End of first international large-scale research project on ocean acidification

EPOCA
European Project on OCean Acidification

Over the past 250 years, the ocean has absorbed about one third of the carbon dioxide released as a result of human activities. The process results in ocean acidification, often referred to as 'the other CO_2 problem'. Whereas the chemical consequences of this CO_2 uptake are well known (decrease in pH and shifts in sea-water carbonate chemistry), the biological impacts are poorly understood.

The European Project on Ocean Acidification (EPOCA) was the first international project that focused on ocean acidification and its consequences. It comprised over 160 scientists from 32 institutions in 10 European countries. Partly funded by the European Commission (6.5 M€ for a total budget of 16 M€), the project began in May 2008 and ended in April 2012.

EPOCA research was structured around four themes, some highlights of which are provided below.

Theme 1: Changes in ocean chemistry and biogeography

Within theme 1, paleo-reconstruction methods were used to investigate the response of organisms, particularly calcifiers, to past changes in ocean acidification and to assess past variability in ocean carbonate chemistry, nutrients, and trace metals. Observational data were also collected to improve understanding of modern-day carbonate chemistry and the distribution and abundance of calcifiers.

Highlights include results from the Arctic Ocean near Iceland where acidification is occurring faster and is more severe than expected, based on data from a 25-year Iceland Sea time-series station (1984–2008). The decline in surface water pH is 50% faster than average annual rates at subtropical time-series stations in the North Atlantic and Pacific Oceans. The aragonite saturation horizon is shoaling at a rate of four metres per year, encroaching on an additional 800 km^2 of ocean floor every year (Olafsson et al., 2009).

EPOCA also showed that some coastal waters of the Arctic Ocean are now extremely undersaturated with respect to aragonite owing to organic carbon input from thawing permafrost, the plumes of which flow off the shelf into the deep central Arctic Ocean (Anderson et al., 2011).

For the western Arabian Sea, de Moel et al. (2009) found that light, thin-walled shells of the surface-water dwelling planktic foraminifer *Globigerinoides ruber* from the surface sediment are younger (based on ^{14}C and ^{13}C measurements) than heavier, thicker-walled shells, concluding that the age difference was indicative of ocean acidification on top of seasonal upwelling.

Contrasting results were found for the response of the coccolithophorid *Emiliania huxleyi* to ocean acidification. Higher percentages of over-calcified morphotypes were measured in the Bay of Biscay during winter, when conditions for calcification should be less favourable (Smith et al., 2012; see Fig. 1). Conversely, Beaufort et al. (2011) reported a substantial decline in coccolith mass and a decrease in coccolith flux since the 1940s in sediment cores collected in the Western Pacific.

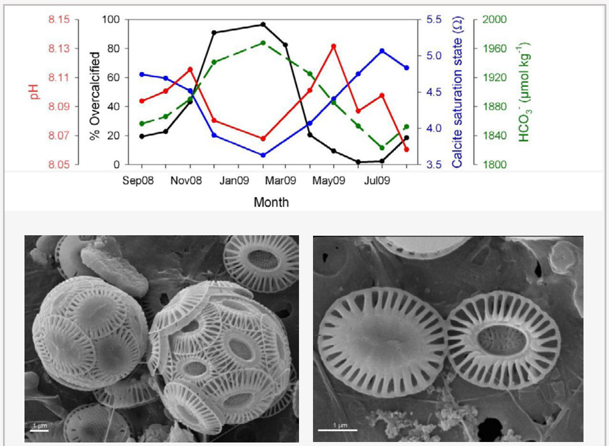

Fig. 1: (Top) comparison of degree of calcification with water chemistry. The black line shows the seasonal changes in the proportion of 'overcalcified' (more heavily calcified) ***Emiliania huxleyi*** cells; the blue lines shows the saturation state of surface seawater with respect to calcite $CaCO_3$ (Ω); the red line shows pH (red line); the green dashed line shows bicarbonate ion (HCO_3^-)concentration (µmol/kg). (Bottom left) the two main morphotypes of *Emilania huxleyi* observed in the water samples: the left-hand cell is Type A overcalcified; the right-hand cell is standard Type A. (Bottom right) two individual coccoliths (calcium carbonate plates), one from each morphotype, that happened to lie next to each other in an SEM image. More calcium carbonate is used to build each Type A overcalcified coccolith (left), as evidenced by infilling of the central area and thicker spokes. (From Smith et al, 2012, reprinted with permission from PNAS)

