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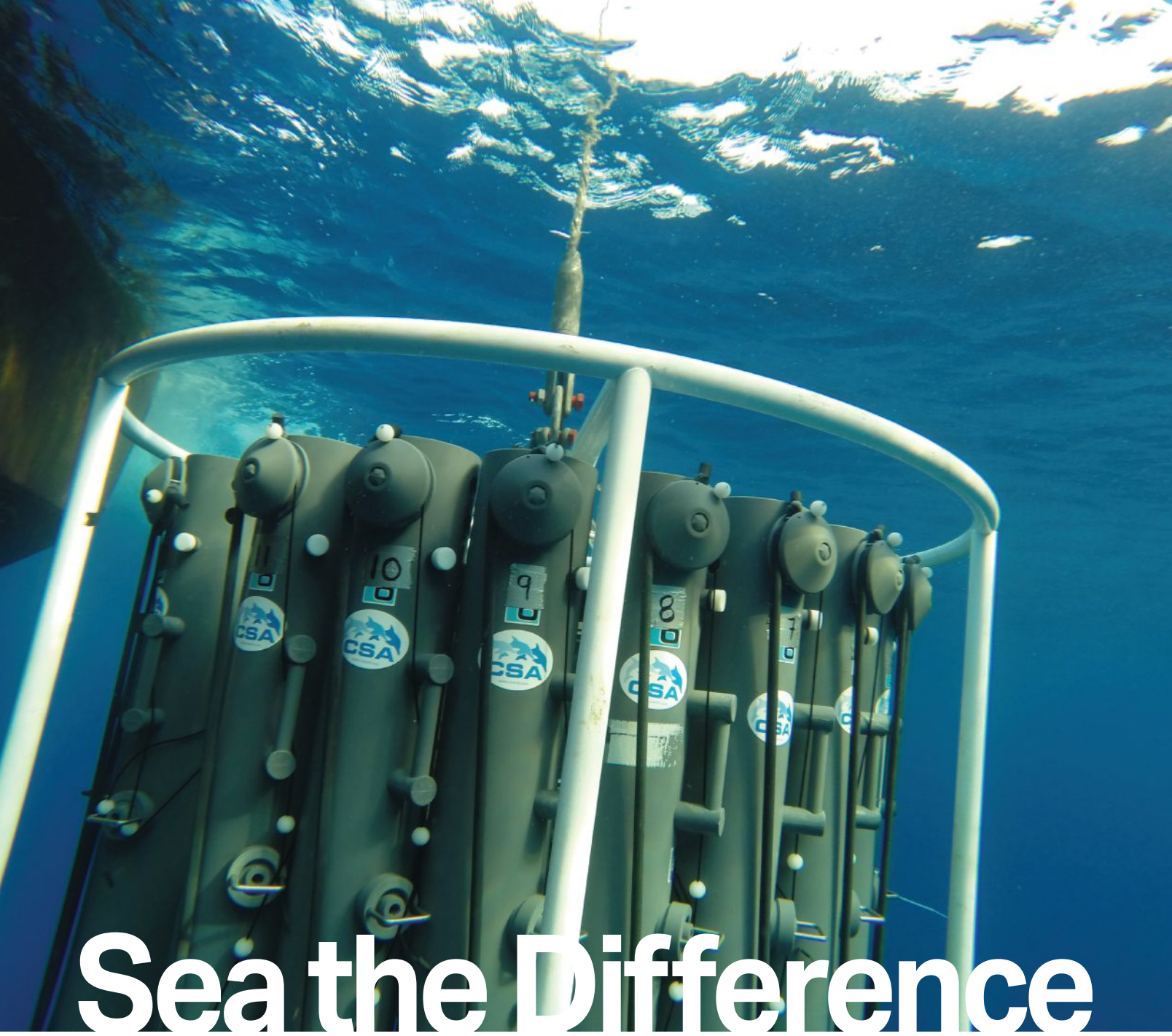

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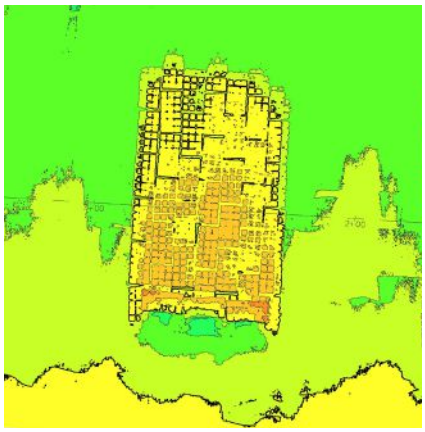

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Changing Science for the Better

By Kira Coley, Senior Editor

At the One Ocean Summit last month, Ursula von der Leyen, President of the EU Commission, announced three key initiatives to preserve and revive the oceans: a new international coalition to protect biodiversity on high seas; a major computing project (The Digital Twin) allowing researchers to digitally simulate the world's oceans; and the EU's research mission to restore our ocean and waters by 2030.

The ocean is still largely a great mystery for humankind, said President von der Leyen in her speech to the world leaders attending the Summit. And to solve this great mystery at pace, we must explore new ways to collaborate, share data, and observe the ocean.

"The more we observe the ocean, the more we see that it is central to improving the health, wealth, and well-being of the human race," writes the esteemed **Dr. R Venkatesan, Programme Director of Ocean Observation Systems at India's National Institute of Ocean Technology**, in his perspective piece introducing this issue's focus on the *Physical Ocean*.

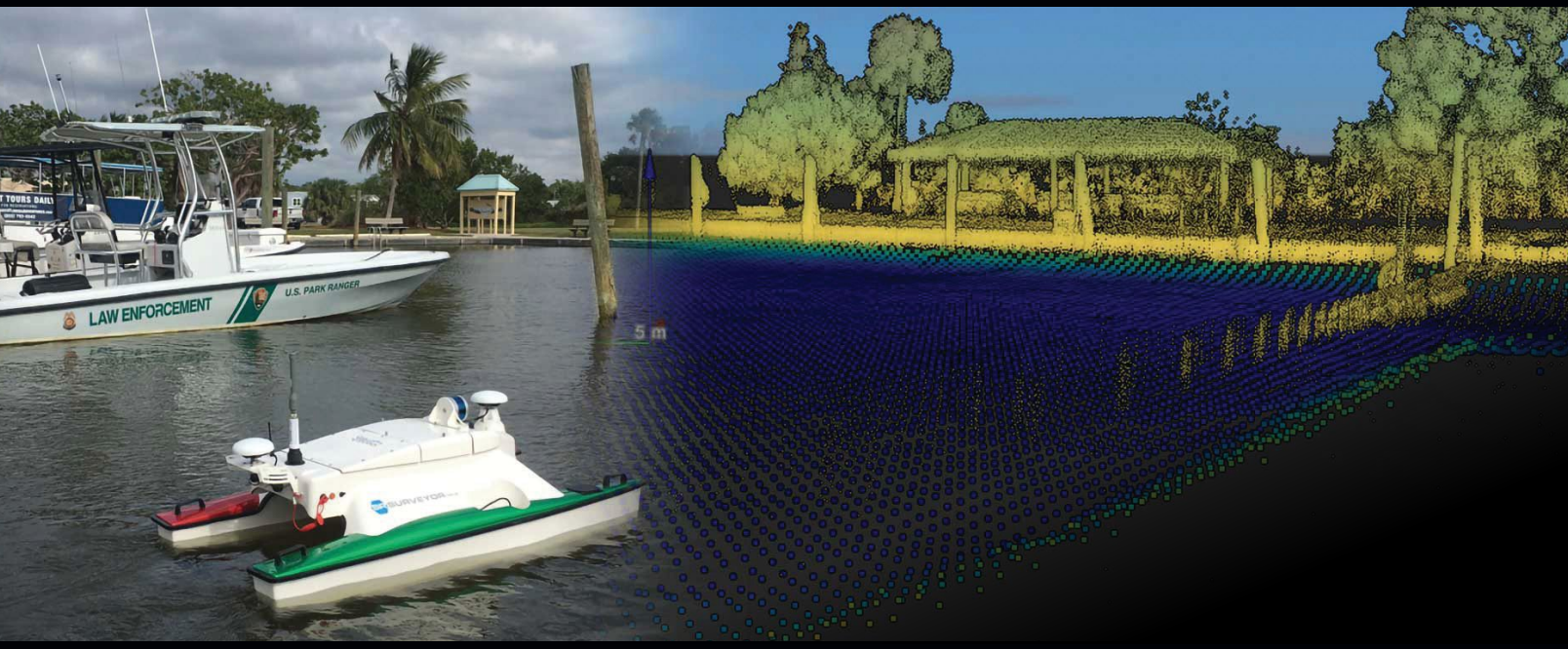
To kick start the new year, we reveal new insights about how our warming climate influences the ocean, and how changes to the ocean's physical and chemical properties impact marine life and the planet. "There are few places on Earth as dynamic as the boundary between ocean and atmosphere," writes **Samantha Andrews** in her story elegantly summarizing the challenges we face monitoring one of the most physically and chemically active environments on the planet. The **air-sea interface** is where heat and gasses are exchanged between the ocean and atmosphere. As such, the ocean is the largest natural carbon sink on the planet. But it cannot absorb the excess carbon from our atmosphere without first paying a high price. Carbon sequestration specialist **Planetary Hydrogen** believes that with the help of the **Ocean Startup Project**, 'wild card' solutions such as ocean-based carbon dioxide removal (CDR) can help rebalance atmospheric carbon, relieving pressure on the ocean.

"...**Ocean Acidification (OA)** is one little-known yet wide-reaching effect of increasing carbon dioxide levels in our atmosphere," writes **The Ocean Foundation.** Often referred to as the 'evil twin' of climate change, there is no surprise that OA features a lot in this Spring issue. We report on the launch of the new Decade-endorsed **Ocean Acidification Research for Sustainability (OARS)** initiative, reveal how The Ocean Foundation is building global OA resilience, discover **PyroScience's** solutions for monitoring pH, and **Pro-Oceanus Systems** discuss how ocean-based CDR may impact OA monitoring.

While we are busy solving these world-sized problems, we also have a responsibility to reduce our own carbon footprint. I spoke with **Leigh Storey, Associate Director of the UK's National Marine Facilities**, about how the need to build net-zero capability in ocean science will require a major overhaul to a firmly ingrained way of doing things in science.

Until we build a truly global ocean observation network, **intelligent ocean modeling** will play a hugely important role in forecasting changes over the next century. Stories from the **University of British Columbia, Woods Hole Oceanographic Institute**, and **Scripps Institution of Oceanography** show how new models can predict the fate of the North American lobster and reveal human footprints in the Southern Ocean.

The **Ocean Decade** has already yielded hundreds of new initiatives, international coalitions, national pledges, and record-breaking funding from governments and the private sector. We must embrace new opportunities such as The Digital Twin and remote data collection so we can transform commitments - such as those announced at the recent Summit - into tangible and impactful outcomes for the ocean. But to achieve this, we must change how we conduct science and work together as a global community for the better.



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(Need for) Sustaining Ocean Observations for Societal Benefits

By Dr. R.Venkatesan, Group Head at the National Institute of Ocean Technology

With 39 years of experience in ocean technology, Dr. R.Venkatesan has established and sustained India's moored met-ocean and tsunami buoy network, has 3 patents, published over 150 papers, and has 7 products transferred to industry. He is currently a member of the WMO Commission for Observation, Infrastructure and Information Systems INFCOM Management Group; Vice-Chair of SG-OOIS, Co-Chair Sub-Group on Capacity Development SC-ON; and Chair of DBCP International Tsunameter Partnership. He also served as a Chair of GOOS Regional Alliances Council UNESCO-IOC; Chartered Marine Technologist; and Founder Chair of MTS India, SM-IEEE. Dr. R.Venkatesan has 21 awards and recognitions, including the MTS Lockheed Martin Award, Joint WMO-IOC Commission for Oceanography and Marine Meteorology (JCOMM), and the National Geoscience Award presented by the President of India for his work in Arctic Observatory.

The current ocean observational network has many data gaps, including in the exclusive economic zones of many coastal nations. The recent interest of policymakers in ocean monitoring gives a ray of hope in achieving a much-needed expansion of the global ocean observation network to attempt to fill these gaps. Moored, drifting, and profiling observation systems have become essential for operational oceanography, weather prediction, climate modeling, and satellite data validation.

Over the last decade, we have witnessed new developments in connectivity, automation, and data analytics coupled with expanded sampling – all of which has facilitated a higher level of understanding of the ocean. In addition, the ocean Internet of Things (IoT) is evolving innovative research with smart devices which will empower the users with timely and reliable information. This embraces the NERVE approach for ocean observations: to meet the Needs, Economy (cost), Reliability, Versatility, and Ease of Use. However, if we are to realize the dream of a 'real' global ocean observation network, the focus should be on cost-effective, eco-friendly technology.

A success story can be found in the long-term sustenance of the Indian Moored Buoy Network. Set up by the National Institute of Ocean Technology's Ministry of Earth Sciences, this network has been invaluable for improving weather forecasts and tsunami early warning. A suite of sensors in these moored buoys has collected and transmitted real-time met-ocean data for the past 25 years despite innumerable challenges, including throughout the pandemic. The early warning services make use of the *in-situ* moored buoy observations, particularly the tropical cyclone heat potential, to better predict the track and intensity of cyclones. The India Meteorological Department is also able to release a unique cyclone with a storm-surge forecast, thanks to the continuous support of buoy observations. The high-frequency observations of Rapid mode data transmission (Patent pending) were especially useful during Cyclone Amphan, which struck the Bay of Bengal in May 2020. A joint data portal of the OMNI-RAMA buoy network launched as part of an India–US collaboration shares the meteorological and oceanographic data worldwide. This is a successful partnership model of contribution from both nations in data sharing with the international community.

There is a severe resource crunch in many nations due to the COVID pandemic, and newer cost-effective methods should be explored to collect real-time data. A recent pilot study on Fishing Vessel-based Basic Ocean Observing System (FV-BOS) (Patent pending) in collaboration with the local fishing community demonstrates a new low-cost avenue for collecting data using the widespread platform already at sea.

The ocean sector has a clear emerging vision for observing the ocean, with Gliders, AUVs, new uncrewed surface vessels, and autonomous subsea platforms all controlled from the shore. The acquisition of ocean technology companies by Silicon Valley is a major welcome scenario, which might bring the same 'dot. com transformation' to global ocean monitoring activities. Here an "Idea Factory" approach can bring unlike minds together to create the right atmosphere for problem-solving ocean observation challenges. However, the real global presence of an observational network is only possible with systematic capacity development and partnerships like the India–US data portal. This requires global and regional dialogues and calls for knowledge management – which includes indigenous skills - to achieve a truly global "ocean enterprise" or Blue Economy.

We live in a time of brilliant technologies, and the rhythm of innovation is increasing at an unprecedented pace. That can only benefit society as we try to realize the dream of a "real" global ocean observation network.

Ocean news in numbers

30 new countries
have joined the High Ambition Coalition for Nature and People. There are now 84 countries committed to the goal of protecting 30% of land and marine areas by 2030

500,000 km²
French Polynesia announced the creation of a new 500,000 km² marine protected area in the southeast of the archipelago

80% of the ocean
will be mapped by 2030, announced UNESCO at the One Ocean Summit

30 governors
of coastal cities around the world have signed the Sea'ties Declaration, urging governments to intensify mitigation and adaption measures to reduce the impact of sea level rise

27 member states
of the European Union and 16 non-EU countries recently launched the "High Ambition Coalition for a High Seas Treaty" in an effort to revitalize global ocean governance

~40 Heads of State
and Government responded positively to the invitation of the President of the French Republic to commit for the ocean at the One Planet Summit for the Ocean in Brest this February

New Species of Marine Plankton Discovered

Researchers have just announced the discovery of two new and unusual species of diatoms in the waters off Hawai'i. The organisms were also found to fix nitrogen, a critical process that supports productivity in the nutrient-poor open ocean they inhabit.

Diatoms, with their intricately patterned cell walls made of glassy silica, are some of the most well-known and charismatic phytoplankton. They fare best in nutrient-rich conditions. In the nutrient-poor open ocean waters around Hawai'i, diatoms struggle to acquire enough nitrogen to grow. To solve this problem, some diatoms have established symbiotic relationships with nitrogen-fixing cyanobacteria. These special endosymbiotic cyanobacteria can take dissolved nitrogen gas -- which is plentiful in seawater but not accessible to the diatoms -- and convert it into ammonia, a form of nitrogen that the diatoms can easily use, but which is otherwise exceedingly sparse in the open ocean. By harboring the cyanobacteria inside their glass houses, diatoms have their own personal nitrogen generators. They become a self-fertilizing system.

"Oceanographers have known about these diatom-cyanobacteria symbioses in waters around Hawai'i for many years," said Christopher Schvarcz, the lead author on the study, "but the species we discovered are something quite different."

The better-known examples of these types of symbioses are very easy to spot under the microscope, because the diatom hosts are large "centric" cells with radial symmetry, and the cyanobacterial endosymbionts living inside them form chains of cells that emit a bright yellow-orange fluorescent glow when illuminated with blue light.

The new diatom species isolated by Schvarcz are smaller and belong to a different lineage with an elongated, or "pennate" shape with bilateral symmetry. Their symbionts are also smaller, unicellular, and do not glow under fluorescent light because they do not contain chlorophyll, making them nearly invisible inside the diatom.

Another surprise came when the team measured the daily patterns of nitrogen fixation of the cultures. Species that had been studied previously tend to concentrate their nitrogen fixation activity either during the day or at night, but the new species did both. The discovery and cultivation of these species opens many exciting avenues of further research.

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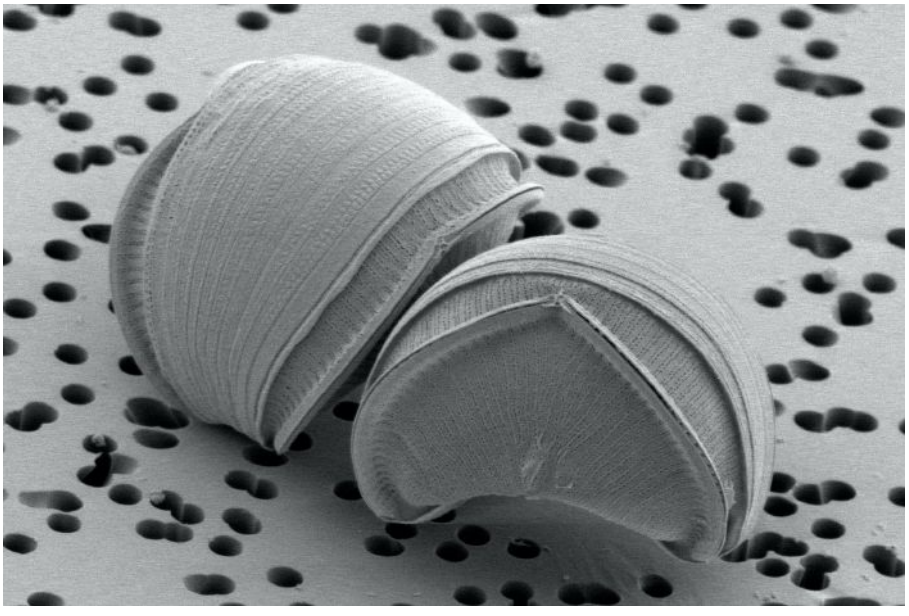

Epithemia pelagica. Photo by C. Schvarcz

Pacific Ocean as the Greatest Theater of Bird Migration

With a surface larger than all the continents together, the Pacific Ocean is the most extreme environment a migratory bird can encounter. Yet there are several bird species that conquer this enormous body of water almost routinely. In the latest issue of the scientific journal *Ornithology*, migratory bird researchers from the Netherlands, the United States and Canada provide a synthesis of all the knowns, and especially the many unknowns about the extreme performances of migratory birds such as bar-tailed godwits, whimbrels and red knots, which fly over the Pacific Ocean.

