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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.

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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 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 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.

Supporting specialist groups to provide a forum for discussion.

Publication of a range of documents dealing with aspects of Marine Science and the programme of meetings of the Society.

Membership provides the following benefits:

An opportunity to attend, at reduced rates, the biennial five-day UK Marine Science Conference and a range of other scientific meetings supported by the Society.

An 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

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The subscription for 2008 costs £40 (£20.00 for students in the UK only). If you would like to join the Society or obtain further information, contact the Executive Secretary, Challenger Society for Marine Science, Room 251/20, National Oceanography Centre, Waterfront Campus, Empress Dock, Southampton SO14 3ZH, UK;
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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. If at all possible, they should be well illustrated. Copy may be sent electronically.

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CONTENTS

CONTENTS

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The cover was designed by Ann Aldred Associates.
The photograph of Autosub on the cover is by courtesy of Chris Banks.

Message from the President of the Challenger Society

UK marine research is of very high quality, yet is poorly coordinated, fragmented and underfunded. These are the views of politicians, first expressed in 1986 by the House of Lords Select Committee on Science and Technology. They were reiterated last year in a weighty report, *Investigating the Oceans,* produced by the House of Commons Science and Technology Committee. This report was widely welcomed by the academic and business communities, but less well received by the government.

In particular, the government rejected the report's central recommendation relating to marine science and policy coordination – how to achieve efficient and effective alignment between the interests of government departments and agencies, research councils, university researchers, and the private sector. This strategic role is currently provided by the Inter-Agency Committee on Marine Science and Technology (IACMST) which includes all the relevant bodies but has relatively little influence or resources. *Investigating the Oceans* was critical of IACMST (somewhat unfairly in my view), and recommended that a new marine agency be established, with executive powers and a budget to oversee operational observations. In contrast, the government view is that IACMST should be replaced by a body of more limited membership, the Marine Science Coordination Committee (MSCC), primarily directed at promoting intra-government liaison. Thus the proposed MSCC will have no independent members, nor any representation of marine industries or universities.

If the marine agency concept is unacceptable, it would be better to strengthen IACMST rather than replacing it with a largely governmental body. Importantly, there is no clarity in the government's response about the reporting line(s) for the proposed MSCC, which was one of the major criticisms of IACMST. The proposal to have a rotating chair for the MSCC selected from the (governmental) members is unlikely to provide the independent, committed and enthusiastic leadership that is needed.

The major positive part of the government's response is the acceptance that the UK needs a national strategy for marine science. However, this may be a couple of years away, and it is far from clear how it will be developed and documented. IACMST had volunteered to take the lead role in this but its likely demise means that core capability for such an exercise will be lost. It is said that industry will be consulted by the MSCC, whereas one would have thought they needed to be central to the process. This feeds the suspicion that MSCC will have tight control over development of the strategy, with only weak consultation and input from outside government.

Those aspects of the government response contributed by NERC are lacking in several respects. For example, an opportunity missed relates to the widely-felt need for a new coastal research vessel. Whilst NERC is prepared to review the evidence of need, no time-scale is given and one detects no sense of urgency. Why not take steps to initiate the review now? There is inevitably a long lead time involved in getting funding and building a vessel, and planning should be in step with the UK Marine Bill and the proposed Marine Management Organisation which will greatly increase the requirement for coastal observations.

Finally, a vital national need is to secure long-term funding of marine observations. The situation is particularly severe for non-statutory measurements such as those from the *Jason* satellite and Argo buoys, and observations relating to marine CO_2. These and other important observations have no assured long-term funding and serious problems are encountered when funding needs to be renewed. Finding a satisfactory funding arrangement for such measurements will be a key test of the MSCC's effectiveness.

In summary, the government response to *Investigating the Oceans* is defensive, retrograde and inward looking, and could worsen the current situation. Many Challenger Society members have expressed similar views. This is particularly disappointing given the substantial work put into the report, by both parliamentarians and the wider community, which led to a very positive and far-reaching document. In contrast, the government's response seems woefully inadequate.

Peter Liss

News and Views

Molybdenum and the rise of multicellular life in the oceans

It is thought that the level of oxygen in the Earth's atmosphere rose from initally low levels in two main phases, the first heralding the start of the Proterozoic Era 2500 Ma ago, the second near its end 542 Ma ago. The course of evolution of life on Earth, particularly that of animals, is closely tied to the degree of oxygenation of the oceans during the intervening period.

As atmospheric oxygen levels rose at the start of the Proterozoic, the upper ocean could support photosynthesizing (oxygen-producing) bacteria. However, the diversity of these single-celled life forms remained low, and multicellular animals did not appear for another 2000 million years (about 500–600 Ma ago).

It is estimated that the minimum level of atmospheric oxygen needed for animal life to survive and expand on Earth is of the order of 1–10% of present levels. Research by a team led by the University of California, reported in *Nature,* **452**, 27 March 2008, suggests that the evolution of animal life in the oceans (and hence on Earth) may have been delayed by a deficiency of oxygen, and an associated lack of the heavy metal molybdenum, in the oceans. Molybdenum, like iron, is a redox-sensitive micronutrient, and is essential for nitrate reduction and nitrogen fixation by present-day cyanobacteria.

Levels of molybdenum in ancient sulphide-rich black shales (organic-rich sedimentary rocks) provide an indication of the amount of dissolved molybdenum in the seawater in which the shales were laid down, which in turn reflects the supply of molybdenum to the ocean through oxidative weathering of continental rocks. For decades it has been assumed that the full depth of the ocean became oxygenated shortly after the initial rise in atmospheric oxygen, but the researchers found that shales containing levels of molybdenum consistent with persistent and vigorous oxidative weathering (as occurs today) were not being laid down until ~ 2150 Ma ago, more than 200 million years after the intial rise in atmospheric oxygen.

It seems that in the mid-Proterozoic, conditions in the deep ocean resembled those in today's Black Sea, with low levels of oxygen and high levels of sulphide. The low levels of oxygen and molybdenum may have had a negative impact on the evolution of early eukaryotes (organisms whose cells have nuclei). Furthermore, molybdenum levels in shales indicate that the oceans as a whole were not well oxygenated until around 550 million years ago. This timing would suggest that complete oxygenation of the oceans and the appearance of animal life occurred shortly after the last global glaciation, at the end of a period when our planet may have been a 'Snowball' (see next item).

'Slushball' not 'Snowball'?

Interestingly, recent results from a climate model developed by Canadian researchers, cast doubt on the 'Snowball Earth' theory, which proposes that around 700 Ma ago there was a sequence of glaciations so deep that they effectively prevented any photosynthetic activity. By coupling a climate model to a model of a carbon cycle believed to be appropriate to the Neoproterozoic (the last ~460 million years of the Proterozoic) they have shown that the increased drawdown of atmospheric oxygen into the ocean, as surface temperatures declined, would have increased the rate at which a massive pool of dissolved organic carbon would have been released back into solution in the ocean, and thence back into the atmosphere as CO_2. The rise in the level of atmospheric CO_2 would have enhanced greenhouse warming of the surface of the Earth, and would have prevented the onset of a 'Snowball Earth'. Instead there would have been a less extreme situation (referred to as 'slushball Earth' when it was first proposed in 2000) in which areas of ocean near the Equator would be only partly covered in ice, and life would have had a much easier time.

The Neoproterozoic immediately preceded the 'Cambrian explosion', a great increase in the diversity of animals in the oceans, and the appearance of animals with more complex body forms and life-styles, so what conditions on Earth were like at that time has enormous implications for our understanding of evolutionary biology.

See *Nature*, **450**, 6 Dec. 2007.

How events in space affected the course of life on Earth

It's hard to imagine how an event in the asteroid belt 470 million years ago might have affected the evolution of life on Earth. The event in question was the break-up in the asteroid belt of a body so large that even today ~ 20% of meteorites falling on the Earth originate from it.

During the Cambrian explosion 540 Ma ago (cf. previous item) a large number of new phyla appeared, but during the mid-Ordovician, large numbers of new families, genera and species appeared, including relatives of present-day gastropods and bivalves. The trigger for the 'Great Ordovician Biodiversity Event' has long been debated by palaeontologists, not least because it is unusual in that, unlike other marked increases in biodiversity, it is not directly related to recovery from a mass extinction.

Studies of fossil-rich Middle Ordovician strata in Baltoscandia and China show that around 470 Ma ago there was a dramatic increase in the the flux of extraterrestrial dust, small meteorites and also larger km-sized bodies; this seems to be exactly coincident with the increase in diversity. The period of heavy bombardment lasted for 10–30 million years, and the proposal is that the enormous numbers of impacts caused widespread environmental disruption, resulting in new ecological niches at different depths in the ocean.

See *Nature Geoscience*, **1**, No.1, 49–53.

Marine Bill Progresses

The key issues covered by the Draft Marine Bill, published on 3 April are:

- The creation of the Marine Management Organisation (MMO)
- Planning and licensing of activities in the marine area
- Marine nature conservation, management of marine fisheries; reform of inland and migratory fisheries
- An administrative penalties scheme for domestic fisheries offences; modernisation and streamlining of enforcement powers
- Improving access to coastal land.

Defra is seeking views on the proposals set out in the draft Bill and looking for input to the supporting Impact Assessment. To view the draft Bill and other relevant documents, see http://www.defra.gov.uk/corporate/consult/marinebill/

The deadline for responses is 26 June

In the summer, the draft Bill will go for parliamentary pre-legislative scrutiny, i.e. discussion by a Committee of the House, which also hears from interested individuals and organizations. The timetable and sitting days will be announced on the Parliament website. The earliest that the amended Bill can be introduced to Parliament is the parliamentary session in the autumn, and then only if the Parliamentary time-table allows.

President's Photographic Prize

Reflecting the theme of SOLAS (Surface Ocean–Lower Atmosphere Study), the topic for the photographic competition at Bangor 2008 in September, will be:

'Sea and Sky'

Photographs (max. size: 30 cm x 40 cm) may be handed in at the conference registration desk up until Wednesday lunchtime. Each should have a title.

For more about the 13th Biennial Challenger Conference for Marine Science *see p.16* and wwwchallenger-2008.co.uk

Are some kelp communities safe from global warming ...

Kelp flourishes only in temperate latitudes, and in warm, nutrient-poor tropical waters is replaced by corals – right? This is what the textbooks say, but ...

A research team led by Moss Landing Marine Laboratories/San José State University and the University of California, Santa Barbara, Marine Science Institute, decided to search for kelp using a computer model incorporating oceanographic and ecophysiological information, which predicted likely kelp habitats on the basis of information about light, depth and nutrient availability obtained from satellites and oceanographic instruments.

The model accurately identified the sites of all known kelp populations and, using the same criteria, predicted the existence of more than 23 500 km^2 of unexplored tropical kelp habitats worldwide, in unexpected cold spots at depths of 30–200 m. These tended to be in regions where bathymetry and upwelling resulted in the mixed layer shoaling above the depth of minimum annual light levels for kelp survival.

The research team then tested the model by travelling to a site off the Galápagos where the model predicted that kelp would be found. Scuba-diving alongside Galápagos marine iguanas they discovered, 10–50 m below the surface, extensive forests of the kelp *Eisenia galapagensis*, a species thought to be rare, which the World Conservation Union recently added to its database of threatened species. The kelp increases in abundance with increasing depth from 10 m to >60 m, and supports cold-water organisms with temperate affinities.

Field observations of kelp are surprisingly rare. The succesful prediction of the 'new' deep-water kelp forests (as well as of the ones already known about) suggests that there may be another ~23 000 km^2 of deep-water tropical kelp, so far undiscovered. Furthermore, by identifying unexpected places to search, the model may lead to the discovery of other marine communities presumed to be rare and/or endangered. All this has implications for assessments of regional productivity and biodiversity, and for studies of tropical food webs. Also, the fact that kelp forests may continue to thrive at depth, relatively unaffected by surface warming, suggests that tropical marine biodiversity may be more tolerant of climate change than previously assumed. The model could be particularly useful for work involving global distributions of marine habitats – such as the recent study of human impact on marine ecosystems worldwide (see pp.6–7).

See Graham *et al.* (2007) in *Proc. National Acad. Sci.*, ***104**, No. 42.*

... and will some reefs benefit from the 'ocean thermostat'?

A recent study of coral reefs in the area of ocean known as the 'Western Pacific warm pool' suggests that corals that have evolved to live in unusually warm areas of ocean could be protected from climate change, because temperatures in such areas remain relatively stable, as a result of the 'ocean thermostat'.

The 'ocean thernostat' theory aims to explain the observed upper limit to sea-surface temperatures (so far at least): ~30–31 °C in the open ocean, more (~33–34 °C) in enclosed seas like the Red Sea. This upper temperature limit is presumed to result from negative feedbacks between the upper ocean and the atmosphere, involving increased evaporation leading to more cloud cover and reduced incoming solar radiation, and/or changes in surface currents caused by changes in wind patterns and/or pressure gradients in the upper ocean.

Unfortunately for corals, the sea-surface temperature of most tropical waters is well below the 'thermostat limit'. Furthermore, computer models suggest that the Western Pacific warm pool will warm at a similar rate to surrounding areas, rather than being constrained by the thermostat. It is not clear whether the models are not capturing the processes involved in the thermostat, or if global warming is occurring so rapidly that it is 'overwhelming' the thermostat.

See Kleypas *et al.* (2008) *Geophys. Res. Lett.*, ***35***. L03613 (online).

Ransom A. Myers (1952–2007)

Ransom Myers – 'Ram' to those who knew him – died in March 2007 at the age of 54. At the time of his death he held the Killam Chair of Ocean Studies at Dalhousie University in Halifax, Nova Scotia. He had begun his university studies with mathematics and physics, and this background informed his seminal work on living populations.

He is best known for his work on causes of the collapse of fish stocks, particularly the cod stocks off eastern Canada. He compiled datasets relating to the dynamics of fish populations all over the world, and these data, consisting of over 800 time-series, provide the empirical basis for his theoretical analyses. He realised that by treating each population as the result of a natural experiment, it would be possible to discover natural patterns previously obscured by the 'noise' of the dynamics of individual populations. This approach makes it possible to tackle problems in population biology and management of living resources, and he was actively involved in developing methods for the optimal management of exploited populations. He was not optimistic, however, and his most recent work had turned to models of extinction, particularly of salmonid species, sharks and other elasmobranchs, and marine turtles.

The following passage is taken from the website of Ram's research group:

'There is no question that Ram has changed the world with his scientific genius, ability to untangle 'impossible' data, and compulsion to speak the truth at all costs. He has also changed the world through his influence on those he worked with, who will continue to do the science needed to understand our oceans and speak out to stop the ecological destruction that Ram revealed and fought so hard to bring to a halt.'

Ransom Myers was not only a powerful influence on those who knew him, but through his diverse and numerous scientific publications he also influenced many who never met him. He was a teacher in the widest sense of the word. Details of just three of his >100 papers, including one published just after his death, are given below:

Worm, B., H. Lotze, and R.A. Myers (2003) Predator diversity hotspots in the blue ocean. *Proceedings of the National Academy of Science USA*, **100**, 9884-88.

Myers, R.A., and B. Worm (2003) Rapid worldwide depletion of predatory fish communities. *Nature*, **423**, 280-83.

Myers, R.A., J.K. Baum, T.D. Shepherd, S.P. Powers, C.H. Peterson (2007) Cascading effects of the loss of apex predatory sharks from a coastal ocean. *Science*, **315**, No. 5820, 1846–50.

This tribute was compiled using notes from the Ancona conference (p.15), and a number of websites relating to Ram's work. Ed.

Investigating the Oceans: the background to a political saga

Phil Williamson

In November 2006, twelve MPs belonging to the House of Commons Science and Technology Committee began an enquiry into the organization and funding of marine science. The process of evidence-gathering and reporting was then expected to be completed within a few months, concluding with a formal government response.

A year-and-a-half later, the final outcome of *Investigating the Oceans* is still uncertain. In part, that is because marine science is a larger, more important, and more labyrinthine topic than the MPs had originally anticipated – but there have also been additional complications along the way. These included a departmental restructuring that ended the existence of the Science and Technology Committee (STC). Most of the STC's functions were transferred to a new Innovation, Universities and Skills Committee (IUSC), that subsequently re-included Science in its title (becoming IUSSC). Although some members changed, continuity between these Committees was maintained through their common chair, the Liberal Democrat MP Phil Willis.

A more basic reason for the enquiry becoming a political saga is that the STC's core proposals were rejected by the government, as discussed by Challenger Society President, Peter Liss, at the start of this issue.

For those not directly involved, many of the procedures and discussions associated with a Select Committee enquiry can seem arcane. A summary account of the main events relating to *Investigating the Oceans* follows below.

Evidence gathering

The STC invited written submissions – from both individuals and organizations – on the topic of marine science, with the Committee's specific interests identified as: the relative importance of polar and non-polar seas; the UK's international role; the development of marine technology and engineering; the state of the UK's research and skills base; marine Sites of Special Scientific Interest; and climate change. A total of 45 memoranda were received and subsequently published, including inputs from the Challenger Society, the Natural Environment Research Council (NERC), the Institute of Marine Engineering, Science & Technology (IMarEST), the Directors of NERC-funded marine laboratories, and several conservation bodies and NGOs.

Six oral sessions were subsequently held between May and July 2007, when a total of 27 witnesses (mostly organizational representatives) were publicly questioned by the Committee. The discussions were broadcast online, and subsequently published verbatim. Witnesses included Peter Liss, on behalf of the Challenger Society, and myself, supporting Alan Thorpe for NERC. Whilst much of the information presented was 'common knowledge', these sessions did tease out some deep-seated problems. These included the under-funding of marine monitoring, despite its national importance; the increasing demands on marine science to assist the development of marine renewable energy, Marine Protected Areas and other resource-related planning issues; and governmental uncertainties regarding policy responsibilities for marine and maritime science, and associated 'ownership' of the Inter-Agency Committee on Marine Science and Technology (IACMST).

STC members visited Plymouth, Southampton, Cambridge, and Woods Hole for additional informal discussions, and received 13 supplementary items of written evidence as clarifications and in response to specific requests.

Formal report

The STC's report *Investigating the Oceans* was published on 18 October 2007, in two volumes totalling 430 pages. It considered that marine science was fundamental to the continuing ability of the human species to survive comfortably on this planet, and expressed strong concerns regarding the lack of an overall national marine research strategy, the shortcomings of existing coordination arrangements for promoting coordination, and the inadequacy of the level of government investment. The Recommendations included:

- the formation of a new Marine Agency, with responsibility for marine monitoring and coordinating marine science;
- the establishment of pilot Marine Protected Areas, ahead of the Marine Bill;
- an increase in Arctic research;
- development of a strategy for UK marine science that would be 'part of a national plan for maritime affairs';
- that NERC make a case for a new coastal vessel;
- that clear responsibility for the marine strategy and its implementation should lie with a 'Minister for Marine Science' within Defra.

