"Now we have a way of proactively identifying these candidate areas of milky seas," said Steve Miller, a senior research scientist at Colorado State University and lead author of the new study, which was published in *Scientific Reports* (bit.ly/milky-seas). "If we do have assets in the area, the assets could be forward-deployed in a SWAT-team-like response."

Rapid observations of the fleeting phenomena could help answer several lingering mysteries around milky seas, including how and why they form and why they are so rare.

"We really want to get out to one of these things and sample it and understand the structure," Miller said.

Turning On the Lights

Milky seas have been described by sailors for more than 200 years. Reports characterize them as having a pale glow, and travel through them is described as like moving across a snowfield or cloud tops. Ships' propellers create a dark wake as they move through the seas. The glow is so faint that moonlight renders it invisible to the human eye. The unusual waters seem more like the stuff of science fiction than science; indeed, they played a role in the Jules Verne novel *Twenty Thousand Leagues Under the Seas.*

Scientists experienced the spectacle only once, when R/V *Lima* chanced upon glowing waters in the Arabian Sea in 1985. Water samples from the ship identified algae covered with the luminous bacteria *Vibrio harveyi*, leading scientists to hypothesize that milky seas are associated with large collections of organic material.

Small groups of *V. harveyi* and other similar bacteria lack the faint shimmer found in milky seas. But once the population grows massive enough, the bacteria switch on their luminescence by the process of quorum sensing. Each individual bacterium seeds the water with a chemical secretion known as an autoinducer. Only after the emissions reach a certain concentration do the bacteria begin to glow.

"You know when you see these lights that there are a lot of luminescent bacteria there," said Kenneth Nealson, who along with Woody Hastings identified the phenomenon in the 1960s and was not a part of the new study. Nealson, a professor emeritus at the University of Southern California, estimated it would take around 10 million bacteria per milliliter of water to turn on the lights.

Gathering so many bacteria in one part of the ocean requires a significant source of food, and scientists suspect the bacteria are feasting on the remains of massive algal blooms. "If you give them something good to eat, they'll double about every half hour," Nealson said. "It doesn't take more than a day for them to have well over 10 million per milliliter."

Unlike algal blooms that drive phenomena like red tides, which are supposed to drive fish away, milky seas may be working to attract them. Fish eat the bacteria as well as the dying algae, and consumption doesn't end the bacteria's life cycle.

"For [the bacteria], the inside of a fish's stomach is a favorable environment," said Steve Haddock, a biologist at Monterey Bay Aquarium Research Institute in California and one of the authors of the new research. "They can live inside [a fish's] stomach just like bacteria live inside our bodies."

Seas from Space

This isn't Miller's first foray into using satellites to hunt for milky seas. After he and his colleagues questioned whether bioluminescent activity could be detected from space, Miller wondered what sort of ocean activity might be visible. He found a report from *Lima* that listed its coordinates and the date and time of the 3-day-long encounter. Using this information, he hunted through archival data collected by the U.S. Defense Meteorological Satellite Program constellation of satellites, a collection of polar-orbiting satellites surveying Earth in visible and near-infrared light. In 2005, he and Haddock, along with two other researchers, reported the first detection of a milky sea from space (bit.ly/first-milky-sea).

"It was really difficult to find that milky sea in that older generation of data," Miller said. He attributed the success to the clear records kept by *Lima*. "There was no way to pick it out on my own independently." It turned out that the ship had navigated through only a small part of the 15,400-square-kilometer glowing sea, which stretched to roughly the size of the state of Connecticut.

Encouraged by his success, Miller turned his attention to the newly launched Suomi NPP and its Day/Night Band (DNB) instrument, which breaks down light into gradients. Suomi NPP can sift through lights from cities, wildfires, and the atmospheric glow caused as ultraviolet light breaks apart molecules. Finding the faint light from milky seas required looking for dim seas and pulling out the short-lived events.

"It was a decade of learning," Miller said of the time spent culling transient events in search of milky seas.

After determining that most historical sightings of the glowing bacteria over the past 200 years occurred in the Indian Ocean and around Indonesia, researchers concentrated their hunt on that region. Moonlit nights were eliminated because they were too bright. Ultimately, Miller and his coauthors identified a dozen milky sea incidents between 2012 and 2021.