Theme 2: Biological and ecosystem responses, acclimation and adaptation

EPOCA researchers studied a broad range of taxonomic groups, communities, habitats, and processes, with a regional focus on the European shelf seas and the high Arctic Ocean. This was achieved through a multidisciplinary approach that combined laboratory studies, field experiments, and observations with a suite of model studies that focused on processes from the cellular and organismal level up to ecosystems and ranging in complexity from 0- and 1-D up to Earth system models. Major field activities included research cruises from the NW European continental shelf up to the Arctic, two joint mesocosm experiments in Svalbard that focused on bottom-dwelling organisms and processes influenced by them in 2009 and on the plankton community and elemental fluxes in the water

Fig. 2: Mesocosm facilities developed at the GEOMAR | Helmholtz Centre for Ocean Research Kiel, used during the second EPOCA campaign in Svalbard, summer 2010.

column in 2010 (Fig. 2), and extensive studies at a natural CO_2 venting site in the Mediterranean Sea.

EPOCA has helped to clearly demonstrate that many calcifying organisms are adversely affected by ocean acidification, while also revealing considerable variability in sensitivity between closely related species and even between different strains of the same species; some species appear tolerant to ocean acidification in the range of pCO_2 levels projected until the end of this century. Observed variability was shown to reflect the genetic diversity within populations (Langer et al., 2011; Hagino et al., 2011) or to be related to regional differences between populations (Thomsen et al., 2010). In several groups, early life stages were particularly sensitive to ocean acidification (e.g. Gazeau et al., 2010). High CO_2 resulted in delayed larval development of crustaceans, bivalves, and echinoderms.

Several EPOCA studies highlighted the importance of long-term exposure to allow for proper acclimation. Some species that were sensitive to ocean acidification in short-term incubations became insensitive when kept under high pCO_2 for extended periods of time (Form & Riebesell 2011, Dupont et al., 2012). Reduced fitness of sea urchins was observed when consecutive life-stages were exposed to high CO_2.

EPOCA also made considerable progress concerning the mechanisms underlying the observed responses for some taxonomic groups. For coccolithophores, some of the transporters involved in calcium and carbon acquisition were identified (Mackinder et al., 2011; Richier et al., 2011). Very efficient mechanisms to regulate internal pH using proton pumps were identified in echinoderm larvae. A decapod crab was capable to compensate for ocean acidification by acid-base regulation, however, at the expense of metabolic repression.

As ocean acidification occurs with changes in other environmental stressors, such as ocean warming, deoxygenation, and eutrophication, EPOCA research examined possible interactive effects of multiple stressors (Pörtner, 2010). Several EPOCA studies indicated that ocean acidification narrows the thermal tolerance of many organisms (e.g. Walther et al., 2009), while another showed that interacting effects of warming and acidification are expected to alter community structure and biodiversity (Hale et al., 2011).

Studies of natural communities along CO_2 gradients (Charalampopoulou et al., 2011) and at CO_2 venting sites proved to be a powerful test bed to assess results obtained in previous laboratory-based studies. Relating coccolith mass to seawater carbonate chemistry in different oceanographic regions as well as in sediment cores suggested much stronger sensitivities in coccolithophores than obtained in the laboratory (Beaufort et al., 2011). Drastic changes in benthic community composition and biodiversity were observed at volcanic CO_2 vents (Barry et al., 2011; in *Ocean Acidification*).