The biggest unknown appears to be the energy consumption of the birds. A bar-tailed godwit departing from Alaska weighs more than a pound (485 g) on average. Once it arrives in New Zealand, only 215 g of that remains.

"When we start calculating from the energy content of the fat burned and the assumed air resistance of birds, it seems that a bar-tailed godwit can fly for a maximum of 4 days at a time," lead author of the paper, migratory bird researcher Theunis Piersma of NIOZ, Royal Netherlands Institute for Sea Research and University of Groningen says. "The truth is, they fly for an average of up to 9 days at a time. We know this from research with satellite-tagged birds. We therefore must conclude that the birds fly much more efficiently than what we calculate on the basis of known flight properties."

In addition to being efficient fliers, birds also appear to be good meteorologists, to the enormous surprise of the meteorologists among the researchers. For example, birds adapt their departure from the northern hemisphere to the weather systems they will later encounter over the southern hemisphere. In addition to this meteorological knowledge, birds also have an 'internal GPS' and a map of the vast ocean, according to the researchers.

Piersma said, "There is no other way to explain how bar-tailed godwits departing from Alaska, fly over the open ocean almost without landmarks, continuously adjusting for wind drift, and then arrive spot-on in New Zealand 12,000 kilometers later."

Departures from wintering areas are also adjusted to changes those individual birds have observed in previous years during migration. "Bar-tailed godwits flying from New Zealand to Alaska refuel in the Yellow Sea, off the Chinese and Korean coasts. We have seen that individuals can leave earlier the following year. This could very well be an adaptation to the worsening food situation in the Yellow Sea. It is important to note that this could therefore be an adjustment of individual animals, in addition to an evolutionary process, where 'earlier birds' have an evolutionary advantage over later ones," added Piersma.

The overview of scientific knowledge on Pacific migrants is, in a sense, a wish list of the researchers: what remains to be discovered?

"At the same time, it is also a warning," Piersma says. "Changes to the habitat of migratory birds and certainly changes in climate can have enormous consequences for the fragile balance during such an immense endeavor as migrating across the Pacific."

The world record holder for long-distance migration is a bar-tailed godwit that departed Alaska on September 16, 2020, with a transmitter on its back. The bird arrived in New Zealand eleven days later, after a flight of a whopping 12,854 kilometers.

> "We know that these severely emaciated birds want only one thing after arrival: not to eat but to sleep," said Piersma. "This is still an unofficial record, though. Only when this achievement is recorded in a peer reviewed scientific journal, does the record really count."

> www.ecomagazine.com/33q8

First Records of Killer Whales Hunting Largest Animals on Earth

In late March 2019, researchers performing annual whale and dolphin research surveys discovered the first ever record of killer whales hunting and killing an adult blue whale. Just two weeks later a blue whale calf was taken by many of the same individuals. Since then, an additional event of another blue whale calf predation was recorded in 2021.

> www.ecomagazine.com/33rr

Venomous Australian Sea Anemone May Lead to Life-Saving Drugs

An entirely new toxic compound found in an Australian tropical sea anemone is being analyzed as a potential new drug therapy, after it was discovered by biomolecular scientists during investigation of the species' multiple venoms. Animal venoms had been used to treat humans throughout history, with snake venom administered medicinally as early as the seventh century BCE.

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New Research Bites Holes into Theories About Megalodons

A new study leaves large tooth marks in previous conclusions about the body shape of the Megalodon, one of the largest sharks that ever lived. The study makes use of a pioneering technique for analyzing sharks. While there is no dispute that they existed or that they were gigantic, the shape of this species is still unknown.

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Study Suggests Extreme Heat is the 'New Normal' for the Ocean

A century-and-a-half of data show the majority of the ocean's surface has experienced extreme heat since 2014.

New Monterey Bay Aquarium-led research reveals excessively warm ocean temperatures driven by climate change are the new normal. The study, published today by *PLOS Climate*, establishes that more than half of the ocean surface has exceeded a historical heat extreme threshold on a regular basis since 2014.

And it is these heat extremes, researchers say, that increase the risk of collapse for crucial marine ecosystems, including coral reefs, seagrass meadows, and kelp forests -- altering their structure and function, and threatening their capacity to continue to provide life-sustaining services to human communities.

Researchers conducted the study by mapping 150 years of sea surface temperatures to determine a fixed historical benchmark for marine heat extremes. The scientists then looked at how often and how much of the ocean surpassed this point. The first year in which more than half of the ocean experienced heat extremes was 2014. The trend continued in subsequent years, reaching 57 percent of the ocean in 2019, the last year measured in the study. Using this benchmark, just two percent of the ocean surface was experiencing extremely warm temperatures at the end of the 19th century.

"Climate change is not a future event," said Dr. Kyle Van Houtan, who headed the research team during his tenure as chief scientist for the aquarium. "The reality is that it's been affecting us for a while. Our research shows that for the last seven years more than half of the ocean has experienced extreme heat."

"These dramatic changes we've recorded in the ocean are yet another piece of evidence that should be a wake-up call to act on climate change," he added." We are experiencing it now, and it is speeding up."

The study grew from separate research into the history of kelp forest changes throughout California. Van Houtan and team discovered that sea surface heat extremes, which are key stressors for canopy kelps, needed to be quantified and mapped along the California coast throughout the last century. The researchers then decided to expand the investigation beyond California to better understand the long-term frequency and location of extreme marine heat across the global ocean surface.

Using historic records, aquarium scientists first determined the average temperatures for the ocean's surface over the period spanning 1870 to 1919. Then they identified the most dramatic ocean warming that occurred during that period -- the top two percent of temperature increases -- and defined that as "extreme heat." The team then mapped the extremes over time, examining whether they occur regularly or are becoming more frequent.

"Today, the majority of the ocean's surface has warmed to temperatures that only a century ago occurred as rare, once-in-50-year extreme warming events," Van Houtan said.

The researchers say the new normal of extreme heat across the majority of the ocean's surface is further evidence for the urgent need to drastically reduce emissions from the burning of fossil fuels, which are the driver of climate change.

> www.ecomagazine.com/33rf

Gabon Provides Blueprint for Protecting Oceans

Gabon's network of Marine Protected Areas (MPAs) provides a blueprint that could be used in many other countries, experts say.

Since announcing a new MPA network in 2014, Gabon has created 20 protected areas-- increasing protection of Gabonese waters from less than 1 percent to 26 percent.

The new paper -- by Gabonese policymakers, NGOs and researchers from the University of Exeter -- highlights the lessons from this work and its relevance elsewhere.

"A combination of factors made this MPA network possible, but a crucial first step was the creation by President Ali Bongo Ondimba of a government-led initiative called 'Gabon Bleu' in 2013," said Dr Kristian Metcalfe, of the Centre for Ecology and Conservation at Exeter's Penryn Campus in Cornwall.

"This sent out a clear signal that the Gabonese government wanted to develop an MPA network.

"That ensured all sectors -- from government agencies to ocean resource users -- were engaged in the planning process, and it gave confidence to external funders and the private sector to support the research that underpins the MPAs.

Dr Emma Stokes, Wildlife Conservation Society Regional Director for Central Africa & Gulf of Guinea, added: "This political will and long-term engagement was vital -- creating a 'tipping point' towards effective change.

"Collective action has accelerated progress, and the country has now committed to the 30x30 pledge to protect 30 percent of its oceans by 2030."

Global MPA coverage is still short of a 10 percent target set in 2010, partly due to limited progress in many low-income and middle-income countries. However, a few of these countries -- including Gabon -- have met or exceeded international commitments on land and sea.

The MPAs are based on detailed evidence, resulting in an inter-connected network tailored to protect important habitats, as well as globally important populations of sea turtles and marine mammals, with protected zones extending from north to south, and from coastal waters to 200 nautical miles offshore.

The new paper argues that lessons from Gabon can be used to inform Post-2020 global biodiversity commitments and implementation.

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Accelerating Nature's Ocean-Based Carbon Removal Process

Carbon sequestration specialist Planetary Hydrogen aims to take one gigaton of carbon out of the atmosphere every year starting from 2035. After winning the Ocean Startup Project (OSP) Oceanshot Award in 2021, this group of passionate entrepreneurs, scientists, and engineers are now closer to making this dream a reality.

By Eric Siegel, Executive in Residence, Ocean Startup Project

"The way we see it, there are three things humans need to do to resolve the climate crisis: we must adapt to the changing climate, we must reduce emissions, and we must remove carbon," said Planetary Hydrogen CEO Mike Kelland. "Our Accelerated Carbon Transition platform is one of those rare systems that address all three things."

The ocean is the largest natural carbon sink on the planet, absorbing 25 percent of global emissions and holding 88 percent of Earth's surface carbon. This carbon uptake is primarily due to a natural process called mineral weathering.

"If we stopped all emissions today, then in 100,000 years, the carbon would rebalance based on this natural process. But, of course, we don't have that long, so we need to speed things up," added Kelland.

Planetary Hydrogen's technology creates a very mild and pure form of alkalinity from mineral sources which can be placed directly into the ocean, replicating and massively accelerating this natural process. The alkalinity is manufactured by processing waste from mining sites using renewable energy. Two by-products of the manufacturing process include hydrogen, a clean fuel source, and critical metals for batteries.

In partnership with Dalhousie University and the University of Miami, Planetary Hydrogen is funding research on the impact of adding alkalinity to the ocean and observing the effects on corals, oysters, and phytoplankton. "On the Great Barrier Reef, an experiment where alkalinity was added resulted in a seven percent increase in calcification," said Kelland. "Our system could help restore coral-based ecosystems, which 500-million people rely on worldwide."

Applying Ocean Alkalinity Enhancement (OAE) to increase CO_2 capture capacity by one percent means reducing the atmospheric burden by 11 percent globally. While the impact is large, these adjustments in pH are very small, and alkalinity rapidly disperses as soon as it's added to the ocean. "Planetary Hydrogen must develop a framework to measure and verify the capture of carbon in the ocean as a result of its system. That is a critical challenge for us now, and it was the focus of our submission for the OSP Challenge."

Kelland continued, "Directly measuring the weight of carbon captured will be challenging. What we can do is track pH changes and alkalinity measurements at the point of insertion and extrapolate data from laboratory studies into oceanography models. From this, we can build a new model which helps us validate as best we can with further ocean measurements."

In 2021, Planetary Hydrogen won the Oceanshot Award from OSP and $100,000 for tackling large, challenging, uncharted problems that, if successful, could lead to a huge impact on ocean sustainability and create a massive market opportunity.

The funding will support the development of a platform for monitoring, reporting, and verification (MRV) of carbon captured with OAE. They have now hired an ocean chemist and science director, and have pilot projects running in Halifax, Miami, and the southwest of the UK to quantify the impact of their technology.

"The Ocean Startup Project has been critical to accelerating the development of an MRV platform thanks to their funding, guidance and the access we now have to a global community of scientists and engineers," added Kelland. "We *must* solve the issue of climate change. If we don't, we're all in trouble, and we need solutions like this to do it."

Pink Pumice Key to Revealing Explosive Power of Underwater Volcanic Eruptions

In research published in the Nature portfolio journal *Communications Earth and Environment*, the researchers were intrigued by the occurrence of pink pumice within the massive pumice raft that resulted from the Havre 2012 deep-sea eruption.

The publication of the new research comes after the recent dramatic explosion of the Hunga Tonga Hunga Ha'apai volcano in Tonga, about 1,200 kilometers north of the Havre volcano, which has sharply brought the world's attention to the explosive potential and hazards associated with submarine eruptions.

Professor Scott Bryan, who has been studying pumice rafts for more than 20 years, said the pink pumice produced in the 2012 Havre eruption revealed insights into how magma can shoot out and up from underwater volcanoes.

"Unlike Hunga Tonga-Hunga Ha'apai, Havre is in a much more remote location. Its summit is 900 meters below sea level, and the nearest populated areas are around 800 kilometers away on the North Island of New Zealand," Professor Bryan said. When the volcano erupted in 2012, there was no one to see it happen. But the colour of the pumice tells the story of what happened.

Joseph Knafelc, lead author of the research, said the new model put forward in the research challenged the known depth limits for explosive eruptions. "The common theory is that underwater eruptions, particularly in deep water such as at Havre, cannot be explosive and instead make lava flows on the seafloor," Mr Knafelc said. "But few submarine eruptions have been able to be observed, and past studies had failed to consider the existence of the pink pumice in the pumice raft.

"The colour in this case is critical -- the pink to red colour tells us the pumice had to be ejected into the air at temperatures above 700°C for tiny iron minerals to then oxidise and cause the reddening.

"The problem is that it was an underwater eruption that had to push up through nearly 1 km of ocean. The only way it can do this is if the eruption was very powerful and able to punch through the ocean water and produce an eruption column in the air."

The research details how the core of the eruption was a powerful jet and able to be shielded from the surrounding water.

"The pink pumice and its thermal history tell us that the core of the eruption column was untouched by the cooling effects of the ocean water," Professor Bryan said. "This was a very powerful eruption. The problem is that previous studies had not recognised or downplayed the explosive potential of submarine eruptions even in very deep water and thus the hazards posed by submarine eruptions.

> www.ecomagazine.com/33rc

Monitoring the Air-Sea Interface

By Samantha Andrews, Ocean Oculus

There are few places on earth as dynamic as the boundary between ocean and atmosphere. This is where carbon dioxide is exchanged between ocean and air, where the air deposits plastics, sand, and atmospheric pollutants into the ocean, and where the ocean outgasses nitrous oxide and oxygen into the atmosphere, to name a few. Such air-sea fluxes influence multiple aspects of our climate cycles such as the water and carbon cycle, trade winds, and even the ozone layer itself.

Gauging air-sea fluxes is a challenging affair, especially as many fluxes cannot be measured directly. Instead, a suite of "essential ocean and climate variables" is used to estimate fluxes. Estimating heat fluxes, for example, requires high measurements of surface winds, surface humidity, air temperature, surface albedo (upward solar radiation), downward longwave radiation, longwave surface emissivity, and sea surface skin temperature. Such measurements aren't only vital for air-sea interface studies, but for configuring, calibrating, and improving ocean, climate, and weather models that we use to predict, plan for, and mitigate against changing conditions.

In recent years, numerous scientists and organisations have highlighted the need for more measurements of essential ocean and climate variables. In 2020, the Scientific Committee on Oceanic Research launched a new working group dedicated to improving our knowledge and monitoring of air-sea interface. In 2021, their program—Observing Air-Sea Interactions Strategy (OASIS)—was adopted as a Program within the U.N. Decade of Ocean Science for Sustainable Development for matching several Decade outcomes: "a predicted ocean"; "a safe ocean"; "a healthy and resilient ocean"; and "a sustainable and productive ocean."

Eyes in the Sky

Satellites provide near-global and increasingly finer-scale data on a host of essential ocean and climate variables. Sitting some 1,300 kilometres above us, the recently-launched Sentinel-6 Michael Freilich satellite, fitted with Thales Alenia Space's Poseidon-4 altimeter, will provide altimetry data at an accuracy of up to 2.9 centimetres. Altimeter readings can be used to calculate the transfer of gases such as dimethyl sulphide and carbon dioxide.

Satellites have revolutionised data collection of a host of ocean and climatic variables, but there are some limitations. Some variables, such as sea level pressure, cannot be measured with satellites. In other cases, variables can be measured, but because of the orbit of the satellites, they aren't collected from polar regions. One example is the Global Precipitation Measurement mission, which observes rain and snow between 65°N and 65°S. Scale is also a consideration. Sub-mesoscale features important to air-sea fluxes may be too small for satellites to detect.

Satellite technology and coverage are improving, but *in-situ* platforms are, and likely will be for some time, major players in data collection.

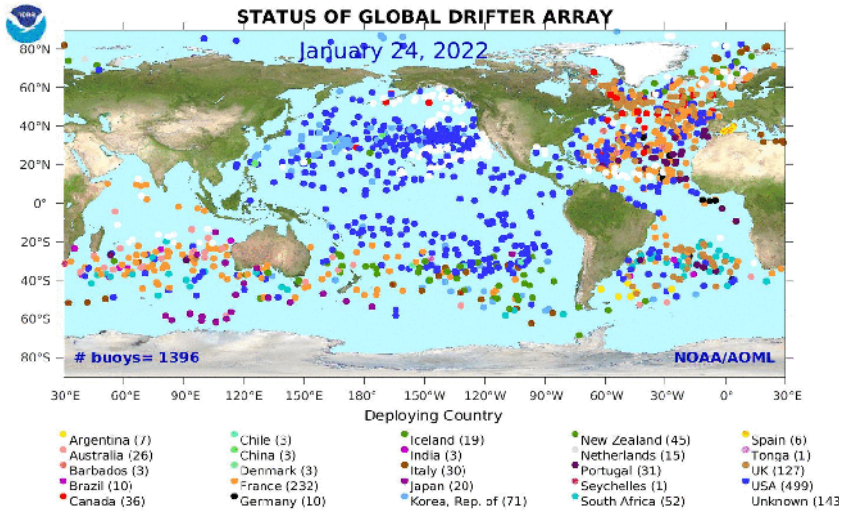
Ship-Shape Observations

Arguably the oldest and longest-running ocean-climate data collection program is the World Meteorological Organization's Voluntary Observing Ship (VOS) scheme. Since 1853, passenger, cargo, and other ships have recorded and reported a range of at-sea oceanographic and meteorological measurements such as wind speed and direction, humidity, sea state, and sea temperature using either specially fitted or the ships' own instruments. While historically measurements were submitted using snail-mail, today, the WMO Global Telecommunication System makes it possible to deliver data in near-real-time. Some 7,700 ships contributed data via the VOS in the mid-1980s, but today this number has almost halved.

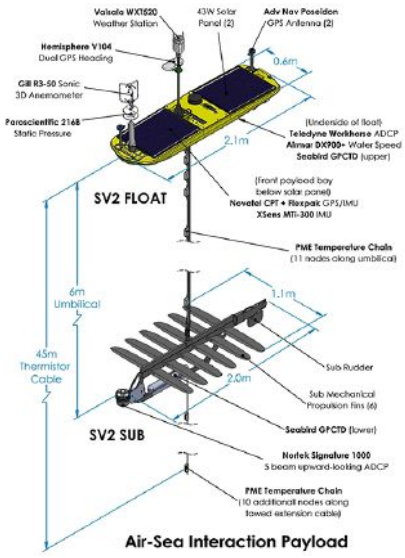
Other ship-based measurements come from dedicated research vessels. Unsurprisingly the instruments onboard these vessels can be more sophisticated than may be found onboard VOS participants. For example, the R/V *Pourquoi Pas,* operated by French oceanographic institute Ifremer, is equipped with multiple instruments, including a Sea-Bird Scientific Thermosalinograph that can measure temperature and conductivity and a weather station that includes a Seatronics barometer to measure pressure. In 2017, instruments onboard the R/V *Pourquoi Pas* enabled scientists to study the impact of Saharan dust in the air-sea interface during a deposition event in the Mediterranean Sea.

Staying in One Place

Moored buoys networks can provide long-term *in-situ* measurements on a host of ocean and climate variables needed to calculate air-sea fluxes, including surface currents, humidity, wind, and short and longwave radia-



Location of the surface drifters in the Global Drifter Array program. (As of Jan 24, 2022). Obtained from /www.aoml.noaa.gov/phod/gdp/. (Photo: NOAA)



Setup of the Wave Gliders with instruments in the 25-day mission between San Clemente and San Nicholas Islands. (Grare *et al*,) 2021)

tion. The Indian moored buoy network, developed by India's National Institute of Ocean Technology (NIOT), has provided real-time measurements for almost 25 years across coastal and deepwater locations in the Arabian Sea and Bay of Bengal. Data is transmitted every three hours, and additional high-frequency data can be stored on the moorings for retrieval later.

