OCEAN Challenge

The Challenger Society for Marine Science

Towards equality in sea-going science • Why we need to know more about iron colloids • A tour of RRS *Sir David Attenborough* • Covid-19 and CO_2 emissions • Gaining experience through CLASS • Predicting the 2020 iceberg season off Newfoundland

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The views expressed in *Ocean Challenge* are those of the authors and do not necessarily reflect those of the Challenger Society or the Editor.

SCOPE AND AIMS

Ocean Challenge aims to keep its readers up to date with what is happening in oceanography in the UK and the rest of Europe. By covering the whole range of marine-related sciences in an accessible style it should be valuable both to specialist oceanographers who wish to broaden their knowledge of marine sciences, and to informed lay persons who are concerned about the oceanic environment.

NB *Ocean Challenge* can be downloaded from the Challenger Society website free of charge, but members can opt to receive printed copies.

For more information about the Society, or for queries concerning individual or library subscriptions to *Ocean Challenge*, please see the Challenger Society website (**www.challenger-society.org.uk**)

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OCEAN Challenge

The Magazine of the
Challenger Society for Marine Science

SOME INFORMATION ABOUT THE CHALLENGER SOCIETY

The Society's objectives are:

To advance the study of marine science through research and education

To encourage two-way collaboration between the marine science research base and industry/commerce

To disseminate knowledge of marine science with a view to encouraging a wider interest in the study of the seas and an awareness of the need for their proper management

To contribute to public debate and government policy on the development of marine science

The Society aims to achieve these objectives through a range of activities:

Holding regular scientific meetings covering all aspects of marine science

Setting up specialist groups in different disciplines to provide a forum for discussion

Publishing news of the activities of the Society and of the world of marine science

Membership provides the following benefits:

An opportunity to attend, at reduced rates, the biennial UK Marine Science Conference and a range of other scientific meetings supported by the Society (funding support may be available)

Receipt of our electronic newsletter *Challenger Wave* which carries topical marine science news, and information about jobs, conferences, meetings, courses and seminars

The Challenger Society website is
www.challenger-society.org.uk

MEMBERSHIP SUBSCRIPTIONS

The annual subscription is £40 (£20.00 for students in the UK only). If you would like to join the Society or obtain further information, see the website (given above).

ADVICE TO AUTHORS

Articles for *Ocean Challenge* can be on any aspect of oceanography. They should be written in an accessible style with a minimum of jargon and avoiding the use of references.

For further information (including our 'Information for Authors') please contact the Editor:

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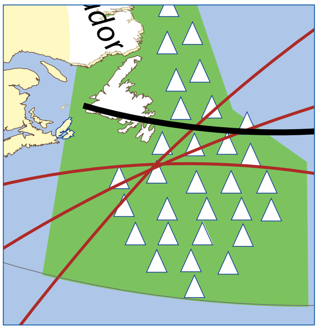

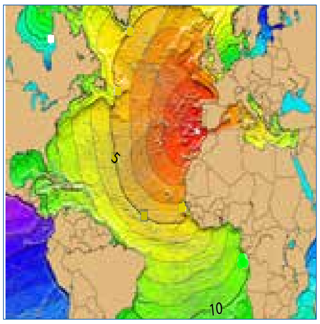

Most of the maps and diagrams were drawn by The ArtWorks.

The cover and heading graphics were designed by Ann Aldred.

Cover photo: Matt Gubbins, Marine Scotland Science.

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Message from the Editor

Welcome to *Ocean Challenge*! I'd like to begin by thanking all the contributors for helping get this issue together, despite the difficult circumstances over past months, and I look forward to receiving articles from the unfortunate authors who were locked out of their offices for months on end, were grappling with teaching online, or simply found themselves stuck in the wrong place.

Women in marine science feature prominently in this issue. An article by Katharine Hendry and co-authors considers successes in improved gender equality in sea-going science, and asks whether initiatives similar to those which have helped women can be used to improve diversity at sea in general. We have an interview with Liz Thomas who leads the British Antarctic Survey's ice-core group, and a piece celebrating the five women who, 50 years ago, lived in, and undertook research from, an underwater 'habitat' off the US Virgin Islands.

Also in this issue, Koko Kunde explores why colloidal iron plays such a significant role in ocean biogeochemistry. This article is based on Koko's prize-winning talk at the last meeting of Challenger's AMBIO (Advances in Marine Biogeochemistry) Special interest Group (SIG). Joining a SIG is a great way to expand your knowledge of your discipline and make new contacts. Information about the other Challenger SIGs can be found on the Society's website; if you would like to know more about ocean modelling, see the next page!

Angela Colling

Challenger Society Conference 2020
is happening on 6–10 September 2021
hosted by the Scottish Association for Marine Science
See http://www.challenger2021.co.uk

The new RRS Sir David Attenborough departing Cammell Laird shipyard
(Photo: Michael Glostein)

See pp.14–15 for photos of the inside of the vessel.

The Ocean Modelling Special Interest Group

Dave Munday

It would be difficult to overestimate the contributions of the late Peter Killworth to theoretical oceanography and numerical modelling of the ocean. As well as writing over 120 oceanography papers, Peter also wrote over 50 papers on social network research and some of the first commercial computer games. As the person in charge of developing one of the UK's first ocean models (FRAM, the Fine Resolution Antarctic Model), he made important advances in modelling and understanding the Southern Ocean. Peter also played a significant role in the founding of the Challenger Society's Special Interest Group for Ocean Modelling.

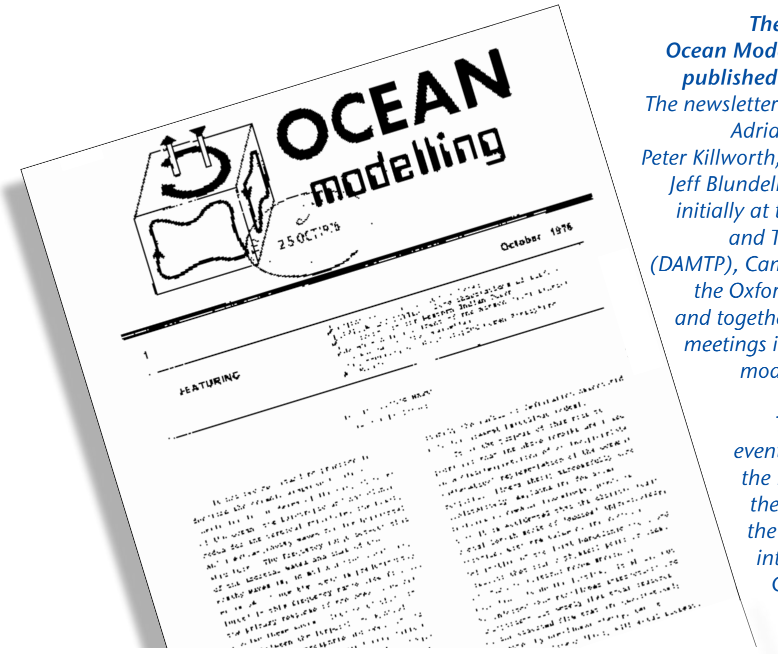
Commonly known as OMG – which at times has made for some panicked sounding email subjects – the SIG tries, in some small way, to live up to Peter's enthusiasm for science and his support of students and early-career researchers. In its present incarnation, the Ocean Modelling SIG exists to connect UK ocean modellers of all flavours, from those running coupled General Circulation Models to conceptual modellers, from geophysical fluid dynamicists to biologists, from students to senior professors. Our goal is to promote interaction, especially among early-career ocean modellers, and to showcase the breadth and brilliance of UK ocean modelling. We take a very broad and ecumenical view of what constitutes an ocean model. If someone, somewhere, thinks it's an ocean model, then they are more than welcome to be involved with the SIG.

Peter Killworth (Photo: Tony Barnes)

The SIG's annual meeting

At OMG's annual science meeting, this philosophy leads to a fascinating mix of presentations on topics as diverse as eddy parameterisation, global ocean biogeochemistry and the circulation and aquaculture in Scottish lochs.

The annual meeting is usually held in September. This is an opportunity to meet other SIG members and hear about their latest work. The format is one of short talks (~8–10 minutes) in order to pack in as many talks as possible. Typically each meeting has around 40 speakers and perhaps twice as many attendees. Anyone is welcome to speak, although we prioritise Ph.D students and early-career researchers in the schedule. We strive to make these meetings open, friendly and inclusive. Personally, it has become the highlight of the conference season and my favourite way to meet new and old friends. The quality of our student speakers is now so high that the prize for best student talk is hotly contested, with many worthy winners being pipped at the post.



The first issue of the Ocean Modelling newsletter, published in October 1976. *The newsletter was produced by Adrian Gill, assisted by Peter Killworth, David Anderson, Jeff Blundell and Mike Davey, initially at the Dept of Maths and Theoretical Physics (DAMTP), Cambridge, and then the Oxford Hooke Institute, and together with associated meetings it helped bring the modelling community together. The newletter was eventually replaced by the Elsevier journal of the same name, and the meetings evolved into meetings of the Challenger Society Ocean Modelling SIG.*

The annual meetings are movable feasts without a fixed date or venue. In years that the Challenger Society holds its conference we hold a one-day meeting on the Friday. In other years we split the meeting across two days, to allow time to travel to/from the venue, and squeeze in that oh-so-important conference dinner. In these years the location is chosen by whoever volunteers to organise it, although we do try to visit locations that the Challenger Conference itself doesn't reach. If you're interested in helping organise and host a future OMG meeting please get in touch (*see below*). Previous venues have included the University of Reading, Imperial College, and the University of Edinburgh.

The 2020 annual meeting

This year's meeting had to be a little different from normal. Due to ongoing global issues, the Challenger Society made the difficult decision to postpone its 2020 conference until next year. However, we decided to grab the bull by the horns and have our first virtual SIG meeting! Thanks to the magic of the internet, this took place on 10–11 September. We had 30 speakers with a great mix from all levels of academia. At some points we had over 70 people in one Zoom call. Thank you to everyone who contributed to the meeting and helped make it a success, especially when it came to microphone discipline.

How to get involved

The SIG recently setup a JiscMail list to help promote and organise our activities. To join search for OCEANMODELLINGSIG-CHALLENGERSOC at www.jiscmail.ac.uk. For a more personal touch, contact one of the current conveners, Helen Johnson (helen.johnson@earth.ox.ac.uk) or Dave Munday (danday@bas.ac.uk), directly by email. Please contact us if you're interested in hosting an OMG meeting or have ideas for other activities the SIG could promote.

Many thanks to all those who provided information about the origin of the SIG, and a special 'thank you' to Sarah Killworth for organising the photograph, and to Peter Martin for the scan of the first issue of Ocean Modelling.

Gaining experience through CLASS

CLASS – Climate Linked Atlantic Sector Science – is a five-year research programme, begun in April 2018, which is investigating the impacts of climate change and human activities on the Atlantic Ocean, from the surface to the sea bed. Its aim is to deliver knowledge and understanding of the Atlantic Ocean system to assist stakeholders in making evidence-based decisions relating to climate change. Research cruises contributing to CLASS have space on them for early-career researchers who wish to acquire training in making observations at sea, by being actively involved in collecting samples and data. Below, two early-career scientists who have benefitted from going on a cruise contributing to CLASS descibe their experiences. If you would like to know more about CLASS, including how to apply for berths, see p.6.

Discoveries on Discovery*: Joining the PAP-SO benthic science team* **Clara Douglas**

I have always been fascinated by the sea, and a career in marine science has always seemed the natural choice for me. I stepped foot on my first research vessel when I was 10 years old – the original *RRS Discovery* in Dundee. It's fitting that my first research cruise was aboard the most recent incarnation of this historic ship, the fourth to be named RRS *Discovery*.

During the summer of 2019, I had the amazing opportunity to join a research cruise to the Porcupine Abyssal Plain Sustained Observatory (PAP-SO) as part of the scientific team. PAP-SO monitors long-term change in the North Atlantic Ocean, south-west of Ireland. It records atmospheric conditions, surface ocean physics, chemistry and biology, conditions in the deep ocean interior and deep-sea ecosystems, all important for observing and analysing the effects of climate change.

The PAP-SO is the site of one of the longest running ocean time series. Indeed, 2019 was the 30th year of the particle flux time series obtained from sediment traps which collect organic debris and other particles as they make their way from the surface to the depths of the ocean, and so measure the flux of carbon to the sea bed.

Some research at this site dates from before the PAP-SO was established, and the Porcupine Abyssal Plain has been the source of many important discoveries. In particular, time-lapse photographs collected in 1982 using Bathysnap showed that the deep seas experience seasonality, much like the surface ocean: increased fluxes of organic material reaching the sea floor after spring phytoplankton blooms allow bursts of benthic activity. Since then, long-term research has continued to examine how environmental changes far above the ocean depths impact fauna in the abyss. One notable example is the three-fold increase in population density of the sea cucumber *Amperima rosea* – a phenomenon referred to as the '*Amperima* Event' (doi: 10.1016/j.dsr2.2009.02.001).

Sampling the sea floor

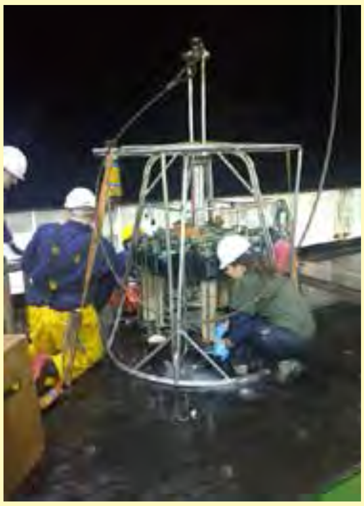
It took a couple of days to reach the PAP-SO site, during which I staved off minor seasickness by prepping sample bottles and labels during the day and teaching Mah-Jong to the science team and crew in the evenings. I was volunteering as part of the benthic team, which meant adapting to working the night shift during sampling.

The first sampling we carried out was using the megacorer, taking sediment core samples from the sea bed at a depth of ~4850 m. Many areas of research would be utilising the sediment cores – from biology to biogeochemistry as well as work on environmental DNA (eDNA) and microplastics. The cores were carefully sliced at specific depths, at intervals varying from 1 to 5 cm for investigating the fauna in the sediment, to 0.5 cm increments for some of the biogeochemistry samples.

Video footage and still photographs of the sea floor were taken using HyBIS – a camera system lowered to the sea floor beneath the ship. Line transects were undertaken very slowly to allow HyBIS to get photos of the sea bed and the animals living there for quantitative analysis by the benthic team at the National Oceanography Centre. It was great being able to watch the live camera footage, seeing what creatures dwell in the depths. It was also valuable preparation for the trawls that were yet to come …

Collecting creatures from the deep

Despite the fact that the benthic team did most of their work at night, some samples were recovered during the day. During these times, whales and dolphins



Left *The megacorer being deployed at the PAP-SO site. In one deployment it can collect eight large cores and two small ones. (Photo: Andy Gates)*

Right *Some of the benthic team retrieving the sediment samples from the megacorer. (Photo: Clara Douglas)* were seen both close to the ship and in the distance, and we had several visits from common dolphins and pilot whales playing nearby – first time sightings for me!

Amphipod trap recovery and trawl sorting brought the benthic team back to the day shift. Amphipods are small crustaceans, benthic species of which can be caught by sending traps baited with mackerel to the sea bed. This work monitors long-term changes in the scavenging fauna on the abyssal plain and dates back to 1986. A shift in the amphipod community over the past 30+ years has been linked to environmental changes in the upper ocean. Despite the length of the study, new species continue to be identified from the PAP-SO (doi: 10.1016/j.pocean.2020.102292).

The method was highly effective, with entire mackerel consumed within just 48 hours in some traps, while other traps attracted slightly less voracious amphipods, meaning we had to search through the fish to find any sneaky amphipods hiding in the flesh … Many species of amphipods were caught, with sizes of individuals ranging from <1 cm to over 6 cm.

Finally, the trawl was an entirely different barrel of fish (literally). Nothing could prepare us for the 'distinctive' smell of deep-sea cucumbers. We watched from a safe distance as the trawl net was brought on board and the contents were spilled into numerous crates for us to clean and sort through.

Right *Clara merrily sorting through deep-sea sea cucumbers (*Psychropotes*) in the chill room, with the help of Dr Andy Gates. (Photo: Emmy McGarry)*

Below *Amphipods of varying species and sizes caught in anti-slip material; amphipod individual ~6 cm long. (Photo: Clara Douglas)*

Unfortunately, the deep ocean hasn't escaped the impact of humans, and the trawl brought up litter of various kinds, particularly clinker. Clinker is burnt coal, which was produced extensively on steam ships, and then thrown overboard. The sharpness of the clinker, litter and the nature of trawling itself meant that some of our specimens were damaged, enhancing the production of the pungent smell of deep sea fauna.

We spent nearly 10 hours per trawl cleaning the specimens, photographing the best ones, and sorting them all into pots, bags, buckets and barrels for later analysis. It was really interesting being able to see in real life the types of animals that we had previously watched on HyBIS.

Sediment and trawl samples unloaded from the ship and ready for storage with the rest of the Discovery Collections in Southampton. (Photo: Clara Douglas)

Water column science

Benthic research wasn't the only work taking place at PAP-SO. The pelagic team sent down CTD rosettes, which collect water samples at various depths, while recording conductivity (salinity), temperature and density through the water column. The water samples were used to measure nutrients, carbon and chlorophyll, among other things. Some visiting scientists from Plymouth were interested in seeing if any marine fungi were present in the water column.

Technicians were on the ship to run our sampling equipment, retrieve the PAP moorings and make sure the new ones being deployed were in working order – vital for ensuring that information is being recorded by the sensors on and below the surface, and that it can be sent back from the buoys to scientists on land throughout the year.

Final thanks

I am very grateful for the opportunity to take part in this cruise while undertaking my Masters degree, as it reinforced and expanded my knowledge and experience. Meeting all the people – scientists, technicians, crew – who are needed to work together to achieve the science that I had previously only read about was eye-opening and inspirational. I am as eager as ever to get back on the water to carry out research. This has been a valuable experience, and I look forward to what the next stage in my career brings.

Clara has now begun a Ph.D at the National Oceanography Centre, Southampton, studying the carbon cycle in the Southern Ocean. ccd1n18@soton.ac.uk

Using a CLASS Fellowship to make measurements of the surface carbonate system

Hannelore Theetaert

I am a marine chemistry lab technician working in the Flanders Marine Institute (VLIZ) in Ostend, Belgium. I have a BSc. in chemistry and my job involves working in ICOS (Integrated Carbon Observation System). I look after two ICOS stations used to measure carbon parameters in the coastal environment of the North Sea, one on the RV *Simon Stevin* and one on the VLIZ Thornton buoy.

Back in November 2019 I applied for a CLASS Fellowship to install and operate underway systems – systems that use seawater pumped onboard as the ship is in motion – to measure $p\mathrm{CO_2}$ (effectively the concentration of dissolved CO_2) and total alkalinity from the RRS *James Cook* during the CLASS GO-SHIP expedition from Florida to Tenerife (JC191). The setup on the vessel and the capacity to compare the underway systems with conventional analytical methodologies, allowed their performance to be optimised. At the same time, the work allowed me to improve my personal understanding of the biogeochemical processes around carbonate chemistry and carbon fluxes (air–sea, surface water–deeper water) in the area, and in the open ocean in general.

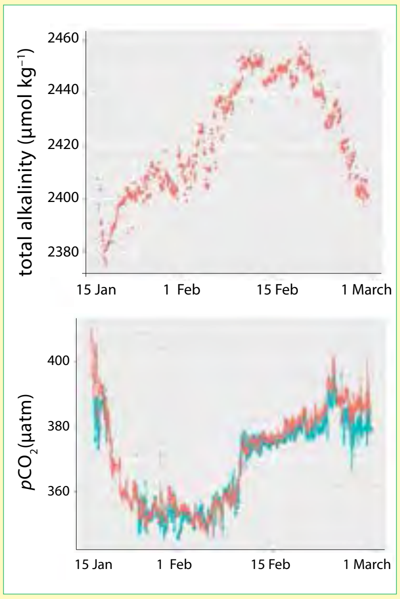
The end of a successful day!

Two systems were used to measure $p\mathrm{CO_2}$, a VLIZ custom-made system and another system based on detection of non-dispersive infrared light (NDIR). For more details of these systems, and of the system used to measure total alkalinity, see the blogpost published during the expedition (https://projects.noc.ac.uk/class-project/blog/nightshift-jc191). The graphs (*right*) show preliminary total alkalinity and $p\mathrm{CO_2}$ data from the cruise.

Successful retrieval of the deepest CTD cast deployed by the night shift (6455 m)

(Photos: Hannelore Theetaert)

I'm now processing and correcting the data, using relationships between the underway sensor data and manually collected descrete samples taken from the water bottles sent down with the CTD casts or from the underway system. I intend to submit the data to the international *Surface Ocean* CO_2 *Atlas*.



Preliminary data collected during the cruise. ***Upper*** *Total alkalinity measurements.* ***Lower*** $p\mathrm{CO_2}$ *measurements; turquoise = VLIZ system; red = NDIR system.*

Measuring underway $p\mathrm{CO_2}$ and total alkalinity were not the only things I did while on board the RRS *James Cook*. During the nightshifts, I was part of the oxygen and nutrients team led by Dr Edward Mawji. Being part of this team was a very interesting, educational and fun activity, and it was rewarding to share knowledge and learn new things. Thank you VLIZ and CLASS!

Hannelore is now doing her 'normal' job involving lab work and looking after the ICOS stations on the RV **Simon Stevin** ***and the VLIZ Thornton buoy.***

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How to gain research experience through CLASS

CLASS is supporting the UK science community by providing opportunities for early-career researchers (ECRs), i.e. graduate students and postdocs, to work with us. CLASS also offers funded ECR Fellowships to support extended visits to the National Oceanography Centre and the Scottish Association for Marine Science, which could include joining a cruise. Find out how to apply for berths on cruises and CLASS ECR Fellowships, by signing up to our email bulletins on the website: proj.noc.ac.uk/class. You can also contact us by email (class@noc.ac.uk) or Twitter (@CLASS_URI).
As well as delivering world-leading research, datasets, facilities and advice, CLASS activities will form the basis of new research projects. We encourage you to get in touch if you have ideas you would like to develop into proposals with CLASS researchers.

Stop Press: *Although schemes are suspended due to Covid-19 restrictions, please keep an eye on the website and email bulletins for news about when they will be back up and running.* ***Penny Holliday***

Five stepped forward

John Phillips

With hindsight, the two decades between 1960 and 1980 were an era of 'underwater habitats', when saturation diving seemed to offer a highway to the investigation and exploitation of the continental shelf. Today most of the few that remain are used for diver training or tourism, their former role usurped by minisubs and robots.

The Tektite project of 1969–1970 was based on one such underwater habitat installed at the modest depth of 15 m in Great Lameshur Bay, US Virgin Islands. It was an experiment partly funded by NASA and designed to study, among other things, the behaviour of a group of individuals isolated within an alien environment, whether beyond the atmosphere or beneath the sea. In 1969 (Tektite I) a crew of four men occupied the habitat for two months. Tektite II, in 1970, was a series of ten two-week residencies, including the first by an all-woman crew (Mission 6), led by Sylvia Earle.

At that time Earle was a postdoctoral research fellow at Harvard, specialising in marine algae. The other members of the team were Renate True, Alina Szmant, Ann Hartline, and Margaret Ann (Peggy) Lucas. All were volunteers and, with the exception of Peggy Lucas, marine biologists – she was an electrical engineer from the University of Delaware.

