UNIVERSITY OF LIVERPOOL

100 Years

since 1919 Oceans 100

Ocean Sciences at the University of Liverpool

History • Undergraduate Programmes • Sea Practical • Climate Change
Sea Level • The Arctic • The Role of Iron • Physics to Fish • Pollution

This brochure highlights learning and teaching in Oceanography at the University of Liverpool.

It also highlights some of the Department's research contributions to the major global challenges of the 21st century.

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University of Liverpool Ocean Sciences staff

Professor Chris Hughes

Professor Claire Mahaffey

Dr Pascal Salaün

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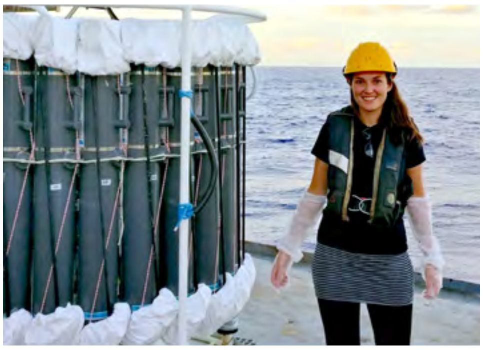


Dr Hannah Whitby

Professor Ric Williams

Professor George Wolff

History of Ocean Sciences at Liverpool

Martin Preston and George Wolff

The city of Liverpool has always been associated with the oceans through its role as a major port. Oceanography also has a rich history because of the pioneering work on tidal measurements by Jeremiah Horrocks (1618–1641) and William Hutchinson (1715–1801). The formal beginning of the Department of Oceanography at the University of Liverpool occurred in 1919, when Sir William and Lady Herdman endowed the first Chair in Oceanography as a way to draw together Herdman's work with the Marine Biological Station at Port Erin on the Isle of Man, with the Lancashire and Western Sea Fisheries Committee.

Portrait of William Hutchinson (1715-1801)

While Herdman's background was in marine biology, having started his career at Edinburgh University working on the results of the Challenger expedition, he viewed oceanography as 'the Science of the Sea in all its aspects', indicating a multi-disciplinary view that still pervades ocean sciences at the University of Liverpool. Herdman was the first Chair in Oceanography, succeeded in 1920 by James Johnstone who held the chair until his death in 1932. The early studies concentrated on marine biology, though physical oceanography at the University had also started in 1919 with the formation of the Liverpool Tidal Institute, initially based in the Physics Department, led by Joseph Proudman. In the 1930s, physical oceanography assumed an increasing importance under the leadership of Proudman, who was Professor of Oceanography between 1933 and 1954, and his successor, Kenneth Bowden who retired in the early 1980s.

William Herdman : The first Oceanography Professor and Founder of the Department of Oceanography.

In the immediate post-war years, the marine biologists moved to the Port Erin Marine Station on the Isle of Man. At the same time, marine chemistry was boosted by a number of appointments, notably Professors John Riley and, some years later, Roy Chester, so that by the mid-1970s the Oceanography department presented a balanced programme of research and teaching in chemical and physical oceanography.

Developments in the 1980s led to the merger of the Oceanography and Geological Sciences departments in 1987 to become the Department of Earth Sciences, now the Department of Earth, Ocean and Ecological Sciences in the School of Environmental Sciences. In 2004, the relocation of the Proudman Oceanography Laboratory (formerly the Liverpool Observatory and Tidal Institute, based at Bidston Observatory and to which Liverpool's tidal work had been relocated in 1929) rejuvenated Oceanography on the University campus. The Proudman Laboratory became a part of the National Oceanography Centre in 2010. There is now a strong community of undergraduate and postgraduate students as well as research, technical and academic staff. Excellent teaching facilities and research contributions contribute to Liverpool's reputation as a globally important centre for oceanography.

Ocean Sciences Undergraduate Programmes

Undergraduate Ocean Sciences began in Liverpool as a subject rooted in the physical oceanography of tides. The teaching has, however, always responded to the research interests of departmental staff. Physical oceanography and marine chemistry became key pillars of teaching from the 1950s onwards.

More recently the University of Liverpool degree programmes in ocean sciences have developed to reflect the increasingly multi-disciplinary nature of our staff and their research. As research projects progress, the new insight and results are continuously drawn into teaching, from the introductory material in year one lectures all the way through to students' final year projects and to advanced lectures on emerging topics in ocean sciences.

We currently run four undergraduate degree programmes:

1. BSc and MOSci in Ocean Sciences: This is the programme for students with any science and/or maths background who want to gain training across all the ocean science disciplines.

2. BSc in Marine Biology with Oceanography: This programme sits between our ocean sciences degree and the marine biology degree. Students learn about the oceans with more biological and ecological emphasis.

3. BSc in Geography and Oceanography: Students with interests in physical geography can work on this programme to develop a more holistic view of how our planet works, across the terrestrial and ocean environments.

4. BSc in Mathematics with Ocean and Climate Science: A strong background in mathematics can be used to develop skills aimed at understanding climate dynamics and climate change.

All our degree programmes aim to foster a sense of curiosity in how the oceans work and how they contribute to life on our planet. We provide training that focuses on the three key University of Liverpool hallmarks: of applying knowledge to real world problems; developing new knowledge with internationally renowned researchers; and understanding knowledge in a global context.

Students learn how to pose hypotheses, how to design suitable scientific methods to test hypotheses, and how to analyse and interpret data using industry-standard tools. A vital component of all of our degree programmes is training at sea during the Sea Practical field course.

The Sea Practical

Harry Leach, Martin Preston and Jonathan Sharples

Back in the mists of time, practical work at sea for oceanography students was conducted aboard the university's research vessel, the *William Herdman*, however the first Sea Practical of the modern era was run by Harry Leach and Martin Preston in 1994. This was based at the University's Port Erin Marine Laboratory and used its vessel, the RV *Roagan* and laboratory facilities, for the modest sum of £500 a week.

Following the earlier reorganisation of marine sciences in higher education (UGC Review, 1986) the oceanography group only possessed some heritage equipment, such as some old yellow plastic NIO bottles and mercury-in-glass reversing thermometers, an old direct-reading current meter, old salinometers, and a red surface float to make a drifter, so Harry and Martin started off by improvising. However, as time went by, they were able to buy a Valeport current meter and taught themselves how to do moorings. They borrowed a CTD and a sediment grab from Port Erin, and bought a plankton net to catch zooplankton. In due course they were able to teach maritime meteorology, hydrographic and current measurements, sampling for dissolved oxygen, nutrients and chlorophyll, zooplankton and sediments.

