

# Ocean acidification, the other CO<sub>2</sub> problem: how far will life resist?

## A quest for answers in the Arctic

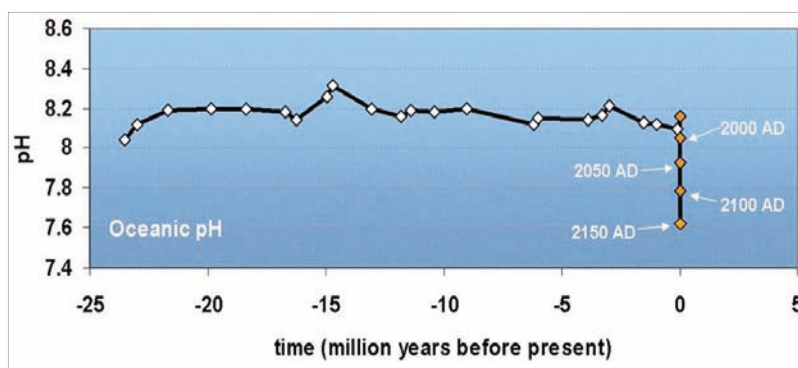
### Teachers and pupils,

- learn what happens as the CO<sub>2</sub> we massively emit invades the ocean!
- follow our experiments in the Arctic at the genesis of a new field of science!
- visit our labs, invite us to your classrooms and share our fascination for the planet!
- make your own experiments and reduce your own CO<sub>2</sub> emissions!

Since the industrial revolution fossil-fuel burning, deforestation and cement production have released more than 400 billions of tons (half of it during the last 30 years only) of carbon dioxide in the atmosphere, causing global warming through enhanced greenhouse effect. Fortunately more than half of this extra CO<sub>2</sub> has been taken up by vegetation and oceans, considerably limiting climate change, but at a huge cost: when CO<sub>2</sub> dissolves in seawater, the water acidifies<sup>1</sup>. The process is known as "ocean acidification", the "other CO<sub>2</sub> problem" documented more recently and still less known than climate change, but potentially with equally dramatic consequences. Observations and recent studies show that the extreme rate of CO<sub>2</sub> invasion and ocean acidification caused by man is 100 times quicker than has ever happened in the past 25 millions years.

The ocean is sick and suffering, and biologists are now wondering: how will animals and plants living in the sea react to our ever-increasing dumping of CO<sub>2</sub> waste? Who will die? Who will adapt and survive? We frankly still don't know. Investigating the impacts of a high-CO<sub>2</sub> ocean has therefore become a first priority on research agendas worldwide, leading us in Europe to launch EPOCA, the European Project on Ocean Acidification<sup>2</sup>. In this framework we are preparing a major experiment in Spitzbergen, far remote in the icy Arctic ocean, where acidification is thought to strike first because of the low

temperature of the water. We want to better understand what is happening in this critical area. We want to learn how Arctic marine life reacts to high-CO<sub>2</sub> waters. We want to share our findings with pupils and we warmly invite schools to join us in the adventure!



*Ocean acidification is happening now at a rate and to a level not experienced by marine organisms for at least 20 millions years. Turley et al. 2006; Blackford & Gilbert 2007*

### The Monaco Declaration

More than 150 leading marine scientists from 26 countries are calling for immediate action by policymakers to reduce CO<sub>2</sub> emissions sharply so as to avoid widespread and severe damage to marine ecosystems from ocean acidification. They issued this warning in the Monaco Declaration, released on 30 January 2009. More information on [www.ocean-acidification.net](http://www.ocean-acidification.net)

1) The pH decreases but remains above 7: the water acidifies, but remains alkaline and doesn't become acidic.

2) Started in May 2008 for a duration of 4 years, EPOCA involves more than 100 scientists from 27 institutes in 9 countries with a budget of 16,5 millions €, including 6,5 from the EU.