EPOCA research found several key processes driving biogeochemical cycling in the ocean to be sensitive to ocean acidification. This includes phytoplankton photosynthesis, nitrogen fixation by diazotrophic cyanobacteria, and calcium carbonate ($CaCO_3$) production by calcifying plankton organisms. These responses cause changes in ocean biogeochemistry, including the C:N:P composition of organic matter and the ratio of $CaCO_3$ to organic matter in the export flux (the rain ratio) as well as associated ballasting of the organic matter flux to the deep ocean (Gehlen et al., 2011; in *Ocean Acidification*). Changes in these processes affect storage of carbon in the deep ocean, which feeds back on the climate system.

EPOCA research has substantially improved our understanding of biological sensitivities to ocean acidification, but major questions remain. Little is known about how biotic responses will affect competitive and trophic interactions. Will marine food webs differ in a warmer, more acidified ocean? Will organisms be able to adapt to ocean acidification?

Theme 3: Biogeochemical impacts and feedbacks

In theme 3, EPOCA modellers used coupled Earth system models (ESMs), forced global and regional ocean models, and a sediment model to project how ocean acidification will alter ocean biogeochemistry. Results from seven IPCC AR4-era ESMs were stored in a central, publicly available archive. The same interface was extended to allow comparison with the ESMs from the Coupled Model Intercomparison Project, part of the ongoing assessment of the Intergovernmental Panel on Climate Change (IPCC AR5).

One ESM projects that around 10% of Arctic surface waters will become undersaturated within 10 years during summer, and that climate change has little effect on acidification except in the Arctic where it is exacerbated, mainly from freshening due to ice melt (Steinacher et al., 2009). Model formulations of $CaCO_3$ production and dissolution as well as the particulate organic-to-inorganic carbon ratio were made to depend on CO_2 levels, but there was little sensitivity in resulting air-sea CO_2 fluxes. Similarly, explicitly modelling aragonite makes little difference (Gangstø et al. 2009).

New forced ocean model simulations with variable C:N:P composition suggest that acidification-induced changes in primary productivity and carbon export (Tagliabue et al., 2011) will counter general reductions from climate change (Steinacher et al., 2010). New sensitivity tests indicate that coarse-resolution global models may generally underestimate the magnitude of variability of surface pH, saturation states, and air-sea CO_2 flux by a factor of two or more.

New regional model simulations have demonstrated the high vulnerability of some nearshore regions. In the Northwestern European Shelf Seas, simulations indicate large spatiotemporal variability, sometimes locally dominated by effects from river input and organic matter degradation, exacerbating acidification (Artioli et al., 2012). In the California Current System, an eastern boundary upwelling system (EBUS), there is a strong seasonal upwelling of undersaturated waters and a trend that will cause half the waters above 250 metres

