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CLIMATE CHANGE IN THE MARINE REALM

An international summer school in the framework of the European Campus of Excellence

Edited by
Angelika Dummermuth and Klaus Grosfeld
with contributions of the participants

HELMHOLTZ | GEMEINSCHAFT

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PREFACE

Today's graduate education in climate related sciences is still highly disciplinary and topic specific. Our young academics are well trained and specialized in their disciplines. However, research on climate change and its impact on environment as well as on society demands an interdisciplinary and multidisciplinary approach in order to better understand the Earth System as a whole. Bridging the gap between disciplines and a basic knowledge of other disciplines enables graduate and early PhD students to cooperate and exchange views on the common theme of global environmental change.

In order to foster this process and to promote young gifted students from different disciplines and universities the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research and the MARUM - Centre for Marine Environmental Sciences at the University of Bremen have initiated a two-weeks summer school in the framework of the European Campus of Excellence (ECE) funded by the Stiftung Mercator. The "International Summer School on Climate Change in the Marine Realm" took place in September 2012 at the Wadden Sea station in List on the island of Sylt and at the MARUM in Bremen. The summer school aimed at strengthening the cooperation of students from different disciplines, widening the view for themes beyond the ordinary master programmes and disciplines. Forty students at masters and early PhD level from 15 different countries contributed to the articles presented here. Their educational background ranged from biology, chemistry and geology to environmental physics oceanography and environmental geosciences.

The summer school provided insights into the role of the ocean in the climate system and the complex interactions within the Earth system using examples of the marine realm: Variability of the heat transport; uptake of climate gases; marine carbon cycle; climate impacts on marine and coastal ecosystems, biological productivity of a warming ocean; oxygen minimum zones influenced by climate change; control of precipitation by the ocean in Africa.

This issue of Reports on Polar and Marine Research summarizes the results of the summer school. It includes basic experiments showing how climate change interacts with the oceans and impacts the biota from species to ecosystem level. The report also includes ideas about how to deal with climate change impacts in coastal systems– a topic of relevance for society. In depth previous knowledge was not a prerequisite to learn about climate change and we are glad that this issue represents an alternative access to this topic.

The first chapter, "Marine Ecosystems and Climate Change", covers experiments demonstrating the impact of rising temperatures and ocean acidification on plants and animals. It mimics potential future changes that may affect the marine ecosystem at large.

Chapter two deals with “Climate Change in Costal Systems”. Two thirds of the worlds’ largest cities are located within coastal areas. They are endangered by sea level rise and also by land subsidence. This increased vulnerability to flooding projected for the future is of great concern for the people of coastal regions. In addition, coastal erosion is a major factor shaping coastlines in the Wadden Sea. Governments are forced to increase the protection of coasts at very high costs. The focus discussed here is on the island of Sylt in the Wadden Sea and the efforts to protect its coasts against erosion and flooding.

The fact that the oceans are not only subject of change but also influence the climate system is shown in chapter three “Oceans and the Climate System”. Looking back into the climate of past periods helps us to better understand current changes and to predict possible future trends. The sediment cores from the sea floor have preserved indicators of past climates and are the tools to unravel its changes.

Chapter four “Observing the Oceans” deals with measuring the major variables of the marine ecosystem. It also introduces the essential monitoring programmes which are needed to observe the variability of the marine system and to provide the data for climate models.

The final chapter addresses a seemingly different field, “Climate Services”, which presents the link between research findings and societal needs. The civil society, governments, media, or interested individuals are all stakeholders of our science and they have different requirements. This needs to be addressed in our transfer of knowledge into society.

We hope that this report will contribute to a better understanding of this complex issue, providing information on the different aspects of climate change in the marine realm. We also hope that it will support a broad and comprehensive education on the topical questions of climate change.

Bremerhaven, 15/05/2013

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Umweltwissenschaften

Participants of the "International Summer School on Climate Change in the Marine Realm", September 2012

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MODULE 1
MARINE ECOSYSTEMS AND CLIMATE CHANGE

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Introduction

Carbon dioxide, CO_2, is an important gas in the atmosphere. Although it exists in low concentrations compared to other atmospheric gases, CO_2 plays an extremely important role in the climate system. It also plays a crucial role for the biological functioning of the ocean.

You may not be able to see them, but microscopic plants living in the ocean use sunlight, CO_2 and water to produce sugars as energy source for growth. This process is called photosynthesis[1]. The organisms are called phytoplankton[2], and they are essential components of the marine environment, serving as a basis of the food web for small and large animals like fish and marine mammals. Phytoplankton is also critical for cycling elements, especially carbon, through the Earth system. Phytoplankton species build their shells from carbon in the ocean, and some species make hard external skeletons out of limestone, or calcium carbonate[3], which is a white mineral. These microscopic plants are known as calcifying phytoplankton[4], and when they die (just as calcifying zooplankton), they sink to the bottom of the ocean and gradually build up sediments. The white cliffs of Dover (Fig. 1) are a fantastic example of trillions of these tiny creatures turned into rock over a long time period. This sedimentation process takes carbon out of the surface waters and transports it into the deep ocean, where it is effectively trapped from the atmosphere because the time it takes for water deep in the ocean to circulate around the world and reach the surface again is extremely slow. In fact, it would take about 1,000 years for a droplet of water to circulate around the world.

1 Photosynthesis: Biological process where plants take-up carbon dioxide, nutrients and water to produce organic matter for growth and oxygen (as a by-product) using energy from sunlight.
2 Phytoplankton: Microscopic, single celled algae that live in the ocean (and freshwater). They need sunlight for growth and support the entire marine food web.
3 Calcium carbonate: White mineral formed from the elements calcium, carbon, and oxygen. Chalk and limestone are examples.
4 Calcifying plankton: Particular species of phyto- and zoo-plankton that create external shells of calcium carbonate.

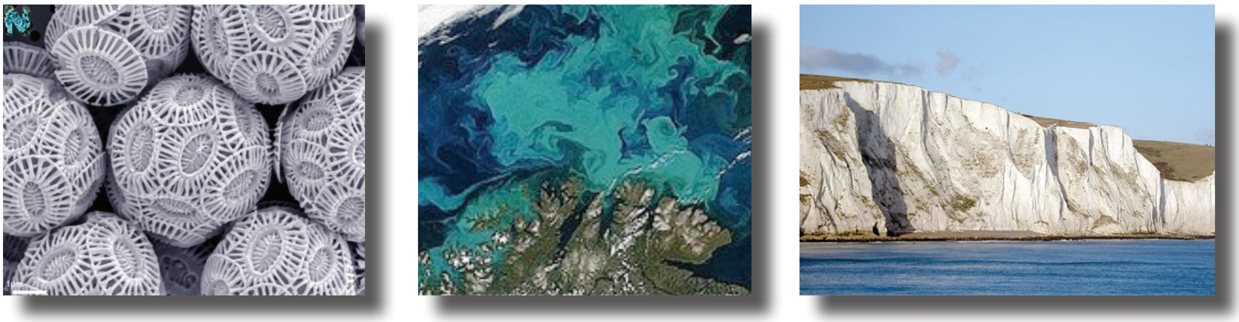


Fig. 1. "Organisms in the ocean may be small, but they have a big impact globally. This microscopic marine algae is called Emiliania huxleyi and the intricately designed shells that make up its external skeleton are created from calcium carbonate, which is limestone (left, source: http://www.co2.ulg.ac.be/peace/intro.htm). Although they are too small to be seen with the naked eye, they are so abundant in the ocean that at certain times in the year they can be seen from space. Their white shells reflect sunlight. This satellite image of turquoise swirls is of a phytoplankton bloom off the northern coast of Norway (middle, source: MODIS, www.fas.org). When phytoplankton and other marine organisms die, they sink to the seafloor. Over thousands of years the layers build up and turn into rock under high temperature and pressure. Rocks created from calcifying organisms are very white, such as this photograph of the 'White Cliffs of Dover', on the south coast of the United Kingdom (right, source: www. bathknightblog.com). This geological process cycles carbon from the atmosphere, through the ocean and into rocks and makes up part of the carbon cycle."

The amount of CO_2 in the atmosphere is increasing each year due to the use of fossil fuels[5] in our day-to-day lives (anthropogenic[6] carbon). If the concentration of atmospheric CO_2 increases, it also increases the amount of CO_2 dissolving in the ocean. This is because the ocean and the atmosphere are always trying to find a balance in the concentrations of the gases they contain - CO_2 from the atmosphere dissolves in water when the CO_2 concentration is higher in the atmosphere than in the ocean (just as any other gas). The amount of CO_2 that can dissolve in the water is depending on the temperature of the water. If the water is cold, more CO_2 (and other gases) dissolve into the ocean. This means that more CO_2 will be taken up in the Arctic and Southern Ocean where the average sea surface temperature ranges between -2°C and +10°C. When CO_2 dissolves in seawater, it reacts with H_2O forming carbonic acid (H_2CO_3). This is the important difference between CO_2 and the other major gases in the atmosphere such as N_2 and O_2. H_2CO_3 is not very stable deprotonates into bicarbonate ions (HCO^{3-}) carbonate ions (CO_3^{2-}; building blocks of calcifying organisms) and thus increases the concentration of hydrogen ions in seawater, which in turn reduces the seawaters` pH. This phenomenon is called ocean acidification (OA; Caldeira and Wickett 2003).

CO_2 and carbonate ions (CO_3^{2-}) are taken up by phytoplankton and calcifying organisms, respectively. In doing so, around 60% more CO_2 can be transported from the atmosphere into the oceans in addition to the natural dissolution process. If it wasn't for this fantastic feature of the ocean's biogeochemistry, the present concentrations of CO_2 in the atmosphere would be much higher than they are today!

5 Fossil fuels: Coal, oil, and natural gas. All produce carbon dioxide when they are burned in the presence of oxygen, along with other greenhouse gases.
6 Anthropogenic: "Human" driven or produced.

The hydrogen ion concentration is responsible for water being acidic or basic, the degree of which is measured on the pH scale. The oceans typically have a slightly basic pH of ~8.2, but with the extra amounts of greenhouse gases in the atmosphere, more and more H^+ ions are being produced in the ocean, making the ocean more acidic. This isn't the same as saying that the ocean is now acidic. It means that the pH of the water has decreased but it is still basic as the pH is greater than 7. The decrease in ocean pH has been approximately 0.1 units over the last 100 years. This may not sound that significant, but it could have drastic consequences for the microscopic organisms living in the ocean, particularly those that calcify. Their shells and skeletons dissolve faster in water becoming more acidic, which may also affect their ability to grow and other physiological processes. It could also have a very complex range of impacts on other animals and plants within the food web due to combined effects of ocean acidification with increased sea surface temperatures and other changes in environmental conditions. Some of these are summarized in the diagram below (Fig. 2).

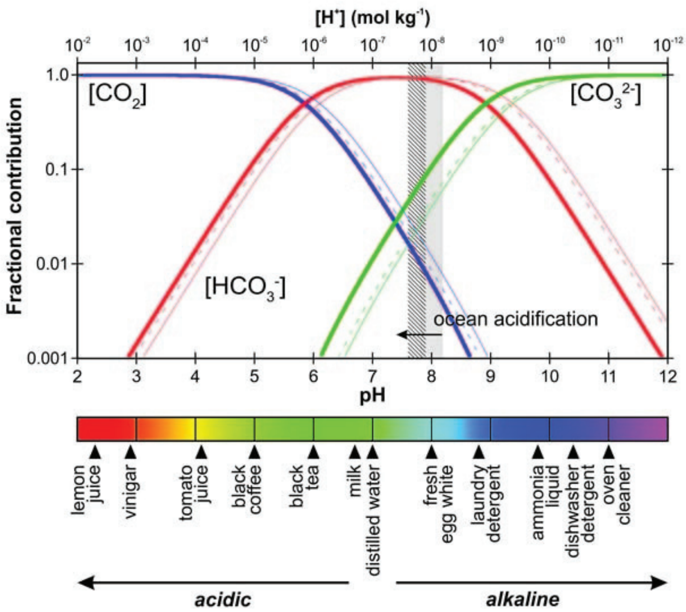


Fig. 2. "The chemistry of carbon compounds in the ocean at different pH. Carbon dioxide is soluble in water. Dissolved CO_2 (blue curve) makes up most of the ocean carbon when the pH of the water is highly acidic (low pH). The two other carbon species, bicarbonate (red curve) and carbonate (green curve) exist in various concentrations at different pH. The pH of the ocean is currently 8.2. If the pH is lowered (made more acidic), the amount of carbonate ions decreases and the amount of dissolved CO_2 increases (source: Barker and Ridgwell 2012)."

Considering the combined effects of these factors on marine organisms, one can image that they become extremely stressed outside of their favourite living conditions. For cold adapted species the geographical region in which they live starts shrinking with increasing sea temperatures, leading for example to pole ward migrations of species trying to keep within their preferred temperature range. Areas with sufficient concentration of carbonate ions, that are needed for growth of calcium carbonate shells, constrict and start to become corrosive to the organisms. In particular, it is expected that within the next 40 years the Southern Ocean will become corrosive to calcifying organisms through the whole depth of the ocean, meaning that their productivity will diminish with severe consequences for the animals feeding on them. Observations by satellites indicate that increasing stratification of the ocean in the tropics and subtropics have a negative effect on nutrient availability, and therefore, primary productivity is reduced in these areas (Behrenfeld *et al.* 2006). The response of phytoplankton in high latitudes may in some cases be positive as warming and reduced mixing may enable longer growing seasons (Doney 2010). The impacts outlined above will affect marine ecosystems at all levels; species will move geographically and vertically and the spawning time of prey and predators may become mismatched seasonally, resulting in food limitation and less recruitment. This has repercussions all the way up the food web, affecting fisheries in the years to come.

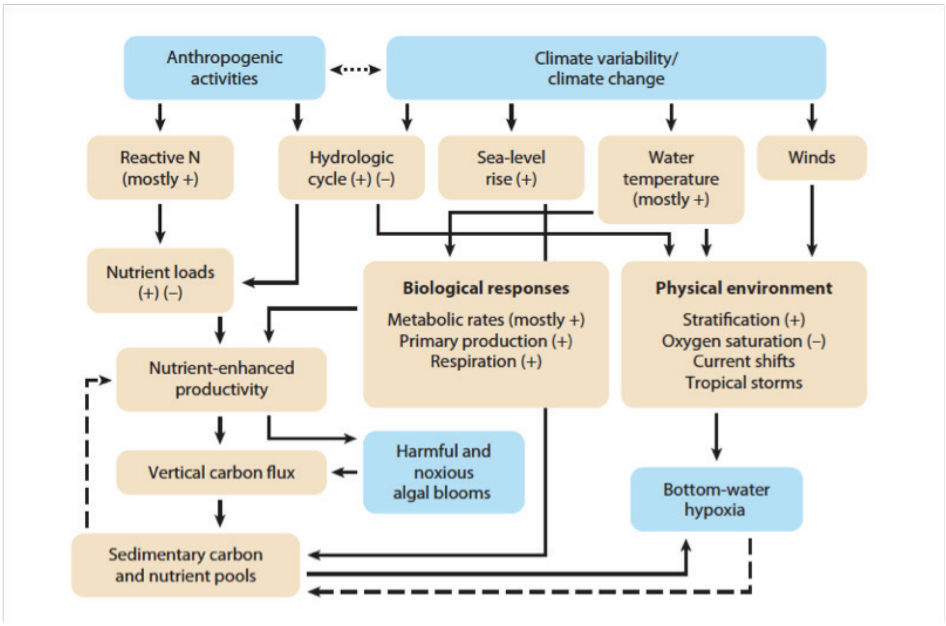


Fig. 3. Interactions of climate change effects and ocean biology (source: Doney et al. 2011).

Ocean Acidification in the Past

Studying the climate of the past (palaeclimatology) can provide extremely valuable information on the natural variability of the Earth's climate. Environmental parameters such as temperature ranges, degree of sea ice cover, and concentration of CO_2 in the atmosphere in the past provide us with ideas about the initiating factors that caused the climate to change and the time period certain changes naturally take. We can assess whether the changes that we currently observe are within the natural scale of variability of the planet.

The last time that the concentration of CO_2 in the atmosphere was as high as it is currently with 390 ppm was more than 25 million years ago. The projections for the year 2100 suggest that atmospheric CO_2 concentrations of beyond 800 ppm, as much as in a period called 'Greenhouse Earth' (no ice present) which ended about 35 million years ago. Organisms that evolved after these periods, never had to live in an ocean that is as acidic as it is projected for the near future.

The last five major global marine extinctions have all been the result of shifts in ocean chemistry impacting the biology of the ocean system. There is strong evidence that this was related to a natural disturbance of the carbon cycle. With the exception of the Cretaceous meteorite impact, all of these disturbances were at least 10 times slower than today. In the last 150 years, the atmospheric concentration of CO_2 has risen by almost 100 ppm. This is similar in magnitude to the degree of CO_2 change between ice ages and warm periods. However, it took about 10,000 years for the glacial-interglacial transition from 180 (glacial) to 280 ppm (pre-industrial).

Predicting how Species and Areas will Respond to Ocean Acidification in the Future

The marine system is incredibly complex, so it is not surprising that it is difficult to make concrete predictions about what a particular area of the ocean will look like in 50 or 100 years, or whether a particular species will respond positively, negatively, or not change at all with decreasing pH. It is important to test how an individual species in different live-stages reacts in the laboratory to decreasing pH, but it must also be considered how these species will interact with their environment. However, it is impossible to test everything! A valuable way of looking at ecosystem-level changes in terms of ocean acidification is to find areas in the oceans that already have much lower pH than other areas of the ocean and to study the species that live there, and how they interact with ech other. Hydrothermal vents are such areas with low pH as CO_2 can be found bubbling through the sea floor from volcanic activity and therefore provide ideal study cases (Fig. 4). Studies on hydrothermal vents show that some species are actually coping fine under low pH conditions. For example, species whose protective outer shells become thinner and less protected but do not have a natural predator in this system. If enough food is available, the additional energy required for maintaining a shell can balance and alleviate the impacts on the organism. As a basic rule, as the ocean becomes more acidic, it becomes more difficult for organisms to survive; either more energy is needed to compensate the stress or organisms will have reduced performance. However, for every species in every community there is a limit to the combined stressors for the organism and the population will eventually decrease leading to changes in the community structure. Therefore it is important to understand the local conditions and their natural variability really well. It may be possible to avoid or at least delay drastic changes in marine communities by reducing the additional human stressors on the system, such as for example fishing pressures, pollution, and tourism, to stabilize and strengthen the resilience to ocean acidification.

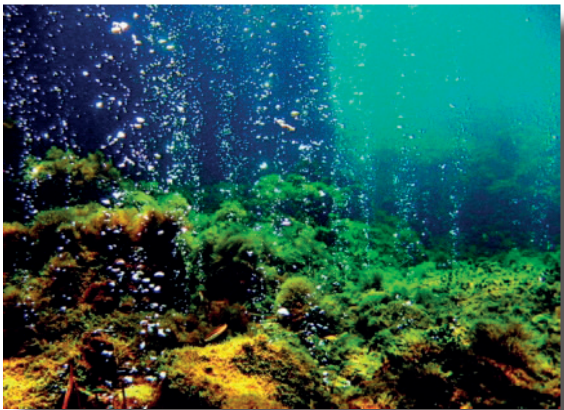


Fig. 4. "Bubbles of carbon dioxide seeping from the seafloor, near Italy in the Mediterranean Sea. Locations like these are extremely valuable for looking at ecosystem responses to low pH ocean conditions and which life forms can survive under such conditions (source: Chemical & Engineering News, 2012, 90, 12-17 by Luca Tiberti)."

A Solution for the Future?

A major focus of current research is how we might be able to limit the impact of climate change on the environment and reduce the severity of any changes in the future (mitigation and adaptation). The concept of geoengineering (or climate engineering) refers to "deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming" (Royal Society 2009, Committee on Science, Engineering, and Public Policy 1992). The Royal Society describes two categories of geoengineering: "1) Carbon dioxide removal techniques which addresses the root of climate change by removing greenhouse gases from the atmosphere. 2) Solar radiation management techniques which attempt to offset effects of increased greenhouse gas concentrations by causing the Earth to absorb less solar radiation." According to the Intergovernmental Panel on Climate Change (IPCC 2007) geoengineering options remain largely unproven.

The following experiments aim on understanding the effects of increasing CO_2 concentrations, ocean acidification and potential engineering ideas to capture CO_2.

Experiment 1:
Marine Biochemistry in Bucket Experiment

Introduction

Besides the gas exchange between the oceans and the atmosphere, carbon dioxide (CO_2) can get into or be drawn from the ocean by photosynthesis and respiration of marine autotrophic organisms such as algae and sea grasses. During the process, of photosynthesis organisms use energy from the sun to produce organic matter from carbon dioxide and water (equation 1).

$$6\,CO_2 + 12\,H_2O \longrightarrow 6\,O_2 + C_6H_{12}O_6$$

carbon dioxide — water — oxgen — organic matter

In contrast, heterotrophic organisms, as most animals, rely on organic matter as an energy source. In this reaction, they respire organic compounds to carbon dioxide and water using oxygen (equation 2).

$$C_6H_{12}O_6 + 6\,O2 \longrightarrow 6\,CO_2 + 12\,H_2O$$

organic matter — oxgen — carbon dioxide — water

The carbon dioxide resulting from both processes interacts with the carbonate system in the ocean. Consequently, organisms influence environmental parameters such as oxygen content and pH. If organisms are contained in small enclosed environments such as tidal pools, these effects become clearly detectable. In this experiment, this effect was simulated in buckets to answer the questions:

How do species influence oxygen and pH in a small scale marine system?

And moreover, might this be of any use in terms of mediating acidification and oxygen depletion in oceans?

Material and Methods

To assess the impact of autotrophic species the sea lettuce (*Ulva lactuca,* Fig. 5, right) was used, while the common periwinkle (*Littorina littorea,* Fig. 5, left) was used as an example for heterotrophic organisms.

Fig. 5. Photo of the common periwinkle, Littorina littorea, (left, source: http://www.schnecken-und-muscheln.de/galerie/galerie_littorinidae.htm) and sea lettuce, Ulva lactuca (right, source: http://en.wikipedia.org/wiki/Ulva_lactuca).