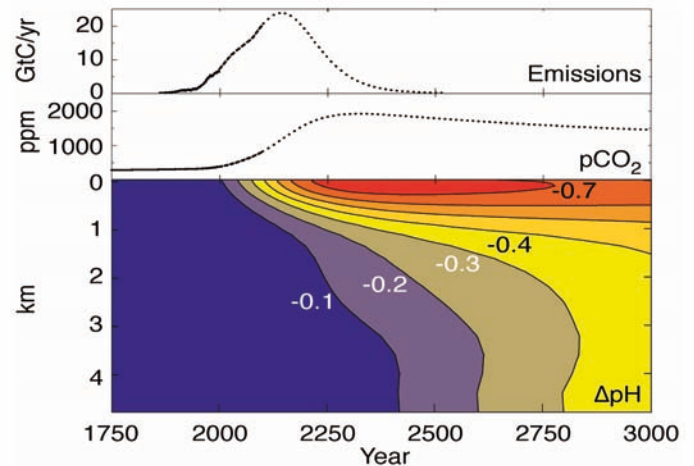
## The physico-chemical certainties

- Ocean acidification has started and is fully detectable: since industrialisation began, the acidity of surface seawater has already increased by 30%<sup>3</sup>, corresponding to a pH drop from about 8.2 to 8.1.

- Acidification is accelerating, directly following the acceleration in world CO<sub>2</sub> emissions (+3,5%/year since 2000 compared to +0,9% in the 90's, which is greater than projected for the worst-case scenario formulated a decade ago)

- In addition to a decline in pH, the dissolution of CO<sub>2</sub> in sea water also provokes a decrease in calcium carbonate, that calcifying marine organisms such as corals, mollusks, crustaceans and urchins use to form their calcareous shells or skeletons. At the current pace of CO<sub>2</sub> emissions, in only 10 years about 10% of Arctic surface waters will already become undersaturated with respect to aragonite, one of the natural forms of calcium carbonate. Such waters will therefore turn corrosive to aragonite and might cause shells and skeletons to dissolve. By 2100, all polar surface seawaters will become corrosive to aragonite if emissions continue to increase as they currently do.

- Contrary to the greenhouse effect, which involves a lot of complex interactions, the physico-chemical reactions involved in ocean acidification are straight-forward and can be predicted with full certainty for a given level of atmospheric CO<sub>2</sub> concentration. Across the range of IPCC emission scenarios<sup>4</sup>, by 2100 surface ocean pH will

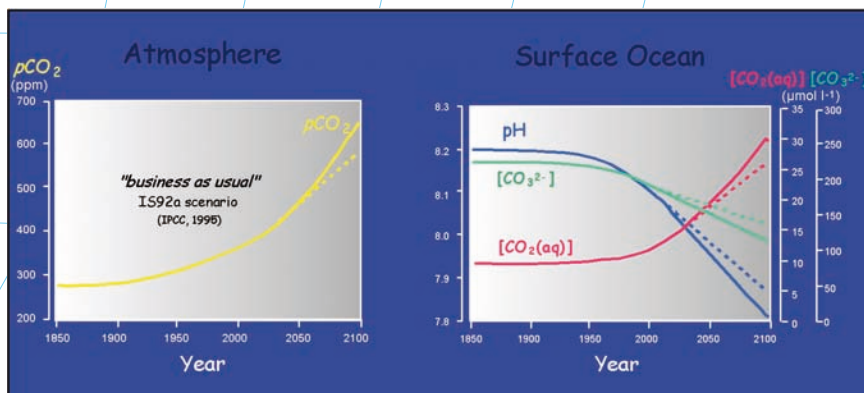


At present the seawater pH has already changed by 0.1 (blue zone) due to absorption of anthropogenic CO<sub>2</sub>. If emissions continue to rise until the known fossil fuel reserves are burnt, the increase in CO<sub>2</sub> atmospheric concentrations will reduce the surface ocean pH by up to 0.77 (red zone). (Caldeira & Wickett 2003, Nature)

decrease by 0.3 to 0.5 pH units relative to preindustrial conditions, which is a hundred times faster than any previous natural change that has occurred over the last many millions of years.

