UK Ocean Acidification Research Programme

UK Ocean Acidification programme synopsis

Variability and trends in ocean pH

www.oceanacidification.org.uk

What determines ocean carbon chemistry at regional and local scales?

Ocean acidification has a global driver (increasing atmospheric CO_2) but it is not occurring at the same rate everywhere: regional and local factors are responsible for spatial and temporal variability in the changes in ocean carbon chemistry. To interpret observations and assess impacts, it is essential to gather sufficient data to understand these patterns and processes.

The UKOA consortium **Observations and synthesis to establish variability and trends of oceanic pH** was led by Andrew Watson, initially at the University of East Anglia and subsequently at Exeter University. National partners included Plymouth Marine Laboratory, the National Oceanography Centre Southampton, Cefas, Marine Scotland, and the British Antarctic Survey. The consortium added its own measurements to a sound foundation of pH-related observations already carried out by Cefas from buoys and ships around the UK, as well as data collected by international partners from around the world.

Aims of the consortium study:

- To quantify the rate of change of ocean pH in the North Atlantic, European shelf (UK coastal waters in particular) and parts of the Southern Ocean
- To determine pH from commercial 'ships of opportunity', research vessels, and the regular surveys undertaken by the Centre for Environment, Fisheries and Aquaculture Science (Cefas)
- To collaborate with ocean acidification researchers worldwide to obtain a more complete picture of the issue through the Surface Ocean CO_2 Atlas (SOCAT, http://www.socat.info). SOCAT is synthesising new and historic global data on surface ocean carbonate chemistry to determine how pH has changed in the recent past, and how it is likely to change in future
- To maintain and upgrade existing observation systems which measure ocean CO_2, to ensure that data can be used to accurately calculate pH
- To encourage new observations in UK waters using surveys undertaken by Cefas, Marine Scotland and others
- To improve understanding of how acidification will proceed, under future CO_2 emission scenarios.

Main outcomes and conclusions:

- Seawater pH around the UK is highly variable, both spatially (in three dimensions) and temporally (year-to-year, seasonally and on shorter time-scales); there is now in place a national ocean acidification observing system which needs to be continued on a longterm basis.
- Surface seawater pH in sub-tropical regions of the open North Atlantic is much less variable decreasing at a rate primarily determined by the rate of rising CO_2 in atmosphere.
- Elsewhere in the open North Atlantic, unexpected changes have occurred, with year-to-year pH decreases being more rapid than anticipated in some regions (particularly in mid- to high latitudes) and slower in others. However, these regional anomalies in longterm trends do not persist for more than a few years. Their causes are not known; either physico-chemical or biological factors may be involved.
- Time series have been started in Antarctic waters. The three years of coastal data collected so far show large seasonal and interannual variation in ocean pH, with strong influence of seasonal ice cover.
- A leading role has been taken in the international Surface Ocean CO_2 Atlas (SOCAT) project, documenting pH-relevant observations in the upper ocean, and using these to synthesise information on how pH has varied in the recent past on a global scale.
- UKOA has also strongly engaged with other monitoring-related initiatives in this area, including the Integrated Carbon Observing System (ICOS), the Global Ocean Acidification Observing Network (GOA-ON) and the work of OSPAR and ICES.
- Extended and new platforms for sustained observations of pH and other carbonate chemistry parameters are needed, including fixed and free floating buoys, autonomous vehicles and gliders, with associated developments in sensor technology.

How much does pH vary?

The decrease in pH (acidification) of seawater is a consequence of the rising concentration of carbon dioxide (CO_2) in the atmosphere, and its uptake by the ocean. Measurements and models indicate that this CO_2 uptake has resulted in a global mean pH decrease of 0.1 units in surface waters since pre-industrial times. On current trends, the total mean decrease is projected to reach 0.4 units (an increase of H+ of around 170%) by 2100, with potentially serious consequences for many marine ecosystems.

However, acidification is not occurring uniformly everywhere; evidence from the scattered measurements available suggests that surface pH varies substantially. Variations can be on a local and regional space scales; also on daily, seasonal, annual and decadal time-scales, and with water depth. These natural variations form the (changing) 'baseline' against which further human-caused changes may be measured. Acidification that moves the natural system beyond its existing variations is likely to be more damaging than changes that remain within natural bounds. It is important therefore to establish current natural variability, by increasing systematic measurements.

As data collected by UKOA are added to data collected internationally through collaborating projects, patterns are beginning to emerge. It is clear from UKOA research and data collection that in the main central areas of ocean basins (gyres) the picture is one that was anticipated–an incremental lowering of pH in line with increases in atmospheric, and hence oceanic CO_2. What is less clear is what is happening in coastal waters and shelf seas where there is much greater variability, resulting from their hydrodynamic complexity, seafloor and riverine influences, and high biological activity. Understanding what is happening in coastal waters is of paramount interest, not just because of the ecological richness of these waters but also due to their importance in providing goods and services to human society. A key thrust of the consortium has been to bring together existing measurements as well as encourage the collection of new data.

UKOA funding, through the consortium, has funded and implemented underway CO_2 measurement systems with colleagues who already had some experience of such techniques. Additional measurements have also been supported, to ensure that accurate estimates of pH could be obtained.