Four different buckets were prepared with different combinations of seawater, animals, and algae. Bucket one was used as the control and contained only seawater to ensure that any impact was the result of the added species rather than that of microorganisms or other factors in the water. Bucket two contained 28 g of *U. lactuca* to assess the impact of photosynthesis. Bucket three contained 25 specimens of *L. littorea* to examine the effect of respiration on the system. Finally, bucket four contained 25 snails as well as 28 g of algae to assess the combined effect of respiration and photosynthesis. An overview of all buckets is shown in Fig. 6.

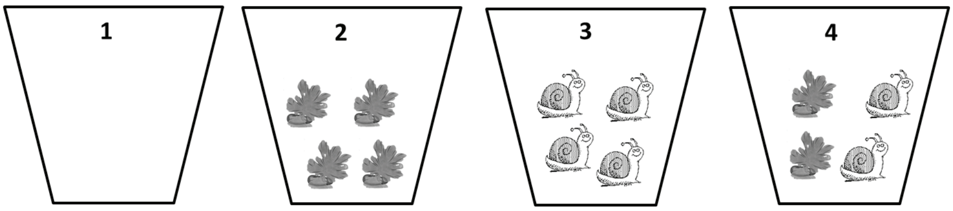


Fig. 6. Overview of all buckets prepared in this experiment.

For each bucket, dissolved oxygen content (mg/L) and pH were recorded regularly by using an YSI sampling probe for measurements of pH, dissolved oxygen, temperature, and salinity. In addition to the regular sampling throughout the day, an automated logger was set up to collect data every thirty minute overnight in the photosynthesis set up. The experiment ran for roughly 24 hours starting and ending around 10:00 am.

Results and Discussion

The concentration of dissolved oxygen as well as the pH in the buckets containing selected marine species varied considerably throughout the day (24 h). Before the start of the experiment, at about 10:00 am, all buckets displayed similar values of 6.5 to 7.0 mg/L oxygen and a pH of approximately 8.2 (Fig. 7).

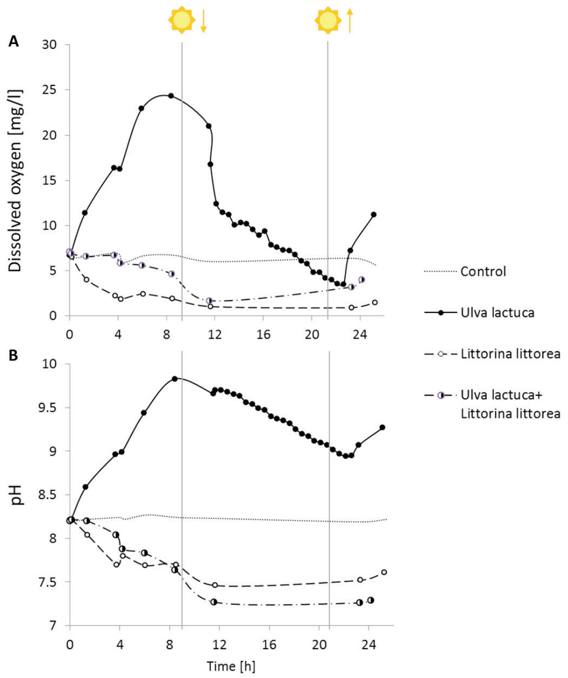


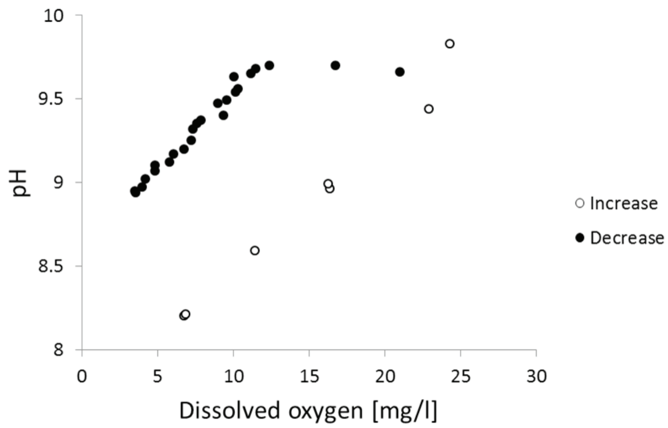
Fig. 7. Changes in dissolved oxygen content (top) and pH (bottom) of seawater over the course of one day in buckets containing selected marine species; dotted line without markers: control (sea-water), straight line and solid circles: photosynthesizing species, dashed line and empty circles: non-photosynthesizing species, dashed/dotted line and semi-solid circles: photosynthesizing and non-photosynthesizing species; time measured since the start of the experiment, grey vertical lines depicting time of sunset and sunrise.

In bucket two, which contained the photosynthetic alga *Ulva lactuca,* both parameters increased until sunset, reaching an oxygen concentration of almost 25 mg/L and a pH as high as 9.7. These values dropped during the night when the *alga* stopped photosynthesizing and switched to respiration now consuming oxygen and producing CO_2. When photosynthesis started again a short time after sunrise, oxygen and pH started to rise again rapidly (Fig. 7). A strong correlation between oxygen concentration and pH (Fig. 8) was determined. However, the intercept of the relationship was different when compared between day and night, i.e. increasing and decreasing oxygen values. At increasing oxygen concentrations while active photosynthetic phase during day pH was generally lower than at night when oxygen decreased suggesting a buffering capacity that prevents pH values from dropping immediately with starting respiration.

L. littorea in bucket three consumed oxygen and released CO_2, due to respiration. Oxygen concentrations and pH immediately started to drop after the start of the experiment. Sunrise and sunset did not affect this trend. After about 12h, O_2 and pH did not decrease any further. At that time, values as low as ~1.5 mg/L dissolved oxygen and 7.3 pH had been reached (Fig. 7). Most snails tried to escape these conditions by climbing out of the water, which prevented a further decrease of oxygen and pH.

The fourth bucket containing *U. lactuca* and *L. littorea* simulated the situation of a tidal poolwhere the species occur in the same area. During the first hours of the experiment a stable oxygen concentration was measured not deviating much from the control (Fig. 7). Towards the evening with decreasing sunlight, *U. lactuca* reduced and then stopped photosynthesic activity resulting in a decreasing oxygen concentration. At night, O_2 continued to drop, but dissolved oxygen levels were never as low as in the bucket only containing snails. However, snails escaped the water here as well leading to a bias in the measured values. The decrease in pH was not as pronounced in this bucket than in bucket three containing just snails. This changed after sunset, when pH values dropped below those of the other bucket (Fig. 7). After sunrise oxygen and pH values started to increase again due to the photosynthetic activity of the seaweed.

Fig. 8. Relationship between dissolved oxygen content and pH in the bucket containing Ulva lactuca; empty circles: during the increase of oxygen, solid circles: during the decrease of oxygen.



Conclusion

The results show that oxygen concentration as well as pH are influenced considerably by marine organisms. In isolated conditions, photosynthesizing species such as *Ulva lactuca* increase oxygen and pH during the day, whereas at night the stop of photosynthesis leads to a decrease in O_2 and pH due to respiration. Non-photosynthetic organisms such as *Littorina littorea* consume O_2 and produce CO_2 regardless of the time of day, leading to rapidly decreasing oxygen concentrations and low pH values of the surrounding water. In a functioning ecosystem the co-occurrence of both species usually leads to a balance in water parameters.

Concerning the issue of bioremediation of oxygen depleted and acidified areas, the ability of *Ulva lactuca* to produce high amounts of oxygen and therefore significantly increasing pH offers a promising opportunity. However, these processes are depending on sun light. At night *Ulva lactuca* consumes O_2 and produces oxygen just like non-photosynthetic species. Introducing large amounts of seaweed to an ecosystem would then result in more severe depletion of oxygen and decrease in pH at night than in its previous state. This is just one aspect that should be considered in bioremediation.

Experiment 2:
Impact of Elevated CO_2 Concentration on Marine Organisms

Introduction

Atmospheric CO_2 has increased from the preindustrial level of 280 ppm to 390 ppm currently. By the year 2100, a CO_2 concentration of 730-1,020 ppm is predicted, leading to a continuous rise of average temperature (IPCC 2007). The world's oceans represent a major sink of CO_2 absorbing the atmospheric CO_2.resulting in the described phenomenon ocean acidification. Ocean acidification can impact development, physiology survival and growth, of marine invertebrates.

Echinoderms are a group of marine invertebrates that includes sea stars and sea urchins. They play a key role since they are considered as "builders" and "engineers" of ecosystems. The removal of echinoderms from the sea can generate changes in the functioning and composition of ecosystems (Boudouresque & Verlaque 2007). However, despite echinoderms important role in ecosystems, there are only two studies investigating the possible impact of elevated CO_2 concentrations on their immune-response. Hernroth *et al.* (2011) showed that exposure to high CO_2 concentrations (900 ppm) for a duration of one week to six months induces a reduction in the number of immune cells in the sea star *Asterias rubens* by 50 percent. After an exposure of more than 6 months to high CO_2 concentrations, the immune system was significantly affected. These changes were associated with an uncompensated reduction of the pH in the hemolymph (the extracellular fluid=blood). Dupont & Throndyke (2012) also showed that an elevated CO_2 concentration of 1,275 ppm leads to a reduction of the extracellular pH in sea star *Leptasterias polaris* and the sea urchin *Strongylocentrotus droebachiensis*. While in the sea star *L. polaris* this drop of pH was not compensated after seven days of exposure, the pH in the sea urchin *S. droebachiensis* returned to control conditions after five days. For both species, the drop of hemolymph pH was associated with an increase in total immune cell number, and in *S. droebachiensis* this drop was also associated with a reduction in vibratile cells (a certain type of immune cells). A relationship between extracellular pH and phagocyte (cells that protect the body by ingesting harmful foreign particles, bacteria, and dead or dying cells) numbers was observed in *S. droebachiensis* suggesting a direct link between extracellular pH and cellular immune-response.

This experiment aimed to investigate the impact of short-term (24 hours) exposure to a CO_2 concentration of 1,000 ppm (expected for the year 2100) compared to 390 ppm (current values, but see discussion for caveat on this value). This comparison was intended to evaluate the effect of a low pH on the immune system of the sea star *Asterias rubens* and the sea urchin *Paracentrotus lividus*. This experiment was used to test our hypothesis that the rise of CO_2 concentration in seawater may impact the cellular immune system showing a reduction of extracellular pH as well as the number of immune cells in hemolymph.

Materials and Methods

Adult individuals of the sea star *Asterias rubens* and the sea urchin *Paracentrotus lividus* were collected from the Wadden Sea in rocky and sandy substrates during the low tide in List on the island of Sylt, Germany (Fig. 9).

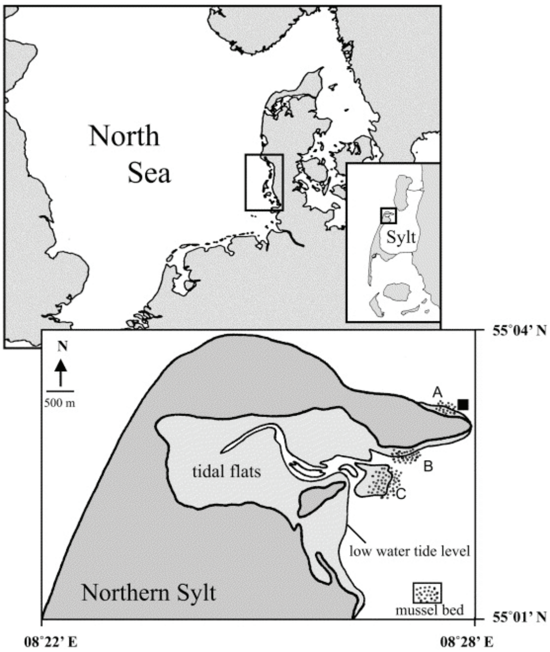


Fig. 9. Study area – Wadden Sea, North of Sylt (source: http://www.sciencedirect.com/science/article/pii/S1385110101000673).

The animals were transported to the laboratory and kept in 30 L tanks at 10 °C using bubbled seawater from the sampling site (temperature = 9 °C, salinity = 34‰, pHnbs = 8.16). Animals were not fed during the experiment and were exposed to two different pH levels. One reservoir served as the control with a pH of 7.92, and the second was filled with seawater with 1,000 ppm CO_2 concentration, resulting in a lower pH of 7.79. The control tank was filled with the bubbled seawater only. Thee xperimental tanks were prepared with seawater containing 1,000 ppm CO_2 for each of the three species, n=3; and bubbled with an air stone (Fig. 10, left). Unfortunately, the seawater used in the experiment had a slightly lower pH than ambient conditions (see discussion).

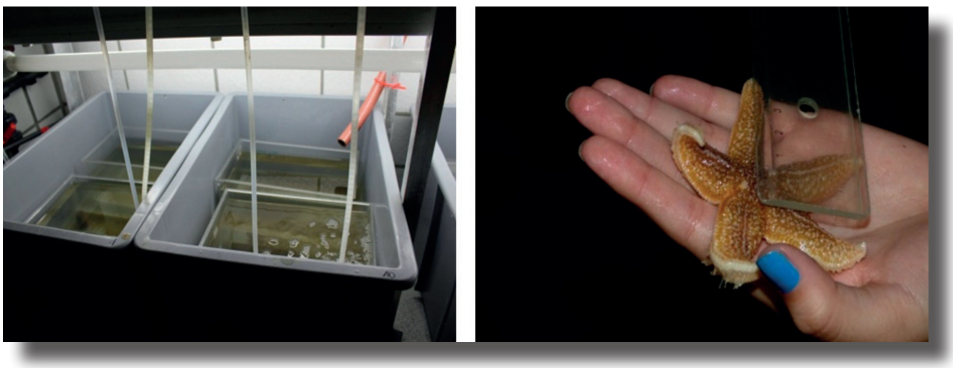


Fig. 10. "The animals were kept in tanks (left) and measurement of size of the seastar Asterias rubens (right)."

The animals were kept in the tanks for 24 hours. After this time period, scientists measured the pH values in every aquarium using a pH meter (Met Rohm 827 pH lab). The size of each sea star was determined with a ruler measuring the distance from the centre of each animal to the end of one arm (Fig. 10, right). For the size determination of the sea urchins, the diameter of each animal was measured.

In the sea stars, the hemolymph was collected after amputation of an arm tip and in sea urchins by sinking a syringe into the mouth. None of the animals died – sea stars can regenerate their arms. One third of the hemolymph was immediately fixed in formalin for cells counts. The rest of the hemolymph (appr. 20 µl) was used for pH measurements. Cell counts were performed by counting formalin-fixed cells in a Bürker chamber (BT, Brand, Wertheim, Germany), which is a tool designed for counting cells (Fig. 11). Results are presented as cell counts per 20 µl. All measurements were performed within five minutes after sampling (Dupont and Thorndyke, 2012). As the volume of hemolymph extracted from the sea urchins was too small for accurate measurements, only the sea stars could be used for pH-measurements and cell counts.

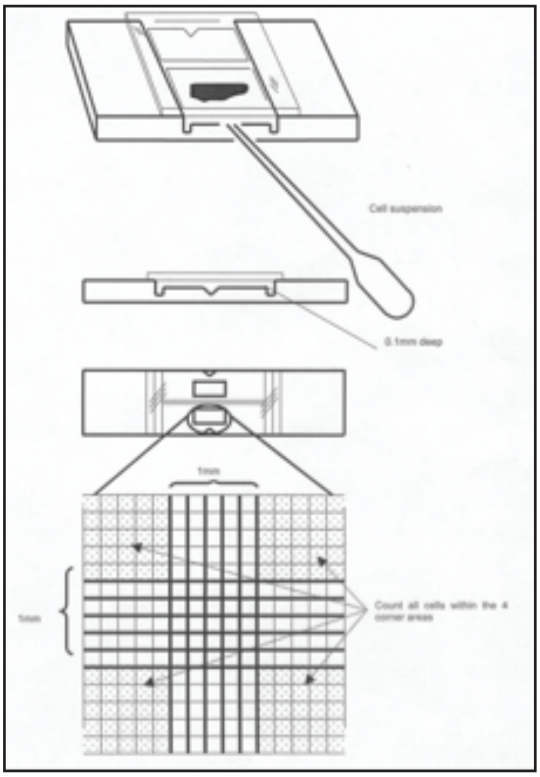


Fig. 11. Schematic view of a Bürker chamber (source: http://www.who.int/vaccines/en/polioIab/webhelp/Chapter_04/4_2_Cell_culture_procedures.htm).

Each measurement is displayed as the arithmetic mean ± standard deviation. The software package "GraphPad PRISM" was used to create graphs and provide the statistical analysis. A two-tailed t-test was used to check whether there is a significant difference between the results of two study groups of organisms.

Results and Discussion

The pH in the seawater reservoir for control conditions had a value of 7.92 only slightly higher than the experimental treatment (1,000 ppm CO_2) with a pH of 7.79. Seawater usually has a pH of ~8.1 and a CO_2 concentration of 390 ppm. Unfortunately the actual level was not measured. Therefore it seems likely that the actual CO_2 concentration was higher reducing measurable differences between the control and treatment groups.

Under control conditions an extracellular pH of 7.23 ± 0.12 was measured in the hemolymph of the sea star *Asterias rubens* (Fig. 12, left). After 24 hours of exposure to acidified conditions of 1,000 ppm CO_2 an extracellular pH of 7.15 ± 0.05 was observed. While there is a trend for lower extracellular pH in the experimental group, no statistical difference between these two values was detected. The results obtained do not conform to the hypothesis that the extracellular pH of

Echinodermata would decrease during increased CO_2 concentrations and would recover between 5-7 days as postulated by Dupont *et al.* 2012. However, the number of animals used for these measurements was very small with an n=3 for each treatment and standard deviation rather high. An increase of the number of animals may thus lead to detectable changes.

The immune cell count for sea stars in the control was 45.7 ± 3.3, which was higher than the cell count of 37.0 ± 10.6 observed under 1,000 ppm CO_2 conditions (Fig. 12, right). Again, statistical analysis did not show significant differences between the two treatment groups.

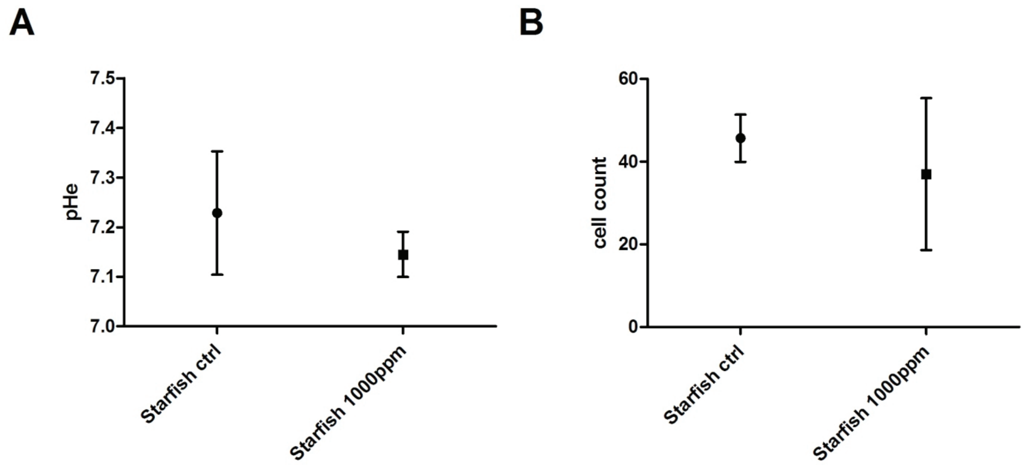


Fig. 12. Extracellular pH (left) and immune cell count (right) measured in Asterias rubens kept for 24 hours in seawater with 390 ppm CO_2 (sea star control, but see caveat in text) and 1000 ppm CO_2 (sea star 1,000 ppm). Arithmetic means ± Standard Deviation are shown. The number of animals used was 6 for the measurements of pH and 3 for the Immune cell count.

Conclusions

Ocean acidification is caused by increasing CO_2 concentrations and subsequent reduction of pH in the world's oceans. Former studies show that echinoderms such as sea urchins and sea stars are affected by ocean acidification leading to a reduction of pH in the hemolymph and to a measurable immune response displayed by alterations in the number of immune cells in the hemolymph. The aim of this experiment was to investigate the impact of ocean acidification on echinoderms by exposing the seastar *Asterias rubens* to recent CO_2 concentrations of 390 ppm and increased CO_2 concentrations of 1000 ppm predicted for the year 2100 and observe the extracellular pH and the immune reaction measured as number of immune cells. Statistical analysis did not show any significant differences of the hemolymph pH between animals kept in the control and experimental conditions. Also, no significant differences in the number of immune cells were detected. In future experiments, it would be useful to increase the number of animals in each group to reduce the standard deviation and to thus increase the detectability of CO_2-induced changes. Furthermore, it is essential to ensure the correctness of the assumed CO_2 concentrations in the water reservoirs as otherwise physiological changes might become undetectable.

Experiment 3:
Let the Earth help us to save the Earth

Introduction

Over the last 250 years, the oceans have absorbed 530 billion tons of CO_2, triggering a 30 percent increase in ocean acidity. Before people started burning coal and oil, ocean pH had been relatively stable for the previous 20 million years, but now, ocean acidification is happening faster than it has in the last 300 million years. Researchers predict that if carbon emissions continue at their current rate, ocean acidity will more than double by 2100. In nature, ocean acidity is stabilised through the weathering of rocks, which react with CO_2 either in the atmosphere or the ocean and convert it to alkalinity which restores ocean pH, allowing calcifying organisms to produce sediments again that finally store the CO_2 as solid rock again (equation 3).

$$Mg_2SiO_4 + 2\ CO_2 \rightarrow 2MgCO_3 + SiO_2$$

Many suggestions have been made to speed up this process to prevent the increase in ocean acidification. A rather radical concept has been proposed by Schuilling & Krijgsman (2006). They postulate that the mineral Olivine may be used to enhance the rate of weathering thereby trapping atmospheric CO_2. Olivine is a greenish mineral consisting of magnesium silicate (Mg_2SiO_4). It is the most common mineral on Earth accounting for 90 per cent of the Earth's crust (Fig. 13, left) and is abundant in many countries of the world in mountain ranges. Olivine forms magnesium carbonate and silicon oxide when reacting with CO_2 in the atmosphere. The magnesium carbonate is washed into the ocean and will form new sedimentary rocks at the seafloor. Silicon oxide is just sand and therefore neutral in the natural environment. The concept is to crush olivine rock, simply spread a thin layer over any available surface where it will react with the CO_2 in the atmosphere. Spreading it over beaches would even enhance the effect, as the wave action would break down the rock into smaller pieces. This concept is simply an accelerated natural process. It may prove to have far fewer side effects than other geo-engineering options for removing carbon dioxide from the atmosphere. However it remains to be seen if it would be feasible.