- Recovery will require thousands of years for the Earth system to reestablish ocean chemical conditions that even partially resemble those found today; and hundreds of thousands to millions of years will be needed for coral reefs to return, based on the past record of natural extinction events.

- The only way to stop ocean acidification is to stop increasing CO<sub>2</sub> concentrations in the atmosphere.



The decrease in pH (blue) and carbonate ions (green) are a direct consequence, with full certainty, of the CO<sub>2</sub> uptake by the oceans (red) resulting from human CO<sub>2</sub> emissions (yellow). Wolf-Gladrow, Riebesell, Burkhardt, Bijma, 1999

3) 30% more H<sup>+</sup> ions. The pH scale is logarithmic, therefore this increase corresponds to only 0.1 units of pH.

4) Predictions of greenhouse gas emissions by human activities according to several socio-economic scenarios formulated by the Intergovernmental Panel on Climate Change



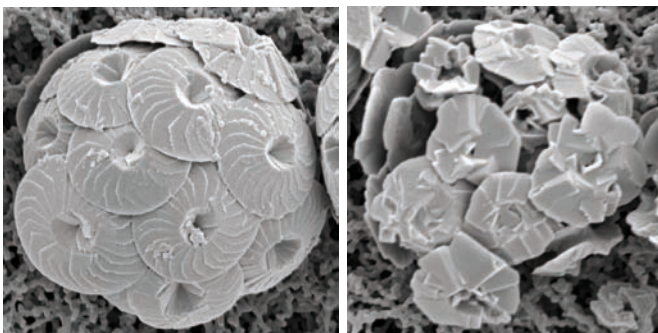
## The great biological unknowns

While we are perfectly able to predict the decline in pH and carbonate ion concentration, we know very little on how this is going to impact life in the ocean. How will marine calcifiers react to such a rapid and extreme change directly affecting their body structure? Which species will adapt and survive, which will die and disappear, what will be the consequences on the food web, biodiversity and fish stocks? We definitely do not know the answer, but what is at risk is clear:

- Coral reefs, already suffering from global warming, are in great danger of extinction. Due to the decrease in carbonate ions, formation of many coral reefs is expected to slow down to the point that reef erosion will dominate. Coral reefs provide fish habitats, generate billions of dollars annually in tourism, protect shorelines from erosion and flooding, and provide the foundation for tremendous biodiversity, equivalent to that found in tropical rain forests.

- Laboratory experiments show that most calcifying organisms have difficulties growing when pH is low. This could affect marine food webs, commercial fish stocks and species such as mussels and oysters, threatening protein supply and food security for millions of people as well as the multi-billion dollar fishing industry.

- Naturally CO<sub>2</sub>-enriched waters in places such as nearby Ischia, Italy, show that when pH reach values that are expected for the end of the century, some species are totally absent, the biodiversity is highly reduced, and the regime shifts to completely different ecosystems, where seagrasses and invasive species thrive.



An example of vegetal plankton (here coccolithophores) affected by high-CO<sub>2</sub> values - on the left, with current CO<sub>2</sub> values, on the right with values planned for 2100.

- past records of natural high-CO<sub>2</sub> events show a high correlation between elevated concentrations in the air and extinction of marine species.

We urgently need to learn more about the scope of these risks and predict with more certainty what will really happen if CO<sub>2</sub> emissions continue to rise. So far, most laboratory experiments were carried out in the short-term (hours to weeks), neglecting potential acclimation and adaptation by organisms. The overall goal of EPOCA is therefore to progress in these numerous gaps in our understanding of the effects and implications of ocean acidification:

- We will dig back in the Earth archives, in particular through sediment cores and deep-sea corals, to find out what past natural variations in ocean chemistry can teach us for the future.