Less Antarctic sea ice, reduced ocean CO_2 sink

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For the full annual cycle, Ryder Bay is a net sink for atmospheric CO_2 with the seasonal sea ice cover reducing the winter out-gassing and promoting biological uptake when it melts in spring. Since future warming in the region is expected to reduce seasonal sea ice cover, that could greatly decrease its 'beneficial' role with regard to carbon uptake.

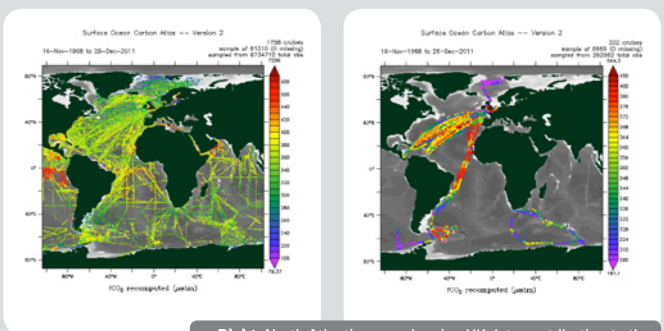
In the wider Southern Ocean, future ocean acidification is expected to reduce carbonate saturation state for aragonite to below 1.0 at all water depths by 2100; i.e. making the water corrosive to organisms with unprotected aragonite exoskeletons. However, there is very little routine monitoring of such changes.

UK leadership for international ocean carbon initiatives

Surface Ocean CO_2 Atlas (SOCAT)

The UK has played a key role in bringing the Surface Ocean CO_2 Atlas (SOCAT; www.socat.info) to a level where it is now a powerful synthesis product documenting the ocean carbon cycle. Its huge data resource now facilitates quantification of the global ocean CO_2 sink; allows for estimates of the progress of ocean acidification; and is available to validate ocean biogeochemical processes.

UKOA scientists have played major roles as Chair of the Global Group of SOCAT and leader of the North Atlantic Group for version 3 of the Atlas. SOCAT has been evolving since the early 1990s and today provides an open-access, quality-controlled database, funded from a range of sources, including UKOA through the work of UK scientists. The database currently has 10 million measurements – covering everything currently known about sea surface CO_2 over the whole planet. Data are freely accessible, enabling anyone to make their own calculations or observations about how pH has changed, and are available individually or as a gridded product of 1 longitude by 1 latitude squares for every month from 1968. If a measurement exists for a particular square, it is reported; if there is more than one measurement, an average is shown. This now provides a very strong baseline from which to compare future measurements and monitor further changes; thus there is need for constant updating as new data become available.



Right: North Atlantic maps showing UK data contribution to the SOCAT v2. Data collected and collated under UKOA are included. **Left:** all contributions to SOCAT demonstrating Atlantic coverage. Maps courtesy of SOCAT: www.SOCAT.info.

SOCAT represents a huge amount of work, because the data are quality-controlled and complex data-based papers, with high information content, are produced from them. UKOA funding has helped to bring this valuable project to its current stage, but longer term studies are required to maintain and improve SOCAT, to give the best opportunity for future projections of the effects, impacts and consequences of ocean acidification in all parts of the global ocean, including near-coastal regions.

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Other international involvement

UKOA work has underpinned the UK as a leading contributor to the marine component of the Integrated Carbon Observation System (ICOS), a European infrastructure project dedicated to high precision monitoring of greenhouse gas fluxes.

The UK, in partnership with Norway, hosts the ocean thematic centre for ICOS, ensuring that marine aspects, including ocean acidification, are served by a recognised source of expertise, with access to, and a better understanding of, all relevant European data on the ocean carbon system.

Additional international engagement has included strong UK participation in developing regional ocean acidification monitoring policy and associated research, through the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) and the International Council for the Exploration of the Seas (ICES), and at the global level, through the Global Ocean Acidification Observing Network (GOA-ON).

Outputs include:

Bakker DCE, Pfeil B, Olsen A, Sabine CL, Metzl C, Hankin S, Koyuk H, Kozyr A, Malcczyk J, Manke A & Telszewski M (2012) Global data products help assess changes to ocean carbon sink. Eos: Transactions of the American Geophysical Union 93, 12; doi: 10.1029/2012EO120001.

Bakker DCE and 80 others [including U Schuster, NJ Hardman-Mountford, V Kitidis & AJ Watson] (2014) An update to the Surface Ocean CO_2 Atlas (SOCAT version 2). Earth System Science Data 6, 69-90; doi: 10.5194/essd-6-69-2014.

ICES (2014) Final Report to OSPAR of the Joint OSPAR/ICES Ocean Acidification Study Group (SGOA). ICES CM 2014/ACOM:67. 141 pp. [UK involvement by Cefas, Marine Scotland, NOC Southampton, UEA, University of Plymouth, and Heriot-Watt University]:

Kitidis V, Hardman-Mountford NJ, Litt E, Brown I, Cummings D, Hartman S, Hydes DJ, Fishwick JR, Harris C, Martinez-Vicente V, Woodward EMS & Smyth TJ (2012) Seasonal dynamics of the carbonate system in the Western English Channel. Continental Shelf Research 42, 30-40; doi: 10.1016/j.csr.2012.04.012.