The network has provided vital data for a host of studies on the air-sea interface. One recent example comes from Samar Ghose (Indian Institute of Technology Bhubaneswar) and colleagues who studied how heat flux varied in and out of the monsoon seasons in the two basins. He found latent heat flux to be higher during the monsoon season, with pre-monsoon wind speeds and relative humidity regulating latent heat flux and sea surface and air temperature in sensible heat flux. However, there were some variations. The role of relative humidity, for example, was much stronger during the southwest monsoon season in the Arabian Sea than in the Bay of Bengal.

Going with the Flow

While moored buoy networks provide vital long time series of data from fixed locations, enabling studies of the essential ocean and climate variables that control air-sea fluxes over time, the Global Drifter Array program employs some 1,300 surface drifters to gather data as they float on the ocean surface.

Manufactured by specialist companies such as Marlin-Yug, longevity of the drifters varies, but drifter #26028 currently holds the record for transmitting data for over ten years. Transmitting data every few hours, all drifters measure sea surface temperature, near-surface current velocity, and location. Since the mid-1990s, drifters have been equipped with pressure sensors, providing more accurate reading than those taken from ships due to proximity to the sea surface. A smaller number of drifters are also equipped with sensors to measure wind, salinity, and waves.

Alongside research, surface drifters play a pivotal role in calibrating and validating measurements obtained from satellites. These include the Sentinel-3 satellite, which has contributed to climate products such as the European Centre for Medium-Range Weather Forecasts' ERA-Interim global atmospheric reanalysis.

Without the need for onboard people-power, surface drifters—and equally moored buoys—aren't just cheaper to deploy than ships, they can be used in areas where *in-situ* observations aren't typically gathered. This includes places or times where conditions are hazardous, where ship traffic is low, and particularly remote ocean areas.

Of course, drifters face their own set of challenges. By their very nature, surface drifter movements are dictated by surface flow, potentially taking drifters away from areas of interest. In equatorial regions, for example, maintaining drifter presence is difficult as divergent surface flows tend to drag the drifters into the sub-tropics.

Other challenging locations include the Polar regions, particularly when sea ice poses a threat to manned and unmanned vehicles, and powerful storms can take drifters off course. In fact, when it comes to air-sea fluxes and essential ocean and climate variables, the remote and vast Southern Ocean is one of the most data-deficient Oceans on Earth. However, a new breed of instruments is helping unlock its secrets

The Future is Autonomous

Autonomous (or unmanned) underwater and surface vehicles were first developed in the late 1950s, but it is only in recent years that they are becoming more prominent in research. Unlike drifters, these vehicles have some propulsion, enabling researchers to send them to specific locations for data collection. For example, in 2017, a Liquid Robotics Wave Glider vehicle equipped with a host of sensors such as laser wave gauges and ADCPs set out on a 25-day data-collection mission between San Clemente and San Nicholas Islands to understand how fluxes operate across and into the ocean mixed layer. In the winter of 2018/2019 a Wave Glider, paired with a Teledyne Webb Slocum G2 glider set out on a 56-day mission south of the Antarctic Polar front to gather data on carbon dioxide outgassing during winter storms.

The Wave Glider and Slocum G2 glider aren't the only autonomous vehicles contributing to air-sea interface research in the Southern Ocean. In 2019 autonomous surface vehicle Saildrone successfully circumnavigated Antarctica in 196 days. Equipped with an anemometer, a CTD to measure sea surface temperature and salinity, and a system to collect a surface and marine boundary layer atmospheric carbon dioxide and sea-level atmospheric pressure, the platform delivered hourly carbon dioxide flux estimates. If Southern Ocean storms weren't challenging enough, in September 2021, a specially modified version of the vehicle became engulfed by Hurricane Sam, a Category 4 event. Not only did the Saildrone survive, but it came out with the world's first video footage from inside a hurricane.

Autonomous vehicles like the Saildrone, Wave Glider, and Slocum G2 glider won't completely replace other *in-situ* instruments. However, their ability to tolerate harsh conditions and collect data for long periods with an array of different instruments, combined with ongoing improvements in A.I., automation, and robotics, means autonomous vehicles are likely to become ever more critical in our quest to understand, measure, and predict the air-sea interface.

To Cut Emissions by 2040, Scientists Must Make Changes too

A new report from the U.K.'s National Oceanography Centre (NOC) details the need to build net-zero capability in the oceanographic sector – and it will require a dramatic shift in how we conduct science

By Kira Coley

This year marks 150 years since the HMS *Challenger* expedition (1872-1876) – a scientific program widely considered to be the world's first oceanographic research expedition, laying the foundations of modern oceanography. Arguably, the way we collect oceanographic data hasn't changed much over the last one and a half centuries. Scientists board a ship, go out to the ocean, throw measuring instruments into the water and retrieve samples. One of the most significant developments in recent years has been in remote sensing from satellites and autonomous platforms. These relatively new tools have given birth to the concepts of digitalizing the ocean and 'digital twins', offering scientists an opportunity to reimagine how they collect, use and share oceanographic data.

Leigh Storey, Associate Director at the NOC's National Marine Facilities, said: "Typically speaking, once a scientist gets a grant to cover research costs, they get privileged access to the data for usually 1 to 2 years. But data from satellites or floats increasingly gives near-instant access to any scientist using global data portals such as Copernicus. The growing use of autonomous platforms supporting 'observing networks' presents an opportunity to move that model on another step."

There are two major implications for this new approach. First, the access to ocean data and the digital twin concept (which allows you to digitally alter variables to observe potential changes in the ocean) means whether you are an economist, physical oceanographer, or historian, you can access and 'play with' the data. The perhaps more important implication is around equality. If all you need to do is to access data through an online portal, it suddenly becomes accessible to scientists outside of the Northern Hemisphere – where around 99 percent of science is published – enabling an era of truly international research.

There are other benefits to changing the way we conduct science. Scientists are limited by how long they can stay out at sea and collect data, often needing to extrapolate for the rest of the year. If instruments can be left in the ocean year-round, we can collect more data points resulting in more accurate ocean modeling and weather forecasting. A recent example is how the U.S.'s National Oceanic and Atmospheric Administration (NOAA) are achieving ground-breaking hurricane datasets in the Tropical Atlantic with the help of Saildrones – gathering never-seen-before data from inside Hurricane Sam in 2021. This data will go a long way to improving hurricane forecasts and have a direct impact on coastal communities.

There is also the need to reduce our carbon footprint.

The NOC has one of the largest autonomous fleets in Europe and has been pioneering the development and use of marine autonomous systems in the U.K. for the last 20 years. With more platforms joining their fleet of 50-plus vessels, they sought to uncover what operating model scientists might want and need using autonomous platforms. And figure out if the NOC can deliver it.

Then in 2020, the UK Research and Innovation (UKRI) published an environmental sustainability strategy announcing their ambition for the U.K.'s science community to become net zero by 2040.

"It's brilliant that the UKRI set that challenge. But where are the big emitters in the UKRI footprint? It's the U.K.'s three research vessels by some way. So, those two things effectively came together: we need to meet this target and work out what we do with our research vessels, and we need to plot a path to how we integrate this new technology and continue to enhance the science by improving what data we can capture," said Storey.

Transitioning to Net-Zero

The NOC's Net Zero Oceanographic Capability Strategy report, published in January 2022, identified several important changes that the U.K. (and the rest of the world) would need to make by 2025 to stay on pace for zero emissions. This includes:

- Reducing the need for scientists to work in ship-based laboratories by making an immediate and significant investment in developing scientific sensors that can be fitted to autonomous platforms and floats.
- Investing in the development and operation of autonomous platforms that, operating in swarms and as part of a wider observing network, can start to replace capability currently available only on research ships.
- Linking the observing network to data portals that can be accessed by multiple users; and
- Taking advantage of commercially developed technology that enables 'green' research ships, i.e., using green Hydrogen or Ammonia.

Since the lifespan of a ship is around 25 to 30 years, meeting this goal would mean any new ships being built today should have a clean energy source such as hydrogen. But the global infrastructure needed to scale-up clean energy is still lacking in the maritime sector. And then there is the challenge of space onboard the ship itself.

"Using the RRS *Discovery* as an example, the storage of diesel fuel is about 13 percent of the ship's volume. If you replace this with hydrogen fuel cells, it goes up to around 40 percent, so you must find 27 percent extra volume without compromising endurance or functionality. The way you find that space is to increase the capability of autonomous platforms and onshore some of the roles traditionally carried out at sea," said Storey.

While the maritime sector is solving challenges around clean fuel, Storey believes the oceanographic sector should develop and scale-up autonomous fleets. Using this approach, by the time we reach the UKRI's 2040 target, research vessels can be retrofitted or built with clean energy and be surrounded by an ecosystem of autonomy without impacting the science.

Storey adds, "That is the best-case scenario. The worse-case scenario is the UK losing direct access to multi-role research vessels because we haven't reduced our carbon footprint, leaving us with only a few gliders to share nationally. That will have dramatic consequences on the science community. The challenge now is how to develop the technology while running the ships, which is expensive. Can the UKRI afford to meet those initial costs over the next 15-18 years?"

Collecting oceanographic data using autonomous fleets isn't necessarily cheaper. And it's certainly not easier. There are still significant development costs alongside the capital costs of scaling up this new technology. A fleet of around 300 gliders requires infrastructure and technical support staff to operate and maintain the platforms. And, in the end, it costs almost the same as operating and maintaining a large research vessel (if you take into consideration the depreciation cost of the ship). Over time, the price of autonomy will eventually reduce and their unique capabilities will open up new areas of exploration.

Building the Autonomous Capacity

The NOC has 50-plus autonomous platforms in its fleet. But, according to Storey, they need to expand this to 500 (alongside developing new sensor payloads) to have the impact and data-collection capacity the science community needs. Other nations, including the U.S., are also growing their fleets and starting to experiment with how best to operate large numbers of platforms together during one mission.

There are still many issues that engineers are trying to resolve to make remote, long-term data collection missions and 'swarming' capabilities a reality. These include preventing biofouling on sensors and how to dock and recharge platforms while they are still in the water.

"There have been some nice projects with an unmanned surface vessel (USV) and a glider. If you can redock the glider into the USV, you can upload the data, potentially clean the sensors and send it off again with recharged batteries. That will be of interest to several industries. Then there are the issues around data ecosystems - the 'C3' Comms, Command and Control components. How do you control these assets and get the data to the users in a way they want to use it, efficiently and cheaply? Ocean Infinity is one of many organizations working in this area of robotics. Once you unlock those challenges then that in itself will be transformational in terms of our remote sensing capabilities."

Autonomous platforms come in all sizes, from the 1-meter-long ecoSub which you can transport in a rucksack to Boeing's 51-foot-long Echo Voyager. Operating large diverse fleets in a cohesive manner is not easy, but it's a challenge many in the industry are working to resolve.

Once the technologies are working harmoniously together in the water, how can scientists' use the systems to their benefit? Storey suggests the answer could be adopting a similar model to that of the Hubble Space Telescope. A scientist can 'hire' fleets for a few hours to collect data, have the ability to turn certain sensors on/off as needed, then pass the controls along to the next scientist to use. But if we are to build a net zero oceanographic sector, there needs to be a fundamental shift in how we conduct science on an international scale.

Adopting a New Net-Zero Approach

Storey said, "The biggest challenge is that it will require change. Not just in our industry but every industry. Almost everyone on the planet is up for reducing our impact on the climate but when it comes to changing our own behaviors – which isn't always convenient – we are usually less keen."

There needs to be a major overhaul to a firmly ingrained way of doing things in science. The first thing on Storey's to-do list is to change the way we use our research vessels. "Countries are often determined to conduct national science using their own vessels, even if it means traveling 3,000 miles when there is already a research vessel from another country there."

Using the Marine Facilities Planning system (MFP), it is now possible for scientists to see the location of almost every research vessel on the planet. In an ideal scenario, a UK-based Principal Investigator can reach out to the scientists onboard an Iceland-owed vessel that happens to be in the location of interest and ask them to take some measurements. This new approach to planning will require a systematic change to funding and in how scientists work together as a global community.

Are scientists going to have to compromise? Storey thinks so, but there are also opportunities for accessing novel data sets that wouldn't be available under the current ecosystem.

"One of the things we don't currently do is estimate our footprint upfront when we are planning research expeditions – it's just not something we automatically consider. When this becomes part of the process, it becomes part of the estimate and planning cost and that drives some of the behavioral changes in how, where and when we choose to conduct the science."

Storey adds, "Some may argue that the data collected and the good that comes from that research offset the carbon impact of collecting the data. No one should take away from the report 'stop doing science'. But if we as a scientific body are telling society to change their behavior otherwise the climate crisis will get worse, that is undermined if we can't demonstrate we are doing it ourselves."

The report shows that it is possible for the oceanographic sector to become net zero. It is expensive and requires changes across the entire ecosystem. But it is possible. Fortunately, one thing that hasn't changed over the last 150 years is scientists' ability to reimagine and create novel experiments when the need is there. Now it's time to reimagine our approach to how we conduct science.

Access the Marine Facilities Planning system at:
> http://nerc.marinefacilitiesplanning,com/programme

Unique Seagrass Nursery Aims to Help Florida's Starving Manatees

More than 1,000 manatees died in 2021, due mostly to starvation. A new study shows that about 7,400 acres of seagrasses were lost in the Florida's Indian River Lagoon (IRL) between 1943 and 1994. Between 2011 and 2019, about 58 percent of seagrasses were lost. To help with recovery efforts, researchers are experimenting with growing seagrass in large tanks and then transplanting it into the IRL to try to restore some of the lost seagrass beds.

> www.ecomagazine.com/33ra

Paris Agreement Limits Still Catastrophic for Coral Reefs

Scientists have discovered that more than 90 percent of tropical coral reefs will suffer frequent heat stress -- their number one threat -- even under Paris Agreement climate warming limits. The study suggests that the future of coral under 1.5°C heating is even worse than predicted by the Intergovernmental Panel on Climate Change.

> www.ecomagazine.com/33r3

'Taste' and 'Smell' of Coral Reefs Provide Insights into a Dynamic Ecosystem

Hundreds of molecules that are made by important members of the coral reef community were recently discovered by a team of scientists. Together, the compounds -- modified amino acids, vitamins and steroids -- comprise the 'smell' or 'taste' of corals and algae in a tropical reef, and will help scientists understand both the food web dynamics and the chemical ecology of these ecosystems.

> www.ecomagazine.com/334x

Why Are Some Stony Coral Species Better at Surviving Ocean Acidification?

Hard corals grow by generating calcium carbonate ($CaCO_3$) from seawater and adding it to their skeletons, where it crystallizes. This process -- and coral survival -- are threatened by ocean acidification. However, scientists report that corals produce the $CaCO_3$ in compartments protected from seawater and not, as previously believed, in exposed locations. The findings, and differing crystallization rates, could explain why some species are more resilient to this threat.

Stony corals extract calcium and carbonate ions from seawater to make $CaCO_3$, which is then attached to the growing skeleton in the form of amorphous particles that gradually harden into the less-soluble "aragonite" crystal structure. Conventional wisdom holds that the particles form and grow in a 2-micron-thick layer of liquid on the skeleton surface known as the extracellular calcifying fluid (ECF). Because of photosynthesis by symbiotic organisms in the coral, the ECF's pH rises in the daytime and then drops again each night. Normally, that wouldn't be a problem, but because it is partly exposed to seawater, the ECF also acidifies to some degree when seawater pH declines. That would interfere with $CaCO_3$ formation and deposition, and kill corals that are most sensitive to a drop in pH. If, instead, nucleation and growth of $CaCO_3$ particles occur in intracellular compartments protected from seawater and the ECF, then even sensitive species could have a chance at surviving acidification, as long as the pH doesn't go too low.

In coral samples, the research team detected amorphous $CaCO_3$ particles in a layer of cells that lie above the ECF. This finding is consistent with the growth of the particles inside closed vesicles -- or tiny sacs -- within these cells, the researchers say. That means the particles are formed safely away from seawater and not in the ECF. However, once attached to the growing skeleton surface, they're exposed to the ECF, where they're at risk of dissolving before they crystallize. The team found that crystallization rates vary significantly across species. For instance, the freshly added $CaCO_3$ crystallizes more quickly, and therefore remains soluble for a shorter time in *Stylophora pistillata*, a species known to be less vulnerable to ocean acidification.

> www.ecomagazine.com/33qh

African Heritage Sites Threatened by Sea-Level Rise

A global team of climate risk and heritage experts have provided the first comprehensive assessment of exposure of African cultural and natural Heritage Sites to extreme sea levels and erosion associated with accelerating Sea Level Rise.

Ruins in Tipasa, Algeria, are in danger of coastal flooding and erosion, says new research.

A global team of climate risk and heritage experts have provided the first comprehensive assessment of exposure of African cultural and natural Heritage Sites to extreme sea levels and erosion associated with accelerating sea level rise.

The team invested a year identifying and painstakingly mapping the physical boundary of 284 African coastal heritage sites. They then modelled the exposure of each site at future global warming scenarios.

They found 56 sites (20 percent) are at risk from a one-in-100-year extreme sea-level event including the iconic ruins of Tipasa (Algeria) and the North Sinai archaeological Sites Zone (Egypt). The paper's authors shared, "By 2050, the number of exposed sites is projected to more than triple, reaching almost 200 for high emissions."

At least 151 natural and 40 cultural sites will be exposed to the 100-year event from 2050 onwards, regardless of the warming scenario. The authors explained, "There are several countries which are projected to have all their coastal heritage sites exposed to the 100-year coastal extreme event by the end of the century, regardless of the scenario: Cameroon, Republic of the Congo, Djibouti, Western Sahara, Libya, Mozambique, Mauritania, and Namibia."

Under the worst-case scenario, this is also true for Côte d'Ivoire, Cabo Verde, Sudan and Tanzania. They added: "This is very concerning because none of these countries currently demonstrate adequate management or adaptive capacity to anticipate or establish heritage protections commensurate with the severity of these hazards."

A co-author on the paper shared, "Small Island heritage sites are especially at risk. For example, Aldabra Atoll, the world's second-largest coral atoll, and Kunta Kinteh Island could both see significant amounts of their extent exposed by 2100 under high emissions raising questions of their survivability under climate change."

The results highlight the importance of climate change adaptation and mitigation responses to protect and reduce the exposure of these iconic heritage sites.

The authors explained: "If climate change mitigation successfully reduces greenhouse gas emissions from a high-emissions pathway to a moderate emissions pathway, by 2050 the number of highly exposed sites can be reduced by 25 percent. This would be a significant saving in terms of Loss and Damage from climate change. These findings help with prioritizing sites at risk and highlight the need for immediate protective action for African Heritage Sites; the design of which requires in-depth local-scale assessments of vulnerability and adaptation options. Urgent climate change adaptation for heritage sites in Africa includes improving governance and management approaches; site-specific vulnerability assessments; exposure monitoring; and protection strategies including ecosystem-based adaptation."