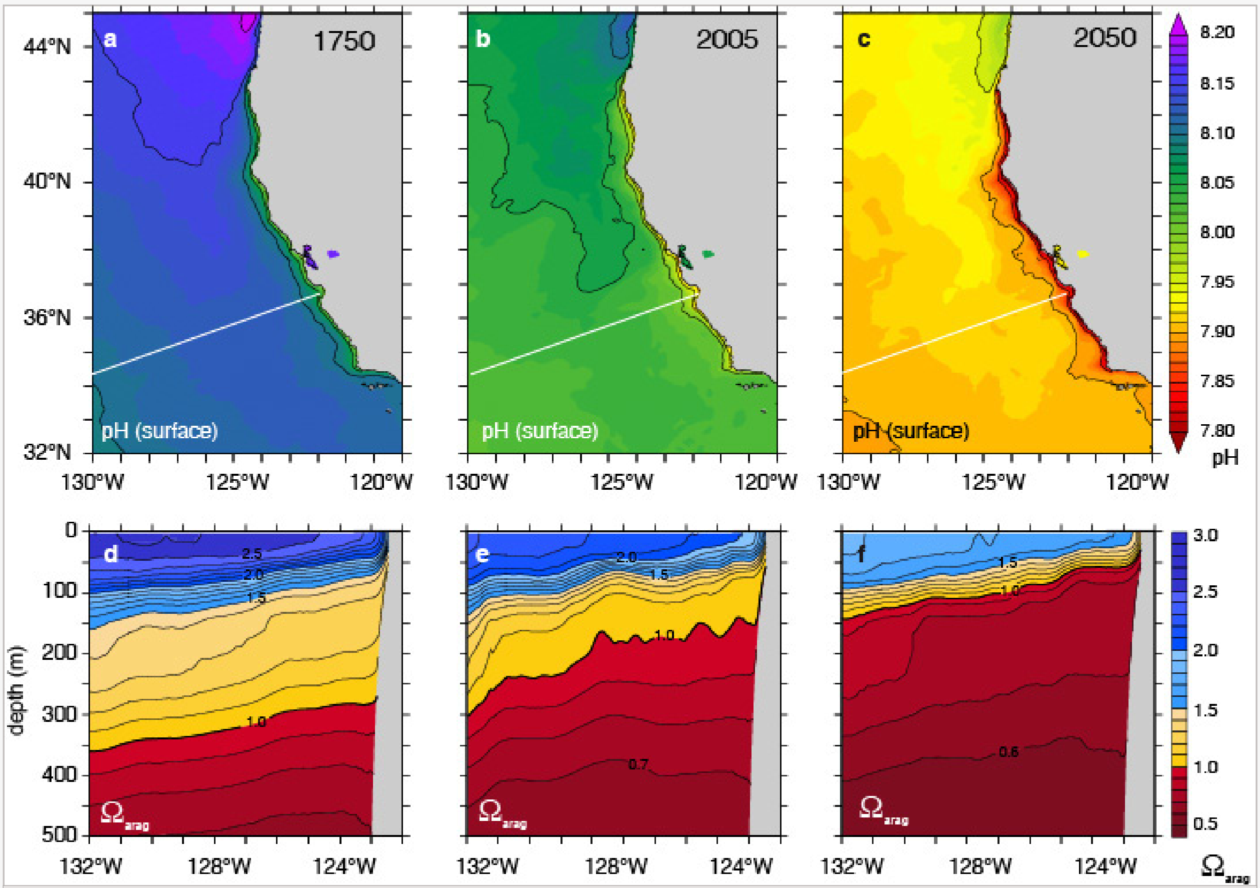

Fig. 3: Acidification of the California Current System in 1750–2050 under the A2, IPCC scenario. (A to C) Maps of annual mean surface pH, illustrating its decline. (D to F) Offshore depth sections reveal the corresponding decline in annual-mean saturation state of seawater with respect to aragonite, Ω_{arag}, and the shoaling of the saturation horizon, Ω_{arag} = 1. White lines in (A) to (C) indicate the position of the offshore section (From Gruber et al., 2012, reprinted with permission from AAAS).

to become undersaturated by year 2050 (Hauri et al., 2009; Gruber et al., 2012; Fig. 3). Two other EBUS systems (Humboldt and Canary) also reveal heightened vulnerability.

Projections from a global coastal sediment model indicate that alkalinity generation from benthic carbonate dissolution provides a negligible feedback against ocean acidification in coming centuries (Krumins et al., 2012, submitted).

Some of the advances from EPOCA's modelling initiative are detailed in three chapters of the book *Ocean Acidification* and focus on recent and future changes in ocean carbonate chemistry, biogeochemical impacts, and effects from climate-change mitigation (Orr, 2011; Gehlen et al., 2011; Joos et al., 2011; in *Ocean Acidification*).

Theme 4: Synthesis, dissemination and outreach

EPOCA has helped to raise awareness of ocean acidification worldwide through its contributions to major policy activities, scientific assessments (e.g. IPCC AR5), and reports for policy-makers and other research users, all available on the EPOCA website (Fig. 4). The EPOCA blog has been the first point of call for researchers and policy-makers for new science, policy and media information on ocean acidification with almost 4000 posts and more than 500,000 visits during the duration of the project.

The EPOCA Ocean Acidification Reference User Group (OA-RUG), formed in 2008, rapidly evolved to incorporate UK, German, and Mediterranean research programmes and recently other countries to form the International Ocean Acidification Reference User Group (*i*OA-RUG). Its many outreach products include three multilingual guides that outline the essential facts for policy-makers and decision-makers on ocean acidification and have been scrutinized by the scientific members of the RUG to ensure scientific integrity.