For reasons of safety, it was essential that every Tektite crew included an engineer, but female engineers with suitable aquatic experience were scarce (and mixed crews unthinkable) in 1970. So the proposal for an 'all-woman' crew lay in jeopardy until Peggy Lucas seized this opportunity. On Mission 6 her principal duties were to monitor life-support systems, in particular the pressure (~2·4 bar) and composition (9% oxygen, 91% nitrogen) of the habitat's internal atmosphere, and to manage communications with the outside world. She became Assistant Scientific Coordinator for the Tektite II programme as a whole.

Research by members of the team covered a wide range of ecological studies: the colonisation of an artificial seagrass bed and its role as a shelter for fish (True), the escape response of a species of damselfish to visual dangers (Hartline and Szmant) and the influence of grazing fishes on marine plants (Earle). In addition Earle catalogued the algal flora of the area, identifying 153 species, including 26 never before recorded in the Virgin Islands. Their results were published in a series of bulletins from the Natural History Museum of Los Angeles County.

The five female volunteers in the Tektite II programme fifty years ago: left to right, Ann Hartline, Sylvia Earle, Alina Szmant, Renate True and Peggy Lucas

All these observations benefitted from the ability to remain at depth indefinitely with virtually unlimited access to the underwater environment, night or day. The availability of a newly developed 'rebreathing' scuba system provided a further advantage, making possible dives of up to four hours' duration in which the near silence of their almost bubble-free operation minimised disturbance to the behaviour of the sea's natural inhabitants. The value of an underwater field station and laboratory was amply proven.

There is another reason why Peggy Lucas was vital to the successful completion of Mission 6: she averted a diving accident that could have had serious, perhaps fatal, consequences for Sylvia Earle. Returning together from a normal dive using conventional scuba equipment, Earle was left without an air supply through the combination of a sand-clogged regulator and a faulty valve on her reserve tank. Taking turns to breathe from Lucas's mouthpiece they reached the habitat without further problems. Of course this was a 'routine' emergency, a situation for which divers train, but all emergencies have a tendency to escalate – the reason this one didn't was that nobody panicked and Peggy Lucas calmly did the right thing.

Needless to say, the all-woman crew attracted a lot of media attention. Peggy Lucas always looks relaxed in the photographs that appeared in the press, with only two exceptions which, taken together, seem to illustrate a self-confident personality with a mischievous streak. The first shows her in the training pool making an inevitably awkward underwater entry headfirst into the submersible transfer capsule. Two waving legs in black socks follow a crumpled white shirt through the open hatchway. The second shot, taken through a window of the decompression chamber back on land after the mission, shows the whole team killing time in their swimsuits. Peggy Lucas is sitting nearest the window and rightly objects to such intrusive behaviour by sticking out her tongue at the photographer. It would be pleasing to think that this salute was her revenge for the unflattering shot taken in the training pool several weeks earlier. Sylvia Earle sits facing her, keeping a straight face.

The author has to admit to being a little in love with his impression of Peggy Lucas! The real Peggy followed a varied career as ocean engineer, Professor of Computer Sciences at the American University of Paris and journalist for *Financial Times* business publications covering technical subjects. She is now Peggy Lucas Bond, an environmental activist living on Maui in the Hawaiian Islands. Ann Hartline changed direction in 1980 and joined the Department of Justice, becoming a trial attorney in the Environmental Enforcement Section. Alina Szmant remained a coral-reef ecologist throughout a long academic career and is now CEO of Cisme Instruments, a company manufacturing underwater respirometers. Renate True taught anatomy and physiology at the College of the Mainland in Texas for thirty years. She died in 2017, a respected and much loved teacher and friend to her students. Sylvia Earle, who celebrated her 85th birthday in August, became the outstanding champion of the marine environment that she remains today.

John Phillips is a marine bibliophile.
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Covid-19 and climate change

What energy-use changes during 'Lockdown' might tell us

Covid-19 was first identified on 30 December 2019, and was declared a global pandemic on 11 March 2020. As various states began to introduce measures to combat the virus, many of us concerned about climate change wondered what effect these changes would have on CO_2 emissions, and how many researchers might be planning a paper on the topic! The first paper to appear, in *Nature Climate Change*, was by Corinne Le Quéré and colleagues, and makes use of data up to the end of April 2020 (diagrams here are taken from that paper).

Given the lack of reliable data on emissions the authors devised an alternative approach. They identified three levels of restriction intended to reduce the spread of the virus ('confinement indices', see Table 1) and investigated how they affected the six main types of economic activity that result in emission of CO_2.

The analysis was done for 69 countries, 50 US states and 30 Chinese provinces, which together represent 85% of the world population and 97% of global CO_2 emissions. During the early confinement phase, beginning on 25 January 2020, around 30% of global emissions were from areas under some confinement (Figure 1). By mid March, when Europe, India and the USA began to implement confinement measures, and China began to relax them, this had increased to over 85%; a peak of 89% was reached in early April.

Using available data and information on levels of confinement (Table 1) the authors made estimates of the changes in CO_2 emission from the six economic sectors. They collected time-series data (mainly daily) relating to proxies, rather than changes in CO_2 emissions *per se* (Figure 2). Changes in power-sector emissions were deduced from electricity

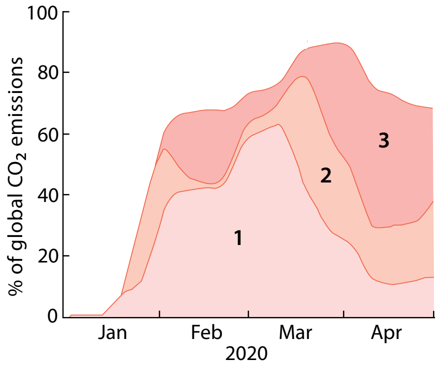


Figure 1 *CO_2 emissions from countries, states and provinces experiencing each confinement level (Table 1) as a percentage of global CO_2 emissions. (CO_2 emissions are from the Global Carbon Project; see Further Reading)*

data from Europe, the USA and India. Changes in industry were inferred mainly from industrial activity in China and steel production in the USA. Changes in emissions from surface transport and aviation were deduced using indicators of traffic from a range of countries. UK smart meter data were used to estimate changes in emissions from the residential sector, and changes for the public sector were estimated using assumptions based on levels of confinement. All the activity changes were calculated relative to typical activity levels prior to the Covid-19 pandemic.

The greatest estimated daily decrease in global CO_2 emissions between 1 January and 30 April 2020, relative to the mean level of emissions in 2019, was 17 $MtCO_2$ day^{-1} (or 17%) on 7 April; the values in $MtCO_2$ day^{-1} are close to the corresponding percentages because global emissions are currently about 100 $MtCO_2$ day^{-1}. The average maximum daily decrease for individual countries was higher, averaging 26%, but occurred at different times in different countries. Interestingly, 17 $MtCO_2$ day^{-1} equates to the seasonal amplitude in emissions, which results primarily from higher energy use in winter in the Northern Hemisphere.

Perhaps unsurprisingly, the reduction in global emissions from surface transport made the largest contribution to the total emissions decrease (36%) (Figure 2). Emissions fell by 7.4% in the power sector, by 19% in the industry sector, and by 21% in the public sector. Because of the disproportionate effect on air travel, the aviation sector showed the largest relative decrease (60%), but nevertheless contributed only 10% of the decrease in global CO_2 emissions. As many people were 'locked down' at home, globally there was a small increase (2.8%) in emissions from the residential sector.

The total decrease in emissions up until the end of April is estimated to be 1048 $MtCO_2$, equivalent to 8.6% of the emissions during January–April 2019. The decrease was largest in China (242 $MtCO_2$), followed by the USA (207 $MtCO_2$) then Europe (123 $MtCO_2$) and India (98 $MtCO_2$).

The Le Quéré *et al.* paper was published before there were any 'second waves' of Covid-19, but it is probably safe to say that the overall decrease for 2020 will be lower, but comparable with the rates of decrease needed year-on-year over coming decades if we are to limit global warming to 1.5 °C.

What do these changes tell us?

It is tempting to feel slightly cheered by these figures, but of course a decrease in CO_2 emissions does not immediately affect the concentration of the gas in the atmosphere, as the effective atmospheric residence time of CO_2 is of the order of centuries. In any case, as the authors observe, most changes that occurred in 2020 are likely to be temporary as they do not reflect structural changes in the economic, transport or energy systems. (And then there is methane ... .)

Table 1 *Definitions of the confinement indices (CI) abbreviated from Le Quéré et al. (2020)*

CI	Characteristics	Policy examples
1	Policies targeted at long-distance travel or small groups of individuals suspected of carrying infection	Isolation of sick/symptomatic individuals; banning of mass gatherings >5000; restricted international travel
2	Regional policies that stop a city, region or ~50% of society undertaking normal daily routines	Closure of national borders; closure of schools, universities, public buildings, religious or cultural buildings, restaurants and other non-essential businesses within a city or region; banning of public gatherings >100
3	National policies that greatly restrict the daily routine of all but key workers	Mandatory national 'Lockdown': household confinement, with the exception of key workers; banning of public gatherings, social distancing.

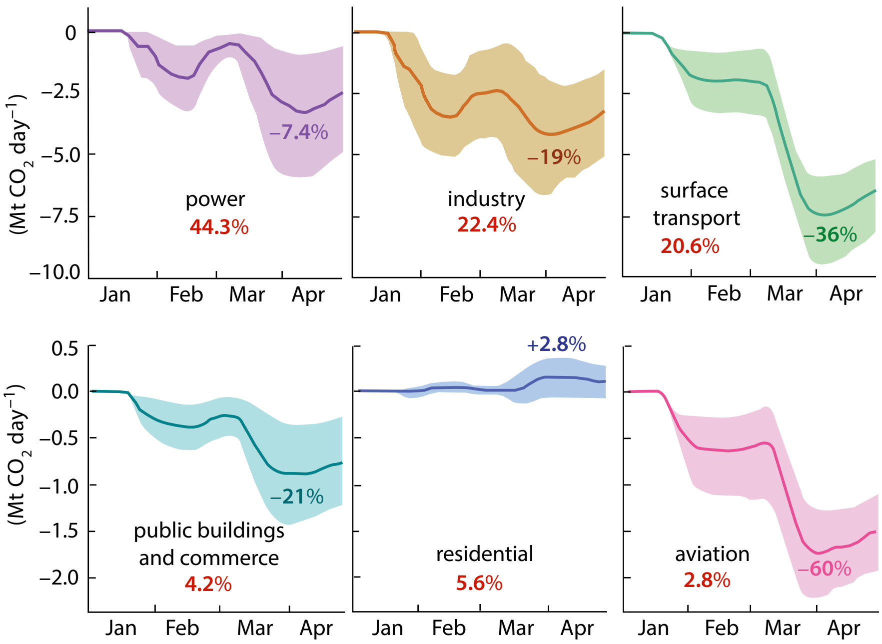


Figure 2 *Changes in estimated daily CO_2 emissions for the six sectors relative to annual mean daily emissions from those sectors in 2019. Shaded areas represent the full range of the estimates. Note the different ranges on the y axes in the upper and lower panels. The red numbers show the percentage of global fossil fuel emissions caused by the sector concerned. Also shown is the decrease in the sector at 7 April.*

Nevertheless, we now have opportunities to make some fundamental changes to encourage low-carbon pathways. For example, the study reveals how responsive the surface transportation sector can be to policy changes and economic shifts. Areas of cities were made car-free and people did more walking and cycling (including on e-bikes) and appreciated the decrease in air pollution. But there are always unexpected side-effects; for example, in the UK at least, many people now shunning public transport turned to driving, and some are opting for cheaper, older, less efficient second-hand cars.

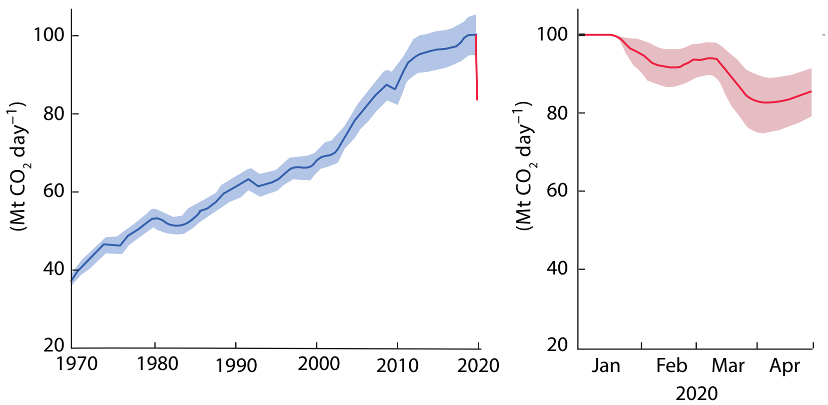
On the positive side, follow-up research could explore further the potential for reductions in emissions in the surface transport sector that could be delivered quickly, perhaps even with a positive impact on societal wellbeing. Bringing forward the infrastructure to support widespread use of electric cars might be a good example.

The changes in CO_2 emissions during the confinements, due to forced changes in human behaviour, highlight how much – or rather how little – it is possible to reduce CO_2 emissions with the current energy mix: societal responses alone will not drive the large sustained changes needed. Le Quéré *et al*. note that some of the energy scenarios being explored are encouraging. For example, some researchers believe that PV solar panels could provide 30–50% of the energy market.

Lack of real-time data on emissions

Keeping track of evolving CO_2 emissions could help governments make sensible decisions about their future energy policies in the wake of Covid-19, but the authors had to make their estimates based on proxies because there are no systems to monitor global emissions in real time.

Figure 3 (a) *Annual mean daily emissions during 1970–2019 (blue line), updated from the Global Carbon Project, with uncertainty (shading) of ±5%. The red line shows estimated daily emissions in 2020 up to the end of April.* ***(b)*** *Estimated daily CO_2 emissions in 2020 and the uncertainty (red shading). NB: The decrease in daily emissions by 7 April only took them back to 2006 levels.*



International bodies, industries and countries report CO_2 emissions as annual values, but these may not be reliable and are often released months or even years after the end of the calendar year. Observations of CO_2 concentration in the atmosphere are available in near real time, but over a short period the large natural variability of the carbon cycle and of the atmospheric circulation masks the variability in human-generated CO_2. Satellite measurements of the CO_2 in a column of atmosphere have large uncertainties and also reflect the variability of natural CO_2 fluxes.

What hope for the future?

The authors state that 'the extent to which world leaders consider the net-zero emissions targets and the imperatives of climate change when planning their economic responses to Covid-19 is likely to influence the pathway of CO_2 emissions for decades to come.' The view of this worried non-specialist is that the motivations for world leaders will have to be economic – possibly including the prospect of having to move coastal cities inland as sea-level rises. What's more, there may have to be financial incentives from the rest of the world to sway leaders who refuse to believe in climate change, or don't care.

Meanwhile, we have forest wildfires in California and, more worryingly, around the Arctic, and a Brazilian Minister for the Environment who, as the Amazonian rainforest burns, is recorded advising the Brazilian Cabinet to push through further environmental deregulation while the public is distracted by the Covid crisis ...

Ed.

Further Reading

Le Quéré, C. and 12 others (2020) Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement. *Nature Climate Change* doi:10.1038/s41558-020-0797-x

https://www.globalcarbonproject.org/carbonbudget/

https://www.unenvironment.org/news-and-stories/press-release/united-science-report-climate-change-has-not-stopped-covid19

Predicting the severity of the 2020 iceberg season off Newfoundland

Jennifer Ross and Grant Bigg

Icebergs originating mainly from western Greenland have long been a hazard to shipping in the north-west Atlantic (Figure 1), with collisions having been reported since the 17th century. However, it was the sinking of the *Titanic* in 1912 that brought iceberg risk to the attention of the public. To reduce the risk of further collisions, the International Ice Patrol (IIP) has been monitoring iceberg activity off Labrador and Newfoundland, Canada, since 1913. This area, and some major shipping routes across the North Atlantic, can be seen in Figure 1(b). Monitoring is done through air surveillance, ship reports, satellite analysis and modelled iceberg trajectories, and results in daily maps of iceberg numbers and locations which are distributed through the North American Ice Service.

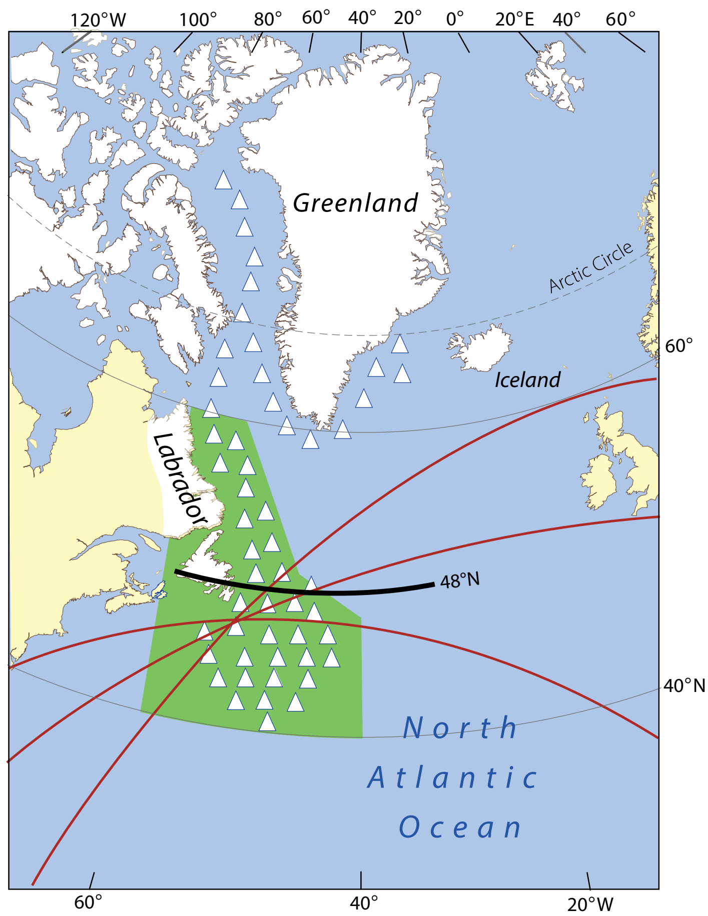
These daily reviews of iceberg risk help a ship's captain to alter course whilst underway. This greatly reduces the risk of serious collisions, but for shipping operators it would be more efficient to have advance warning of iceberg severity. Then a ship's departure time or route could be altered to avoid regions with large numbers of icebergs, or in 'low' years take a more direct route south of Newfoundland (red lines in Figure 1(b)). For several years, therefore, we have trialled seasonal forecasts and communicated these to the IIP. In January of this year we released the first ever public forecast of iceberg numbers in the north-west Atlantic, for the 2020 ice season.

The forecast model

The research team developed an innovative control system model* where measures of the changing properties of the three key environmental parameters relating to the Greenland ice sheet – its surface mass balance, ocean temperature (as given by the mean surface temperature of the Labrador Sea) and the state of the atmosphere (given by the phase of the North Atlantic Oscillation, NAO) – are used to produce a prediction of the monthly evolution of iceberg numbers off Newfoundland for the following ice season. This longer term forecast of iceberg abundance 6–9 months ahead, is made possible by the lag in the system which results from icebergs taking up to a few years to reach Newfoundland from their calving sites.

*The control systems approach is a new way of modelling time variation in systems. It monitors the model structure through time and makes it possible to observe the contribution of variables and lags, along with the behaviour of the model terms.

(a)



(b)

Figure 1 ***(a)*** *The main currents that determine iceberg movement into the North Atlantic.* ***(b)*** *The area patrolled by the IIP (green) with some northerly shipping routes in red; the black line is along 48°N. The white triangles show where icebergs are most likely to be reported.*

The team behind the forecast originally worked independently, having been inspired by a meeting of the Second International Glacial Hazard Workshop in St Johns, Newfoundland, in 2017. The importance of the project, and its wider links to the impact of a melting Greenland Ice Sheet on the North Atlantic more generally, has led to it being funded by the insurance firm AXA XL's Ocean Risk Scholarships programme.

The control systems model has been used to provide iceberg season forecasts to the IIP for three years. The seasonal forecasts of the total number of icebergs found south of 48°N have a 70% level of confidence on the basis of a 'sliding window' 20-year verification study, while the cruder estimate of whether the seasonal iceberg risk will be high or low has an accuracy level of 80%. The IIP currently use the forecast to inform their advance planning of the balance of aerial and satellite reconnaissance for the forthcoming ice year.

This year we have expanded the range of forecasts that we provide. In what should currently be regarded as experimental analysis, we have used a range of machine learning tools to produce forecasts of both the number of icebergs which travel south of 48°N (known as the annual I48N number) and the rate of change of the seasonal increase. This is a useful measure of iceberg severity, as the number of icebergs which travel south of 48°N is generally accepted to reflect the number found in the Labrador Sea, and 48°N is the latitude at which icebergs enter the trans-Atlantic shipping routes (Figure 1(b)).

The machine learning tools we used are linear discriminant analysis, a linear Support Vector Machine algorithm and a quadratic Support Vector Machine algorithm. These have an accuracy range of 43–52% for predicting yearly severity, and 39–49% for the rate of change.

The expanded forecasts for 2020

The IIP defines a year with 230 or fewer icebergs travelling south of 48°N as a 'low' year. A 'moderate' year has between 231 and 1036 such icebergs, and in a 'high/extreme' year there are 1037 or more. Across all measures of the 2020 ice season the forecast was for a low to moderate number of icebergs. Observational data from the IIP now show that iceberg numbers do reflect a low iceberg year for 2020, with 203 icebergs sighted south of 48°N between January 2020 and the start of June.

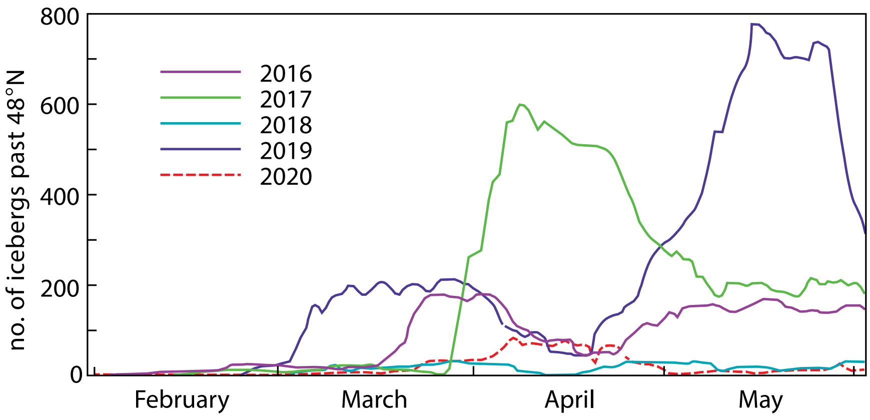


Figure 2 *Plot of the number of icebergs observed south of 48°N (i.e. the I48N number) between February and the start of June, since 2016. The 2020 season is shown by the dashed red line.*

While late surges can occur in iceberg numbers in the region, in most years April and May are the peak months. In the last 10 years, the average cumulative number of icebergs past 48°N by the start of June is 576, which is significantly higher than the number seen this year; last year 1515 icebergs passed 48°N.