We went to Port Erin for the last time in 2002, just before the lab was closed. After this, the operation was transferred to Oban, Scotland, and since 2003 has been based at Dunstaffnage Marine Laboratory using the RV *Calanus*. Here, methods were brought up to date by hire of a rosette sampler, an enhanced mooring capable of working at 150m water depth and a sediment-corer to allow analysis of profiles of properties within the sediments, such as water content and a CN-analysis. Since 2003, laboratories in Liverpool have been used for the analysis of samples and data. Students spent three days at sea. Typically, on the first day there would be a hydrographic section along the Sound of Mull with sampling for oxygen, nutrients and chlorophyll. On the second day in the Firth of Lorn there would be current measurements with a mooring and drifter, hydrographic stations with water bottles and reversing thermometers and plankton netting, and the third day sediment samples with a grab and a corer would be taken at a series of stations north of Dunstaffnage.

Starting in 2018 the Sea Practical began to use two vessels, the RV *Calanus* for the 'offshore' work and the smaller RV *Seol Mara* for work inside Loch Etive. This allows the students to focus their write-up on the contrasts and connections between the physical, biological and chemical oceanography of the enclosed sea loch and of the adjacent coastal ocean. For instance, why are the deep waters in Loch Etive low in oxygen, and when and how might the oxygen be replenished? Why are the zooplankton populations in the deep basins of Loch Etive so different to those found outside? The aim is to give the students experience of writing up a focused, practical piece of work similar to a research paper or to a commercial survey report.

We should thank the administrative and sea-going staff at both Port Erin Marine Laboratory and at the Scottish Association for Marine Science for supporting our endeavours over the decades and making this module the highlight of our students' undergraduate experience. We should also thank Valeport Ltd, of Totnes in Devon, for servicing our current meter free of charge on occasion. Our own technical and financial support staff in Liverpool should also be thanked, particularly Carmel Pinnington for managing the equipment and laboratory activities.

The Ocean and Climate Change

Ric Williams

Few can argue that our planet is warming and there is strong scientific evidence that links increased global surface temperatures with increased concentrations of atmospheric carbon dioxide. The research of Professor Ric Williams aims to understand how much warmer the planet is likely to become if carbon continues to be released to the atmosphere. The extent of surface warming is affected by how the ocean takes up heat and carbon (Fig. 1).

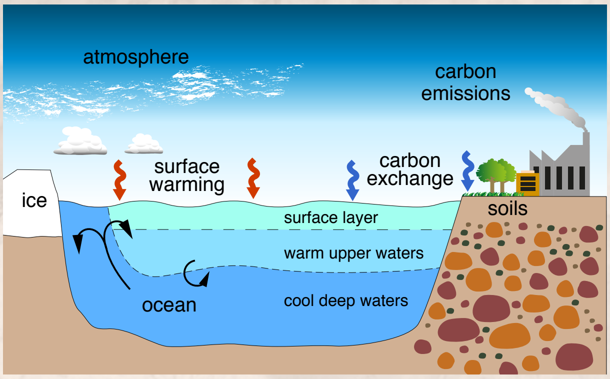
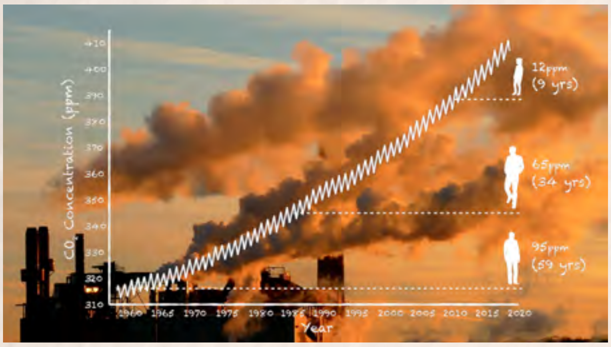
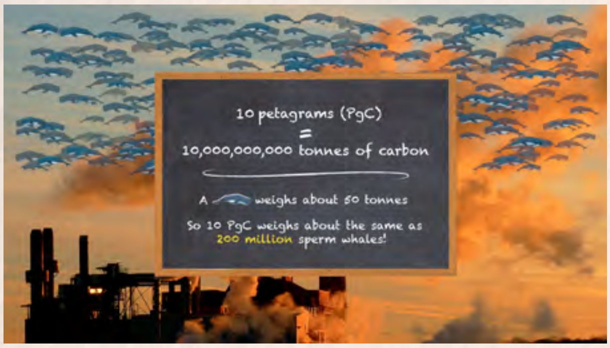


Figure 1. A schematic view of how heat (red arrows) and carbon (blue arrows) are exchanged in the climate system. The extent of surface warming is affected by the physical circulation and mixing in the ocean, redistributing heat and carbon over the globe.

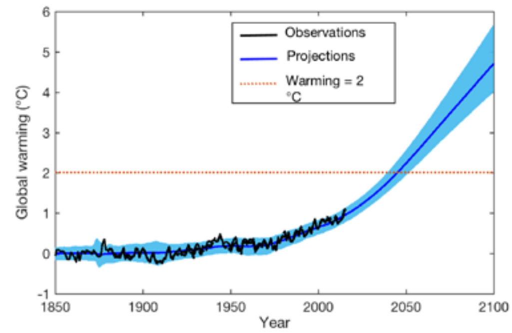
Climate models are used to estimate how much warming will occur for a given carbon emission. All climate models show the same generic response --- the more carbon we emit, the warmer our climate will become. However, there are inter-model differences in the amount of surface warming. One of the reasons for this is due to differences in how heat and carbon are taken up in the ocean part of the climate model.



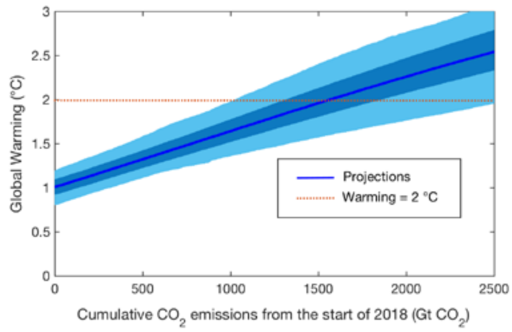


View our Climate and Carbon YouTube videos:
What happens to emitted carbon?
https://youtu.be/B6uOvO1263g
Paris or Bust https://youtu.be/0BF6f5bgA8w
Carbon emissions and surface warming
https://youtu.be/CBl-HncKC5c

WARMING PROJECTIONS



This graph shows when we are likely to reach 2°C warming if there is no change in emissions.



This graph shows how much carbon may be emitted before we reach 2°C warming.