The experiment aims to prove the hypothesis that *"Increased surface area of olivine will increase the rate of CO_2 uptake".*

Fig. 13. Olivine mineral (left, source: www.chemistry.about.com) and natural olivine beach being weathered by the sea (right, source: www.myamazingearth.com).

Method

Seawater Chemistry

Before and after the experiment temperature, salinity, pH and total alkalinity of the seawater were recorded assuming no nutrients present. Temperature and salinity were measured using a handheld WTW multi-meter and for pH measurementsa handheld WTW 3301 pH meter and WTW SenTix 81 pH electrode 0…14/0…100 °C 3M KCl were used, employing the National Bureau of Standards (NBS). 100 ml of water per bottle were taken for total alkalinity analysis and stored in glass bottles. After the experiment, the seawater was filtered through 47 mm filter paper with a pore size of 0.4 microns (Whatman GFF) to remove particles that would compromise accurate total alkalinity analysis. Total alkalinity was determined using titration. The principal is described by Dickson *et al*., (2007). TA was corrected with a calibration factor. Carbonate system parameters that were not measured directly had to be calculated using measured pH and total alkalinity values in the computer programme CO2SYS (Pierrot *et al.,* 2006), employing constants from Mehrbach *et al.,* (1973) refitted to the NBS scale by Dickson and Millero (1987) and the KSO_4 dissociation constant from Dickson (1990).

Experimental Set-up

For the experiment 22 µm filtered seawater at pH 7.81 was used, as this is the predicted pH for 2060. One liter of seawater was then poured carefully in to four 2-liter screw-top bottles, to avoid bubble formation, which would alter the pH. One litre of headspace on the bottle represents the atmosphere and one litre of seawater represents the ocean. 30 g of olivine powder of varying sizefractions were carefully added to the seawater to ensure that no olivine sticks to the sides of the bottle. The three treatments differed in sizefraction: fine, coarse, and a mixture of fine and coarse powder (15 g of each) (Fig. 14). It is thought that fine powder has a larger surface area to volume ratio than the same weight of coarse powder and therefore more area for CO_2 to react with, thus the reaction should occur faster. Mixed powder were used in order to simulate natural conditions of weathering. As a control pure filtered seawater was used.

Fig. 14. "The four treatments used to measure the effect of the sizefraction of olivine on the rate of carbon dioxide uptake from acidified seawater."

Once the olivine was added to the 2-litre bottles, the were carefully placed on a shaker table (Edmund Bühler GmbH KS10 Shaker Table, Laborgerätebau Glastechnik Umwelttechnik, Germany) at 175 cycles per minute for 18 hours. By shaking the bottles kinetic energy is added to increase the reaction rate.

Results

Seawater chemistry remained stable in the control treatment throughout the experiment, while it differed between the three treatments (Table 1). Salinity remained stable in all treatments (29.9 ppt). Temperature increased in all treatments compared to the control, with the highest temperature rise of 0.5°C in the fine crystals treatment compared to the coarse or mixed treatment (0.4 and 0.3 °C respectively) (Fig. 15, right). The pH was higher in all treatments than the control with the fine treatment ending more alkaline (pH 8.0) than the coarse or mixed treatment (pH 7.8 and 7.9 respectively) (Fig. 15, left). A positive relationship was observed between pH and temperature (Fig. 16). The representative atmospheric and seawater CO_2 concentrations were closely linked (Fig. 17). Total alkalinity increased in all treatments compared to the control by more than 135 mequiv. kg^{-1}. Furthermore, the fine treatment demonstrated higher total alkalinity, pCO_2, HCO^-, CO_3^{2-}, and TCO_2 compared to the mixed and coarse treatments (Table 1). The saturation states of calcite and aragonite were higher in all treatments compared to the control and reached highest values in the fine treatment.

Tab. 1: Seawater chemistry in the initial seawater at the beginning of the experiment and in the four treatments after the experiment.

Parameter	Initial	Control	Fine	Coarse	Mixed
Salinity (ppt)	30	29.9	29.9	29.9	29.9
Temperature (°C)	24.9	22.8	23.3	23.2	23.1
pH	7.678	7.676	7.970	7.793	7.906
TA (mequiv kg^{-1})	2276	2275	2535	2410	2498
pCO_2 (µatm) *	1092.3	1098.7	596.6	864.0	666.2
HCO^- (mmol kg^{-1}) *	2050.9	2050.8	2092.5	2108.9	2111.8
CO_3^{2-} (mmol kg^{-1}) *	93.3	93.0	186.7	126.1	162.6
TCO_2 (mmol kg^{-1}) *	31.8	2175.7	2295.8	2260.0	2293.8
Ω cal *	2.34	2.33	4.68	3.16	4.08
Ω ara *	1.52	1.52	3.05	2.06	2.65

Note. Data are seawater parameters measured or calculated during the duration of the experiment: salinity (ppt), temperature (°C), pH, total alkalinity, carbon dioxide partial pressure (pCO_2), bicarbonate and carbonate ion concentration (HCO^- and CO_3^{2-}), total CO_2 and calcite and aragonite saturation states (Ω cal and Ω ara). '' parameters were calculated using the CO2SYS program (Pierrot et al., 2006), employing the dissociation constants of Mehrbach et al., (1973) as refitted by Dickson and Millero (1987).*

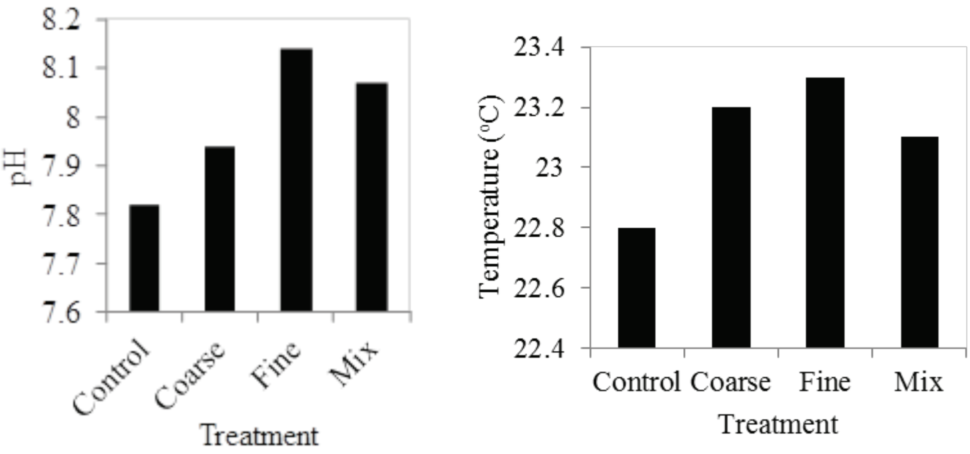


Fig. 15. Seawater pH (left) and temperature (°C) (right) in the different treatments after the experiment.

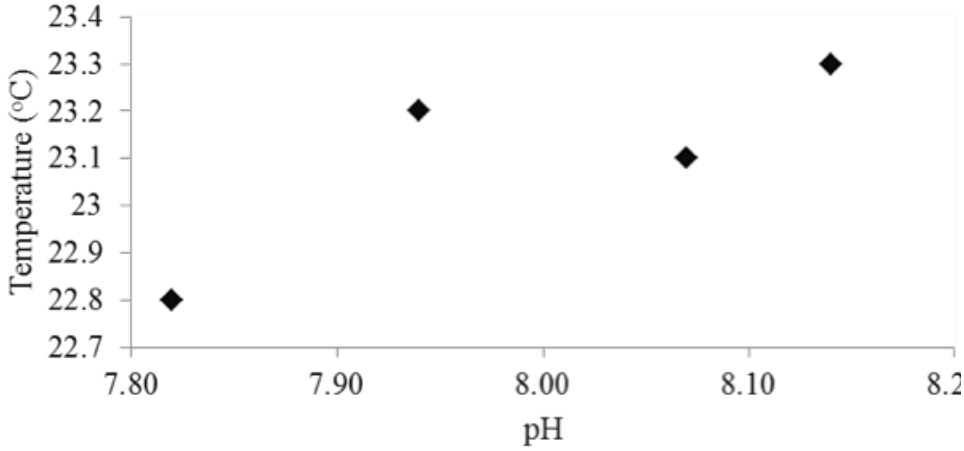


Fig. 16. Correlation between pH and temperature (°C).

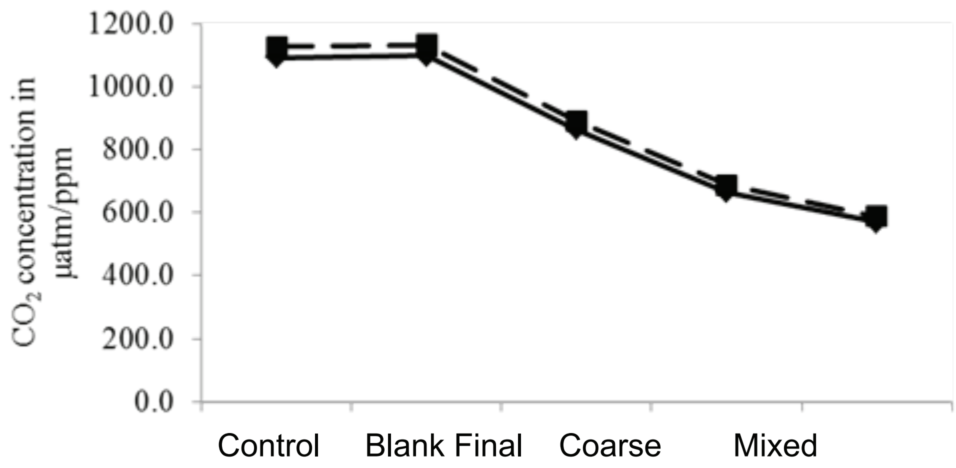


Fig. 17. Relationship between atmospheric CO_2 (µatm) (solid line) and seawater CO_2 (ppm) (dashed line) in the original seawater and in each of the treatments after the experiment.

Discussion

The relationship between atmospheric and seawater CO_2 is closely correlated. As in nature, the atmosphere and the sea act in equilibrium, any decrease in seawater CO_2 concentrations, also decrease atmospheric CO_2 concentrations. In the real world, this means that by tackling ocean acidification with olivine, CO_2 could diffuse out of the atmosphere reducing atmospheric CO_2 in turn reducing the effects of global warming. As the reaction of olivine with carbon dioxide is exothermic, producing heat, it is clear from temperature data that the fine crystal treatment allows the reaction to occur faster due to the increased surface area to volume ratio of the fine crystals. When the reaction is sped up, CO_2 is converted faster in to CO_2 containing solids. The pH data supports this, showing that pH increased most in the fine powder treatment due to the decrease in CO_2 dissolved in the seawater, which dissociates with water into higher concentrations of carbonate and bicarbonate.

The other chemical parameters showed that the fine crystal treatment caused a larger reduction of CO_2 in the atmosphere and corresponding increase of pH in the seawater than the treatments with coarse crystals or a mix of both crystal sizes. The calculated saturation states of calcite and aragonite were higher in the fine crystal treatment than in the other treatments. In nature, such higher saturation states build favourable conditions for marine calcifying organisms such as corals, barnacles, and pteropods as they use calcite and aragonite to build their shells as protection against predation.

Conclusion

When weathering occurs, carbon dioxide is transformed to alkalinity (increased carbonate ion) which is subsequently fixed by calcifying organisms that produce solid limestone that is taken out of the system. Taking carbon dioxide, one of the main drivers of climate change, out of the system could help to reduce the impacts of climate change, including ocean acidification. This experiment was carried out to show that fine olivine crystals have the potential to increase the weathering rate substantially.

When distributed on beaches, abrasion through tidal movement would allow for a natural way of making olivine sand that, through a larger surface, would increase the weathering rate and therefore the amount of carbon that is then stored in solids. By taking the help of tidal forces to grind the olivine, the olivine solution becomes much cheaper than traditional carbon trade.

References

Barker, S., Ridgwell, A. (2012) Nature Education Knowledge 3(6): 21.

Behrenfeld, M.J., O'Malley, R.T., Siegel, D.A., McClain, C.R., Sarmiento, J.L., Feldmann, G.C., Milligan, A.J., Falkowski, P.G., Letelier, R.M., Boss, E.S. (2006) Climate-Driven Trends in Contemporary Ocean Productivity. Nature 444: 752-755.

Boudouresque, C.F., Verlaque M. (2007) Ecology of *Paracentrotus lividus*. In Lawrence JM (ed).

Caldeira, K., Wicket, M. (2003) Nature 425: 365.

Dickson, A.G., Millero, F.J. (1987) Deep Sea Research – Part A. 34(10):1733-1743.

Dickson, A.G., Sabine, C.L. and Christian, J.R. (Eds.) 2007. Guide to Best Practices for Ocean CO_2 Measurements. PICES Special Publication 3, 191 pp.

Dickson, A.G. (1990) Thermodynamics of the Dissociation of Boric Acid in Synthetic Seawater from 273.15 to 318.15 K. Deep Sea Research 37 (5): 755-766.

Doney, S.C. (2010) Science 328:1521-1516.

Doney, S.C., Ruckelshaus, M., Duffy, J.E., Barry, J.P., Chan, F., English, C.A., Galindo, H.M., Grebmeier, J.M., Hollowed, A.B., Knowlton, N., Polovina, J., Rabalais, N.N., Sydeman, W.J., Talley, L.D. (2012) Climate Change Impacts on Marine Ecosystems. Annual Review of Marine Science 4: 11-37.

Dupont, S., Thorndyke, M. (2012) Journal of Experimental Marine Biology and Ecology 424–425: 32–37.

Hernroth, et al. (2011) Aquatic Toxicology 103:222–224.

Intergovernmental Panel on Climate Change (IPCC) (2007) Climate Change 2007: The physical Science Basis, Contribution of Working Group 1 to the Fourth Assessment Report. Cambridge University Press, UK pp.747-845.

Lawrence, J.M. (2001) Edible Sea Urchins: Biology and Ecology. Elsevier, Florida: 243-285.

Mehrbach, C., Culberson, C.H., Hawley, J.E., Pytkowicz, R.M. (1973) Measurement of the Apparent Dissociation Constants of Carbonic Acid in Seawater at Atmospheric Pressure. Limnology and Oceanography 18: 897-907.

Pierrot, et al. (2006) CO2SYS Dos Program Developed for CO_2 System Calculations. ORNL/CDIAC-105. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, United States Department of Energy, Oak Ridge, Tennessee.

Royal Society (2009) Geoengineering the Climate: Science, Governance and Uncertainty (Report). p. 1. ISBN 978-0-85403-773-5.

Schuiling, R.D. (2012) Climate change and ocean acidification: 2 problems 1 solution. International Summer School on Climate Change in the Marine Realm, AWI Germany. Personal communication.

Schuiling, R.D., Krijgsman, P.J. (2006) Climatic Change 74(1-3):349-354.

MODULE 2
CLIMATE CHANGE AND COASTAL SEAS - WITH A FOCUS ON THE ISLAND OF SYLT, GERMANY

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Summary

In this module, numerous challenges facing coastal seas in the wake of climate change were introduced. The challenges presented are coastal protection measures, local scale developments, and introduction of alien species. For each of the problems, classroom discussions were held to explore the issues and solutions. It has been demonstrated that coastal defense measures can vary greatly, and may need to be used in concert to obtain the desired protection. The proposed sand nourishment for the List shore was optimized in terms of its ecological, educational and recreational benefits. The introduction of alien species may lead to a drastic change in coastal ecosystems such as homogenization. Since the impacts of alien species cannot be conceived beforehand, prevention measurements and coastal protection should aim for minimal habitat change when adapting to sea level rise.

Introduction

The changing climate poses distinct challenges to coastal sea regions. Global warming, sea level rise, changes in hydrographic parameters and increasing frequency of extreme weather events are risks that require immediate modern coastal protection measures. It is not only the humans that will be affected directly, but also the ecosystems in coastal areas with further impact on human economies like fisheries and tourism. Different aspects of these challenges were explored on a local and regional scale as well as on species level in the showcase of the island of Sylt, Germany and its surrounding tidal flats. The development of the Eastern shore of the Island of Sylt in terms of adaptation measures has been exercised.

Coastal protection defends coastal areas against flooding and erosion. Methods for coastal protection have evolved from hard structures like groins, seawalls, and revetments to new techniques like sand nourishment. Sand nourishment is the addition of sand to a sedimentary coastline to extend the lifetime of the higher intertidal zones and beaches and disperses the wave energy effectively. Sand nourishment is proposed as the best option for caostal protection for the island of Sylt.

Site Description

Sylt is the most northern German island in the North Sea with an area of about 99.1 km^2 (Fig. 1). It has been connected to the mainland by the Hindenburgdamm causeway in 1927. The island extends in a north-south direction. The western part of the island consists of a 40 km sandy shoreline while the eastern part is dominated by extensive tidal flats, which belong to the Schleswig-Holstein Wadden Sea National Park. Most of the Wadden Sea became a UNESCO World Heritage site in 2009.

The island shape has been continuously changing, leaving it with a distinctive shape and shoreline due to the constant loss of land from the sandy shores that are subjected to erosion. The North Sea is a particularly rough Shelf Sea, therefore the islanders of Sylt have a long tradition of sea defenses to protect themselves from drowning and losing their island. Various stabilization strategies with hard structures generally failed leading to the use of sand nourishment techniques since 1972 to compensate for the losses of sand. However, only the western part of Sylt has been protected with sand nourishment against the longshore drift erosion so far. For the first time, sand nourishment in the Wadden Sea, in the eastern part of Sylt is planned to be undertaken in 2013.

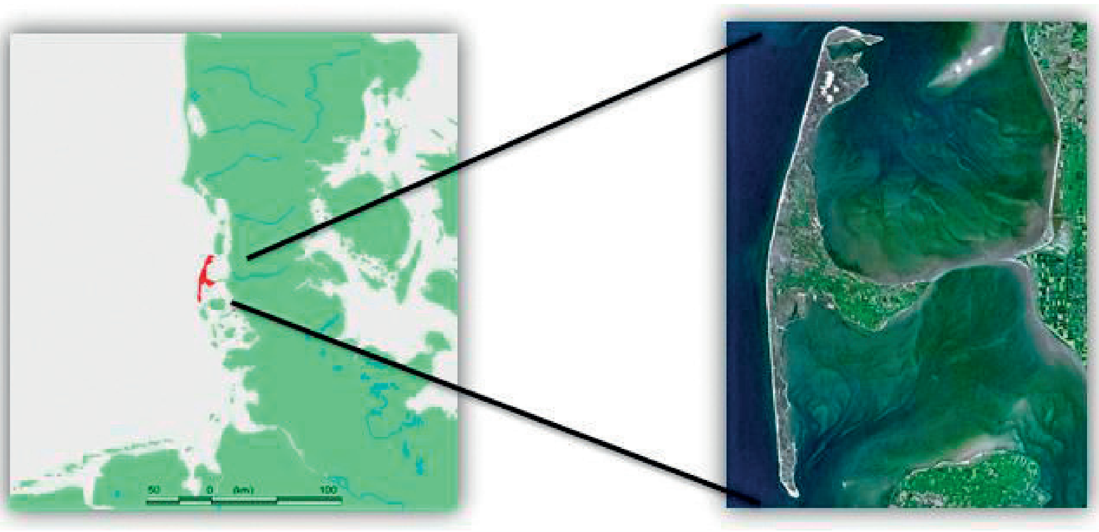


Fig. 1: Sylt location and close up.

Exercise 1: Planning for the Future in the Face of Climate Change

Introduction

The western coastline of Sylt has been retreating during the second half of the 20th century because of large sediment losses due to strong winds and waves especially during the wintertime.

As most of the south-eastern North Sea islands Sylt is called a “barrier island” protecting the mainland located behind it. The waves behind the barrier are lower reducing the energy input to the coast. Consequently, a tidal flat area developed to the East of Sylt because the lower energy of the waves allows sand and mud to settle out of the water. Huge amounts of material are transported with every tidal cycle (approximately 4.5 tipper truck loads) accumulating within the basin. In rare events though, even huger amounts are transported out of the basin as for example a storm event. These regular inputs and event-based outputs form the sediment balance of the tidal flat.

In general, less energy is necessary to transport a small grain of sediment than for a big one. The water in the Wadden Sea looks “dirty” because many small grains are floating in the water column. It takes a long time for them to settle, but the tidal currents stir them up constantly. Beaches on the other hand have a light color as they are composed of larger quartz grains and all the tiny particles are washed away into the sea. The Wadden Sea and island of Sylt is a constantly changing, dynamic system.

Problem Definition

Locals and property owners on the island are afraid of the coastal retreat will reach their houses and wash away the ground they are built upon. Another problem for the inhabitants is the migrating sand dunes. Since the houses are in the path of the moving dunes, it was decided to plant grass on top to stop them from moving with the wind. Sylt is also a very popular holiday destination, therefore there is huge interest in conservation of the island . The attractiveness is partly due to the unique character of the island’s natural landscapes. To protect and preserve the island’s current shape, hard structures, dykes and groynes have been built.

These protective structures have consequences for the natural cycling of the intertidal sedimentary system around Sylt. For one, because the sand dunes are not migrating anymore, there is no input of sand into the Wadden Sea any longer. Tidal flats have lost material and the tidal channels have also become much wider (Madsen 1999). There seems to be more energy in the system because of an increasing sea level which is responsible for higher amounts of water masses entering the system which causes erosion due to stronger hydrodynamics. Dykes are also problematic as they stop water masses from flowing landward, but do not absorb the energy of the waves. This energy can build up along the dyke and accelerate coastal erosion elsewhere. Twice every day, water masses are pushed into the basin by the tides, but as areas (mostly on the mainland) are dyked today, the same amount of water has to be accommodated in a smaller space. In a natural system, the energy would be absorbed by the marshes on the mainland that are today an important area for livestock grazing.

In theory, tidal flats are in equilibrium with sea-level rise. However, it is expected that the rate of rise is exceptionally fast and that tidal flats may not keep up with sea-level rise. A net loss of sediment on the backside of Sylt has been observed in the period from 1968 to 1994 (Madsen 1999).