> www.ecomagazine.com/33q4

Championing the Issue of Ocean Acidification

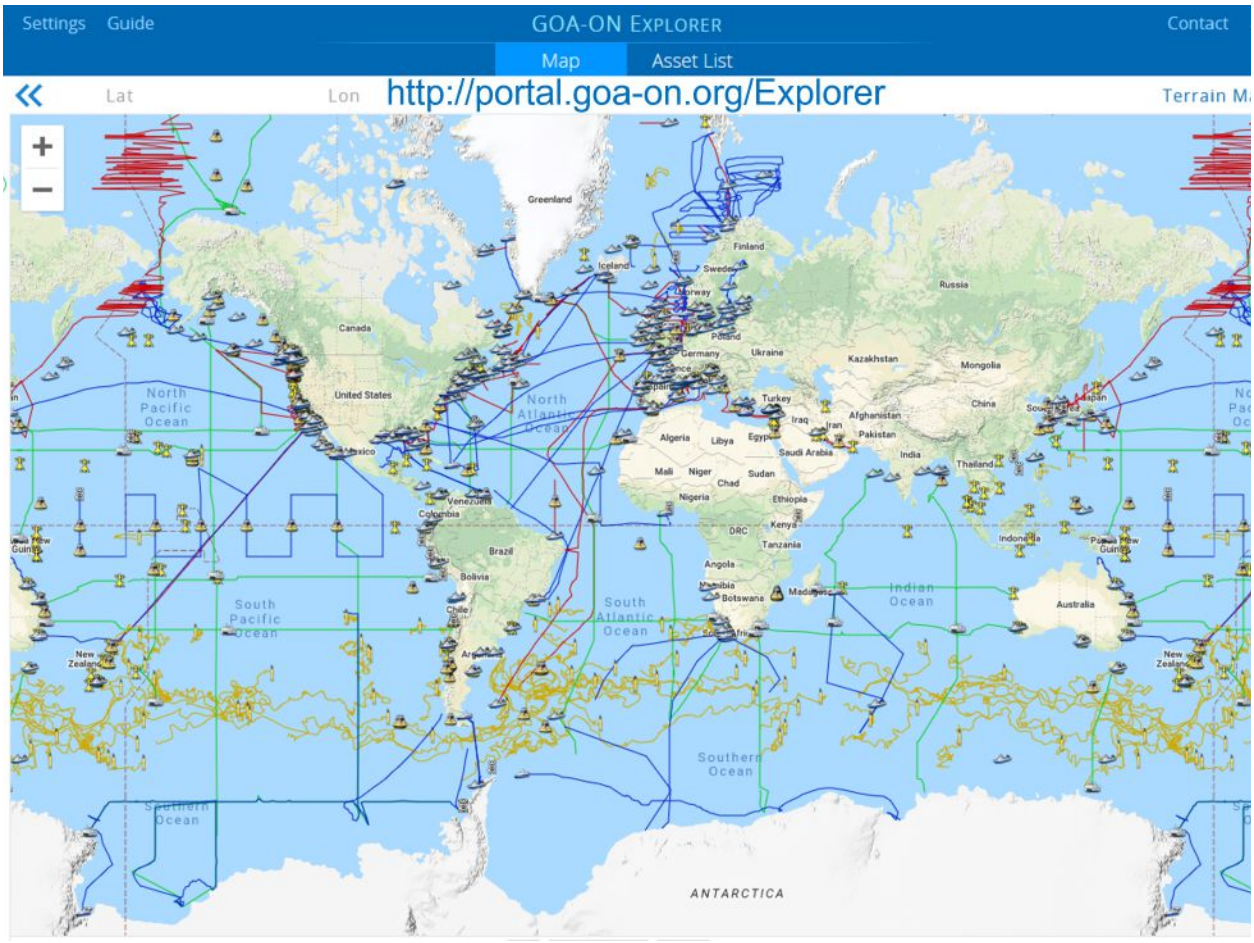
Pacific Islands OA Training

By Katherina L. Schoo (IOC-UNESCO), Kerri L. Dobson (NOAA Katherina L. Schoo (IOC-UNESCO), Kerri L. Dobson (NOAA OAP), Jan Newton (University of Washington), Steve Widdicombe (Plymouth Marine Laboratory), Kirsten Isensee (IOC-UNESCO), OARS Champions

The surface ocean has absorbed roughly a quarter of all carbon dioxide (CO_2) emissions resulting from human activities (McKinley *et al.,* 2016; Gruber *et al.,* 2019; Friedlingstein *et al.,* 2020). This natural process has helped to buffer the effect of climate change on the planet. However, this comes at a high cost to the ocean. As the atmospheric CO_2 dissolves into the ocean, it reacts with seawater, driving changes in ocean carbonate chemistry and increasing its acidity. Cumulatively, these processes are called ocean acidification (OA).

Changes in the ocean's carbonate chemistry can have wide-reaching impacts on marine organisms and ecosystems. For example, OA can reduce many marine organisms' ability to calcify, including reef-building corals and shelled mollusks. And it has been shown to cause a range of physiological and behavioral responses at the organism level that can affect biodiversity and ecosystem structure. Direct consequences for marine life growth, reproduction, development, and survival can propagate through the food web. In turn, this can affect ocean-related services and uses, including food security from fisheries and aquaculture, livelihoods, transportation, coastal protection, tourism, and cultural heritage. Coastal regions are expected to be strongly affected by OA. But their highly dynamic nature and the additional influences on these environments, such as temperature changes, freshwater run-off, nutrient influx, and biological activity, make it challenging to uncover the specific controls and impacts of OA alone.

Photo Credit: Renata Romeo, Ocean Image Bank



A Global Climate Indicator

The need for improved research, observation, and prediction of OA - and its global impacts - has been recognized at intergovernmental levels. This includes the UN General Assembly, the UN Convention on the Law of the Sea, the Convention on Biological Diversity, and the Intergovernmental Panel on Climate Change (IPCC).

In 2015, the UN General Assembly established ocean acidity as one of 10 targets for the Sustainable Development Goal (SDG) 14: Life below water. The Intergovernmental Oceanographic Commission (IOC) of UNESCO is the custodian agency for the Indicator under Target 14.3, which calls to *"minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels"*. The Methodology for the SDG 14.3.1 Indicator provides guidance on measuring seawater carbonate chemistry and how to facilitate reporting on ocean acidity by the Member States. In 2018, the World Meteorological Organization established OA as a headline climate indicator for reporting to the UN Framework Convention on Climate Change (UNFCCC) and has included ocean acidification in its yearly Statement on the State of the Global Climate.

Enhancing OA Observation

We must monitor carbonate chemistry to improve our understanding of the variability and rates of change in OA at local to global scales and combine these observations with studies of biological impacts. These are central aims of the Global Ocean Acidification Observing Network (GOA-ON) . The network consists of researchers covering many ocean science fields, stakeholders, civil society, and policymakers, working together to develop capacity and awareness of OA worldwide. This integrated global observing network is increasing our understanding of the biological impacts of OA in the context of multiple stressors, including increased temperature, changes in nutrient concentrations, and lower dissolved-oxygen concentrations. GOA-ON members use these observations to ground-truth forecasts and optimize biogeochemical and biological models related to ocean acidification.

In 2021, GOA-ON's Ocean Decade Action entitled "*Ocean Acidification Research for Sustainability - Providing society with the observational and scientific evidence needed to sustainably identify, monitor, mitigate and adapt to ocean acidification; from local to global scales (OARS)*" was endorsed as a program of the UN Decade of Ocean

Science for Sustainable Development. OARS builds on the successful work of GOA-ON by broadening the development of OA science by enhancing OA observation and research capacity. The end outcome will increase our understanding of ocean chemistry changes and their impacts worldwide, especially in locations where this data is lacking. Specifically, OARS will provide systematic evidence of the impacts on marine ecosystems on local and global scales. And support society and decision-makers with the information needed to mitigate and adapt to OA, facilitating the development and evaluation of strategies to offset future impacts.

Building on the success and lessons learned from the work of GOA-ON in supporting the OA community, OARS will expand this network to address broader community needs, such as interactions of OA with multiple ocean stressors, as well as greater engagement with and knowledge delivered to specific regions, industry, and policymakers.

The OARS programme provides a vision for ocean acidification research for the next decade, which sets out a roadmap that, when implemented in collaboration with multiple partners, will deliver against seven outcomes by 2030. These outcomes are:

1. Enable the scientific community to provide ocean acidification data and evidence of known quality.
2. Identify data and evidence needs for mitigation and adaptation strategies, from local to global, by 2022.
3. Co-design and implementation of observation strategies in collaboration with data/information producers and end-users by 2025.
4. Increase understanding of ocean acidification impacts to protect marine life by 2030.
5. Provide appropriate data and information necessary to develop societally relevant predictions and projections.
6. Increase public awareness of ocean acidification, its sources, and its impacts.
7. Develop strategies and solutions to enable countries and regions to include measures to reduce ocean acidification in their respective legislation.

OARS was first introduced to the global community during a UN Ocean Decade Laboratory satellite event, which coincided with GOA-ON's "Ocean Acidification Week 2021" virtual conference. A short video outlined how the OARS programme will support the Decade's implementation at the satellite event, officially launching the initiative. In addition, a panel discussion took place with remarks from UN Special Envoy for the Ocean, Peter Thompson. The OARS programme was also promoted at COP26 by GOA-ON representatives, including GOA-ON co-chair Professor Steve Widdicombe and OARS Coordinator Dr. Kirsten Isensee.

Looking Forward

Looking forward, the OARS team hopes to contribute to the Our Ocean Conference in Palau (April 2022), to which GOA-ON co-chair Professor Jan Newton has been invited. A side event will also be held at the UN Ocean Conference in Portugal in June 2022. In September 2022, the OARS programme will be well represented at the 5th International Symposium on the Ocean in a High-CO_2 World in Peru. The team plans to leverage the gathering of the ocean acidification community to increase actions towards the OARS programme. A side event will bring the leaders of the nine GOA-ON regional hubs to discuss OARS efforts and synergies.

To ensure the successful implementation of the OARS programme, co-champions have been identified by GOA-ON and its partners. These co-champions - who are experts within their fields - will assemble working groups tasked with finding the path towards achieving the seven outcomes by identifying the key actions, drivers, and enablers needed.

Over the next 12 months, the working groups will draft implementation plans outlining the delivery of their outcome. They will follow a "Theory of Change" structure and prepare a draft timeline and indicative budget to support the implementation plan. The co-champions and working groups will also seek funding to develop key actions and projects. Furthermore, they will identify and engage with key partners and funders and forge links with other UN Ocean Decade endorsed programs to support the delivery of the outcomes. This will broaden the scope of GOA-ON and involve all of the partner agencies involved. The main GOA-ON partners are NOAA and its Ocean Acidification Programme (NOAA OAP), the IAEA and its Ocean Acidification International Coordination Centre (IAEA OA-ICC), and the IOC-UNESCO. Other partners in OARS include the Global Ocean Observing System (GOOS), the International Ocean Carbon Coordination Project (IOCCP), the International Alliance to Combat Ocean Acidification, The Ocean Foundation (TOF), and two other UN Ocean Decade Programmes, namely the Global Ocean Oxygen Network's (GO2NE) Global Ocean Oxygen Decade (GOOD) and the Marine Biodiversity Observation Network's (M-BON) Marine Life 2030. Together, the co-champions and working group members will put OARS on the path to achieving the overarching vision of this program by providing societies with the observational and scientific evidence needed to sustainably identify, monitor, mitigate, and adapt to ocean acidification from local to global scales. Countries can then better manage, mitigate, and reduce the impacts of ocean acidification on marine ecosystems, the goods and services they provide, and the human communities that rely on them.

By delivering the seven outcomes, OARS will create a number of ultimate benefits: providing a clean, diverse, productive ocean capable of supporting the health, well-being, and livelihoods of human societies dependent on marine resources. If you, too, would like to be involved in this effort and contribute to the UN Ocean Decade through actions, please contact either Dr. Kirsten Isensee (k.isensee@unesco.org) or the GOA-ON Secretariat (Secretariat@goa-on.org).

Discover more at:

- http://goa-on.org/
- http://www.goa-on.org/oars/overview.php

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Compact, Flexible and Easy-to-Use Sensor Technology for Ocean Measurements of pH and Oxygen

By Anfisa Berezina & Evgeniy V. Yakushev (Norwegian Institute for Water Research (NIVA), and Andrea Wieland (PyroScience GmbH)

The CO_2 uptake by oceanic surface waters results not only in lowering of the world's ocean pH value (Bellerby 2017), but as a consequence also in an undersaturation of essential carbonate minerals. Research suggests that many of the effects of ocean acidification on marine organisms and ecosystems will be variable and complex with disruptions to large components of the marine food web. Many questions remain regarding the biological and biogeochemical consequences of ocean acidification for marine biodiversity and ecosystems, and the impacts of these changes on oceanic ecosystems (Secretariat of the Convention on Biological Diversity (2009).

Studies on such phenomena require robust sensors that can detect multi-scale changes of dissolved oxygen and pH. Moreover, studies of ocean acidification should be based on measurements of pH on the total scale, which is more relevant for seawater (Dickson *et al.* 2007).

Advantages of Optical pH Sensor Technology

The criteria for an affordable, robust and reliable sensor for global pH monitoring can be met by optical sensor technology. The optical pH sensors from PyroScience are based on a unique optical detection principle (REDFLASH technology) and provide a viable alternative to traditional pH measurement devices such as pH electrodes.

The REDFLASH technology utilizes red excitation light and uses the NIR emission of the new pH (luminescent) sensor to overcome background fluorescence of the sample which was already successfully applied for optical oxygen sensors from PyroScience. The pH sensors feature an outstanding low cross-sensitivity to ionic strength at marine conditions, as well as an exceptional sensitivity at defined pH range, and are also available for measurements on the total pH scale.

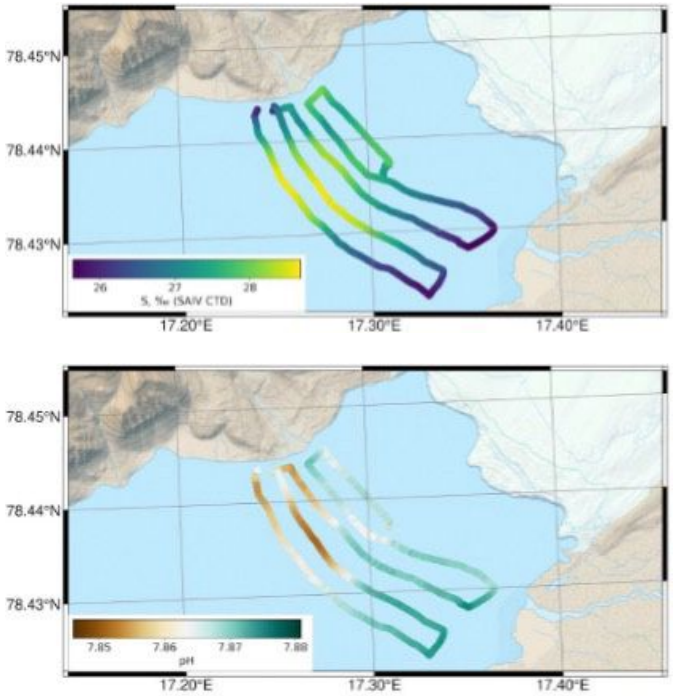

Figure 1: Distributions of salinity (top) and pH (bottom) in the Tempelfjord (Spitsbergen, NO) (data from Anfisa Berezina & Evgeniy V. Yakushev, NIVA)

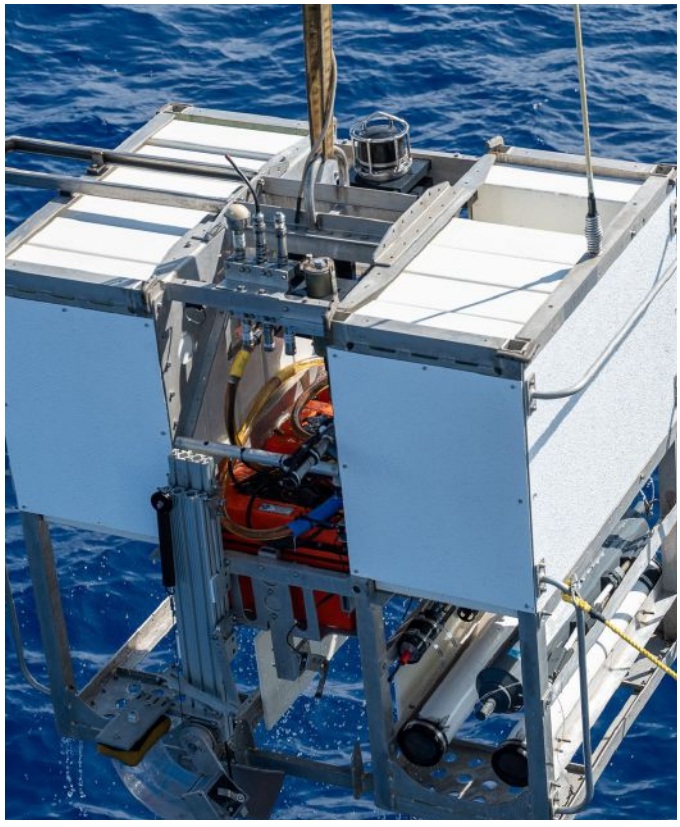

Figure 2: Deep dive of the new AquapHOx deep sea logger with the new optical pH sensor for the total scale in the Hawaiian Islands. (Credit: Discover Our Oceans LLC)

These optical pH sensors can be operated with the flexible multi-channel PC-operated fiber-optic meter FireSting©-PRO or the underwater AquapHOx© long-time loggers and real-time data transmitters. For these one-device solutions, a great variety of different optical sensor formats for pH and O_2 is available, including minimally invasive micro- and minisensors, robust probes, sensor caps, and contactless sensor solutions (flow-through cells, sensor spots & vials). This allows for maximum flexibility concerning analyte (pH, O_2, T), diverse sensor formats, and application on ships/research vessels with freshly collected water samples or underwater *in situ*.

Total pH Transects in the Tempelfjord (Spitsbergen)

An example of measurements performed in freshly collected water samples with the PyroScience seawater pH sensor for the total scale in combination with the FireSting©-Pro are shown in Figure 1. In repeated transects with a distance of 150 meters in a fjord in Spitsbergen (Norway), zones with lower and higher pH were detected and corresponded to low saline waters affected by melting glacier and higher saline open seawater.

In Situ Deep Sea pH Measurement

Besides the application of PyroSciences' sensor systems in sampled water, application of the new compact and easy-to-use underwater AquapHOx© platform could help to investigate the distribution of oceanographic parameters (O2, pH, T) and their dynamics also at greater water depths *in situ*.

The new AquapHOx© technology comprises various products like single analyte (O_2, pH, T) shallow water long-term loggers for stand-alone operation during long monitoring approaches and transmitters with real-time data transmission for water column profiling. The flexible deep-sea multi-analyte logger/transmitter can be operated down to 4,000-meter water depth with various optical oxygen, pH, and temperature sensor formats.

With the pH sensors from PyroScience, sensitive measurements of ocean pH on the total scale can be performed even under harsh deep-sea conditions with negligible impact of salinity, and can be used to study the effects of ocean acidification on marine calcifying organisms of this important and essential ecosystem.

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Equipping Scientists and Communities

How The Ocean Foundation Builds Ocean Acidification Resilience Around the Globe

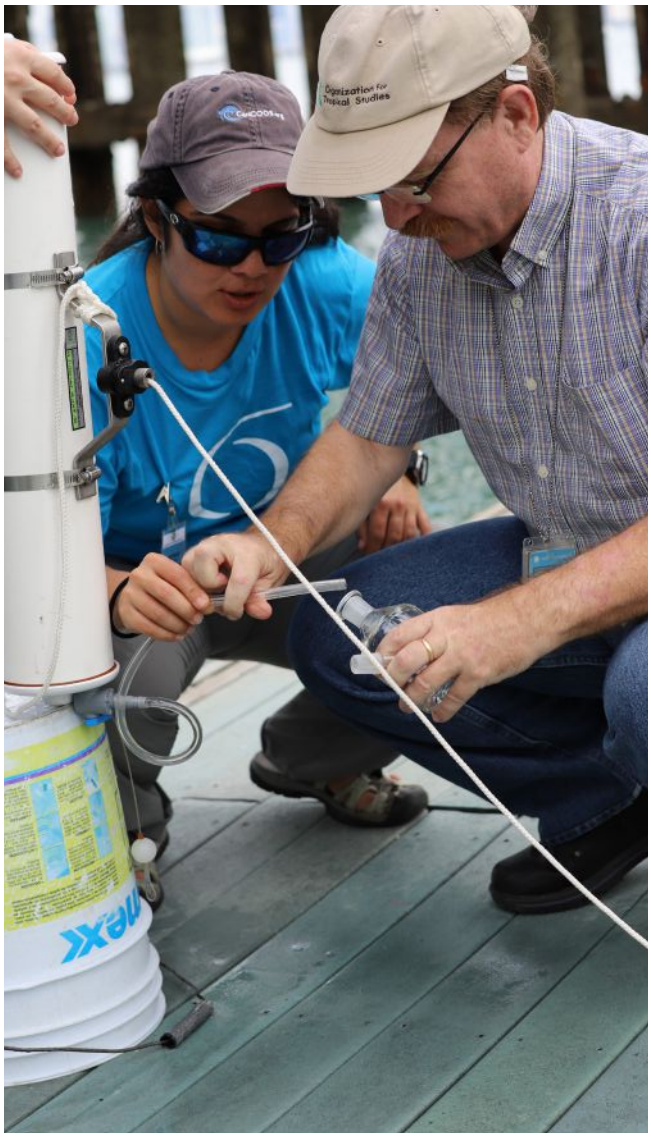
There is a lot we still don't know about the ocean. What we do know is that the ocean is intimately affected by — and affects — the balance of carbon dioxide on our blue planet. And Ocean Acidification (OA) is one little-known yet wide-reaching effect of increasing carbon dioxide levels in our atmosphere.