The report was presented and discussed with the marine research community at a meeting held at the Royal Society, London, on 20 November, sponsored by the Foundation for Science and Technology, the Challenger Society, IMarEST and the National Oceanography Centre, Southampton. Although NERC corrected a misunderstanding relating to an apparent (but incorrect) reduction in its funding for marine science, there was no challenge to the STC assessment that overall R&D support was declining at a time when policy needs were dramatically increasing, both at UK and European levels.

Government response – and aftermath

The government's response to the report was provided to the IUSC on 19 December, and published online in mid-January. As indicated above, many of the report's substantive recommendations were not accepted. Normally that's the end of the process, with the government having the final word. Nevertheless, the IUSC decided to pursue the issues further, initially by inviting comments on the government response, and subsequently by holding a meeting with marine community representatives on 19 February. The Committee – now IUSSC – has also called for Hilary Benn (Secretary of State for Environment, Food and Rural Affairs) to provide additional oral evidence on 22 April 2008.

Although the 19 February session was 'off the record', it was clear then that IUSC/IUSSC members felt strongly that the government response neither understood nor addressed their main concerns. Whilst the development of a UK marine strategy was welcomed, the government's proposed coordinating mechanism (a departmental Marine Science Coordinating Committee) was considered highly unsatisfactory, potentially weakening, rather than strengthening, UK marine science. That view is shared by the President of the Challenger Society, IMarEST and many leaders of marine research organizations.

The STC report, including the Challenger Society's submission, is online at www.publications.parliament.uk/pa/select.htm and published as: House of Commons Science and Technology Committee (2007) *Investigating the Oceans. 10th report of Session 2006–07* (Vols I and II), The Stationery Office Ltd, London. The government response is online at www.parliament.uk/documents/upload/itogovtresp.pdf

Mapping the impact of humans on marine ecosystems

In February, the results of a global study of the effect of people on seas and oceans was presented at a press conference held by the American Association for the Advancement of Science. These results were widely publicised in the media, which in itself was a valuable outcome for marine conservation, and the global datasets combined in map form provide a foundation into which results of future surveys can be incorporated, as they become available.

The study, reported in *Science* (see opposite for details) used information on the impact of 17 different anthropogenic factors on 20 different types of ecosystem (Table 1) to produce a map representing the overall effect of the impacts. The researchers divided the ocean into 1 km^2 cells, and for each determined which human activities would have impacted them, and to what extent (on a scale of 1–5). When the modelled effects of all 20 harmful impacts had been combined, it was found that 41% of the area of seas and oceans was suffering a medium-high or high impact (see map opposite). 0.5% of the oceans – an area of 2.2 million km^2 – is suffering an extremely high level of impact.

In some ways, the results were not surprising – and no educated Briton should have been surprised to learn that the northern North Sea and the Channel are some of the most badly impacted areas of sea in the world. Other greatly damaged areas are the South and East China Seas, the Caribbean Sea, the east coast of North America, the Mediterranean Sea, the Red Sea, the Persian Gulf, the Bering Sea, and various parts of the western Pacific.

Almost nowhere in the ocean can now be classed as pristine. The least impacted areas are around Antarctica and in the Arctic Ocean – areas that are currently under ice for much of the year. As global warming progresses, and sea-ice disappears, the writing will be on the wall for these areas too, unless something is done to protect them.

A huge undertaking

Compiling the map (Figure 1) was a huge undertaking. Global datasets relating to marine ecosystems were largely non-existent. The authors assessed data-availability for 23 different types of ecosystem, and were granted access to, or developed, the spatial data for 20. For coastal ecosystems for which there are no global data, they assumed a uniform distribution along coastlines.

Table 1 *The ecosystems and impacts addressed by the model.*

20 ecosystems	17 impacts
beach	artisanal fishing
intertidal soft bottom	demersal non-destructive low-bycatch fishing
rocky intertidal	demersal non-destructive high-bycatch fishing
subtidal	demersal destructive fishing
saltmarsh	pelagic low-bycatch fishing
seagrass	pelagic high-bycatch fishing
mangroves	
coral reefs	population pressure
rocky reefs	organic pollution
suspension-feeder reef	inorganic pollution
kelp	nutrient input
hard shelf (30–200 m)	invasive species
soft shelf (30–200 m)	commercial activity (shipping)
hard slope (200–2000 m)	benthic structures (oil rigs)
soft slope (200–2000 m)	ocean-based pollution
deep soft benthic	
deep hard bottom	
deep seamount	climate change (sea-surface temperature)
surface waters (< 60 m)	climate change (effects of UV)
deep waters (> 60 m)	ocean acidification

As far as human impacts are concerned, the researchers began by considering the global availability of data in 38 categories of anthropogenic causes (drivers) of change in marine ecosystems, developed through expert workshops. They then rejected drivers for whch data was global in scope but was patchy, as inclusion of such data would make comparisons between different parts of the globe unreliable. Factors that were therefore omitted included: hypoxic zones, coastal engineering (piers etc.), non-cargo shipping (cruise ships etc.), aquaculture, disease, recreational fishing, changes in sedimentation and the input of freshwater, and tourism.

Considerable effort was put into making datasets comparable so that the effects of different drivers could be represented by a common currency. The cumulative effect of the impacts considered was estimated as follows. For all the impacts, the data were converted into a unitless scale (from 0 to 1), and for each ecosystem, each 1 km^2 square was assigned 'present' or 'absent'. Then for each square, the ecosystem and impact data were multiplied together, and weighted. The weighting factor (on a scale of 0–3) had been determined by an expert survey that assessed the vulnerability of each ecosystem type (in the area in question) to each driver, on the basis of five ecological traits: spatial scale and frequency with which the driver acts; the proportion of the ecological community affected; the resistance of the community to being affected; and the recovery time needed.

For example, the weighting factor for the impact of nutrient input was 0.0 for deep water but a relatively high value of 1.8, 1.8 and 2.1 for mangroves, coral reefs and seagrass beds respectively. For each km^2, these weighted driver × ecosystem scores were summed to produce a total impact score.

Impacts from the land and ports

Many of the datasets for individual drivers – including all the land-based ones – were specially developed. One of the most exciting was a major improvement to the global-scale dataset of watershed delineations which was needed to allow mapping of how pollutants reach river mouths. Representation of how pollutants spread into the coastal zone was simplified; near-shore circulation patterns are known for only a few small areas of the world, so the spread of pollutants from river mouths had to be modelled on the basis of simple diffusion, assuming decay of 0.5% for each successive cell away from the source.

The 'population pressure' driver represents direct impacts of people, such as the effects of coastal engineering, noise pollution from land, and trampling of the intertidal zone. This was modelled on the basis of the coastal population (in effect, the number of people within 25 km of the coast).

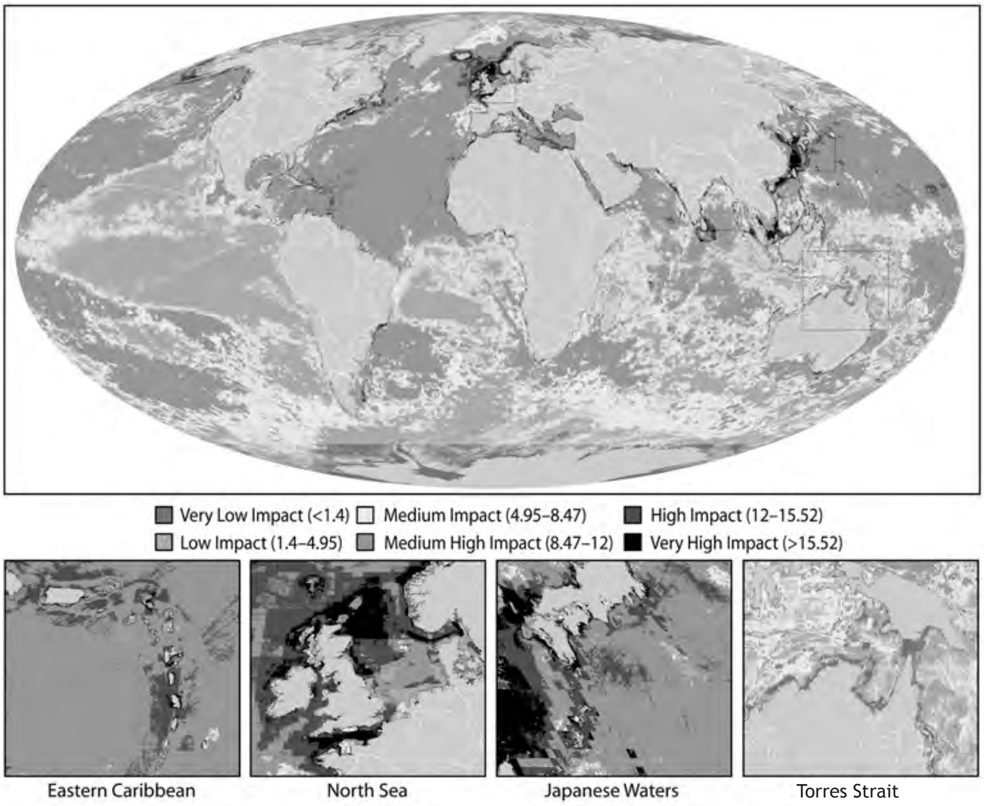


Figure 1 *The global map of cumulative impacts produced by the study, along with three maps of heavily impacted regions (the eastern Caribbean, the North Sea, and Japanese waters), and one relatively pristine area (the Torres Strait between Australia and Papua New Guinea).*

By courtesy of Benjamin Halpern and colleagues, University of California, Santa Barbara.

The full reference is: A global map of human impact on marine ecosystems by Benjamin Halpern and 18 others. Science *15 February 2008,* ***319****, No. 5865, 948–52 doi: 10.1126/science.1149345S. Supplementary information (including background information on how the datasets were compiled) may be found online at www.sciencemag.org/cgi/content/full/319/5865/948/DC1*

Most invasive species arrive in foreign ports by travelling in ballast water, so the impact of such species was modelled on the basis of the distribution of ports and the amount of cargo traffic passing through them. This method does not, of course, take account of species that arrive as a result of stocking aquaculture enterprises.

Fishing

Fishing was addressed by classifying fishing methods according to the level of habitat modification they cause (see Table 1). The global commercial catch data used was that developed by the Sea Around Us Project (http://www.seaaroundus.org/project.htm) on the basis of data from the FAO and other sources, detailing gear type and species caught for the most recent years for which data has been compiled (1999–2003). On the assumption that high catch rates have a greater impact in low productvity regions than in high productivity regions, the catch/area values were then divided by the average productivity in each cell, derived from the Vertically Generalized Production Model. This way of adjusting the catch data in a sense takes account of the size of the standing stock, but the authors make clear that it is only a proxy measure and is a poor indicator of impacts on highly migratory fish. Also, of course, the method cannot take account of all the fishing that has taken place over the course of centuries and even millennia, and was having a noticeable effect on fish stocks as long ago as the 16th century.

Structures and shipping

As might be imagined, determining the global distribution of benthic structures was not straightforward. In the model, the distribution of benthic structures is in effect the distribution of oil rigs. This is because the researchers based their distribution on the Stable Lights of the World dataset produced by NOAA's Defense Meteorological Satellite Program – stable lights in the ocean are generally flares from oil rigs, whereas moving lights may be lights being used by vessels fishing for squid and shrimp. Pipelines carrying gas and communication cables do not produce any lights, and so their impacts are omitted from the model.

The effects of commercial shipping were modelled on the basis of data supplied by the World Meteorological Organization Voluntary Observing Scheme (VOS) for 12 months starting in October 2004. This year had most ships with vetted protocols, but as the VOS system is voluntary much commercial shipping is not captured by it.

Implications for conservation

So what are the implications of the model's results for marine conservation? In particular, do they provide any guidelines for where best to site Marine Protected Areas (MPAs)? The first thing to note is that as the aim of the study was to produce a global picture, decisions about special conservation areas will always also require local information (as mentioned above, producing information at comparable levels of detail across the globe meant that resolution on a smaller scale was lost).

MPAs need to be sited where they will have the greatest effect. The study confirms what many people already believe, that this will usually mean choosing places where the dominant cause of damage is fishing. However, in areas where fishing has a relatively low impact, but (say) run-off or shipping have serious deleterious effects, the study suggests that the priority should be mitigating these effects, rather than spending precious resources establishing an MPA. At the same time, it is also important to target protective measures at areas that the study has identified as most pristine, and areas where fishing is currently light and fish populations are healthy and diverse, so that these can thrive and spread to surrounding areas.

Although it may seem that MPAs cannot address global drivers of change like global warming, the report authors point out that it is likely that by preserving more balanced and diverse food webs, and especially top predators and herbivorous fish, MPAs help to keep ecosystems more resilient to stress. Researcher Liz Selig (one of the report authors) and her colleagues have just finished a study showing that coral reefs sited in MPAs have fared better during bleaching events induced by warming than have corals outside MPAs. *Ed.*

We would like to thank Kim Selkoe and the other report authors for their help.

Lord Kelvin's legacy to marine science

The centenary of the death of William Thomson – better remembered as Lord Kelvin – was commemorated on 17 December 2007 by a wreath-laying ceremony in Westminster Abbey and by the unveiling of a new commemorative stone at a wreath-laying ceremony, organized by the Royal Philosophical Society of Glasgow, at the Thomson family tomb in Glasgow.

Born in Belfast in 1824, Thomson moved to Glasgow in 1832 when his father, James Thomson, became Professor of Mathematics. At the age of ten, he enrolled at the University; he went on to study at Peterhouse, Cambridge, and abroad, before becoming Professor of Natural Philosophy at Glasgow – aged just twenty-two – in 1846.

In the same year, he estimated the age of the Earth: he assumed that when created it was at the temperature of the Sun, and then he applied a rate of cooling appropriate to a body of the size of the Earth. (The age he deduced – around 100 million years – did not take account of the heating effect of radioactivity.)

During his half-century as Professor, Thomson attracted some 7000 students from all over the world, and established an advanced class in mathematical physics and a laboratory in which his students could undertake experimental work, mainly on problems derived from his own scientific and engineering research in electricity.

Perhaps the most widely known of Lord Kelvin's prodigious and varied achievements is the absolute temperature scale, now known as the Kelvin thermodynamic temperature scale. This formed part of his wide-ranging research in the fields of mechanical energy, heat and thermodynamics.

However, it is probably true to say that modern oceanographers know of Kelvin because of his interest in tides.* Around 1867 he devised the method of harmonic analysis whereby tidal motions are resolved into their component simple harmonic motions. The British Association for the Advancement of Science (BAAS) appointed a committee to promote the extension, improvement and harmonic analysis of tidal observations and the resulting report, prepared by Thomson, was published by the BAAS in 1868. The first tide-predicting machine (now in the Science Museum), designed by Thomson, was made in 1872 under the auspices of the BAAS. Kelvin-type tide gauges were the main gauges used to observe tides from 1891 until relatively recently.

The tide-predicting machine on display at the Proudman Oceanographic Laboratory is a Doodson–Légé Tide-Predicting Machine. Doodson's contribution to this machine resulted from his interest in the tide-predicting machine acquired by the Tidal Institute in 1924. This had been built by Kelvin, Bottomley and Baird of Glasgow, a firm whose origins lay in the highly successful partnership between Thomson and James White, a maker of optical instruments. White supplied apparatus for Thomson's laboratory in the new University premises at Gilmorehill, and worked with him on experiments. By 1854, White was using Thomson's designs to produce electrometers and electrical balances.

Of course, oceanographers are also familiar with the name of Kelvin because of Kelvin waves (including tides); and those interested in turbulence refer to 'Kelvin-Helmholtz instability'. Details of the original papers, and that concerning Kelvin's circulation theorem, are given below.

Although he published more than 600 scientific papers, in his lifetime Thomson was as famous for his inventions as for his academic work. His mariner's compass (produced by White) was the first instrument to provide a true reading of magnetic North in a ship with an iron hull. Earlier compasses were affected by the permanent magnetic moment of the ship and the additional moment induced in the hull by its orientation to the Earth's magnetic field.

Again in the marine field, he invented depth-sounding apparatus, to address problems encountered in laying the first trans-Atlantic cable, the success of which owed not a little to his expertise in transmission of electrical signals along cables, and signal detection.

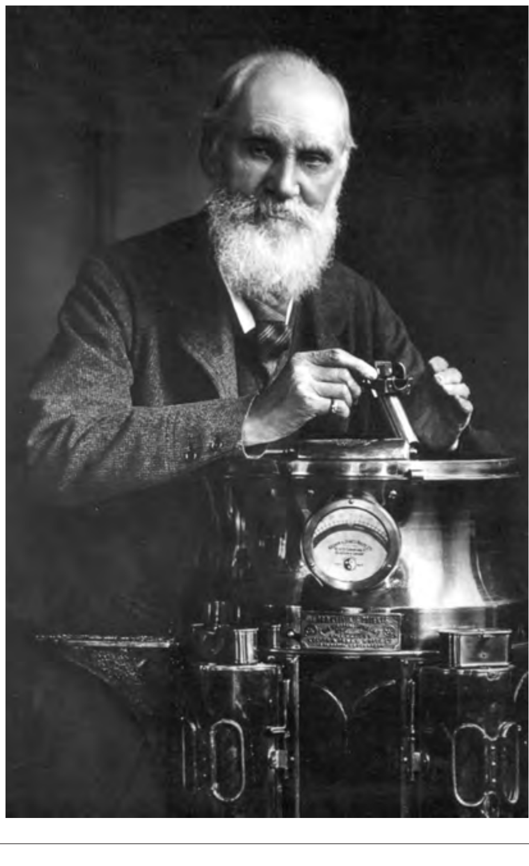
In 1866 he became the first ever scientist to be knighted, and in 1892 he was elevated to the peerage when he was created Baron Kelvin of Largs ('Kelvin' is a reference to the river that flows past Glasgow University).

In 1899, after 53 years as Professor of Natural Philosophy, Thomson resigned his chair at Glasgow. However, he promptly enrolled as a research student, making himself at the same time one of the youngest and oldest students in the University's history.

Thomson, W. (1869) On vortex motion. *Trans. Roy. Soc.* Edinburgh, **25**, 217–60. (This gives rise to Kelvin's circulation theorem.)

Thomson, W. (1879) On gravitational oscillations of rotating water. *Proc. Roy. Soc. Edinburgh*, **10,** 92–100. (The 'Kelvin wave' paper.)