EPOCA joined with a range of partners on outreach. Examples are, *Ocean Acidification: Frequently Asked Questions* in response to the growing research across disciplines and the increasing need for clear answers by experts, a range of other policy documents including *Hot, Sour and Breathless: Ocean Under Stress* and side- and media-events and exhibition stands at the United Nations Framework Convention on Climate Change Congress of Parties, the Planet Under Pressure Symposium, and the Rio+20 Earth Summit.

EPOCA worked with 11–15 year old students from Ridgeway School in Plymouth, who made their concerns about the state of the world's oceans clear through the award winning animation *The Other CO_2 Problem*, suitable for children and policy-makers alike and now available in several languages. The movie *Tipping Point* mostly describes EPOCA research and has received three awards including 'Best Scientific Movie' at the Mediterranean film festival. Both have been shown at science and policy meetings around the world with copies distributed worldwide.

An editorial, *The Societal Challenge of Ocean Acidification*, addressed for the first time the issue of vulnerable regions and biodiversity and how this would be a challenge for policy makers. The

Fig. 4: Some EPOCA outreach products and activities.

Guide to Best Practices for Ocean Acidification Research and Data Reporting regroups standards and guidelines on ocean acidification research and has been widely distributed to the international scientific community. *Ocean Acidification*, edited by the EPOCA coordinator and manager, is the first book on ocean acidification with the majority of the synthesis chapters written by EPOCA experts.

Conclusion

EPOCA advanced scientific understanding of ocean acidification and its impact on marine organisms and ecosystems, while providing a new paradigm for outreach. It produced 21% of the research articles on ocean acidification published during the period 2009–2012, more than 200 papers. It has provided key products that will be used by the research community and policy-makers. Results from EPOCA will influence the IPCC's Fifth Assessment Report as well as new studies on socio-economic impacts of ocean acidification.

European research on ocean acidification continues through the EU project MedSeA, the German project BIOACID, the UK project UKOA, and the project eFOCE. But ocean acidification research remains in its infancy, so it is essential that new projects emerge in the near future. It is vital that these projects be coordinated at the international level, as emphasized by the SOLAS-IMBER Working Group on Ocean Acidification and the *i*OA-RUG.

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European Forest Fire Information System: Current situation in Europe

13 August 2012 – The 2012 fire season has been characterized by a high number of fires in the early season. Over 100,000 hectares had already been consumed by fire at the end of March. July brought critical fire episodes in Spain and Portugal, which led to a number of human casualties.

Fire danger has been very high in southern Europe during the last weeks, in particular in Portugal, Spain, southern France, central and southern Italy (where a large number of fires are still active), the Balkan region, Greece and Turkey. The current fire danger forecast provided by the European Forest Fire Information System (EFFIS) confirms a slight improvement in the situation at the beginning of this week as forecast end of last week.

However, fire danger conditions remain very high in the western part of the Mediterranean region, in Portugal, Spain and France, and will return to a situation of critical fire danger in the overall Mediterranean region by the end of this week.

The forest fire situation in Europe is constantly monitored by EFFIS, a system developed and run by the European Commission's in-house science service, the Joint Research Centre (JRC) in collaboration with the Directorate General for Environment (DG ENV) and the Directorate General for Humanitarian Aid and Civil Protection (DG ECHO).

EFFIS provides updated and reliable information on wild land fires in Europe supporting forest fire prevention and fire-fighting services in the European countries, the European Commission's Monitoring and Information Centre (ECHO MIC), based in Brussels, and other organizations in the field.

EFFIS provides fire danger forecast up to six days in advance, enhancing the preparedness of the countries at risk of fire. Furthermore, fires are monitored and mapped by EFFIS, providing near-real time estimates of fire damages across Europe. Maps and key data on fire danger and individual fire effects can be consulted at http://effis.jrc.ec.europa.eu/current-situation.

Up to now, approximately 580,000 hectares have been burnt this year in the area monitored by EFFIS, which includes Europe, Middle East and North African countries.

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