Figure 2 shows the number of icebergs reported south of 48°N daily since 1 February 2016. The dashed red line shows data for 2020. While some ice years record two peaks, usually associated with sea ice trapping icebergs further north, then releasing them as the ice melts, this year's plot has only one peak in mid April. Numbers of icebergs south of 48°N are also very low in May, which Figure 2 shows is often a high iceberg month. While icebergs are sometimes reported past 48°N in late summer, very few made it this far south in 2020, keeping the season in the low/moderate range.

Looking forward

While this year's forecast and observational results reflect a low ice year, iceberg numbers crossing 48° N have, on the whole, been increasing over the last hundred years. Between 1920 and 1990, around 350 icebergs were recorded annually on average, compared with nearly 600 in the last 30 years. Iceberg warnings are more accurate than at the start of the 20th century due to significantly better monitoring of the ocean, but accidents do still occur on a regular basis. As global temperatures rise, and sea-ice extent decreases, more vessels are venturing into iceberg-prone regions, either to reduce journey time or for tourism, and this can only increase future risk, especially when combined with increased calving from the Greenland Ice Sheet.

As iceberg risk increases, having an early seasonal forecast of iceberg severity could prove an important asset to the shipping industry. Trans-Atlantic routes could be refined for each year's ice conditions, reducing both the need for costly diversions and the overall voyage length. While this has clear safety benefits for the crew, marine emissions may also be reduced, which is a primary concern of the International Maritime Organisation. We therefore plan to continue to release an annual forecast of iceberg severity to the IIP at the beginning of each year.

Further reading

Bigg, G.R., Y. Zhao, and E. Hanna (2019) Forecasting the severity of the Newfoundland iceberg season using a control systems model. *Journal of Operational Oceanography*, 1–13. doi: 10.1080/1755876X.2019.1632128

Zhao, Y., E. Hanna, G.R. Bigg and Y. Zhao (2017) Tracking nonlinear correlation for complex dynamic systems using a Windowed Error Reduction Ratio method. *Complexity*. doi: 10.1155/2017/8570720

https://www.sheffield.ac.uk/geography/iceberg

https://www.navcen.uscg.gov/?pageName=IcebergLocations

Jennifer Ross is a Ph.D student at the University of Sheffield, and is funded by AXA XL's Ocean Risk Scholarships programme. Her research focusses on how a shrinking Greenland Ice Sheet affects the ocean, in terms of meltwater input and iceberg calving. jbross1@sheffield.ac.uk

Grant Bigg is Professor of Earth Systems Science in the Department of Geography of the University of Sheffield and leads the iceberg risk component of AXA XL's programme. Also on the team are Dr Yifan Zhao at Cranfield University and Professor Bob Marsh at the University of Southampton. grant.bigg@sheffield.ac.uk

An interview with an adventurous polar scientist

Liz Thomas leads the British Antarctic Survey's ice-core group, which investigates climate variability in the polar regions using high-resolution chemical and stable isotope records. Liz, who has recently been recognised as a National Geographic Explorer, chatted to Laura Grange from the School of Ocean Sciences at Bangor about her career so far.

How did your interest in the polar regions begin?

By accident! During my degree I intended to study oceanography or climate-related science in the tropics, but I accepted a short-term research position at BAS to gain some lab experience. That was 17 years ago and I am still here!

So what has sustained your interest in the poles?

Back in 2004 I was invited to go to Antarctica for the first time. That first season was amazing. I spent three months working in a remote field camp as part of my first ice-core drilling expedition, and after that I was hooked. I was fortunate to spend time on the research station and witnessed the amazing landscape of the Antarctic Peninsula as we flew to our field camp. My scientific interests have continued to grow, sustained by the stunning scenery and unique wildlife which keep drawing me back.

Has your pathway into a scientific career been a traditional one?

No, not that traditional. I studied chemistry and oceanography at university after which I took a position at BAS as a laboratory-based research assistant, as a chemist. It was only after I started working at BAS that I decided I wanted to do a Ph.D, which I completed whilst working as a research assistant. I never felt like a student, and most people didn't realise I was studying for a Ph.D at the time. I had a lot of flexibility and was able to develop my own project and ideas, rather than choosing a topic that somebody else had devised. Then I was fortunate enough to be offered a postdoc position at BAS and since then have been offered permanent positions, so I didn't travel around and do postdocs in different places as many people do.

Do you think undertaking your Ph.D alongside paid work was beneficial?

I think it was beneficial in some ways. For example, even before finishing my Ph.D I was offered an open-ended position. In science, I think that is quite unusual. That being said, there have been drawbacks. For example, being in the same place for most of my career has meant I have not necessarily had the opportunity to work in a variety of different ways, which might have been possible had I worked in different places in different labs.

Working in one place also initially limits your chances of building networks and the research collaborations that might otherwise be possible by moving around doing different postdocs. I have since developed networks through working relationships but it has meant that I have had to work a bit harder at reaching out and connecting with other researchers.

Having said that, I have gone up the career ladder quite quickly. By being in one place and having a permanent position relatively early on, I have been able to fast-track my career development and build a lab group.

What's been your most memorable work-related experience?

It's hard not to think about the most recent experiences. However, the most excited I have been in my career was when I visited Bouvet Island. It is the most remote island in the world – the nearest landmass is Antarctica. The island is located in the South Atlantic, it is covered by ice and is an active volcano. I am one of the few people in the world to have set foot on it. In fact, I spent a whole day there and drilled the very first ice core, which is an amazing thing to be able to say you have done.

In addition to being one of the most exciting things I have done, it is also one of the scariest in that we were being deployed from a ship by helicopter and once we had been dropped off there was no way of getting off the island. If the weather had come in we would have been stranded there for a long time as the helicopters cannot fly in poor-contrast conditions or cloud. As it was, we were lucky. We got a good weather window and when the clouds started to descend we called for an emergency uplift. By the time we had loaded everything, got on the helicopters, left the island and looked back, the island was completely covered in cloud.

What is it like participating in fieldwork in remote places?

It is funny actually. Because it is very remote you expect to feel very isolated, but actually there is usually a small community and you are surrounded by people. I used to try and visualise Google Earth, to zoom out and remind myself where I am and that I am so remote. So you may be a long way from anywhere in this huge open space, but you are actually living in a tent in a space smaller than a double bed with another person for weeks at a time – it can actually feel very cramped as you have nowhere else to go – so it is quite a strange feeling, but a good strange feeling. Many people probably think it should feel like isolation but it definitely doesn't!

What is the most challenging aspect of the field science that you do?

The cold is a challenge – I am not designed to work in cold places! I get really cold fingers which is a problem when handling metal drills with small fiddly screws.

In addition to the cold the biggest adjustment is living and working as part of a small, intimate community. You get to know people very well. So it's the human element I find the hardest – being away from the ones you love but very close to people you might have only just met.

Another side to your job is that as a BAS senior scientist you have to manage a team of people. What is it like managing a team?

Management is one of those things that also happened by accident. What I wanted to be was a scientist – I enjoy collecting the data, interpreting those data, answering a science question and hopefully publishing my work. However, not only am I now managing a team but that team is expanding. There are currently twelve researchers in the ice core team: seven science staff – post-docs and research fellows – two lab staff and three Ph.D students. It is nice having people around to work with, especially enthusiastic early-career researchers, but aspects of it are mundane – for example, budgets and paperwork – but it is all part of the job.

You have also engaged quite a lot in outreach activities and being a STEM ambassador. Do you enjoy that aspect of your work?

I began doing outreach – going into schools and participating in events like science festivals – as soon as I started at BAS. I like the interactions that type of engagement brings. As a scientist I think it is easy to get lost in your own little world and you forget how important it is to communicate what we do to the wider community – science is not useful science unless you can pass that knowledge on. We do that in the science community by publishing our results but there is a whole other community out there – the general public need to know why we do what we do. I think it is important we share our knowledge with the wider community, from children and teachers to politicians and policy-makers.

You have recently been recognised and funded as a National Geographic Explorer.* What research will that support?

The funding was originally awarded for collecting ice cores in northern Greenland. However, that research is on hold due to Covid-19. A second National Geographic project, led by my student Dieter Tetzner, was successful in drilling an ice core from the Southern Patagonian Ice Field in February. We have additional National Geographic funding for retrieving a deeper ice core, in collaboration with colleagues in Chile, next spring.

If you could drill an ice core anywhere in the world, where would it be and why?

For years I have been trying to get to the South Atlantic island of South Georgia. I managed it two years ago, but was not able to get to the sites I really wanted to drill. We were able to collect samples from a number of low elevation glaciers. The ice at these glacial terminus sites is approximately 10 000 year old, suggesting that a deeper ice core from this island could extend into the last glacial period. South Georgia is important due to its position within the Southern Hemisphere westerly wind belt. These winds are important drivers of the global oceanic circulation and govern changes in the uptake of carbon dioxide and heat in the Southern Ocean. South Georgia therefore provides an opportunity to investigate how these westerly winds have changed over hundreds to thousands of years and how they have influenced regional climate. However, the thicker ice that we really need to drill is above 1500 m, which means using helicopters to get there. That is a key challenge, but I am still working on it! Watch this space.

What will your next adventure be?

In 2019 I hosted a laboratory exchange and workshop with the ice-core team from India and have since been fortunate to have a return visit with their team in Goa. These visits highlighted our common goals and research interests so we are now collaborating on a joint UK–Indian ice-core drilling project. The team will be supported from the Indian Station of Maitri, in Queen Maud Land, East Antarctica. The new ice core will be used to reconstruct past climate, sea ice and snow accumulation over the past ~ 5000 years. We would be working in a part of Antarctica we would not normally have access to, which is very exciting.

What advice would you give to aspiring scientists?

Work with people you like. Find people among your peer group who share your interests and who you enjoy working with.

Liz meeting King Penguins in South Georgia
(Photo: Amy King)

*For more see https://www.nationalgeographic.co.uk/family/2020/08/natgeo-explorers-live-ice-stories-with-liz-thomas-august-6th-7pm

A tour of RRS Sir David Attenborough

Michael Gloistein

In 2017, *Ocean Challenge* published an article on the new polar ship RRS *Sir David Attenborough*. Since then much has happened although sadly, at the time of writing, the Coronavirus pandemic is having an effect on the build.* The photographs show the vessel as she was in October 2020.

The first thing that strikes you when you see the RRS *Sir David Attenborough* is that it she is huge. With a length of 129 m, breadth of 24m, 12 decks and a proposed draft of 7 m, she will be the largest British research vessel ever built; she will also be the first to have a 'moon pool' (see below). She has a range of 19 000 nautical miles at 13 knots (24 km hr^{-1}) cruising speed – more than enough for a return trip from England to Rothera Research Station in Antarctica, or to circle the entire Antarctic continent twice! The vessel's endurance is 60 days and she is capable of breaking ice up to 1 m thick.

Decks 1 and 2 of RRS *Sir David Attenborough* make up the machinery spaces, below which are the 'tank top' (above the ballast tanks) and double bottom (where all the acoustic sensors are located). The engineers have their stores and workshops here too. To the aft end of the ship will be found the three cargo holds, the science hold and chemical stores as well as the special fridges and freezers for scientific samples.

Deck 3, which is the main working deck, is where scientists will deploy equipment, over the side or from the aft end of the ship, or via the moon pool† – a 4 m x 4 m vertical shaft open to the sea. The ship's main thoroughfare runs forward from the moon pool giving access to the numerous labs and spaces. The main thoroughfare is nice and wide, which will make moving instruments and samples easier; it will be possible to move a standard pallet along its length. A lift is also located along here, and will take you as far as Deck 7, should the stairs be too much trouble! Also on this deck are the scientists' laundry and a well-equipped gym, with sauna.

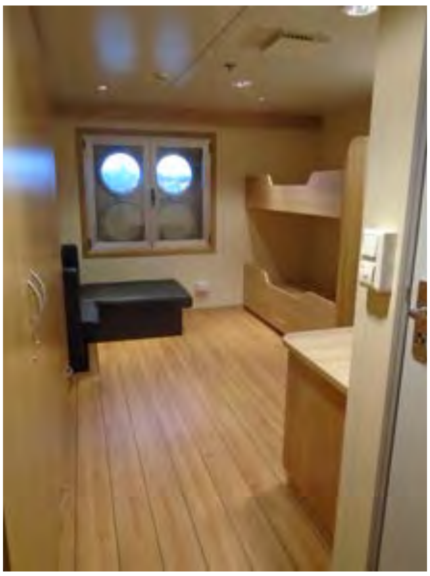
The acoustic sensors within the bottom of the vessel

The main laboratory on Deck 3

The helicopter hangar

Accommodation is to a very high standard. For the scientists and passengers there are a mixture of spacious single- and twin-berth cabins, all with *en suite* bathrooms. There are 17 twin-berth cabins on Deck 3, and seven single- and eight twin-berth cabins on Deck 4. Every cabin will have WiFi, a telephone and a TV. The TV will utilise the British Forces Broadcasting Service, meaning the scientists and crew can watch live UK TV and radio on most cruises. When TV and radio are not available, the latest films and TV series can be accessed via an offline system. The Principal Scientist's cabin, on Deck 6, is very spacious, with a separate bedroom and a large day room to work from.

The conference room and open-plan science office are located on Deck 4, along with the data suite, IT and electronics workshops and two large changing rooms.



Scientists' cabins: Two-berth cabin (left); The Principal Scientist's cabin (below)

*For the latest news on UK research vessels go to @gm0hcq on Twitter.

†The term 'moon pool' arose because on calm nights the water under a drilling platform could reflect the moonlight and give the impression of a calm swimming pool.

There are a number of 'coffee shops' dotted around the ship, which will allow those in working clothes to get a hot drink and snack without needing to get changed. The galley, dining mess, bar and day room are located on Deck 5. The mess, bar and day rooms all have large windows, which will give fantastic panoramic views and make the spaces light and airy. Towards the aft end of Deck 5 is where all the scientific winches and cables are located, along with the winch control room. Up forward, starboard, is the atmospheric science lab and store.

The helideck and hangar, along with the helicopter workshop and reception room, are accessed on Deck 6, which also houses accommodation for the crew. The hospital is also located on this deck, along with crew accommodation, and the Principal Scientist's cabin.

Deck 7 is home to the Captain and Officers of the ship. There is a ship's office and a small laundry. Deck 8 is a technical area, housing much of the electronics and instrumentation on board, as well as some of the heating and ventilation equipment.

Deck 9 is the bridge. It's a large space with big windows all around, offering clear views in all directions. There is a lot of equipment installed here, ranging from the dynamic positioning system, used to keep the *Sir David Attenborough* on station during science work, to the helideck monitoring system, where all flying will be managed from. The bridge is the only space on board that has opening windows, albeit just two! There are no opening ports/windows anywhere else, which should help keep the temperature throughout the ship at a comfortable level.

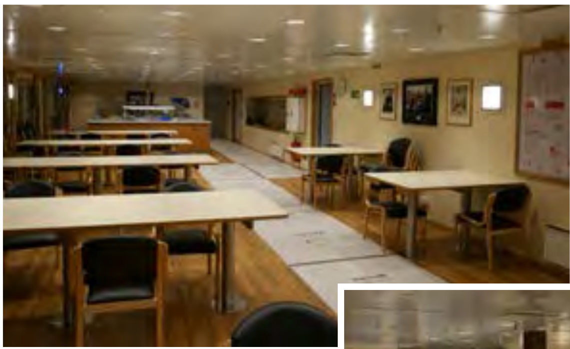
Deck 10 may well be the most popular deck on board, certainly if the weather is not too rough. Here you will find the aerosol met lab and a lounge, with tea- and coffee-making facilities. It's possible to access the outside deck from here and I suspect it will be in demand for enjoying wildlife and taking in the stunning views.

Deck 11 is the crow's nest. The Captain may navigate the ship from here when working in pack ice as the extra height will give a much better view of what is ahead, making it easier to spot leads and 'watersky' (the dark underside of a cloud layer above open water) and determine the easiest route.

Deck 12 is for access to the main mast and assorted antennae and sensors, such as the radar, GPS and anenometers.

The superbly equipped galley

The dining mess



The spacious bar/lounge

With the exception of the winch and acoustic equipment, the RRS *Sir David Attenborough* comes with little in the way of scientific equipment. She has been designed as a scientific platform that can easily adapt to the many ways in which scientific experiments are carried out. Having worked on the RRS *James Clark Ross* since the early '90s, I have seen the changes in the way science work is conducted, and in particular the way equipment changes over time. Some equipment, such as the Continuous Plankton Recorder, has not changed since it was first used, while other equipment changes from year to year. In order to provide the best possible service, the *Sir David Attenborough* is designed to interface with anything that is brought on board.

In addition to her scientific role, the RRS *Sir David Attenborough* will also support the resupply of the five Antarctic research stations operated by the British Antarctic Survey. This is where the holds come into their own. The size and flexible design of the ship's cargo hold allows for efficient stowage of containers and other cargo. This doesn't just include food and supplies, but also scientific equipment used on the stations. The RRS *Sir David Attenborough* also carries a workboat (*Erebus*), which can be fitted with a shallow-water swath bathymetry system, a cargo tender (*Terror*) for logistical work at the small bases that the ship can't access directly, and several inflatables, used to support boating and logistics activities.

Michael Gloistein has worked on the ships of the British Antarctic Survey since 1990 and has been involved with the build of the *Sir David Attenborough* from December 2018. He was awarded the Polar Medal in In 2004. mepg@bas.ac.uk

Trends in marine science publishing

Changes in publication rates and collaborative publishing over the past 80 years

Neil Mitchell

There is broad interest in how the marine sciences have developed and in the UK's role in that development. Although imperfect as a measure of performance, the most straightforward metric of a subject's output is article publication rate. Following a request from the British Council for an article on UK–German collaborations in marine sciences, I carried out a broader bibliometric study of both oceanography and marine geoscience. This article summarises the results; for full details of the paper, see p.18. Examining the trends that emerged can help us to appreciate how influences such as the Cold War, and a growing interest in resources and the environment, may have affected the development of the subjects. On a personal note, I was a doctoral student with the Institute of Oceanographic Sciences in the 1980s and knew many of the key researchers in marine geoscience at that time, so it was interesting to see articles representing their efforts alongside the major trends in their subject, and in oceanography.

Sources of information

Locating articles in oceanography from reference databases turned out to be complicated, as the oceanography classifications used by the database compilers do not encompass all of the subject; furthermore, some databases suffer from incompleteness and even the term 'article' has been interpreted variably. After some experimentation, I settled on a search based on the names of journals, as the bulk of oceanography articles tend to be published in journals with 'marine' or 'ocean' in their name or are otherwise recognised as specialising in oceanography.

The oceanography results presented in Figure 1(a) were derived from the Scopus database. Note that this graph has a logarithmic vertical axis so exponential increases in publication rates appear as straight lines. International collaborative articles in oceanography represented in Figure 2 (*opposite*) were mostly derived from Web of Science in a similar manner. Further graphs in Figure 3 (*opposite*) show how the number of authors on UK oceanography articles has changed since 1972.

* For the purposes of this study, a 'UK oceanography article' is defined as any article with UK authors or co-author(s).

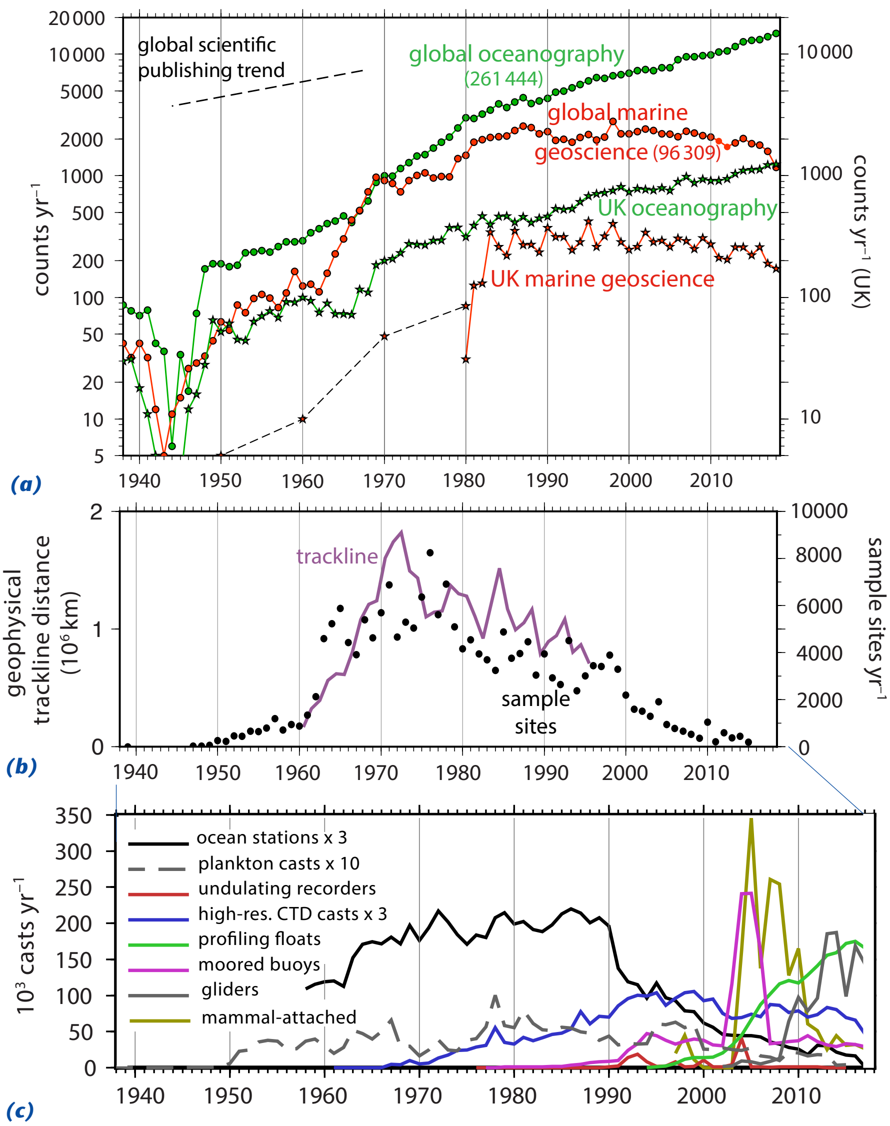


Figure 1 ***(a)*** *Variation in global and UK oceanography and marine geoscience article publishing rates using journal titles in Scopus and Georef. Values in brackets are total counts for the oceanography searches. The global exponential rate of scientific publishing (dashed line) is from Bornmann and Mutz (2015).* ***(b)*** *Global rates of geophysical surveying (Wessel and Chandler, 2011) and sea-bed samplings (major archives, data from GeoMapApp).* ***(c)*** *Rates of collection of ocean casts by various methods obtained from the World Ocean Database 2018 (Boyer* et al.*, 2018). For ocean stations, plankton casts and CTD casts, values on the axis need to be divided by 3, 10 and 3, respectively.*

For the marine geoscience data shown in Figure 1(a), I found that searching Georef using a combination of subject area classifications to be the most effective method. However, although that was accurate before 1990, after that date 44% of the UK articles were outside the subject (they were mostly oceanographic articles and articles on island geology). This means that the rate of decline in publishing in UK marine geoscience after 1990 was greater than shown.