Proposed Solution

In order to address such a complicated problem, a detailed action plan is needed. To keep the island as an economic center, any plan must address the issue of island remodeling. To do so, a three phase plan was developed with the goals of first promoting the economy and then preserving the island.

Stage 1 - Economic Growth

The first step of the action plan for the island of Sylt is to create coastal protection to keep the strong tourism as economic factor. A new law could be put into place that ensures the economic sustainability of the island after initial growth - for instance that part of the taxes are stored into a fund for coastal and nature protection.

A primary component of coastal protection is the use of a groyne made of sandbags in the north-western part of the island to stabilize the northern tip of the island. A groyne is basically a wall reducing the velocity of the seawater as it passes into the tidal flat. By slowing the seawater down, erosion is lowered and more sediment is built up. Further, the sand normally washing away with the current would be trapped and could be used to build beaches. In case any unknown problem would arise the sand bags could easily be cut and the sand released back into the natural system.

Another approach accumulating sand to the island would be a “sand engine” which is a large deposition of sand naturally spreading sand over the coast with the existing current. The sand engine would also promote the formation of dunes, which protect the island. Usually sand for the nourishments or the sand engine stem from offshore areas. The idea of installing a pump offshore, which continuously pumps sand onto the beaches, could replace the ships transporting sand from offshore to the coast. Further, it may be possible to run these pumps with wind power in order to use a clean energy supply.

Some final protections for the island and tidal flats would be the planting of sea grasses and mussel beds in order to stabilize and increase sand deposition. Replacing the land bridge with one that can be opened and closed would allow direct control of the flow of water into and out of the tidal flat area.

The most important aspect of these geo-engineering approaches is that the energy within the tidal flat system is lowered to reduce erosion and increase deposition. Hard structures may protect the island in part, but they also cause erosion in other parts. Therefore alternatives should be used instead.

Stage 2 - Transition

The entrance into stage two occurs when the costs for maintaining the island’s shape and coastal protection exceed the profit from islands economy by e.g. tourism. From this point coastal protection measures would be scaled back and only sand nourishments to build dunes would be maintained. It is important that the revenue for doing so be gathered during stage one when the economy of the region is strong. This stage also marks the start of the controversial matter that most inhabitants of the island would need to move to the mainland.

Stage 3 - Natural Preservation

By allowing natural processes to reshape the island the system will return to stability. During this time period, the natural environment on the island will expand forming a nature reserve and hopefully attracting many species to resettle. For instance the island may in this stage be used for eco-tourisms and new ways of earning money will be available. Especially for tourists interested in birds building up a nature reserve with controlled access could be established. The replacement of the causeway by a bridge would allow for the local eradication of foxes that invaded the island when the causeway was built, allow the restoration of breeding bird populations on Sylt (Fig. 2).

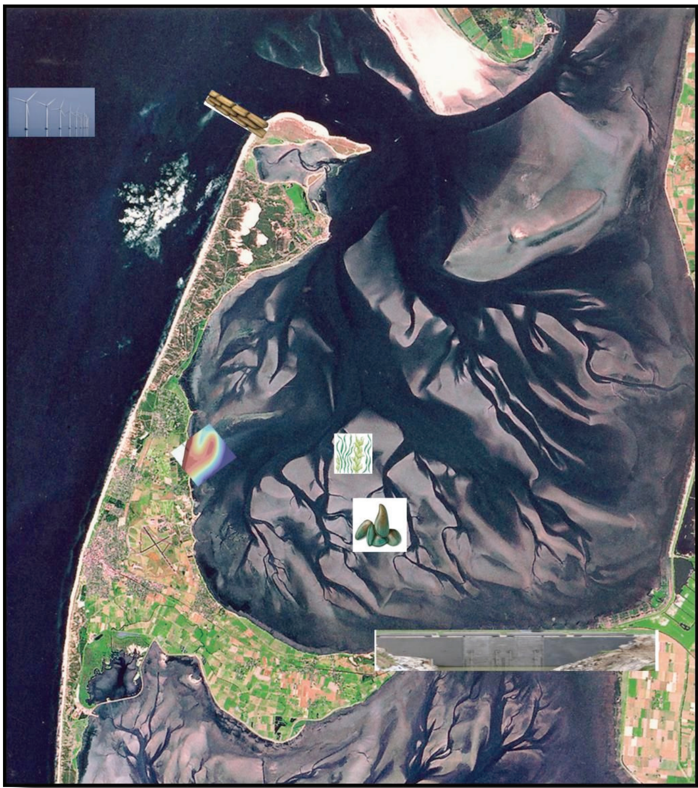


Fig. 2: Proposed coastal protection sites along Sylt.

While the plan presented here is a true method of balancing finances with conservation, there are a number of issues to be resolved. Most of these issues are studied by economics and social sciences. How and when the transition between the phases will happen should be recommended by economists and social scientists dealing with the consequences of ending coastal protection on the island inhabitants and decided by policy makers.

Exercise 2: Exploring Multiple Benefits of Sand Nourishment

Introduction

During this exercise, the local challenge of coastal defence against sea level rise was explored for the List shoreline. List is a small town on the west side of the northern point on the island of Sylt (55° 1’N, 8° 26’E; 2 m a.s.l.) and surrounded by the Wadden Sea. The objective of this exercise was to design sand nourishment in order to improve coastal protection and recreational value, as well as to achieve habitat restoration at the specified List shore. Sand nourishment in this area will be realized in near future, therefore the design exercise also aimed to take the position/point of view of different stakeholders.

Problem Definition

In the exercise the development site has been separated into areas of different use, a beach and dune area. Extended discussions were carried out in order to prepare an argumentation for the discussion process. The similarities between the wishes of the "tourists" and the "scientists" were surprising, and allowed for the overall proposed plan of the development site to evolve efficiently.

Beach Site Proposal

The beach site (Fig. 3, Site 1), which will receive nearly 60 m^3 of sand per meter distance, was proposed to serve mainly as a recreational area. Since the waterfront is comparatively shallow, sheltered and easily accessible (parking facilities nearby), this area is perfect for leisure activities, any kind of water sports and can easily be equipped with safety precautions as e.g. buoys and signs. Since the given beach profiles suggest a wide beach area (Fig. 4), the creation of an artificial dune exhibition on the upper five metre beach was proposed. This dune exhibit will feature native dune grasses and will thus act as an educational tool for the Erlebniszentrum Naturgewalten Sylt sited nearby. This exhibit can also be extended across the coast in front of the Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (AWI) to function as an experimental field site for various research projects. With these developments, the sand nourishment area will achieve its original objective by providing coastal defence to the beachfront, and offering an effective educational and recreational platform.

Fig. 3: Proposed development site at List.

Dune Site Proposal

The dune site (Fig. 3, Site 2) will be receiving 210 m^3 of sand per meter distance in the future to maintain its stability and protect the ecological conservation site to the north. A slow addition of sand to this area, at a rate of 50 m^3/yr is proposed to preserve the natural dune grasses present and to avoid excessive disturbance of the habitat. Currently, this dune area is heavily used by tourists and locals and an informal network of trails has developed across it. Therefore, we propose to build up a wooden boardwalk to restrict the public to stay on this trail, to guide

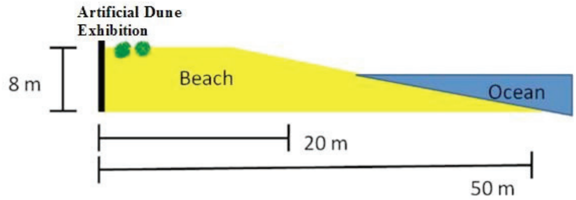


Fig. 4: Beach site profile.

the public through these dune areas and thus avoid erosion and damage to dune grass. Information signs on the natural dune grasses and landscape could be placed along the boardwalk, ideally structured to appeal to both children and adults. In order to combat the growth of invasive species, a local volunteer program should be initiated in which the invasive species are manually removed. This will provide education on invasive species and encourage environmental stewardship among the locals and tourists. The proposed dune site will function mainly as a natural educational area, and will thus hopefully detract tourists from wandering across the ecological reserve to the North.

Stone Revetment

At the dune site, there is currently an old stone revetment (Fig. 3, Site 3) that does not function as a coastal defense measure any longer. At this point the currents and sedimentation dynamics of this waterfront are unclear/unknown. Therefore, it is difficult to propose an effective development plan for this revetment area. It was suggested to extend the stone revetment further into the water and to create a boardwalk on top in order to feature an information sign or local art display. Since the effects of this type of development approach on the area are unknown, it was also suggested to use the extended part of the stone revetment for experimental setups. AWI could provide knowledge on the environmental impacts of these structures. However since both of these suggestions threaten the ecological integrity of the waterfront, thorough understanding of the physical and biological states of the waterfront is required before proceeding.

Wave Breaker

In order to protect the sand nourished beach from erosion, it was suggested to construct an offshore wave breaker, which protects the shore from easterly winds and swell (Fig. 3, Site 4). This could be an artificial reef or a sand bar run parallel to the beachfront. The artificial reef could be constructed out of stones, or could consist of old statues/art pieces, and thus would function as an underwater tourist attraction. This suggestion was heavily debated mainly due to its negative effects on the ecosystem. It is well known that hard substrates attract benthic species for colonization purposes usually not common in the Wadden Sea, and therefore the creation of an artificial reef will most likely encourage the settlement of invasive species. The ecological consequences of these invasions are not yet well understood, thus the environmental protection aspects of the artificial reef approach is doubted. In summary, the sand bar was recommended as best offshore wave breaker option, yet a large-scale development such as this would heavily manipulate the ecosystem and should only be installed under drastic erosion conditions.

Exercise 3: Invasive Species, McDonaldization within Climate Change

Introduction

Globalization has led to a highly connected world with a shift from traditional thoughts to global management approaches. This can be seen for example in the presence of similar shops and restaurants in most of the cities, worldwide. It seems that this development can directly be applied to the species distribution. The homogenization (“McDonaldization”) is especially feared in coastal ecosystems, where modern shipping traffic steadily increases. Along with the ships more and more organisms from foreign coasts enter the North Sea and Wadden Sea. They survive a transcontinental journey lasting weeks across the seven seas in the ballast water or attached to the ship hulls. Therefore, in the context of climate change, introduced species are of great concern, because a changing environment may lead to an increased establishment success. The Wadden Sea is regarded as showcase to address the general, controversial discussion about non-native species in a changing environment.

For the Wadden Sea, 66 foreign macrobenthic species are known (Buschbaum 2012a). The term 'macrobenthic' describes the species which live on the seafloor and are visible to the naked eye because they are not smaller than 1mm. At present approximately one exotic species per year establishes in the southeast North Sea. One prominent example is the Pacific oyster (*Crassostrea gigas*). The oyster originates from East Asia, mainly from the shores of Japan and Korea. Since 1964 it has been observed on many beaches around Europe and also in the Wadden Sea. It has mainly settled down in the intertidal zone, and over several generations the distribution has increased from solitary oysters to coherent reefs (Fig. 5). As the oyster needs a hard substrate to fix itself to the ground they use the shells of the native blue mussel (*Mytilus edulis*) to settle down. Due to the massive creation of oyster beds during the last decade, the abundance of blue mussel has decreased drastically. This has effects on the food web in the Wadden Sea as e.g. oystercatchers and Eider ducks feeding on blue mussels nowadays find less prey (Buschbaum 2012b, Reise 2010, Reise *et al.* 2005).

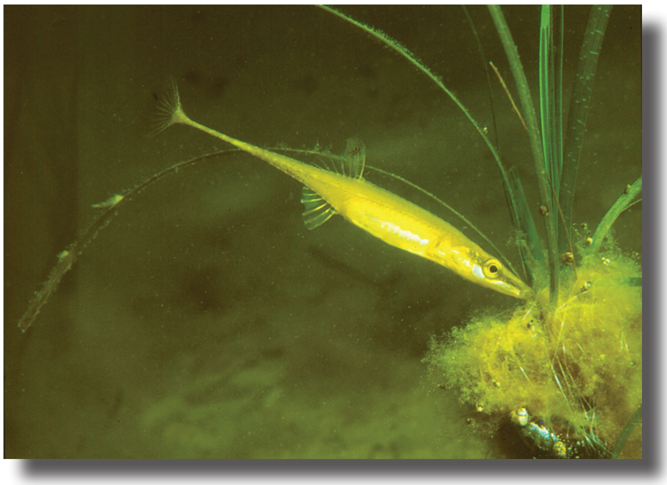
Fig. 5: Aggregated Pacific oysters, Source: Karsten Reise.

Although this example shows negative impacts on the unique ecosystem of the Wadden Sea, the invasion of new species does not necessarily harm native species.

Fig. 6: Japanese seaweed, Source: Christian Buschbaum.

Since 1980 the Japanese seaweed (*Sargassum muticum*) has been noticed in the Wadden Sea. This species uses oysters and mussels as substrate and can reach a length of up to four meters (Fig. 6). Even though the seaweed is foreign to the

Fig. 7: Sea stickleback.



Wadden Sea, no negative consequences for the ecosystem have been monitored yet. The seaweed is not likely to become a competitor for local algae because it requires different habitat conditions. Due to its complex branches the seaweed provides additional habitat for native fish species. It offers spawning ground for herrings and shelter for other species such as sea stickleback or pipefish (Fig. 7), (Buschbaum et al 2006, Buschbaum 2008, Lang & Buschbaum 2010).

The two examples from the Wadden Sea show that invasive species can have both negative and positive effects. These impacts differ among ecosystems and therefore, are not predictable in advance. The increased average temperature in the North Sea during the last years may be one important reason for a successful establishment of non-native species as the habitat conditions approach their natural environment. However, in the sandy Wadden Sea the establishment of non-native species is greatly favored by a habitat change due to the increasing use of artificial hard structures for coastal protection. The stone revetments literally pave the way for new invaders. About two thirds of the 66 invasive macrobenthic species are sessile or at least associated with sessile communities. From an ecological point of view we, therefore, recommend the use of sand nourishments only, and to stop the use of hard structure for coastal protections.

Conclusions

It has been demonstrated that coastal defense measures can vary greatly, and may need to be used in concert to obtain the desired protection.

References

Buschbaum, C., et al. (2012a, in press) Nonnative macrobenthos in the Wadden Sea ecosystem, Ocean & Coastal Management (2012), doi:10.1016/j.ocecoaman.2011.12.01.

Buschbaum, C. (2012b) Neobiota, Presentation on September 13, (2012), at the Summer School "Climate Change in the Marine Realm".

Buschbaum, C., Chapman, A.,S., Saier B., (2006) How an introduced seaweed can affect epibiota diversity in different coastal systems, Marine Biology (2006) 148:43–754 DOI 10.1007/s00227-005-0128-9.

Lang, A., Buschbaum, C. (2010) Facilitative effects of introduced Pacific oysters on native macroalgae are limited by a secondary invader, the seaweed *Sargassum muticum* JOURNAL OF SEA RESEARCH, 63(2):.

Madsen, A.T., Murray, A.S., Andersen, T.J., Pejrup, M. (1999) Spatial and temporal variability of sediment accumulation rates on two tidal flats in Lister Dyb tidal basin, Wadden Sea, Denmark. Earth Surface Processes and Landforms 35, pp. 1556–1572.

Reise, K. (2010) How to deal with alien species in the Wadden Sea, Wadden Sea Ecosystem No. 26, 2010, p. 69-73.

Reise, K., Dankers, N., Essink, K., (2005) Introduced species. In: Essink, K., C. Dettmann, H., (eds.) Wadden sea ecosystem 19.

MODULE 3
THE OCEAN IN THE CLIMATE SYSTEM

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Our Changing Climate

As the popular saying goes, "climate is what you expect and weather is what you get", the climate at a certain location is the weather averaged over a long period. Climate is usually described in terms of the mean state and variability of temperature, precipitation and wind over a period of time, ranging from months up to millions of years (the classical period is 30 years, as define by the World Meteorological Organization). Ultimately, both of these systems are manifestations of energy. However, the weather system is more unpredictable than the climatic system. For example, it is impractical to predict the weather, be it in Bremen or at the North Pole, a month from today. Will these places be hot, cold, windy, rainy or sunny in a month from today? This is a tough question to answer. However, since we have observed the weather on average for many years at both places, we can say with certainty that the North Pole will be colder. How? This is because man has been observing, recording and studying the parameters of the properties of the atmosphere and the ocean on a global basis for the last about 200 years. Observations are vital in expanding climate science as they examine the validity of theoretical hypotheses. Ongoing research into improving our observational methods is extremely important as well.

However, the Earth has been around for a much, much longer time than 200 years. The age of the Earth has been estimated (through various geochemical methods) to be around four and a half billion years old. Has the climate of the Earth been the same for all those billions of years? Much of the evidence of past climates coming from the geological record indicates that the Earth, as we know now, has been drastically different in the past. In the past, the Earth has been both an icehouse and a greenhouse. It is important to understand how the climate of the Earth has varied in the past because of the need to understand the natural variability of the climate system, with all the forcing factors and feedback mechanisms (Fig. 1). Further, climate change plays an influential role in mediating ecological systems.

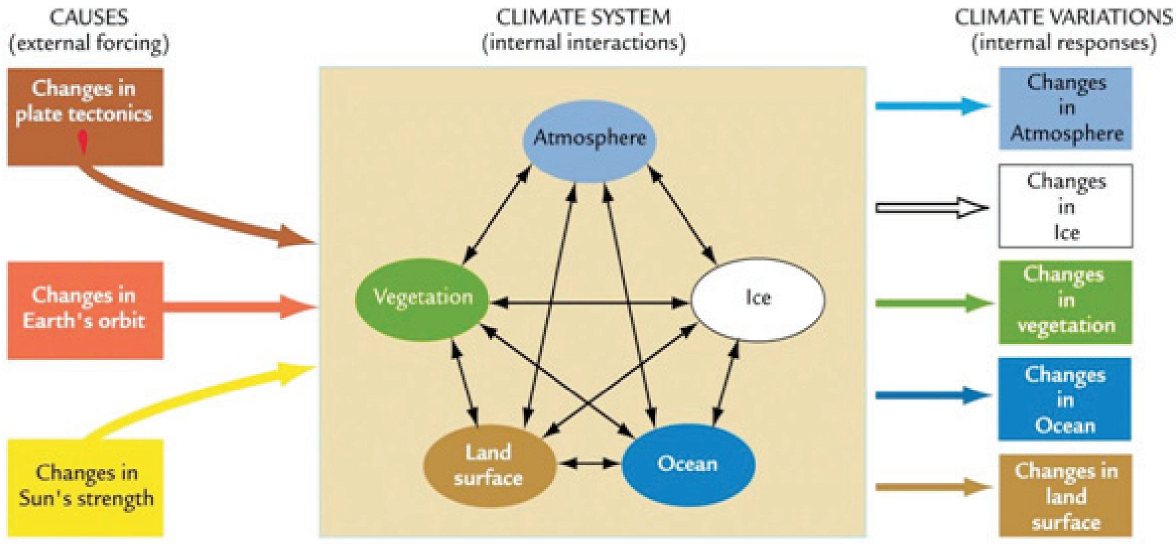

Fig. 1: The climate system and its components (Ruddiman, 2008).

Fundamentally, the Earth's climate is just a result of the reorganization of the incoming solar radiation, or the energy that the sun provides (Fig. 2). This incoming radiation is balanced by outgoing radiation that is radiated back to space by the Earth – without which the Earth's temperature would increase monotonically. This delicate radiation balance and its reorganization throughout the Earth system is the basis for the establishment of the Earth's global climate.

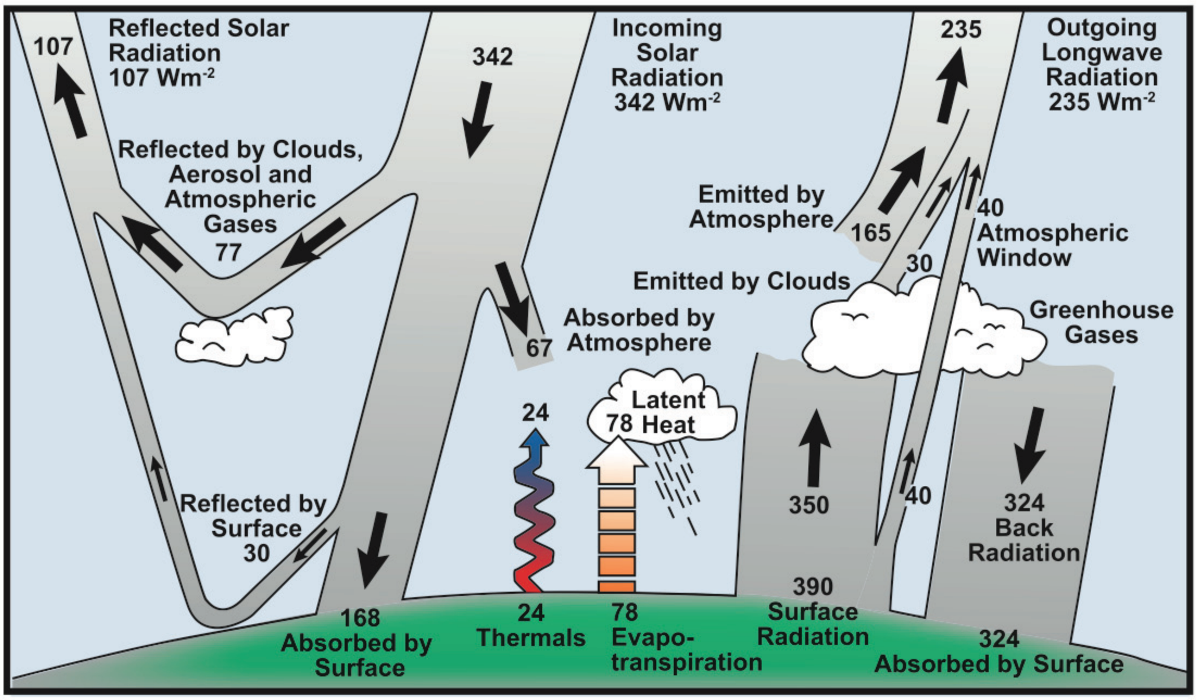

Fig. 2: The Earth's annual and global mean energy balance (IPCC AR4, 2007).

