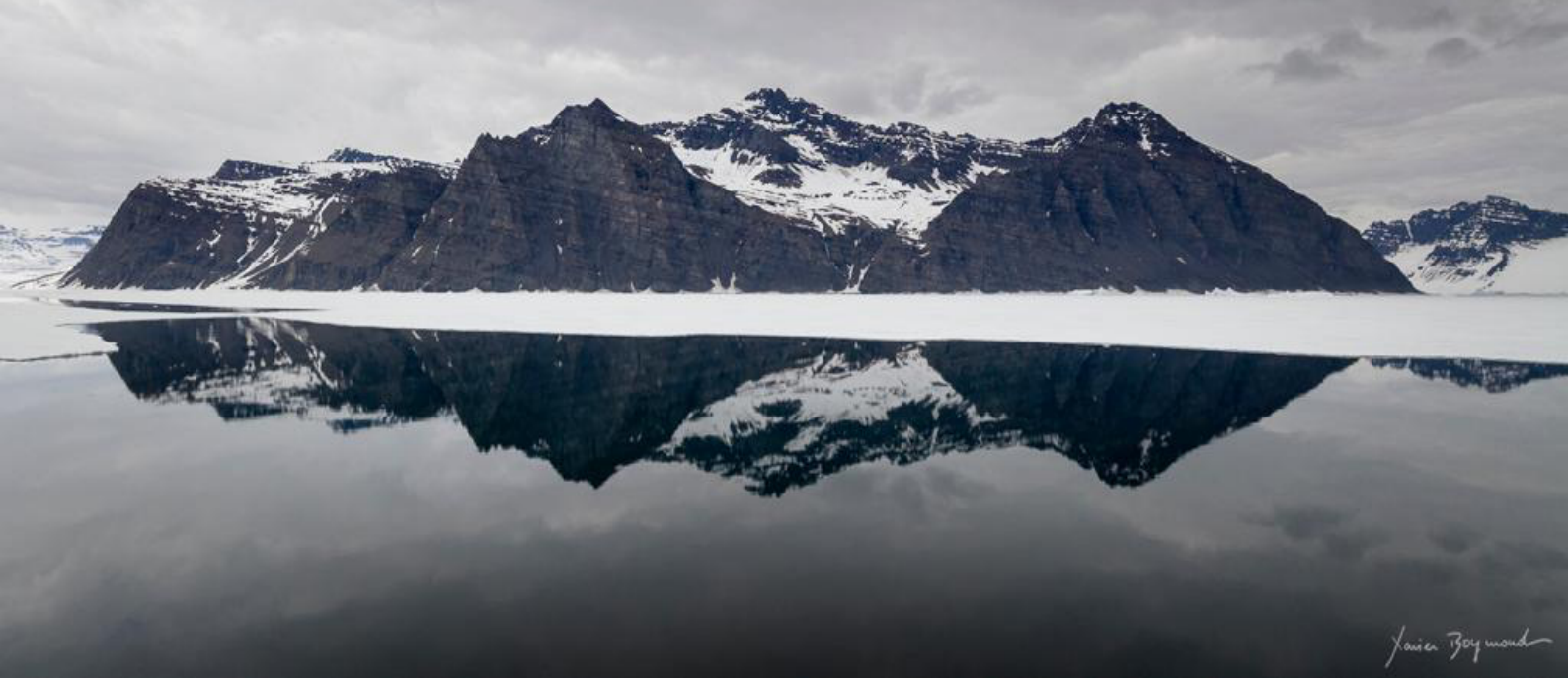

Beneath the Arctic Ice: The Subtle Ebb of Ocean Oxygen

Metallic footsteps echo through *Le Commandant Charcot's* narrow passageways, mingling with the ship's soft mechanical hum. Dr. Tim Boxhammer rubs his face to fight fatigue as he makes his way to the After Mooring Deck at the back of the vessel. A blast of ice-cold wind hits him as he steps outside. "Woah. That woke me up!" he exclaims, hastily pulling a navy beanie over his head. For the past five days, the new state-of-the-art icebreaker has been cutting through icy waters past Greenland, en route to Svalbard, one of the world's northernmost inhabited areas. This far north, the sun never sets. "It's hard to sleep when there's constant daylight," he says.

It's 9 a.m., and the ship is stationary off Greenland's east coast. Most of the passengers are listening to the safety briefing in preparation for leaving the vessel. It's a perfect opportunity to collect data. The other three members of the science team have already begun preparing the equipment. "Ça va?" greets Boxhammer. He peers over the railings to check for drifting ice that might cut the line or damage the gear, and smiles appreciatively as he takes in the scene. "The view takes my breath away every time," he says. A vast white ice sheet envelops the ship, stretching for kilometres in every direction. Its path is barred by an imposing snow-drenched mountain range, jagged peaks appearing ebony against grey overcast skies. The only colour in sight is the red lifeboats onboard the *Charcot* and the orange safety jackets worn by the passengers and crew now roaming the frozen fjord.