Marine science publishing trends

Oceanography

After a sharp recovery following World War II, global oceanographic publishing rose with a moderate exponential rate, then accelerated in the 1970s, during which the article publishing rate doubled in 6.5 years. This was followed by a more gradual exponential rise, similar to that in the 1950s, up until the present day. UK publishing in oceanography also increased, though more

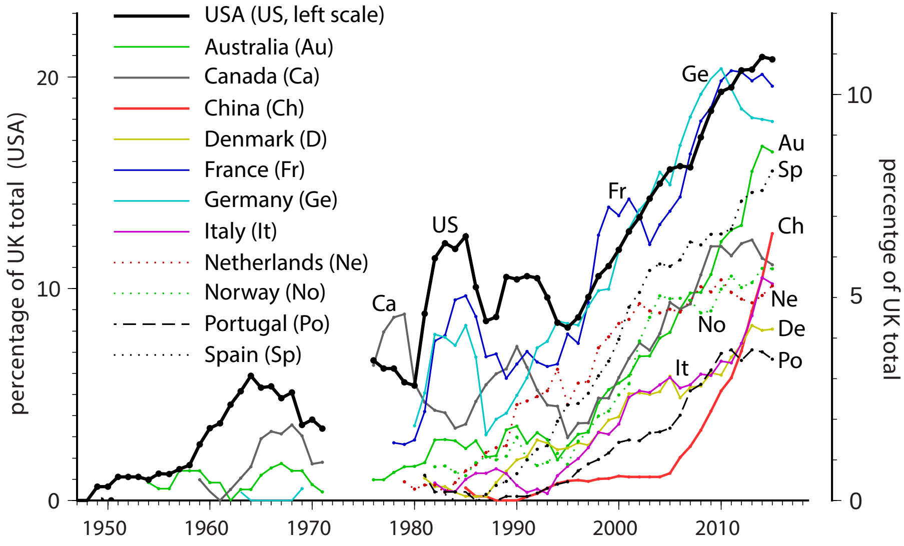


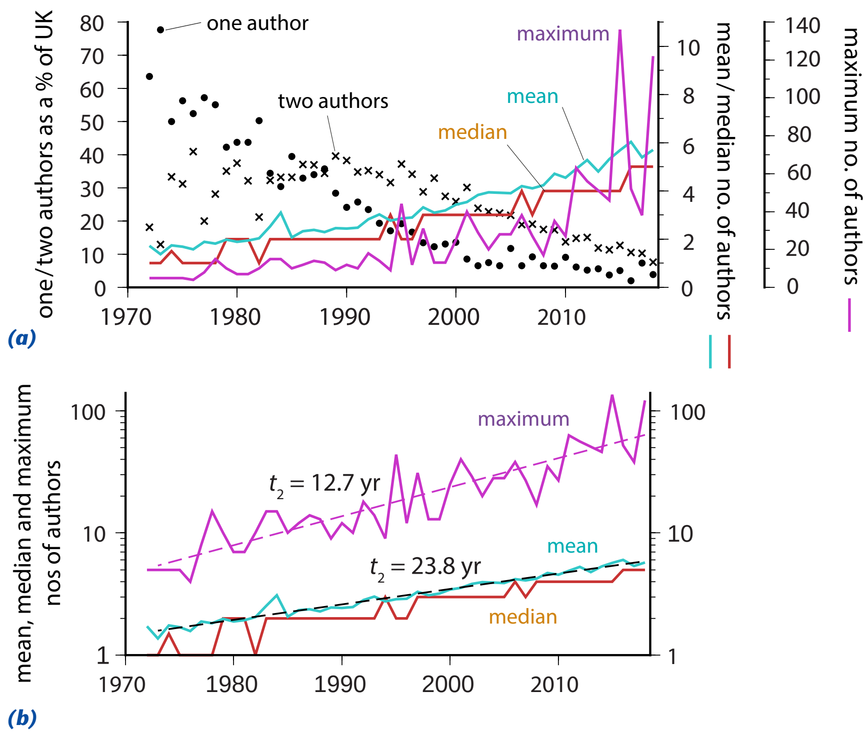
Figure 2 *Percentage of UK-authored oceanography articles co-authored with researchers of the countries shown. Note that the right-hand axis is expanded compared with the left-hand side. A 5-year running average has been applied to reduce variability. (The gap in the 1970s is due to a change in the database used, from Scopus to Web of Science.)*

gradually. UK authors published 28% of all oceanography articles in the 1950s, but by 2018 that had decreased to 8%.

For UK publishing, the number of collaborative articles in oceanography expressed as a percentage of the total number of oceanography articles increased progressively with time (Figure 2). The increase in the percentage of articles with USA-based researchers is almost exponential and has a doubling time of 19 years. Many of the countries shown are either European or English-speaking. When population sizes are taken into account, the figures show that there is a preference for collaboration with researchers in countries with sea areas adjacent to that of the UK. The rise of UK–China collaboration has been especially dramatic and the percentage of co-authored articles has doubled from 2014 to 2018.

Also reflecting the increasing preference or necessity to work collaboratively, the numbers of single-author and two-author oceanography articles have steadily declined, while multi-author articles have increased. The annual maximum of author numbers has a shorter doubling time (t_2) of 12.7 years than the mean number of authors (23.8 years) (Figure 3(b)). Interestingly, whereas author maxima in the similarly expensive subject of physics have increased in a series of stepped plateaux, this has not been the case in oceanography. In particle physics, for example, initial publications arising from work using particle accelerators tend to be co-authored by people from a wide range of locations, reflecting the effort expended in raising the funding. In oceanography, the most expensive instruments used are satellites, and articles using satellite-derived data may tend not to require such broad-based co-authorship. There have been many large research programmes which have led to articles with long authorship lists, but they have overlapped with one another so the maximum number of authors shows more of an exponential rise than 'stepped plateaux'.

Figure 3 *Change in the numbers of authors of UK-authored oceanography articles between 1970 and 2018, derived using information in the Web of Science Oceanography category.* ***(a)*** *Black circles and crosses: the percentage of articles with only one or two authors (left-hand axis). Coloured plots: Mean, median and maximum numbers of authors (right-hand axes).* ***(b)*** *The coloured data as in (a) but plotted with a logarithmic vertical axis. According to the dashed regression lines, the doubling time (t_2) for the maximum number of authors is approximately half that of the mean number of authors.*



Marine geoscience

The rate of global marine geoscience publishing also rose strongly after World War II, with a particularly strong exponential rise in the 1960s. The exponential rate subsequently decreased, and after the late 1980s there was a gradual decline in publication rate (upper red plot in Figure (a)). UK marine geoscience publishing followed those trends in a broad sense, though rapidly increased in the early 1980s (lower red plot in Figure 1(a)). The continued rise in the 1970s was due to the UK joining the international sea-floor drilling programmes, initially the Deep-Sea Drilling Project in the 1970s. As shown in the original paper, the impact of scientific drilling on the field can also be seen in international collaborations, and in the mean and maximum numbers of authors of these articles, which both peaked around 1990 at the time of most intensive engagement with scientific drilling.

Interpreting these changes

Ocean Challenge readers may have their own thoughts on the origins of these publishing trends. Although finding explanations is problematic as they have social as well as other origins, the rapid rise in oceanography publishing until the 1980s can be attributed to the Cold War (which arguably lasted until he Glastnost era of the late 1980s), interest in the oceans as a source of resources – notably fisheries – and interest in environmental change.

For marine geoscience, the Cold War also provided an impetus as knowledge was needed about sea-bed conditions, acoustic transmission, low-frequency noise and safety of navigation. Interest in potential sea-bed resources was probably also a strong influence. There is evidence that the importance of North Sea oil to the UK economy affected the UK decision to join the Ocean Drilling Program; now, though, a major part of marine geoscience research is environmental work.

There have been great shifts in the way both oceanography and marine geoscience have been carried out and it is interesting to look at how the overall efficiency of research at sea has changed over time. In marine geoscience, geophysical data are routinely collected while vessels are transiting to areas of study and while carrying out surveys within those areas, so 'trackline' distances provide a reasonable way of assessing activity. Those distances and the number of sea-bed samplings (Figure 1(b)) rose rapidly through the 1960s and into the 1970s, before declining. Up until 1972, roughly 1000–2000 km of research vessel surveying was required to collect the data for each geoscience article. For context, a research ship at sea travelling at 10 knots covers 444 km in 24 hours, so at that time each article reflected a few days of sea time. The decline in ship activity after the mid 1970s was accompanied by the 1970s reduction in the exponential increase in articles globally, but this was followed by a second wave of increasing publishing rates in the 1980s. Evidently, geoscience research became progressively more efficient, so that by 1995, on average an article represented only 323 km of trackline.

There are many possible explanations for the decrease in trackline distance per article. The development of the sea-floor spreading hypothesis and plate tectonics led to work re-analysing geophysical data collected previously, i.e. new data were not needed for those papers to be written. (My own work to a large extent involves re-analysis of datasets.) Similarly, sediment cores were further sampled and analysed for oceanographic, climatic, volcanic and other signals. Instrumentation on research ships has progressively become more sophisticated so that more information can now be collected during each cruise. Marine geoscience has benefited from computer-based modelling and from satellite-derived data, such as the marine gravity field from satellite altimetry, which has allowed global sea-bed topography to be mapped to ~10 km resolution.

As oceanography is such a diverse subject, it is difficult to find data to represent global shipboard activity, but temperature and salinity profiles are commonly collected. The sum of the ocean station and CTD cast numbers in Figure 1(c) rose along with global oceanographic publishing until about 1990, but then declined as more efficient ways of collecting data, such as *Argo* profiling floats, were developed. Global publishing rates continued to rise, though the exponential rate of increase declined from 1990 onwards, nevertheless remaining greater than global scientific publishing indicated by the straight dashed line in Figure 1(a).

The data discussed in this article of course reveal nothing about the quality of marine geoscientific and oceanographic research. The fact that UK publishing has been falling behind global publishing is not necessarily a concern. Indeed, it could be viewed as a positive sign of developing nations taking on our disciplines. It would also be risky to extrapolate trends into the future – at the time of my doctorate in the late 1980s it was not at all obvious that my own field of marine geoscience would soon begin a long period of decline.

How did the UK's various assessments of research performance, and changing policies of research councils, affect these subjects? It is difficult to say of course, though greater focussing of funding resources, starting with the first Research Assessment Exercise in the late 1980s, may have led to greater concentration on quality and less on quantity, so contributing to UK oceanography publication rates falling below the global trend. We can speculate that changes such as the UK leaving the European Union could be disruptive. On the other hand, communications are becoming more effective, as we are now finding out, so international collaboration may continue to increase. Although interpreting these trends is difficult, hopefully readers will find them interesting, and that they will provoke thoughts about how the subject has changed over the past 80 years, which is roughly equal to two 40-year generations of working careers.

This article is a greatly shortened version of:

Mitchell, N.C. (2020) Comparing the post-WWII publication histories of oceanography and marine geoscience. *Scientometrics* 124, 843–66. https://doi.org/10.1007/s11192-020-03498-2

Further Reading

Bornmann L. and R. Mutz (2015) Growth rates of modern science: a bibliometric analysis based on the number of publications and cited references. *J. Assoc. Inform. Science Technol.* **66**, 2215-22.

Boyer, T.P., O.K. Baranova, C. Coleman, H.E. Garcia, A. Grodsky and 8 others. (2018) World Ocean Database 2018. In: A.V. Mishonov (Technical Editor) *NOAA Atlas NESDIS 87*, p.207.

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Neil Mitchell is a marine geoscientist based at the University of Manchester. He is interested in interdisciplinary research, particularly how oceanography can help explain sedimentary features. He says that he undertook bibliometric research to satisfy his curiosity, expecting it would be straightforward, but it turned out to be more like sailing into strong wind!
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Equity at Sea
Gender and inclusivity in UK sea-going marine science

Katharine R. Hendry

with: Amber Annett, Rehemat Bhatia, Gillian M. Damerell, Sophie Fielding, Yvonne L. Firing, Eleanor Frajka-Williams, Sue Hartman, Sian F. Henley, Karen J. Heywood, Penny Holliday, Veerle A.I. Huvenne, Rachel A. Mills, Berit Rabe, Carol Robinson, Alejandra Sanchez-Franks, Denise Smythe-Wright, Michelle L. Taylor and Margaret Yelland

Today, we can celebrate a strong representation of women in sea-going science in the United Kingdom, providing positive role models for early-career female marine scientists. However, women continue to face challenges to their progression in their marine science careers, especially those who are also members of other under-represented groups. In this article we consider gender equity and equality in participation and leadership in sea-going marine science in the UK, discussing successes and lessons learned for the future. After a brief history of UK women in ocean science, and a summary of some recent advances in gender equality, we look at further areas in need of improvement, and ask whether successes in improved gender equality can be transferred to tackling other forms of under-representation in sea-going science.

Women in UK sea-going marine science: the historical context

In the majority of countries undertaking marine research, women were largely excluded from sea-going expeditions until the mid-20th century, with the exception of those formidable few who dressed as men, stowed away, or controversially joined expeditions with their husbands. The exclusion of women from ships affected not only areas of science and technology, but also participation and leadership in areas such as marine governance, policy-making and sustainable development. The historical explanation was that this marginalisation was largely a result of an 'ancient taboo', which considered allowing women on ships to be bad luck – a taboo that has lasted until surprisingly recently. More recent barriers to women working in marine subjects – especially on sea-going expeditions – included perceived limitations associated with traditional family roles (including parental responsibilities), health and safety (including suitability for physically challenging activities), and what were often considered insurmountable challenges in supplying facilities and provisions for women (including separate cabins, bathrooms and supply of sanitary products). That these barriers actually existed is highly questionable – they could well have been a convenient pretext for a more complicated narrative involving discrimination.

Box 1 Under-represented groups in science

Within the Science, Technology, Engineering, Mathematics and Medicine (STEMM) disciplines, women and minority groups have faced significant challenges in gaining employment and attaining leadership roles, and so are under-represented within their chosen fields. Under-represented groups include: individuals who identify as Black, Asian or as a member of another ethnic minority group, women, and individuals who identify as lesbian, gay, bisexual, transgender, queer, intersex, asexual, or as having other gender/sexual identities (collectively referred to as LGBTQIA+), those from low-income backgrounds, and those who have a form of disability.

The influence of gender (see Box 2) in STEMM disciplines has been discussed widely, probably more so than barriers experienced by other under-represented groups. In many STEMM areas, women, and those who identify as non-binary, are still under-represented in more senior positions, and statistics show that they are also more likely than their male counterparts to lose out on earnings. Furthermore, gender-based discrimination often operates in tandem with other forms of discrimination, including unequal treatment on the basis of, for example, socioeconomic background, race, sexuality, disability and/or mobility impairment; those who belong to intersectional groups (e.g. a woman of colour, a transgender person, or a disabled woman) may be disadvantaged in multiple ways. In the geosciences, only 3.8% of tenured or tenure-track individuals in the top one hundred departments in the US are people of colour, and over the past 40 years in the US there has been no improvement in diversity within geosciences as a whole.

Box 2 Definitions of gender, gender identity, gender equality and gender equity

Our first aim here is to provide a brief history of UK women in sea-going ocean science, but we have to acknowledge that historically, gender was viewed as binary, so we have not been able to capture the situation across the full gender identity spectrum. So what are the differences between gender and gender identity, and what do we mean by gender equality and equity?

Gender and gender identity Gender is defined as an individual's sense of self, i.e. male, female, both or neither of these, and is developed socially and culturally. Gender identity can be expressed in many ways, including the way someone might dress, their name, the pronouns they use, and behaviours. Individuals can also identify as agender – this is when an individual identifies as gender neutral. If an individual identifies as transgender, this is described as having a gender identity and/or gender expression which is different from what is typically associated with the sex they were assigned (based on genitalia) at birth. Identifying as non-binary is defined as having an identity, or expressing an identity, which doesn't fit with man or woman. From Stonewall (2020), GLAAD (2020), Gender Minorities Aotearoa, New Zealand (2020)

Gender equality is the 'equal valuing by society of both the similarities and the differences between women and men and the different roles they play'. Intergovernmental Oceanographic Commission of UNESCO (2017)

Gender equity is the 'process of being fair to women and men. To ensure fairness, strategies and measures must often be available to compensate for women's historical and social disadvantages that prevent women and men from otherwise operating on a level playing field. Equity leads to equality.' United Nations Population Fund, UNFPA (2020)

Indeed, women's traditional role in the family home as 'stewards of natural and household resources' could have been considered an advantage for working in ocean governance and natural resources (e.g. fisheries). Thankfully, there are now few proponents of the idea that supplying provisions for women in a ship's bond is problematic, and few who believe that women are not capable of carrying out physically challenging roles in any occupation.

The history of sea-going women in research begins in 1766, when Jeanne Baret (1740–1807), dressed as a teenage boy, joined expeditions as assistant to the naturalist Philibert Commerçon onboard the ships *La Boudeuse* and *L'Étoile*. This French botanist became the first known sea-going woman scientist, was the first to reach Antarctic waters, and is recognised as the first woman to complete a circumnavigation of the globe. It was not until the last century, however, that women were included in leadership roles in marine science itself. Maria Klenova (1889–1976), a Soviet researcher who, in 1929, worked as a marine geologist on the RV *Perseus*, was the first woman to lead a scientific expedition.

Sea-going botanist, Jeanne Baret, disguised as a boy

The UK story of professional female marine scientists can be said to have started with Rosa Lee (1884–1976), who was the first woman to graduate in Mathematics from Bangor University and the first woman to be employed by the Marine Biological Association (MBA). Rosa was a statistician, and initially worked at the MBA's Lowestoft Laboratory.* In 1910 the staff were transferred to the Board of Agriculture and Fisheries, which 'did not employ women scientists'; following protests by the MBA, Rosa was allowed to continue her work as a civil servant. Rosa's achievements include realising that growth rings on fish scales could be used to assess changes in

Rosa Lee in a group of staff at the Marine Biological Association's Lowestoft laboratory in 1907

(Photo courtesy of Cefas)

*This later became the main lab of what is now the Centre for Environment, Fisheries and Aquaculture Science (Cefas).

fish growth rate with age. Rosa's discovery (later known as the Rosa Lee Phenomenon) was published in a 1920 issue of *Nature* and is still relevant in fisheries science today. Rosa's achievements are all the more impressive given that she was not allowed on research vessels, and her employment as a civil service scientist came to an end in 1919 simply because she married.

Marine biologist Marie Lebour (1876–1971) published a paper on molluscs in 1900, but her professional research career began in 1915 when she joined the MBA in Plymouth. Marie was well known for her work on life cycles of marine animals, notably molluscs and their parasites, and fish. She was also interested in microplankton and discovered at least 28 new species. Marie published extensively, and many of her publications are still referred to today.

In 1922, Sheina Marshall (1896–1977), an expert in copepods, was appointed to the staff of the Marine Biological Station at Millport, where she later became Deputy Director. During 1928–29 she went on an expedition to the Great Barrier Reef, led by Maurice Yonge. Uniquely for the time, this expedition involved women in active roles both on the boats and in the shore party, and Sheina had key responsibilities in both science and logistics. She received many accolades throughout her career, breaking considerable ground for a woman in science in the mid-20th century, including being one of the first women to be elected as a Fellow of the Royal Society of Edinburgh in 1949 (winning their Neill Prize in 1971), becoming a Fellow of the Royal Society in 1961, and being honoured with an OBE in 1966.

The first woman to go to sea as a scientific researcher in UK waters was Dorothy Elizabeth Thursby-Pelham (1884–1972). Dorothy worked on North Sea plaice populations from the 1930s onwards, gaining great respect in the field both nationally and internationally and becoming an active member of the International Council for the Exploration of the Sea (ICES).

Dorothy Thursby-Pelham, photographed at the Fisheries Laboratory in Lowestoft in the 1930s.
(Photo courtesy of Cefas)

Sheina Marshall.
This photograph is on display at the Scottish Association for Marine Science (SAMS, Oban) which evolved out of the Marine Biological Station at Millport. Text accompanying the photograph describes Sheina as 'among the founders of biological oceanography'.
(By courtesy of SAMS)

Despite these pioneers, largely in the fisheries sector, in the mid 20th century there were very few women working in UK marine science – in any role. Women faced considerable obstacles to participation in UK marine science; notably, the Challenger Society only allowed women to join after the Second World War. By the 1950s, the National Institute of Oceanography (NIO) had been established in Wormley, but less than a fifth of the scientists who worked there were women, and they represented a much smaller proportion of the sea-going staff. The vast majority of female staff were researchers in computer science and mathematics; they developed a number of key theoretical ideas, but very few carried out observational or sea-going research.

No women were allowed to sail on the RRS *Discovery II*, and it wasn't until 1963 that marine microbiologist Betty Kirtley sailed on the first *Discovery III* cruise, becoming the first woman from the NIO to sail on an expedition. This notable event was described as 'breaking new ground' by Anthony Laughton (Director at Wormley, 1978–1988) in an interview with the British Library in 2010. Three years after Betty Kirtley worked at sea, Carol Williams, from the Department of Geodesy and Geophysics at Cambridge University's Madingley Rise site, became the first woman to go to sea as a geophysicist. Carol went on to have a long career in Cambridge and as an international scientific leader, including having a coordinating role on the scientific committee of the Deep Sea Drilling Project.

Women also went to sea on NIO cruises in the 1960s in technical and computational roles. In Scotland, the Fisheries Research Services (FRS; now Marine Scotland Science) tried to involve more female scientists in its cruises in the late 1960s and early '70s but FRS's *Explorer* and *Scotia 2*, and their smaller vessels, were perceived to lack suitable accommodation/provisions as they only had shared facilities. *Scotia 3*, launched in 1971, finally had one *en suite* cabin for potential female scientists.

In the mid 1950s, marine biologist Eve Southward began to investigate benthic fauna in the Bay of Biscay, in collaboration with her husband Alan Southward, who was on the staff of the MBA at Plymouth. This work involved a long series of cruises on RVs *Sarsia* and *Frederick Russell;* Eve also worked on RVs *Sonne*, *Challenger* and *Shackleton*. In the 1970s, she was invited to join US cruises to the newly discovered hydrothermal vent sites in the Pacific, on RV *Atlantis*; she also went down in the submersible *Alvin*. Despite being highly respected for her expertise, Eve remained an unpaid independent researcher; she was often accompanied by female assistants.

Eve Southward sorting mud on RV Sarsia*, in the Bay of Biscay in 1974 (Photo: Alan Southward)*

Denise Smythe-Wright was, we believe, in 1975 aboard the RRS *Shackleton*, the first woman scientist in the UK to go to sea as a Ph.D student. She was required to take a final-year female undergraduate with her as a companion, and they had to use the Captain's bathroom as there was no other provision. Denise was also – to the best of our knowledge – the first UK oceanographic mother-at-sea having given birth to her son three months before a five-week expedition to the North Atlantic in August 1991; she was nicknamed 'Mum' by the crew. Aenea Reid from Scotland's FRS's gear section was the first woman to lead a cruise onboard FRS *Explorer* in the 1970s, despite there being no adequate facilities on board.

Opportunities for women at sea began to gradually change in the UK during 1979–1980, when the Institute of Oceanographic Sciences (IOS, previously the NIO) hired thirteen new staff to work on radioactive waste in the oceans. Four of the new scientists were women: three chemists (including Denise Smythe-Wright and Sarah Colley) and a geophysicist. Sarah Colley went on to be a PSO (Principal Scientific Officer) on ships in the 1980s, and in 1988 Penny Barton was the first female PSO of *Discovery III*. Denise was the only woman on a committee that was responsible for the banning of radioactive waste dumping at sea in 1985, and was the Scientific Secretary to the International Scientific Steering Committee of the World Ocean Circulation Experiment (WOCE) for five years in the 1980s and subsequently the UK WOCE Project Manager.