Across the globe, ocean chemistry is changing faster now than at any other time in history. And on average, seawater is 30 percent more acidic than it was 200 years ago. As the ocean becomes more acidic, marine life can't easily contend with these rapid changes and neither can the communities that depend on these resources.

Building the capacity to track, understand, and respond to ocean chemistry changes is critical to adapt to OA. Since 2003, The Ocean Foundation (TOF)'s International Ocean Acidification Initiative (IOAI) has fostered innovation and partnerships to support scientists, policymakers, and communities around the world. Our global strategy involves *monitoring* how and where ocean chemistry changes are occurring, *analyzing* the effects of OA on natural and human communities, *engaging* in coalitions with stakeholders, and *acting* with legislation to help communities mitigate and adapt.

Resilience to OA requires dynamic and adaptive management. And this management requires a constant feedback loop between science and policy. TOF strengthens this loop by working with countries to advance national frameworks for understanding and responding to OA. In Mexico, we are helping to build a data hub to support their national ocean policy and ensure both scientific and policy instruments sufficiently address ocean threats. TOF is also supporting multi-year efforts to build regional monitoring, adaptation, and policy capacity in West Africa and the Pacific Islands, as well as a one-year regional vulnerability assessment in Puerto Rico. And in partnership with the International Alliance to Combat Ocean Acidification, we held a workshop for 200 scientists in more than 20 countries to learn how to engage with policymakers to advance science-based management.

TOF is also increasing access to tools that make it easier for scientists and resource managers to understand and respond to a changing ocean. One such approach, the "Global Ocean Acidification Observation Network (GOA-ON) in a Box", is a kit of field and lab equipment that helps scientists take high-quality local measurements of OA and share these data globally. To lower the cost of addressing OA in shellfish hatcheries, TOF imagined and funded the creation of the pCO_2 to Go sensor, a low-cost, handheld sensor built by Dr. Burke Hales and tested with Alutiiq Pride Marine Institute that helps achieve optimal growing conditions for young, vulnerable shellfish.



GOA-ON in a Box in action: During a hands-on training in Panama, course participants learn how to collect samples for ocean chemistry analysis using established global practices. (Credit: Alexis Valauri-Orton at TOF)

The Ocean Foundation works to ensure every country has a robust OA monitoring and mitigation strategy, driven by local experts to address local needs. Our International Ocean Acidification Initiative is how we help build the science, policy and technical capacity of practitioners worldwide and in their home countries.

For more information, visit us at:

> https://oceanfdn.org/projects/ocean-acidification/

Impacts of Ocean Carbon Dioxide Removal on Ocean Acidification Monitoring

By Mark Barry, Pro-Oceanus Systems

Long-term, high-quality ocean acidification (OA) monitoring programs have revealed the subtle yet critical changes occurring in our global oceans resulting from increasing atmospheric CO_2 concentrations. Key to the success of these programs is consistency of the measurements by scientists through a collaborative effort. The stability of these programs may be challenged in the future with new technologies for removing CO_2 from the atmosphere that seek to use the ocean as a tool for effectively storing CO_2.

Ocean Carbon Dioxide Removal (CDR) is gaining global attention as a potential method of atmospheric CO_2 removal, and though yet to be proven, it has attracted substantial funds in an initial exploratory phase of development, testing and verification.

On-land methods such as carbon capture, utilization and storage (CCUS) have been established for more than 25 years, with subsea carbon, capture and storage (CCS) having been tested in a number of locations to date. However, there are many unanswered questions on ocean CDR impacts.

The ocean is the single largest sink of carbon in the world. We need to understand critical ocean chemistry dynamics as they are today, as well as how ocean-based CDR technologies will affect and drive changes in the future. This requires scaling of projects to considerable size and testing in international waters. In turn, this necessitates having a global approach through government involvement in policy development to ensure that these technologies are both safe and quantified by meaningful parameters such as dissolved CO_2, pH, dissolved inorganic carbon, and alkalinity, as well as ecosystem monitoring to determine biological impacts of the desired chemical changes.

With this in mind, the future will bring about more change in ocean chemistry. But how we interpret the data will undoubtedly become more complex with ocean-based CDR methods that, in most cases, will be highly localized and not necessarily focused on OA mitigation as their true measure of success.

As industry becomes a major advocate and technology innovator for counteracting climate change, quality long-term monitoring of ocean chemistry will come with new challenges and opportunities in understanding the global impact this will have with respect to OA. All parties involved will need to work together and generate a synergetic understanding and direction for this major effort moving forward.

| Photo Credit: Alex Mustard, Ocean Image Bank

Antarctic Research Reveals Link Between Warming and Fish Abundance

A long-term study in the Southern Ocean reveals a clear correlation between warming waters, decreased sea ice, and reduced abundance of Antarctic silverfish. These small, abundant fish are important prey for penguins, seals, and other regional marine life, in a role similar to that played by anchovies or sardines in more temperate waters.

Photo Credit: Andrew Corso/VIMS

Lead author Andrew Corso, a doctoral candidate at William & Mary's Virginia Institute of Marine Science, says, "This is the first statistically significant relationship reported between sea ice and the long-term abundance of any Antarctic fish species. With continued regional warming, these fish could disappear from the region entirely, triggering major changes in the marine ecosystem."

The study is based on Corso's analysis of more than 7,000 larval fish specimens collected over 25 years (1993-2017) as part of VIMS' participation in the NSF-funded Palmer Antarctica Long-Term Ecological Research program.

Adaptations that allow Antarctic silverfish to thrive in the region's frigid waters -- they can make up more than 90 percent of fish biomass in coastal areas of the Southern Ocean -- also make them susceptible to ocean warming and loss of sea ice.

"Sea ice plays a unique role in the life history of these fish," says Corso. "They deposit their eggs within sea ice -- which also serves as a nursery area for newly hatched larvae -- so a loss of sea ice for them is akin to a loss of milkweed for monarch butterflies."

The health of these fish, both larvae and adults, is also likely to be impaired by warmer water temperatures. Previous experiments with closely related Antarctic fishes have shown that a 9°F (5°C) increase in water temperature can kill some species outright, and also reduce the rate at which these fishes assimilate their food.

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Deep Insights into the Arctic of Tomorrow

Hundreds of international researchers are currently analyzing observations from the one-year MOSAiC expedition, during which hundreds of environmental parameters were recorded with unprecedented accuracy and frequency over a full annual cycle in the Central Arctic Ocean.

They have now published three overview articles on the MOSAiC atmosphere, snow and sea ice, and ocean programs in the journal *Elementa*, highlighting the importance of examining all components of the climate system together.

Diminishing sea ice is a symbol of ongoing global warming: in the Arctic, its extent has almost halved in summer since satellite records began in the 1980s. Less well studied but equally relevant are the thickness and other properties of the ice. The question of what this means for the future Arctic and how these changes will affect the global climate were the impetus for the historic MOSAiC expedition with the German research icebreaker *Polarstern* from September 2019 to October 2020. With these results coming out now the researchers are building the most complete observation-based picture of climate processes in the Arctic, where the surface air temperature has been rising more than two times as fast as on the rest of the planet since the 1970s.

During the expedition, the icebreaker froze to a large ice floe and drifted with the natural transpolar drift across the Arctic Ocean. And this is where the first surprises came. "We found more dynamic and faster drifting pack ice than expected. This not only challenged the teams on the ground in their daily work, but above all resulted in changed sea-ice properties and sea-ice thickness distributions," reports Dr Marcel Nicolaus, sea-ice physicist at the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) and co-leader of Team Ice in the MOSAiC project.

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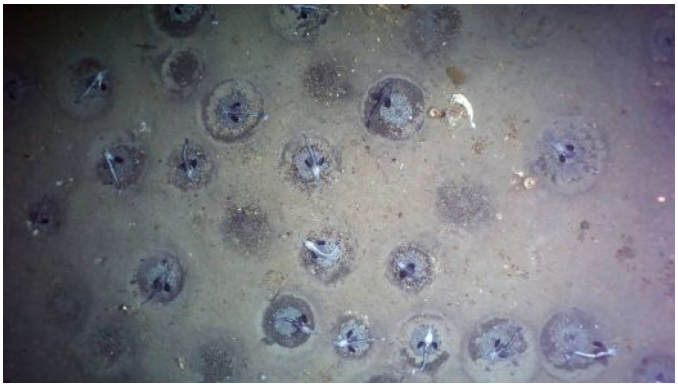
World's Largest Fish Breeding Area Discovered in Antarctica

Near the Filchner Ice Shelf in the south of the Antarctic Weddell Sea, a research team has found the world's largest fish breeding area known to date.



| Photo Credit: PS124, AWI OFOBS Team

A towed camera system photographed and filmed thousands of nests of icefish of the species *Neopagetopsis ionah* on the seabed. The density of the nests and the size of the entire breeding area suggest a total number of about 60 million icefish breeding at the time of observation. These findings provide support for the establishment of a Marine Protected Area in the Atlantic sector of the Southern Ocean. A team led by Autun Purser from the Alfred Wegener Institute publish their results in the scientific journal *Current Biology.*

The joy was great when, in February 2021, researchers viewed numerous fish nests on the monitors aboard the German research vessel *Polarstern*, which their towed camera system transmitted live to the vessel from the seabed, 535 to 420 meters below the ship, from the seafloor of the Antarctic Weddell Sea. The longer the mission lasted, the more the excitement grew, finally ending in disbelief: nest followed nest, with later precise evaluation showing that there were on average one breeding site per three square meters, with the team even finding a maximum of one to two active nests per square meter.

The mapping of the area suggests a total extent of 240 square kilometers, which is roughly the size of the island of Malta. Extrapolated to this area size, the total number of fish nests was estimated to be about 60 million.

"The idea that such a huge breeding area of icefish in the Weddell Sea was previously undiscovered is totally fascinating," says Autun Purser, deep-sea biologist at the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) and lead author of the current publication. After all, the AWI has been exploring the area with its icebreaker *Polarstern* since the early 1980s. So far, only individual *Neopagetopsis ionah* or small clusters of nests have been detected here.

The unique observations are made with a so-called OFOBS, the Ocean Floor Observation and Bathymetry System. It is a camera sledge built to survey the seafloor of extreme environments, like ice-covered seas.

Several types of fish nests were distinguished: "Active" nests, containing between 1,500 and 2,500 eggs and guarded in three-quarters of the cases by an adult icefish of the species Neopagetopsis ionah, or nests which contained only eggs; there were also unused nests, in the vicinity of which either only a fish without eggs could be seen, or a dead fish. The researchers mapped the distribution and density of the nests using OFOBS's longer-range but lower-resolution side scan sonars, which recorded over 100,000 nests.

For AWI Director and deep-sea biologist Prof. Antje Boetius, the study is a sign of how urgent it is to establish marine protected areas in Antarctica. "This great discovery was enabled by a specific under-ice survey technology we developed during my ERC Grant. It shows how important it is to be able to investigate unknown ecosystems before we disturb them. Considering how little known the Antarctic Weddell Sea is, this underlines all the more the need of international efforts to establish a Marine Protected Area."

> www.ecomagazine.com/3399

Observing Human Footprints in the Southern Ocean

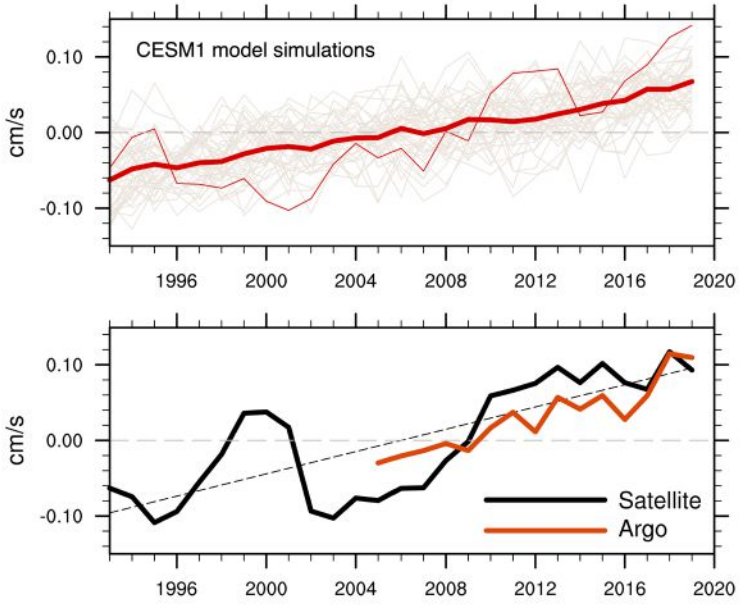
By Jia-Rui Shi (Woods Hole Oceanographic Institution), Lynne Talley and Shang-Ping Xie (Scripps Institution of Oceanography)

The Southern Ocean is far from major population centers but has emerged as a major player in the global climate system by absorbing vast amounts of human-induced heat and CO_2. The upwelling process in the Southern Ocean brings rich nutrients to the surface and fertilizes three-quarters of the biological productivity of the global ocean. The Antarctic Circumpolar Current, the only ocean current that circumnavigates the planet, is the primary agent that transports various oceanographic properties such as heat, salt, and nutrients between the Atlantic, Indian and Pacific basins. Recent observations have revealed that the Antarctic Circumpolar Current is speeding up and, this acceleration is due to ocean warming as a result of human activities.

Recent and Modern Observations in the Southern Ocean

Until recently, the Southern Ocean was among the most poorly sampled regions of the global ocean not only due to its remote location but also its severe environmental conditions such as the strong westerly winds, storms, high waves, sea ice, and strong ocean currents.

Satellite observations began to improve this situation in the early 1990s. In particular, satellite-mounted microwave altimeters have accurately measured sea surface height since 1992. Sea level, averaged over the globe, has risen at a rate of 0.33 centimeters per year from 1993 to 2019. This has mainly been caused by melting of glaciers and ice sheets, and by the ocean expanding as the water warms. It has been found that the sea level in the Southern Ocean experienced a big and significant change due to the change of ocean heat content, the energy stored within the ocean. This heat content change can be measured by the network of autonomous Argo floats, which profile ocean conditions such as temperature and salinity from the surface down to 2,000-meters depth. The global Argo network began in 1999 and reached full capacity in 2007. There are currently 4,000 floats scattered across the world's oceans that are collecting data. Without direct measurements of ocean velocity, the collected temperature and salinity can be used to estimate the upper layer velocity relative to a certain depth, say 2,000 meters.



Acceleration of Southern Ocean flow (48˚S-58˚S in latitudes) from model simulations (upper panel) and observations (bottom panel). Adapted from Shi *et al.* 2021

Southern Ocean Flow Acceleration Due to Ocean Warming

Its unique structure and physical processes make the Southern Ocean a major reservoir of anthropogenic heat. For instance, the Antarctic Circumpolar Current separates cold water in the south from warmer subtropical water just to its north, and this warmer flank of the Southern Ocean takes up more heat associated with human activities than its cooler flank. As the gradient between warm and cold water increases, the currents that border them speed up. The speedup of the Antarctic Circumpolar Current is centered on its Subantarctic Front.

Prevailing westerly wind over the Southern Ocean also has sped up in the context of global warming. However, climate models show that the wind speedup only plays a secondary role in accelerating ocean currents. The acceleration largely results from uneven warming of the ocean. It is also worth noting that the speedup of the Antarctic Circumpolar Current has just emerged from the background noise, taking advantage of the longer and extending observations in the water and from space. The observed change, together with corroborating climate model simulations, indicates that the speedup of the planet's most powerful ocean flow is a response to human activities.

Perspectives

The remote Southern Ocean is responding to and shaping global climate change in important ways. For example, faster ocean circulation can alter the ocean's property distributions and change how nutrients are carried across ocean basins and around the world, with important effects on marine lives and global ecosystems. Expanding deployments of biogeochemical floats will help us detect additional human impacts within the ocean, including acidification, and changes in nutrient and oxygen distributions. The researchers from the Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) project are actively involved in efforts to develop a global biogeochemical observing system of ~1,000 Argo floats equipped with SOCCOM-type biogeochemical sensors. It's important to note that the Southern Ocean zonal flow acceleration is expected to continue, given the continued uptake of anthropogenic heat by the Southern Ocean. In addition to setting the pace of global warming, the Southern Ocean heat uptake is a key driver for atmospheric circulation change between the Northern and Southern Hemispheres. Enhanced and sustained observations, together with model simulations, will offer better views of human footprints deeply hidden in the remotest seas.

To read more about Southern Ocean flow acceleration, please see Shi, J.-R., L. D. Talley, S.-P. Xie, Q. Peng, and W. Liu, (2021): Ocean warming and accelerating Southern Ocean zonal flow. *Nat. Clim. Chang.,* 11, 1090–1097.

The research project Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) aims to unlock the mysteries of the Southern Ocean and determine its influence on climate by utilizing cutting-edge observations and modeling studies. Find more information about the SOCCOM project: https://soccom.princeton.edu.

Detecting Ocean Life with a Wave-Propelled, Long Endurance Uncrewed Surface Vessel

Given the challenges we face with a changing climate, developing long-endurance, net-zero capability in ocean observations have never been more important. As well as meeting low-emission requirements, the modest speed and sound of the wave propelled AutoNaut uncrewed surface vessel (USV) is proving an asset in detecting marine mammals. The vocalizations of whales and dolphins were recently recorded throughout two passive acoustic baseline surveys in West Africa and Scotland.

A 75-day acoustic baseline survey was carried out off the West African coast between late 2018 and early 2019. During the survey, the first records of beaked whales, including Cuvier's beaked whale Ziphius cavirostris, were reported in the territorial waters of the Democratic Republic of São Tomé and Príncipe, Gulf of Guinea (African Journal of Marine Science, 43:4, 443-454, DOI: 10.2989/1814232X.2021.1982769).

The results suggest that beaked whales, which are sensitive to disturbance associated with underwater sound sources, did not avoid the small, wave-propelled vessel. Passive acoustic methods appear well-suited to surveys of this species group, possibly because the slow-moving USV optimised opportunities to detect them between their deep foraging dives.

In 2021, the 5-meter AutoNaut 'Oban' completed a 115-day, 4,000 nautical mile voyage down the shelf break west of Britain, operated remotely via a satellite link. Funded by Innovate UK and partnered by the Scottish Association for Marine Science (SAMS), with numerous other institutes involved, this was a proving trial for the 'AutoNaut for Extreme Environments' project. This project aims to develop a high latitude USV capable of operating in the Arctic Circle and the Southern Ocean – eventually in winter. Sensors deployed during this survey included Nortek's Signature500 ADCP, Seiche microPAM, SBE 49s CTD, and the Aanderaa Motus wave sensor from Xylem.