There are three fundamental ways to change the radiation balance of the Earth:

1. by changing the incoming solar radiation (e.g., by changes in Earth's orbit or in the Sun's emission itself);
2. by changing the fraction of solar radiation that is reflected (called 'albedo'; e.g., by changes in cloud cover, atmospheric particles or vegetation);
3. and by altering the longwave radiation from Earth back towards space (e.g., by changing greenhouse gas concentrations).

Climate, in turn, responds directly to such changes, as well as indirectly, through a variety of feedback mechanisms (as shown in the Fig. 2).

The amount of energy reaching the top of the Earth's atmosphere each second on a surface area of one square meter facing the Sun during daytime is about 1,370 Watts, and the amount of energy per square meter per second averaged over the entire planet is one-quarter of this. About 30% of the sunlight that reaches the top of the atmosphere is reflected back to space. The residual radiation energy penetrates the atmosphere and is absorbed, partly by the Earth's surface and the atmosphere. This amount is approximately 240 watt per square meter. To balance the incoming energy, the Earth itself must radiate, on average, the same amount of energy back to space. This occurs by the emittission of outgoing longwave radiation. Everything on Earth emits in terms of longwave radiation, continuously, depending on its own temperature, e.g., the thermal energy one feels emitting from a fire; the warmer an object, the more thermal energy is emitted. On average, the Earth's surface temperature is about 15°C. The reason for this temperature is the presence of so called greenhouse gases in the atmosphere, which act as a partial blanket for longwave radiation coming from the surface. While shortwave radiation penetrates the atmosphere, longwave radiation is partially absorbed, causing heating. This blanketing effect is known as the natural greenhouse effect. The most important greenhouse gases are water vapour, carbon dioxide, methane, nitrous gas and ozone. In the upcoming exercise 1, the importance of greenhouse gases is revealed through simple energy-balance physics.

Oceanic and Atmospheric Circulation

From rising sea levels to increasingly acidic oceans, the ocean's role in climate change is becoming increasingly important.

The ocean and the climate system are closely linked. The climate is driven by the large-scale circulation patterns and interaction of the atmosphere and the oceans. There is a temperature gradient that is created by the uneven heating of the Earth's surface: more solar radiation is received at the equator than at the poles. The warmed air rises from the equator and moves toward the poles, creating atmospheric circulation. (Fig. 3.) The same process applies to the ocean, where water is warmed at the equator and then flows north or south toward the poles. The circulation patterns are complicated by the presence of continental land masses and the rotation of the Earth, which creates the Coriolis Force. This effect acts on large-scale movement of air or water; instead of the air moving in a straight line from the equator to the poles, the Coriolis Effect causes the air to be deflected to the right (in the Northern Hemisphere) or to the left (in the Southern Hemisphere) (see Fig. 3).

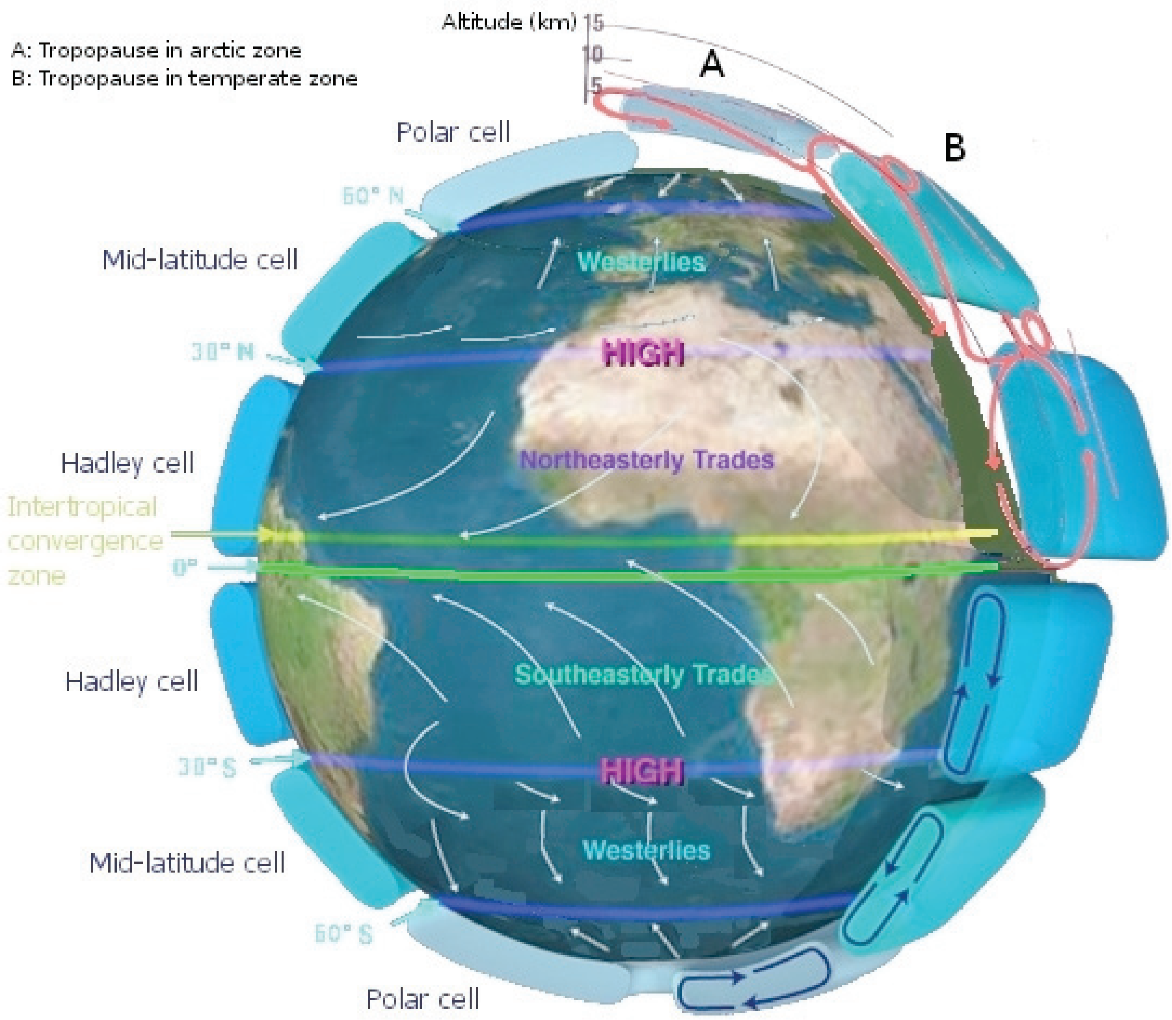

Fig. 3: Basic circulation of the atmosphere, with rising and sinking air cells caused by differential heating of the Earth's surface (from http://sealevel.jpl.nasa.gov/overview/climate-climatic.html)

The circulation of the atmosphere also drives currents on the surface of the ocean. The wind blows across the surface of the ocean, pushing water along. These currents help to transport heat in the ocean from the equator toward the poles. Strong atmospheric pressure systems can also generate movement in the surface ocean by creating circulating gyres. These gyres are one way that water moves vertically in the ocean. Low-pressure systems move deeper water toward the surface while high-pressure systems push water downward.

The large, deep currents in the ocean are primarily driven by a buoyancy or density gradient: water that is warmer or less saline is less dense and tends to rise, while colder or more saline water is denser and tends to sink. Both the temperature and salinity of the water determine the density.

There is a lot of heat energy transferred between the atmosphere and the oceans, which helps to maintain the circulation of both systems. Toward the poles, the water is warmer than the air, so the water loses heat to the atmosphere. As the water gets cooler, it tends to sink and eventually circulates back to the equator, where it gets warmer again. This heat transfer from the ocean to the atmosphere near the poles makes the climate warmer on land at high latitudes. On a global scale, the major ocean circulation is called thermohaline circulation – water movement driven by differences in temperature (thermo) and salinity (haline). (Fig. 4). Thermohaline circulation in the oceans and temperature differences in the atmosphere are responsible for distributing heat from the tropics all over the world.

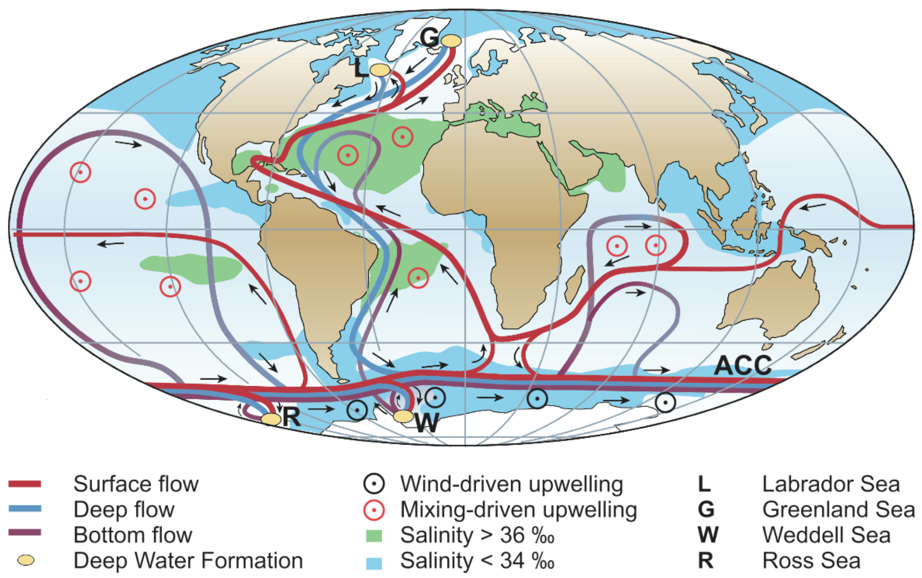

Fig. 4: Idealized schematic of global thermohaline circulation, where warmer water is shown in red and cooler water is shown in blue. The main regions of sinking water include the North Atlantic and the Southern Ocean (after Kuhlbrodt et al., 2007)

As the climate continues to change, it is increasingly important to understand how the warming ocean will affect climate. One of the most important effects that have been observed in the changing climate is the increased rate at which sea ice and glaciers are melting. When sea ice and glaciers melt, they release cold, fresh water, which is more buoyant than the saline ocean water. This freshwater layer sits on top of the saline ocean water, acting as a lid to prevent cold and saline water from sinking. If enough ice melts and prevents water from sinking in the thermohaline circulation pattern, this might start to slow down the general overturning circulation of the ocean. If ocean circulation were to slow, it could reduce the amount of heat transported from the equator toward the poles and ultimately affect the climate on land.

Another challenge the oceans are facing is increasing acidification. The world ocean is the biggest sink for atmospheric Carbon dioxide (CO_2). Once the CO_2 is in the water, it dissociates and forms an acid. Because of the increasing amount of CO_2 in the atmosphere, more and more CO_2 is getting absorbed by the oceans, causing the ocean to become more acidic. There are many marine organisms that cannot tolerate an increased amount of acidic in the water, such as corals and molluscs, because components of their physiology begin to dissolve and they cannot survive on lower pH levels, partly due to additional factors such as an increasing exposure to predation.

Because scientists are not certain what impacts climate change will have on the oceans system, it is vitally important to observe and monitor the ocean as it begins to change. The most efficient and easiest way to obtain these observations is to use robots to monitor the ocean characteristics.

Observing the Oceans

One of the biggest challenges that scientists face is obtaining in-situ data for monitoring long-term changes in the ocean. There are many vessels crossing the oceans regularly and collecting data on the temperature, salinity and velocity of the ocean currents, but the ships do not cover the whole ocean and do not always take the same path or return at the same time intervals. In an effort to create a better ocean monitoring network, scientists are starting to turn to robots for ocean monitoring. There is a growing network of permanent, moored ocean observation systems, but the oceans are too big that more observations are needed.

Consequently, there is a movement towards using robotic systems to monitor the oceans, both in moored stations and mobile platforms. Some of the advantages of using robotic systems include frequently-obtained time series data, data from areas that do not have ship traffic and that the robots are not as affected by stormy conditions.

Three types of robotic systems are mainly in use, moorings, floats and gliders. Moorings are stationary observation systems, deployed and recovered with research vessels at a fixed position. In moored observation systems a collection of deployed devices are fixed to a wire and anchored at the sea floor. The mooring is held up in the water column with various forms of buoyancy. The attached instrumentation often includes CTDs (conductivity, temperature depth sensors), current meters, biological sensors, and other devices to measure various parameters. Long-term moorings can be deployed for durations of two years or more. Despite the fact that biofouling can create difficulties for the measurements moored systems provide valuable observations. Surface moorings are also used but they are more subject to vandalism and they are less preferred.

Passively drifting floats are used extensively in ocean monitoring. The number of floats in the oceans was more than 3,500 floats in August 2012. They are passive systems that flow with the ocean currents at a certain pressure level. After the floats are deployed to the ocean, they can sink to about 1,500 m depth and ascent to the surface to connect with satellites for sending their data in regular time intervals. During the ascending phase floats collect CTD-data form a vertical profile of the water column. Since their location can be followed with GPS satellites, they provide an extensive area of ocean monitoring.

Ocean gliders can profile the upper 1 km of the ocean. These robots can manipulate their mass distribution and buoyancy characteristics to move in the ocean without a propeller.With the help of their wings, theyconvert vertical velocity to forward velocity. When they are denser than the water, they glide downward and when they are buoyant, they move upward. Glider provide real time data, they can last up to 6 months and they can cover long distances.

It is evident that composite systems of satellites and in-situ measurement systems create an invaluable platform for ocean monitoring (Fig. 5). The data obtained through these networks is not only important to be used in climate models and weather prediction but also in transportation, marine hazards warning, naval applications and ecosystem monitoring. There are many examples of successful ocean observations, e.g., monitoring the changes in salt concentration in the Atlantic Ocean from the 1960s to the 1990s. From this it can be seen that the ocean is getting saltier in already salty areas (tropics), whilst it is getting fresher in already relatively fresh areas (poles). As temperature increases, more water evaporates into the atmosphere resulting in increased rainfall in wet areas. This is an example of positive feedback on the hydrological system. (For further reading, see e.g., Curry *et al.* (2003))

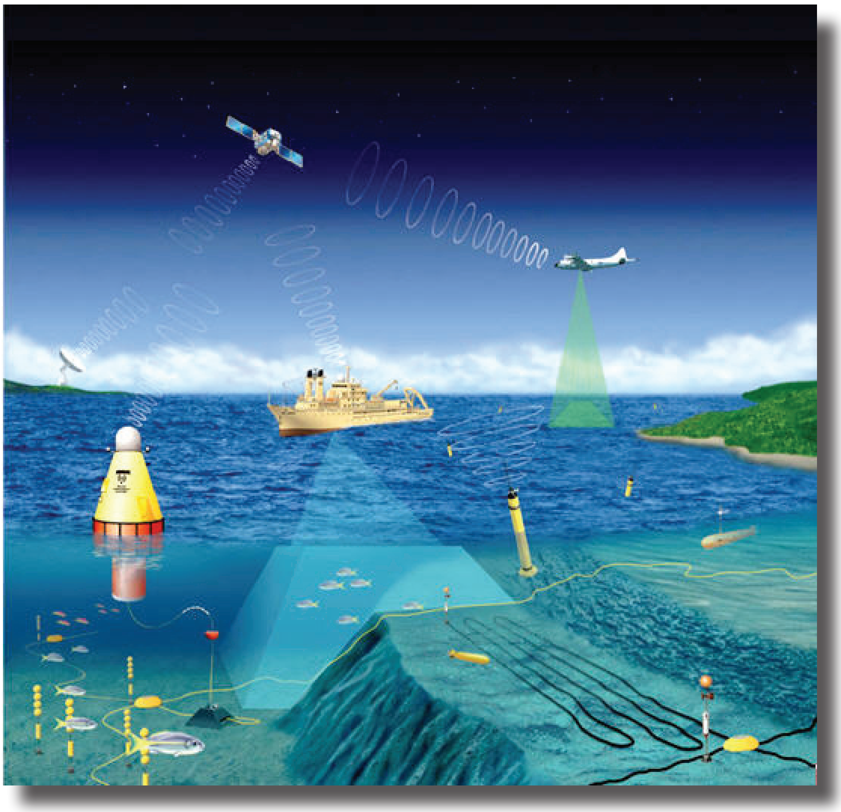

Fig. 5: Ocean observation methods include satellites, flights, commercial and research ships, surface drifters, observational platforms, tagging of animals, and robots (http://celebrating200years.noaa.gov/visions/ioos/obs_system.html, accessed 22/09/2012).

Different observation platform provide different information and data in respect to areal coverage, data accessibility and quality, sensor arrangement, etc. An overview about commonly used platforms, their advantages and disadvantages is given in Table 1.

Tab. 1: Summary of the pros and cons of different observational techniques.

Tool	Methods	Advantages	Disadvantages
Satellites:  (http://oco.jpl.nasa.gov/ accessed 22/09/2012)	Observing station in space orbiting the Earth.	Global coverage with many repeated measurements. Multipurpose with many different sensors.	Expensive to install. Often low resolution. Only see the surface of the oceans.
Flights:  http://www.montereybay.noaa.gov/ accessed 22/09/2012)	Scientific equipment mounted on aeroplane.	High-resolution data.	Expensive and labour intensive for data from a small area.
Ships of Opportunity:  (http://www.noc.soton.ac.uk accessed 22/09/2012)	Scientific equipment hitchhikes on commercial vessels.	Many routes covered and often repeated for relatively little cost.	Restricted data collection to shipping routes. Some ships are doing fewer repeat routes.
Surface Drifters:  (http://www.aoml.noaa.gov accessed 22/09/2012)	Network of surface drifters recording the sea surface temperature. Some also record pressure.	Can be used to check accuracy of satellite data.	Data collection restricted to the surface and requires a research vessel for deployment.
Observational Platforms:  (http://www.neptunecanada.com/ accessed 22/09/2012)	Construction of monitoring station under the sea.	Continual recording of many types of real-time data over a long time at depth.	Expensive to build and technologically challenging.

Tool	Methods	Advantages	Disadvantages
Research Surveys:  http://www.whoi.edu accessed 22/09/2012	Research vessel deployed for a scientific survey.	Control of where/ when the survey will happen. Many different measurements can be taken.	Expensive.
Robots:  http://www.whoi.edu accessed 22/09/2012	Scientific equipment mounted on moorings, free floating, or actively gliding.	Large amount of data on global scale. Can use several different robots together. Automatic and provide real-time data Cheap and easy to use.	Require research vessel for deployment. Both vandalism and sea life growth interfere with data collection.

Past Climate Variability

Climate has changed considerably over the geological past. This is predominantly due to changes in the external factors such as plate tectonics, solar radiation and orbital forcing. Plate tectonics move the continents, create mountains, and thus impact the climate. Solar radiation directly warms the planet by energy transformation to heat whilst the impacts of orbital forcing influences the amount of radiation reaching the Earth's surface (a more indirect influence,e.g. Milankovitch cycles as shown in Fig. 6). These changes are amplified by internal feedback mechanisms. This means, for example, that a slight change in temperature can trigger mechanisms that magnify the warming.

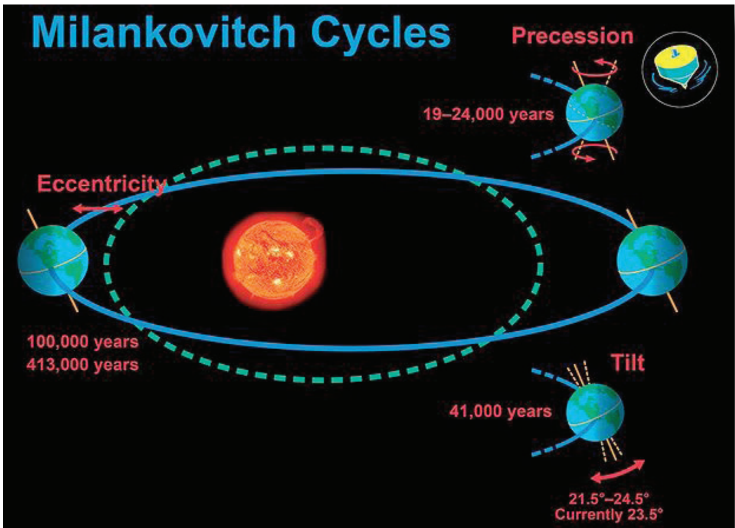

Fig. 6: Milankovitch cycles are the result of three components (i) Eccentricity - the Earth's orbits around the sun on a 100,000 and 413,000 year cycle; (ii) Precession – the trend in the direction of the Earth's axis of rotation varies on a 19,000-24,000 year cycle; (iii) Tilt – the angle of the Earth's axial tilt varies in respect to its orbit on a 41,000 year cycle.

In order to decipher climate changes from the Earth's history, climate archives as represented for instance in sediment cores from marine and terrestrial records are investigated. Proxies in sediment cores can be of biological (fossil remains of small animals -> paleontology), mineralogical (minerals), or biogeochemical (different chemical compounds) origin. Terrestrial records comprise geo-morphological features, ice cores, macrofossils and others. The fossils remain of many organisms, specifically mollusk shells and the smaller organism foraminifera are retained in sediment cores through time.

A very common proxy for climate reconstruction is the stable oxygen isotope ratio ($\delta^{18}O$). This can be measured in the fossil remains of organisms that precipitate calcium carbonate ($CaCO_3$). Oxygen has three stable forms (isotopes) that do not decay with time. The number reflects the number of neutrons and protons within each oxygen atom, and varies with the numbers of neutrons (8, 9 and 10) giving ^{16}O (~ 99.75% of global oxygen), ^{17}O (~0.04%), and ^{18}O (~0.2%). $\delta^{18}O$ is the ratio of ^{18}O to ^{16}O and changes over time. ^{16}O is lighter and therefore it evaporates from oceans more readily. In general, due to fractionation processes, more of the lighter ^{16}O is locked in ice sheets during glacial times leading to elevated $\delta^{18}O$ ratio in the ocean. During interglacial times, this ice melts, returning the locked ^{16}O to the oceans (see Fig. 7).