- Through a new range of lab and field experiments we want to determine the sensitivity of marine organisms, communities and ecosystems to ocean acidification. How species react and what are their limits of resistance: what are the “tipping points” beyond which life is giving up? We will intensify laboratory experiments focusing on key organisms selected on the basis of their ecological, biogeochemical or socio-economic importance. And we will investigate on the field, as much in situ as possible, in conditions as close to reality as possible, what is underway in the most sensitive region to ocean acidification: the Arctic.

- We will compile all our findings in ocean-climate computer models to upscale the various processes involved and be able to project future responses of the Earth system to ocean acidification, combined with the effect of climate change.

- We will assess uncertainties, risks and thresholds related to ocean acidification from the cellular to the ecosystem scale, and from local to global. We will determine where are the most critical tipping points - those thresholds beyond which the system undertakes irreversible major shifts - what scenarios of CO<sub>2</sub> emissions are required to avoid them, and we will describe the state change and the subsequent risk to the marine environment and Earth system should these emissions be exceeded.



**CO<sub>2</sub> perturbation experiment in Kongsfjord, Spitzbergen, 79° North: how arctic marine life reacts to drastic pH changes?**

**Why study polar regions? Corrosive waters will first be seen in the Arctic and in the Southern Ocean**

The colder the water, the more CO<sub>2</sub> it absorbs: consequently, polar regions will be the first places where surface seawaters will become undersaturated with respect to aragonite, a form of carbonate ion used by marine organisms to make their shells and skeletons, and which decreases as CO<sub>2</sub> invades the water.

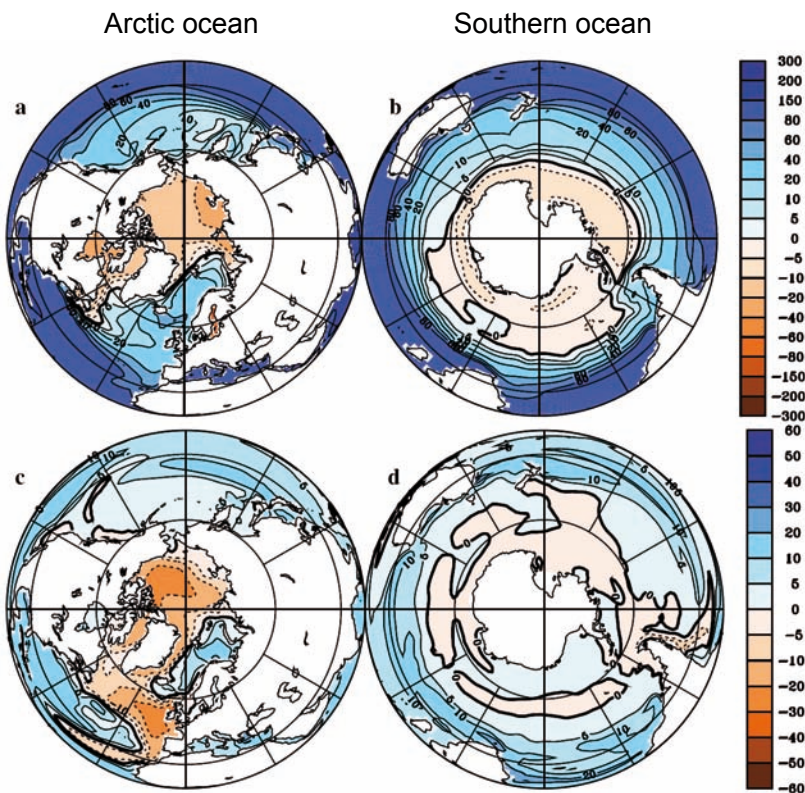
With respect to aragonite, all surface and near sub-surface waters have been supersaturated for the past several million years, right up until the present time. In 2008, we have observed near-subsurface waters in Canada Basin becoming undersaturated due to human CO<sub>2</sub> emissions. The phenomenon progresses at a critical speed: recent projections indicate that if CO<sub>2</sub> emissions continue to rise as today, 10% of arctic surface waters will be undersaturated by as early as the year 2018, 50% by 2050 and 100% by the end of the century.