Thomson, W. (1871) Hydrokinetic solutions and observations. *Phil. Mag.*, **42**, 362–77. (This relates to 'Kelvin–Helmholtz instability'.)



William Thomson, Lord Kelvin, with his marine binnacle compass, around 1904. Of the 70 patents successfully filed by Thomson, 25 relate to marine navigation.

The collection of research and demonstration apparatus gathered together by Lord Kelvin, and used in his pioneering research into electricity, telegraphy, and navigation, are to be found in the Hunterian Scientific Collection. His original tidal predictor may be seen at the Science Museum.

Photo by courtesy of the University of Glasgow

* See for example: *Scientific Papers. The Harvard Classics. 1909–14. The Tides.* (Evening Lecture to the British Association at the Southampton Meeting, Friday, August 25th, 1882) by Sir William Thomson (Lord Kelvin) http://www.bartleby.com/30/16.html

Aviso: a window on the world

Almost anyone interested in oceanography will find material of interest on the Aviso website (http//www-aviso.cnes.fr), but it is not as well known as it might be. Here is a quick overview

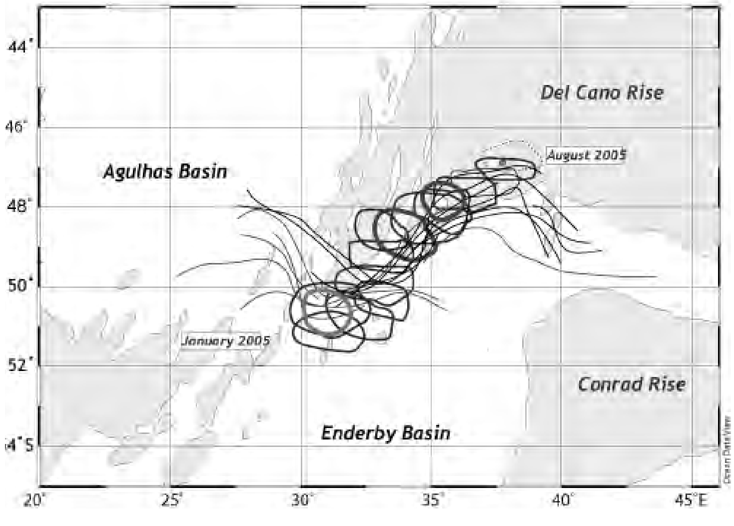
The Aviso user service was set up in 1992 to distribute *Topex/Poseidon* ocean altimetry data – Aviso stands for Archiving, Validation and Interpretation of Satellite Oceanographic data. It is fully funded by CNES (Centre National d'Etudes Spatiales, the French industrial and commercial institution in charge of French space policy) and now validates, archives and distributes data from SSALTO (Segment Sol multi-mission d'Altimétrie, d'Orbitographie et de localisation précise). AVISO (and its US counterpart PO DAAC) distribute data relating to satellite missions *Jason-1*, *ERS-1* and *ERS-2*, *EnviSat* and *Doris* (used for global positioning). Products are distributed on CDs, DVDs, and by FTP and LAS sites, and can be ordered via the online catalogue. Acquisition of the data and their distribution are funded by CNES, so access is free.

More generally, AVISO promotes the use of satellite data, and aims to make access to them easier and quicker. Over the years, the scope of its activities, and the range of its 'customers' have widened considerably. The website covers satellite data relating to: geodesy, geophysics, bathymetry and tsunamis; ocean circulation (large-scale and mesoscale); operational oceanography; tides, mean-sea-level and the greenhouse effect; seasonal changes in the North Atlantic and the Mediterranean; ice-sheets and sea-ice; climate (images relating to El Niño and the NAO, other decadal oscillations and seasonal changes); and atmospheric phenomena, wind and waves, rain and hurricanes. Marine biologists and biogeochemists also find much to interest them. The biology-related images available relate to the distribution of phytoplankton in relation to eddies in various parts of the ocean, and the activities of various marine animals in relation to ocean currents.

There are also images and information about land areas – water levels, rivers, lakes and enclosed seas. Methodologies have been developed for extracting data where the tracks of altimetry satellites cross water, even small bodies of water such as result from flooding. This could prove important as increased flooding associated with global warming is expected to result in the increase of certain diseases. Analysis of water-level variations measured by the *Envisat* satellite of an area of flooding adjoining deforested areas in Brazil, showed a clear correlation between water level and nearby hospital admissions for infectious parasitic diseases (e.g. malaria): both follow an annual cycle and appear to be increasing.

A regular feature is 'Image of the month', each of which is an image and/or animation constructed using a time-series of observations. For example, the 'image of the month' for January 2008 shows the trajectories of rafts of pumice produced by the eruption of Home Reef volcano to the east of Australia in 2006. The trajectories can be viewed as an animation – this could be of interest to marine biologists as the rafts collect a wide variety of organisms.

The topographically controlled path of a cold-core eddy between January and August 2005, superimposed on bathymetry, in the Southern Ocean. The dark circles correspond to the –20 cm sea-level anomaly produced by the eddy; about three such eddies are generated per year. (Thin lines represent the paths of various eddies generated between 1993 and 1998.)



Taken from: Swart, N.C., I.J. Ansorge and J.R.E. Lutjeharms (2008) Detailed characterization of a cold Antarctic eddy, *J. Geophys. Res.*, **113**, C01009, doi:10.1029/2007JC004190.

The 'image of the month' for April 2008 shows the sea-level anomaly and computed geostrophic currents of a cold-core eddy in the Southern Ocean (see below).

The 'Lively Data' section relates to the Live Access Server (LAS), which is a tool enabling online interactive visualization of scientific data.

Recent additions to the website include a new feature 'Sea views', dedicated to altimetry visualization, which provides global or regional images of absolute dynamic topography (i.e. geostrophic currents) and sea-level anomalies, and of wind speed and significant wave height.

It is also possible to follow the progress of the La Niña episode which has been occuring in the equatorial Pacific since the beginning of 2007. After an interruption in spring 2007, this event is continuing into the first part of 2008.

Educational and research resources

The resources on the website are targeted at different levels of expertise. The one headed 'Novices' relates to resources for schoolchildren, including the Argonautica educational programme. The 'Experts' section is for those wishing to use altimetry in their own work.

Ed.

Waves and weather from *Galileo*?

Since 2003, the GPS Reflectometry Experiment has been attempting to demonstrate that GPS reflections could be used to determine sea-surface roughness, using a method called 'bistatic radar' or 'forward scatterometry'. The Experiment has now successfully detected a 'fragment' of a reflected *Galileo* satellite navigation signal. The signal (reflected from the surface of the Arafura Sea, north of Australia) was only 20 s long, but its shape gave an indication of sea-surface roughness and hence of wind speed and weather at the place in question.

Using *Galileo* in this way would be a very cost-effective means of remote sensing, as a special transmitter would not be required (GPS signals are already broadcast to the Earth 24 hours a day). Furthermore, a satellite dedicated to GPS reflectometry would only need to carry a modified miniaturised GPS/*Galileo* receiver and an antenna, which could be accommodated on a tiny 10 kg satellite platform, meaning that a number of satellites could be launched together.
It is hoped that the improved satellite coverage of the ocean would make storm warnings possible, and potentially even detect tsunamis, as well as providing data for global climate models.

The magic of modelling: a tribute to Peter Killworth (1946–2008)

Amongst his varied spare-time pursuits Peter Killworth was a magician; perhaps that explained how he managed to contribute so prolifically to such a wide range of oceanographic studies. Or, more likely, it was because he possessed a keen intellect, an intuitive understanding of theoretical oceanography, and exceedingly good time-management abilities! In either case his output was remarkable. He published over 120 oceanography papers in refereed journals, predominantly high impact publications such as the *Journal of Physical Oceanography* (*JPO*). Many of his papers have been very influential; examples range across his broad spectrum of interests, from his earlier work on deep convection (his 1983 review of 'Deep Convection in the World Ocean', in *Reviews of Geophysics*, has been cited over 180 times) through to his more recent studies of planetary wave propagation (for example, Killworth, Chelton, and de Szoeke in *JPO* 1997 has over 140 citations). It is hard to think of an aspect of theoretical oceanography that Peter did not study. He advanced our understanding of detailed processes as well as contributing to the development of large ocean models. His papers encompass baroclinic instability, the effects of topography, lake dynamics, wave dynamics, inverse models, propagating features, sea ice, thermocline theory, the Antarctic Circumpolar Current, rotating hydraulics and flow over sills, western boundary currents, data assimilation, and more. Having identified a problem and a gleam of a solution, Peter would dive in and make the initial, fundamental breakthrough. Typically he would then put the problem aside as 'solved' (or 'impractical'), but then when the next critical issue was identified he would be back to solve the problem to the next level.

Peter gained his Ph.D in 1972 at the Department of Applied Mathematics and Theoretical Physics, University of Cambridge, supervised by Adrian Gill who had a great influence on Peter's development. Apart from a postdoctoral year at Scripps Institute of Oceanography, Peter continued at DAMTP until the mid-1980s. His early work concentrated on models of deep convection, with major papers on Antarctic Bottom Water formation and deep convection in the Mediterranean Sea. An early sideline on Rossby waves and baroclinic instability became the next focus of his research with a series of seminal studies. In 1985, he joined the newly formed Robert Hooke Institute in Oxford, a collaboration between the UK Met Office, the University of Oxford and the Natural Environmental Research Council. There Peter was put in charge of the project to construct and run the Fine Resolution Antarctic Model (FRAM), which was the first British ocean general circulation model. He turned to practical process studies in order to develop proper surface and bottom boundary conditions for the model, to identify the origin of variability associated with topography that dominated early FRAM simulations, and to understand the dynamical balances of the Antarctic Circumpolar Current. At the Hooke Institute, Peter attained the standing of an 'Individual Merit scientist' at 'Band 3 level'. That represents an honour awarded across the UK's research councils that few scientists attain, and yet, having joined the then Southampton Oceanography Centre (now the National Oceanography Centre, Southampton, NOCS), he achieved Individual Merit promotion to a still higher level, equivalent in standing to being the Director of a large research centre. He also held a Personal Chair within the School of Ocean and Earth Science of the University of Southampton.

Individual Merit posts are meant to allow outstanding scientists to concentrate on research without the managerial burden that high status normally entails. Peter used that freedom to develop the Bernoulli inverse method to analyse ocean currents. Peter developed the theory and method but then a student appeared to show it did not work in practical applications so they gave up on the topic. When later investigators resurrected the Bernoulli inverse by showing how it could be made to work with numerical model data, Peter came back to develop the technique into an operational scheme for making 10-day nowcasts of Atlantic circulation. He repeated the process with Rossby waves. When the first global sea-surface height observations from satellites showed that Rossby waves propagate faster than predicted by linear theory, Peter returned to the problem he had 'solved' 15 years earlier to develop the theory to take account of currents, bottom topography and the slope of the thermocline, leading to better agreement between observations and the advanced theory.

Peter Killworth, who died in January 2008

Despite his Individual Merit post, Peter did not back away from science administration. His oceanographic expertise and sharp insight were much in demand and led to his making significant and enthusiastic contributions to the organization and infrastructure of UK and international oceanographic science. His involvement in UK national committees ranged over radioactive waste disposal assessment, ocean research strategy, Antarctic research, and e-Science. He was a member of Working Groups of the Scientific Committee for Ocean Research (SCOR) on Arctic Ocean Heat Budget, Southern Ocean Circulation, and Improved Global Bathymetry. He contributed to the international planning and implementation of climate research, initially through the IOC/SCOR Committee on Climatic Changes and the Ocean of which he was Vice-Chair, and more recently through the World Climate Research Programme (WCRP). It was by applying his *theoretical* knowledge that he made a major contribution to the implementation of the World Ocean Circulation Experiment (WOCE), the largest collaborative *observational* oceanographic experiment undertaken to date. He became Co-Chair of the WOCE Scientific Steering Group and, as such, also attended, and contributed constructively to, meetings of the Joint Scientific Committee for the WCRP. His interest in polar science led also to his membership of the WCRP Arctic Climate System Study Steering Group (ACSYS).

Apart from his many scientific papers, Peter's contribution to scientific literature included a term as Associate Editor of the *Journal of Physical Oceanography* (1994 to 2000). More recently he applied his keen critical skills as Editor-in-Chief of *Ocean Modelling* which Peter was largely responsible for developing from a newsletter format into a well respected, partly web-based, scientific journal. He had a lecturing style which was both entertaining and informative, with the ability to enlighten both specialists and non-specialists alike. Hence he was a popular guest lecturer at several summer schools including the Woods Hole Geophysical Fluid Dynamics Program and, in the UK, the Earth System Science Summer School. Peter was extremely good with Ph.D students, being inspirational for the good students, but also generous with his time for less able students to help them finish. Many students that he supervised are now leading figures in oceanography in their own right, having received an unparalleled start to their research careers from Peter. He built excellent research teams, first in Oxford and then again in Southampton, in a creative, interactive working environment, demonstrating an instinctive approach to social networks.

Thus Peter Killworth's contributions to Oceanography include an outstanding body of publications, considerable service on national and international Working Groups and Committees, and a major contribution to the organization of a large international observational programme, as well as lecturing and journal editorship responsibilities. In recognition of his contributions he was made a Fellow of the American Geophysical Union (2000), and awarded the Fridtjof Nansen Medal by the European Geophysical Society (2002) and the Henry Stommel Research Award of the American Meteorological Society (2008).

For most people, these achievements would have been more than enough. However, if further proof of his intellect is needed, 'in his 'spare time', Peter separately pursued a second career in social network research, collaborating with US researchers, and publishing around 50 papers in that field. After-all, he was a magician! Peter's other hobbies included writing some of the first commercial computer games; he enjoyed travelling and was a keen hiker. At one committee meeting in Boulder, Colorado, while most of us were content to wander the snowy lower level paths during the lunch break, Peter climbed right to the top of the mountain. And he returned in time for the afternoon session! However it was on another US hiking trip that he had an uncharacteristic stumble. Probably this marked his first symptoms of Motor Neurone Disease. Despite his all too rapidly deteriorating physical condition, Peter continued to work at NOCS through to his untimely end.

Peter Killworth was born in Birmingham in 1946. He died at home on 28 January, 2008. He is survived by his wife, Sarah, his sons, Paul and Andy, their partners Louisa and Lucy, and his much-treasured grandchildren, Alice and Alexandra.

Peter Taylor and Harry Bryden
National Oceanography Centre Southampton

How to weigh water more accurately ....

As all physical oceanographers know, the velocity of geostrophic currents, and the flow patterns of water masses, depend upon the distribution of density in the oceans. Reliable determination of flow velocities depends upon the density of seawater samples being measured with an extremely high degree of accuracy, i.e. with an uncertainty of only ~0.001 $kg\,m^{-3}$ (1 in 10^6).

The normal way of measuring the density of a liquid is the hydrostatic method, i.e. the density of the liquid concerned is determined by means of Archimedes' principle: a sinker suspended on a wire is lowered into a tank of the fluid, and its apparent loss of weight (equal to the weight of fluid that has been displaced) is used to calculate the density of the fluid. This method has several disadvantages, particularly when the fluid in question is water. For one thing, the meniscus which forms where the wire passes into the water is rather variable and contributes significantly to the uncertainty in the measurement. Also, as the system is open, the gas content of the water, which affects its density, is difficult to control. Furthermore, any temperature gradient along the wire adds to the uncertainty in the measurement.

In order to eliminate these sources of uncertainty, and allow more accurate measurements of fluid densities over a large temperature range, Physikalisch-Technische Bundesanstalt (PTB), the German institute for metrology (measurement), has developed and recently refined a technique known as 'magnetic flotation'. Here, the wire has been replaced by a magnetic coupling: a controllable magnetic field produced by an electromagnet acts on a small magnet mounted at the holder of the sinker. The current needed to keep the sinker in a fixed position is a measure of the buoyancy experienced by the sinker, and hence of the density of the fluid that it is immersed in. The liquid is linked with the outside world only via a thin pipe by means of which the pressure can be regulated, so it is possible to measure using fully degassed water.

The magnetic flotation equipment. The sinker lies on a holder whose weight is compensated for by the buoyancy of a hollow sphere and an adjusting weight.

Using this new system, measurement of water density can be achieved to better than 1 in 10^6. However, there are still discrepancies around 4 °C – the temperature at which freshwater (but not seawater) attains it maximum density. This will affect the calibration of the equipment, which involves using ultra-pure water as a reference fluid.

Calling all writers!

At every Challenger Society biennial conference, *Ocean Challenge* offers a prize for the best report of the meeting, which is published in the next appropriate issue. If you are interested in writing, please consider having a go. The Editor of the new *Nature* journal, *Nature GeoScience*, won this prize at the conference held in Bangor in 1996.

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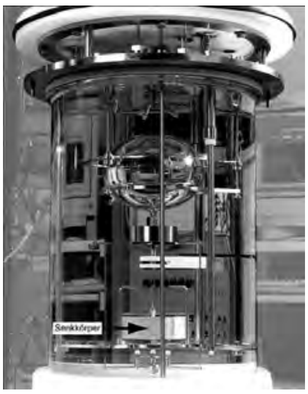

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A Svalbard summer: tales from the Arctic

Science and sight-seeing at the IPY International Sea Ice Summer School

Graham Tattersall

At the beginning of July 2007, I was invited to attend the International Polar Year (IPY) Sea Ice summer school, being held on the island of Spitsbergen. There were 80 successful participants selected from around 200 applicants, the criteria for attendance being an active interest in polar research and the status of non-established scientist. It was a fantastic opportunity to learn about current Arctic and Antarctic research and also a great chance to visit the most northerly town on the planet – Longyearbyen.

Spitsbergen is the largest of the four main islands of the Svalbard archipelago in the north-east corner of the Greenland Sea. Svalbard has an interesting status as a sort of international 'no-man's land', which has been governed by Norway since 1920 under the Svalbard Treaty. All citizens of nations who are signatory to the treaty have the right to live and work there, as long as they respect Norwegian law, so there are no passport controls or immigration procedures.

Longyearbyen has a population of around 2000, is about 1340 km from the North Pole, and lies in a glaciated valley beside Adventfjord, surrounded by snow-covered mountains. Longyearbyen was originally built as a coal-mining settlement, and the one remaining mine now supplies coal to the town for power and heat. The scenery is breathtaking Arctic tundra, where nothing grows for nine months of the year and then in June the brief summer brings flowers and grasses. The town itself looks untidy, with pipelines and buildings on stilts and roads raised on embankments to prevent the underlying permafrost from melting. Having said that, the place is spotlessly clean and the ground is littered only with skidoos which are parked up for the summer.