The vocalizations of whales and dolphins were recorded throughout the long voyage. Preliminary analysis of the Passive Acoustic Monitoring (PAM) survey data showed from many acoustic encounters with harbor porpoise and dolphin schools in the Sea of the Hebrides and in Stanton Banks Special Area of Conservation. An exciting series of high-frequency narrow-band vocalizations were also recorded, which may represent the first detection of a *Kogia* pygmy or dwarf sperm whale in this region. The analysis is ongoing, with results expected from comparisons with a range of moored acoustic arrays over which the AutoNaut conducted precise 'hourglass' transects. Analysis of ADCP data, also ongoing, is relevant to studies of the Atlantic sub-polar meridional overturning current and also to comparative analysis of wave data at Met Office deep-sea buoys M6 and M3.

"Such long endurance in that extreme environment proves the robustness of the AutoNaut wave-propulsion system," said Harry Spedding, General Manager of AutoNaut Ltd. "And it has been a great demonstration to our scientific and commercial stakeholders. With no fuel required, AutoNaut offers a long endurance ocean going platform with some special attributes."

The initial 'AutoNaut for Extreme Environments' 3-year project was interrupted by COVID-19. As a result, IUK funded this 'Extension' proving trial in 2021. Technology challenges for high latitude operations include anti-icing, the detection and avoidance of small ice in large waves, ice abrasion, materials combinations suitable for extreme cold, and providing 'hotel' power when it is dark for command, control and communications (C3), as well as sensors and other electronics.

The unique AutoNaut wave propulsion system, which uses pitch and roll of the hull in waves to drive small wings below the keel through the water – much like a penguin's wings but with no muscle required – does not produce electrical or other power. But it is inherently straightforward and robust and, therefore, suitable for extreme environments where it is dangerous to send ships. PV panels on deck are typically used to provide hotel power. Other power solutions are being tested for long endurance at high latitude in winter.

In addition to these novel technological challenges, the boat itself was 'hardened' to be capable of surviving repeated capsize and pitchpoling in large Southern Ocean waves.

Thorough drop and ice-impact tests were carried out in Phase 1 to test the newly designed rudder, struts, foils, fixing inserts, hatches, and hull parts. The 4,000-nautical mile voyage validated these improvements.

In the initial project, the University of East Anglia used its 'sea-ice chamber' facility to test all aspects of anti-icing and the effects of extreme cold and ice abrasion on build materials and PV panels. This proving trial showed the hydrophobic anti-icing solution remains effectively hydrophobic after 115 days at sea. However, it had already had a year of environmental exposure ashore.

In Phase 1, a solution to detect small ice in waves was identified. Work continues ashore with infra-red video and machine learning to inform the existing collision avoidance system.

As well as successfully verifying the technological solutions developed in Phase 1, the Extension trial was designed to demonstrate AutoNaut's new potential to external stakeholders. SAMS joined the project as a research partner and helped develop the science program. Other stakeholders became associated with the data collection component as the project developed. These included the Irish Marine Institute, Galway Marine Institute of Technology, OSNAP and iFADO partners, National Oceanography Centre, CEFAS, University of Exeter, and UK Met Office. The data collected is made freely available to all partners.

AutoNaut can steer a track between waypoints within a few meters of the line. A feature that was used to good effect in getting safely offshore through the Firth of Lorn, and later in completing repeated precise transects at Stanton Bank and S1, and further north with ADCP between EB1E and EB1W, on the shelf break to the Rockall Trough. From there, AutoNaut Oban zig-zagged south down the shelf break, eventually being recovered to Penzance in Cornwall.

Marine mammals are sensitive to disturbance associated with underwater sound sources, making observations via ship or motorized ocean platforms challenging. However, the slow-moving, wave-powered USV has proven its capability for close-range marine mammal observations. Now, we hope to send the AutoNaut USV into extreme environments to collect much-needed data in often unreachable regions of the ocean.

Widespread Sound Communication Among Fish

A new study from Cornell University finds that fish are far more likely to communicate with sound than generally thought -- and some fish have been doing this for at least 155 million years. They found 175 families that contain two-thirds of fish species that do, or are likely to, communicate with sound. Study authors found that sound was so important, it evolved at least 33 separate times over millions of years.

> www.ecomagazine.com/33r6

Lighted Nets Dramatically Reduce Bycatch

In a win-win for commercial fisheries and marine wildlife, researchers have found that using lighted nets greatly reduced accidental bycatch of sharks, rays, sea turtles, and unwanted finfish. Lighted gillnets reduced total fisheries bycatch by 63 percent, which included a 95 percent reduction in sharks, skates, and rays, an 81 percent reduction in Humboldt squid, and a 48 percent reduction in unwanted finfish, while maintaining catch rates and market value of target fish.

> www.ecomagazine.com/33r8

Blueprint to Reduce Overfishing and Protect Florida's Valuable Reef Fish

A new study found that more than 85 percent of the grouper and snapper studied are overfished. For black grouper, by increasing the current minimum catch size, the spawning population would grow to 40 percent, large enough to produce a meaningful number of new juveniles.

> www.ecomagazine.com/33qf

New Research Suggests Ocean Oxygen is Falling at Unnatural Rates, Impacting the World's Fisheries

Photo Credit: Paul Einerhand

New research finds the ocean's middle depths, home to many commercially fished species, started losing oxygen at unnatural rates in 2021.

By 2080, around 70 percent of the world's oceans could be suffocating from a lack of oxygen as a result of climate change, potentially impacting marine ecosystems worldwide, according to a new study. The new models find mid-ocean depths that support many fisheries worldwide are already losing oxygen at unnatural rates and passed a critical threshold of oxygen loss in 2021.

Scientists have been tracking the oceans' steady decline in oxygen for years, but the new study provides new, pressing reasons to be concerned sooner rather than later.

The new study is the first to use climate models to predict how and when deoxygenation, which is the reduction of dissolved oxygen content in water, will occur throughout the world's oceans outside its natural variability.

It finds that significant, potentially irreversible deoxygenation of the ocean's middle depths that support much of the world's fished species began occurring in 2021, likely affecting fisheries worldwide. The new models predict that deoxygenation is expected to begin affecting all zones of the ocean by 2080.

The ocean's middle depths (from about 200 to 1,000 meters deep), called mesopelagic zones, will be the first zones to lose significant amounts of oxygen due to climate change, the new study finds. Globally, the mesopelagic zone is home to many of the world's commercially fished species, making the new finding a potential harbinger of economic hardship, seafood shortages and environmental disruption.

"This zone is actually very important to us because a lot of commercial fish live in this zone," says Yuntao Zhou, an oceanographer at Shanghai Jiao Tong University and lead study author. "Deoxygenation affects other marine resources as well, but fisheries [are] maybe most related to our daily life."

> www.ecomagazine.com/338x

Shifting Ocean Closures Best Way to Protect Animals from Accidental Catch

Many nations are calling for protection of 30% of the world's oceans by 2030 from some or all types of exploitation, including fishing. Building off this proposal, a new analysis led by the University of Washington looks at how effective fishing closures are at reducing accidental catch.

Researchers found that permanent marine protected areas are a relatively inefficient way to protect marine biodiversity that is accidentally caught in fisheries. Dynamic ocean management -- changing the pattern of closures as accidental catch hotspots shift -- is much more effective.

"We hope this study will add to the growing movement away from permanently closed areas to encourage more dynamic ocean management," said senior author Ray Hilborn, a professor at the Univery of Washington School of Aquatic and Fishery Sciences. "Also, by showing the relative ineffectiveness of static areas, we hope it will make conservation advocates aware that permanent closed areas are much less effective in reducing accidental catch than changes in fishing methods."

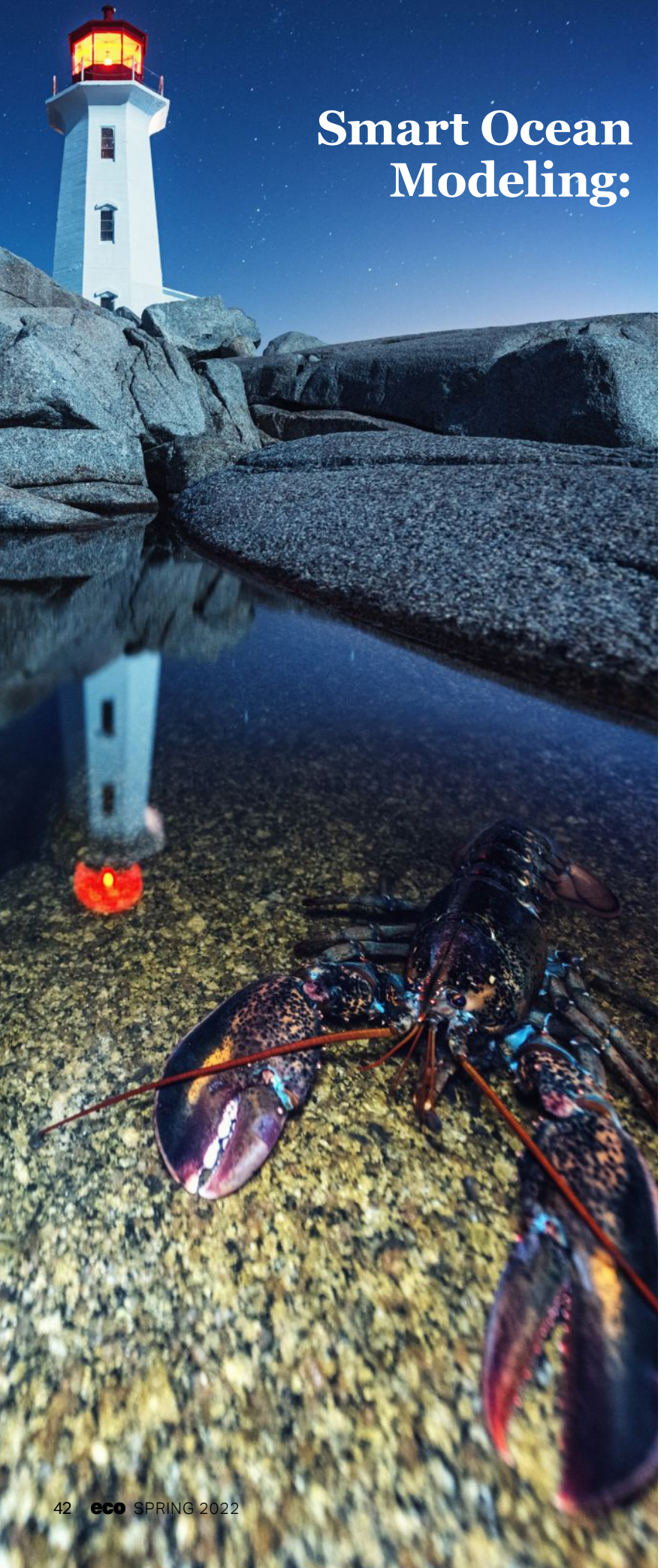
Techniques could include devices that keep sea turtles away from shrimp fishing, or streamer lines on boats to deter seabirds from getting caught in fishing lines.

The international team of researchers looked at 15 fisheries around the world -- including Californian swordfish, South African tuna and Alaskan pollock -- and modeled what would happen both to the targeted fish and to species caught accidentally, called bycatch, if 30 percent of fishing grounds were permanently closed, compared with dynamic management. In practice, dynamic management tracks real-time data of bycatch and closes smaller areas that can move year to year based on where species are most affected.

One of the critiques of permanent marine protected areas is that many of the species they are supposed to protect move around and may leave the protected area altogether. The study found that, on average for all fisheries studied, restricting fishing in 30 percent of a fixed area did reduce bycatch by about 16 percent. But in dynamic closed areas, over the same fraction of the ocean, bycatch was reduced by up to 57 percent.

The authors acknowledge that goals differ for various marine protected areas, and if the main purpose is to protect a critical habitat, a biodiversity hotspot or unique feature, static closures might be more effective and easier to enforce.

> www.ecomagazine.com/33qq



Smart Ocean Modeling:

What Will Happen to North American Lobsters?

By Travis Tai, University of British Columbia

An interdisciplinary team of scientists based in Canada uses smart ocean modelling to reveal the impacts of environmental change on Atlantic lobster biology, populations, and fisheries—and proposes possible solutions to mitigate future decline.

Atlantic lobsters are one of the most valuable fisheries in Canada and the US, and one of the most valuable and widely traded seafood commodities in the world. However, as with all other species across the planet, they are faced with a rapidly changing environment caused by greenhouse gas emissions and in more ways than one. The ocean is absorbing heat from the atmosphere leading to rising water temperatures. But, the ocean is also absorbing excess atmospheric carbon dioxide (CO_2), decreasing ocean pH—a process known as ocean acidification. As a result, these lobsters (and all sea life as we know it) are being exposed to unprecedented change. Understanding how they will respond to these changes is essential for adaptation and mitigation efforts.

Researchers from the University of British Columbia, Université du Québec à Rimouski, and Fisheries and Oceans Canada combined data from previous studies to model impacts of future climate change on lobsters. Lobsters have multiple life stages before maturing as adults. These stages differ in their susceptibility to environmental change, with younger larval and juvenile stages generally being the most sensitive to changes in ocean chemistry and temperature. Previous lab-based studies have suggested declines in survival, delayed development, and reduced growth rates in response to warming and acidification. Using spatial models, researchers can project how these valuable animals may move and respond to future environmental change.

| Photo Credit: Brent Wilson

If ocean warming and acidification continue to increase, the model suggests there will be a decline in future populations and, therefore, fisheries catch. It also revealed that the impacts of ocean warming have a considerably greater effect than ocean acidification, but together they have much larger additive effects. While the effects of warming are better understood, acidification effects are less clear, having shown a variety of responses in laboratory studies and field observations. In addition, the impacts of acidification vary by life stage, and responses have been inconsistent across studies published so far.

The size of lobsters may also decrease due to warming, a consistent trend already observed in many marine species. Smaller lobsters have significant implications for the fishery. Lobsters are typically categorized into two class sizes: canner-sized for lobsters less than 1 lb (454g) and market-sized for lobsters greater than 1 lb. Canner-sized lobsters are typically sold for less than market-sized lobsters, which could mean less catch revenue. Since fishers naturally target larger lobsters, the likelihood of seeing smaller numbers in abundance, catch, and body size is heightened when considered alongside this fishing pressure.

Ocean warming has also led to poleward (in this case, towards the north pole) shifts in the distribution of marine species as they seek cooler waters, and lobsters were no different according to the model. Lobsters are moving out of areas at the south end of their distribution, such as the Gulf of Maine, and towards the outer coast of Newfoundland and Labrador into the Labrador Sea.

While modeling the impacts of climate change and fishing pressure on lobsters, the researchers also introduced some broad interventions that could mitigate the effects. Scaling back fishing effort has a considerable positive impact on the overall abundance and catch. Implementing more stringent size limits may also positively affect abundance and catch. However, climate change effects still prevail in the long run, overshadowing most of the gains from enforcing changes to fishing effort and size limits. While drastic changes in fishing regulations may help with lobster abundance with future climate change scenarios, the most effective strategy is to limit climate change as a whole. Keeping greenhouse gas emissions to the lowest possible for projected trajectories has the biggest influence on reducing impacts on lobsters.

One of the significant gains from this study is the integrated structure of the model developed by the researchers. Laboratory data were used to quantify the complex relationships of how ocean warming and acidification affect lobster biology and populations. However, there is still much to learn and integrate into these models. In the study paper published in *Scientific Reports,* the authors note the need for collaboration and to include diverse research disciplines to achieve more holistic and end-to-end studies. Efforts to reduce the impacts of climate change on natural and social systems will be more successful with these approaches.

Lobsters weren't always the highly valued species they are today; they were once so abundant that they would reportedly wash up on shore stacked a few feet high. Yet, its bountiful abundance earned its reputation as a "protein for the poor." Fast forward a few decades, and these lobsters are some of the most prized shellfish, served at upscale restaurants around the world.

In late 2020, there was a significant acquisition involving the largest shellfish producer in North America—Clearwater Seafoods—that also holds many lobster harvest licenses. It was especially important as the single largest seafood investment by an Indigenous group in Canada, underscoring its importance for building healthy and integrated relationships between Indigenous and non-Indigenous groups to sustainably and equitably manage and utilize marine resources.

The lobster fishery supports the livelihoods of many people, and many small coastal communities were built around and are highly dependent on this fishery. If we are to protect this species and the livelihoods of these communities, we must work together to find solutions.

This story is based on the following science paper:

Tai, T.C., Calosi, P., Gurney-Smith, H.J. Cheung, W.W.L. Modelling ocean acidification effects with life stage-specific responses alters spatiotemporal patterns of catch and revenues of American lobster, *Homarus americanus*. *Sci Rep* 11, 23330 (2021). https://doi.org/10.1038/s41598-021-02253-8

Giant Sponge Gardens Discovered on Seamounts in the Arctic Deep Sea

Sponges grow in large numbers and to impressive size on the peaks of extinct underwater volcanoes.

| Photo Credit: Alfred Wegener Institute / PS101 AWI OFOS system

Massive sponge gardens thrive on top of seamounts in the Central Arctic Ocean, one of the most oligotrophic seas on Earth. They appear to feed on the remnants of an extinct fauna. Scientists from Bremen, Bremerhaven and Kiel and their international partners discovered this unique hotspot of life during a *Polarstern* expedition and now report their findings in the journal *Nature Communications*. They stress the need for a better understanding of the diversity and uniqueness of Arctic ecosystems in the light of global and local change.

Little food reaches the depths below the permanently ice-covered Arctic Ocean, because light limits the productivity of algae. However, scientists now discovered a surprisingly rich and densely populated ecosystem on the peaks of extinct underwater volcanoes. These hotspots of life were dominated by sponges, growing there in large numbers and to impressive size.

"Thriving on top of extinct volcanic seamounts of the Langseth Ridge we found massive sponge gardens, but did not know what they were feeding on," reports Antje Boetius, chief scientist of the expedition, head of the Research Group for Deep Sea Ecology and Technology at the Max Planck Institute for Marine Microbiology and director of the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research.

Using samples from the mission, first-author Teresa Morganti, sponge expert from the Max Planck Institute for Marine Microbiology in Bremen was able to identify how sponges adapt to the most nutrient-poor environment. Morganti explains: "Our analysis revealed that the sponges have microbial symbionts that are able to use old organic matter. This allows them to feed on the remnants of former, now extinct inhabitants of the seamounts, such as the tubes of worms composed of protein and chitin and other trapped detritus."

> www.ecomagazine.com/334d

Scientists Uncover 'Missing' Plastics Deep in the Ocean

About 51 trillion microplastics are floating in the surface waters of oceans around the world. Originating from various types of plastics, these tiny fragments (less than 5 millimeters in length) pollute natural ecosystems. Hundreds of studies have surveyed plastic debris on the surface or near surface of the ocean. However, these studies only "scratch the surface," and do not provide a complete inventory of what's lurking beneath.

A study led by Florida Atlantic University is the first to unveil the prevalence of plastics in the entire water column of an offshore plastic accumulation zone in the southern Atlantic Ocean and implicates the ocean interior as a crucial pool of 'missing' plastics.

Results, published in the journal *Global Change Biology,* demonstrate that small microplastics are critical, underexplored and integral to the oceanic plastic inventory. In addition, findings show that weak ocean current systems contribute to the formation of small microplastics hotspots at depth, suggesting a higher encounter rate for subsurface particle feeders like zooplankton.

"Our study highlights the urgency for more quantification of the deep-ocean microplastics, especially the smaller size fraction, to better understand ecosystem exposure and to predict the fate and impacts of these microplastics," said Tracy Mincer, Ph.D., senior author and an assistant professor of biology at FAU Harbor Branch Oceanographic Institute and FAU Harriet L. Wilkes Honors College.