There was also a greater representation of women in active support roles at sea. From the 1970s there were a number of women who regularly supported cruises as computer scientists for typically three to four months each year on the UK research vessels and charter vessels (RRS *Discovery*, RRS *Shackleton*, RRS *Challenger*, MV *Starella*, MV *Farnella* plus others). These women included Ruth Sherwood (*née* Howarth), Theresa Cooper (*née* Colvin), Doriel Jones, Daphne Heathershaw and Kay Batten (*née* Potter) *(see below)*. Initially, their involvement was via IOS Wormley,

Sea-going women computer scientists from the RVS Shipborne Computer Group
Left *Doriel Jones and Kay Batten on board RRS* Charles Darwin *in February 1985 on their way into Falmouth following instrument trials prior to the vessel's first scientific cruise. Others in the photo are (from left to right) John Sherwood, Martin Beney and Chris Jackson. (Photo: Ted Lawson)*
Below *Theresa Cooper (*née *Colvin), RVS Shipborne Computer Group, c.1980 alongside the S1 PDP11/34 System in Barry; the system was portable and first installed in the on-board clean room during the RRS* Discovery *cruise D94. (Photo: Edward Cooper)*

The RRS* Discovery *CTD rosette then and now
Left Discovery III *cruise D200 in 1993. (Photo: John Gould)*
Right Discovery IV *cruise DY078 in 2017. (Photo: Penny Holliday)*

before they were transferred to the IOS (then RVS, Research Vessel Services) Shipborne Computer Group at Barry. All were at least degree qualified. Daphne Heathershaw sailed on RRS *Discovery* in 1974 whilst a postgraduate at Bangor (University College North Wales) prior to joining IOS Barry. Doriel worked on UK- and US-based cruises for over twenty years, including on the RRS *Discovery* in 1984, with physical oceanographer Karen Heywood and a female radio officer, and on the HMS *Farnella* in 1985, with US Geological Survey scientist Kathy Scanlon.

By the 1990s, the cohort of physical and chemical oceanographers at IOS (now IOS Deacon Laboratory, IOSDL) expanded for UK WOCE, which included a significant number of cruises. Both men and women from IOSDL, and its Southampton-based James Rennell Centre, were encouraged to go to sea once a year, whatever their position in the organisations. At the time, there were a number of women employed – mainly in junior grades – as James Rennell Centre science and technical staff. These cruises, in addition to expeditions led by UK universities (notably Bangor University), presented sea-going opportunities for the growing number of oceanography Ph.D students and post-docs from the UK and overseas.

Support for women scientists at sea was, however, often lacking. Even basic amenities such as waste disposal bins for sanitary products were not always provided, and some younger women were told by older women to throw them over the side, secretly, at night. Furthermore, the culture on board could be very confrontational and challenging, perhaps even more so than in the 1970s and ’80s. Women also described persistent unwanted attention, sexual harassment, and bullying; with no guidelines about behavioural standards, and no reporting procedures in place, women (and indeed anyone who was targeted) were effectively unprotected. On the more positive side, WOCE highlighted some excellent role models active in observational oceanography – senior women who were leading cruises and producing outstanding research – particularly in the US, but also including Denise Smythe-Wright and Karen Heywood in the UK. In 2005, after several years of expeditions at sea, as well as involvement in WOCE, Karen became the first female Professor of Physical Oceanography in the UK. In 1990, Carol Pudsey was the first PSO on an Antarctic cruise; many cruises later in 2003 she was awarded the Polar Medal for services to Antarctic science. In Scotland more female scientists joined cruises on the converted MV *Clupea*, MRV *Alba-Na-Mara* and MRV *Scotia* 4, including sporadically as PSOs on those vessels and charters (from the 2000s).

The Valkyries – sometimes known as the Physics Team – during a cruise led by Margaret Yelland on the RRS James Clark Ross *in December 2011. All bar the engineer, Robin, were women – a far cry from Margaret’s first cruise in 1989 when she was the only woman on the ship.*
From left to right: Helen Snaith, Vikki Frith, Robin Pascal, Sarah Norris (now Sarah Dennis), Mairi Fenton, Margaret Yelland and Penny Holliday.

Women working in UK institutions have been (and are largely still) under-represented in leadership positions within Higher Education Institutes and national organisations, and on scientific steering committees of international marine programmes. It wasn't until 2009, when Lisa McNeill co-led Expedition 319 to the Nankai Margin, south-west Japan, that there was a woman Co-PSO from a UK institution in the Integrated Ocean Drilling Program (IODP). Lisa also went on to be the first person to be a Co-PSO on all three International Ocean Discovery Program (IODP) drilling platforms in 2017. Other international organisations have also only recently promoted women to leading positions. Denise Smythe-Wright was elected as President of IAPSO* (2015–2019), sat on the SCOR† executive, and is now the International Union of Geodesy and Geophysics (IUGG) liaison officer to the International Oceanographic Commission of UNESCO. Carol Robinson was elected Chair of the Integrated Marine Biosphere Research project (IMBeR) in 2016.

*IAPSO is the International Association for the Physical Sciences of the Oceans, which is part of the IUGG.

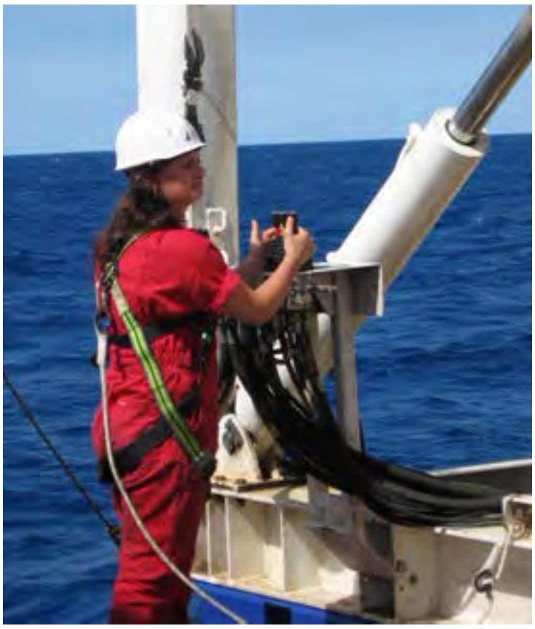
†SCOR is the Scientific Committee on Oceanic Research. IMBeR is one of SCOR's Large Scale Ocean Research Projects.

Carol was also the first female President of the Challenger Society (2008–2010); since then, the Society has had two further female Presidents (Hilary Kennedy, 2012–2014, and Rachel Mills, 2016–2018), with Ros Rickaby taking on the role for 2020–2022. There has however been severe under-representation in recognition and awards, especially for senior female scientists (e.g. celebratory conferences or 'lifetime achievement' awards).

Present-day situation and recent successes

Gender balance in UK marine science has improved greatly in recent years, and there has been a growing appreciation of the benefits of gender diversity in field-based research. Advances and achievements have also come in marine governance and science policy, in addition to leadership roles in technical and ship's crew positions. To illustrate this progress we present a few case studies; we cannot use aggregated information on cruise participation by gender, as data on self-verified gender identity, acknowledging the full gender spectrum, are not available.

Sue Hartman and Hannelore Theetaert (Flanders Marine Institute, VLIZ) during the June 2019 RRS Discovery *cruise to exchange the moorings and instrumentation on the PAP-SO buoys (one can seen close up on the left). (Photo: Jon Campbell)*



Marine technician Ella Richards, here shown during an RRS James Cook *cruise in 2015. (Photo: Veerle Huvenne)*

In summer 2017, for the first time the three main UK research vessels had concurrent expeditions led by female PSOs: the RRS *James Clark Ross* was in the Barents Sea as part of the UK NERC Changing Arctic Ocean programme (PSO Joanne Hopkins); the RRS *Discovery* IV was in the Iceland Basin and in the vicinity of Rockall, traversing the NERC Extended Ellett Line and servicing UK OSNAP moorings (*p.23, above right*) (PSO Penny Holliday, Captain Jo Cox); and later in the Labrador Sea as part of the EU-funded ICY-LAB project (PSO Katharine Hendry, Captain Jo Cox, and two female technicians, including Ella Richards (*above*)); and the RRS *James Cook* was in the tropical Atlantic as part of the NERC-funded ZIPLOC project (PSO Claire Mahaffey).

Expeditions serving longer time-series studies are useful for assessing improvements in gender equality through time. For example, the Porcupine Abyssal Plain Sustained Observatory (PAP-SO) cruise programme has been running since 1985. Previous PAP expeditions have had a good representation of women, including crew. However, to date there have been very few women PSOs on the PAP programme. Sarah Colley was the first woman to lead a PAP expedition, in 1991 on board the RRS *Charles Darwin*. Most recently, Sue Hartman from the National Oceanography Centre (NOC) was PSO in 2019 (*left*), and Jennifer Durden was due to take the position in 2020 (the cruise was cancelled because of the Covid-19 crisis).

Women have been less represented in scientific leadership in the Atlantic Meridional Transect (AMT) programme, with only one woman PSO (Carol Robinson) in 2003; whilst there is good representation of women in the AMT programme, the majority of these scientists have been early-career researchers. Long-term observations of the hydrography in the Faroe–Shetland Channel have been conducted by Marine Scotland Science (and predecessors) since the late 19th century, with the first female PSO (Berit Rabe) in 2014, onboard MRV *Scotia*; since then, at least one out of three Marine Science Scotland's regular cruises in the Faroe–Shetland Channel has been conducted by a female PSO.

When using such time-series programmes as case studies of progress in gender equality in leadership roles it is important to bear in mind that they are often institution-based, and so there may be various reasons behind PSO designation (e.g. a small 'pool' of available researchers, or established PSOs who hold their positions until retirement, etc.). Larger international programmes – which are becoming increasingly important for addressing broad ocean–climate interactions – provide further insight into the leadership roles played by UK women in marine science. For example, the Overturning in the Subpolar North Atlantic Programme (OSNAP) is a large (£50M) and successful international observations-based research project that has UK women in strong leadership positions, including PSOs Penny Holliday and Helen Johnson. Similarly, IODP expeditions on the RV *JOIDES Resolution* have become more balanced in terms of participant gender.

In addition to leading scientific research, women scientists in marine science are also keen innovators: for example, in recent years they have been the driving force behind the use of some of the latest robotic technology for marine observations, including the use of *Autosub Long Range*, ocean gliders and remotely operated vehicles (ROVs). Since 2013, most of the expeditions using the National Marine Facility ROV *Isis* were coordinated by women, and in 2015 Veerle Huvenne was the first PSO to use three different robotic vehicles (*Autosub6000*, the ROV *Isis* and a Seaglider) in a simultaneous, combined operation during an expedition on the RRS *James Cook*.

As well as gender equality amongst scientists and technicians, there is also the question of gender equality for other essential roles at sea, which – again – cannot be assessed without the collection of relevant data on participation. However, there are some examples of continued improvement in gender balance, including the appointment of Alexis Lee as the first female Officer in Charge of a Marine Scotland Compliance expedition – an acheivement that was celebrated in a blog for Merchant Navy Day in 2019.

What has driven these successes?

Many of the women who now occupy leadership positions in UK institutions were trained in the period 1980–2000: the era of significant growth in the UK science base when there was a significant rise in the number of individuals studying for Ph.Ds. With this growth came a new generation of Ph.D supervisors who recognised that talent and hard work are found across all parts of society. Pioneers in this area included key members of the Challenger Society community such as Paul Tyler, Harry Elderfield, Peter Liss and Tim Jickells, who supervised many female Ph.D students who went on to hold positions in leading institutes and universities, supervising their own students and researchers. This combination of mentorship, championing of new talent and providing opportunity for interaction with the wider science community was a key driver of this change.

Assessments of gender diversity in marine science have focussed on the importance of two aspects: improved mentoring schemes and consistently supportive work environments.

Mentoring Mentoring is critical during all stages of a researcher's life, and is key to retaining under-represented groups in STEMM. An example from the marine sciences is the US-based Mentoring Physical Oceanography Women to Increase Retention (MPOWIR) organisation, which since 2007 has funded mentoring activities for women in their early career stages (postgraduate research and onwards). A survey of MPOWIR participants revealed that the scheme has had a positive impact on retention of early-career female researchers in the field, with 80% of participants with Ph.Ds completed prior to 2012 being employed in 'university/government/nonprofit research positions'. A few of the scientists who benefited from this mentoring scheme are now working in the UK and have led UK-based research expeditions. UK researcher Heather Ford (Lecturer at Queen Mary University of London and NERC Independent Research Fellow) together with Jennifer Hertzberg (postdoctoral researcher at Old Dominion University in the US) established the AGU Paleoceanography/Paleoclimatology Section mentoring scheme in December 2018. This scheme showed that participant feedback is a useful means for assessing success of mentoring schemes and identifying pathways for improvement.

The above examples of mentoring programmes all take place on land, but there are also valuable opportunities for mentoring at sea. For example, Marine Scotland Science have a pioneering new scheme for training PSOs, involving appointing a Co-PSO for each expedition. Whilst this programme is open to everyone, there was an expedition in 2019 on the MRV *Scotia* where the PSO and Co-PSO, Berit Rabe and Helen Smith, were both women (*photo below*).

Berit Rabe (right) and Helen Smith (PSO and Co-PSO, respectively) along with Matthew Gray, during a 2019 Scotia *cruise. (Photo: Matthew Gray)*

Improved work environments Work environments have been improved through flexible schemes for carers, more high visibility roles for women (including those belonging to other under-represented groups), emphasis on collaboration rather than competition, and the perception of reduced gender bias and overt sexism.

There have been a number of specific schemes and scholarships to promote women and other under-represented groups in marine science within the EU and US. In the UK, the most prominent scheme for improving the workplace environment for women is the Athena SWAN Charter, launched in 2005. This aims to promote and advance the careers of women across all STEMM disciplines. One example of a positive policy change, which arose from an Athena SWAN award submission by Marine Scotland Science, is the creation of a gender-balanced pool of trained PSOs, an action endorsed by its Board in July 2020. However, actions that have been implemented as a result of Athena SWAN accreditation (such as mentoring programmes) are generally limited to within institutions or informal arrangements, and nation-wide (or UK-led international) schemes for particular areas of marine science are still few and far between.

Networking Assistance with networking can also help women, and other under-represented groups, make connections and build collaborations. One good example of this, albeit from a broader subject base, is the Earth Science Women's Network (ESWN), a non-profit international organisation that started from informal beginnings in 2002 and is sponsored in part by the University of East Anglia. In addition to providing networking support for women in the geosciences, members of the ESWN leadership board have also been instrumental in securing funding for projects aimed at improving the work environment for women.

The Challenger Society now has a Diversity in Marine Science (DiMS) network which aims to improve networking for under-represented groups, and address other problems they might face. A DiMS event was held at the Challenger 2016 Conference in Liverpool, and another, for early-career researchers, was organised (with the UK Polar Network) at the Challenger 2018 Conference in Newcastle; this covered diversity at sea/in the field, alternative career paths, unconscious bias, mental health in academia, and digital media.

Continuing challenges for under-represented groups in sea-going research

A good cruise can help a scientist embrace a career in sea-going marine science, but a bad experience for themselves or a friend or colleague could make someone change their career plans, and this does happen. This problem disproportionately affects under-represented groups, given that they are more likely to be targeted by harassment or unwanted attention. Unacceptable behaviour is likely to impact those in early-career stages more strongly, but it is experienced by under-represented groups at all career stages.

PSOs generally receive little or no training in how to support team members who feel they are being unfairly treated, although videos covering harassment are now mandatory at the beginning of expeditions on the main NERC research vessels. The burden of tackling unacceptable behaviour often still lies with the victim. It can be extremely difficult to find the courage to report unacceptable behaviour at sea if the culture and expectations of behaviour standards are not explicitly set out by those in charge. A consistent change in culture to prevent such behaviour is needed.

There are still shortcomings in the availability of health and safety provision specific to women. Many ships are still stocked with personal protective equipment (PPE) that is not suitable or sufficient for use by the women on board: a potentially dangerous example of equipment etc. being designed with the average man – not woman – in mind (as written about recently in *Invisible Women: Exposing data bias in a world designed for men* by Caroline Criado Perez). For example, safety or survival suits are often provided predominantly in larger sizes that are both cumbersome and dangerous for smaller people, who are disproportionately, though not exclusively, women.

Menstruation at sea is still often a taboo subject. It was not until the 1990s that the issue of sanitary bins on research ships was raised. When the RRS *Discovery* was revamped in 1991, the ship was fitted with an incinerator and women were asked to put used sanitary products directly in bins ready for burning as it was not fair to ask the stewards to empty cabin bins. Provision of sanitary bins in the shared toilets on ships has been an ongoing battle, and women have had to raise the matter at cruise planning meetings, or request crew members to buy bins in port before agreeing to sail. Paper bags were sometimes provided, but were often not fit for purpose, especially for anyone experiencing heavy periods. The situation has mostly improved in the last two years or so, with the introduction of small, sealable bags and appropriate bins in both cabins and toilets in public areas.

The increased participation of women in sea-going research has not led to equality in leadership positions. This may be a result of the lack of women in other high profile roles, the fact that (as mentioned earlier) the appointment of PSOs often lacks open and fair access to training, and because there are few opportunities for women to engage with the early planning stages of a cruise: if women are not involved from the start, it is unlikely that they will be able to take a leadership role in the final expedition. Furthermore, there may be a reluctance for women to propose sea-going research because of the long time-scales involved in the planning processes (it can take many years from the initial proposal to completion of a scientific expedition). Being away for weeks at a time is still challenging for many women due to caring commitments and other personal circumstances; women might decide to leave oceanography if they feel that caring duties and career progression do not go together.

Improved attitudes towards, and accommodation of, women at sea are probably a result of the gradually increasing number of women on ships, rather than the other way around, and there is still a stark imbalance among technicians and crew. Our research has revealed that there have been very few 'top-down' schemes that were designed to support women in sea-going marine sciences within the UK. For example, there are no UK-wide mentoring or networking schemes specifically for female marine scientists. Success has largely been driven at the level of institutions, or by individuals – often, but not only, by women, including scientists, crew and technicians. These individuals have been instrumental in driving forward informal mentoring schemes, being role models at different career stages, and repeatedly raising concerns about conditions at sea (harassment, PPE, sanitary provision etc.) until they are successful in forcing change.

How can we extend successes in gender equality to other under-represented groups?

In addition to improving inclusivity, bringing in the views of women and other under-represented individuals results in better collaboration and greater scientific impact. Can we, on a national and international level, transfer the mechanisms of success in improving gender balance in marine science to tackling other forms of under-representation?

Whilst there have been improvements in gender equality, women working in science still face discrimination and inequality, especially if they also belong to another under-represented group, even one protected by equal rights law (e.g. relating to ethnicity or disability). There is a plethora of evidence to suggest that under-represented groups face more discrimination and harassment in their workplaces, fewer opportunities to speak at conferences, have fewer collaboration and leadership opportunities, and will be less likely to apply for promotion. They might also face hostile attitudes if they speak up about these issues. Although numbers for UK marine science have not been published, anecdotally more women, individuals identifying as Black, Asian or as a member of another ethnic minority group and/or as LGBTQIA+ and/or with disabilities, are participating in sea-going research during early career stages, but are still under-represented.

Critically, under-represented groups do not see individuals with whom they identify in leadership roles. For many years, NOC Southampton proudly displayed on the wall outside the National Oceanographic Library an array of male, white leaders whose legacy was the UK oceanography discipline. These images were moved this year to a more fitting range of locations, where of course the important contributions of these pioneers of science will be recognised individually and with appropriate respect. However, it is clearly now time to enhance the diversity of those celebrated and on display, and to raise the profile of under-represented groups within ocean sciences, not only to inspire the next generation of marine scientists, but also to retain those currently in the field. Here are a few key recommendations for making it happen.

1. Introduction of UK-based schemes for under-represented groups in marine science

The establishment of funded nationwide schemes that target under-represented groups in marine science, specifically sea-going science, would drive increased availability of opportunities through 'top-down' schemes, as well as peer-to-peer engagement. Schemes such as MPOWIR and STEMSEAS (a US initiative aimed at facilitating undergraduates from diverse backgrounds taking part in short marine expeditions) could act as templates for such ventures, by providing support and opportunities for sea-going experience and mentoring. However, such schemes don't support some of the earlier career stages, so need to be expanded to encompass all career levels. The point at which undergraduate, Masters and Ph.D students are recruited is critical, especially for people from under-represented groups who could otherwise miss out on opportunities. Scholarships or fellowships could be designed specifically to support these very-early-career researchers.

The Climate Linked Atlantic Sector Science (CLASS) programme already provides opportunities for early-career researchers from all backgrounds to take part in sea-going expeditions and learn new skill sets (see pp.4–6). However, salary and some other costs are not provided, and this could present a barrier to those who already face more hurdles in acquiring funding than their white male peers. Such programmes could be extended to encourage participation from women and other under-represented groups, and to build in specific skills, and be supported by ring-fenced funding (such as exists within the STEMSEAS programme). Waiting for equality to trickle up to marine science leadership roles will take too long, and more affirmative action at high levels is needed to stimulate diversity initiatives. Within the UK, there are schemes at Marine Scotland Science and the National Oceanography Centre to partner early-career researchers with senior staff, who could help them 'learn the ropes' and gain the experience they need to write their own research proposals and apply for cruises. Mentoring and networking schemes that bring together participants from academia, funding agencies and other stakeholders would be greatly beneficial and could go some way to help improve the diversity of successful grant holders.

2. Visibility of role models

One factor that has been shown to be greatly beneficial for widening participation is the visibility of role models from under-represented groups. We all need to tell more stories celebrating marine scientists, technicians and crew who have had achievements in the field of sea-going science, despite facing barriers, real and perceived, as a result of their backgrounds. However, greater improvements in this area can come from deliberate policies within individual groups and organisations, such as taking decisions to name awards, or rooms, or buildings after women or representatives of minorities. The Centre for Environment, Fisheries and Aquaculture Science (Cefas) and the Scottish Association for Marine Science (SAMS) both took steps in the right direction by naming a room and a teaching building after Rosa Lee and Sheina Marshall respectively. The majority of major awards in marine sciences are named after men, although a notable exception is the Challenger Society's biennial meeting poster prize, which is named after oceanographer Cath Allen.

Another new initiative, led by Rehemat Bhatia and the Micropalaeontological Society, is promoting under-represented groups through new awards, and through naming existing unnamed society awards after micropalaeontologists from under-represented groups. The AGU Earth and Planetary Surface Processes committee also recently (May 2020) announced the Marguerite T. Williams Award, named after the first Black person in the US to be awarded a geology Ph.D. Further deliberate policies could be introduced – and promoted via targeted and open advertising – to enhance diversity. For example, the Challenger Society has a goal to alternate the position of President between men and women. Conference organisers could promote visibility of under-represented groups – especially those in their earlier career stages – as session chairs and keynote speakers, using inclusive activities of the European Geosciences Union as exemplars.

Increasing the visibility of women and under-represented groups at sea is key: funding agencies, research organisations, charities and universities need to ensure diversity in the images on their websites, and in promotional or teaching materials. Care also needs to be taken to combat unconscious bias in terms of the written or spoken language used to describe science leads in these websites and documents. For example, cruise or programme websites should ensure that women and other under-represented groups are given prominent positions, and described using the same words and terminology as their male colleagues. Depiction of minority groups in marine science in the media needs to be improved in all spheres, from inclusion in news and documentary interviews to representation in fiction.