The summer school was organized by Dirk Notz from the Max-Planck-Institute for Meteorology in Hamburg and Karolina Widell from the University of Bergen, and was funded by Norway as part of their contribution to the IPY. It was hosted by the University Centre in Svalbard, UNIS, which specialises in Arctic science, and was in fact the third international summer school on sea-ice; the previous one was held in Finland in 1994. The summer school was arranged with typical Norwegian efficiency, from the moment we were met at the airport until the barbecue on the last night everything was very well organized and took place on time – just a few minutes late and the bus left without you! If there was a complaint it was the lack of vegetarian options on the menu – a problem in a frontier town that relies on hunting and shipped supplies rather than farming.

The organizing committee should be congratulated for arranging a very enjoyable and informative programme in one of the most beautiful and remote places on Earth. The venue was an stunning building constructed from wood and glass, with an open air viewing platform on the roof. The corridors were light and airy and the canteen was very

The former coal-mining town of Longyearbyen – at 78.15°N, the most northerly town on Earth.

spacious, giving a relaxed feel to the more informal parts of the programme. True to the tradition of Longyearbyen, outdoor shoes were left at the door, a custom that harks back to the coal-mining days when boots were generally covered with coal dust. It is very liberating to spend the day attending lectures and walking around poster sessions in your socks; but not so enjoyable when using the loo!

The programme was very comprehensive with eleven days of lectures spread over two weeks, covering everything from large-scale Arctic oceanography, down to the very small scale (what happens to water molecules as seawater cools below the freezing temperature in a laboratory experiment). The majority of the audience were physicists but about a third were scientists from other disciplines; the programme was sufficiently broad to interest everyone, covering aspects of chemistry, biology and biogeochemistry, as well as physics, technology and exploration. A few of the lectures contained a fair amount of advanced mathematics which was not understood by the entire audience but the majority of the lectures were accessible to most delegates. The prize for the best lecture series (awarded by the students) went to Don Perovich for his talks on albedo and how reflectance depends on the age of the ice in polar regions. His lectures were well planned, were understood by all and included a certain amount of humour. However, the most memorable lecture was given by an eminent professor who covered the overhead projector in maple syrup – all in the name of science – only to exclaim afterwards, 'Oh Dirk! I've forgotten the transparency!'

A boat trip was arranged for the rest day to see a glacier in Isfjord and visit the Russian mining town of Barentsberg. A barbecue was served on the aft deck in front of the glacier and we all grew steadily colder as the wall of ice sucked all warmth from us. After lunch we were informed that the barbecued meat had been a local delicacy – whale – which was not appreciated by all who had partaken. By mid-afternoon the day had brightened up and we approached a sunny Barentsberg. The once proud outpost of the USSR still recalls the Soviet glory days, with huge murals decorating the facades of many buildings. The town, however, has seen much better times, and the buildings are failing into disrepair as the population dwindles. From about 2000 at its height, it has now fallen to less than 500 inhabitants, of whom some 350 are miners and the remainder are their families. We were treated to a rapid tour of the settlement by the local guide who was also the interpreter, and then we were allowed to send postcards from 'Russia' (using the Norwegian postal service!), visit the local museum (where an understanding of elementary Russian gave you a slight advantage) or peruse the gift shop, which was open for about an hour whilst the boat was in port. It is possible to stay in Barentsberg (the single hotel offers reasonable rates in Norwegian krone), but no-one in our party took up the offer.

As well as the packed lecture schedule, there was also plenty of time for socialising. Svalbard is so far north that the sun remains in the sky from April through to August, dipping close to the horizon about 1 a.m. every morning. The light at this time is similar to that at dawn, so the human body receives no natural signals to go to sleep, which can be confusing – especially when you are spending all day in a darkened lecture theatre! The inhabitants of Longyearbyen sleep for about four or five hours a night in summer, making up for it in winter by sleeping for nine or ten. The weather was particularly good during the summer school, most days were sunny and the temperature even reached 10 °C. July (the only month when it gets above freezing) is usually cloudy and rainy with an average temperature of 6 °C.

Long daylight hours and good weather meant hiking after lectures was very popular. The main danger when hiking on Svalbard, particularly in summer, is hungry polar bears. It is only 12 years ago that two students were hiking a few miles from town when they happened upon a hungry young bear who hadn't migrated north with the retreating ice. One of the students was killed and the other sustained serious injuries as she jumped down the mountain to escape. The bear also met an untimely death and can now be seen in the foyer of the local hospital as a warning to people not to leave the town unarmed.

For 150 krone (about £12.50) you can hire a rifle straight over the counter – you don't need any identification or licence and you don't even need to prove that you know how to load it! There is an apocryphal tale of one tourist handing back a loaded weapon, with a big smile on their face, unaware that they had been posing a danger to the neighbourhood! Every few years there is a debate as to whether it is more dangerous to have hungry polar bears roaming the hills or untrained tourists carrying weapons.

The author – armed only with a walking stick ...

On the final evening of the summer school we enjoyed an Arctic barbecue on the beach, defending ourselves from the local tern population who seemed to think that the beach was their property, having spent the summer nesting there. Dancing was very popular as the weather had turned more seasonal and a stiff north-westerly breeze struck the beach head on. Little did we know a polar bear had been spotted on the edge of town looking for food by the docks. Men from the Governor's office chased the bear across the fjord, first by boat and then by helicopter; such chases can be life-threatening to bears as they can easily overheat in the summer. This time there was a happy ending as the bear escaped alive and headed north to find seals at the ice edge. That evening we all said our good-byes to friends old and new, many choosing to party until their flight home at 5 a.m.

Graham Tattersall is a shelf-sea modeller working at the Proudman Oceanographic Laboratory in Liverpool. His interests include modelling shelf-sea processes and recent climate change, particularly focussed on the European and Arctic shelf seas.

Challenger Society gets together in Galway

The Challenger Society Special Interest Group on Biogeochemistry and Biophysical Interactions in the Ocean met in September 2007 at the Martin Ryan Institute on the National University of Ireland campus in Galway, Ireland. Unusually for a Special Interest Group meeting, it was in the form of a conference attended by people from both within the Challenger Society and outside of it. The Challenger Society AGM was held at the end of the second day.

Robin Raine of the host instituion opened proceedings with a presentation on the prediction of harmful algal blooms (HABs) – proliferations of algae that can cause massive fish kills, and result in contamination of seafood with toxins and/or ecological damage through the development of anoxia or habitat alteration. Shellfish production is a significant activity around the coast of south-western Ireland, so it is important to be able to predict HABs. There is now considerable evidence that certain HABs, or at least their associated impacts, may be increasing globally. For more on this topic see http://ioc.unesco.org/hab/geohab.htm.

Barbara Berx discussed how tidally driven advection of chlorophyll favours high levels of mussel production in the Menai Strait, North Wales (see article on pp.17–20). Strangely perhaps, Martin White's presentation on the Tisler Reef – a cold-water coral reef, 70–160 m deep in the Skagerrak – recalled some of the ideas discussed by Barbara Berx, as they involved the extraction by the reef community of useful compounds, as water was advected over the reef in tidal currents. The reef has been the subject of an intensive measurement campaign within the EU-HERMES project, and results suggest that such communities may significantly affect fluxes of carbon and nutrients at continental margins.

Contourites are sediments found along continental margins, deposited at particular depth levels by geostrophic currents. Nick Owen discussed how contourites laid down along the Porcupine Bank in glacial and interglacial periods can be related to different climatic conditions (and different deep water masses). Modern (interglacial) deposits contain remains of a relatively high diversity of infaunal species of foraminiferans consistent with a seasonally high input of nutrients, whereas deposits laid down during the Last Glacial Maximum contain remains of more epifaunal species.

Peter Statham explained why islands are likely to be an important source of iron for phytoplankton living in the HNLC (high-nutrient–low chlorophyll) 'desert' of the Southern Ocean. (For more see Planquette *et al.*, http://eprints.soton.ac.uk/49509.)

Boris Kelly-Gerryen and David Hydes both stressed the value of long-term use of 'ships of opportunity' for collecting physical, chemical and biological data. Analysis of data collected using the 'FerryBox' on the *Pride of Bilbao* is suggesting a solution to a 100-year mystery – the summer appearance of low-salinity waters in the western English Channel. The cause seems to be flow from rivers entering the Bay of Biscay 500 km away; this freshwater input may be connected to intense blooms of the toxic dinoflagellate, *Karenia mikimotoi*.

Tom Rippeth considered the cause of seasonal subsurface chlorophyll maxima in shelf seas. He explored the implications of a series of estimates of the vertical diapycnal nitrate flux, which plays an important role in fuelling new production in the thermocline once the spring bloom has exhausted the photic zone. The largest values correspond to locations close to major topographic features such as a mound and the shelf break. Values for mid-shelf locations suggest that the vertical nitrate flux accounts for about half the new production in seasonally stratified continental shelf seas.

Stan van den Berg described a new way of determining humic substances in natural waters. The technique is based on voltametric detection after saturation of fulvic and humic acids with iron. Using this method it has been shown that humic substances are widespread (but in low concentrations) throughout Liverpool Bay.

It is estimated that up to half the biological export of carbon from surface waters comes from subtropical gyres – the 'oceanic deserts'. Ric Williams considered how biological export is maintained in these gyres, given that traditional estimates of nitrate supply to the photic zone (assumed to be limited by flux from below) only account for half the observed production. The latest models suggest that, away from western boundary currents, eddies etc. bring in relatively little nutrients; nitrogen-fixation plays a minor role. Surface waters of the ocean contain large amounts of dissolved organic nitrogen (DON) and phosphorus (DOP) but the extent to which they are taken up by phytoplankton in low-nutrient waters is unclear. Model studies suggest that DON plays a minor role, but that DOP formed in upwelling zones along the eastern boundery is transported into the interior of the gyre and recycled.

Developing the theme, George Wolff described results obtained when enzyme kinetics were used to assess reactivity and turnover times of bio-available DON and DOP in the North Atlantic during two cruises along the Atlantic Meridional Transect. It was found that, perhaps due to phosphorus-limitation in the northern subtropical gyre, turnover of DOP was significantly faster in the northern subtropical gyre than in the southern, but that there was no such contrast for DON. In the Atlantic subtropical gyres, the potential contribution of DON to primary production is <10%, but for DOP it reaches ~35% in the northern gyre.

Guillaume Charria used a 3D coupled physical/biogeochemical model to demonstrate that (particularly in subtropical gyres) the signature of planetary (i.e. Rossby) waves can be seen in surface chlorophyll concentrations/primary productivity, with local maxima generally associated with the wave crest, and minima generally associated with the trough. Both vertical and horizontal motion play a part.

Sue Hartman described multidisciplinary results from the long-term monitoring site on the Porcupine Abyssal Plain (the PAP site). Autonomous year-round measurements provide key winter nutrient data, which are still relatively rare from research cruises. Small inter-annual latitudinal shifts in the winter mixed layer result in large changes in nitrate supply and hence in spring productivity and particle flux; this sequence of events can be tracked over seasonal and interannual time scales.

Denise Smythe-Wright began her talk with a useful summary of the different groups of phytoplankton, which brought out the fact that chlorophyll is by no means the only pigment in marine algae. Many groups of phytoplanton have distinctive suites of pigments (e.g. zeaxanthin and divinyl-chlorophyll are characteristic of *Prochlorococcus*). This has important implications for the reliability of the algorithms used for satellite studies of ocean colour, as these are based around reflectances of chlorophyll.

The potentially serious consequences of ocean acidification for calcifying organisms, because of its effect in depressing levels of saturation of carbonate ion (CO_3^{2-}), are becoming increasingly apparent. Drawing on both data and modelling, Toby Tyrrell discussed seasonal and spatial variations in CO_3^{2-} concentration and levels of calcite saturation: e.g. the strong seasonal cycle of CO_3^{2-} in temperate surface waters is driven mainly by drawdown of dissolved inorganic carbon during the spring bloom. Globally, there is a strong latitudinal trend in surface ocean CO_3^{2-} concentration, which increases from poles to Equator.

Introducing the session on air–sea interaction, Colin O'Dowd explained that the production of aerosols is considerably more complicated than previously thought. Biogenic processes play a major role, affecting the concentration of aerosols and their chemical make-up; some aerosols contain a large proportion of organic matter.

Adrian Callaghan discussed why relationships between wind speed and white-cap coverage are not straightforward, particularly in swell-dominated seas. Areas of white-caps can also be spread by tidal currents.

The open ocean is generally assumed to be a source of ammonia to the atmosphere. However, Martin Johnson reported a study that found that the direction and magnitude of sea–air NH_3 exchange is highly dependent on water temperature, so that NH_3 fluxes were consistently *into* the ocean at high latitudes; in spite of very low dissolved NH_3 concentrations in surface water the flux is predominantly *out of* the ocean in the Atlantic subtropical gyres.

Saharan dust is an important source of iron for the North Atlantic. Alexandra Xylouri explained how iron oxide in dust changes its form during cloud formation, with an increase in the proportion of amorphous iron hydroxide, in the form of minute particles, which may be an important source of bio-available iron in the water column. Dissolution of iron from dust is increased by complexation of the iron with organic molecules, which Micha Rijkenberg demonstrated not to be supplied with Saharan dust, but to be of marine biological origin.

The final academic session was devoted to an overview of the work of the Irish Marine Institute, provided by Glenn Nolan and Evin McGovern (see http://www.marine.ie). The Institute's new headquarters are on the coast of Galway Bay at Oranmore, and are breathtakingly beautiful. It was not hard to see why this exceptional building, which was opened in 2006, has won two prestigious architecture awards.

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Environmental and marine scientists meet in Ancona

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The conference was extremely wide-ranging, with no less than forty talks covering environments ranging from open oceans and lakes, to mountains and forests; organisms from microbes to wolves; and scales from intracellular to global. On the walls of the conference venue there were hundreds of posters, covering a similarly broad range of topics – encountering disciplines seen as tangential to oceanography, that we knew little about, made studying the posters all the more interesting.

It is impossible to give a comprehensive account of all the sessions of this wide-ranging conference here. The abstracts (some in Italian and some in English) may be found online at http://www.congresso.ecologia.it/atti/abstracts_XVII.pdf.

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Ron O'Dor spoke about the global Census of Marine Life (CoML) programme, and was followed by Graham Shimmield who focussed on the European component of the project, EuroCoML, which has now been operational for three years. (For more on these projects and their historical component, the History of Marine Populations, see *Ocean Challenge*, Vol.15, Nos.1 and 2.)

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EFMS

How mussels get their "five-a-day"

Tidal advection of phytoplankton in the Menai Strait

Barbara Berx and John Simpson

In 2005, the Menai Strait mussel fishery accounted for 50% of the total landings of blue mussels (*Mytilus edulis*) in the UK. Even though the industry of the mussel fishermen is undeniably a significant factor in the success of the region's mussel production, the environmental conditions in this particular ecosystem also play a large role in the success story. A recent study involving a numerical model as well as observations has confirmed the hypothesis that the supply of phytoplankton through tidal advection from Liverpool Bay is the crucial element in promoting mussel growth in the Strait.

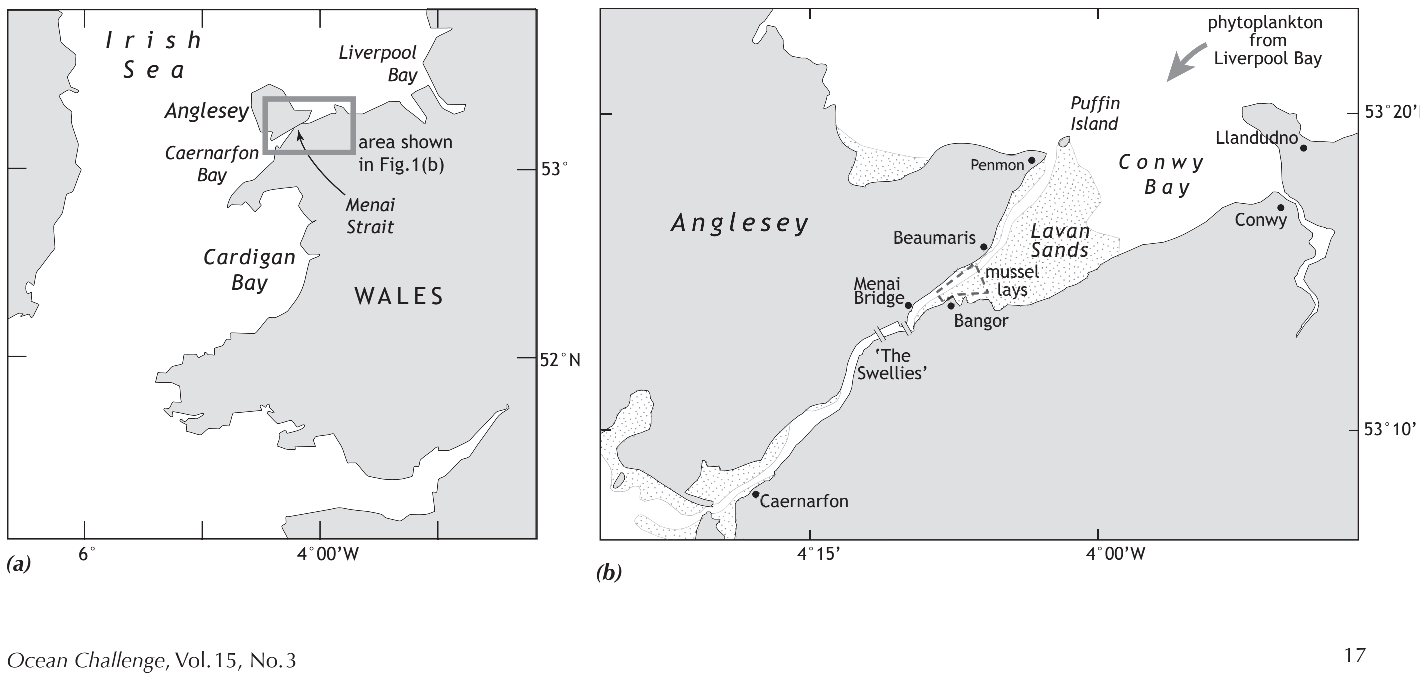
Separating the UK mainland from the Isle of Anglesey in North Wales, the Menai Strait not only supports the largest mussel fishery in the country, but also is an important habitat for other benthic species, such as sponges which also thrive in the channel. Located near the north-eastern entrance to the channel, the commercial mussel lays (i.e. mussel beds) extend along a large part of the intertidal and subtidal areas (see Figure 1(b)). The cover and density of mussels in these beds is apparent in the photograph in Figure 2 which shows the extensive intertidal lays near Bangor Pier.