Legge OJ, Bakker DCE, Johnson MT, Meredith MP, Venables HJ, Brown PJ & Lee GA (2015) The seasonal cycle of ocean-atmosphere CO_2 Flux in Ryder Bay, West Antarctic Peninsula. Geophysical Research Letters (in press) doi: 10.1002/2015GL063796.

Le Quéré C and 61 others [including V Kitidis & U Schuster] (2015) Global carbon budget 2014. Earth System Science Data 7, 47-85; doi: 10.5194/essd-7-747-2015.

Pfeil B and 82 others [including DCE Bakker, N Hardman-Mountford, D Hydes, U Schuster & AJ Watson] (2013) A uniform, quality controlled Surface Ocean CO_2 (SOCAT). Earth System Science Data 5, 125-143, doi: 10.5194/essd-5-125-2013.

Sabine CL and 75 others [including DCE Bakker, N Hardman-Mountford, D Hydes, U Schuster & AJ Watson] (2013) Surface Ocean CO_2 Atlas (SOCAT) gridded data products. Earth System Science Data 5, 145-153; doi: 10.5194/essd-5-145-2013.

Schuster U, McKinley GA, Bates N, Chevallier F, Doney SC, Fay AR, Gonzalez-Davila M, Gruber N, Jones S, Krijnen J, Landschuster P, Lefevre N, Manizza M, Mathis J, Metzl N, Olsen A, Rios AF, Rodenbeck C, Santana-Casaino JM, Takahashi T, Wanninkhof R & Watson AJ (2013) An assessment of Atlantic and Arctic sea-air CO_2 fluxes, 1990-2009. Biogeosciences, 10, 607-27; doi: 10.5194/bg-10-607-2013.

Schuster U, Watson AJ, Bakker DCE, Boer, A de, Jones EM, Lee GA, Legge O, Louwerse A, Riley J, Scally S (2014) Measurements of total alkalinity and inorganic dissolved carbon in the Atlantic Ocean and adjacent Southern Ocean between 2008 and 2010. Earth System Science Data 6, 175-183. doi: 10.5194/essd-6-175-2014.

For a full list of publications arising from this component of the UKOA programme, see separate hard-copy document or online at www.oceanacidification.org.uk. Data are available via the British Oceanographic Data Centre (BODC) and the Carbon Dioxide Information Analysis Center (CDIAC).

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What is ocean acidification?

The global ocean currently absorbs more than a quarter of the CO_2 produced by burning fossil fuel and other human activities, slowing the rate of climate change. Global warming would therefore be far worse if it were not for the ocean. However, there is a cost: when CO_2 dissolves in seawater it forms carbonic acid, decreasing the pH and causing other chemical changes. These processes are known as ocean acidification.

The acidity (H+ concentration) of the surface ocean has already increased by nearly 30% due to these events, mostly in the past 50 years. If future CO_2 releases continue to follow current global trends, by 2100 ocean acidity will increase by as much as 150%, at a rate of change 10 times faster than at any time in at least the last 65 million years. Such a major alteration in ocean chemistry will have (and is already having) wide implications for marine life.

Ocean acidification is a relatively new field of research, with the overwhelming majority of studies carried out over the last decade. While the topic is attracting increasing attention among policy makers, international leaders and the media, there is still much to be understood about the fundamental biogeochemical, physiological and ecological processes; interactions with other stressors (notably temperature change) and the consequences of ocean acidification for society. UK scientists are at the forefront of these research areas, working in partnership with many international colleagues.

What is the UK Ocean Acidification research programme?

Widespread concern about ocean acidification emerged after the Royal Society report Ocean acidification due to increasing atmospheric carbon dioxide in 2005. A range of research initiatives were subsequently developed at both the national and international level.

The £12m, five year UK Ocean Acidification research programme (UKOA) was the UK's response, starting in 2010 and jointly funded by the Natural Environment Research Council (NERC), the Department for Environment, Food and Rural Affairs (Defra) and the Department of Energy and Climate Change (DECC).

The overall aims of UKOA were to increase understanding of processes, reduce uncertainties in predicting impacts and improve policy advice. Scientific studies have included observations and surveys; impacts on upper-ocean biogeochemistry; responses by seafloor organisms; effects on exploited species, food-webs and human society; ocean acidification in the geological past; and regional and global modelling. In addition to national policy liaison, UKOA has made significant contributions to the work of the Intergovernmental Panel on Climate Change (IPCC), the UN Framework Convention on Climate Change (UNFCCC), the UN Convention on Biological Diversity (CBD), the UN Sustainable Development Goals (SDGs) and many other governmental and non-governmental initiatives and activities.

NERC 50 SCIENCE OF THE ENVIRONMENT

Department for Environment Food & Rural Affairs

Department of Energy & Climate Change

Living With Environmental Change

Boot KJ, Watson A, Bakker D, Schuster U, Greenwood N, Turley C, Williamson P (2015)
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