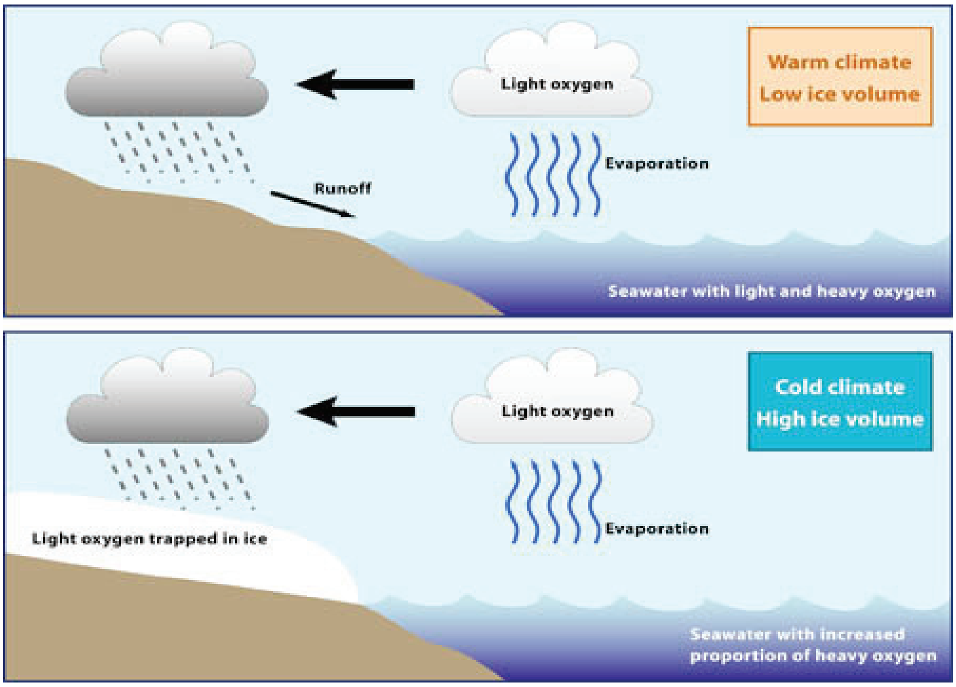

Fig. 7: Isotopic signatures during cold and warm climates (Image courtesy of National Oceanography Centre, Southampton, http://www.noc.soton.ac.uk/gg/IPY/background.html#isotopes)

Direct climatic observations are only available from relatively recent times (e.g., the last about 150 years); however marine sediments are accumulated over millions of years, providing many historical climatic clues. A few examples of sediment core interpretations are given below (see Fig. 8 for locations). Each core represents a different time period with different climate regimes and thus different patterns of sediment deposits in the ocean.

Fig. 8: Locations of sediment cores discussed during the summer school.

The oldest core described here is from the Cretaceous period, ~ 100 million years ago (Mya). It was taken from the Demerara Rise, off the North coast of South America. The core is laminated (there are stripes of lighter and darker layers), representing different material deposited in each of the layers (Fig. 9).

Fig. 9: Sediment core from the Demerara Rise, off the North coast of South America, age 100 Mya.

The Cretaceous is often called a 'hothouse period' since temperatures were much higher than during most other times. The continents of Africa and South America were much closer together than they are today and only a narrow basin existed between them. Increased rainfall stopped the mixing of the different ocean layers, and there was nearly no oxygen in the bottom water. Consequently, no animals lived on the ocean floor disturbing the sediment (bioturbation did not occur).

The second core (Fig. 10) shows the period when the dinosaurs (and many other species) became extinct. It is the boundary between the Cretaceous and the Tertiary period ~65Mya ago. Theis sedimentcore was taken off the Coast of Florida at a water depth of 2.5 km (Fig. 10).

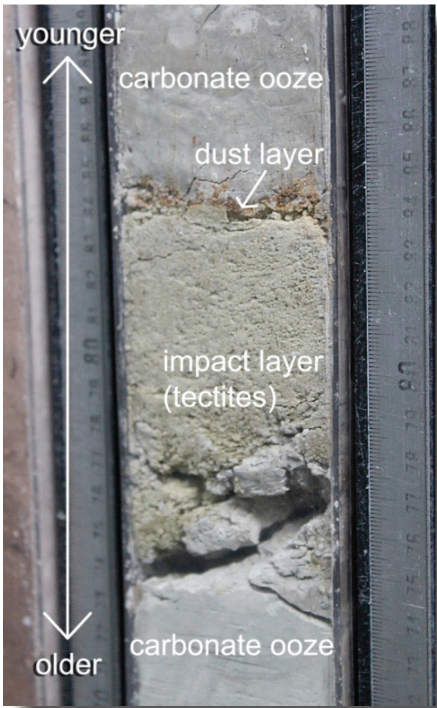

Fig. 10: Sediment core from off the Coast of Florida, age 65 Mya.

It contains several distinct layers:

- The first layer starting from the bottom is a light grey layer consisting mainly of carbonate ooze from the shells of tiny organisms called coccolithophores (Fig. 11). The sedimentation rate was ~1.1 cm per 1000 years.

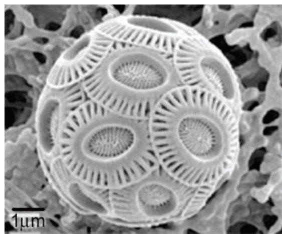

Fig. 11: Picture of a Coccolithophore.

- Above the tectite-containing greenish layer is a section that contains small spherules made of natural glass that are created when a big meteorite hits the Earth. This ~10cm 'impact layer' took less than a day to be deposited! The meteorite hit the Earth close to the current Yucatán peninsula of (Mexico), close to where the core was taken. Consequently, the disruption of the normal layering due to the shock wave created by the impact is visible. Above the impact layer, a ~1cm brownish dust layer occurs: This is composed of predominantly iron oxides with small concentrations of the element iridium. This layer results from the huge amounts of material the meteorite blasted at high velocity into the atmosphere. A similar layer can be found in cores of the same age all over the world. It was responsible for blocking the sunlight and resulted in a period of acid rain. It took only a few years for this layer to be deposited (sedimentation rate = few mm/year).
- Above the dust layer there is a dark grey organic layer. After the impact there was only very low bio productivity and it took the system 100,000 years to recover.

The third oldest core was taken off the coast of Namibia. It contains sediments that are 55 million years old (Tertiary period, the Paeogene and Neogen):

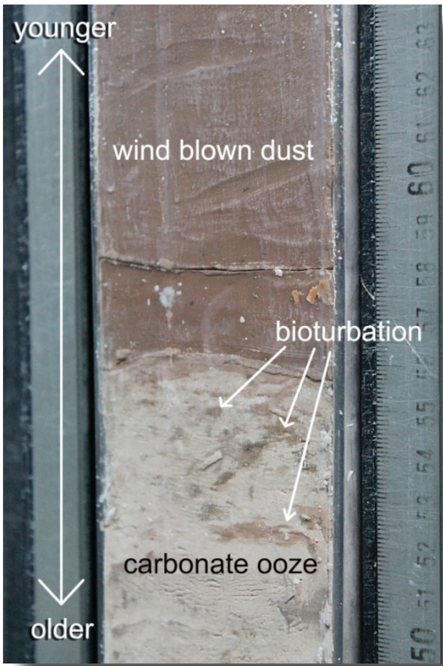

Fig. 12: Sediment core from off the coast of Namibia, age 55 Mya.

- There is a white layer containing coccolithic ooze mixed with dust blown sediments from the continent. (See Fig. 12.) Bioturbation is visible due to the activity of animals that live on the ocean floor and build their burrows in the sediment.
- Directly above, a brown layer consisting entirely of windblown dust occurs. This layer does not contain any carbonates, and there is no bioturbation visible. During this time, the Earth warmed a lot (~5-9 °C), and the atmospheric and oceanic CO_2 content increased, leading to ocean acidification and dissolution of carbonates. Consequently, a major extinction event took place. This period is often referred to as the Paleocene-Eocene Thermal Maximum (PETM). The brown layer gradually changes into white again (not shown on Fig. 12) representing the subsequent decrease in CO_2 content and the oceans recovery.

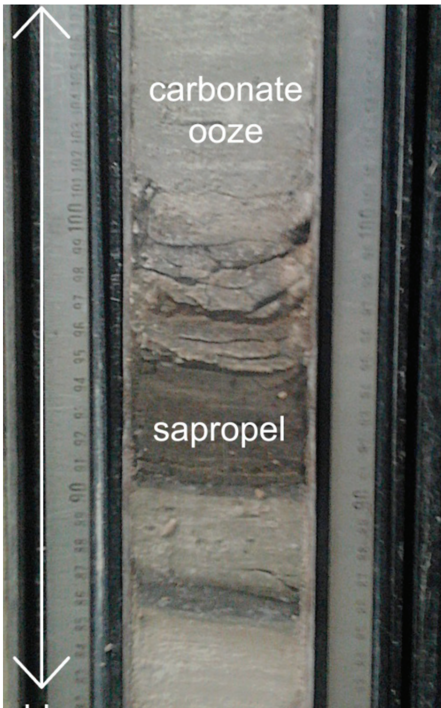

Fig. 13: Sediment core from the Mediterranean Sea, south of Greece, age 2.5 Mya.

The youngest core described here (from 2.5 Mya, the Quaternary epoch) is from the Mediterranean Sea, south of Greece (Fig. 13). It contains two different layers that occur in regular intervals:

- Dark layers of sapropel are visible within the core. These are the result of lacking oxygen in the deep ocean. In this instance, they were created by increased freshwater flow from the river Nile into the ocean. This freshwater flushed the saline ocean water preventing mixing of different layers within the ocean. This sediment core reflects an increase in rainfall over tropic continents during this time period, a natural phenomenon, resulting from orbital forces.
- Pale layers of carbonate ooze alternate with the dark layers. They were deposited during times when the oceans did not become anoxic.

Abrupt Climate Change and Humans

Earth's climate has been shown to have varied in the past on a range of timescales and amplitudes. Climate change on short timescales, termed "abrupt climate change," is known to have had consequences on our species. It is possible that it even influenced our dispersal across the globe. The forcing behind abrupt climate change is poorly constrained. However, climate reconstructions suggest that changes of up to 10 °C in a decade have occurred in the past; therefore the issue of abrupt climate change is of relevance to us today.

An important concept when considering changing climate is the response time. This is the time that the system takes to respond to a certain forcing. Within the Earth system as a whole, response times vary hugely. Response times vary from the seasonal response of, e.g., vegetation to changing temperature and light, to the slow response of ice sheets to the changing orbit of the Earth. The term "tipping point" is also used to describe a rapid response of the system to a certain forcing, however the response of a tipping point is controlled by the system itself and not by the forcing. In other words, a tipping point can be viewed as a kind of domino effect where the response may be more or less severe than expected.

In recent times, human forcing of the climate system has raised questions as to whether this may cause abrupt climate changes. Again, this is of particular relevance given that the ecological and economic consequences may be severe. The severe droughts seen in the Sahel region of Africa during the late 20th century provide an example of how abrupt climate change can impact humans. In countries such as Ethiopia, where vulnerability is high, the impacts are felt to the highest extent. Over 400,000 people died in northern Ethiopia alone between 1983 and 1985.

Humans (*Homo sapiens*) have been around for approximately 200,000 years. During that time, climate change has influenced humans in a variety of ways, from flooding to drought, on timescales of decades to glacial-interglacial cycles of tens of thousands of years. It is thought that changing climate patterns may have influenced the timing of human dispersal across the globe. Geneticists believe that humans moved out of Eastern Africa in two 'waves': the first occurring between 100 – 130 thousand years ago and the second between 40 – 60 thousand years ago. We can see from ancient cave paintings that some areas of the desert were, at some time, much wetter (Fig. 14). Climate scientists can reconstruct the changes in rainfall patterns over North Africa by examining the types of plants that grew there in the past. It appears that human dispersal occurred during periods of higher rainfall over the Sahel region. This is consistent with the idea that humans would move inland only when food was available, and otherwise remain on the coastlines. Both lines of inquiry – genetics and climate science – suggest that humans may have migrated into Europe and Asia around 40 – 60 thousand years ago. It also appears that the opportunity of this dispersal may have been created by changing weather patterns.

It is clear that humans are influenced by changes in climatic regimes and are particularly vulnerable to rapid and unpredictable shifts. We currently have too little understanding of the mechanisms of abrupt climate change to predict future changes. Continued scientific research is important to aid our understanding and ability to plan for potential future changes.

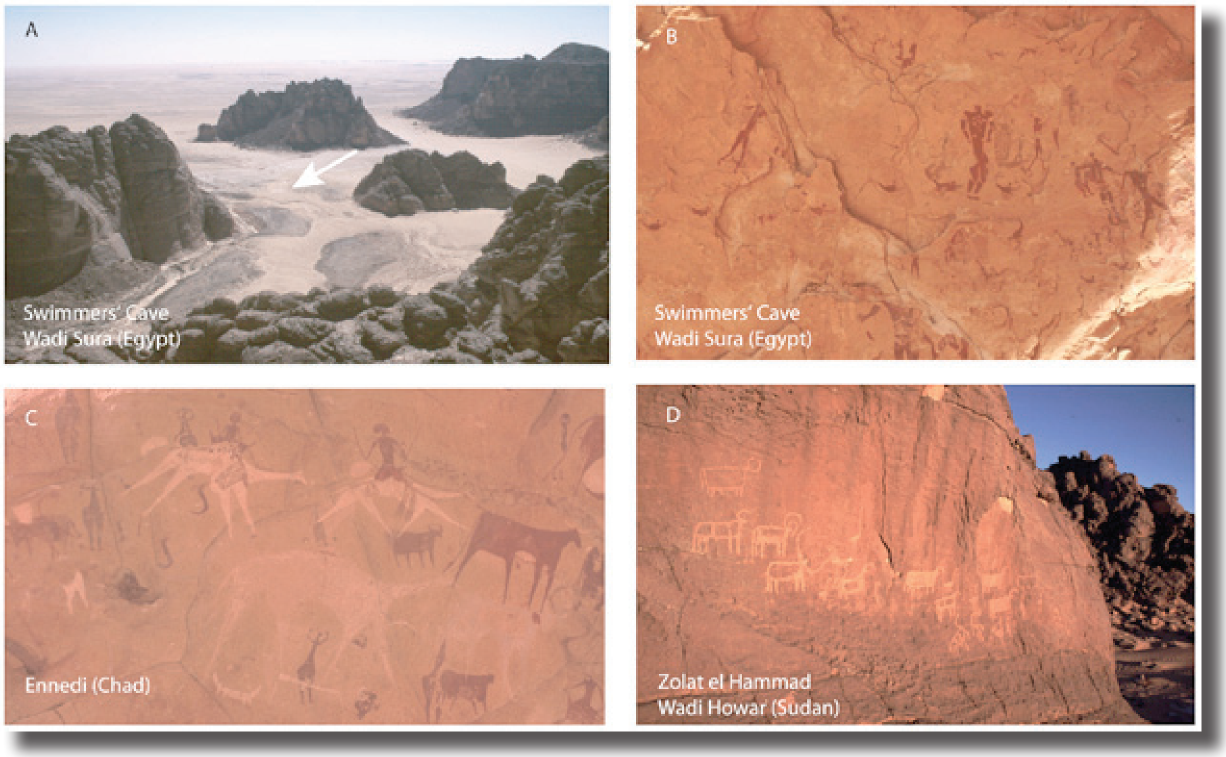

Fig. 14: Images of North African prehistoric rock and cave paintings. From (a, b) Swimmer's Cave (Wadi Sura, southern Egypt), (c) the Ennedi massif (northeastern Chad) and (d) Zolat el Hammad, Wadi Howar (northern Sudan). © 2012 Nature Education. All photographs courtesy of Dr. Stefan Kröpelin (University of Köln). All rights reserved.

Modern Climate Change and Humans

There are many causes for climate change. Some of the causes are due to natural forces such as the regional variations of solar radiation, cycle of solar activities, temperature differences caused by the motion in the atmosphere and the ocean, etc. Those are the natural driving forces that operate the "climate machine" that is now being additionally affected by human activities. It is one of the strongest impacts humans have had on the natural environment.

The human population is growing faster than ever before. For more than 2.5 million years after mankind first appeared on the Earth, the world population is estimated to have remained below half a billion people. However, over the last approximately 500 years, we have expanded and continue to expand reaching the milestone of 7 billion people in March 2011. Today, the world population is estimated to be 7.041 billion people by the United States Census Bureau. (Fig. 15.)

Along with the large increase in population, the demand for food, natural resources, energy, infrastructure, etc. is also growing. The consumption of energy has been growing significantly. The use of fossil fuel causes a huge amount of carbon dioxide (CO_2) to be released into to the atmosphere. This gas accumulates in the atmosphere and enhances the greenhouse effect, which is the main cause of global warming. Loren Cobb in "The Causes of Global Warming: A Graphical Approach" shows that since 1850, world fossil fuel use is rising in general (Fig. 16). The red line stands for annual mean fossil fuel use and has increased dramatically since 1950, at a rate of more than two times that rate during the previous 100 years. If we look at the global mean temperature (blue line) in the same period from 1850 until now, the temperature is rising along with the human consumption of fossil fuel. Although there are some increasing and decreasing periods due to natural variations, the overall trend of temperature is an increase, anyhow.

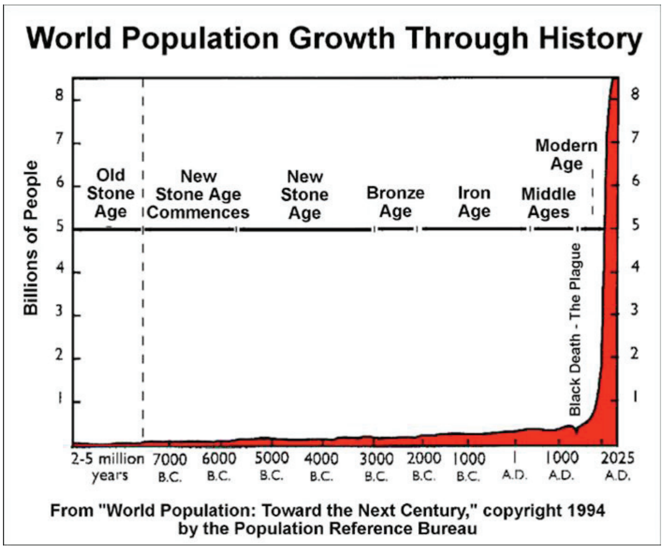

Fig. 15: World population growth (reference is given on the Figure).

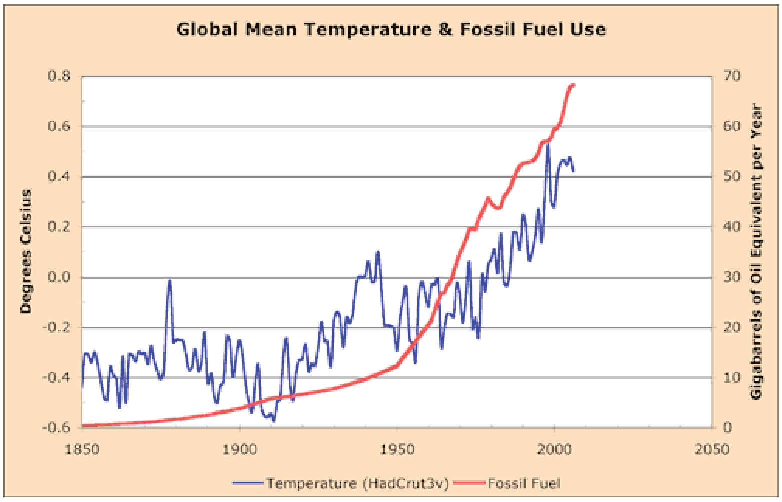

Fig. 16: Global mean temperature versus fossil fuel use (Cobb, 2008).

Burning fossil fuels is not the only reason for the increase in CO_2 concentration in the atmosphere: 78% of CO_2 in the atmosphere comes from fossil fuel burning, while the other 22% comes from the change in land use. The growing population and the shift to a high standard of living are putting a burden on natural resource availability, such as when large areas of forest are cut down and used as fuel or building material all over the world. The satellite images taken from the area of Rondonia in Brazil show the natural green in 1975 changed to artificial concrete by 2001 (Fig. 17). Because plants play a large role in the absorbtion of CO_2 from the atmosphere, deforestation not only reduces the forest function but also exacerbates the increase of CO_2 emission.

Fig. 17: Land use change in Rondonia, Brazil from 1975 to 2001.

Human has been dramatically changing the natural processes, and we, in turn, are affected by the changes that we have induced. Climate change is strongly linked to an increase in the number of extreme weather events on our planet: in recent years, we have experienced more disasters than ever before. Flood, drought, strong rain and snow now affect people and their infrastructures all over the world

Changes in the storm tracks of North Atlantic mean that tropical storms are negatively affecting the northeast coast of North America more frequently than has been recorded previously. From 1925 to 1991, the average number of North Atlantic storms was averaged at 10.6 per year. During the period from 1991 to 2005, this number increased to 15. There are more high intensity storms with increased damage and human consequences, which is strongly correlated to the change in climate since the mid 1800s (Fig. 18).

Fig. 18: Annual frequency of North Atlantic tropical storms (graphic from: http://blueandgreentomorrow.com/2012/10/30/watching-hurricane-sandy-shows-us-the-future-of-our-climate/).

As the temperature continues to raise, the economic losses due to weather-related disasters is also increasing in many parts of the world. With a general temperature increase of 0.5 °C higher than average in 2005, the USA lost more than 60 billion USD due to damage from storms (Fig. 19).

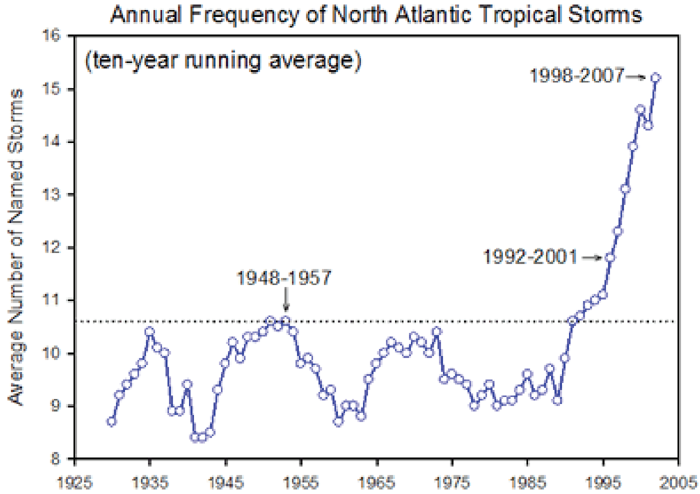

Fig. 19: Relation of temperature increase and normalized weather-related damage costs (reference herein).