Since the 1980s, and with the rise in the price of European mussels, the fishery has found its second wind through adoption of new techniques and investment in new harvesting vessels. We have postulated that the high rate of mussel production in this area, and the consequent success of the industry, is the result of the exceptional environment conditions within the Menai Strait.

So, what is so special about the ecosystem of the Menai Strait, and what sets it apart from other coastal regions? First of all, there is the unique topography of the channel. At the northern end, the Menai Strait is dominated by the large shallow region of the Lavan Sands, immediately to the south-west of which are the commercial mussel beds (Figure 1(b)). In the central section, the channel becomes shallower and severely constricted in a region termed 'the Swellies', where flow speeds exceed $2\,\mathrm{m\,s^{-1}}$.

The Menai Strait mussel lays owe their high productivity to the unusual tidal circulation in the channel and their proximity to Liverpool Bay

Figure 1 **(a)** *The setting of the Menai Strait between Anglesey and the Welsh mainland.* ***(b)*** *The position of the commercial mussel beds near the north-eastern end of the Menai Strait.*



Annual landings of mussels in the Menai Strait vary between 4000 and 10 000 tonnes, accounting for about half the UK total in 2005

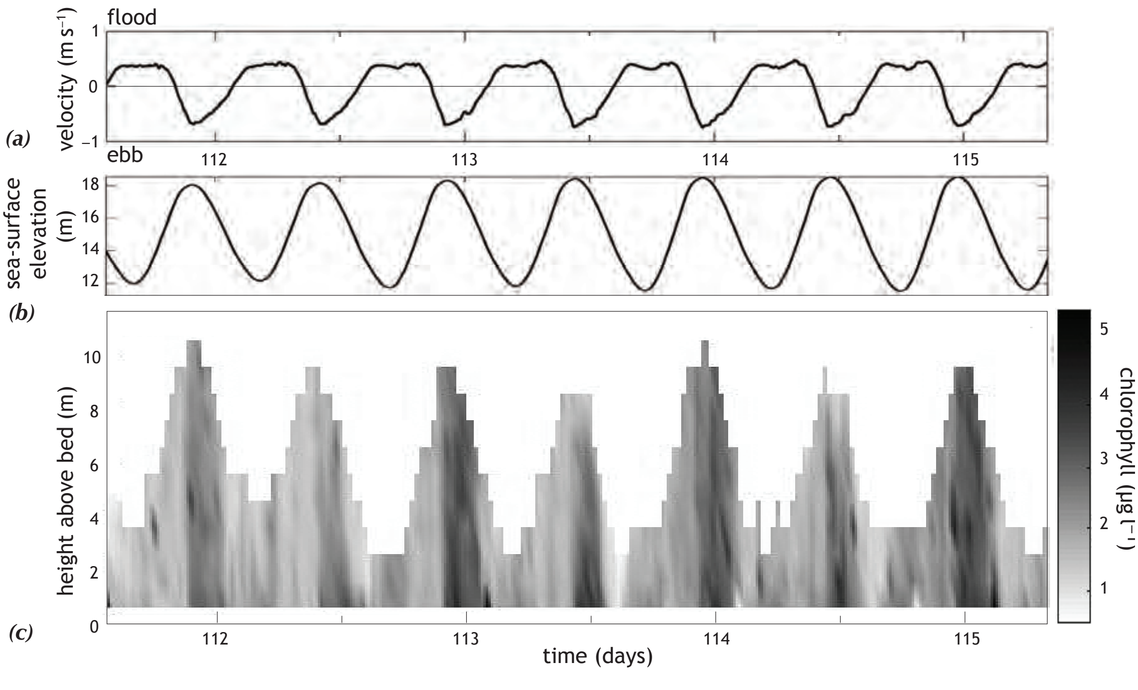
Figure 2 *The intertidal mussel beds of the Lavan Sands close to Bangor Pier. Commercial mussel growers initially seed mussel spat on the intertidal zone so that through exposure to the air the young can build tougher shells which will protect them from predation when they are moved into the subtidal zone to fatten up.*

The tides in the Strait are also different from most other coastal environments around the UK because the tide ebbs and floods from both ends of the channel, and the tidal ranges at the two ends are different. The former means there is a tendency to form a standing wave in which the current velocities are zero at times of high and low water, and strongest at mid-tide. The latter causes a slope in the sea-surface along the channel, which drives a current in phase with the elevation. In the resulting combined tidal wave, the phase difference between the velocity and elevation changes by ~130 degrees along the Strait.

When the transport is averaged over a tidal cycle there is a pronounced net transport towards the south-west (~300 $m^3 s^{-1}$ at neaps and ~800 $m^3 s^{-1}$ at springs), which is equivalent to the volume transport of a large river flowing through the channel. At spring tides, it only takes a couple of days for material to be advected from the northern inlet to the southern exit of the channel by the residual flow generated by the tide.

This study has looked into the possibility that the large residual transport is responsible for supplying the mussels with the food which they need to grow. Observations in the Menai Strait close to the mussel beds indicate pronounced

Figure 3 *Observations obtained in the Menai Strait in April 2005.* ***(a)*** *Depth-averaged along-channel velocity (m s^{-1}) and* ***(b)*** *sea-surface elevation (m) from an Acoustic Doppler Current Profiler deployed near the mussel beds. Note that the highest velocities occur during the ebb tide (and at peak tidal elevations).* ***(c)*** *Observed chlorophyll concentration (μg l^{-1}), with the highest chlorophyll concentrations twice a day at peak ebb tide. (cf. (a)).*



Observations in the Menai Strait show semi-diurnal oscillations in chlorophyll concentration, with much higher concentrations on the ebb than on the flood

When feeding, the average mussel can filter over 2 litres of seawater per hour

Figure 4 ***(a)*** *Mussels feeding on planktonic organisms, mainly phytoplankton, but also other organic particulate material, which they draw in through their frilly inhalant siphons (clearly visible in the mussels in the close-up in* ***(b)****); they expel the filtered water through their exhalant siphons (visible in the mussel at bottom right of (b)).*

Images by courtesy of Jens larsen, Danish Natural Environmental Research Institute (NERI).

semi-diurnal oscillations in the phytoplankton concentration, as indicated by measurements of chlorophyll fluorescence in the water column. In Figure 3, it can be seen that on the ebb tide (when the velocity is negative, i.e. flow is to the south-west), the chlorophyll concentration is much higher than on the flood tide, when the water flows back over the mussels. The reduction in chlorophyll concentration by a factor of approximately two is the result of filter-feeding by the dense population of mussels in the commercial lays (cf. Figure 4).

The presence of so many filter-feeders depletes the concentration of food downstream of the mussels, and this is observed in along-channel sections of chlorophyll. The interaction of mussel filtration and tidally driven transport is quite subtle and, in addition to the semi-diurnal (M_2) oscillations mentioned above, it also produces two important variations in chlorophyll concentration, with periodicities of ~6 hours (quarter-diurnal) and 14 days (the spring–neap cycle). The former is due to the flow at peak ebb being so fast (cf. Figure 3(a)) that it limits the influence that mussel feeding has on the water column's phytoplankton content: the mussels don't get a chance to filter out as much of the chlorophyll on the ebb flow, so that some relatively high-concentration water returns on the flood. This effect is most pronounced in the observations during spring tides, when currents are strongest.

The changes of chlorophyll concentrations in the Menai Strait on a spring–neap time-scale are related to these changes in the water transport through the channel over a 14-day period. Within a given period of time, more water flows over the mussels on a spring tide than on an ebb tide. However, the rate at which the mussels clear particles from the water varies much less. As a result, at neap tides, the mussels have a better chance at filtering out more chlorophyll than at spring tides, when the water moves faster. Downstream of the mussels, the concentration of phytoplankton is therefore lower at neap tides.

All these features of the space and time variations of the phytoplankton concentration are reproduced by the numerical model we have developed. It is based on a geometrically simplified one-dimensional advection–diffusion–filtration model (PHYBIO) which has been extended into a two-dimensional vertical model above the mussels. The model represents mussel-feeding through a single parameter which has been tuned to match the observed semi-diurnal oscillation in chlorophyll. This can be seen in Figure 5(c) (overleaf) where the oscillations in the predicted chlorophyll concentrations close to the mussel beds have a similar amplitude to the observations. In the analysis, the seasonal variation in primary productivity has been removed by dividing chlorophyll concentration by the input chlorophyll concentration at Puffin Island (cf. Figure 1(b)). This tuned filtration parameter is consistent with previous measurements of filtration by mussels.

In Figure 5(b) (overleaf) it can also be seen that, in the vicinity of the mussel beds, the semi-diurnal (M_2) chlorophyll oscillations in the numerical model lag the elevation signal by approximately 70–80°, which is in fair agreement with the observed phase lag.

The PHYBIO model, which includes advection, diffusion and mussel filtration, reproduces the observed oscillations in chlorophyll concentration

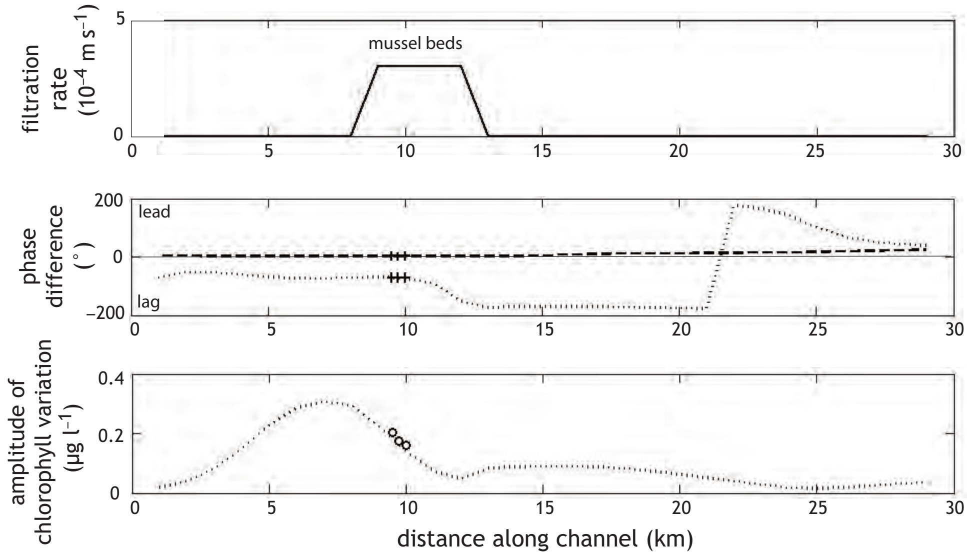
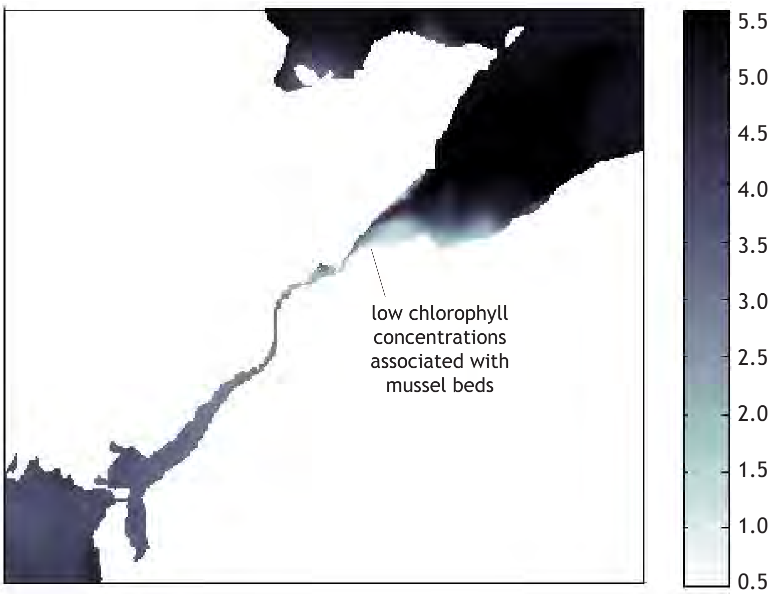


Figure 5 *Comparison of characteristics of the semi-diurnal chlorophyll oscillations in the Menai Strait predicted by the one-dimensional PHYBIO model (dotted lines) with observations obtained close to the southern edge of the mussel beds (individual data points). Distance is in kilometres in the along-channel direction, starting from Puffin Island at the north-eastern end of the Strait (cf. Figure 1(b)).* ***(a)*** *The variation along the Strait of the filtration parameter used by the model; the location of the mussel beds can be seen in the increase in filtration rate from 0 to ~ 0.0003 m s^{-1}.* ***(b)*** *The phase difference between semi-diurnal chlorophyll variations (dotted line) and the change in elevation due to the semi-diunal tidal signal (dashed line), which is effectively constant along the Strait. In both cases, crosses are observations.* ***(c)*** *The amplitude of the semi-diurnal changes in chlorophyll after the effect of seasonal variations in primary productivity has been removed (see text). The large increase in the semi-diurnal amplitude ~ 5–10 km down the channel reflects filtering by mussels.*

2D model simulations show the strong effect mussel filtration has on the chlorophyll concentration in the Menai Strait

Figure 6 *Modelled chlorophyll concentration (μg l^{-1}) in the Menai Strait, shortly after peak ebb, from a simulation with the two-dimensional TELEMAC model.*



This work is the result of a recent Ph.D research project at Bangor University, funded by the European Social Fund and Myti Mussels Ltd. For further information, the reader is referred to a recent paper entitled 'The interaction of tidal advection, diffusion and mussel filtration in a tidal channel', published in *Journal of Marine Systems*, **68**, 556–68 (2007).

A two-dimensional horizontal tracer model (TELEMAC), with a more realistic representation of the Menai Strait, has also been used as part of this study. It can be seen in Figure 6 that the model predicts a strong gradient in chlorophyll between Liverpool Bay and the Strait's interior. This is the effect of consumption by the mussels which has also been observed in time-series observations and along-channel sections. Moreover, analysis of the model results shows the oscillatory displacement of the gradient over the mussel bed by the tidal currents.

From this study, it can be concluded that the main process driving the food supply to the Menai Strait mussels is tidally forced residual advection from Liverpool Bay. The intense consumption of phytoplankton by the mussels results in clear space and time signals which are apparent in our observations and reproduced by the results of our model simulations. Further research to represent changes in the strength of mussel feeding in time and space (e.g. the effects of changes in mussel density or feeding behaviour on the sink term for chlorophyll) would be the next step in the development of models of this kind.

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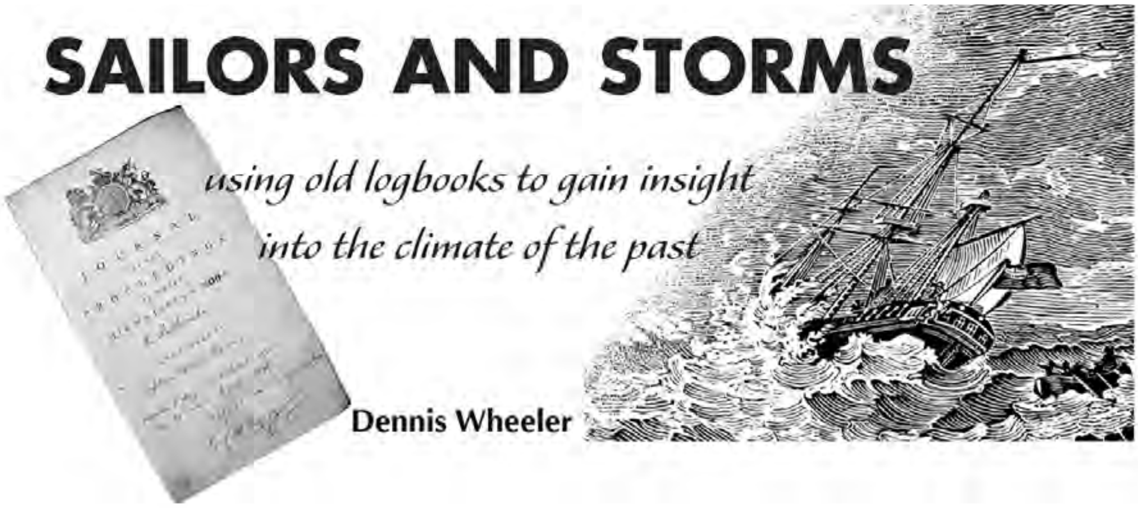
SAILORS AND STORMS

using old logbooks to gain insight into the climate of the past

Dennis Wheeler



At a time when climatic change in general, and global warming in particular, excite interest and concern in the scientific community and beyond, there is an understandable urge to know more about the way in which climate has behaved in the past. Land-based observers have left a legacy of diaries, accounts and observations of the weather that date back to the 17th century, and even earlier in some cases. Yet the land surface represents only some 30% of the planet's area; the greater extent of the ocean, and its intimate connection with our climatic system, mean that the sea-surface is of far greater importance. Over the past twenty years these connections and the role of oceans in governing climate have been increasingly recognised, yet reliable, long-term datasets for 'ocean' weather and climate are hard to come by and compare poorly with their land-based counterparts. There is, for example, nothing to compare with the well-known Central England temperature series of monthly means that goes back to 1659. On the other hand, monumental efforts have been made in recent years to collate and make available the growing volume of marine climate data.

Most important amongst the endeavours to secure instrumental data have been those of the ICOADS*/NOAA team (based in Boulder, Colorado). This database, freely available at http://icoads.noaa.gov/, provides instrumental data collected as far back as the mid-19th century; from this time onwards, shipboard instrumental data became increasingly standardized as a result of decisions made at the First Maritime Conference, held in Brussels in 1853, at the instigation of the US hydrographer Matthew Maury. But climatology remains an empirical science with an unquenchable thirst for data and information, and it is reasonable to ask whether marine observations survive from before the 1850s. At one stage, the answer would have been a resounding 'No', but recent work by a number of climatologists has demonstrated that far from there being a paucity of data, there is a hitherto unexpected abundance in the form of daily observations entered in the logbooks of ships from the so-called 'age of sail'.