EPOCA scientists from France, Germany, the Netherlands and UK will gather in Ny Alesund, the northernmost scientific base in the Arctic, for two intensive experiments in May 2009 and June 2010. Not only the icy winds and waters, watching of polar bears and excitement of discoveries will keep us awoken - but also at this time of the year the sun never sets down!



*Ny Alesund in May: a scientific village facing Kongsfjord in the immensity of the pristine polar wilderness.*



J Orr, 2008

Negative values (brown colours) indicate undersaturation, i.e. pure aragonite would dissolve. **a-b** shows the aragonite saturation state of surface waters when atmospheric CO<sub>2</sub> reaches 567 ppmv (i.e. twice the pre-industrial value). **c-d** shows the same combined with the effects of climate change, which intensify the phenomenon, particularly in the Arctic where undersaturation will occur 10 to 30 years sooner and more intensely than in the Antarctic: ice melting in the Arctic will render wide areas of ocean available to take up atmospheric CO<sub>2</sub>, and release huge amounts of soft waters which also further increase acidification.

## What do we want to learn & how?

How will the rapid transition to undersaturated waters affect Arctic calcifiers such as bivalve molluscs and their predators? Potentially all marine calcifiers which

are abundant on the Arctic shelf are at risk, and as these species serve as a major food source for walrus, grey whales, bearded seals, and spectacled eiders, their loss would have a profound impact on the entire Arctic ecosystem. In particular we want to find out where the tipping points are: what is the degree of elasticity of life for the key species in the food chain? Before waters become permanently corrosive, there will be several years when undersaturation will happen only seasonally: during this key intermediate stage (also corresponding to the time-span where we can hope that policy measures will stop CO<sub>2</sub> emissions), to which extent sensitive species will be able to recover when the conditions get back to normal, and for how long can they stand this seasonal stress?

Finding new answers to these pressing questions is the purpose of our «CO<sub>2</sub> perturbation experiment». The principle is quite simple: we collect water, algae and animals and reproduce their ecosystem in

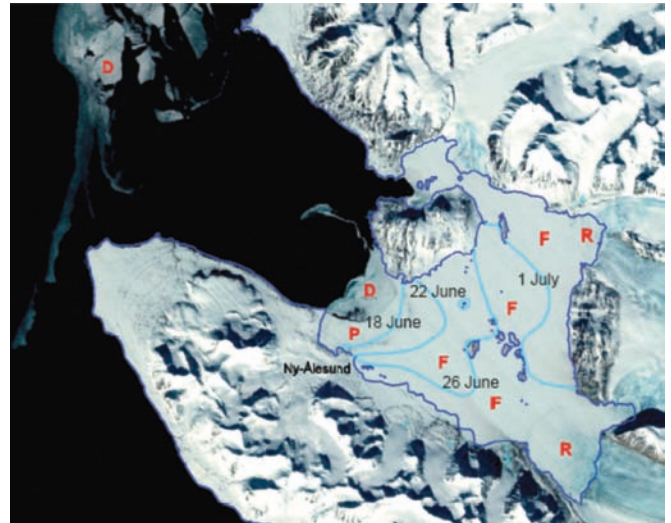
closed environments where we can then manipulate the water to mimic future CO<sub>2</sub> levels. We call «mecocosms» these closed mini-ecosystems - meaning «medium-world» in ancient greek, like microcosm means «mini-world». To allow comparisons we install several mesocosms: we use some as controls (kept at ambient CO<sub>2</sub> & pH) while in others we expose the species we want to study to different CO<sub>2</sub> concentrations and therefore pH and carbonate saturation values. Then we observe what's happening: how they respire, feed, reproduce, die etc.- and what differences we can see between the mesocosms exposed to different CO<sub>2</sub> values. In Spitzbergen we will run the experiment for 4-6 weeks during the Spring plankton bloom, i.e. at the time when organisms calcify the most (since we first and foremost want to see how their calcification is affected).