We have also estimated how much time we have until we exceed the Paris global warming targets of 1.5°C or 2°C. Our work suggests that if we continue to emit the same rate of carbon to the atmosphere, then we only have just under two decades before reaching 1.5°C and between three and four decades before reaching the 2°C threshold. Our work was used in the Intergovernmental Panel for Climate Change *Special Report on Global Warming of 1.5°C.*

Our latest research has also considered what might happen in our future if we eventually stop emitting carbon to the atmosphere. Unfortunately, we believe that there is a sting in the tail: if when we finally cease emitting carbon, high amounts of carbon dioxide remain in the atmosphere, then surface temperatures are likely to continue to rise at a slower rate as less heat is taken up by the ocean interior, so that peak surface warming occurs after carbon emissions cease; this delayed response is like how your oven will continue to warm, even after you turn it off.

This delay in peak warming is even more reason for us all to act now to reduce emitting carbon to avoid future dangerous climate.

Further reading: P Goodwin, A Katavouta, VM Roussenov, GL Foster, EJ Rohling and RG Williams, 2018. *Pathways to 1.5°C and 2°C warming based on observational and geological constraints.* Nature Geoscience, 11, 102-107,doi: 10.1038/s41561-017-0054-8.

RG Williams, V Roussenov, TL Froelicher and P Goodwin, 2017. *Drivers of continued surface warming after cessation of carbon emissions.* Geophysical Research Letters, 44, doi.org/10.1002/2017GL075080

TIME IS LIMITED

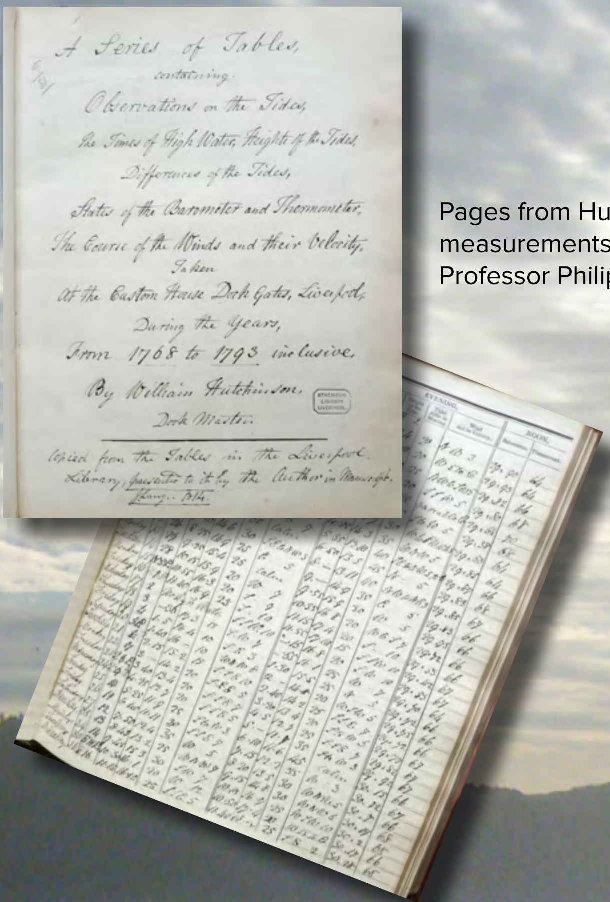
We have found that, if nothing is done to curb increasing carbon emissions, we will reach 2°C warming in 30 years and 1.5°C of warming in under 20 years

Liverpool PIs: Professor Ric Williams, Dr Phil Goodwin (now Associate Professor at Southampton University, previously PhD at Liverpool) Senior Research Associate Dr Vassil Roussenov, Dr Anna Katavouta (now at National Oceanography Centre), Dr Jon Lauderdale (now at MIT), PhD student Katherine Turner, Dr Andy Heath (for the impact work).

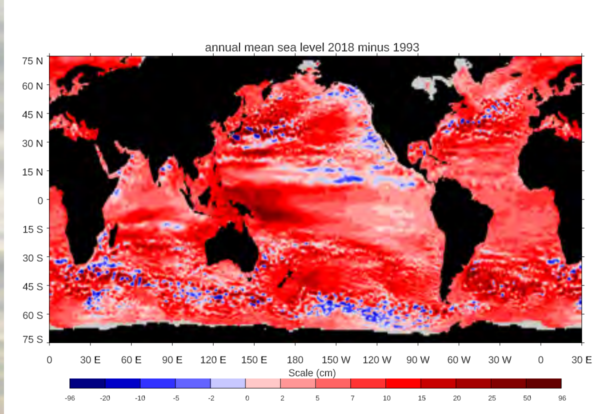
External PIs: Professor Thomas Froelicher (University of Bern), Professor Laurent Bopp (Paris), Professor Mick Follows (MIT)

Sea Level and Liverpool

Chris Hughes



Pages from Hutchinson's Journal, including tide measurements (Hutchinson pictures courtesy of Professor Philip Woodworth).

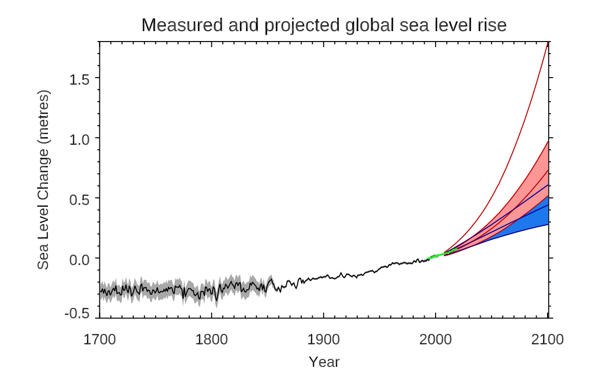


The rise in sea level between 1993 and 2018 as measured by satellite. The global average value is 7.5 cm.

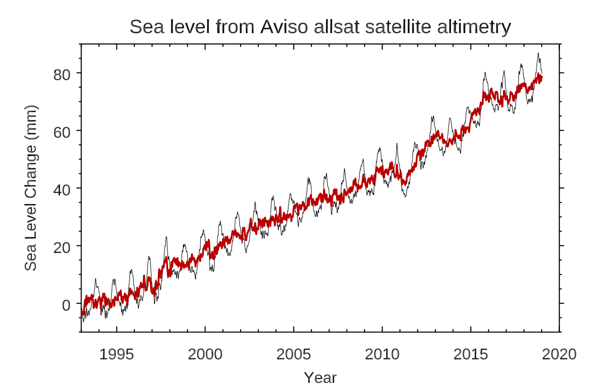
Liverpool has a long history of sea level measurement and interpretation. Sadly, the measurements made by Jeremiah Horrocks in 1640 have been lost, but the Dockmaster (and ex-privateer) William Hutchinson measured the time and height of high tide every day from 1764 to 1793, and we still have all but the first four years of that record, which makes Liverpool one of the longest sea level records in the world, and the longest in the UK.