3. Better training for sea-going scientists

There are clear benefits in improving and broadening training for participants in sea-going science at all career levels – PSOs, scientists, technicians and crew. Barriers that hinder under-represented groups must be recognised in the first instance, in order to be broken down. Researchers and funders (especially those with senior oversight of cruise activities) need to be fully aware of challenges faced on board cruises, and build and implement necessary protocols and codes of conduct. Training for all participants in mental health, avoiding unconscious bias and bystander behaviour should be essential – rather than recommended – additions to pre-cruise preparation. This training, which is the responsibility of research institutes, funding agencies and universities, will help sea-going researchers understand how to manage the expectations of other participants and colleagues, and help improve the experience of everyone on board.

4. An inclusive environment on ships

Every expedition needs to have an inclusive environment that is comfortable for everyone, which can be achieved by the reasonable accommodation of requirements, in addition to suitable training in diversity issues. Provision of health and safety equipment that reflects the range of people on board should be standard. Although there are financial and logistical implications, shorter expeditions (e.g. 2 x three weeks rather than six weeks) and provision of additional expenses (e.g. for extra child-care provisions) could facilitate involvement by those with caring responsibilities which, for a range of socioeconomic reasons, disproportionately includes under-represented groups. A well advertised, easy-to-access system for supporting additional caring costs that arise when people are away at sea would make a big difference. Cruises could also be made more inclusive through schemes that allow more flexible approaches, such as the schemes to split tasks between a PSO and Co-PSO, currently being implemented by Marine Scotland Science.

The way forward

We urgently need to diversify our discipline through proactive mentorship, and by promoting and implementing positive change. Leading UK organisations, such as the Challenger Society for Marine Science, should show the way by implementing actions that will make a genuine difference, converting our ideas into a practical reality. The following proposals can be summarised as a call for a strong vision for equality and diversity in marine science, led by the membership of the Challenger Society. In developing each of these ideas we need to consider which initiatives that have helped women might also be effective in supporting other under-represented groups, and for which groups, and under what circumstances, the approaches might need to be different.

We should:

- Lead initiatives (websites, award-naming, guest seminars etc.) to increase visibility of past and present under-represented groups in sea-going marine science, for example: women, people identifying as Black, Asian or as from another ethnic minority, people identifying as LGBTQIA+, and people identifying as having a disability.
- Champion and ensure diversity in the Challenger Society (e.g. in the composition of Council, and with respect to those who receive awards) as well as in UK oceanography in general (e.g. in academic appointments, acceptance of Ph.D candidates, and during promotion processes).
- Fund and promote bursaries for under-represented groups to go to sea, particularly in leadership positions.
- Ensure that articles in Challenger Society publications are authored by – and feature – a diverse range of individuals.
- Lobby to encourage the community to take up opportunities to appoint a Co-PSO for every cruise, where either PSO or Co-PSO is an early or mid-career researcher, and to monitor and record the diversity of people in those positions, and their career progression in the longer term. This procedure has recently started on Marine Scotland Science cruises with very positive feedback.
- Lobby for NERC to provide resources for extra childcare and other additional costs incurred by sea-going staff.
- Lobby for the adequate provision of PPE for sea-going women.
- Lobby for the collection and analysis of diversity and inclusivity data for all sea-going scientists, technicians and crew.
- Refocus the Society's Diversity in Marine Science (DiMS) initiative to form a Special Interest Group that includes scientists at all career levels. This group could formulate an effective training programme suitable for all, identify existing and new resources and formalise the Society's commitment to accelerating progress towards equity.
- Create a Society award to recognise those working towards improving diversity in UK marine science.

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Further Reading overleaf ➢

Heading in the right direction! A happy group of researchers in coastal waters off Greenland in 2018 – the team is predominantly female and has representatives from a wide variety of backgrounds and four different countries. (Photo: Ellen Pedersen)

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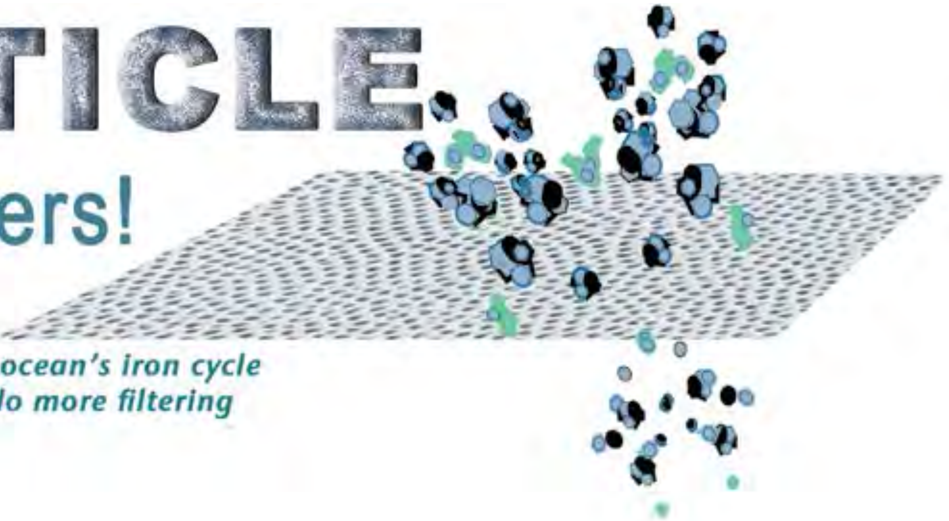
PARTICLE Size Matters!



To really understand the ocean's iron cycle biogeochemists need to do more filtering

Koko Kunde

'Give me half a tanker of iron, and I will give you an ice age.' Many of us have come across John Martin's proposal, made in the late 1980s, to seed the ocean with iron to stimulate the growth of phytoplankton where the natural iron supply is insufficient. This would draw down CO_2 from the atmosphere, triggering the cooling of our planet Earth. With the global climate crisis in full swing, natural iron fertilisation is a hot topic, and research into the oceanic iron cycle is accelerating. Iron biogeochemistry has come a long way in the last thirty years, but major unknowns persist regarding the bioavailability, supply and removal of iron, and its internal cycling, which together shape its distribution in the ocean. One of the main advances is the recognition that it is the form the iron is in, rather than its concentration, that is important for addressing these questions. Recent research from the North Atlantic has shown that of all the iron in the water column, 'colloidal iron' – a variety of iron-bearing compounds in the size range 0.02 – 0.2 μm – is key to the iron distribution at large. I will explore what makes this colloidal iron so special, and why simply emptying a large amount of iron into the ocean will not achieve the desired effect.

Iron's irony

From a marine biogeochemist's perspective there are a few essential nutrients that regulate the growth of phytoplankton, those tiny photosynthetic organisms which use light energy to make carbohydrates from CO_2 and water. Since CO_2 is a powerful greenhouse gas, phytoplankton growth may impact our climate by altering the balance of carbon stored between our ocean and the atmosphere. Three of the nutrients essential for this process, and other vital cellular functions, are nitrogen and phosphorus (key building blocks of large molecular cell structures like wall membranes, and of smaller biomolecules like proteins or DNA) and iron. Individual iron atoms fulfil roles of structural or functional centres of certain proteins that are involved in photosynthesis or that help phytoplankton acquire nitrogen and phosphorus. Of the three nutrients, iron behaves in the most complicated and seemingly paradoxical way: despite it being necessary for life-maintaining cellular processes, it is a 'trace metal', present at vanishingly low concentrations in the ocean. While nitrogen and phosphorus are typically present at micromolar concentrations (equivalent to 1 ml of tonic in 1000 litres of gin), iron is at least a thousand times less abundant, so phytoplankton often struggle to obtain sufficient amounts. When they are unsuccessful, their growth is limited by the availability of iron, i.e. the rate at which iron is recycled or added to the surface ocean. So, what controls the delivery of iron to the ocean?

The primary source of iron to the sunlit surface ocean, where phytoplankton flourish, is iron-rich crustal material from the continents. In the case of the North Atlantic Ocean, a large proportion of this takes the form of Saharan desert dust that is picked up by wind, transported seaward and deposited far offshore. Dust deposition occurs throughout large regions of the tropical and subtropical Atlantic, all the way to the American continents, subject to strong seasonality in wind and precipitation patterns. In other oceanic basins or nearer to the continental margins, iron-rich soil material transported by rivers, glaciers or icebergs, or release of iron from marine sediments, can represent more significant sources. More recently, the role of upwelled, hydrothermally derived iron has also been under investigation.

In the Southern Ocean, iron sources are too far away or too weak to meet the iron demands of biological activity in the surface ocean. But even in the North Atlantic with its enormous supply of Saharan dust, phytoplankton growth can become limited by low iron availability. How is this possible? Various factors come into play here, such as variability in dust supply in time and space, and small mismatches in iron supply and its demand by the photosynthetic community. Most importantly, however: Not all iron is the same. Instead, the natural oceanic iron pool consists of a whole continuum of different forms of iron.

The iron continuum

It would be simply false, and fatal for our understanding, to imagine oceanic iron as free floating iron atoms in the water column. While a minute part of the iron pool (< 1%) does exist in this form, modern seawater conditions (temperature, pH, O_2 concentration) and biological processes push most, though not all, individual iron atoms into molecular structures. These different iron 'species' are distinguished on the basis of their physical characteristics (e.g. size) and chemical characteristics (e.g. how weakly or strongly the iron is bound, or whether a species is organic or inorganic; Figure 1). Such distinctions are key because they let us investigate differences in species' chemical reactivities (which determine their residence times) and the bioavailability of the iron within them (the ease with which organisms can access the iron). While only a handful of these species are identified and characterised in detail, some tools exist to distinguish overarching classes of iron. One of these is by means of filtration, targeting a physical characteristic, namely size.

When in the 1920s pioneers of trace metal biogeochemistry set out to measure iron distributions in the ocean, concentrations were measured in unfiltered samples, determining the 'total iron' pool. With greater understanding of the iron cycle and the recognition that distinctions by size may be important, a crucial first filtration step was introduced in the 1980s. Using a membrane with a pore size of 0.2 μm (occasionally 0.45 μm), the total iron pool was now separated into what was termed 'dissolved iron' (<0.2 μm) and 'particulate iron' (>0.2 μm). After another twenty years of insights, from the early 2000s researchers have used ultra-filtration, which further separates the dissolved pool into what are termed 'colloidal iron' (0.02 μm to 0.2 μm) and 'soluble iron' (<0.02 μm). The current view is therefore that – from a size-partitioned perspective – total iron is the sum of particulate iron, colloidal iron and soluble iron.

So from a physical (filtration-based) perspective:

In the 1920s we measured **total iron**

Since the 1980s,
total iron = particulate iron + dissolved iron

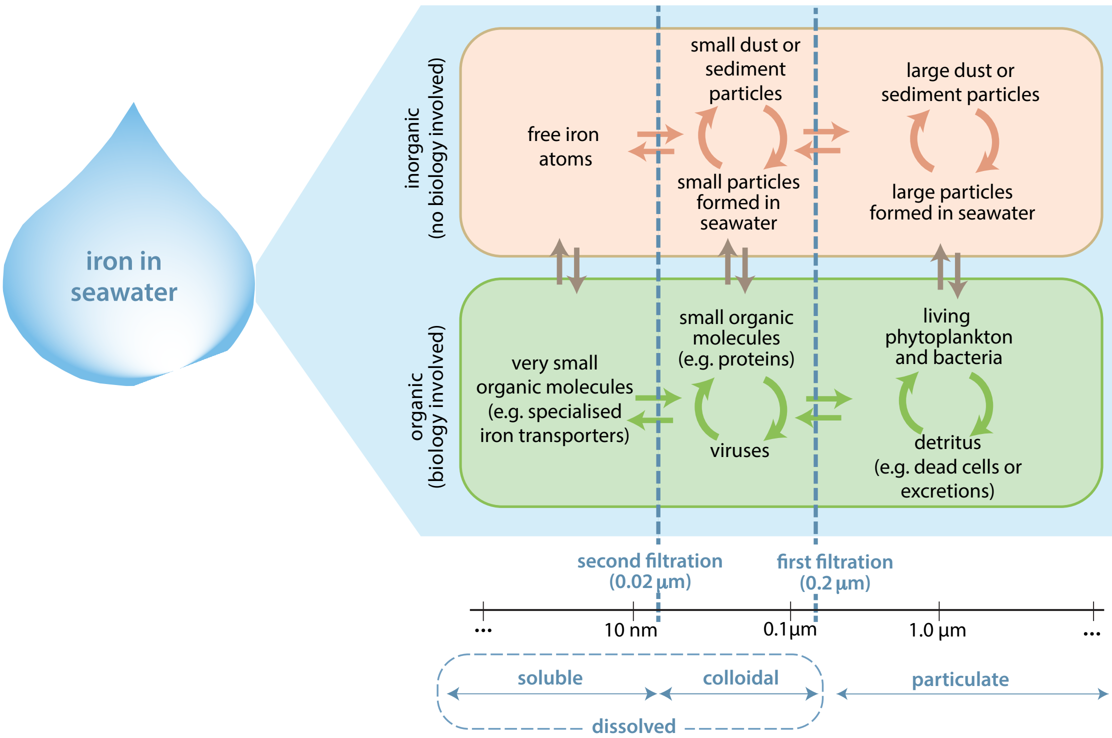
Since the 2000s,
total iron = particulate iron + colloidal iron + soluble iron

Box 1

Although the size cut-offs are operationally defined, and naming conventions are arguable, significant progress has been made over the last century of iron biogeochemical research. This has been rooted in the traditional understanding that the smaller dissolved iron species are more readily bioavailable than the larger particulate iron species, the latter being considered to consist largely of iron trapped in mineral phases. This was a crucial first distinction for investigating oceanic iron, but it soon became clear that even within 'dissolved' or 'particulate' iron there are a range of different physicochemical characteristics (Figure 1).

Figure 1 *Iron in seawater can broadly be categorised into inorganic (top) and organic (bottom) as well as into different size fractions: soluble, colloidal and particulate (along the x-axis). The filtrations used to distinguish between the size fractions are indicated by the vertical dashed lines. By a plethora of processes, iron can cycle between the different compartments (horizontal and vertical arrows), and also within compartments (curved arrows).*

Iron in seawater is an ever-changing mixture of different physical and chemical forms



Particulate iron (> 0.2 µm)

As you might expect, some particulate iron is structurally locked into 'chunky' mineral particles, but other kinds of particles (Figure 1) contain iron which behaves very differently. For example, iron is largely insoluble under modern seawater conditions, so that free iron atoms rapidly form (oxy)hydroxide complexes by binding to OH^- or O^{2-} groups in the surrounding seawater. These complexes aggregate over time until they reach a size that means they can be separated by a filter. In comparison with a dust particle which is more crystalline, such a particle is more easily degradable, especially during its freshly formed, amorphous stage. Yet other species of particulate iron are not inorganic at all, for example if iron is present in the cell of an organism (green area in Figure 1). In this case, iron is readily released back into the seawater when the organic matter decomposes. Just these few examples of types of particulate iron demonstrate how levels of reactivity within one size fraction can be extremely variable.

Dissolved iron (< 0.2 µm)

Long gone is the idea that dissolved iron in the ocean is a uniformly highly bioavailable pool.

Soluble iron (< 0.02 µm) The current, tentative working hypothesis posits that it is the soluble iron that represents the truly bioavailable fraction, because it comprises the miniscule pool of free, unbound iron atoms and a particular iron species in which iron is bound to very small organic molecules known as siderophores. Siderophores have a strong affinity for iron atoms and are actively synthesised and excreted by certain organisms to capture limited iron resources and prevent them being transformed into less accessible iron species.

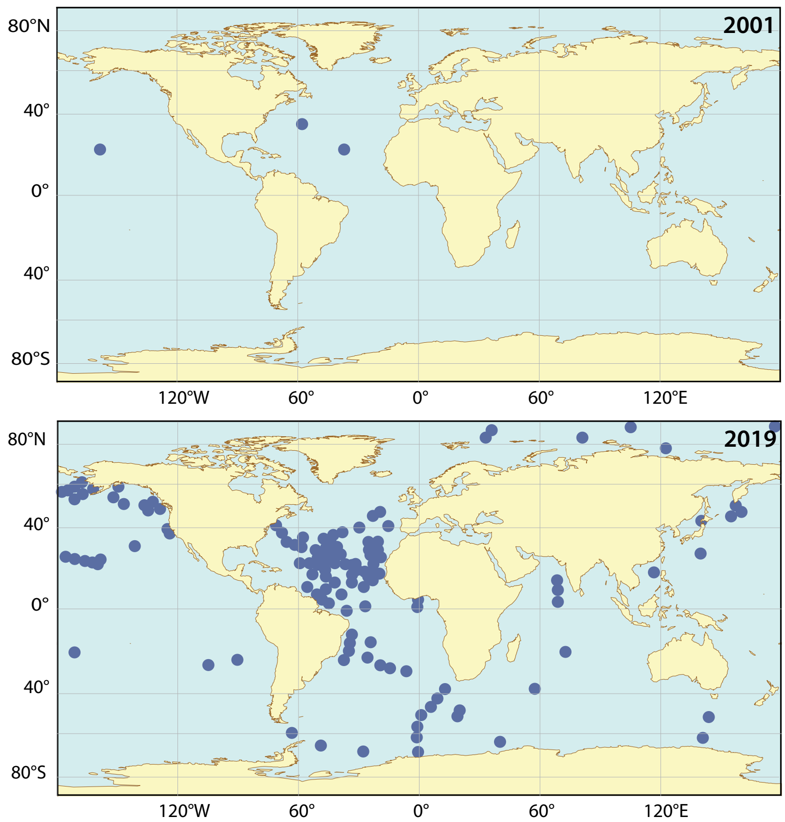
Colloidal iron (0.02 – 0.2 µm) In contrast, colloidal iron is generally understood to be less bioavailable and at best a back-up option for phytoplankton, as getting access to the iron in colloidal species may be energetically and metabolically costly. One possible reason for this is that colloidal iron can take the form of mineral phases that are not dense enough to be affected by gravitational settling. Imagine them as tiny versions of inorganic particulate iron, which – as discussed above – structurally lock in iron atoms. Alternatively, iron may be bound to small biological compounds in the water column that fall within the colloidal size range – e.g. viruses or extracellular proteins – and is thus protected from chemical and biological processing. It is important to note that the approach to bioavailability of soluble versus colloidal iron presented here is fairly crude and this topic is an active field of research. The specifics depend, amongst other factors, on the type of organism in need of iron.

Having introduced a variety of physicochemical species within the total iron pool, it is critical to recognise that this is by no means a static continuum. Instead, the different species interact with each other or with other third-party species in the ocean, continuously cycling individual iron atoms between them. For example, what is at one moment a free-floating iron atom – classified as 'soluble' by our filtration method – may be incorporated into a phytoplankton cell the next – and hence it would have shifted into the particulate class. Or, iron that is bound to the surface of a dust particle could be released, allowing it to float freely in the ocean, and then rapidly re-adsorbed by a second, perhaps smaller, dust particle, so passing through a whole cycle from the particulate to the soluble, and back to the particulate (or perhaps colloidal) class. For phytoplankton in need of bioavailable iron, the system resembles a game of Tetris but with the pieces constantly reshaping.

Exploration of the oceanic iron continuum is picking up. In 2001 there were only three sites for which profiles of soluble and colloidal iron could be shown separately, but now there are at least a few measurements in every ocean basin (Figure 2). Nevertheless, data are still scarce, not least because the extra filtration step is time-consuming and adds a high risk of sample contamination to the already contamination-prone traditional iron sampling. To minimise this risk, at sea and on land, iron biogeochemists work in designated trace-metal laboratories where clean air is continuously streaming in and where white plastic overalls, hair nets, rubber shoes, and a double layer

Between 2001 and 2019 measurements distinguishing colloidal iron increased by more than 30-fold

__Figure 2__ World map of oceanic iron measurements where both filtration steps were applied to separate the dissolved iron pool into a soluble and a colloidal fraction, in 2001 __(top)__ and 2019 __(bottom)__.



Sampling, filtering and measuring iron come with a high risk of contamination

Figure 3 ***Left*** *A typical sampling set-up at sea, inside the trace metal clean lab. The sampling team consisted of the author, Neil Wyatt and David González-Santana (left to right).* ***Right*** *A second clean area onboard, where iron measurements were conducted with a portable flow injection system. (Photos: Right: Maeve Lohan; Left: the author)*

of gloves are worn to isolate potential metal contaminants from the samples (Figure 3). Since the results from this extra filtration step are promising, it is probably worth the hassle and the fashion look is not so bad either!

But what are these results? With all the different characteristics between and within the subclasses of dissolved iron, it is unsurprising that soluble and colloidal iron exhibit distinct distributions in the ocean. Thus, they contribute differently to the dissolved iron profile, the shape of which is still the most common way of studying the iron cycle.

The colloidal hourglass

There is no point in keeping the secret from you any longer: colloidal iron and soluble iron behave differently and it is colloidal iron that most affects the dissolved iron distribution. Whenever we detect an increase in the dissolved iron concentration (indicating a source), it is predominantly the colloidal iron concentration, not the soluble iron concentration, that has increased. Similarly, whenever we detect a decrease in the dissolved iron concentration (indicating a sink), it is the colloidal iron concentration that has decreased. Since the soluble fraction is much less variable, a useful metric for the strength of such sources and sinks is the relative contribution of the colloidal iron concentration to the dissolved iron concentration (Box 2).

relative colloidal contribution (%)

$$= \frac{\text{colloidal iron}}{\text{dissolved iron}} \times 100$$

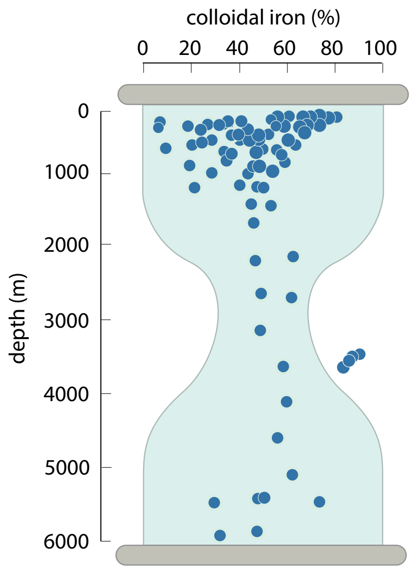
where:

dissolved iron = colloidal iron + soluble iron

Box 2

Figure 4 *The distribution with depth of the contribution to the dissolved iron pool of colloidal iron, expressed as a percentage, forms the shape of an hourglass. The data come from iron profiles in the subtropical Atlantic between 60° W and 30°W; the four data points outside the hourglass are from a hydrothermal source. (Data from Kunde* et al. *2019)*

In the upper ocean and near the sea bed dynamic processes result in a wide range in the % of colloidal iron, while in the less dynamic ocean interior colloidal iron is at around 50%



The further the ratio of colloidal iron to total dissolved iron is from 50%, the stronger the sink or source of dissolved iron. In the top and bottom sections of the water column the relative contributions are far from equal, whereas in between they are close to 50 : 50. Taken together, this results in the hourglass shape (Figure 4).