5) If you stand outside naked when it's zero degrees celcius you don't die immediately. You fight, burn all your energy to survive, and then only after a certain threshold you will pass over. This is the same for all living organisms exposed to harming living conditions - and some are much more resistant than others.

In Ny Alesund we are going to settle two different kinds of mesocosms:

- in May 2009, we will study benthic organisms, i.e. organisms living on the seafloor, like bivalves, mollusks, foraminiferas- a widely spread family of tiny single-celled animals with shells (the rocks the Egyptians used to build the pyramids are made of them!). The mesocosms will be big water tanks indoor where we will try to reproduce conditions as close as possible to the natural seafloor.

- in June 2010 we will study pelagic organisms, i.e. those living inside the water column, like plankton and fish. For these organisms we will be able to isolate them «in situ», i.e. inside big plastic bags which we directly open and close inside the sea, and then manipulate. We will use 20 meter deep, 2 meter diameter mesocosms with an integrated sampler able to pump water from all depths in the column. Installing that in such a harsh environment as Kongsfjord in May is a high-risk experiment and has never been done before! Temperature can still be minus 10 degrees, sometimes with strong wind and bad weather, with a constant enemy to our fragile plastic membranes: ice! Ice can get formed on the fjord, or fall down from the land when glaciers are carving (which happens constantly in the spring all around the fjord), or pushed by the wind from the open sea: we will have to choose our mooring site very carefully to reduce the risks as much as possible.



*This satellite picture shows the ice extension in Kongsfjord at different dates as the ice melts in the Spring and early Summer. The big glaciers falling directly in the sea are well visible North & East to the fjord.*



*Manipulating CO<sub>2</sub> concentrations and seawater pH in situ*



Join us on the field through our Arctic blog at [www.epocaarctic2009.wordpress.com](http://www.epocaarctic2009.wordpress.com)

### Three examples of concrete questions - three scientists to follow

- **Helen Findlay:** I am investigating the impacts of climate change and ocean acidification on intertidal marine animals (such as barnacles, which you can find on most rocky shores). I carry out field work and experimental laboratory work at Plymouth Marine Laboratory in the UK, to see how these creatures survive, grow and develop in different conditions and then I use that information to predict what will happen to their populations in the future, using modelling tools. Many of the barnacles are able to survive but the rates that



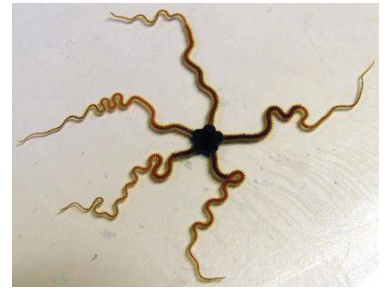
they develop at seem to be slowed by ocean acidification. Importantly when they are subjected to high temperature and ocean acidification the populations can be seriously impacted.

- **Hannah Wood:** I am also from Plymouth Marine Laboratory in the UK where I study how ocean acidification and the warming of the ocean (from global warming) will affect marine animals- in particular I look at brittlestars which are a type of starfish. I have already looked at some brittlestar species in Europe where I found that lowering pH causes the animals to grow faster and make their skeleton faster

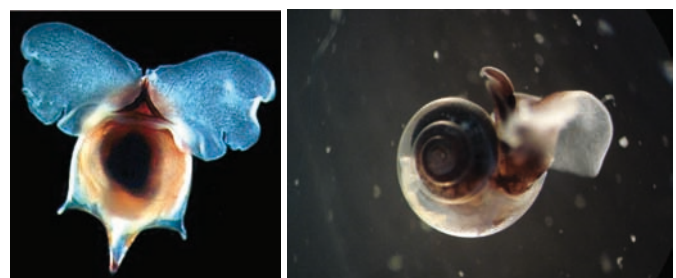


(to replace what is dissolved by the low pH seawater). But the brittlestars did not have enough energy to do all these things so fast and their arms that they use to collect their food got weaker as a result which ultimately will affect their survival. I have also found that changing the temperature of the water effects how the

brittlestars respond to pH change. Now I am going to look at how arctic brittlestars are affected by changing temperature and pH. Because temperature is very stable in the arctic I want to see how the arctic animals cope with these two important conditions changing at the same time, which is what will happen in the future.