The University's second Professor of Oceanography, Joseph Proudman, was an expert on tides, he became director of the Liverpool Tidal Institute, which made tidal predictions for the world's ports and played an important role in the timing of the D-Day landings. The study of tides led on to other aspects of sea level science, including flooding from storm surges (catalysed by the great floods of 1953), the relationship of sea level to ocean dynamics, and the foundation of the Permanent Service for Mean Sea level, which is the World Data System centre for global tide gauge measurements, now within the National Oceanography Centre.

A wave splashing over the coastal defences at Hoylake, Wirral, January 2014 (the winter of 2013-2014 included a lot of storm surges and floods).



Global mean sea level as inferred from tide gauge measurements (black), measured by satellite (green) and projected into the future assuming either a peak in CO_2 emissions by 2020 (blue, shaded), continuing rise in emissions (red, shaded), or rapidly-melting ice sheets (red line).



Global mean sea level rise from satellite measurements. Black shows the raw measurement, red is after subtracting the seasonal cycle.

The focus is now on sea level rise and climate change. In the UK, a good rule of thumb is that, for every 32cm of sea level rise, flooding events will occur 10 times more often unless coastal defences are enhanced. We now have satellite measurements as well as tide gauges and can see that sea level has risen globally by about 7.5cm in the last 25 years, with the rise round the UK typical of the global average. By the end of the century, projections show a likely further 20-50cm rise if CO_2 emissions peak before 2020, or 40–90cm if emissions continue to rise. But there is great uncertainty about how the major ice sheets will respond to warming, and a possible scenario leads to a further 1.7m of rise, and possibly over a metre even if CO_2 emissions peak soon.

Liverpool researchers are still at the forefront of this work, learning how changes to the ocean circulation might affect sea level rise regionally, and improving our understanding of the causes of the sea level changes we can measure.

Liverpool PIs: Professor Chris Hughes, Professor Ric Williams, Dr Angela Hibbert (now head of the Sea Level group at National Oceanography Centre), Dr Chris Wilson (now at National Oceanography Centre), PhD students Anthony Wise and Peter Hogarth.

Liverpool Associate PIs at National Oceanography Centre: Professor Philip Woodworth, Professor Kevin Horsburgh, Dr Svetlana Jevrejeva (currently at Singapore Centre for Climate Research), Dr Simon Williams, Dr Joanne Williams, Dr Francisco Mir Calafat.

The Arctic

Claire Mahaffey

Figure 1. Arctic seascape during research expedition JR16006 to the Barents Sea. (Photo: Dr Jo Hopkins, Co-PI, ARISE).

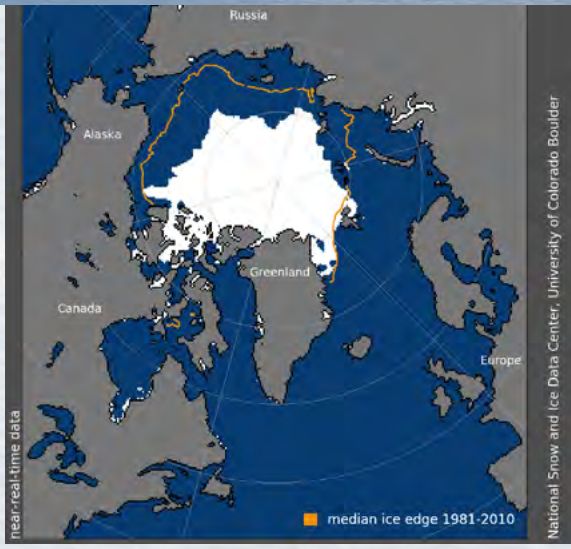


Figure 2. Sea ice extent on 19th August 2019 (white) compared to median ice edge between 1981 and 2010 (orange line). Source: National Snow and Ice Data Centre, University of Colorado, Boulder.

The Arctic Ocean is unique. It is the smallest, shallowest, freshest and most isolated ocean on Earth. It is ice-covered for half the year, making it a challenging environment for marine organisms to live there. But they do. Sea ice provides an essential platform for a range of organisms, from microscopic plankton that live in brine channels in sea ice, to fish, seals and polar bears that use sea ice to feed, breed, hunt, haul out and moult.

The Arctic is changing rapidly. Due to climate change, it is warming twice as fast as the rest of the planet. Sea ice extent has declined by 13% per decade since 1979, meaning the habitat that Arctic marine life relies on is disappearing rapidly (Fig. 2). Change in the physical environment is having knock-on effects over the entire Arctic, causing changes in productivity, river flow, rainfall, ocean chemistry and ocean circulation. Detecting the impact of the changing environment on the Arctic ecosystem is a significant challenge due to the remote and extreme location, as well as the highly seasonal and migratory behaviour of animals that live there.

As part of the NERC Changing Arctic Ocean programme (https://www.changing-arctic-ocean.ac.uk/), ocean scientists and marine biologists in Liverpool, and colleagues from other UK universities and research centres alongside 27 international project partners are tackling this challenge by developing a new approach to detect how and why Arctic ecosystems are changing via the ARISE project (https://arcticarise.wordpress.com/aims/). ARISE scientists have participated in over 15 research expeditions to the Arctic Ocean to collect samples of water and plankton, representing the base of the food web. Using stable isotope biomarker analysis, we are studying how sensitive the base of the food web is to environmental change, and the impact this has on ice-dependent predators, specifically the harp seal and ringed seal. We are using satellite tags to study the migratory and foraging behaviour of harp seals (Fig. 3) and historical data and remote sensing of sea ice and productivity to study how sensitive they are to a changing sea ice regime. To unravel the effect climate change has over decadal timescales, we have access to an archive of seal teeth back to the 1950s. Seal teeth grow a bit like tree rings, laying down growth layers annually (Fig. 4). By analysing the stable isotope of biomarkers in the growth layers of teeth, we can reconstruct the food web dynamics of their populations over decadal

Above: **Figure 3**. Harp seal off the coast of Newfoundland with a satellite tag attached. (Photo: Dr James Grecian, University of St. Andrews, Postdoctoral Researcher, ARISE).

Figure 4. Tooth section. (Photo: Dr Jo Kershaw, Postdoctoral Researcher, ARISE).