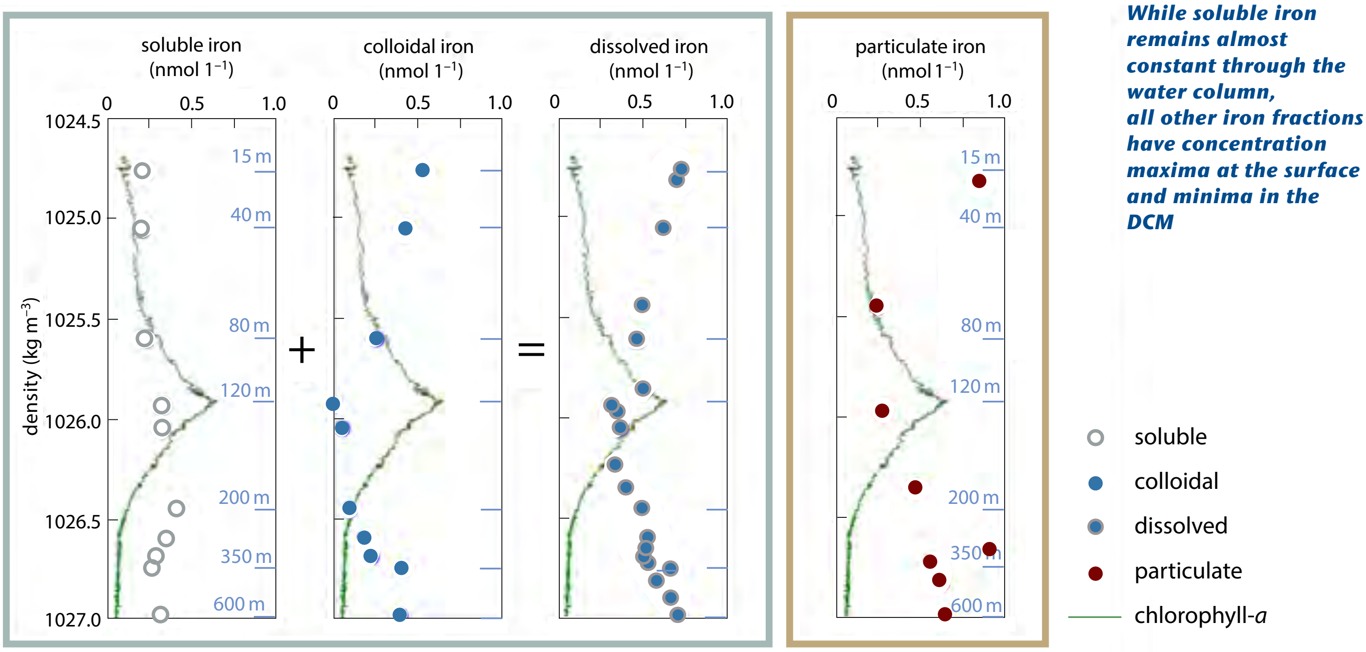
What are the processes behind this distinct hourglass shape? Let us take a journey down through the water column and see how colloidal and soluble iron behave differently at different depths (Figure 5). Note that the focus here is on the North Atlantic water column, which in terms of iron cycling is arguably the best resolved oceanic region, but also carries the bias of very high dust deposition. At the ocean's surface, therefore, dust is the major external source of iron and driver of the system. The arrival of dust goes hand in hand with increased concentrations of colloidal iron near the surface (second plot in Figure 5), while the effect on soluble iron is less (first plot in Figure 5). This means that the relative contribution of colloidal iron to the dissolved iron pool increases as more dust is deposited (up to 90%). The strong colloidal signature of dust is due to two processes that start with iron in the particulate class and end up with iron in the colloidal class. The first process is the erosion of dust particles into smaller, colloidal-sized fragments during atmospheric transport or after deposition in the ocean. The second process is the release from dust particles of free iron atoms (in the soluble size range) followed by their rapid transformation into more stable nano-sized oxyhydroxide minerals or by their capture by small organic molecules. Both of these fall into the colloidal size range.

Continuing on our journey down through the water column, we see that the colloidal maximum does not persist, and that colloidal iron starts to disappear. By around 120 m depth (cf. Figure 5) it has reached a concentration minimum and the relative contribution of colloidal to dissolved iron has also diminished, sometimes down to 0%. The green line in Figure 5 is a rough measure of phytoplankton biomass and it seems that the colloidal minimum is associated with a biomass maximum – the deep chlorophyll maximum (DCM). At first sight, there seems to be a simple explanation: phytoplankton take up colloidal iron. But don't phytoplankton prefer *soluble* iron (p.33)? Either we are getting things wrong here and colloidal iron is more bioavailable than we think, or removal of colloidal iron is driven by another process. If iron were being taken up by phytoplankton cells, we would expect an increase in particulate iron, but instead there is a *minimum* of particulate iron alongside the minimum of colloidal iron (second and fourth plots in Figure 5). This minimum arises because a lot of colloidal iron becomes loosely attached to the surfaces of sinking particles (mostly dust in our North Atlantic case, but also dead cells and faecal pellets), and colloids and particles together sink to deeper layers – an example of a complex process known as scavenging (see Box on p.36) As a result, between the surface and the DCM, a very small depth range in oceanographic terms, we have moved from a colloidal iron maximum to a colloidal iron minimum. This demonstrates the highly dynamic nature of the iron cycle in the upper ocean.

As we go even deeper, to around 1500 m, it is dark and the phytoplankton population has disappeared. Now it is time for heterotrophic bacteria to shine, as unlike phytoplankton they are not light-dependent. They obtain carbohydrates by breaking down organic debris, and in doing so, replenish the dissolved iron pool. This process can be aided by siderophores, which draw some of the iron being released into the soluble size class. At the same time, interactions betweeen sinking dust and surrounding seawater release some iron from these inorganic particles into the collidal class (as in surface waters); meanwhile, iron that has been released from dust or organic matter is being re-scavenged back into the particulate class. These competing processes determine how much colloidal iron is eventually present at these intermediate depths.

By now, many dynamic processes have acted on and shaped the dissolved iron distribution, but we are just a quarter of the way down into the full water column. However, from here on downwards, the processes that affect how iron is partitioned between colloidal and soluble forms become rather uniform. At these depths we are too distant from any external sinks or sources for them to have any direct effect, and biological activity

Figure 5 *Representative upper ocean profiles (down to approximately 600 m) of soluble, colloidal, dissolved and particulate iron concentrations against density from the central North Atlantic (23° N, 40° W) during summer 2017. Approximate corresponding depths are shown in blue on the right-hand axes. The green line shows the chlorophyll-*a *concentration (in arbitrary units), a rough measure of biomass, and its peak is the deep chlorophyll-*a *maximum (DCM). (Data from Kunde* et al., *2019)*



While soluble iron remains almost constant through the water column, all other iron fractions have concentration maxima at the surface and minima in the DCM

What is scavenging?

In virtually all iron-related scientific publications, you will find a phrase like 'removal due to scavenging'. Scavenging is an exceptionally important process in the oceanic iron cycle, especially with regards to colloidal iron, but what does it actually involve?

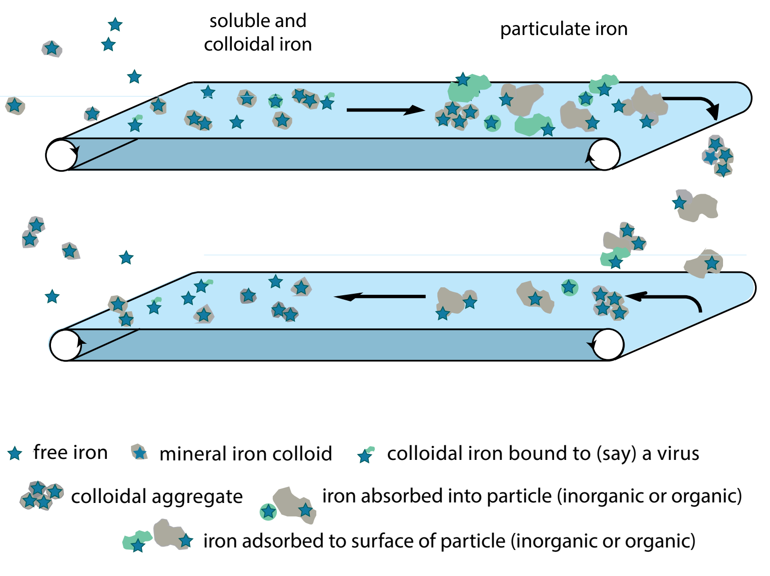
Imagine a free iron atom in the ocean. Under modern seawater conditions (temperature, pH and so on), it is unstable and seeks to rapidly bind with components of the surrounding seawater. The charged surfaces of inorganic (e.g. dust) and organic particles (e.g. a phytoplankton cell) make them ideal binding partners, and they compete for iron. Over time, surface-adsorbed iron can become internalised – either by active uptake into a cell or by incorporation into the mineral phase. While biological uptake is not typically considered a scavenging mechanism, the preceding adsorption steps and absorption into the mineral matrix of inorganic particles are. These processes gradually move iron from the dissolved (left-hand side of the upper 'conveyor' belt) to the particulate phase (right-hand side).

As discussed earlier, much of the iron in seawater is present in colloids, for example as fragments of mineral phases, oxyhydroxides formed *in situ*, or bound to colloidal-sized organic matter. These bump into each other and colloid–colloid interactions lead to the formation of colloidal aggregates that can be separated out by filtration. Hence, colloidal aggregation is the other process by which iron gradually moves along the conveyor belt from the dissolved to the particulate phase.

Therefore, when we speak about dissolved iron being removed from the water column by scavenging, we are really referring to the combined effect of a variety of processes – adsorption, absorption, and colloidal aggregation – which transfer iron from the dissolved pool to the particulate pool.

These processes are generally reversible, so transfer can occur from the particulate pool back into the dissolved pool (lower conveyor belt). When organic matter is degraded, dust dissolves, surface-bound iron is desorbed or particle clusters disaggregate, seawater is replenished with dissolved iron, and the processes on the top conveyor can start again.

As particle-bound iron is removed by gravitational settling through the water column, rates of scavenging and replenishment compete to set the residence time of free iron at a given depth. In the future, we are hoping to determine these rates for different environments.



Scavenging (upper conveyor belt) results in soluble and colloidal iron being converted to particulate iron, but the reverse process (lower conveyor belt) also occurs. The distinctive depth profiles of soluble, colloidal, dissolved and particulate iron that we observe (e.g. Figure 5) are the net result. (Adapted from Honeyman and Santschi, 1989)

reflects a more stable biogeochemical habitat. In fact, at these depths lateral transport of water masses is probably a more influential driver of the relative abundances of colloidal and soluble iron. Within water masses of the ocean interior, the iron cycle is subject predominantly to internal interactions, meaning continuous transformations from soluble to colloidal and back again until a steady-state equilibrium is reached. For much of the ocean interior, dissolved iron is 50% soluble and 50% colloidal, corresponding to the tight neck of the hourglass in Figure 4.

But the picture can change dramatically as we approach the sea floor. When fast deep-sea currents interact with sea-bed topography, benthic storms can be generated and sediment particles can be ejected up into the water column. The strength of these storms as well as the amount and mineralogy of the suspended material probably control whether the sea floor at any given location acts as a source of iron through sediment dissolution, or a sink through scavenging onto mineral surfaces. As you may suspect by now, these mechanisms proceed via the intermediate colloidal stage, and the competition between release from, and scavenging by, sea-floor sediment can drive the relative contribution of colloidal iron away from the 50 : 50 equilibrium in either direction, to form the wide bottom of the hourglass.

Of course, there is always an exception to the rule and in the framework of the colloidal iron hourglass, the exception is iron from hydrothermal venting (see the four data points outside the hourglass in Figure 4). During our sampling campaign, we crossed the hydrothermally active Mid-Atlantic Ridge, a huge source of iron to the abyssal ocean. To put it into perspective, on a global scale hydrothermal venting dominates over dust deposition in setting the total water-column iron inventory. However, it is up for debate how far this iron can travel through the ocean, and whether it could ever get into the sunlit ocean to serve the CO_2-fixing phytoplankton. While evidence is steadily accumulating, we need to ask what protects some of the hydrothermal iron against particle formation close to the vent sites and so prevents it from sinking back down to the sea floor. Again, the answer is colloids – or at least, that is one of the answers. Our iron samples from the water column just above a hydrothermal vent called 'Snakepit' are made up of almost 100% colloidal iron, and almost no soluble iron (Figure 4). These hydrothermally derived colloids are suspected to be either inorganic nano-particles, in the form of iron sulphides or iron oxyhydroxides, or iron bound to small organic molecules. Either way, they are so stable that their signature persists over large distances from the hydrothermal source (~ 100 to 1000 km).

The future is filtered

Having identified the differing behaviour of the two fractions of the dissolved iron pool – soluble and colloidal iron – we will now be able to better quantify the processes that supply and remove iron. Needless to say, this knowledge is of paramount importance as the fine balance between iron supply and removal impacts on the success of phytoplankton – not only in the North Atlantic but on a global scale: biological CO_2-fixation and its effect on climate are intimately linked to the oceanic iron cycle. This is also why global biogeochemical models which aim to predict the future of the iron cycle under global change will be improved by inclusion of field observations of size-partitioned iron distributions. Until not long ago, global biogeochemical models used only one combined term, i.e. the concentration of the dissolved pool, but it is now recognised that representing soluble and colloidal iron separately may lead to improved representation of, and less uncertainty in, iron distributions in the ocean, which are important for predictions of future climate.

Like a conduit, colloidal iron sits at the intersection of the bioavailable soluble fraction, which serves phytoplankton growth, and the not-so-bioavailable particulate fraction, which replenishes the dissolved iron inventory in the ocean. We have seen that iron cycles rapidly through different versions of itself and thereby changes its reactivity and bioavailability continuously, producing an intricate and highly heterogeneous continuum. This complexity, which we are only beginning to comprehend, is one of the reasons that John Martin's idea might not be as straightforward as initially thought. Regardless, studying the different distributions of colloidal and soluble iron promises to further our understanding of the oceanic iron cycle. Some of the important questions to target with future research are: How quickly does iron transform from one size fraction to another? How bioavailable are different iron species, and how do different organisms access them? What is the exact composition of colloidal iron? And what secrets would be revealed by size fractionation of other biologically important trace metals, such as zinc, cobalt and manganese? Ultimately, the most intriguing question of all is: What will we discover if we continue to filter into even more size fractions?

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A 'cranky little vessel': The story of HM steam vessel Lightning

Part 6: A digression into Portuguese politics and geology

Tony Rice

In the previous episode of the *Lightning* saga (*Ocean Challenge* Vol.23(2)) we left the vessel in early 1828, now carrying the proud title HMS and under the command of her first commissioned officer, Lieutenant George Evans, involved in a bit of a fracas concerning whose orders took precedence in the strict hierarchy of the late Georgian Navy. In late January Evans was told by his boss, the then Lord High Admiral HRH the Duke of Clarence, that important dispatches had arrived from Portugal and that a naval squadron to go to Lisbon was being assembled at Plymouth. That Portugal was flavour of the month, so to speak, would have been no surprise to Evans because, a month earlier, the *Lightning* had carried a servant of a senior Portuguese royal, Dom Miguel de Bragança, from Calais to Deptford while Miguel himself had travelled in the more luxurious Royal Yacht. Now the *Lightning* was to help man the Lisbon squadron by transporting men from HMS *Ramilles*, anchored off the Kent coast, down to Plymouth, where he would receive further orders. Having delivered the men, Evans insisted on staying to help tow the Lisbon squadron out to sea against contrary winds, and against the direct orders of the C in C Plymouth to return to Portsmouth immediately. This in turn led to a shortfall of fuel and a row with the Plymouth Dockyard Commissioner about the supply of coal. Eventually, Evans' behaviour was rewarded with promotion while his Plymouth adversaries were both replaced.

So the question is, why was Evans so certain that the departure of the Lisbon squadron was so urgent? The short answer is that Evans knew that both his boss, the Lord High Admiral and, perhaps even more significantly, Britain's brand new Prime Minister the Duke of Wellington, were hell bent on getting Dom Miguel back to Lisbon where, they hoped, he could be controlled by Britain. The Lisbon squadron was a key part of this strategy, but to understand why, we have to delve a little into Portuguese history and, tangentially, into the influence of earthquakes on the ocean. But it will take two of these episodes to tell the story adequately; this is the first.

The world's longest continuous alliance, that between England and Portugal ratified at the Treaty of Windsor in 1386, has been of considerable benefit to both countries over the centuries, but the balance has almost always been in favour of England. This was particularly so after the signing of the Methuen Treaties of 1703 under which Portugal had a guaranteed British market for its wine on preferential terms compared with France and Spain, while Britain was able to export textiles and clothing to Portugal. But the wine trade was never sufficient to balance the rising costs of Portuguese imports from Britain, so the deficit was paid for from the exploitation of gold from the Portuguese colony in Brazil, which had begun in the 1690s. In the first half of the 18th century 25 million pounds' worth of bullion was shipped to Britain, much of it through a rich and powerful English merchant class, particularly in Lisbon and Oporto.

During the same period, Brazilian gold also financed a golden age for Portugal, or at least for its ruling groups, the royal family, the Braganças, the nobility and the Church. The result was a great flowering of Portuguese art and culture unseen since the early 16th century. But the wealth and power reached only the few, for the vast majority of the Portuguese population lived as peasants in almost feudal conditions.

Then, as the bonanza was starting to dry up in mid century, Portugal was hit by a most appalling natural disaster, the Lisbon earthquake of All Saints Day, 1 November 1755, which totally changed Portuguese society.

The earthquake had its epicentre well out at sea, to the south-west of Lisbon (see map on p.40), where it disturbed a huge quantity of mud from the sea floor on the upper part of the continental slope. The resulting millions of tonnes of mud suspended in water then flowed down the continental slope into the deep ocean. Travelling at tens of kilometres an hour, this turbidity current fanned out across the abyssal plain at depths between 4000 and 5000 m, gradually slowing down and dropping its sediment load as a thick layer of mud which is still recognisable in cores taken from the sea bed in the region today.

All this, of course, was completely unknown to the people of Portugal, who had much more pressing matters to deal with. Lisbon itself was hit by a series of shocks which killed over thirty thousand people and virtually destroyed the city. Fortunately for Portugal, the King's Chief Minister (appointed by José I when he had acceded to the throne in 1750), though ruthless and self-serving, was brilliant and innovative. Before his appointment, the

Figure 1 *Contemporary hand-coloured copper engraving of the devastation caused by the Lisbon earthquake on the shipping in the Tagus and on the city beyond. Note the 16th century Belém Tower (to the left of the sinking ship), one of the few buildings in central Lisbon to survive the earthquake (see also Figure 3). (Wikimedia Commons)*

Marquis of Pombal (Figure 2) had served a long diplomatic apprenticeship in Vienna and London and had strong views on how Portuguese society needed to change. The more or less clean slate provided by the earthquake gave him the ideal opportunity to instigate his ideas.

After dealing with the immediate problem of the thousands of dead and injured, and the lawlessness and looting. Pombal's first and most pressing task was rebuilding Lisbon, ultimately resulting in the city we see today. When Pombal fell from power on the death of King José in 1777 the reconstruction was still in its early stages and large numbers of peasants were still living in squalid shanties distributed around the city. But he had made much greater, though less tangible, changes to Portuguese society. Some of his reforms, such as abolishing slavery within Portugal (though not in the colonies) and freeing Jews from Church persecution, look quite liberal at a distance, but were rather more to do with economic pragmatism than with humanity. Other policies were much more obviously based on his despotism, for Pombal was determined to reduce the power of the nobility, the Church – and Britain. He attacked all three targets ruthlessly and before his departure from office he had fragmented the nobility, greatly limited the power of the Church, and had severely reduced the British domination of Portuguese trade, encouraging home-grown industrialisation, particularly in textiles, and bringing the wine trade under Portuguese control, especially his own!

Many of these 'reforms' had been achieved with merciless determination and often appalling violence, so that by the time José died, Pombal had many enemies, not least the very religious Queen Maria I who succeeded her father in 1777. There was no place for Pombal in the new regime and he fell from grace, as did many of his ideas. Nevertheless, although the Church and the aristocracy regained some of their lost powers under the devout Maria, the final two decades of the 18th century in Portugal were characterised by continuity of what Pombal had started so that, by the end of the century, the indigenous trading class had grown to some 80 000. However, despite Pombal's wishes, the British influence was still strong, particularly in milking the increasingly lucrative Brazilian empire, a situation not unnoticed by Napoleon Bonaparte!

When Napoleon's army marched into Portugal from Spain in 1807 the royal family and many members of the court were evacuated by the British navy and taken to Brazil, where they were to remain for fourteen years. Moves for Brazilian separation from Portugal had already begun, partly inspired by the North American independence movement, and were strengthened by the flight of the court, particularly when, in 1810, the old Methuen Treaty was superseded by a new Anglo-Portuguese Treaty giving British traders direct access to Brazil. Brazilian independence eventually came in 1822, the year before the *Lightning* was launched.

Figure 2 *Sebastião José de Carvalho e Melo, 1st Marquis of Pombal (1699–1782) (Painter unknown; Wikimedia Commons)*

In the meantime, back in Portugal, the so-called Peninsula Wars included a series of attempts by Napoleon to take possession of the country which were repulsed by British forces eventually supported by Portuguese conscripts. The French were finally driven out of Portugal in 1811 by a force commanded by Sir Arthur Wellesley, the future Duke of Wellington, and a British military authority was established over the seriously impoverished country. During the next ten years, opposition to the British occupation became linked to a growing liberal revolutionary movement wishing, amongst other things, to restore the monarchy along with a parliamentary government and re-establish the Brazillian trade. The revolution began in 1820 and was to last in one form or another for more than 30 years; essentially the conflict was between two polarised factions – the revolutionary radical one proposing a constitutional monarchy with rather liberal values owing a good deal to the principles behind the American and French revolutions, and the opposite, absolutist faction backed by Britain, essentially wishing to restrict power to the monarchy and a small elite. The controversy even split the royal family and became extremely messy.

Figure 3 *The Belém Tower on the northern bank of the River Tagus, instigated by King João II to defend Lisbon from enemy ships, and completed in 1514. Following the Lisbon earthquake, the Marquis of Pombal used the Tower to control the movement of ships along the Tagus and so prevent looters carrying away goods from the ruined city.*

(Photo: Alvesgaspar / CC BY-SA; https://creativecommons.org/licenses/by-sa/3.0)

Maria I had died in exile in Brazil in1816, to be succeeded by her son, João VI. In 1821 João VI returned to Lisbon, leaving the affairs of Brazil to his son, Pedro, who became Emperor as Pedro I when Brazil became independent in 1822. But when João died in 1826 Pedro pushed the claim of his own 7 year-old daughter Maria to the Portuguese throne, supported by the radicals, while Maria's uncle, Pedro's younger brother Miguel (our very own Infante Dom Miguel; Figure 4), and Maria's grandmother, João's widow the Dowager Queen Carlota, claimed the throne adopting the absolutist stance. But an already complicated situation was to get even more so, as we will discover in the next episode.