Aside from economic losses, human populations are beginning to experience health problems due to changing climate. Temperature rise is increasing the latitudinal dispersion of tropical diseases, so it is more likely they can reach higher latitudes. This increased risk will require populations to adapt to the new threats of disease. However, this is never easy to change: until populations are more able to prepare themselves for a changing climate, we will witness more human and economic losses due to the changing climate.

Geo-Engineering

Geo-engineering (climate engineering) has emerged as an option for fighting with climate change. It is an intentional manipulation of the climate system elements by engineering to offset the effects of climate change. While "mitigation" measures attempt to decrease CO_2 emissions and "adaptation" measures try to decrease the climate impact on human welfare and ecosystems; geo-engineering takes its place in between. One form of geo-engineering is oriented towards solar radiation management with projects for cooling the Earth. It has been suggested that if cloud cover is increased by spraying seawater into the atmosphere inducing cloud formation, subsequently less heat will reach the Earth, and cooling will be achieved. Other projects aim to cool the Earth by reflecting incoming solar radiation with increased amount of stratospheric aerosols or by building mirrors in space. The second field of geo-engineering is oriented towards increasing the CO_2 sinks and removing CO_2 from air. The main idea is to enhance the ability of natural systems to take up more CO_2. Suggested projects include ocean fertilization with iron to increase plankton population that absorbs CO_2; addition of carbonate to oceans to facilitate CO_2 uptake; reforestation and building artificial trees to absorb CO_2 from the atmosphere. Although more geo-engineering projects are being designed, the debates over advantages and disadvantages continue. Scientists, governments and investors want to be certain that systems would work, and are manageable in terms of both costs and environmental benefits before committing to such a strategy (Fig. 20).

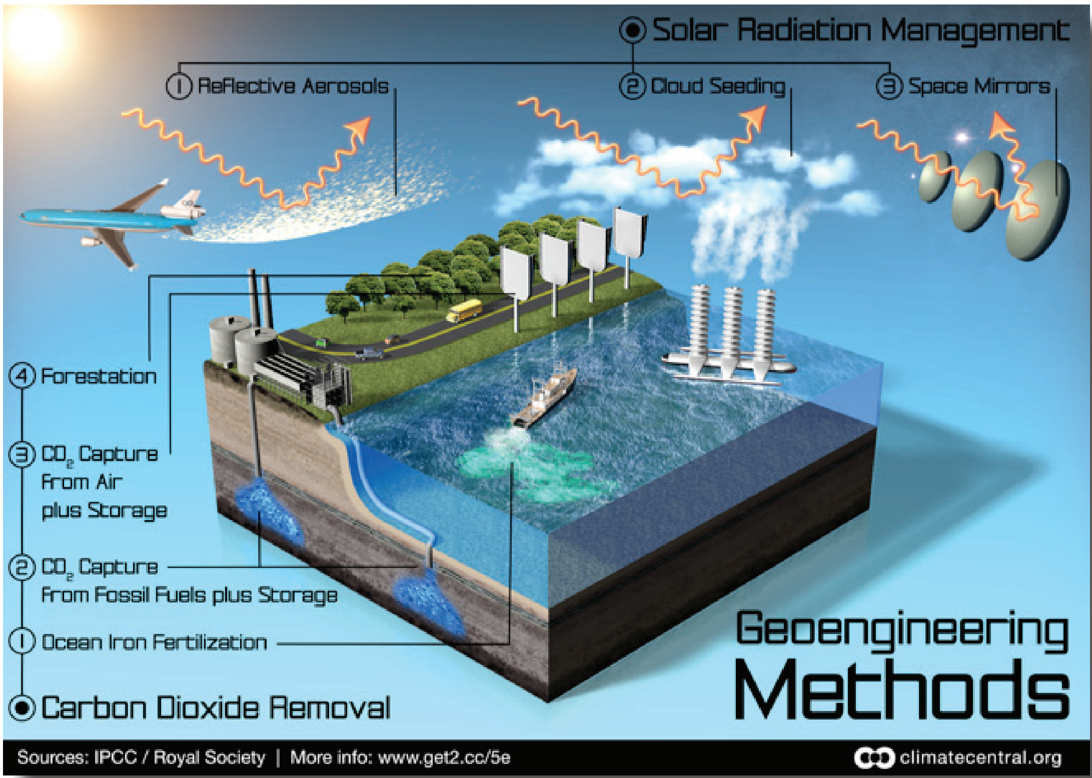

Fig. 20: Geo-engineering strategies and methods (adapted from Climate Central: www.climatecentral.org).

The main views during the debate "Cure or Malpractice?" are as follows: Some of the participants stated that governments would not support geo-engineering options as, before initiating such projects, they must be certain that they will work without adding additional adverse effects. Others advocate that people should be more open to the idea of engineering the climate, as this force the community to realize the significance of the climate change problem with the possibility of outreach. Overall, all participants agreed that the first step is to know the effects of the proposed projects and for this, investments should be diverted to research to understand them. Starting on a small scale initially is favorable. However, the overall effects will not be entirely understood before running a full-scale project. While governments and companies can allocate sufficient funds, no one will take responsibility for the unknown future effects of these projects. Geo-engineering is considered as a combination of many scientific professions, therefore a multi-disciplinary approach should be taken.

References

Cobb, L., 2008. The causes of global warming: a graphical approach, (http://www.quaker.org/clq/2007/TQE158-EN-GlobalWarming.html, accessed 22/09/2012)

Curry, R., Dickson, B., and Yashayaev, I., 2003. A change in the freshwater balance of the Atlantic Ocean over the past four decades. Nature. 826-829. IPCC AR4, 2007

Kuhlbrodt, T., A. Griesel, M. Montoya, A. Levermann, M. Hofmann, and S. Rahmstorf,2007, On the driving processes of the Atlantic meridional overturning circulation. Rev.Geophys., 45, RG2001.

Ruddiman, W.F., 2008, Earth's Climate: Past and Future, W.H. Freeman and Company, 2nd revised edition, 388 pp.

Energy Balance Exercises

Exercise 1: Radiative Equilibrium Temperatures

Calculate the radiative equilibrium temperatures, TR, of Venus, Earth, and Mars. The albedo of Venus, Earth, and Mars are 0.77, 0.30, and 0.24, respectively. The solar radiative flux density S_0 = 1,368 Wm^{-2} at rE, the Sun–Earth distance. The surface temperatures, TS, of these planets are 760K, 288K, and 230K, respectively. Explain the differences between TS and TR.

The radiative equilibrium temperature in any planet is a result of the flux of energy budget between the energy input from the Sun and the energy emitted by the planet itself. The first term depends on the distance between the planet and the Sun (a_0, in astronomical units), and the temperature and the radius of the Sun (T_{eff} and r_s, respectively)

$$S_E = \sigma T_{eff}^4 \left(\frac{r_s}{a_0} \right)^2$$

- where sigma is the Stefan-Boltzmann constant, equal to 5.67 x 10^{-8}. This energy flux is known as the solar constant, and it takes a value of S_0 = 1,368 Wm^{-2} when a_0 is 1, when calculated for the Earth. On the other hand, the energy flux emitted by the planet can be calculated considering the planet like a black body

$$F_E = \sigma T_{eq}^4$$

- where T_{eq} is the equilibrium temperature of that planet. However, while the planet emits energy like a sphere, the energy input from the sun only is distributed for the surface of the planet which is in front of the Sun. Thus, the equilibrium of both fluxes is

- where r_p is the radius of the planet. Finally

$$\sigma T_{eff}^4 \left(\frac{r_s}{a_0} \right)^2 \pi r_p^2 = \sigma T_{eq}^4 4\pi r_p^2$$

$$T_{eff}^4 \left(\frac{r_s}{a_0} \right)^2 = T_{eq}^4 4$$

$$\frac{S_E}{4} = \sigma T_{eq}^4$$

But, in general, the planet does not absorb all the energy from the sun, reflecting a part of the incoming solar radiation. This fraction of the flux of energy is known as albedo (ɑ), and it should be taken into account in the previous equation as

With an albedo of $ɑ_E$ = 0.3, the equilibrium temperature of the Earth results in a value of 254.9K. The results for Venus and Mars derive from the known result of the Earth, comparing both planets

$$\frac{S_E}{4}(1-\alpha) = \sigma T_{eq}^4$$

- where T_{eqP} is the temperature of the other planet, α_P its albedo, and a_P the distance

$$\frac{\left(\frac{S_0}{4}(1-\alpha_E)\right)}{\left(\frac{S_P}{4}(1-\alpha_P)\right)} = \frac{\left(T_{eqE}^4\right)}{\left(T_{eqP}^4\right)}$$

$$\left(\frac{T_{eqP}}{T_{eqE}}\right)^4 = \frac{(1-\alpha_P)}{(1-\alpha_E)} \frac{1}{a_P^2}$$

between the planet and the Sun, in astronomical units. For Venus and Mars these values are

Venus: - $\alpha_V = 0.77$; - $a_V = 0.723$

Mars: - $\alpha_M = 0.24$; - $a_M = 1.523$

Using the Earth equilibrium temperature, the results for Venus and Mars are

T_{eqV} = 227.0, K = -46.0 ºC

T_{eqM} = 210.8, K = -62.16 ºC

Thus, we can see how the equilibrium temperature for the three planets is lower than their surface temperature. The reason for this difference derives from the presence of their atmospheres, which affect the balance of radiation inside the planet. The atmosphere contains some gases, known as greenhouses gases, which can absorb radiation emitted by the planet. Then, these gases re-emit again this radiation and warm the surface of the planet.

Exercise 2: Jupiter, the underdeveloped Sun

The effective radiative temperature of Jupiter has recently been determined by the Pioneer spacecraft as T_{eff} = 125K. This temperature is larger than the equilibrium radiative temperature T_R that is determined from the equilibrium of absorbed solar and emitted infra–red radiation. This difference is attributed to thermonuclear processes in the interior of Jupiter.

a) Determine the equilibrium radiative temperature T_R of Jupiter from the solar constant for Earth (S_0 = 1,368 Wm^{-2}), the Jupiter–albedo (0.51) and the distance Jupiter–Sun ($5.2 \cdot r_E$).

Using the last equations from the first exercise, we can calculate the equilibrium temperature for Jupiter knowing the albedo and the distance Jupiter-Sun

$$\left(\frac{T_{eqJ}}{T_{eqE}}\right)^4 = \frac{(1-\alpha_J)}{(1-\alpha_E)}\frac{1}{a_J^2}$$

That results in a value of: T_{eqJ} = 102,2 K.

b) Determine the energy flux density from Jupiter's interior, which is required to balance the difference between the effective and the equilibrium radiative temperatures. How does it compare to the absorbed solar radiation?

The energy flux from inside of Jupiter is an extra term, and it should be taken into account in the equilibrium between the energy input from the Sun and the energy emitted by Jupiter

$$F_J = \sigma T_{eq}^4 + F_i$$

- where F_i represents this internal flux and T_{eq} the equilibrium temperature of Jupiter. Thus

$$?\left(T_{eff}^4 - T_{eq}^4\right) = F_i = 7.65Wm^{-2}$$

This flux of energy is comparable but a little higher that the absorbed solar radiation, equal to $\sigma T_{eqJ}^4 = 6.19Wm^{-2}$

Exercise 3: Clouds on Earth, Water World and Ice World

The difference between Earth's surface temperature TS and its radiative temperature TR is due to the greenhouse effect of the atmosphere, especially to the clouds. This effect can be taken care of by allowing only a fraction β of the surface infra–red radiation to be lost to space.

a) Earth. How large is the greenhouse factor β assuming that the surface temperature of Earth is T_s = 287.4K and α_E = 0.3?

The factor β can be introduced into the balance equation as

$$\frac{S_0}{4}(1-\alpha) = \beta\sigma T_S^4$$

- and can be calculated using the solar constant, the Earth albedo and the surface temperature.

This is

$$\beta = 0.62$$

b) Water World and Ice World. Use this greenhouse factor to calculate the surface temperature of a totally ocean covered 'Earth' (Water World, α_w = 0.1), and an ice covered 'Earth' (Ice World, α_i = 0.8).

The equilibrium temperature from the previous equations is

$$\frac{S_0}{4}\frac{(1-\alpha)}{(\beta\sigma)} = T_{eq}^4$$

And using the different values for the albedo, it results

Water World: T_{ww} = 305.9 K

Ice World: T_{iw} = 206.0 K

There is, then, the amplitude for the temperature is of about 100 K between both situations, as a result of the different albedo values.

c) Clouds. Assuming that Water World and Ice World are 50% covered with clouds (α_c = 0.6), determine the planetary albedo α and the corresponding surface temperature T_S for both planets. Compare to results of b) and explain.

In this case, we have to add the clouds albedo to the water or ice world ones, taking into account that both values represent the 50% of the surface of the Earth. Thus:

$$\alpha_{wc} = 50\%\alpha_w + 50\%\alpha_c = 0.5 \cdot 0.1 + 0.5 \cdot 0.6 = 0.35$$
$$\alpha_{ic} = 50\%\alpha_i + 50\%\alpha_c = 0.5 \cdot 0.8 + 0.5 \cdot 0.6 = 0.7$$

The equilibrium temperature in both cases results

Water World with clouds: T_{wc} = 282.0 K

Ice World with clouds: T_{ic} = 232.4 K

The albedo introduced by clouds decreases and increases, respectively, the temperature of the planet with respect the result of the part b). In the water world, clouds increase the global albedo of the planet. Therefore, there is more energy reflected by the planet which does not enter in the planet, and its temperature is lower. In the case of the ice world, clouds decrease the albedo of the planet, because the albedo of clouds is lower than the albedo of the ice. Thus, the temperature in this case is higher.

Exercise 4: ET

a) An extraterrestrial organism can travel through interstellar space without spacecraft or space suit. It can keep its body temperature at 37ºC just by the uptake of food. How many calories per day does it have to eat if its skin surface is $2m^2$. Assume black–body radiation and no sunlight.

Without an energy input from the start, like the Sun, the extraterrestrial is not in energy equilibrium and it only emits energy along its skin, depending on its temperature. Thus, considering that it is always at 37ºC, that is, at 310K, the flux of energy is

$$F_{ET} = \sigma T_{ET}^4 S = 1047.2W$$

- where S is the skin surface. The result in calories per day is then

$$1047 \frac{J}{s} \frac{1cal}{4.1868J} \frac{1kcal}{10^3 cal} \frac{86400s}{1day} = 21.6 \cdot 10^3 kcal \quad day^{-1}$$

Considering that 100 g of chocolate provide about 400 kcal, our extraterrestrial should eat 5.4 kg of chocolate per day. Consequently, if it only has vegetables, with an energy mean of about 50 kcal per 100g, the extraterrestrial should eat almost 44 kg of them per day → 2 kg per hour!

MODULE 4
OBSERVING THE OCEANS

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Introduction

The world's oceans cover nearly three quarters of our planet; however its surface, depth and mere nature make this great expanse the last frontier in research. Despite the fact that our exploitation of the oceans has increased drastically in the last 40 years, less than 5% of it has been explored. Oceanography, study of the oceans, is a comparatively young science and is still heavily dependent on methodology and what instruments researchers have at their disposal.

The lack of continuous observations of the atmosphere, oceans and land has always limited the development of numerical models able to describe the climate of the Earth. Recent studies concluded that the currents, transporting heat northwards in the Atlantic and influencing western European climate had weakened by 30% in the past decade. This result was based on just five research measurement campaigns spread over 40 years. Was this change part of a trend that might lead to a major change in the Atlantic circulation, or due to natural variability that will reverse in the future, or is it an artefact of limited observations? In this respect ocean observation systems are important to measure and describe the state of the ocean and monitor its changes over time.

ARGO Floats Program

Concerns about the absence of observations of key factors that influence Earth's climate led governments to form the Global Earth Observation System of Systems (GEOSS) in 2003. In Europe there is an initiative on Global Monitoring for Environment and Security (GMES). GEOSS and GMES aim to provide the measurements needed to make predictions of how global change will influence weather, climate, energy, water, health and disasters. The climate and ocean components of GEOSS are delivered by the Global Climate Observing System (GCOS) and the Global Ocean Observing System (GOOS). In 1999, before GEOSS was set up, an innovative step had been taken by scientists to greatly improve the collection of observations inside the ocean; the Argo initiative (Fig. 1). Before Argo, most of our knowledge about the interior of the ocean came from research ship measurements and from temperature probes (expendable bathythermographs, XBTs) dropped from merchant ships. These observations were relatively sparse, there were more in summer than in winter and there were very few in the remote but climatically important Southern Ocean. Almost all these research observations were maintained only for short periods, making it hard to monitor ocean changes. Oceanographers were poorly equipped to observe and understand ocean climate.

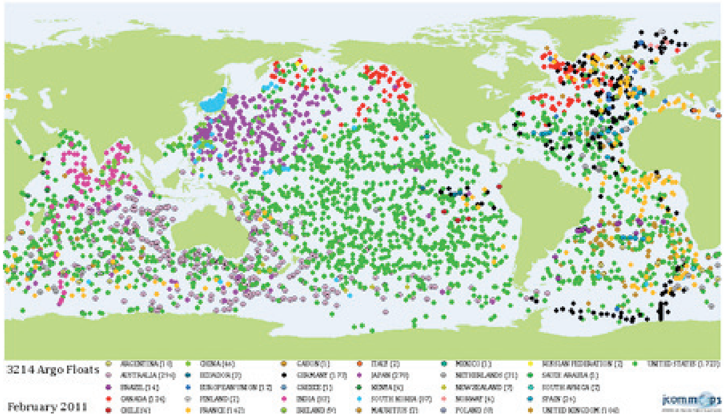

Fig. 1: The status of the global Argo sampling array at the end of February 2011 colour coded by country that launches the float (from http://en.wikipedia.org/wiki/Argo_float).

But the 1990s marked an important advance in this respect. Researchers mounted the World Ocean Circulation Experiment (WOCE) – the largest ocean experiment ever undertaken. WOCE set out to improve the ocean models used in global climate research by collecting an unprecedented set of observations. These came from a new generation of radar satellites that continuously monitor the shape of the ocean surface and its roughness. For the first time they began showing the strength and direction of surface currents, the effects of thermal expansion of the oceans caused by heat storage and the patterns of wind that drive the oceans. WOCE needed to know the temperature and salinity of the oceans and this data came from 20,000 observations made over 8 years by instruments lowered from research ships. It took a total of 25 years at a total cost of $220 million but still left large areas unsampled.

How do Argo Floats Work?

To measure currents below the surface, WOCE used battery-powered neutrally buoyant floats that hovered at mid-depth and surfaced every few weeks to be positioned by satellites. These Autonomous Lagrangian Circulation Explorers (ALACE) mapped currents across entire ocean basins. The float plan was called Argo after the ship in which, according to Greek mythology, Jason set sail in search of the golden fleece. Combining the satellite and float data to define the "state of the ocean" required the use of data assimilation - a technique used in weather forecasting that was applied to the oceans during WOCE. Assimilation combines observations with detailed computer models in a way, ensuring the results to agree with the fundamental physical laws that govern ocean dynamics.

Argo was a completely new concept and required ocean scientists to work in a multinational collaboration to monitor the global ocean for the benefit of all. Argo would be made up of contributions from individual countries, all of which would share their data and make it available to any user anywhere in the world within

24 hours. The first Argo floats were deployed in late 1999. In order to provide information on the constantly-changing array, float deployments and positions are tracked through an Argo Information Centre (AIC) established under the Intergovernmental Oceanographic Commission (IOC) of UNESCO. The floats have a design life of at least 4 years meaning that 800 floats per year would be needed to maintain the 3° x 3° array of 3000 floats.

Fig. 2: A scientist holding an Argo float.

Basically an Argo Float (Fig. 2) is an autonomous underwater robot, which is capable of controlling its depth actively by changing its specific weight. Unlike the depth, the position of the float in the ocean is not controllable as the float does not have any kind of thruster or propulsion unit. Consequently, the float drifts along with currents. Following a pre-programmed procedure, the float comes up to the ocean´s surface, establishes contact to a ground station via the Iridium satellite network and broadcasts the previously gathered data.

The float itself consists of an approximately 200 cm long and 30 cm wide metal cylinder which serves as a pressure hull. This pressure hull houses all pressure sensitive instruments of the float such as the batteries or the depth control. Due to its orientation when submerged, a top and a bottom end of the float can clearly be distinguished. The float drifts in an upright orientation through the water. At the top end, the sensors (e.g., CTD) and the Iridium antenna are mounted. The normal measuring interval, which means the time between contacting the ground station twice, is 10 days. On the first day, the float descends down to 1,000 m and stays at that depth for 9 days. During this phase the sensors are inactive and no data is recorded. On the 10^{th} day, the day where the actual measurement takes place, the float descends further 1,000m down to a depth of 2,000 m. As soon as it reaches this depth, the float activates its sensors and starts the ascension to the surface. The vertical speed is roughly 10 cm/s so that the complete process of ascending to the surface takes about 5,5 hours. While the float rises the instruments record a vertical profile of the water column. When the float reaches the surface it firstly determines its own position via GPS. As soon as the float localizes its own position, it establishes contact to a ground station via Iridium and starts transmitting the gathered data. According to the quality of the connection, the residence time of the float on the surface can vary from 6 to 10 hours. Once all the data have been transmitted, the float descends to 1,000 m again and a new measurement cycle of 10 days begins (Fig. 3).

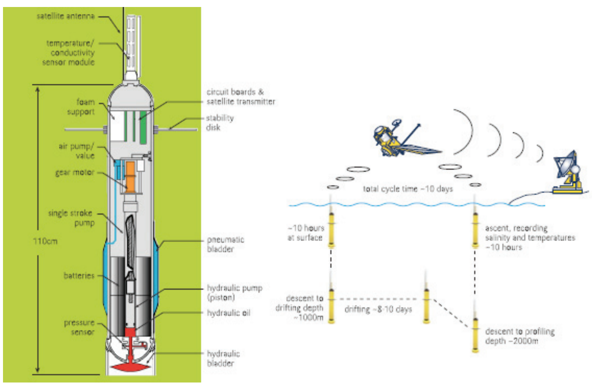

Fig. 3: The interior and the cycle of an Argo float.

Future Plans

For a better understanding of how the global climate system works, it is absolutely necessary to investigate the oceans in detail. The release of as many Argo floats as possible into the ocean will provide a sound knowledge about temperature and salinity and other parameters around the globe. Since Argo project started 15 years ago, the floats' technology kept constantly improving and a lot of new ideas are taking over in this respect. For example, today most of the Argo floats disappear in the oceans when they run out of energy. It should be possible to localize them, install a new battery and use them again. Furthermore, the application of more and new sensors like oxygen, methane and CO_2 is still at the testing phase. It should be, indeed, given more emphasis to this aspect in order to gain more and better data for the climate models. Also important would be a continuous logging system which would also provide more data and a better insight into the ocean system.