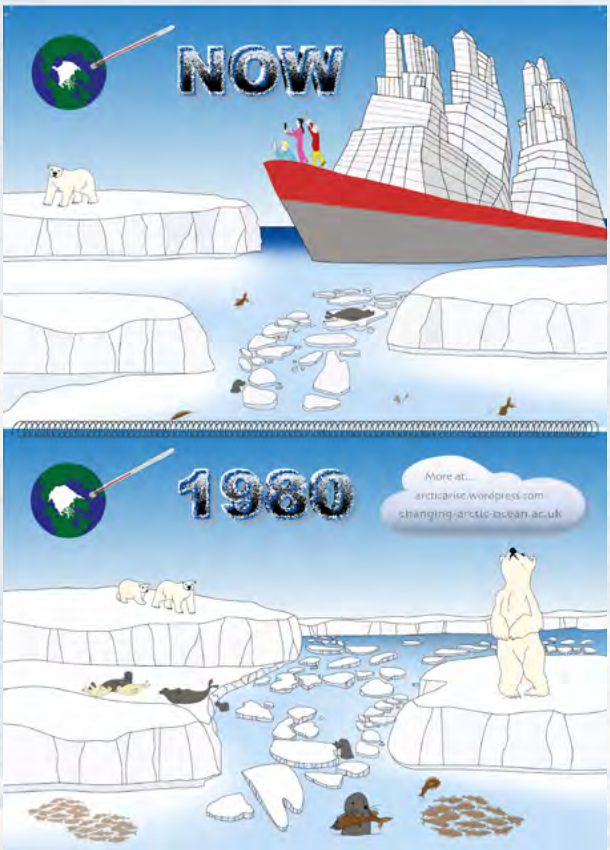


Figure 5. Illustrated poster explaining climate change in the Arctic to GCSE Science and Geography students (Illustration: Dr Andy Heath and Christopher Murray).

timescales. Together with satellite and model output of the changing environment we aim to better understand how climate change has and will affect these ice-dependent predators and important components of the Arctic ecosystem.

Our work in ARISE reaches beyond academia. We are developing posters and lesson plans for schools to introduce the Arctic, climate change, food webs and stable isotopes to GCSE Science and Geography students (Fig. 5). In addition, project partners in ARISE are key players in international organisations tasked with managing Arctic ecosystems, specifically the North Atlantic Marine Mammal Commission (NAMMCO), International Council for Exploration of the Seas (ICES) and Circumpolar Biodiversity Monitoring Programme (CBMP). New understanding developed through ARISE will have the potential to inform future decision making and policy development for conservation and management of Arctic ecosystems.

Liverpool ARISE PIs: Professor Claire Mahaffey, Professor Alessandro Tagliabue, Professor George Wolff, Dr Rachel Jeffreys, Dr Andy Heath. Postdoctoral researchers Dr Camille de la Vega, Dr Pearse Buchanan, Research Technician Dr Louisa Norman, PhD student Elliott Price

Other ARISE PIs: Dr Jo Hopkins (NOC), Dr Sophie Smout (University of St. Andrews), Professor Raja Ganeshram (University of Edinburgh), Dr Rowena Stern (Marine Biological Association), Dr Bart van Dongen (University of Manchester), Dr Claudia Castellani (Plymouth Marine Laboratory), Postdoctoral Researcher Dr James Grecian (University of St. Andrews), Dr Robyn Tuerena (University of Edinburgh), PhD student Emma Burns (University of Manchester).

Iron in the Ocean: into the 21st century

Alessandro Tagliabue

One litre of seawater only contains around 50 nanograms of iron, which is required by life to perform photosynthesis, respiration and other cellular processes. By contrast, a litre of seawater contains over one thousand times more nitrogen and phosphorus. This means that unlike land plants, the vitality of marine plants (known as phytoplankton) is often regulated by iron. Due to the challenges of measuring this scarce commodity, our understanding of the ocean iron cycle, whereby researchers explore what controls the abundance of iron in different parts of the ocean, only really began at the start of the 1980s.

A major challenge with iron is that it is known to be very reactive in seawater and the low levels observed are, in fact, around one thousand times higher than they should be, given the typical temperature and oxygen levels of the sea. The University of Liverpool's Professor Stan van den Berg played a crucial role in solving this conundrum in a suite of research papers published during the 1980s and 90s. He showed that almost all of the dissolved iron in seawater was strongly bound to small organic molecules known as ligands. Today, Drs Pascal Salaün and Hannah Whitby are furthering our understanding of this phenomenon

The scientists, officers, crew and technicians of the RRS *James Cook* at the end of the UK Geotraces GA13 voyage

by addressing how the pH changes associated with ocean acidification will affect the ability of ligands to stabilise iron, and by probing deeper into the exact nature of these molecules and how they make their way into the ocean.

By the turn of the millennium most iron was considered to enter the ocean from mineral particles mobilised into the atmosphere from deserts, which are then transported out to sea where they settle in the surface ocean and release the iron. The Southern Ocean was known to be depleted in iron, except in local hotspots around basaltic sea mounts (South Georgia, Crozet and Kerguelen Islands), where iron is thought to be leached from the igneous rocks to fertilise the surface ocean, influencing other life there, even at the deep-sea floor. The impacts on the carbon cycle and sea floor animals have been studied by Professor George Wolff.

Ligands are thought to stabilise iron at a fixed upper limit and iron uptake by marine phytoplankton was thought to be underpinned by fixed requirements. By playing a key role in the ongoing international effort GEOTRACES, which aims to improve observations of trace metals like iron, Professor Alessandro Tagliabue has shown the unique nature of the ocean iron cycle. The development of merged observational data products and advancement of state-of-the-art global models has shown that iron is controlled by many external sources and that once in the ocean rapidly cycled by both chemical and biological processes. Recently Professor Tagliabue led a UK expedition along the mid-Atlantic ridge to specifically examine the role of different deep-ocean hydrothermal vents as iron sources to the ocean and is now leading research on how genetic datasets can be exploited to assess how life is affected by different iron levels, both now and in the future.

At Liverpool our researchers use a combination of different tools to understand the ocean iron cycle and how it may change in the future. We enjoy bringing together the insights gained from laboratory experiments, ocean-going expeditions and predictive modelling, and are sure that there are more exciting discoveries to be made in the decades ahead.

Liverpool PIs: Professor Alessandro Tagliabue, Dr Pascal Salaün, Dr Hannah Whitby, Professor George Wolff, PhD Student Daniela Koenig, Leo Mathieu, Shaun Rigby, Postdoctoral Researchers Dr Calum Preece, Dr Lavenia Ratnarajah, Dr Camille Richon.