This is not a dedicated research vessel. The Arctic is a remote and challenging environment to access, and only three icebreakers in Europe can get here year-round. Scientists like Boxhammer must make the most of every opportunity, including this new collaboration between the EU-funded Arctic Research Icebreaker Consortium (ARICE) initiative and Ponant, a world leader in luxury cruise expeditions. "It's much nicer than our usual research vessels, that's for sure," he says. "But it means we must be ready to collect data whenever we stop, day or night, often with less than one hour's notice."

The opaque watery trail left behind by the ship's passing gives Boxhammer and the team another opening to collect data on Earth's most life-critical natural gas: oxygen.

Oxygen is critical for all forms of life. Marine organisms, like humans, depend on it to breathe. "However, climate change is having a huge impact on the ocean, and now the ocean is losing its breath," warns Boxhammer, the lead scientist onboard and a marine biogeochemist at GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany.

Ocean warming is one of the more alarming impacts. Acting as Earth's heat sink, the ocean absorbs about 90 per cent of the excess heat from greenhouse gas emissions, leading to a steady rise in ocean temperatures. In August 2023, global sea surface temperatures (SST) reached a record-breaking 21.1°C, surpassing the previous record of 20.8°C set in 2020, as reported by the Copernicus Marine Service.

This does two things, explains Boxhammer, "Firstly, when the ocean gets warmer, it can absorb less gases from the atmosphere. Secondly, it changes the way water mixes together, making it harder for oxygen from the surface to reach deeper waters." In short, as the ocean warms, it loses its oxygen supply, and marine life are suffocating.

Since the 1950s, the global ocean has experienced a two per cent reduction in the global ocean oxygen content, with projections indicating a further loss of between four and five per cent by 2100. The decline in dissolved oxygen levels, known as ocean deoxygenation, is an invisible process with consequences that are all too visible and disturbing.

While a reduction of two per cent doesn't sound very dramatic, there are increasing reports of hypoxic zones – aptly known as dead zones – where the oxygen concentration is so low that many organisms cannot survive. In 2018, a paper published in Science found that hypoxic zones in the open ocean have expanded by several million square kilometres over the last century, and rising nutrient runoff from agricultural lands is exacerbating the issue in coastal zones worldwide.

"People only find out it's happening when dead fish wash up on beaches, often in their thousands," says Dr. Véronique Garçon, co-author of the paper. "It's a distressing sight that is occurring more often and in more places. If marine life starts disappearing, the ecosystem services that the ocean provides humanity will also decline. Hence, monitoring oxygen levels is vital for everyone."

Boxhammer (right) and fellow scientist descending the Conductivity Temperature Depth (CTD) device (top instrument) and Underwater Vision Profiler (UVP) (bottom instrument) during Arctic science campaign in June 2023. Photo credit: Xavier Boymond

A sudden metal clank of the winch, operated by laboratory technician Kerstin Nachtigal, signals that the rope is being lowered. The moment it hits the silvery-black Arctic waters, a strong current begins pulling it away from the ship at a sharp angle. "Quick, grab the line," calls Boxhammer to the *Charcot's* science officer. The rope needs to be straight so they can attach the equipment. "It's a constant pain –fighting the currents and watching for drift ice– but it needs to be done to avoid losing everything," he says.

During the expedition, the team has three main ways to measure oxygen in the water. The *Charcot* has a special system, called a ferry box, that constantly takes in water from below the ship, equipped with sensors that measure oxygen levels. This helps them track oxygen on the sea's surface as the ship moves. When they're out in the open ocean, they use additional tools to measure oxygen from the surface down to deep levels, sometimes as deep as 900 metres. A device called CTD – which stands for conductivity, temperature and depth – is equipped with an additional sensor that can measure vertical oxygen profiles as it goes down. They also collect specific water samples using Niskin bottles, at specific depths, that are lowered down together with the CTD.

The deeper they measure, the more they learn. Modelling and predicting oxygen levels in the ocean is challenging due to a lack of observations and understanding of the underlying processes. This is especially true in the Arctic and the deep sea, where extreme and remote environments make data collection difficult. "The deep waters of the Arctic are particularly important as they form part of the global "conveyor belt" of ocean circulation, influencing deep water masses worldwide," says Garçon. Deep waters are formed where the air temperature is cold, and the sea surface salinity is relatively high. The relatively salty water of the Gulf Stream is cooled down in the Arctic, making the water masses denser and and cold temperatures makes the water mass denser, sinking into the icy depths before being transported around the globe (several thousand metres deep) to come back to the surface somewhere in the equatorial zone of the Pacific.

On days like today, in fjord systems, Boxhammer's team can usually only collect data as deep as 300 metres. "Everything looks good. Let's drop the weight," calls Boxhammer. A quiet 'whoosh' quickly follows as the messenger weight is released down the line to seal the Niskin bottles shut, capturing the valuable cargo inside.

These water samples are more precious than most. Oxygen loss might be the most severe and longest-lasting impact of human-induced CO_2 emissions on the planet. And yet, ocean deoxygenation has been mostly ignored until now, says Boxhammer. "Three of the five global mass extinctions were linked to significant ocean deoxygenation. Even if we stop climate change today, deoxygenation in the ocean will continue for centuries."