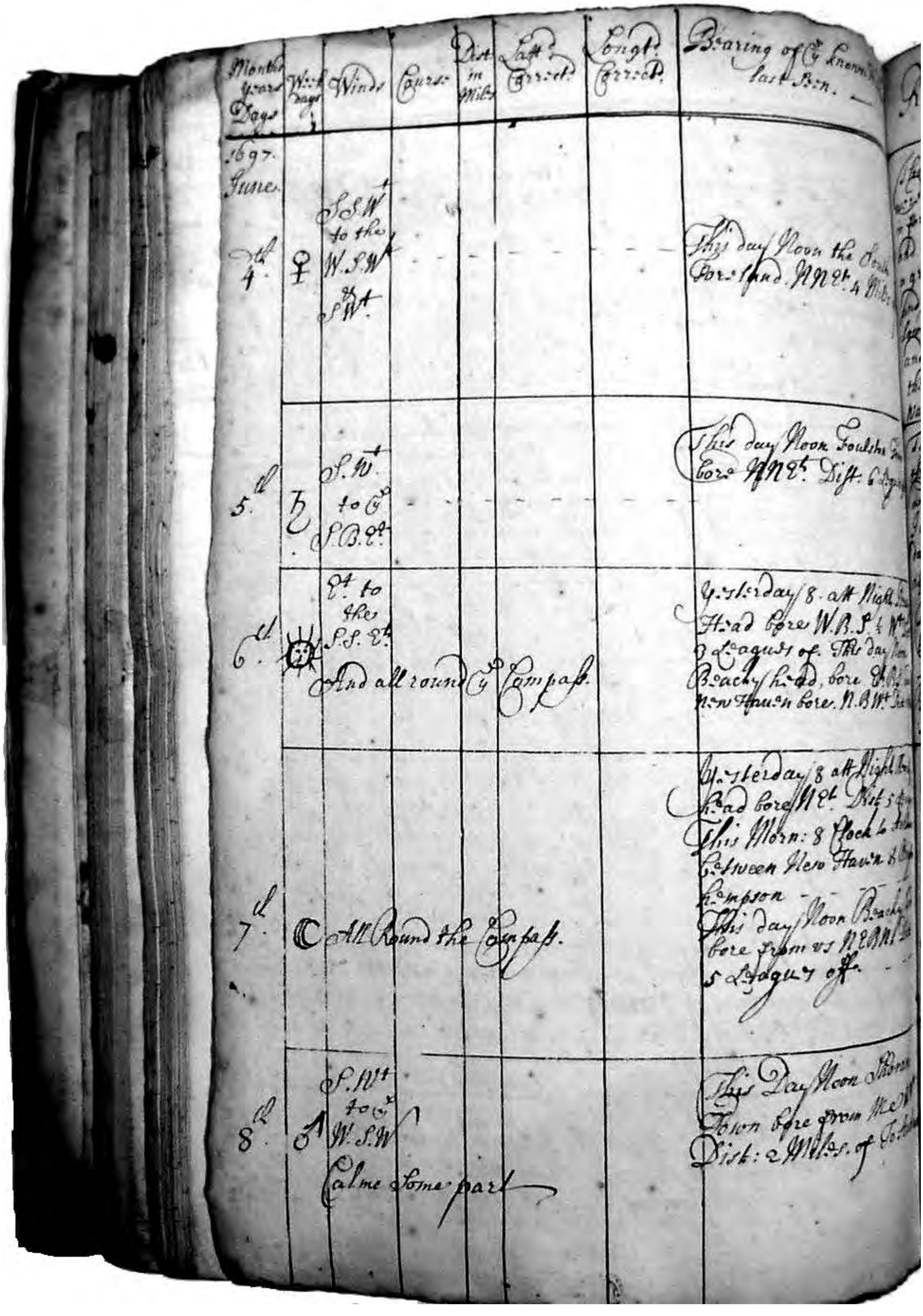
The role and importance of logbooks

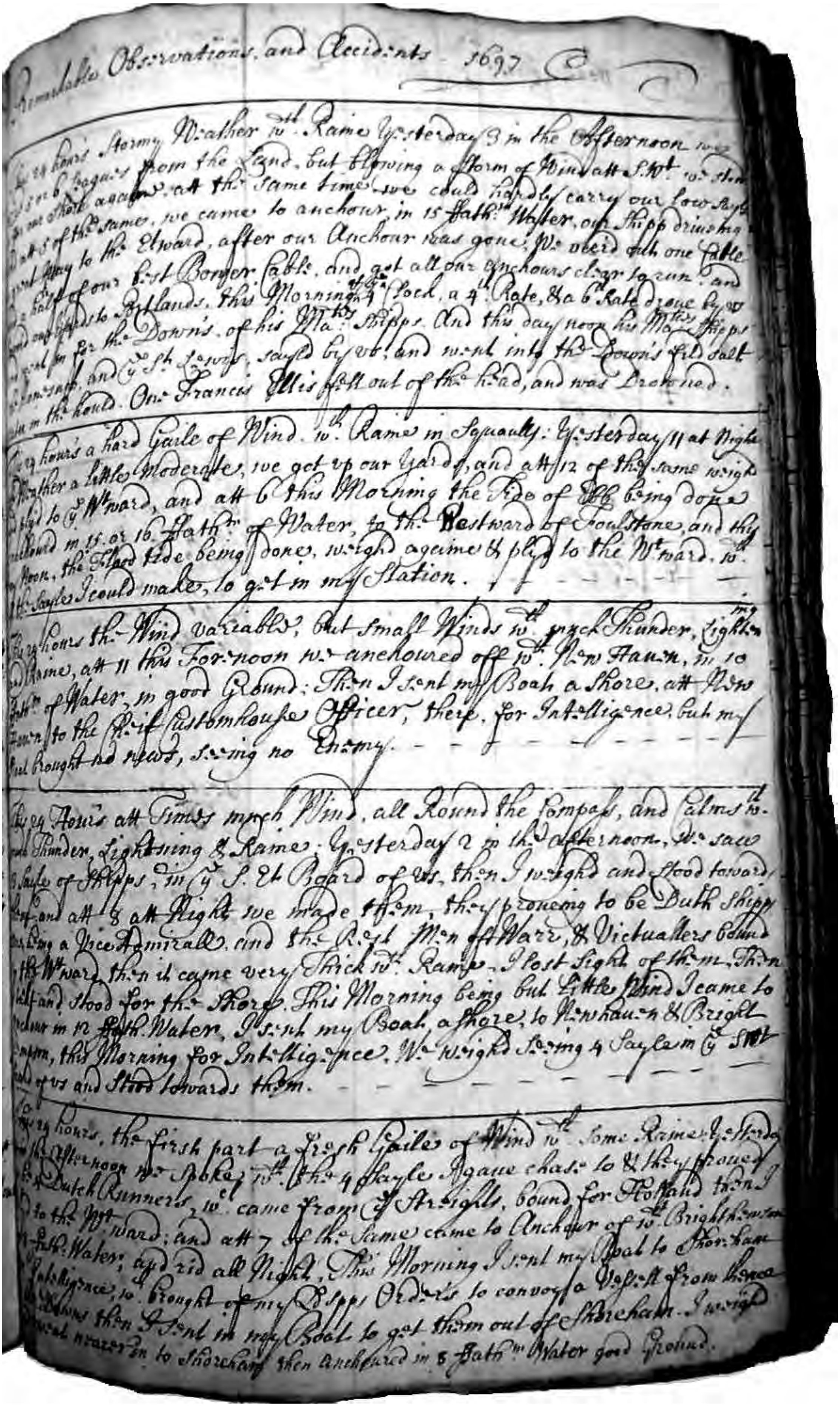
From the earliest days of voyages made out of sight of land, mariners kept journals of their adventures and findings, those of Christopher Columbus being perhaps the most famous. Such accounts acted as guides for later adventurers and began to assume the significance of national documents of great importance – and were therefore often shrouded in secrecy. However, the growth in the 17th century of European maritime empires following the examples set by Spain and Portugal saw the rapid growth in sea-borne trade and communication with, inevitably, the parallel development of fleets to protect national interests. By the late 17th century the early journals and diaries were replaced by more formally organized logbooks, each containing much the same sort of information (although the manner of its presentation differed from country to country). Pages from a typical Royal Navy logbook from the 1690s are reproduced in Figure 1 overleaf, and whilst there were small differences in layout, this was to remain the form of record and presentation for the next two centuries until motorized ocean-going vessels assumed dominance of the seaways. To such legendary figures as Rooke, Hawke, Rodney and Nelson, the completion of the daily record would have been a familiar process long before they reached the lofty status of Admiral, as it would have been to so many less famous, now long-forgotten, captains and commanders.

*ICOADS = International Comprehensive Ocean–Atmosphere Data Set.

So, what information did the logbooks contain, and why are they of such interest to present-day climatologists? As Figure 1 demonstrates, logbooks contained a daily record of the ship's position, its course, and a note on the wind directions and their changes. The right-hand page provided a narrative account of the events on board during the day in question but begin always with a statement of the prevailing wind force and a note of any, as it might be described today, 'significant' weather, which would include fog, rain, snow, thunder, squalls or sea conditions – indeed,

Figure 1 *Pages from one of the logbooks of HMS* Experiment*, for the beginning of June 1697, typical of the late 17th century. The left-hand page shows dates, days of the week, wind direction and navigational data. The use of symbols for days of the week was common from the mid-17th century to the early 18th century. The latitude and longitude columns (columns 6 and 7) are left blank as the captain could navigate from observable landmarks because the ship was on detached duty in the English Channel at the time. On the right-hand page is a general account of the day's activities on board, with each day's record beginning with an observation on the wind force and weather.*




Remarkable Observations and Accidents 1697

These 24 hours Stormy Weather with Raine. Yesterday 3 in the Afternoon [illegible] 5 or 6 Leagues from the Land, but blowing a Storm of Wind att S.W. we [illegible] at the Same time we could hardly carry our low sayls [illegible] of the same, we came to anchour in 15 fath^m Water, our Shipp driving [illegible] to the Elward, after our Anchour was gone, We veered out one Cable [illegible] of our best Bower Cable, and got all our Anchours clear to run, and [illegible] Ostlands. This Morning the Flock a 4th Rate, & a 6th Rate drove by us [illegible] for the Downs of his Ma^ties Shipps. And this day noon his Ma^ties Shipps [illegible] and ye St Lewis sayld by us, and went into the Downs [illegible] [illegible] One Francis Ellis fell out of the head, and was Drowned.

These 24 hours a hard Gaile of Wind with Raine in Squaully. Yesterday 11 at Night [illegible] a little Moderate, we got up our Yards, and att 12 of the same night [illegible] to ye W^tward, and att 6 this Morning the Tide of Ebb being done [illegible] in 15 or 16 fath^m of Water, to the Westward of Foulstone, and they [illegible] Noon, the Flood Tide being done, weighed againe & plyd to the W^tward with [illegible] Sayles I could make, to get in my Station.

These 24 hours the Wind variable, but small Winds with much Thunder, Lightning [illegible] Raine, att 11 this Forenoon we anchoured off of New Haven, in 10 fath^m of Water, in good Ground: Then I sent my Boat a Shore, att New Haven to the Chief Customhouse Officer, there, for Intelligence, but my [illegible] brought no news, seeing no Enemy.

These 24 Hours att Times much Wind, all Round the Compass, and Calms with Thunder, Lightning & Raine. Yesterday 2 in the Afternoon, we saw [illegible] Sayle of Shipps, in ye S. Et Board of us, then I weighed and stood towards [illegible] and att 8 att Night we made them, they proveing to be Dutch Shipps [illegible] a Vice Admirall, and the Rest Men of Warr, & Victuallers bound [illegible] the W^tward, then it came very thick with Raine. I lost sight of them. Then [illegible] and stood for the Shore. This Morning being but little Wind I came to [illegible] in 12 fath^m Water, I sent my Boat a Shore, to Newhaven & Bright [illegible] this Morning for Intelligence. We weighed seeing 4 Sayle in ye S^t [illegible] of us and Stood towards them.

These 24 hours, the first part a Fresh Gaile of Wind with Some Raine. Yesterday [illegible] Afternoon we Spoke with the 4 Sayle Above chased [illegible] they proved [illegible] Dutch Runners, wch came from ye Streights, bound for Holland then I [illegible] to the W^tward; and att 7 of the Same came to Anchour of with Brighthelmston [illegible] fath^m Water, and rid all Night. This Morning I sent my Boat to Shoreham [illegible] Intelligence, wch brought of my Boats Orders to convoy a Vessell from thence [illegible] Downs then I sent in my Boat to get them out of Shoreham. I weighed [illegible] nearer in to Shoreham then Anchored in 8 fath^m Water good Ground.

anything that would have a bearing on the progress, security and management of the ship. As today, the captain's logbook was a vital administrative document to be presented if he needed to justify his actions, courts-martial being the most obvious example.

It must be noted that whilst mariners in the age of sail had a particular interest in wind and weather and had considerable practical knowledge of such things, their interest was not driven by scientific curiosity. Their promptings were far more pragmatic and were the result of the need for safe navigation. Whilst latitude could be determined with reasonable accuracy from the 15th century, the determination of longitude – once described as the great intellectual challenge of the age – remained a problem until the close of the 18th century and the near simultaneous discovery of the method of lunar distances (by the Astronomer Royal, Nevil Maskelyne) and the invention of the marine chronometer (by John Harrison). Even after these two momentous events, longitude determination was hindered by the complexity of the former method (and the need for clear skies), and by the cost of chronometers, whose large-scale and economic production had to wait until well into the 19th century. Until that time, navigation proceeded on the basis of 'dead reckoning' (often thought to derive from 'deduced reckoning'), in which the longitude of the vessel was deduced from a knowledge of the speed and direction of the ship and by making allowances for the effect of wind (force and direction) on its progress.
It was for this reason that ships' officers often became such assiduous observers of the weather: their lives, quite literally, depended upon it.

The close attention to meteorological detail is itself of interest, but what transforms transient interest into scientific value is the number of such logbooks that have, perhaps surprisingly, survived, particularly in the UK archives, offering the possibility of yielding substantial volumes of data.

Logbooks in the sense in which they are currently defined began to be written by Royal Navy officers in the 1670s. Until the early 19th century all senior officers were obliged to maintain a logbook – the captain, the master (the officer responsible for navigation) and the ships' lieutenants (of which there might be up to five depending on the size of the vessel). Figure 3 (overleaf) shows the pre-printed front cover page of a typical 18th century logbook.

On their return from a voyage, officers were obliged to hand their logbooks to the local port officer who, in turn, passed them to the Admiralty. As official documents they were carefully pre-

Transcription of the entries in the logbook pages reproduced on pp. 22–23. The original spelling and punctuation have been retained. The tight binding of the document makes reading of some items unreliable. In column 8, 'Bore' means 'was at a bearing'.

As mentioned on p.22, the latitude and longitude columns were left blank as during the period in question, the captain could navigate from observable landmarks. Note the attention given to descriptions of the weather in the column for 'Remarkable Obervations and Accidents' column.

*Brithelmston is the present-day Brighton.

Left-hand page

	Work days	*Winds*	*Course*	*Dist. in miles*	*Latt^{d} correct^{d}*	*Longt^{d} Correct^{d}*	*Bearing of Ye known land last seen*
1697 June 4th	*Friday*	*SSW^{t} To the WSW & SW^{t}*					*This day Noon the South Foreland NNE^{t} 4 miles*
5th	*Satur-day*	*SW^{t} to ye SbE^{t}*					*This day Noon Foulkstone bore NNE^{t} dist 6 leagues*
6th	*Sunday*	*Et to the SSEt And all round ye Compass*					*Yesterday 8 att night Eastbarrow Head bore WbS ½ W 3 leagues of. This day Noon Beachy head bore NbW^{t}*
7th	*Monday*	*All round the Compass*					*Yesterday 8 att night Beachy head bore NE^{t} dist 5 leagues This morn: 8 Clock to Anchor Between New Haven and Brit helmson – – – – – – – – – – – This day Noon Beachy head Bore from us NEbN 5 Leagues off – – – – – – – – –*
8th	*Tuesday*	*SW^{t} To ye WSW Calme some part*					*This Day Noon Shoreham Town bore from NE Dist: 2 miles of To Anchor*

served and most can now be found in the National Archives in Kew (south-west London). Additional collections of lieutenants' logbooks can be found in the National Maritime Museum in Greenwich. The logbooks of merchant ship officers are scarce indeed, there being no formal system of logbook collection and storage, although mention must be made of the extensive collection of logbooks of officers of the English East India Company* that are held in the British Library and cover the period from the early 17th century to the 1830s. Some 4000 such logbooks exist, but this collection is dwarfed by that of Royal Navy logbooks of which over 120 000 survive for the period 1670 to 1850.† Figure 2 shows the decadal count of logbooks for the pre-instrumental period (up to 1845) and later decades. It is estimated that the average period covered by a logbook is six months and that the collection contains 20 000 000 days of data from before 1850 – a truly notable accumulation of hitherto untapped climatic information.

For the most part, the observational record for this period is non-instrumental and relies on the skill and experience of the observer to assess wind force and direction. It might, as a consequence, be thought that these data lack accuracy. Such concerns are perhaps understandable, but those who harbour them should be reminded that most Royal Navy officers of this period would have joined the Service at the age of 11 or 12, perhaps

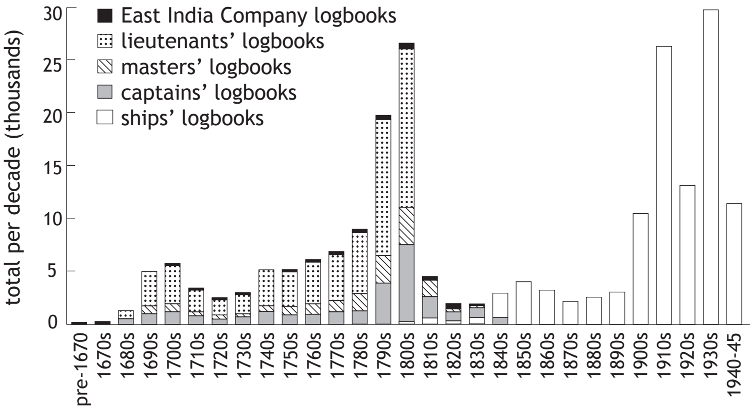


Figure 2 *Decadal count of English logbooks held in the three major British archives: the British Library, the National Maritime Museum and the National Archives. From the early 1800s, logbooks prepared by individual officers – lieutenants, captains and master – were gradually replaced by the single ship's logbook.*

The major British archives contain over 120 000 logbooks, including 20 million days of data from before 1850

*The English East India Company (1600–1873) was formed by London businessmen who banded together to import spices from southern Asia. Eventually, encounters with foreign competitors led to it employing its own military forces.

†RN logbooks for later years and up to the present are also held in Kew but they become increasingly instrumental in character. See also Figure 2.

Right-hand page

Remarkable Observations and Accidents 1697

These 24 hours stormy Weather wth Raine yesterday 3 in the Afternoon was 5 or 6 miles from the land, but blowing a storm of wind att SSWt we stood off our shore again att the same time we could hardly carry our low sails at 5 of the same we came to anchor in 15 ffathms Water, our ship drifting a great way to the E^{t}ward, after our anchor was gone We veer^{d} wth one Cable and a half of our best Bower Cable and got all our anchors clear to run and [.......] This morning a 4 Clock a 4th rate & a 6th rate drove by us and [.......] for the Downs, of His Ma^{ty} shipps, and this day Noon His Ma^{tys} shipps [......] and the [.....] sailed by us and went into the Downs [.......]. One Francis Ellis fell out of the head and was drowned.