- **Steeve Comeau:** I am from the Laboratory of Oceanography in Villefranche-sur-Mer (France). I study a zooplanktonic snail called pteropods (« sea butterfly »). Pteropods can occur in very high abundance in polar oceans and play also a major role in various ecosystems as a prey for higher predators such as herring, salmon, whales and bird. Results of my experiments, carried out on arctic species, show a decrease of their calcification rates when they are exposed to the pH condition expected for the end of the century (7.8). I am currently working on some mediterranean species to study the impact of ocean acidification on their respiration, nutrition and calcification. I am going to do the same perturbation experiments on the Arctic species to understand the impact of ocean acidification and global warming on their physiology. I hope that my results will provide information on the ability of this key organism to survive in a high CO<sub>2</sub> world.



*Two examples of pteropods, a widely spread species of animal plankton affected by ocean acidification.*

## School teachers: how can you use this experiment with your pupils?



*Last check before ballon launch: in a few minutes Italian students from scientific high school "Luigi Pirandello" will sample the atmosphere over the island of Lampedusa*

tional initiative from European scientists to help schools learn about climate change science. Find more about resources, methodology, experiments at [www.carboschools.org](http://www.carboschools.org)

- beyond learning the scientific facts, investigate with your pupils the solutions to climate change and ocean acidification: how can we stop emitting CO<sub>2</sub> in the atmosphere? This requires huge changes both at the global, country and individual levels! At the school level, you can engage a school Agenda 21 or an eco-school (see [www.eco-schools.org](http://www.eco-schools.org)) to actively take part into the global effort for reducing emissions.

To get started about ocean acidification:

\* Animation made by Ridgeway School, Plymouth in collaboration with EPOCA <http://www.youtube.com/user/KellyMarine4>

\* EUR-OCEANS introductory movie (9'30) in English, French, German, Spanish: <http://www.eur-oceans.info/EN/medias/films.php>

\* EUR-OCEANS Fact sheet "Ocean Acidification- the other half of the CO<sub>2</sub> problem"

\* The Pew Charitable Trusts Fact-sheet "Carbon Dioxide and Our Ocean Legacy" <http://www.pmel.noaa.gov/pubs/PDF/feel2899/feel2899.pdf>

\* Read the news: <http://oceanacidification.wordpress.com/>

\* Research community's information website: <http://www.ocean-acidification.net/>

\* EPOCA web site: [www.epoca-project.eu](http://www.epoca-project.eu)

(all these links are given at the Education page, section "What do we do?" in the EPOCA website)

- a first activity could be to give introductory materials and courses to your pupils to explain the basics about CO<sub>2</sub>, climate change and ocean acidification. You can use the CarboSchools educational booklets for this purpose.

- if you are close to one of the labs involved in Spitzbergen, invite one of the scientists who will be going there to come into your classroom to meet with the pupils and help initiate projects and discussions about ocean acidification.

- while we are in Ny Alesund, read our diary & pictures in our blog, send us your questions via e-mail and interview us through the internet - see [www.epocaarctic2009.wordpress.com](http://www.epocaarctic2009.wordpress.com)

- use this as a starting point to initiate broader science learning activities about climate change, and develop your own experiments in the frame of a CarboSchools project. CarboSchools is an educational initiative from European scientists to help schools learn about climate change science. Find more about resources, methodology, experiments at [www.carboschools.org](http://www.carboschools.org)

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