> www.ecomagazine.com/3344

The Abyssal World: Last Terra Incognita of the Earth Surface

| Photo Credit: MEDWAVES/IEO/ATLAS Project

The first unified vision of the world ocean biodiversity, based on analysis of DNA sequences from the surface to deep-ocean sediments, unveils the rich and unknown life in the abyssal realm, the last terra incognita of the Earth surface. This collective effort was made possible by 15 international deep-sea expeditions, including scientists from MARUM.

The deep-ocean floor is the least explored ecosystem on the planet, despite covering more than 60% of the Earth surface. Largely unknown life in abyssal sediments, from benthic animals to microbes, helps to recycle and/or sequester the sinking (in)organic matter originating from pelagic communities that are numerically dominated by microscopic plankton. Benthic ecosystems thus underpin two major ecosystem services of planetary importance: the healthy functioning of ocean food-webs and the burial of carbon on geological timescales, both of which are critical regulators of the Earth climate. Researchers from the Norwegian Research Centre (NORCE), Bjerknes Centre for Climate research, the University of Geneva, as well as from the CNRS/Genoscope and IFREMER in France, have massively sequenced eukaryotic DNA contained in deep-sea sediments from all major oceanic basins, and compared these new data to existing global-scale plankton datasets from the sunlit and dark water column, obtained by the Tara Oceans and Malaspina circumglobal expeditions. This provides the first unified vision of the full ocean eukaryotic biodiversity, from the surface to the deep-ocean sediment, allowing marine ecological questions to be addressed for the first time at a global scale and across the three-dimensional space of the ocean, representing a major step towards "One Ocean ecology."

> www.ecomagazine.com/33d4

Dr. Manet Peña, Dr. Shana Gofredi, and Dr. Victoria Orphan examine samples from the Auka vent field. (Credit: Mónika Naranjo-Shepherd / Schmidt Ocean Institute)

Multidisciplinary Teams Aid in Understanding the Deep

By Brandon Chan

Most of what we know about the ocean is from coastal and nearshore environments, the spaces where light still penetrates. Yet the deep sea remains largely unknown, even though it is the largest habitable space for life on earth. Many species persist in the deep sea, from massive colonies of tubeworms living along hydrothermal vents to deep-sea corals creating ethereal reef structures. While it is estimated that the deep ocean constitutes over 95 percent of the total water volume in the ocean, less than 10 percent has been surveyed. Many deep-sea relationships, and the role it plays within the global earth system, remain unknown.

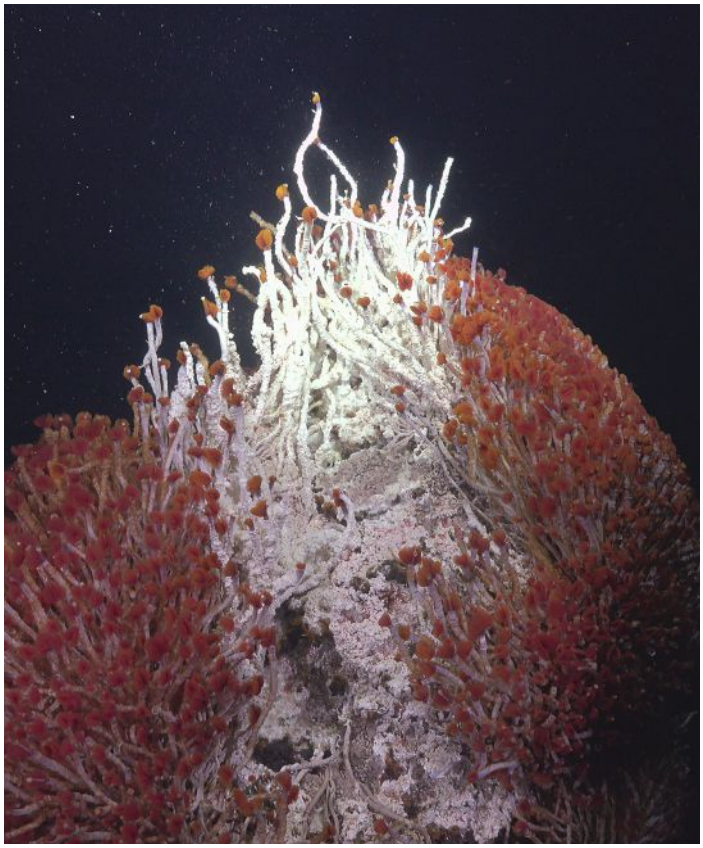
Knowledge gaps pose a significant challenge for understanding how climate change affects the ocean's depths. We know human actions impact the ocean through warming temperatures and increasing acidity, causing cascading effects to life-sustaining processes. However, we are still in the early stages of assessing climate change's impacts on deep-ocean ecosystems.

Multidisciplinary and international deep-sea exploration are necessary for providing a baseline of ocean health in all parts of the water column. A basic understanding of the systems and the species that live within them is required. A recent expedition to the Pescadero Basin in the Gulf of California onboard Schmidt Ocean Institute's R/V *Falkor* demonstrated the effectiveness of collaborative international and multidisciplinary research for better understanding deep ecosystems.

The science team, led by Dr. David Caress from MBARI (Monterey Bay Aquarium Research Institute), has been investigating the hydrothermal vent fields in Pescadero Basin for the past decade. The key to the team's success is bringing together experts in the fields of geology, seafloor mapping, geophysics, microbiology, and ecology to characterize the system comprehensively, each discipline informing and providing insight into the discoveries of the other.

Hydrothermal vents release superheated fluid into cold, deep water, building stunning geologic features that support the surrounding ecosystem. Organisms living around the vents depend on these elements to create energy, and live in symbiosis with larger animals.

The research team has determined that Pescadero Basin vents differ considerably from other known vents around the world. It is the only known system where fluids coming from the vents are transparent instead of opaque and the geologic structures are primarily made from calcium carbonate rather than sulfides.



Fully understanding the hydrothermal vents found in the Pescadero Basin requires a multi-layered approach. The scientists seek to understand if the hydrothermal vents found in the Pescadero Basin are connected, if at all, and use heat flow measurements to help determine this. Preliminary results show that even though the fields are not that far apart, there may be significant differences in hydrothermal vent fluid beneath the surface. Heat flow has implications for the biology of the Pescadero Basin, as there seems to be a higher density of organisms in areas outside the active vents that have more increased heat flow.

Biologists and geochemists then work together to examine how the hydrothermal vent fluid influences microbes and their symbiotic relationships with larger organisms. Many new species have been found in the Pescadero Basin, perhaps because the vent chemistry is so different from other known systems. New species include arrow and roundworms and the first known chemosynthetic cnidarian, an anemone. This multidisciplinary investigation has facilitated scientists creating a comprehensive picture of the biological, chemical, and physical conditions of the hydrothermal vents in the Basin. Together, they have established a baseline for this spectacular environment.

The ocean's biological, chemical, and physical conditions are closely intertwined, and climate change will undoubtedly impact the deep sea. By establishing baselines for deep-ocean ecosystems, scientists will better understand how climate change is affecting the deep sea. Success requires international and multidisciplinary research to understand how ocean systems will respond as a whole so we can observe how they change over time. Further research should look to the approach of Dr. David Caress and his colleagues and the exemplary work they have demonstrated in examining a system through a holistic, multidisciplinary lens.

Top: Pink filamentous bacterial mat with a *Peinaleopolynoe orphanae* scale worm close to white anemones - which strangely, seem to prefer to live in areas of diffuse fluid flow (in which most anemones do not). Located at a depth of 3,656 meters. (Credit: Schmidt Ocean Institute)

Left: The Matterhorn, a hydrothermal vent of Pescadero basin displaying an abundance of red tube worms and white microbial mats. (Credit: Schmidt Ocean Institute)

SEA-KIT Named as a Finalist in Maritime UK Awards

SEA-KIT International has been named as one of the best in the UK's £40bn maritime sector after being shortlisted in the third Maritime UK Awards. The awards recognize the very best of the UK's maritime sector.

> www.sea-kit.com

Aquatec Shortlisted for Best Small Company Award

Aquatec was shortlisted for the prestigious Subsea Expo Awards 2022 and is a finalist in the Best Small Company category. The awards ceremony, organised by the Global Underwater Hub, took place on February 23, 2022, at P&J Live in Aberdeen.

> www.aquatecgroup.com

REX2 Equipped on the NOC's RRS *Discovery*

In early 2021, the National Oceanography Centre enhanced their existing research ships with two RS Aqua WaveRadar REX2 systems, for the RRS *Discovery* and the RRS *James Cook*. The RRS *Discovery* is now equipped with a full REX2 system, while the RRS James Cook REX2 system will be installed later in the year during routine maintenance.

> www.rsaqua.co.uk

Norwegian Tech Company Raises 30M EUR for Cutting-Edge Sustainable Seabed-Harvesting Technology

Through a five-year research project, Norwegian company Tau Tech has developed a technology enabling sustainable seafood harvesting from the seabed. The company has raised 30M EUR from impact investor Norselab, Hofseth International and industrial profiles in Western Norway to start harvesting Arctic scallops on a commercial scale, using the new technology.

The most widespread catching method for shellfish globally - so-called dredging - damages the fragile ocean ecosystem and releases large amounts of naturally stored carbon from the seafloor. Norway is one of the few countries that prohibits this method to protect seabed fauna. As a result, valuable seafood resources along the Norwegian coast have remained inaccessible for 30 years.

Together with Norwegian independent research institute SINTEF, Tau Tech has developed a seabed-friendly harvesting method. In cooperation with the Institute of Marine Research, the Directorate of Fisheries and other leading marine experts, the company has proven over the past five years that its innovative technology makes it possible to identify, select and sort shells without destroying surrounding vegetation and life. This opens up new, sustainable opportunities for fisheries nationally and internationally by providing access to untapped seafood resources, while also protecting fragile marine ecosystems and preserving invaluable carbon sinks.

Tau Tech sees great potential in sustainable seabed harvesting methods and believes the company is behind a historic breakthrough.

"We are very good at capturing species that live in free bodies of water. But on the seabed, we encounter a paradox: either the resources remain untapped, or they are harvested using destructive methods. Our method opens up for a new and sustainable seafood adventure," says Øystein Tvedt, CEO of Tau Tech.

In 2022, the technology company will reopen commercial Arctic scallops *(Chlamys islandica)* harvesting in Norway, after having been awarded an annual quota of 15,000 tonnes for the next five years. Arctic scallops are a globally widespread and sought-after species. However, harvesting is mostly done using methods that face increasing scrutiny from academic communities and engaged consumers.

"It has been over 5 years since we knocked on the Directorate of Fisheries' door with the idea of reopening this fishery based on new technology. Since then, we have been through a long process with the authorities. They have tested, approved and patented the technology and the population of Arctic scallops has been remapped in the authorized zones. In addition, Tau Tech is working on adapting the method to other seabed-dwelling species that are currently challenging to harvest without damaging the seabed," adds Tvedt.

> www.tautech.no

UKHO Contracts OceanWise to Provide Marine Environmental Monitoring Systems

OceanWise has, through competitive tender, been awarded the contract to supply, install, and maintain Marine Environmental Monitoring Systems (MEMS) globally as part of an initial 3-year Framework Agreement with the UK Hydrographic Office (UKHO).

The framework also includes the provision of data collection, management and display system, which will be provided through OceanWise's Port-Log. The framework also includes shore control and GNSS surveys, as well as local training and mentoring.

The UKHO has identified the installation and operation of MEMS as being an important component of a number of UK Government Programmes including the Overseas Territories Seabed Mapping Programme (OTSMP). Countries and territories can benefit from the MEMS through improved navigational safety and improving knowledge of the marine environment to assist with scientific research in understanding of the implications of climate change.

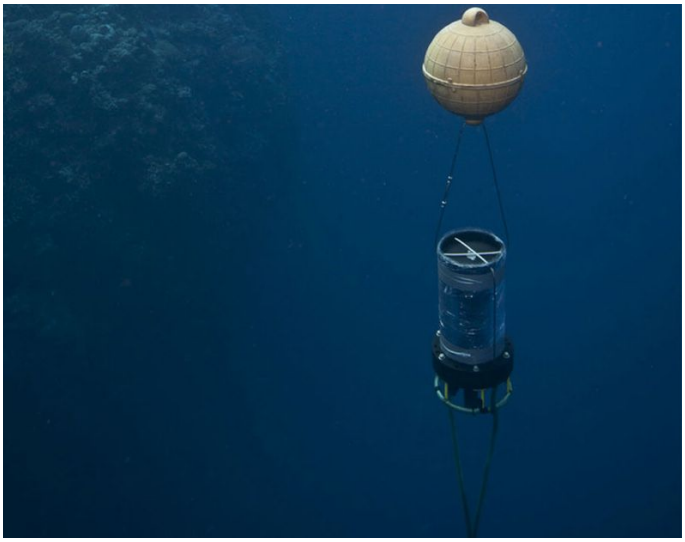
Under the framework agreement, OceanWise is responsible for the supply, installation, and support of professional grade environmental monitoring equipment (such as Tide Gauges and Weather Stations), as well as providing observational data to the local community and global initiatives, such as the Global Sea Level Observing System (GLOSS). OceanWise's data services can benefit the maritime community directly, through such things as the provision of tsunami and storm surge warnings, and via more accurate and up-to-date Tide Tables.

Ralph Bostock, Monitoring Business Manager at OceanWise stated, "We are delighted to be working with the UKHO and to have won this contract after a robust tendering process. We already support and maintain numerous tide gauges and weather stations around the world for our port and renewable energy customers, so this contract is a natural extension of our work. We are particularly looking forward to using our expertise and experience in environmental monitoring systems and applying it to unique and remote locations. Our in-depth technical knowledge of marine data acquisition, telemetry and data management will also be fully utilized in this contract as we support the UKHO in realizing the full benefit that MEMS can offer."

> www.oceanwise.eu

Teledyne and Innovasea Collaborate to Provide Cost-Effective Fish-Tracking Solution

Recently researchers have just upped their game to track tagged fish in the Great Lakes, and Teledyne Webb's Slocum Gliders and Teledyne Benthos' Acoustic Modems are playing a vital role in this research.



For several years, the University of Windsor has been conducting research using Innovasea's VR2W (Wireless), which is used for tracking and recording tagged fish populations. The VR2W, now upgraded to VR4-UWM (Under Water Modem) is a submersible receiver capable of identifying all Innovasea coded transmitters and communicating that data remotely to a surface modem on demand. All subsea data is transmitted via a fully integrated OEM version of the Teledyne Benthos CM-903 Compact Modem.

Researchers can now take advantage of the new technological breakthrough afforded by the upgraded VR4 Underwater Modem (VR4-UWM). The new module for Teledyne's G3 Gliders allows the autonomous underwater vehicles (AUVs) to be dispatched out to Innovasea's VR4-UWM underwater receivers to collect data. The underwater receivers contain a Teledyne Benthos modem that can operate in a data logging mode and hold the data until a glider initiates retrieval via acoustic data transfer. The VR4 receivers can identify any Innovasea coded transmitters and remotely communicate any data to the glider, which then uses the onboard acoustic modem on demand.

> www.teledyne.com

> www.innovasea.com

Monitoring Kelp with Custom Subsea Shackles and Data Loggers

Dynamic Load Monitoring (UK) Ltd (DLM) has designed and manufactured specialised load monitoring and data logging equipment for an R&D project by sustainable organisation, Kelp Blue, whose aim is to grow and manage large-scale kelp forests.

Kelp is a type of large algae seaweed with many sustainable capabilities such as: feed for livestock which helps to reduce greenhouse gas emissions, medicine and textile fibres which support the need for sustainable products. DLM's innovative custom designed equipment will be an integral part of Kelp Blue's floating forest and sustainable vision.

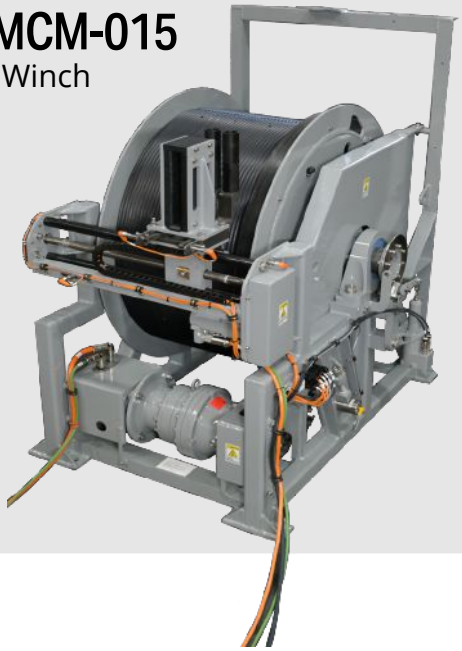
Kelp Blue is managing a kelp forest off the coast of Namibia and came to DLM, who frequently design and manufacture specialised equipment for various subsea and offshore applications, with a proposition to construct equipment for structural monitoring purposes. In the initial design stages, spokesperson Ferdi Knoester, Project Engineer at Kelp Blue requested subsea load monitoring devices to monitor the load tension on mooring lines on a floating structure which is tethered to the sea bed.

The devices sent to Namibia include six of DLM's DL-3.0 Subsea Data Loggers mounted onto three cabled Subsea Shackle Load Cells, which are some of DLM's specialised equipment. The Subsea Shackle Load Cell is used on applications such as subsea moorings, subsea vehicle tension monitoring and anchoring tension monitoring.

> www.dlm-uk.com

Model: MCM-015

MHU USV Winch



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GUEST BLOG

Hydrospatial:
It's All About the Blue of Our Blue Planet and its Contiguous Zones

By Denis Hains, President & CEO, H2i; Co-Leader Hydrospatial Movement Club & Community

The term hydrospatial was first used in the UK in early 2000's. Hydrospatial aims to broaden and expand (not replace) the more widely known term 'hydrography' beyond the realm of sea navigation.

At the end of 2020, a global Hydrospatial Movement Club and Community (HMCC) was established to promote the concept of hydrospatial. The HMCC was first started by a group of professional volunteers in the water domain. In February 2022, the HMCC is now a club of fourteen volunteers and more than 3,500 community members worldwide. All members of the HMCC community are interested in promoting and advocating the importance of marine and aquatic geospatial or blue geospatial data, information and knowledge, and the hydrospatial domain.

In February 2020, a working draft definition of the term hydrospatial was originally derived from the existing International Hydrographic Organization (IHO) definition of hydrography. Although the original draft definition stood for a while; it was considered too long and complex. The HMCC club members gave thoughts on how to simplify the description of the term, which now stands as the following:

"Hydrospatial is a generic concept defining the vast global domain including all the blue of our blue planet and its contiguous zones for a sustainable blue economy. Hydrography is one of many elements of it at the foundation of hydrospatial. Hydrospatial includes all the spatio-temporal physical, biological and chemical data, information and knowledge related to their position on or in the water: surface, column, depth, bottom and sub-bottom; of the oceans, the seas, the estuaries, the rivers, the lakes, the coastal zones and the flooding areas. Safety and efficiency of navigation are part of hydrospatial amongst many more scientific, technical, social, environmental and economic activities."

The club is currently composed of members from African, American, Asian, Australasian and European Nodes. The members coordinate and lead the use and promotion of hydrospatial by generating a momentum to get the ever-growing community making a difference by advocating for the use of hydrospatial as a term.

Everyone interested in joining the professional "volunteers" community can become a member of the HMCC at: https://lnkd.in/eBYG-fkpq. More information on hydrospatial and the HMCC can be found at: https://arcg.is/19fiab.

All interested in joining the hydrospatial movement are invited to join the HMCC via its LinkedIn group.

It is free, it is for the blue of our planet, and it is fun!

Read more at:

> www.ecomagazine.com/33fk

MSM Ocean and Sonardyne Partner on Tsunami Early Warning System

Metocean and environmental data measurement specialist MSM Ocean and marine technology company Sonardyne have agreed to team-up on the supply of a complete solution for warning coastal communities of a tsunami.