Physics to Fish

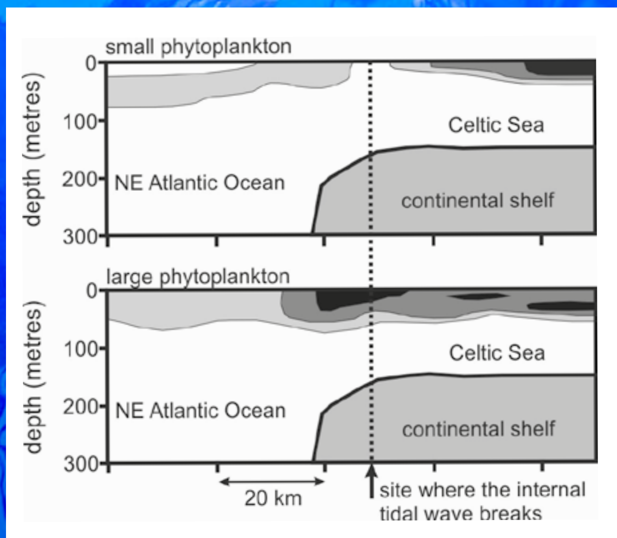
Jonathan Sharples and George Wolff

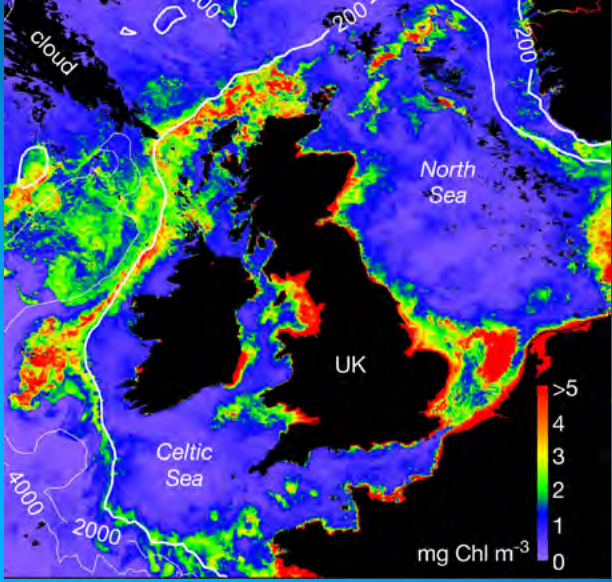
Sub-surface tidal waves have been found to be fundamental in sustaining one of the most important fisheries on the northwest European shelf. These sub-surface waves are caused by the tidal currents as they push water on and off the continental shelf. As the current flows off the shelf and down into the deeper NE Atlantic, the thermocline is pulled downward. When the tidal flow slows down this downward bulge in the thermocline bounces back, sending a wave travelling along the thermocline onto the shelf. The shallower water on the shelf causes this sub-surface tidal wave to break, which leads to mixing of the deeper water up towards the sea surface.

Mixing the deeper water upwards brings nutrients towards the surface. Microscopic single-celled plants (the phytoplankton) in the surface require these nutrients in order to grow. We found that the extra nutrients not only allow the phytoplankton to grow more, they also result in larger species of phytoplankton. The entire edge of the continental shelf is used by socks of mackerel, horse mackerel, hake and other fish species as their main spawning ground. The larger phytoplankton are a vital source of food to the fish larvae just after they have hatched from their eggs. These changes to the phytoplankton at the sea surface over the shelf edge also affect ecosystems deeper on the seabed, such as cold-water corals (CWCs).

Liverpool PIs: ProfessorJonathan Sharples, Professor Claire Mahaffey, Postdoctoral Researchers Clare Davis, Calum Preece, PhD students Juliane Wihsgott, Eugenio Ruiz-Castillo, Nealy Carr.

Other collaborators: Dr Matthew Palmer, Dr Jo Hopkins (NOC), Professor Mark Moore, Emeritus Professor Patrick Holligan, Dr Anna Hickman (University of Southampton), Professor Tom Rippeth, Professor John Simpson and Dr Mattias Green (Bangor University).





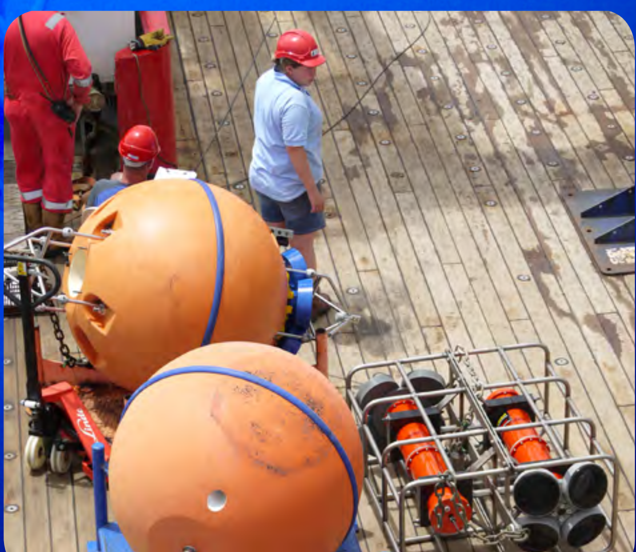
Deep-sea CWCs are perhaps the lesser known relatives of their tropical counterparts. They occur around the world's oceans but have been most extensively studied in the North Atlantic Ocean, particularly at the European continental margin from Norway to Spain, including UK and Irish waters and into the Mediterranean. We know that these vulnerable marine ecosystems (VMEs) have already been largely impacted by deep-water fisheries, but they now are under increasing threat from warming seas, possible changes in circulation and ocean acidification.

Unlike the tropical corals, which are in part fuelled (when healthy) by zooxanthellae, symbiotic photosynthetic algae, the CWCs are heterotrophic, which means they rely on food supply that is ultimately driven by phytoplankton living in overlying waters. Keystone species, such as Lophelia pertusa, can form large reef structures, living over a wide depth range (typically 100–1800m) and are sensitive to temperature (4–12°C). They are cosmopolitan feeders but do require good quality food and so are reliant on the productivity of overlying waters to obtain their 'manna from heaven'.

The Scleractinia framework forming CWCs are largely made up of calcium carbonate and are at potential risk from ocean acidification, especially in high latitude waters, as it is there that pH is likely to change initially, potentially leading to stressful conditions that are deleterious to CWC growth. Through intensive research in collaboration with European, Canadian and US scientists we are assessing these risks in order to establish better management of our precious VMEs.

Liverpool PIs: Professor George Wolff and Sabena Blackbird, Izzy Hassall.