Figure 4
Dom Miguel da Bragança, painted by Johann Ender in 1827 when Miguel was in exile in Vienna, shortly before his visit to England.
(Wikimedia Commons)

Further reading

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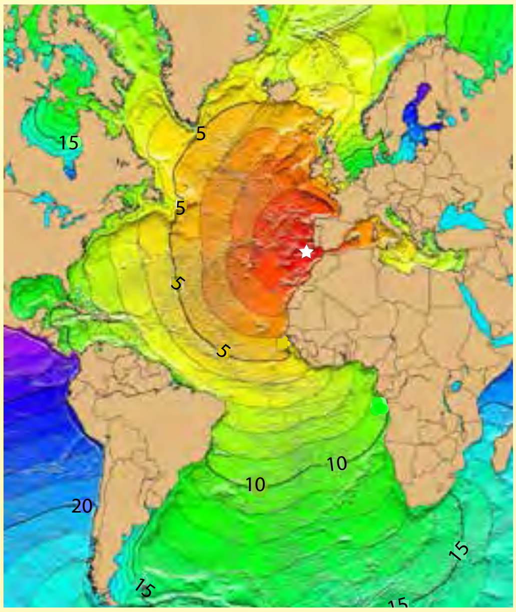
Earthquakes and tsunamis: the Lisbon earthquake and Britain

Earthquakes are caused when the Earth's crust suddenly ruptures and the opposing sides move relative to one another along a fault. Part of the energy released radiates out from the focus in the form of seismic waves, of which seismologists recognise four categories: *P* (compressional) and *S* (shear) waves, which travel through the body of the Earth, and the often more destructive Raleigh and Love waves (named for their discoverers) which travel along the surface of the solid Earth. All of these waves travel rapidly, up to several kilometres per second, the fastest being the *P* waves which are therefore the first ones to arrive at seismographs.

In addition, earthquakes beneath the sea, such as the Lisbon one, may generate tidal waves, or tsunamis, that can also travel at several hundreds of kilometres an hour. Over deep water, where they travel fastest, tsunamis have a very long wavelength and small amplitude, but as they encounter shallow water and slow down, the wavelength decreases and the amplitude increases dramatically, potentially causing extensive coastal damage.

The epicentre of the Lisbon earthquake is estimated to have been at about 36° N, 11° W, some 300 km to the south-west of Lisbon. Since the first of three major shocks to hit Lisbon struck at 9.40 a.m. local time, the earthquake itself must have occurred just a couple of minutes before this, also triggering the tsunami and turbidity currents flowing north into the Tagus Abyssal Plain and south into the Horseshoe Abyssal Plain. The tsunami arrived at Lisbon about 40 minutes after the initial shocks, causing major waves in the River Tagus and adding to the general mayhem.

Epicentre of the 1755 earthquake (star) and calculated travel times (in hours) for the resulting tsunami waves: red within 2 hours, palest orange within 5 hours (National Geophysical Data Center (NGDC) NOAA)



The earthquake affected not only Lisbon, but also many other localities in Portugal and neighbouring countries, and the effects, particularly of the tsunami, were felt over a very wide area around the Atlantic and even into the Mediterranean. A Wikipedia article at https://en.wikipedia.org/wiki/1755_Lisbon_earthquake# includes recent re-evaluations of the effects of the earthquake and the results of an attempt to model the extent of the tsunami over the first 20 hours or so. This suggests that it reached as far north as southern Greenland and large parts of the eastern coasts of North and South America within 8–10 hours.

The effects in Britain were particularly well reported. Following the earthquake, the Royal Society invited its Fellows to send in accounts of any unusual phenomena noticed in their local areas, in both Britain and abroad, that might be associated with it. The result was a series of more than twenty letters from various parts of the British Isles published in the *Philosophical Transactions of the Royal Society* in 1775 and 1776 (available at https://babel.hathitrust.org/cgi/pt?id=uva.x001301614&view=1up&seq=401). They all describe disturbances in water bodies ranging from relatively small artificial ponds to large natural lakes and the sea, but otherwise fall into two broad classes depending on the local time they are reported to have happened. This was more than a century before the establishment of the universal time zones with which we are familiar today. Consequently, all the times quoted were 'real' local times, based on the local noon determined when the Sun, in its apparent passage across the sky, was due south and at its zenith. As a result, moving from east to west, the time got (and still gets) later by 4 minutes for each degree of longitude. With a longitude of *c.* 9 degrees west of Greenwich, Lisbon therefore has the same local time as south-west Ireland, *but is 36 minutes behind Greenwich, about 32 minutes behind Portsmouth and 20 minutes behind Plymouth*.

One group of letters describe events happening in the mid to late morning, ranging from about 9.30 a.m. to 'just before noon'. The reported timing of the rapid rise and fall of water in Loch Lomond every five minutes or so between 9.30 a.m. and 10.15 a.m. must be an error because, with a longitude of 4°34'W, the local time at Loch Lomond would already have been almost 10 o'clock by the time the first shock hit in Lisbon. But otherwise, they all seem consistent with, and explicable by, the fast-moving *P*, *S*, Raleigh and Love waves mentioned above. Several of the accounts describe quite remarkable events, from ships being suddenly rocked violently in otherwise calm waters in Portsmouth harbour at about 10.35 a.m. and in the Thames at Rotherhithe somewhat later, to large volumes of water being erratically sloshed about in ponds and lakes ranging from southern England to Lake Windermere, Loch Lomond (*see above*) and Loch Ness. One of the most dramatic reports was from Philip Carteret Webb, owner of the Busbridge estate near Godalming in Surrey, told to him by his gardeners who were working at the time beside a rectangular 'canal' lake in his grounds, orientated roughly east–west and some 700 feet long by 58 feet wide. Between 10.00 and 11.00 in the morning on that fateful Saturday the gardeners were alarmed to see that the water on one side of the long canal suddenly, and very noisily, '*raised itself in a heap or ridge, extending lengthwise about thirty yards ... and flowed about eight feet over the grass walk on that side of the canal*'. The water having returned to the canal a few seconds later, the gardeners were amazed to see the process repeated, this time on the other side of the canal. Having no knowledge of the earthquake, they must have been terrified.

The other letters published in *Phil. Trans.* are quite different. They all refer to strange movements of the sea and all took place in the afternoon, between about 2 p.m. and 6 or 7 in the evening. Clearly, these all refer to effects of the tsunami. One of the most graphic is that of the antiquarian, geologist and natural historian William Borlase, rector of Ludgvan, Cornwall from 1722 to his death in 1772. Borlase was an FRS and his observations were published in *Phil. Trans*. along with those of his fellow correspondents. But he also included a very similar version in his *History of Cornwall* published in 1758 from which the following is taken: '*On the 1st November, 1755, about two o'clock in the afternoon ... the sea, about half an hour after ebb, was observed, at the pier of St Michael's Mount, to rise suddenly and then to retire. This attracted the attention of the spectators, and to their great amazement, ten minutes after, the sea rose nearly six feet, coming in from the South-East extremely rapid; it then ebbed away with the same rapidity to the Westward for about ten minutes, till it was near six feet lower than before; it then returned again, and fell again in the same space of time, and continued the agitation, alternately rising and falling, each retreat and advance nearly of the space of ten minutes, till five and a half hours after it began.'* Borlase also reported similar strange events in other localities in the Mount's Bay area, but, although he was clearly convinced that they were linked in some way with the Lisbon earthquake, he could not believe that '*... a shock, so far off the coast of Spain, could be so immense as to propagate so violent a motion of the water quite home to the shores of Britain in less than five hours*'. Actually, the effect was even faster than Borlase thought. At a longitude of *c.* 5.5°W, the local time at St Michael's Mount is about 14 minutes ahead of that at Lisbon and 22 minutes ahead of the earthquake's epicentre. So if Borlase's 'about two o'clock' is correct, the tsunami had taken rather less than 4.5 hours to get there, in agreement with the model referred to earlier (*see map*).

Rather surprisingly, Borlase makes no mention of even more dramatic events at Lamona Cove, just a few miles away across the bay from St Michael's Mount. Here, contemporary observers claimed that the sea rushed in '*with such impetuosity that large rounded blocks of granite from below low water mark were swept along like pebbles, and many of them deposited far beyond high water mark*'.

Further reading

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Tony Rice

With grateful thanks to Bob Whitmarsh for improving this biologist's attempt to address some complex geophysics.

Book Reviews

Citizen science comes of age

Handbook of citizen science in ecology and conservation edited by Christopher Lepcyzk, Owen Boyle and Timothy Vargo (2020) University of California Press, 336pp. £33 (paperback, ISBN: 978-0520-28479-1), £70 (hard cover, ISBN: 978-052-028477-7), £33 (ebook, ISBN: 978-0520-96047-3).

The tide is turning for citizen science as its tremendous value in advancing research and instigating community action are being realised as it improves environmental understanding and contributes to some of the most important studies of our time. As humans continue to put strain and stress on the environment, citizen science is becoming ever more important. However, with increasing need comes a greater requirement for good planning and effective evaluation processes, and this is where this *Handbook* comes in. It is an excellent multi-authored book that actively promotes the use of citizen science in a broad range of settings, and discusses its fundamental aspects and the differing approaches that can be taken. Split into three digestible parts, the *Handbook* is full of detailed chapters, case studies and useful resources that would not go amiss on the bookshelves of those with extensive experience, as well as those new to citizen science.

In Part I, the authors provide a thorough introduction offering a well rounded description of citizen science with a broad range of examples of where and how citizen scientists are enormously important. Describing the evolving nature of citizen scientists, the authors go back to the likes of Carl Linnaeus building some of the most valuable collections of specimens in ecology and conservation, still used today. Ensuring the reader has a solid understanding of the history of citizen science, the first part of the book is rounded off with a discussion of current approaches across five project models, laying a strong foundation for the following, more intricate, sections of the book.

Part II, 'Planning and Implementation of Citizen Science Projects', presents a detailed account of the crucial considerations to be borne in mind when instigating a citizen science project. As the core of the book, the chapters range from project planning and participant recruitment to training, high-quality data collection, data visualisation and how to evaluate a project.

Each citizen science project is unique. Such projects have an enormous range of settings, and many questions to answer, and it is unfeasible for the authors to set out, step-by-step, how to design and conduct a specific project. Instead, each chapter contains crucial information that is accompanied by a range of case studies and up-to-date references – encouraging further investigation by the reader. Where this book shines, is in the authors' use of resource tables and web-links as well as pertinent considerations given in concise 'steps' and scannable guidelines, checklists and schematics. For example, Chapter 10 provides a three-page table of tools for data management, analysis and visualisation, followed by a description of each data-handling tool, and a URL for the website where it can be found. With the rigour of project planning, equipping readers with such resources provides a wealth of information, placing them in the best position to develop an impactful project.

The majority of project examples are US-based and are in terrestrial settings. As someone active within the marine sector, this did not trouble me, nor did it make feel excluded from the book. The cases are discussed within the context of the chapter and cover basic aspects of citizen science projects such as training and citizen scientist recruitment; however, the authors also present emerging considerations such as the legalities of data and barriers to participation by those from minority backgrounds and LGBTQ+ individuals.

The book concludes with a six-chapter section that provides examples of the information provided in Part II in the form of extensive case studies. The authors of each chapter discuss example cases, challenges and summaries from a range of projects that includes using citizen science as an educational tool in schools helping indigenous communities in Brazilian Amazonia to monitor biodiversity. Each chapter and case study is unique and delivers a well rounded account of the respective project straight from the authors' experiences. It is an important section that facilitates the contextualisation of broader topics covered whilst further cementing the critical point that 'one size does not fit all', with each project's own cohort of participants, challenges, and outputs. This section clearly outlines how citizen science can be done whilst also acting as a platform to generate ideas and projects.

As science is continually evolving, I suspect that the resources and tools that I have referenced throughout this review will soon be joined by newer, more advanced tools. However, just like the majority of the *Handbook*'s contents, they are essential to any citizen science project and will continue to be integral to establishing the necessary framework for projects long into the future. This is a superb book that has introduced me to new concepts and considerations that I am certain will aid others with their current and future projects.

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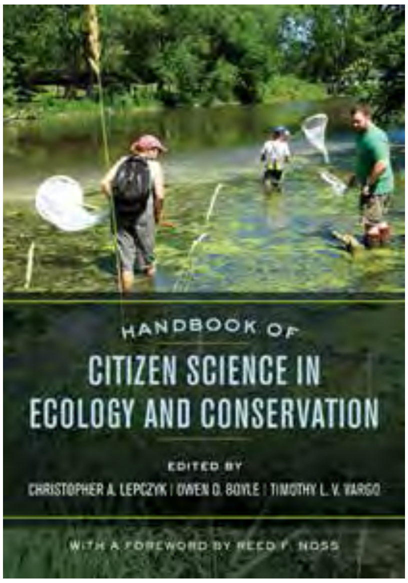


A very personal exploration of the atmosphere

18 miles: The epic drama of the atmosphere and its weather by Christopher Dewdney (2019) Bloomsbury Sigma, 272pp. £19.99 (hard cover, ISBN: 978-1472-96989-7), £11.89 (EPUB/MOBI ebook, ISBN: 978-1472-96992-7).

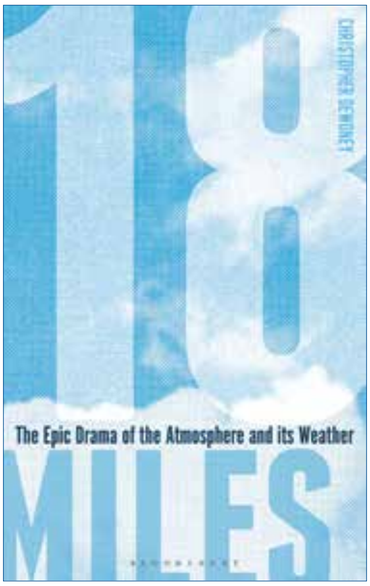
The '18 miles' of the title is the depth of the atmosphere that contains 99% of its mass, a fact that provides the context for this book. For a geologist, this 18 miles is a thin sliver of the planet Earth, while to a meteorologist it is a great thickness – encompassing everything we think of as weather and climate. For the author, award-winning

Canadian poet Christopher Dewdney, it is a palimpsest for exploring his experience and concept of the natural world from the Earth's core to outer space, from before the beginning of life into the greenhouse future.

The author takes us through time and space in a very individual way, with each chapter combining some personal experiences of the Earth system with his understanding of science, as well as its historical development. This approach led to the book being the winner of the Science Writers and Communicators of Canada General Audience award in 2019; the book is a very easy but elegant read. It will help the reader to know that the author is a poet concerned about the natural world and its geologic past, rather than a practising scientist, as this perspective determines the feeling and style of the writing.

About half of the book relates directly to the atmosphere in some way, from the origin of the layers of the atmosphere to the components of weather: clouds, rain, storms and hurricanes. The author had the distinction of being under Hurricane Katrina both as it started as a tropical storm in the Bahamas and when it ended life as an extra-tropical storm in Ontario, giving him an unusual insight into hurricanes as extreme events. These chapters were some of the best and most entertaining in the book. Anyone who observes the weather will immediately recognise the drama the author relates here.

The second half of the book takes the reader on a more varied route through sometimes mythological aspects of the cardinal winds and seasons, a somewhat curiously placed discussion of weather forecasting, and perceptions of climate change from 'Snowball Earth' to extreme weather and greenhouse warming. The ocean gets a minor mention here, mostly as a reservoir of microbial life during Snowball Earth, with a cameo appearance in the final section which takes a rapid tour from the Earth's core outwards. In contrast to the entertaining and mostly factual tour of the atmosphere itself, this second half is less satisfying for an Earth scientist with environmental and historical bents. Some of the information about ice ages, for example, is incorrect, with confusion over what ice cover matched which glaciations, particularly glaringly so for England. Few ecologists would recognise an assertion that springs are getting later and there are some very dubious and idiosyncratic interpretations of the influence of weather on history. The second half is also less satisfying because the author lost his way through departing from a clear focus on the atmospheric structure and weather, and his own experiences, which made the first half of the book such a pleasure to read.



Nevertheless, if you were drawn into climate-related sciences through a fascination with the weather, you will enjoy the mix of fact and personal illumination contained in *18 Miles*. It certainly entertained and distracted me from the cares of the second quarter of 2020!

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Lies, damned lies … and scientific publications?

Science fictions: Exposing fraud, bias, negligence and hype in science by Stuart Ritchie (2020) Penguin, The Bodley Head, 368pp. £18.99 (hard cover, ISBN: 978-1847-92565-7), £9.99 (paperback, ISBN: 978-1473-56425-1); £13 (audio download, ISBN: 978-1473-58407-5).

The title and subtitle of this book do not do justice to its scope. It presents a thorough and thoughtful discussion of the shortcomings of the practice of science in today's institutions. *Science Fictions* presents many very interesting, if disturbing, recent examples of fraud (deliberate lies), (un-declared) bias, negligence (accidental lies) and hype (overselling impact) in the peer-reviewed scientific literature. The examples demonstrate how elements of the mainstream scientific system are letting both scientists and society down. But the real focus is on the 'why': Why is there so much of this bad scientific practice? Richie builds an engaging, informed, well referenced and persuasive argument for how these uncomfortable examples are the products of a broken reward system. He calls on readers – scientist and non-scientist alike – to demand better.

The book weaves its narrative around specific examples of 'science fictions'. It begins by explaining the history and principles of peer review and its importance in the formal scientific process, then moves swiftly on to highlighting its shortcomings. The focus then remains on the negative as the four specific pitfalls given in the subtitle are evidenced and analysed in sequence. The common threads which emerge in these sections draw the reader through, and they are satisfyingly tied together in the overarching broader critique of the institutional failings which have supported the proliferation of these bad practices. Finally, there is the compulsory optimistic forward look, where Ritchie triumphs in avoiding the pitfall of presenting an oversimplified solution to the 'crisis' his book has exposed, in all its complexities.

As an ocean scientist, I initially hesitated to pick up this book because of my own bias: I expected it not to be very relevant to the oceanographic community. I thought that the author's perspective as a psychologist – a field shaken by several high-profile 'science fictions' – would lead to the presentation of that field's problems as directly transferable to all of science, without acknowledging the differences in standard methodologies between fields.

My worry was unfounded. Ritchie is up front about his perspective, throughout referring to psychology examples as being about 'my field'. The book is dominated by examples from psychology and medicine, but on balance care is taken not to over-generalise. By focussing on what leads to '*p*-hacking' (a range of shady statistical practices to dress up unsignificant results as significant) and 'the replication crisis' (the growing number of unsuccessful, often large-scale and inter-laboratory, efforts to reproduce previously published results), Ritchie convinces even the sceptical reader of its broad importance beyond any specific or worst-case example. There is even one example from ocean science.

Where technical understanding is needed to support an example, it is presented clearly and concisely. Enough detail and background are given to follow the argument, without superfluous detail that distracts from the key messages.

For sometimes superfluous information, there are the end notes. These are both fabulous and frustrating. Without flipping to and through the (almost 100-page long) notes section at the end of the book, it's impossible to know what type of note you will find. There are simple references, insightfully annotated references, additional relevant examples, and interesting caveats and asides. Some of these are more than worth the page-flipping. They are among the best examples of the dry humour and conversational tone of the narrative, which makes the book an easy read despite its serious subject matter.

I will be recommending *Science Fictions* to scientist and non-scientist friends alike. As we hear more about 'following the science' in policy and the media, it's an important and timely reminder of how science works, and why it should work better. For those so inclined, there is also an audiobook version – read by the author.

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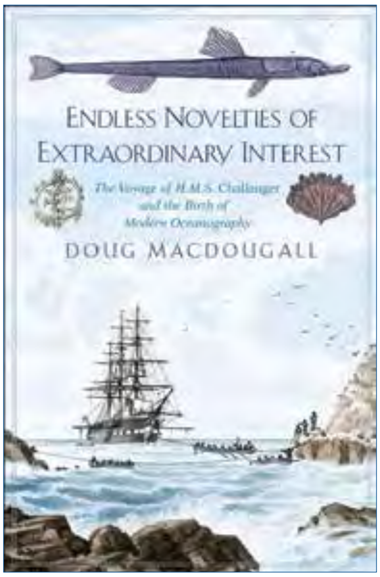
Challenger *in perspective*

Endless novelties of extraordinary interest: The voyage of H.M.S. *Challenger* and the birth of modern oceanography by Doug Macdougall (2019) Yale University Press, 288pp, £20.00 (hard cover, ISBN: 978-0300-23205-9). (Also available for £17 from Tantor Media Inc. on audio CD, MP3 or download, read by Sean Runnette.)

Two years from now we will be marking the 150th anniversary of HMS *Challenger*'s departure from Portsmouth at the beginning of her three-and-a-half-year voyage of exploration. So it is fitting that this accurate and well written book, only the third since 1880 to focus on the *Challenger* expedition and its discoveries, should appear at this time. Moreover, it sets out to span the intervening decades by showing that the *Challenger* investigations lay close to the roots of all the marine sciences that have developed up to the present day. The title, borrowed from



p.49 of Wyville Thomson's *The Depths of the Sea* (1873), is certainly appropriate – it expressed his anticipation of the zoological treasures that would be found in *Challenger*'s deep-sea dredges and trawls.

The author, an emeritus Professor of Earth Sciences at Scripps, is a Canadian now living in Edinburgh, where the expedition's voluminous findings were organised, edited and published for dissemination throughout the scientific world, mostly under the supervision of John Murray, another Canadian by birth. Macdougall's latest book does not pretend to offer a chronological account of the voyage; instead he has chosen a series of topics investigated by *Challenger*'s scientists and describes them from the viewpoint of the participants. Woven between these accounts are examples illustrating related areas of marine research that are currently active. The contrasts revealed emphasise the limited capabilities of the equipment available on board HMS *Challenger* and the enormous advances in methodology since her day.

Importantly, Macdougall does not overlook the broader historical context of the expedition; he deals not only with its origins, but also with its place in the world of Victorian science, setting the work of *Challenger*'s scientists within the culture of curiosity and collecting that fostered the museum boom of the period.

The first three chapters serve to introduce the key elements of the expedition: the vessel, her refit for a voyage of research and her roles as a sampling platform, and the six members of the scientific staff, three of whom had no previous sea-going experience. The second chapter includes an interesting survey of their social and educational backgrounds, but the essential contribution of the naval personnel is rather neglected. The indefatigable Henry Nottidge Moseley, the 'naturalists' naturalist' of the team, features prominently, equally at home botanising on land, wading over coral reefs or examining a dredge haul (while pursuing a strong sideline in ethnography).

The bulk of the work (Chapters 4–11) follows the time-spanning pattern described earlier. To give some idea of the range of subjects covered, here are three of the locations visited by *Challenger*'s scientists that are described in the text, where they introduce discussions of the topics (shown in brackets) currently employed to interpret the earlier findings at these sites: St Paul's Rocks in the equatorial Atlantic (plate tectonics); Tristan da Cunha (evolutionary history of penguins); the sub-Antarctic Kerguelen Islands (plant geography). An apparent disciplinary bias in favour of the life sciences does no more than reflect the expedition's own emphasis on natural history, as shown by the choice of scientific staff and the published results of the voyage. This was almost inevitable at the time; natural history was already an established field of study with a major focus on the marine biota, whereas understanding of the physics and chemistry of the ocean was still fragmentary and lacking a theoretical structure. This is demonstrated by the delayed fruition of the significant but relatively unglamorous hydrographic data collected during the voyage, whose full interpretation had to wait another fifty years.

The final chapter explores the *Challenger* legacy. Macdougall asks why this expedition became so influential, and concludes that such enduring fame is the result of successfully meeting ambitious goals before an expectant public. Behind that success lay careful planning and preparation, not least in the selection of talented individuals to carry out the programme, and the attention they paid to communicating with both lay and scientific readers thereafter in a steady stream of publications, ranging from Thomson's popular journalism for *Good Words*, written during the voyage, to Murray's completion of the massive task of publishing the fifty-volume *Report* over a period of almost twenty years. As Sir Maurice Yonge remarked in his opening address to the Second International Congress on the History of Oceanography, held in Edinburgh to celebrate the expedition's centenary: 'Looking back, it is surprising how little seems to have gone wrong with the *Challenger* and how very much was successfully accomplished.'

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