The two companies can now jointly provide at-risk coastal nations with a single source of supply of tsunami early warning systems. The agreement combines MSM Ocean's expertise in oceanographic measurement buoys, on-board data processing and telecommunications and Sonardyne's highly precise deep water pressure measurement and acoustic through-water telemetry capabilities.

Together, these allow minute changes in deep water pressure at the seafloor that indicate a tsunami to be reliably detected, triggering a direct alert to national emergency organisations via acoustic and satellite communications, all within seconds.

The tsunami early warning system is fully International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) compliant and can be deployed in areas of up to 7,000-meters water depth.

Through the teaming agreement, MSM Ocean and Sonardyne have also agreed to explore further possibilities for combining their technologies in support of remotely connecting ocean scientists to their instruments on the seafloor via buoys.

Sonardyne has been supplying integrated Bottom Pressure Recorders (BPRs) configured for deep water tsunami detection to organisations around the world since 2007. Combining precise sensing, long-life battery and reliable communications in one easy to deploy and recover instrument, they were developed following the devasting 2004 Indian Ocean tsunami. For the past decade, these have been integrated into MSM Ocean's buoy-based Tsunami Early Warning Systems, which have been successfully installed along the Pacific coast of South America.

> www.msmocean.com

> www.sonardyne.com

ecoEssentials

The essential product guide for ocean scientists

Technological innovations push the boundaries of ocean science and exploration. As technology advances, so too does our ability to capture and interpret data allowing us to better understand the ocean and its complex relationship with Earth's various processes and the plethora of Life to which it supports.

Our ecoEssentials section offers a glimpse into the latest innovation available now to use in your research. We encourage you to contact the companies listed here for more information and to discuss your product needs.

Ultimodem Inductive Modems

Enables reliable low-power communications over mooring cable

Specifications:

4800 Baud; 6 milliwatts operating; up to 5000 meter depth

Product Overview:

Soundnine introduces multiple new Ultimodem inductive modems in cylindrical housings. New options include 1500 meter rated plastic or 5000 meter rated titanium housings; standard 15mm or wide 25mm cable opening; and externally powered or two, four, or eight internal batteries. We're ready to help convert internally logging moorings to modern cost-effective real-time platforms.

> www.soundnine.com

Sub-surface Inductive Mooring Controller

Controls sampling and archives data of inductive sensors

Specifications:

700 meter depth, two RS232 ports, includes inductive modem

Product Overview:

Soundnine redesigned their sub-surface inductive mooring controller in an easy-to-use housing. This controller is ideal from collecting data from Soundnine's low-cost XT sensor series including options for temperature, dissolved oxygen, conductivity, pressure, turbidity, and pH. It also has RS232 serial ports for connection to acoustic modems, wave sensors, current meters, or other sensors.

Watch for new versions coming soon with larger batteries and external power options.

> www.soundnine.com

AIRMAR EchoRange™ Smart™ Sensors

Depth sensors for hydrographic survey data from fixed or dynamic platforms

Specifications:

200kHz or 30/200kHz, 0.4m-200m depth reading, NMEA 0183 data via RS422

Product Overview:

EchoRange™ Smart™ sensors deliver processed depth and water temperature data from portable or fixed positions for applications such as hydrographic survey, dredging and bottom characterization. EchoRange™ and EchoRange+™ transfer real-time data via the RS422 standard. A secondary, transmit-only interface with a proprietary protocol using RS485 is also available on EchoRange+. Users can obtain detailed echo envelope data which may be displayed as an analog waveform. The echo envelope is a 900-point time-series of the echo amplitude. By analyzing the shape of the echo envelope, information indicative of the seafloor type is revealed.

> www.airmar.com/echorange

SR-Surveyor M1.8

Multibeam Echosounder, man-portable, customizable sensor suite

Specifications:

Length 1.8 meters, Beam 0.91 meters, Endurance 7hrs at 2 kts

Product Overview:

Intelligent and fully integrated, the SR-Surveyor M1.8 is the ideal solution for any surveyor that requires top quality, reliable bathymetry data. The SR-Surveyor M1.8 allows surveyors to simplify logistics and optimize data recordings in shallow and hard to navigate areas, making it the complete package for bathymetry, habitat mapping, structure inspection and search and rescue. Single software interfacing for robust intuitive surveying. The payload bays, tightly packed into the pontoons, are designed to support ACDPs or DVLs, as well as an AML micro SV sensor to capture sound velocity measurements for the EdgeTech side scan sonar.

> www.searobotics.com/products/autonomous-surface-vehicles/sr-surveyor-class

JPI Oceans Photo and Art Awards: And the Winner is...

JPI Oceans is proud to reveal the winning entries of the Photo and Art Awards, held on the occasion of its 10th anniversary.

The JPI Oceans Art and Photo Awards welcomed entries from around the world, illustrating the artists perception and awareness of our marine environment. Unanimously selected by the independent jury, the **winner of the open competition** is Masoud Soheili with W*here is our Future.* The jury hailed the image as a very strong call to action exposing the enormous challenge of marine pollution while capturing the perspective of the youth looking at the legacy the last decades have left. **In second place in the open competition:** *Walking on thin ice* from Mario Hoppmann. In third place: Bay ice brigands from Hermann Luyt.

In the **JPI Oceans project competition,** the jury selected *New Shades of Blue* of Filipa Bessa, a biologist and researcher participating in the JPI Oceans I-Plastic project. The jury was particularly impressed by the harmonious composition which draws the observer in for a second look. "Looking closer, rather than life you discover it is trash, uniting the beauty and repulsion."

In second place is *Deep sea nodule extraction and nodule epifauna* from Autun Purser, Deep sea ecologist and project partner in the MiningImpact 2 project. **In third place** *Scientists at sea* picture series (see ECO Magazine website for the full series) from Sarah-Marie Kröger, student of marine and environmental sciences and participant in the HOTMIC project.

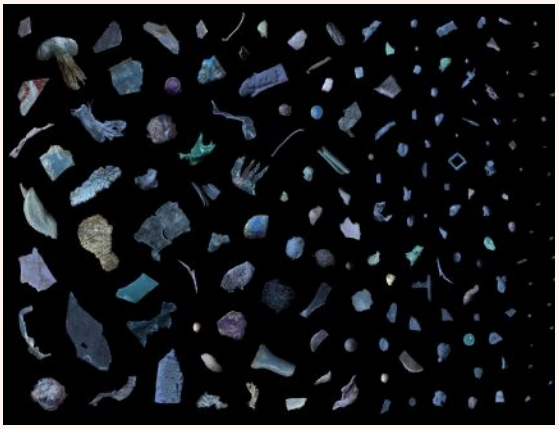
The two winners will be awarded a prize of €1000. The four runner-ups will each be awarded a prize of €500.

Art and photography are vital to close the emotional gap between society and our marine environment. With the Art & Photo Awards JPI Oceans wishes to bolster the role of both media in tackling the challenge of communicating about the environment covering most of our planet.

You can view the winners and full picture series on ECO Magazines website:

> www.ecomagazine.com/33f3

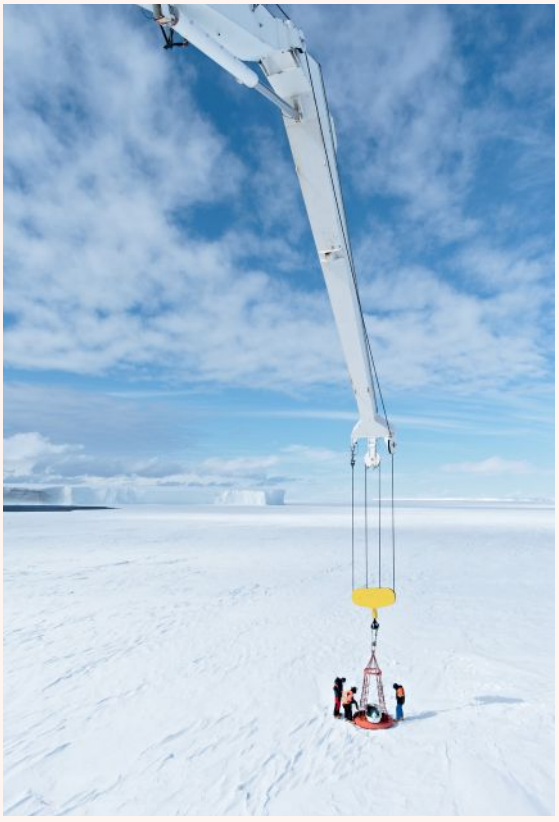
| Open Competition Winner



| JPI Ocean Photos Competition Winner

| Open Competition Runner Up: 2nd Place

| JPI Ocean Photos Competition Runner Up: 3rd Place



| Open Competition Runner Up: 3rd Place

| JPI Ocean Photos Competition Runner Up: 2nd Place

Every Coastline Needs a Local Hero

A Conversation with Marine Biologist and Ocean Educator Dr Asha de Vos

By Thimedi Hetti

Dr Asha de Vos is a Sri Lankan marine biologist and ocean educator, best known for her pioneering work on blue whales and for founding the non-profit *Oceanswell*, Sri Lanka's first marine conservation research and education organization. Its flagship project, the Sri Lankan Blue Whale Project, is the longest-running blue whale project in the northern Indian Ocean. A seemingly never-ending list of accolades and achievements include being named one of BBC's 100 Most Influential Women in 2018, Young Global Leader by the World Economic Forum, TED Senior Fellow and National Geographic Explorer. We originally spoke to Dr de Vos from her home in Sri Lanka as part of the *Frontiers* Women in Science blog series.

Photo Credit: Prishan Pandithage for LMD

What does being a marine biologist/ ocean educator mean and why is it important to you?

My passion is about research that feeds into conservation so that we can have real change on the ground. We have long-term projects such as the *Sri Lankan Blue Whale Project* and the impact of the whale-watching industry, as well as short-term projects such as the effects of COVID-19 lockdowns on small-scale fisheries and other volunteering projects. I want people to have a collective understanding of what's out there and for them to feel like they can be scientists too, to create a community of ocean-conscious individuals. We typically and traditionally see the ocean as a place of extraction and not a place of interaction. So, I want to change that.

When you were growing up, did you have any influences who were particularly women in science?

Unfortunately not. The people I saw in National Geographic magazines growing up didn't represent me in any way, there certainly weren't people of colour and very few women. Luckily for me that wasn't a turn-off, my parents were very supportive role models - their motto being 'do what you love and you'll do it well'.

Being a woman in science, did you face challenges and how did you overcome them?

People tend to listen more if you're a man in government, regardless of whether they're saying something accurate or not. In a country and patriarchal society like Sri Lanka, there are definite challenges for women but I'm just going to keep headbutting against all these challenges. Unfortunately, we live in a world where if you're a woman, you have to work harder, but at this point in time, I tell people to work so hard that they stop seeing you for your gender/age, and instead as the most qualified person in the room.

Parachute science is something you experienced and strongly advocate against. Why is it so important to raise awareness around the issue?

Parachute science is where we have predominantly Western researchers coming into countries like Sri Lanka that have many conservation issues, they collect and publish all this data and their careers are soaring but there's a big gaping void because they haven't engaged with or acknowledged the contributions of the local researchers in that community. The *Sri Lankan Blue Whale Project* was my eureka moment; it's a long-term project that has created opportunities for people locally, we've been able to work with the whale-watching industry and share what we are learning with them.

What would you like to see in the future?

I want to make sure we've brought on enough people that are all so engaged and excited about working for the oceans. My goal is to try to solve these world problems, but fundamentally that's not going to happen unless we have that next generation of amazing, diverse, ocean heroes from all backgrounds working for the oceans.

Read the full interview here: https://blog.frontiersin.org/2021/12/10/every-coastline-needs-a-local-hero/

Ocean Decade News

It has been just over a year since the launch of the United Nations Decade of Ocean Science for Sustainable Development (2021-2030), the "Ocean Decade". A year marked by a wealth of commitments to protect the ocean and use ocean knowledge to unlock solutions for a whole array of global challenges around climate change and sustainability. The goal for 2022 is to go higher and faster – find out the latest developments and upcoming activities for 2022!

Calls for Decade Actions 02/2021

To achieve the Ocean Decade vision, a wide range of partners will implement endorsed Decade Actions in the form of programmes, projects or activities over the next ten years. These Actions are submitted for endorsement through regular "Call for Decade Actions".

Call for Decade Actions 02/2021, the second in a series that will be launched every six months, closed on 31 January 2022. The Decade received submissions for the endorsement of 38 programmes and 134 projects from lead institutions in 33 countries. Programme submissions focused on priorities issues related to marine pollution (7), multiple stressors on marine ecosystems (20) and the ocean-climate nexus (11).

We will be making announcements of the next set of endorsed Decade Action on World Oceans Day on June 8 and look forward to showcasing some of the programmes at the UN Ocean Conference in Lisbon in June 2022. We will also be launching the third Call for Decade Actions on 15 April 2022 – keep an eye on the Ocean Decade website and social media for updates!

> www.oceandecade.org/

Generation Ocean: For the Ocean We Need

Whether we live inland or by the sea, the ocean is essential to life and livelihoods. Its waters connect us to one another, and its influence on our lives can be felt on a daily basis. Still, each passing day demonstrates further that human activities across the world are causing devastating impacts on the ocean, and that this ecosystem is struggling to maintain its role as humanity's support system.

Launched on 1 February 2022, Generation Ocean (GenOcean) is the official public-facing campaign of the Ocean Decade, mobilizing people from around the world to restore, protect and live better with the ocean – because we are the last generation able to do so before we reach the point of no return, and we all have a responsibility to act.

Featuring stories of individuals from different backgrounds and the ways in which they are taking action for the ocean, GenOcean will build on the power of people-led storytelling to grow awareness in the general public around ocean issues and inspire a paradigm shift in their daily lives. The campaign will also be rooted in scientific knowledge and research to bring science closer to people and help them better understand all the ways in which they are connected to marine ecosystems.

Every generation has a part to play. Whoever you are, wherever you're from, no matter what age, we are all GenOcean!

> www.oceandecade.org/news/genocean-starts-today/

Where We Are Now, Where We Are Going

In its first year alone, the Ocean Decade was embraced worldwide by multiple stakeholders from science, governments, the private sector, philanthropy and engaged citizens. With over 15,000 followers across social media and 3,300 active members on the Ocean Decade Global Stakeholder Forum (you can join today at http://forum.oceandecade.org/), we continue to build on this momentum throughout 2022 to further raise the visibility, ownership and understanding of the Ocean Decade.

Here are our key highlights for what promises to be a "super year of the ocean"

Our Ocean Conference (13-14 April, Palau): the conference – whose theme is "Our Ocean, Our People, Our Prosperity" – will be a key moment for countries, civil society and industry to commit to concrete and significant actions to protect the ocean, and showcase youth-led entrepreneurial and innovative ideas for ocean action toward a "Generation Ocean".

African Kick-off Conference for the UN Decade of Ocean Science for Sustainable Development (10-12 May, Egypt): to celebrate the implementation of the Ocean Decade at the continental level and facilitate a discussion on African priorities. The conference will assess the status of ocean science and technology in the region, deliberate on how ocean science in Africa should be supported or reorganized to deliver the required Decade societal outcomes, and promote collaboration in research and development in and outside Africa, acting as a bridge to COP27 in November (Egypt).

Second Ocean Decade Foundations Dialogue (1-3 June, Morocco): the Mohammed VI Foundation for the Protection of the Environment will host this event to expand the dialogue among the world's top ocean-minded philanthropic and grant-making foundations on how best to create the partnerships and funding models that will underpin the enabling environment for the Ocean Decade, and discuss a range of priority themes for the Ocean Decade where foundations will play a leading role.

2022 UN Ocean Conference (27 June-1 July, Portugal): the follow-up to the 2017 conference will seek to propel much needed science-based innovative solutions for global ocean action. In line with this, the Ocean Decade's presence will highlight the diversity of stakeholders engaged and activities happening within its framework, giving partners a platform to discuss with the private sector, philanthropy, etc. and announce commitments.

High-level Political Forum on Sustainable Development (5-15 July, United States of America): central in the follow-up and review of the 2030 Agenda for Sustainable Development at the global level, this year's forum will focus on Sustainable Development Goal 14 on life below water, among others.

International Aquarium Congress (30 October-4 November, France): managers and personnel from aquariums from around the world will come together at Nausicaá (Boulogne-sur-Mer), a longstanding partner of UNESCO, to discuss issues of global interest to sector and how they can creatively engage their visitors to become active contributors to creating the ocean we want by 2030 through the Ocean Decade.

COP27 (7-18 November, Egypt): with the inclusion of the first-ever Oceans Dialogue within the framework of the conference, this year's UN Climate Summit will provide a space for the Ocean Decade and other actors to highlight and catalyze action and expand their networks of coalitions and partnerships.

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Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

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Founded in 1970 as a marine environmental consulting firm, CSA specializes in multidisciplinary projects concerning potential environmental impacts throughout the world and offers a wide variety of desktop and field survey services. CSA is headquartered in Stuart, Florida, with regional offices in Tampa, Florida; Houma, Louisiana; Salinas, California; Houston, Texas; Port-of-Spain, Trinidad; Doha, Qatar; Rio de Janeiro, Brazil and Perth, Australia. We provide clients with objective data collected in the field and scientific research while maintaining an appreciation for the environmental, legal, and political sensitivities.

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Summer **Sustainable Blue Foods**	• Monitoring Water Quality for Cleaner Seas • Innovating for Sustainable Aquaculture	• Seaweed Solutions • Ocean Governance	• May 09 • May 26	• Jun 20	• Seagrass Biology Workshop: Aug 7-12 • Dredging Summit & Expo: July 25-28
Autumn **Ocean Exploration**	• Tracking Ocean Life: eDNA & Bio-Logging • Smart Ocean Mapping & Characterization	• Ocean Sound • Marine Biotechnology	• Aug 15 • Sep 01	• Sep 16	
Winter **Resilient Coasts**	• Measuring Changing Coasts • Plankton Dynamics & HAB Monitoring	• Restoring Biodiversity • Tackling the Plastic Problem	• Nov 14 • Dec 01	• Dec 16	

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2 **Coastal Blue Carbon**	• Jun 20 • Jul 14	• Aug 05	
3 **Invasive Species**	• Sep 26 • Oct 20	• Nov 11	

Oceanology International	**Mar 15-17**	**London, UK**
> https://www.oceanologyinternational.com		
Gulf of Mexico Conference	**Apr 25-28**	**Baton Rouge, LA**
> https://web.cvent.com/event/f677ed8c-31e0-415c-b600-62b6c02d76a6/summary		
Aquaculture UK	**May 3-5**	**Aviemore, Scotland**
> https://aquacultureuk.com		
Global HAB Workshop	**May 9-13**	**Glasgow, UK**
> https://habmodelworkshop.sccoos.org		
Ocean Frontier Institute Biennial Conference	**May 16-19**	**Halifax, Nova Scotia**
> https://oceanfrontierinstitute.com/ocean-frontier-2022		
Int'l Conference on Underwater Acoustics	**Jun 20-23**	**Southampton, UK**
> https://icua2022.org		
Oceans Past Conference IX	**Jun 22-25**	**Seattle, WA**
> https://oceanspast.org/index.php		
UN Ocean Conference	**Jun 27 - Jul 1**	**Lisbon, Portugal**
> https://www.un.org/en/conferences/ocean2022		
Ocean Global Change Biology	**Jul 16-17**	**Waterville Valley, NH**
> https://www.grc.org/ocean-global-change-biology-grs-conference/2022		
ICES PICES Early Career Scientist Conference	**Jul 18-21**	**St. John's, Newfoundland**
> https://www.ices.dk/events/symposia/ecsc4/Pages/default.aspx		
Dredging Summit & Expo	**Jul 25-28**	**Houston, TX**
> https://dredging-expo.com		
World Seagrass Conference	**Aug 7-12**	**Annapolis, MD**
> https://isbw14.org		
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> https://www.was.org/meeting/code/WANA2020		
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