These 24 hours a hard gaile of Wind wth Raine in squally. Yesterday at 11 att night the weather a little moderate, we gott up our yard and att 12 of the same night we plyed to the W^{t}ward, and att 6 this Morning the tide of the ebb being done anchored in 15 or 16 fath^{m} of water to the Westward of Foulstone, and by noone the flood tide being done weighd again and plyed to the W^{t}ward with all the sayle I could make to get in my Station.

These 24 hours the wind variable but small winds wth much Thunder, Lightning and Raine att 11 this fornoon we anchored off wth New Haven in 10 fath^{m} of water in good ground. Then I sent my boat at New Haven to the Chiefe Customhouse Officer there for intelligence but my search brought no news, seeing no enemy.

These 24 Hours Att times much Wind All round the Compass and Calms with much Thunder, Lightning and Raine. Yesterday 2 in the afternoon we saw 8 Sayle of Shipps in the S E Board of us then I weighed and stood towards them and att 8 att night we made them, they proving to be Dutch shipps and being a Vice Admiral and the rest Men of War, and Victuallers bound to the W^{t}wards then it became very thick with Raine I lost sight of them then [.....] and stood for the Shore. This Morning being but little wind I came to anchor in 12 ffath I sent my Boat ashore to New Haven and Brithelmston this Morning for intelligence We weighed seeing 4 sail in ye SW^{t}ward of us and stood towards them*

These 24 Hours, for the first part a fresh Gaile of wind with some Raine yesterday in the afternoon we spoke with the 4 sayle & gave chase so they proved to be 4 Dutch Runners who came from the Straits bound for Holland then I sayled to W^{t}wards and att 7 of the same came to Anchor of Brithelmston in 8 fath: of Water and rid all night This morning I sent my boat to Shoreham for intelligence such brought of my Shipps Orders to convoy a vessel from thence to the Downs and I sent in my boat to get them out of Shoreham. I weighed [......] nearer to Shoreham then anchored in 8 fath^{m} Water good Ground

Logbooks were formal Admiralty documents, often prepared on pre-printed sheets; front covers often included the Royal crest

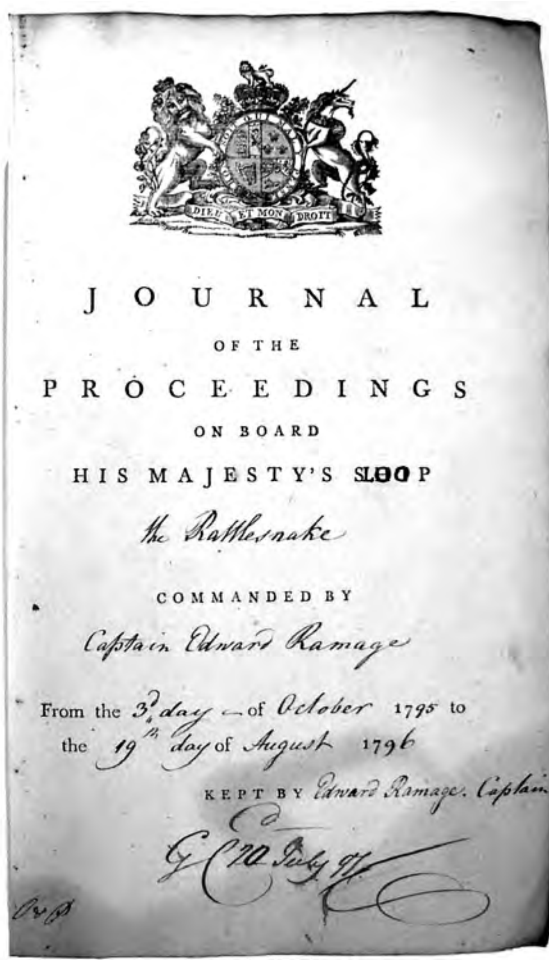


Figure 3 *The cover page of the logbook of HMS* Rattlesnake *for 3 October 1795 to 19 August 1796, compiled by Captain Edward Ramage. During the period in question, the vessel was carrying troops to Ceylon and then engaging with the Dutch off the Cape of Good Hope. The logbook was signed off on 20 July 1797 when the* Rattlesnake *eventually returned to her home port.*

younger, and would have been tutored by experienced officers in matters of observation and ship management, so their expertise must be beyond question.

Even today in the 21st century, observers on VOS's (Voluntary Observing Ships), when preparing reports for transmission to the various national and regional forecasting centres, use the same practices of estimation as their predecessors from two centuries earlier. Indeed, the advice offered by the UK Meteorological Office's *Marine Observer's Handbook* (published in 1977) would have prompted nods of approval by any 18th century naval officer: 'Non-instrumental observations are very important and, being estimates, they are dependent upon the personal judgment of the observer. This judgment is the product of training and experience at sea, together with practice in making the observations.'

Other maritime nations also enjoy a legacy of logbooks. They contain much the same sort of material, although presented in different ways. The number of surviving documents is regrettably small and, for example, Spain has less than 1000 and The Netherlands about 4000. France's collection is in the range of tens of thousands, whilst other, smaller, collections are known to exist in Denmark and Sweden but have not been exhaustively examined.

The CLIWOC project

Numbers notwithstanding, progress has been made in the use of logbooks for climatic research through the medium of the recently concluded CLIWOC project (Climatological Database for the World's Oceans: 1750 to 1850). The project was funded by the EC and supported English, Dutch and Spanish partners. The period in question provides a useful extension backwards in time from the start of the 'instrumental period' and a database of 300 000 days of data can be found at the project's website (www.ucm.es/info/cliwoc). The geographical coverage of the dataset is shown in Figure 4 in which it can be seen that the Indian Ocean and the North and South Atlantic Oceans are well represented but, perhaps not surprisingly, the Pacific Ocean long remained *mare incognita,* with few regular sailings over its vast distances. With that albeit notable exception, the coverage stands comparison with that provided today by the VOS service, and the sailing ships of those bygone days can, in this sense, be viewed as a network of observational platforms not dissimilar to that which exists today.

The task of the CLIWOC team was not one of merely transcribing information from the logbooks into the database, and pitfalls awaited the unwary. Terms for both wind direction and wind force, the two principal meteorological elements that were recorded, required careful adjustment before they could be used for scientific research. The wind directions were estimated with respect to the magnetic compass and had therefore to be corrected to true north. Furthermore, the 'variation' of the compass itself varies over space and time; fortunately such changes are sufficiently well documented for correction to be a relatively simple procedure.

Wind force terms could not be dealt with so easily. The Beaufort Scale, so well known today, was not adopted by the Royal Navy until 1836. For much of the CLIWOC study period, English (and indeed foreign) wind force terms conformed to the unofficial nautical vocabulary of the age. In the case of English logbooks, CLIWOC researchers encountered almost 100 different wind force terms. However, over 90% of all entries embraced the fifteen most frequently used terms, suggesting a widely adopted, if unofficial, vocabulary of wind force descriptors, some of which were adopted by Beaufort, but others of which were excluded from his system, which he first proposed in 1806. In fact, Beaufort's real achievement was not the invention of a scale, which already existed in an informal fashion, but codifying and defining the terms and securing the future of the scale through its formal adoption by the Royal Navy.

The CLIWOC project involved careful analysis of all the wind force terms used over the study period. The vocabulary tended to vary over time, developing towards the situation the young Frances Beaufort would be introduced to in the late 18th century. For example, in the mid-18th century the term breeze was scarcely used and, instead, all winds stronger than 'light airs' but less than 'a storm', were described as 'gales', with a suitable adjectival qualifier. Of the latter, 'strong' and 'fresh' gales are familiar enough, but 'light', 'small', 'gentle' and 'fine' gales are terms that have all passed out of use, to be replaced by the range of breezes that today occupy the lower half of Beaufort's scale and had become part of the mariner's vocabulary only as the 18th century drew to its conclusion. The CLIWOC team were confronted with the task of rendering these and other archaic terms into modern-day Beaufort Scale equivalents. This was done by adapting the methods of content analysis more popular with sociological studies but applicable to text-based narrative such as logbook entries. The result was the *CLIWOC Multilingual Meteorological Dictionary*, copies of which can be downloaded free of charge as pdf files from the project website (see above). As an example of the kind of information that can be found in the dictionary, Table 1 shows the English, Spanish, French and Dutch terms for wind of Beaufort Force 6.

The CLIWOC project has unquestionably brought logbooks to wider attention as far as climatic data are concerned. Not only has it identified this rich source and developed the means by which such archaic observations can be expressed in modern-day terms, it has also confirmed the reliability of the source. There is an obvious *prima facie* case for arguing for their accuracy – safe navigation depended upon it – but in addition use was made of logbooks compiled during convoy and fleet movements, where observations made independently on a number of different vessels could be compared. That these independent series should yield records in close agreement suggests the important conclusion that observational practices were consistent and trustworthy; the results of such studies have been published (see Further reading).

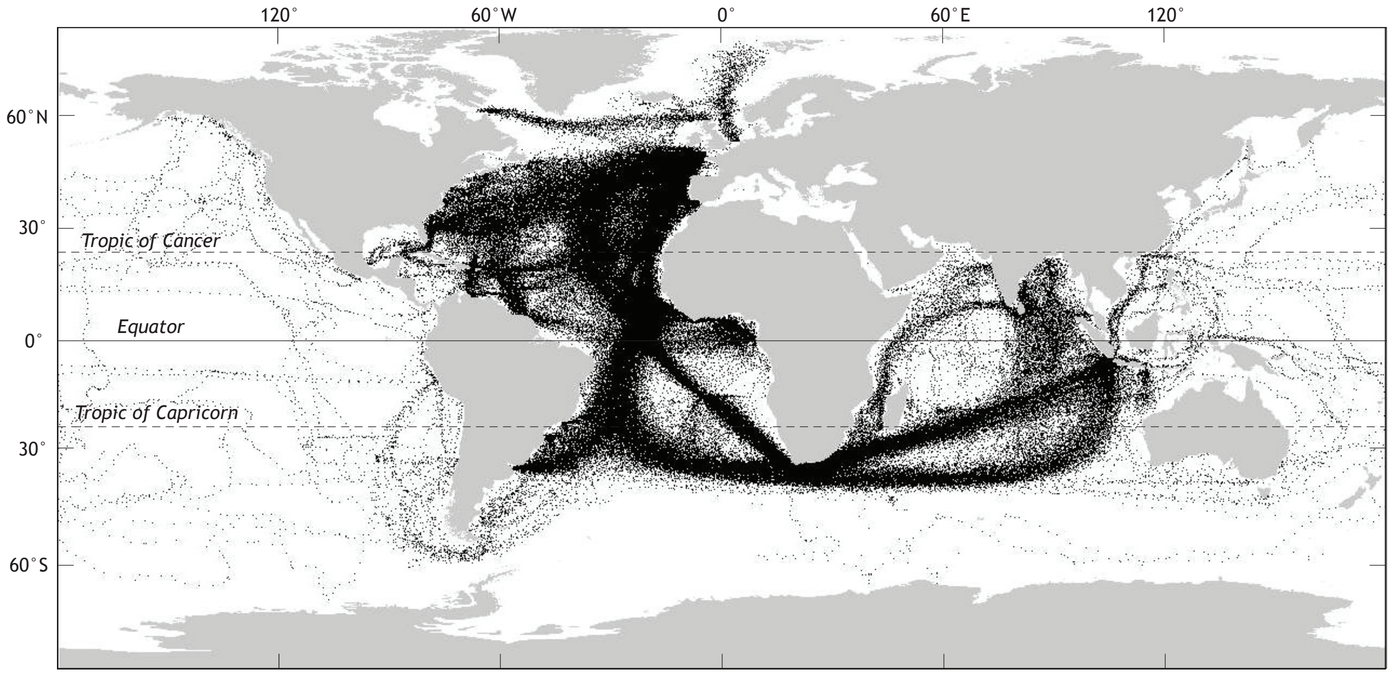
These remain early days for logbook-based studies. Of the 120 000 British naval logbooks from the pre-instrumental period, only 6000 were included in the CLIWOC project, while some sources abroad have yet to be examined, the Danish and Swedish collections being examples. Nevertheless, logbooks are now being used to support research programmes such as the EC-funded Millennium programme (http://geography.swan.ac.uk/millenium/) which will produce a 1000-year climate record for Europe and

Table 1 *English, Spanish, French and Dutch terms for wind of Beaufort Force 6 (strong breeze), taken from the* CLIWOC Meteorological Multilingual Dictionary. *Interestingly, both the Spanish and the Dutch names refer to the sails that would normally be hoisted for the wind strength in question. (As well as terms relating to wind strength, the Dictionary provides general information about logbooks, and names for the various types of sails in the four languages.)*

English	Spanish	French	Dutch
blows fresh	de alta vela	affraichi	dubbelgereefde,
brisk gale	de toda vela	brise carabinée	marszeilskoelte,
fresh trade	de toda vela larga	fraîchir	stijve gereefde marszeilskoelte
fresh wind	durito	frais	
steady gale	fresco	vent frais	stijve koelte
steady trade	frescote	vent moins impéteux	
stiff breeze	fuertecito		
strong breeze	vivito		

Data coverage of the CLIWOC project is good for the Indian and Atlantic Oceans but poor for the Pacific

Figure 4 *Data coverage of the CLIWOC project. The map effectively shows routes that ships followed in order to take advantage of the prevailing winds. These routes were slightly different, inevitably, for outward and for return voyages. The data coverage in the Indian Ocean (subject to seasonally changing monsoon winds) largely reflects the activities of the English East India Company.*



for which logbooks provide important wind field data to supplement and verify those derived from land-based documentary sources and from proxy sources such a tree rings and lake and marine sediments. More recently the RECLAIM project, operated under the aegis of NOAA, is trying to draw wider attention to this important source and is promoting interest through its website at http://icoads.noaa.gov/reclaim/.

Logbooks and the sea-ice margin

Finlo Cottier

Ship logbooks have also been used to reconstruct sea-ice conditions in the Arctic. During many of the voyages of exploration, and commercial whaling and sealing trips, the position of the ice-edge and descriptions of ice conditions were often recorded in the ship' log. However, there are many other sources of similar information: personal diaries, letters, maps and newspaper articles. These archives pre-date the relatively short era of satellite data by many centuries. The first records date from the mid-16th century but the main bulk of logbook records comes from the intense period of sealing and whaling beginning in the mid-19th century. Much of this data has been incorporated into the ACSYS Historical Ice Chart Archive (http://acsys.npolar.no/ahica/intro.htm) in a project led by the Norwegian Polar Institute. Due to the nature of the voyages and the locations of the whaling and sealing areas, the coverage of sea-ice observations is limited mainly to the area between Greenland and the Barents Sea and has greatest coverage in the seasonal period April to August. Analysis of these digitised records has revealed decadal scale oscillations of the northerly position of the sea-ice edge and longer term trends.

Knowledge of the ecology of Arctic species can also help with interpreting logbook records. Harp seals, for example, require particular types and concentrations of sea-ice for successful whelping of their pups. Detailed study of sealing records made during the annual hunt for harp seals has effectively documented changes in ice conditions in the Greenland Sea since the mid-19th century.

Wilkinson, J.P. and P. Wadhams (2005) A method of detecting change in the ice conditions of the central Greenland Sea by the whelping locations of harp seals. *Journal of Climate* **18** (8), 1216–26.

Divine, D. V., and C. Dick (2006) Historical variability of sea ice edge position in the Nordic Seas, *J. Geophys. Res.*, **111** C01001, doi:10.1029/2004JC002851. *(On-line article)*

Evidently, much remains to be done, but progress has been rapid over the past decade and logbooks, previously the domain of writers and historians, might be expected to take an important role in scientific studies. Much of this realised and unrealised potential is described in the CLIWOC project final report (see Further reading), available from the CLIWOC website (see earlier). Attention is also drawn to the interest generated in the scientific and wider communities in this undertaking that draws together climate change studies with historical and naval records that form part of Britain's rich naval documentary legacy.

Further reading

Garcia-Herrera, R. *and 12 others* (2005) *CLIWOC Multilingual Meteorological Dictionary.* Royal Dutch Meteorological Meteorological Institute (KNMI) publication, De Bilt, The Netherlands.

García-Herrera, R., G.P. Können, D. Wheeler, M.R. Prieto, P.D. Jones and F.B. Koek (2005) CLIWOC: A climatological database for the world's oceans 1750–1854. *Climatic Change* **73**, 1–12

García-Herrera, R., D. Wheeler, G. Können, F. Koek, P. Jones and M.R. Prieto (2004) *CLIWOC Final Report*, Universidad Complutense de Madrid.

Wheeler, D. (2005) An examination of the accuracy and consistency of ships' logbook weather observations and records. *Climatic Change*, **73**, 97–116.

Wheeler, D. (2006) Archives and climatic change: how old documents offer a key to understanding the world's weather. *Archives*, **31**, 119–32.

Wheeler, D. (2007) Looking at logbooks: science and the Nelsonian legacy. *Trafalgar Chronicle*, **16**, 130–40.

Wheeler, D., M. Barriendos, and R. Garcia-Herrera (2006) Ships' logbooks as new proxy documentary data for past Mediterranean climates, J. Luterbacher (ed.) in *Mediterranean Climate Variability over the Last Centuries*. Elsevier.

Wheeler, D., R. García-Herrera, G.P. Können and F.B. Koek (2006) *CLIWOC – Climatological Database for the World's Oceans 1750 to 1850: a review of the project.* European Commission, Brussels.

Wheeler, D. and C. Wilkinson (2005) The determination of logbook wind force and weather terms: the English case. *Climatic Change*, **73**, 160–85.

Wheeler, D. and C. Wilkinson (2004) From calm to storm: the origins of the Beaufort Wind Scale. *Mariner's Mirror*, **90**, 187–201.

Dennis Wheeler is Reader in Geography at the University of Sunderland. For several years he has specialised in the study of ships' logbooks as a source of climate information for oceanic areas. He is author of many scientific papers and texts.

Meeting of the Royal Meteorological Society

Saturday 28 June 2008 • National Oceanography Centre, Empress Dock, Southampton • 11 a.m. to 5 p.m.