Other PIs: Professor Murray Roberts (University of Edinburgh), Dr Dick van Oevelen (NIOZ)



From useful proxy in the oceans to deadly toxin in groundwater: the never-ending story of arsenic

Pascal Salaün

Arsenic is certainly one of the most notorious elements due to its insidious toxicity. Tasteless, odourless and colourless, it was so commonly used that one of its names was 'the inheritance powder'. But there were also accidents such as that in 1900 when 115 people died in Liverpool and Manchester because beer was contaminated with arsenic.

Arsenic is also present in marine waters but at trace levels (10–20nM). Surprisingly, it has a depth profile similar to nitrate or phosphate: lower concentration at the surface because it is taken up by algal cells present in the well–lit surface. Why would biology take up a toxic element such as arsenic? Well, it is not really a choice. Arsenic is mostly present as the inorganic arsenate $AsH_2O_4^-$ and $AsHO_4^{2-}$. These molecules are chemically so similar to the nutrient phosphate that arsenate can enter the algal cells through their phosphate channels. If phosphate concentrations are high, the chance of taking up arsenate is low; on the contrary, if phosphate is low, arsenate uptake is high and the algal cells need to deal with this unwelcome element. They do so by first reducing it to arsenite $As(OH)_3$ before excreting it back into the surrounding water. The presence and levels of arsenite in surface seawater can thus be correlated to biological uptake and in turn to phosphate levels in water, making arsenite a useful proxy for phosphate-limited areas in the oceans, areas that are predicted to increase in the future.

Arthur Gourain (PhD student at Liverpool), collecting water under the guidance of Dr Arun Kumar. June 2019 in Bihar, India.

In Liverpool, we have developed new electrochemical methods for the determination of arsenite that are sensitive enough to measure sub to low nM levels of arsenite, levels that occur in these phosphate limited areas. These methods are portable and can be used on-board, directly after sampling of the water. These developments have found strong interest and application in a much different environment.

Arsenic contamination of groundwater is worldwide with all continents being affected. The issue is particularly severe in Asia with Bangladesh and West Bengal considered as 'hotspots'. Several million people are confronted on a daily basis to unsafe arsenic burden, leading to disease, cancers and ultimately death. In the 1970s, millions of wells were drilled to access deeper water without realising that many of these aquifers are naturally contaminated by arsenic. The problem is that arsenic levels are difficult to predict and they vary significantly both spatially and temporally. Recently, we visited a small village next to Patna in the Bihar region of India and we measured arsenic levels in 25 family wells. Concentrations varied from low ppb levels (less than 10, the legal limit) to more than 1,400 ppb, i.e. more than 140 times the legal limit. Wells only separated by few tens of metres had completely different concentrations and the effect was similar on people: some have no apparent signs of arsenic toxicity while their neighbours, irrespective of age, may have clear signs of arsenicosis, a disease that affects the skin.

So what can be done? The first step has to be the analytical determination of arsenic levels to know which wells are safe. Cheap, simple and portable systems for rapid screening are needed; the analytical methodology that we developed in Liverpool for arsenic detection in marine waters has inspired the development of an on-site sensor by an international company, helping now in the much-needed remediation of this huge problem.

Liverpool PIs: Dr Pascal Salaün, PhD student Arthur Gourain, Undergraduate Mollie Allerton, Professor Stan van den Berg, Dr Hannah Whitby and Dr Kristoff Gibbon-Walsh.

Other PIs: Professor Dominik Weiss, PhD student Jay Bullen (Imperial College, London), Dr Arun Kumar, Mahavir (Cancer Research Institute, Patna, Bihar, India), Dr Subhamoy Bowmhick (CSIR-NEERI, Kolkata, West Bengal, India).

On-site analysis of arsenic in West Bengal, India, September 2018. Jay Bullen (Imperial College London), performing arsenic detection by voltammetric techniques.

Examples of arsenicosis, the visible effect of arsenic on the skin. Pictures taken in Bihar, India, June 2019.

Ocean Sciences Outreach

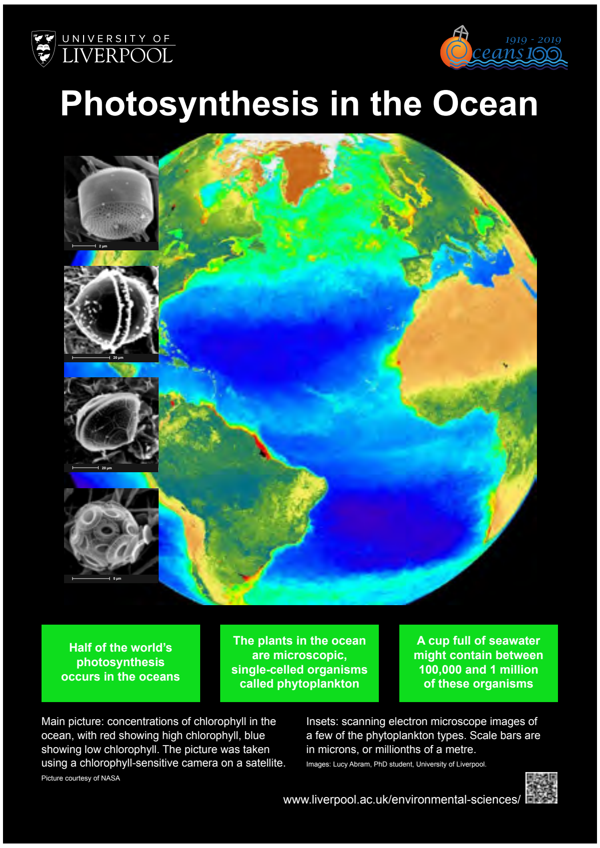
Jonathan Sharples

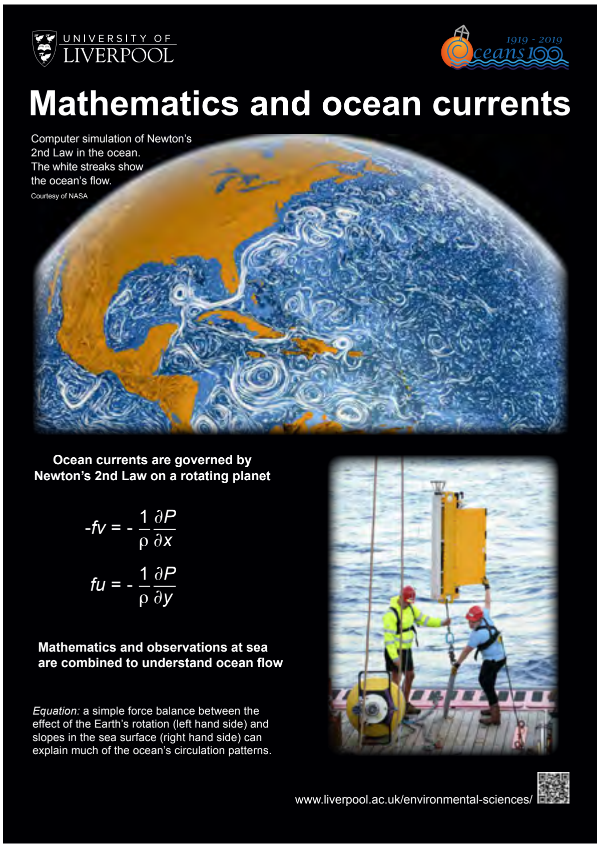
Staff and students in Ocean Sciences regularly present talks or exhibits at public events, and host school visits on campus often using the Central Teaching Laboratories. Recently talks have been given at Pint of Science events (Arctic research), local SciBars in Kirkby, Knutsford and Southport (Plankton and Global Climate), and at the Liverpool Maritime Museum to mark 100 years of tidal science in Liverpool (https://conference.noc.ac.uk/ocean-tide-and-port-liverpool).