The largest milky sea satellite spotting occurred south of Java in 2009. The DNB detected a dimly lit sea on 26 July and continued to track it until 9 August, when the Moon once again drowned out the bacteria. Imagery confirmed that the luminescent sea spanned more than 100,000 square kilometers. Estimates place the number of bacteria involved in the event as exceeding 10 sextillion (a sextillion is 1,000 trillion), making it the largest event on record.

"This is just an inconceivable number of bacteria participating in that event," Haddock said.

Satellite observations also allowed researchers to take stock of the conditions of the ocean when milky seas are present. The new research measured details like water temperature and the amount of chlorophyll present.

"There's no doubt that there's a connection between a high level of chlorophyll and milky seas," Nealson said. "Nobody's been closer to an answer for the phenomena than [Miller, Haddock, and their colleagues]; they did a really wonderful job."

Biologist Peter Herring, a retired professor at the National Oceanography Centre in Southampton, U.K., agreed. "Almost all of the information on milky seas up to the 1990s was anecdotal from people on ships," Herring said. "Now we have remote observations from satellites showing exactly where these phenomena are happening and how they change with time. That's a major step forward."

Diving into the Seas

Although satellite imagery is an important tool, Miller hopes that the project will eventually lead to real-time observations. There are a lot of unanswered questions about milky seas, some quite basic. For instance, scientists aren't sure whether the bacteria form a thin film on the surface or extend deeper into the water. Nor are they certain that algal blooms are the primary food source for the bacteria.

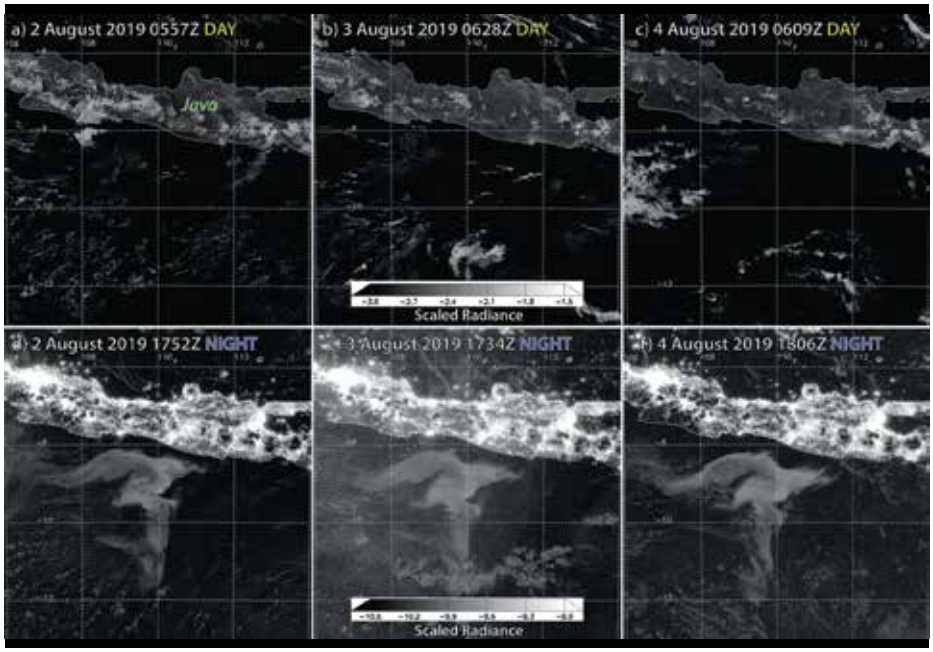
"If you were in the middle of one of these blooms, a lot of the things that we talk about would become obviously right or wrong," Nealson said. "That's very unusual in science, that you could get such a clear answer."

But real-time, in-person study may continue to prove elusive. There are no major ocean facilities near the region where milky seas seem to be most prevalent, and the seas are rife with pirates and other dangers that keep many research vessels away.

Nor have photos or videos ever reliably captured milky seas. The closest attempt was in 2010, when a crew tried to take a photo of the glowing sea using a flash, which promptly washed out the dim phenomenon. Miller hopes more commercial crews can be equipped with cameras specially designed to photograph bioluminescence.

In the meantime, Miller hopes to one day experience the fleeting mystery in person.

"I've always wanted to dive into a milky sea and see if it's still glowing under the surface," he said.



This milky sea phenomenon covered nearly 100,000 square kilometers near Java, Indonesia. The bright patches on the island are city lights. Credit: Miller et al., 2021, https://doi.org/10.1038/s41598-021-94823-z, CC BY 4.0 (bit.ly/ccby4-0)

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