Advances in Southern Ocean meteorology and physical oceanography: the exciting work of the 1920s and 1930s and why it is still important today

See http://.rmets.org/events/detail.php?ID=332

If you wish to attend, please write by 20 June to Mrs Susan Drew, Royal Meteorological Society, 104 Oxford Road, Reading, RG1 7LL, enclosing the registration fee of £10 per person

ICHO VIII

The History of Oceanography in the Mediterranean

26–29 June 2008
Villa Doria d'Angri (Naples)

The eighth meeting of the International Congress of the History of Oceanography (ICHO VIII) will be held this coming summer in Naples (Italy). The Congress is open to a wide range of topics in the history of marine sciences, but it would like to direct the attention of scholars to the following topics in particular:

Special Topics

Prince Albert and Mediterranean Oceanography
The role of the Stazione Zoologica in Marine Science
Marine Stations and Oceanography in the Mediterranean

Sessions

Oceanography and patronage
Oceanography in the time of the Cold War
Exploration
Modelling and forecasting
Outstanding individual scientists
Internationalism
Oceanography as a global science,
Oceanography as an interdisciplinary science
Development of measuring systems
Marine science and the protection of the seas

International meetings under the banner of 'International Congress of the History of Oceanography' have a long history. There have been gatherings in Monaco (1966), Edinburgh (1972), Woods Hole (1980), Hamburg (1987), Scripps (1993), Qingdao (1999) and Kaliningrad (2003).

In past meetings, the location of the Congress usually served as the focal point for many presentations. Since many meetings were held at major oceanographic centres, this orientation often attracted much local support and local interest. These presentations have often been complemented by papers with a broader scope, thus giving rise to the 'local to global' character of many Congresses. We anticipate a similar pattern at the Naples meeting, with its location in the Mediterranean but with its influence reaching far beyond the confines of the local Sea.

To date, all of the congresses have resulted in the publication of a volume of proceedings. Most of the publications have contributed to the emergence and rapid growth of a community of scholars who identify themselves as 'historians of oceanography'. ICHO VIII is intended to advance this scholarship through the participation of over 150 international scholars.

If you are interested in attending, please contact one of the Programme Chairs:

Keith R. Benson krbenson@interchange.ubc.ca
Walter Lenz waltlenz@web.de

Book reviews

A significant oceanographic achievement for 1930s Germany

Die Deutsche Atlantische Expedition 1925–27: Planung und Verlauf (*The German Atlantic Expedition 1925–1927, Planning and Execution*) by Reinhard Hoheisel-Huxmann (2007). Deutsches Schiffahrtsmuseum, Bremerhaven, und Convent Verlag GmbH, Hamburg, 136pp., €14.90 (hard cover, ISBN 978-3-86633-005-4).

May be ordered online from http://www.convent-verlag.de/.

In days of yore, large marine expeditions had an aura of extraordinary national achievement and it was usual for the scientific leader of the expedition to publish a lengthy narrative. Only in a few rare cases have people from succeeding generations retold such narratives – for example, in 1972 Eric Linklater did so for the *Challenger* Expedition. Now another such reappraisal has been published and, in my opinion, it is a very successful one. The original narrative was written by the captain of the *Meteor,* Fritz Spiess, who also served as scientific leader after the untimely death of the expedition's initiator, Professor Alfred Merz, shortly after the start of data-collection.

The German Atlantic Expedition 1925–27 (often called the *Meteor* Expedition) was the first systematic survey of more than half the area of Earth's second largest ocean, and thereby earned an outstanding reputation in the history of oceanography. The scientists conducted fourteen coast-to-coast sections between Africa and South America, along which profiles of various water properties from the sea-surface to the ocean bottom were obtained. Multidisciplinary observations were carried out, and important measurements in meteorology, physical oceanography, chemistry, planktology and geology were recorded at more than 300 stations. While the *Challenger* Expedition marks the beginning of modern oceanography, the *Meteor* Expedition is renowned for its systematic procedures.

In Germany, this expedition gained a special historic significance. After the defeat at the end of the First World War, German scientists and their home institutions were mostly excluded from cultural and scientific exchanges abroad, and even the German language was banned at international conferences. Therefore, when the idea of such an expedition came up, the German government immediately saw an opportunity to counteract the nation's isolation and provided a ship and the necessary personnel. This support engendered great enthusiasm among the chosen participants, because at home everything seemed quite hopeless.

One appealing feature of this newly published book is that it condenses the 442 pages of the original expedition narrative down to 125 without dispensing with many of the figures. In fact, some new ones have been added to illustrate how an understanding of the general circulation of the Atlantic developed during those years. Today we regard it as part of the 'ocean conveyor belt', and this realisation enhances the value of the original data.

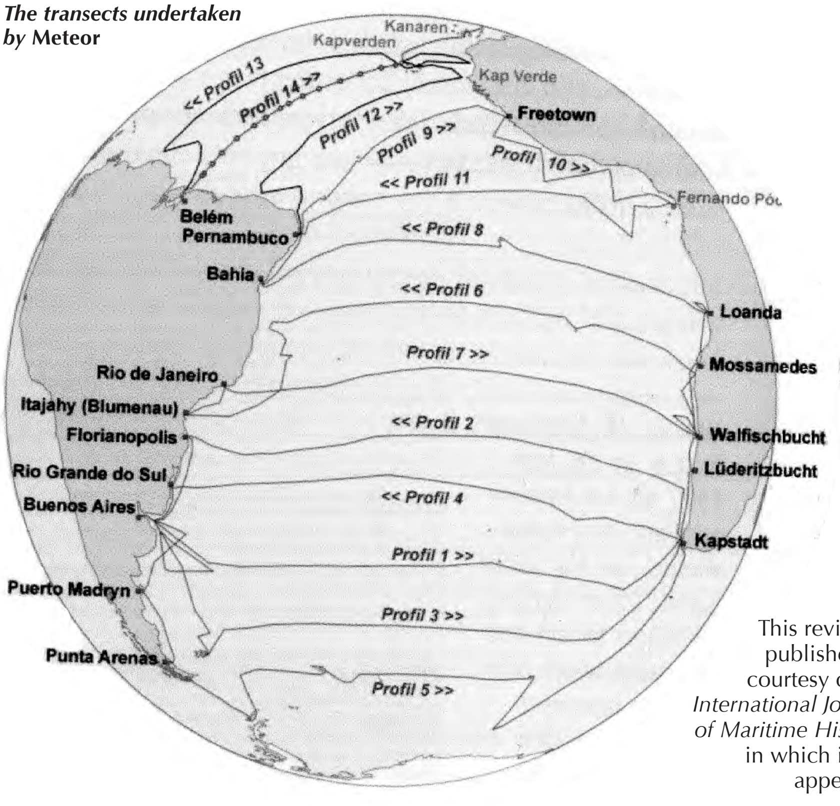
In the first part of the book the author outlines the two main ideas behind the expedition. After 1918 the German government sought for opportunities to demonstrate outstanding activities in areas that were not politically sensitive and which would be visible abroad. The second motive was more pragmatic: the German navy – much reduced in size – intended to put to civilian use one of its remaining medium-sized vessels, which was, in fact, just a hull – only half-completed, but already christened *Meteor*.

An oceanographic expedition to the South Atlantic would achieve both goals. The design of the cruise plan would also meet strategic objectives. Either side of the Atlantic, at the coastal ends of the latitudinal transects, the ship would call into many ports where German settlers would have an opportunity to make contact with their homeland for the first time since the First World War. Last but not least, the expected scientific results promised to be spectacular, as in those days this part of the ocean was mostly unknown.

The second part of the book comprises a detailed description of the observations, the scientific equipment, the crew and the scientific staff, as well as the preparatory activities. During *Meteor's* passage to Buenos Aires, the expedition's starting point, the instrumentation was tested and personnel trained in how to handle it. The routine work began when the vessel left Buenos Aires.

The book continues by describing activities during the course of the expedition, as the sections were traversed. In addition, there are: biographies of the leading personalities, Professor Alfred Merz and Captain Fritz Spiess; discussion of the scientific methods

***The transects undertaken by* Meteor**



This review is published by courtesy of the *International Journal of Maritime History*, in which it first appeared.

employed, statistical summaries of the scientific results, and the schedule of the complete expedition; and descriptions of everyday life on board and sightseeing activities during port calls. There is also a description of how the results of the expedition were disseminated.

The book features an extensive list of footnotes and the archival sources used, a sizeable bibliography, and a complete list of the sixty-two publications based on the scientific results of the *Meteor* Expedition.

Walter Lenz
Centre for Marine and Climate Research
University of Hamburg

Reverse of the Expedition Medal (First Class) (by courtesy of Glenn Marty Stein)

A celebration of the Gulf Stream

The Gulf Stream by Bruno Voituriez (2006). IOC Ocean Forum Series, UNESCO Publishing, Paris, 221pp., €18 (flexicover, ISBN-10: 92-3-103995-9; ISBN-13*: 978-92-3-103995-9).

May be ordered online from http://publishing.unesco.org/

This is a very unusual oceanography book, and is not a textbook in the normal sense. As the author explains at the beginning, it owes its origin to a dialogue between the Académie française and the Clube des argonauts, which tries to bring to public attention the problems posed by climate change.

Chapter 1 starts with the 'Scientific history of the Gulf Stream', beginning with the voyages of Christopher Columbus. Not surprisingly, given the genesis of the book, the longest chapter is that on 'The Gulf Stream and the Earth's climate'. This considers the basics of the climate system, the Gulf Stream's influence on western Europe, the North Atlantic Oscillation, and the part played by the Gulf Stream in driving the thermohaline circulation. Chapter 4 looks briefly at characteristics of the different sections of the current – the Florida Current, the Gulf Stream proper, with its warm-core and cold-core eddies, and the North Atlantic Drift. The short concluding chapter discusses the importance of large-scale oceanographic projects, and the need for a global Earth observation system.

The style is engagingly informal, and scientific ideas are introduced with a minimum of jargon. Each chapter begins with a brief summary, and there is a useful Glossary. However, this is not a book to help the reader get to grips with the basic science – the discussion ranges widely over a number of disciplines, and rigorous explanations would not be possible in the space available.

More importantly, many topics in oceanography (particularly physical oceanography) are very difficult to explain without extensive use of diagrams, and here (as in many other texts), the illustrations are grouped together, and are not close to the relevant text. Sadly, this reduces their usefulness considerably.

The use of language is much more interesting than found in the average textbook, and this adds to the book's charm. Those of us used to reading scientifc textbooks and articles may find the lyricism (and the occasional quaint English) distracting, and feel that sometimes they detract from the clarity of scientific explanations. However, any such doubts are likely to be swept away by the breadth of the content and the enthusiasm and humour with which it is conveyed – it is easy to imagine this book changing the mind of someone who had thought that science was boring!

The book will appeal to people who are interested in the development of ideas, are open to different disciplines, and who revel in the interconnectedness of the Earth's natural systems.

Angela Colling (*Editor*)

Oceans Past: Management Insights from the History of Marine Animal Populations

edited by David J. Starkey, Poul Holm and Michaela Barnard

Readers who enjoyed the article 'The past is the key to the future: how marine historians are providing the long view of marine ecosystems' by Kira Paulli Pravato in *Ocean Challenge*, Vol.15, No.2, will find much of interest in this well illustrated book, based on papers presented at the conference 'Oceans Past: Multidisciplinary Perspectives on the History of Marine Animal Populations', held in Kolding, Denmark, in October 2005.

The chapter titles convey the intriguing nature of the content:

- Oceans past: history meets marine science
- Invasive or native species? The case of the common periwinkle snail (*Littorina littorea*) in northeast North America
- Social conflict, over-fishing and disease in the Florida sponge fishery, 1849–1939
- 'Quite the choicest protein dish': the costs of consuming seafood in American restaurants, 1850–2006
- Baiting our memories: the impact of offshore technology change on inshore species around Cape Cod, 1860–1895
- Mapping historic fishing grounds in the Gulf of Maine and northwest Atlantic Ocean
- There she blew! Yankee sperm whaling grounds, 1760–1920
- Depletion within a decade: the American 19th-century North Pacific right whale fishery
- Sperm whale catches and encounter rates during the 19th and 20th centuries: an apparent paradox
- Understanding the dynamics of fisheries and fish populations: historical approaches from the 19th century
- A political history of maximum sustained yield, 1945–1955

The book was published in 2007 as part of the of the Earthscan Research Editions Series (192pp., hardback, ISBN 978-1-84407-527-0). It may be obtained via http://www.earthscan.co.uk/?tabid=1482 for £65 + £3.50 postage and packing.

Treatments of turbulence

Marine Turbulence: theories, observations and models edited by H.Z. Baumert, J.H. Simpson and J. Sündermann (2005). Cambridge University Press, 630pp. plus a CD-ROM, £112.20 (hardcover, ISBN-10: 0-521-83789-8; ISBN-13: 978-0521-83789-7).

This book is a very large and comprehensive overview of measurement techniques and theories for marine turbulence and mixing processes. It arose from a 'Concerted Action' project of the European Union's 3rd Marine Science and Technology Programme. The

*Books published since 1 January 2007 have a 13-digit ISBN; books published before that have a 10-digit number, and those older books still in print now have both.

project was called 'Comparative Analysis and Rationalization of Second-Moment Turbulence Models' (CARTUM), and it ran for three years, between 1999 and 2001. CARTUM aimed to bring together microstructure observations, turbulence closure models and direct numerical simulations, with the overall goal of improving turbulence models. This 53-author, 630-page book, published in 2005, appears to be the project's major output.

The book is divided into eight main parts. Part 1, 'On the physics of turbulence', begins with a sketch of the physical nature of turbulence, and goes on to discuss stratification, intermittency and horizontal mixing. Part 2, 'Observational methods', describes instruments and techniques such as microstructure sensors, horizontal and vertical profilers, optical, acoustic and tracer methods, and others. Part 3, 'Numerical and computational methods', deals with topics such as direct and large-eddy simulation of turbulence, and aspects of turbulence closure models. Part 4, 'Boundary layers', pertains to the turbulent structure of the ocean surface and bottom boundary layers. Parts 5, 'Estuaries, fjords and lakes', and 6, 'Shelf seas and the shelf edge' discuss special concerns in these regions. By far the largest section is Part 7, 'Large-scale processes', which occupies a quarter of the book. It is about large-scale, quasi-2D turbulent flows (i.e. eddies) and their interaction with 3D turbulence. Finally, Part 8 is 'The CD-ROM: data sets and numerical codes'. It is worth noting that the book is a monochrome production. Colour figures are found on the CD-ROM, and reproduced in the book in greyscale, which is occasionally inconvenient.

George Mellor writes in the Foreword that 'for researchers in the marine-modelling field and for researchers providing the background theory and data necessary for modelling, the book will be a valuable resource'. It covers an enormous range of material, even venturing off-planet to consider zonal jets on gas giants. The author list includes many individuals whose work one would wish to read, but here we find a structural peculiarity. Each of the 64 constituent chapters has its own author list, and that list has been separated from the contents list, so it is a little awkward to see who wrote what. This device gives the impression that the book is a unified entity, and one gets the strong impression that the CARTUM project worked hard to make it so. However, it is unfortunate that the book lacks an index, which makes it hard to search for specifics.

A further step towards a unified structure is made by providing a single integrated reference list at the end. This was not adequately proof-read. For example, references by Peter Rhines appear under 'Rhines, P.' and 'Rhines, P.B.' The same paper (*JFM* **69**, 1975) appears twice, once under each name entry, as 1975a and 1975b. Further evidence of questionable proof-reading is provided right at the start: in the contents list, I found on p. vii 'angmuir cells' (*sic*), and on the inside front page, we read that John Simpson's first degree was a 'B.A., Oxen' (*sic*). In the review copy, pages 155–70 are bound upside-down and back-to-front. Some figures are imperfectly described in their captions; one must search the text for the meaning of axis labels. On these accounts, as well as the fundamental one of cost, I would not recommend that students purchase this book. It is probably best accessed, if required, from the library shelves.

On the one hand, one must treat this book with caution, as one receives a distinct impression of a rushed production. On the other hand, there is a wealth of excellent material contained between its covers, and Mellor is actually quite right to refer to it as a 'valuable resource'. Read with care and possibly a degree of selectivity, it could be very useful to researchers.

Sheldon Bacon
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The Turbulent Ocean by S.A. Thorpe (2005). Cambridge University Press, 439pp., £45 (hard cover, ISBN-10: 0-521-83543-7; ISBN-13: 978-0-521-83543-5).

I found this book very interesting to read, and informative on various aspects of ocean turbulence that I was less familiar with. As a book to dip into and learn from, this is an excellent text, if you can cope with, or are prepared to ignore, some of the mathematical detail. The Preface states that the book aims to 'describe and focus attention on the physical processes that lead to turbulence', and it certainly does that, but it also dives rather quickly into some quite complex mathematics. Thus the first partial differential equation appears on p.15, while tensor notation makes an appearance on p.25 – which may prove daunting for some readers. Nevertheless, even if the reader's mathematical background or ability is not at this level, the book is worth reading for the wealth of physical insights that it provides into the complex processes involved in the generation and maintenance of turbulence in the ocean.

The range of topics covered is impressive and the book displays both the depth and breadth of the author's knowledge of the subject. The book ranges over turbulence in the open ocean, at the surface and bottom of the ocean and in shallow seas. Highlights are the sections which deal with small-scale turbulent processes – the topic of much of the author's own research over many years. Possibly the weakest part of the book is its treatment of large-scale waves, eddies and dispersion (Chapter 13), as this is a very abbreviated section for so broad a subject. Despite this, the chapter provides enough information for the interested reader to be able to delve deeper into the topic.

One of the book's strengths is its use of diagrams, figures and illustrations to explain and exemplify turbulent processes in the ocean. This is slightly marred by the fact that the colour illustrations are gathered together in two separate sections, making it more difficult to refer to them when reading the relevant discussion of the process being illustrated. A further strength is the inclusion of 'conjectures and speculations', alluded to in the Preface and scattered throughout the text. These challenge the reader to think more deeply about some of the outstanding and interesting problems in the field of ocean turbulence. Reading the book I was struck on a number of occasions by possible new lines of research that could be pursued. This is unusual in a textbook, but is clearly an aim of the author's in writing the book. In this respect he has been entirely successful.

The book will be of most benefit to graduate students and researchers wanting to get to grips with various aspects of turbulence in the ocean. For undergraduates, and those wanting a more basic introduction to ocean turbulence, the author's more recently published *An introduction to Ocean Turbulence* (Cambridge University Press, 2007, ISBN 978-0-521-85948-6) would be a better text to start with.

Overall, the book is a welcome addition to my shelves of oceanographic texts and will be dipped into regularly. I think that this book is a well-written and well-illustrated overview of turbulent processes in the ocean, and worth buying if you are working in, or starting research in, any area of oceanography where turbulence is important.

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National Oceanography Centre
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