Climate models currently underestimate the observed ocean oxygen loss by a factor of two or three, adds Garçon, who is part of the Global Ocean Oxygen Network (GO_2NE) established to raise awareness about the importance of oxygen measurements and help coordinate capacity-building efforts. "We don't have enough information about the ocean's physical properties and its natural processes. The more we learn, the better we can predict and address the challenges of decreasing oxygen levels."

The GO_2NE group is the mastermind behind the Global Ocean Oxygen Decade (GOOD) initiative, an endorsed programme of the United Nations Decade of Ocean Science for Sustainable Development (2021-2030). "This is a global problem, so we support GOOD by connecting scientists worldwide, from Africa to Asia," says Dr. Kirsten Isensee, Programme Specialist at UNESCO's Intergovernmental Oceanographic Commission (IOC). "Additionally, we foster public-private partnerships, such as with Ponant for Arctic cruises, addressing the critical need for repeated data collection in the polar regions."

With two expeditions accomplished, Ponant will host scientists on its luxury cruise ship over the next three years and contribute valuable oxygen data for GOOD and the UN Ocean Decade. "We will get a much better picture of the real situation out there because we'll see these yearly fluctuations," says Isensee. "Public-private partnerships can provide crucial support to scientists and encourage outreach. While there are limits to such partnerships, we can't ignore the benefits they offer."

The team has now been outside in freezing temperatures for almost two hours. The water-soaked gloves and rope makes detaching the equipment all the more challenging. "I can't feel my hands anymore," says Boxhammer, separating the last of the Niskin samplers and holding it upright on deck. Nachtigal inserts a small rubber tube in the sampler and drains seawater into a small glass flask. She adds the reagents, seals it, and places it in a wooden crate with the others. "I'm done," she says, flasks gently clinking as she picks them up. "I'll do the rest in the lab – where it's warm."

Nachtigal's job now is to measure and record the oxygen found in the Niskin water samples. She uses a method that's been around since 1888. "The Winkler method is much more precise than any CTD sensor, and it allows us to compare our data with historical measurements," Nachtigal explains. The data will be publicly shared on OSIS – the Ocean Science Information System hosted by GEOMAR, and uploaded to the Global Oxygen Database and Atlas (GO_2DAT) - a project of the GOOD programme.

Le Commandant Charcot, Ponant Science's icebreaker, reaches Svalbard, north of the Arctic Circle, June 2023.
Photo credit: Xavier Boymond

This cruise marks Boxhammer's fourth Arctic campaign, and since his first expedition in 2008 and this last expendition in 2023, he has witnessed the stark environmental changes taking place. "The thinning sea ice, the melting glaciers – it's all more pronounced now, especially compared to what I saw 15 years ago," he reflects.

The oxygen measurements collected by his team this morning could help improve and calibrate climate models, providing better estimates of heat and carbon uptake. "The polar regions are key in determining the future of our ocean. We're lucky to be here collecting this data."

It's now early afternoon. Boxhammer and his team navigate back through the *Charcot's* glossy-white passageways, weary footsteps gently picking up speed as they approach the busy restaurant. Many passengers wave and greet the scientists, keen to hear about their morning activities. After a few brief exchanges, Boxhammer heads to the dessert counter, picking up a delicate-looking crème brûlée. "I think we've earned it," he smiles. The ship begins to shudder, and thunderous sounds of crushing ice signal we're once again on the move.

As *Le Commandant Charcot* charts its course deeper into the Arctic, the rhythm of metallic footsteps and the ship's soft hum become a comforting backdrop to the team's diligent work. The data collected here will contribute to a growing body of knowledge, helping scientists and policymakers make informed decisions. The data they gather will be a beacon, illuminating the path for future expeditions and research. Here, where the sun never truly sets, we're reminded that every effort, no matter how small, contributes to the broader tapestry of our understanding, shaping a more informed and sustainable future.
"The Arctic is a special place. Still, I'm really looking forward to a good night's sleep when I'm back home," Boxhammer muses, a weary but satisfied explorer in a world on the brink.

Photos from top to bottom 1) Dr. Tim Boxhammer, 2) the science team on board the Charcot 3) water samples to measure oxygen levels. Photos credit: Xavier Boymond

The article was written by Kira Coley, an independent scientific journalist, illustrated with photos by photographer Xavier Boymond as part of a communication campaign to showcase EU commitment to and the importance of Arctic Ocean observing and monitoring. Coordinated by the EU4OceanObs team at Mercator Ocean International with funding from the EU, we would like to thank everyone who participated in the campaign, and agreed to be interviewed, photographed, and advise the project along the way – all experts and researchers from the Global Ocean Oxygen Network (GO2NE), the Global Ocean Oxygen Decade (GOOD) programme, GEOMAR, AWI, the Ponant Science team, IOC UNESCO, the European Commission, among many others.

https://www.eu4oceanobs.eu/oceanobserving-awareness/arctic-observing/