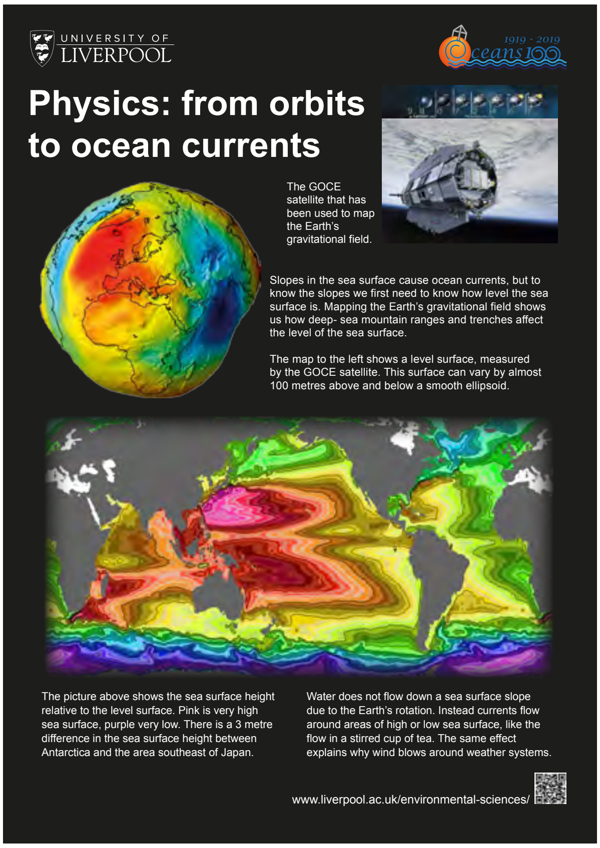
We often present an exhibit at the Mersey River Festival, and have entertained school groups at events such as the Big Bang Northwest (https://www.allaboutstem.co.uk/the-big-bang-north-west/).

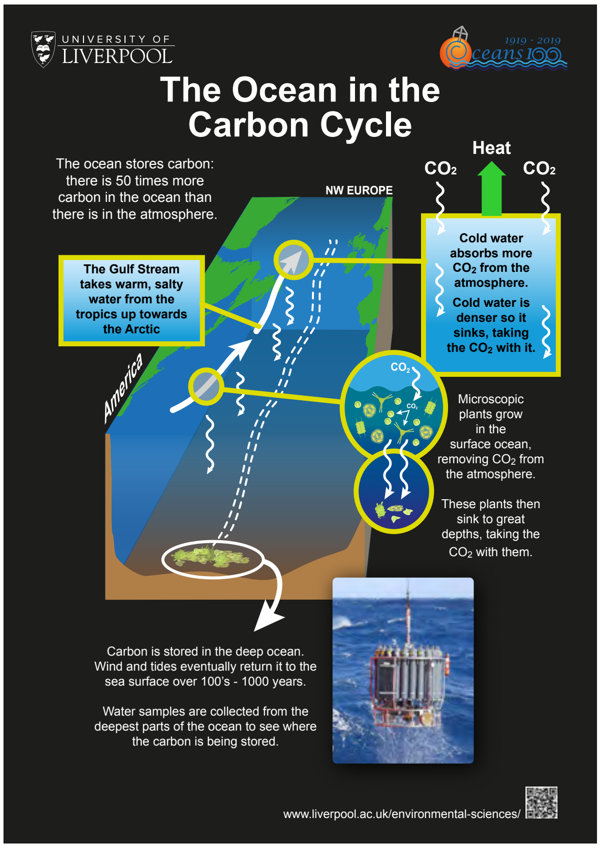
If you want to invite an ocean scientist to give a public talk, or to visit a school, you can contact us at soesms@liverpool.ac.uk. School teachers can also request copies of the posters shown here at the same email address.

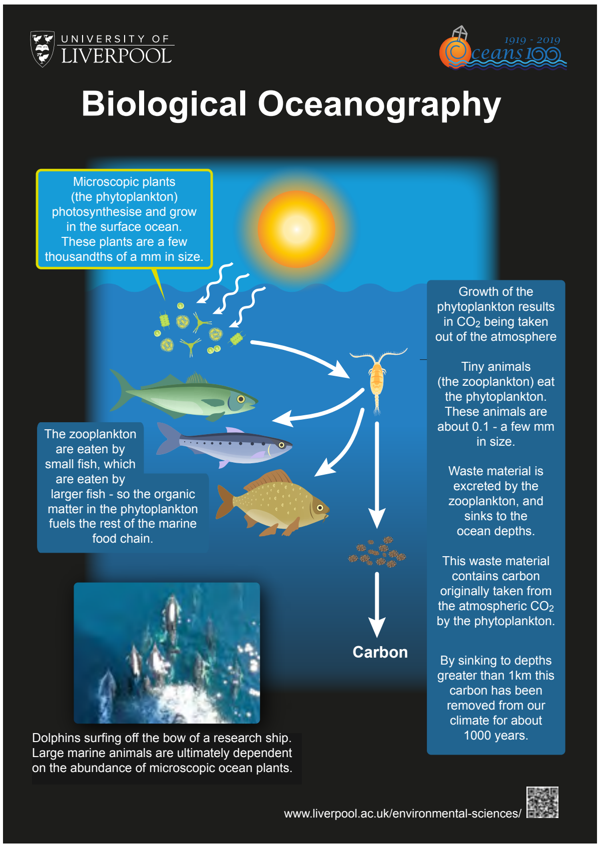
UoL students inspiring future ocean scientists at a recent Big Bang North West event.











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