NEPTUNE Canada and their Research

For centuries fishermen, mariners and other people dependant on the great seas have been developing ways in which to explore the oceans and learn about its cycles, life, etc. But it wasn't until recently that technology has allowed us to plunge right into its depths and start observing from the inside. While it is possible for humans to descend quite deep into the oceans, it is not possible to leave a scientist in there for days, or even months, expect them to be awake constantly and always at our disposal. It is even less probable that we will be able to communicate with them at any time or see through their eyes. But at this day and age, we no longer need to rely just on humans to do this job. Other marine organisms can do it for us (seals for example), but we prefer to simply observe their behaviour without interfering actively, so how can we get all the information we need, whenever we need it? Well, we have managed to explore other planets using robots, so why not the depths of our own planet!

Fig. 4. NEPTUNE Canada undersea observatory with Wally visible to the left and ROPOS in the middle. Artist depiction of the NEPTUNE Canada undersea observatory (from http://www.neptunecanada.ca/about-neptune-canada/).

What is NEPTUNE Canada?

NEPTUNE Canada, amongst others, has developed a program whereby they have deployed an underwater hydrates crawler – Wally (I and II). Wally II, which has succeeded Wally I, was deployed in September 2010 to Barkley Canyon off the coast of North America and is connected to the Barkley Hydrates instrument platform via a 70 m long cable which provides power and communication. Wally II, that got its name from the famous Disney/Pixar character WALL-E (Fig. 5), can be accessed by internet at any time of the day, from anywhere on the globe and can be manipulated to move and look around. Wally II's main job is to help scientists carry out detailed investigations of processes influencing gas hydrates evolution on the sea floor.

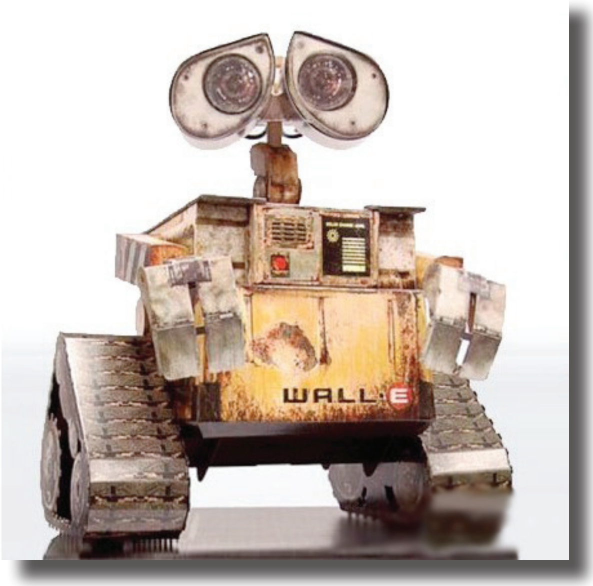

Fig. 5: WALL-E form Disney/ Pixar.

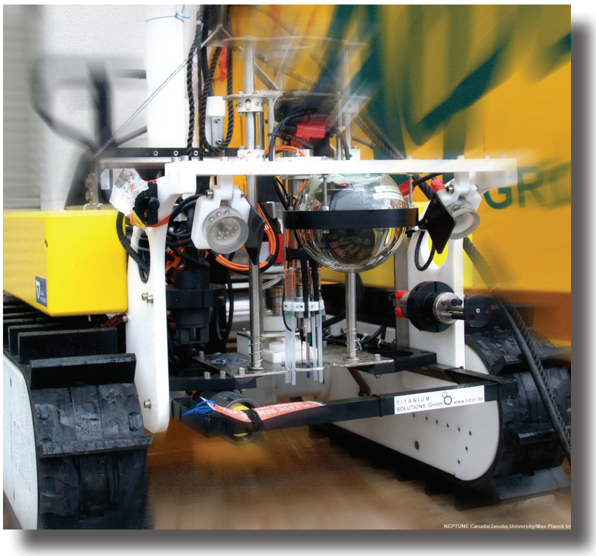

Fig. 6: Wally II waiting for deployment.

Wally II has also been equipped with a custom-built sediment microprofiler which enables the robot to explore microbial habitats around methane hydrates and seeping points (Fig. 7).

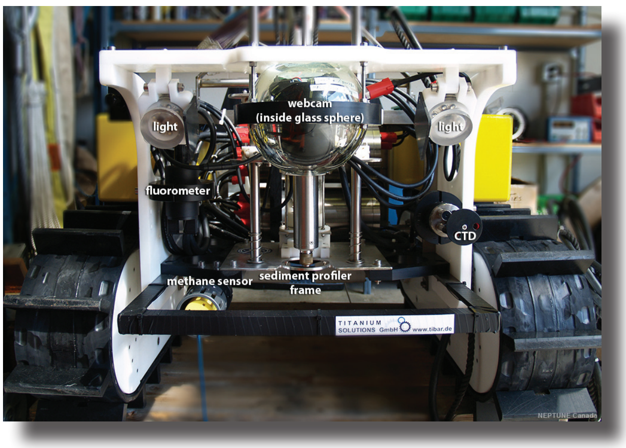

Fig. 7: Wally II instruments.

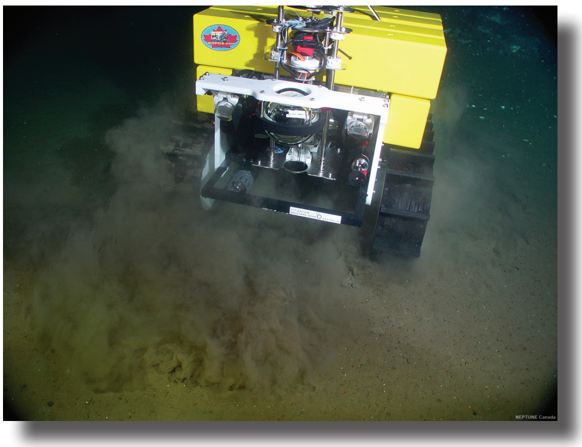

Fig. 8: Wally II underwater.

While all these functions are undoubtedly important and even invaluable to scientists, maybe the most fascinating option for any marine biologist is Wally's underwater camera. Because Wally is mostly stationary and its lights are only turned on when needed, most underwater organisms perceive the robot as a good hiding place.

Wally's cameras have been able to capture many fascinating organisms and their behaviour that was, in some instances, previously unseen. A good example of this is the mating of two Spider Crabs or the image of a beautiful Sea Spider (Fig. 9).

Wally II is not the only underwater vehicle capable of taking amazing pictures and videos – NEPTUNE also has at its disposal a ROPOS (Remotely Operated Platform for Ocean Sciences) vehicle that is mostly used for seafloor mapping and instrument deployment.

Fig. 9: Sea Spider caught by a ROPOS camera.

Data Collection and Analysis

NEPTUNE Canada is also following seismic activity and subduction processes of the Juan de Fuca plate, which is located west of the North American continent. Subduction zones can generate some of the world's largest earthquakes, often associated with devastating tsunamis. One of the researchers' main goals is to better understand the processes and improve their estimates of seismic risk. With high-precision bottom pressure sensors NEPTUNE Canada can detect tsunamis from both local and distant sources. These tsunami and earthquake warning systems were installedas part of an early warning system for alerting people to react before the disaster hits. The time available to react might not be long, but even a short time might be enough to save lives. Imagine, for example, how far you could get with a short time of only ten seconds.

All the data collected by NEPTUNE Canada's many devices is not worth much unless it is properly analysed. In order to do this, various software has been specifically developed. NEPTUNE Canada has an easy-to-use data portal where everyone can register. Within the portal there are large amounts of data available for either on-line viewing or downloading. However, there are different levels of data access as, for example, downloading of data sets is divided to restricted and unrestricted. Many properties of sea water can be followed in real time as the data in the portal is updated constantly (Fig. 10).

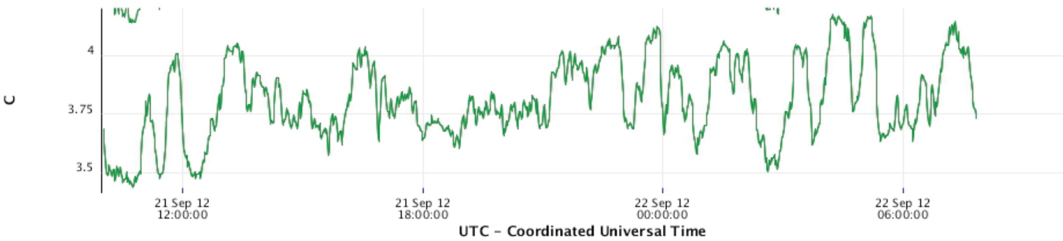

Fig. 10: The plotting utility of the NEPTUNE Canada data portal allows choosing among many variables and plot diagrams for respective time periods. As an example, 24-hour diagram showing temperature variations measured by Wally.

Ocean Colour Sensors

Phytoplankton (microscopic algae shown in Fig. 11) is like tiny plants in the surface of the oceans, it is important for the carbon cycle because they photosynthesize. This means that they can use sunlight to take-up Carbon dioxide (CO_2) like food, and release Oxygen (O_2). This is an important process in the storage of CO_2 which is a greenhouse gas and has been strongly linked to climate change. Therefore, it can aid our understanding of the changing climate to monitor their distribution and abundance. Phytoplankton is also important in food chains as it acts as food for many different organisms in the ocean, such as whales and fish.

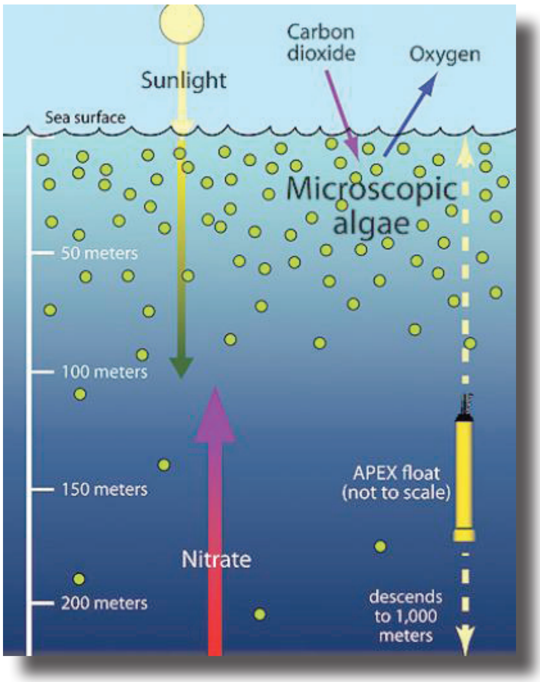

Fig. 11: A diagram showing phytoplankton and its interaction with environment.

What is Ocean Color?

When the light from the sun hits the ocean, part of its spectra (blue light) is absorbed by phytoplankton and organic matter, but most is reflected by the ocean surface (which is why the ocean looks blue). The remaining light (red light) goes into the ocean and is absorbed by water particles.

There are many things in the oceans that can change the color, such as:

- run-off from rivers
- waves and storms stirring up the water
- sand and sediment
- and PHYTOPLANKTON!

How do Ocean Color Sensors Work?

The most suitable approach to monitor the global distribution of marine phytoplankton and to estimate their total biomass is by satellite remote sensing. Using ocean-color sensors, long-term records of aquatic parameters are provided on a global scale, with different applications. Ocean optical sensors, attached to satellites that orbit the earth, measure the ratio of Earth shine backscatter to extraterrestrial radiation, from which the imprints of differential absorption features of all relevant absorbers within the retrieved signal can be extracted. Often there are gaps in the imagery, for example cloud cover and missing data along the satellite paths. There are many corrections required to get the final image (and these can lead to errors), but after this process the final image may, for example, displayed global chlorophyll a concentration (Fig. 12).

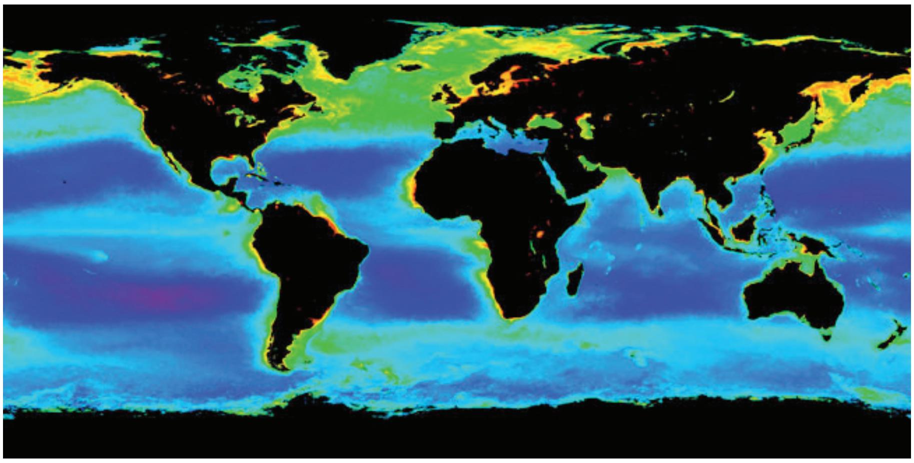

Fig. 12: Global chl a concentration (indicates primary production) from satellite imagery.

Why are Ocean Sensors Good to Use?

To cover the same amount of space as a satellite image using a ship to take measurements would take over **10 years to complete!** Satellite images can cover areas that may be inaccessible or difficult to get to, and can also give results in a much shorter time frame. The resolution of satellite images can be very high, for example, a 1km satellite image is 1,000 km by 1,000 km i.e. **1 million individual measurements!**

Exercise 1: Detection of Change

Introduction

In order to describe the state of the Earth and its changes over time, climate scientists investigate all components of the climate system: atmosphere, ocean, Earth's crust, biosphere (including all living organisms) and also the cryosphere (polar ice caps in Greenland and Antarctica, sea ice, glaciers and snow in the mountains)with special emphasis on two aspects:

Scientific knowledge: to understand how the climate system with all its components works and evolves over time.

Climate change: to determine how human activities (particularly the emission of CO_2 into the atmosphere) affect the climate system. The high amounts of CO_2 in the atmosphere increase the temperature of the planet and, accordingly, lead to higher amounts of CO_2 dissolved in the ocean. This latter effect is what scientists call "ocean acidification", because CO_2 in the ocean makes the water more acid with consequences for its ecosystem.

The increase in the mean global temperature of the planet (especially during the last about 160 years) is one of the big changes that have already been observed and linked with no doubt to human activities, especially to industrial, transport and agriculture activities..

The increasing temperatures, in turn, may have many effects in the climate system, resulting in changes over time. And it is some of these changes that we would like to detect in the following exercise.

One of the clearest impacts of the temperature rise is that of **melting ice.** Especially in the Arctic, the sea ice shows a clear trend in decreasing extent and thickness. However, we might also be interested in detecting how CO_2 and temperature increases are affecting other important elements of the system, especially when their evolution under these circumstances is not as easy to predict as in the case of the ice. This is the case, for instance, for phytoplankton and the rate at which these marine organisms photosynthesize. Photosynthesis is of special relevance because phytoplankton organisms take up CO_2 and under use of sunlight they transform it into oxygen and organic matter, which is then consumed by other bigger organisms. This process, called "Net Primary Production, NPP" is very important for the climate change process as it enhances the takes up of CO_2 from the atmosphere! Therefore, climate scientists and biologists are very interested in knowing how the recent changes in climate due to human activities have influence on the **amount and distribution of phytoplankton** (where they are located around the globe) and consequently the photosynthesis rate.

Objectives

1. **Detection of Arctic sea ice change:** to demonstrate that the amount of ice in the North Polar Region (Arctic sea ice) has been decreasing in the last 34 years (from 1979 to 2012). We will also see which regions are most vulnerable to climate change.
2. **Detection of phytoplankton bloom changes:** to see how and where in the Earth's oceans the amounts of phytoplankton have changed (through the change in magnitude of the yearly bloom).

Data & Tools

Instrumental data: Data on sea ice concentration in the Arctic Ocean and on chlorophyll concentration (related to phytoplankton amounts; ocean color remote sensing) of the global oceans are investigated. Both quantities are retrieved from measurements by several different satellites, in order to get greater spatial and temporal coverage.

Mathematics: We use concepts such as maximum, minimum and average values, calculating them for sea ice and chlorophyll concentration over the time series available (from 1979 to 2012) and for all locations of interest.

We calculate anomalies in the time series, which will indicate changes in sea ice and phytoplankton with respect to the average.

We determine trends within these anomalies. A trend indicates how much, e.g., the sea ice extent or the phytoplankton amounts have increased or decreased during the time of observation in a particular region. A trend analysis is a sensitive concept since it reflects changes in the quantity under study (e.g. sea ice concentration). However, the climate system and its components are very complex and changes can also happen as a result of a large variety of natural modes or internal variability (which are not related to human activities) that last during different time periods.

Computer Software: Windows Image Viewer (WIM/WAM software; www.Wimsoft.com) is a software package by Mati Kahru (Scripps Institution of Oceanography, San Diego) for visualization of the data set on maps, mathematical calculations and data processing.

Results

Sea Ice extent

Fig. 13 shows a time record of the sea ice concentration anomalies in the Arctic and the red trend-line indicates that a decrease in the sea ice thickness has been taking place during the time period considered; the ice in the Arctic Ocean is gradually disappearing during summer!

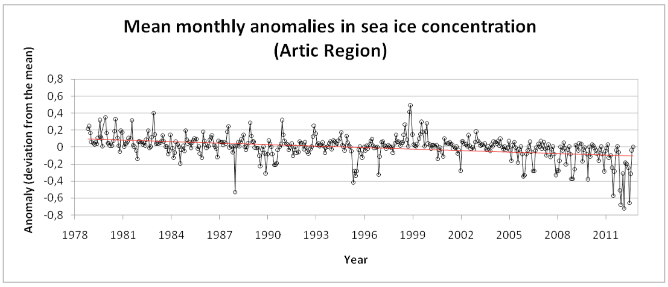

Fig. 13: The mean monthly anomalies in sea ice concentration during summer in the Arctic from 1978-2011.

It can also be seen in Fig. 14, comparing the orange line (the long term mean ice extent in the past) with the current ice extent (white areas), how the ice disappears most easily in the shelf seas of the Arctic Ocean that are close to Russia, Canada and US (Alaska) and how almost half of the summer ice has melted in 2012. In 2012, a historical minimum in sea ice extent has been reached, which is by about 760,000 km² below the former record minimum of 2007.

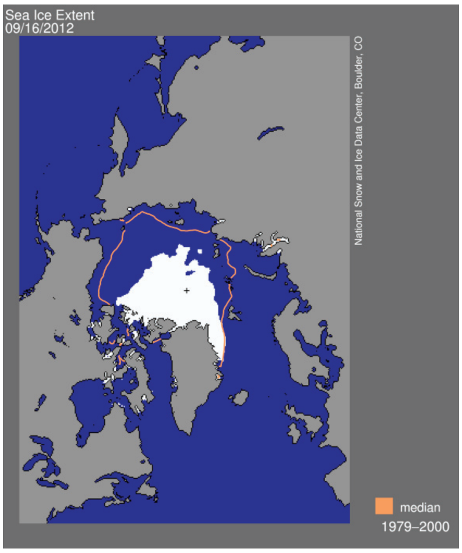

Fig. 14. Sea ice extent in the Arctic on 09/16/2012 in white, the minimum record since satellite observation of the last 34 years, with the median value of 1979-2000 in orange (www.nsidc.org).

Phytoplankton Amounts and Photosynthesis

Fig. 15 serves to analyze the change in phytoplankton amounts and distribution in different lakes and oceans of the Earth, especially in those waters close to the continents (continental shelves of North and South America and Europe). As seen, the dominating color is red, indicating that the amounts of phytoplankton have been predominantly increasing during the last 34 years in the continental shelves, most likely due to the increase in temperature.

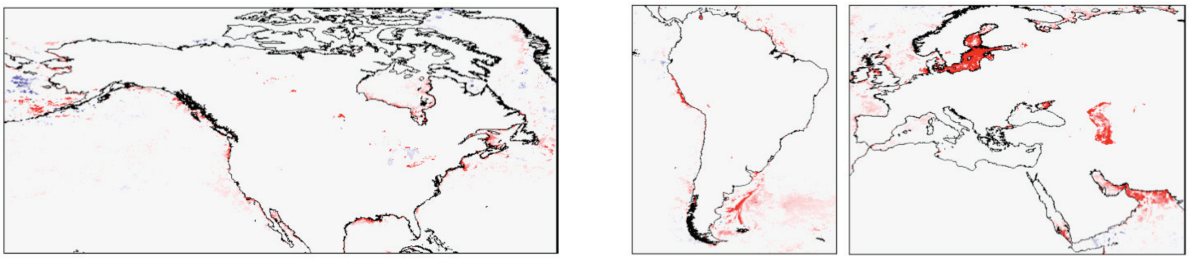

Fig. 15: Changes in bloom magnitude in continental shelves (a) North America, b) Europe) (using a Sen trend estimator, significance of 90%). Increased blooms are shown in red, and decreased bloom magnitudes are shown in blue (taken from Kahru and Mitchell, 2008).

In some areas, especially in the Arctic and North Atlantic oceans (seen in Fig. 16) a decrease over the last 34 years is observed, indicating that the distribution of phytoplankton is also changing.

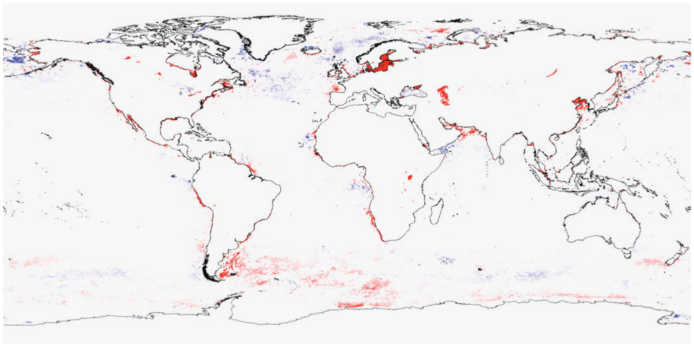

Fig. 16: Global trends in bloom magnitude (using a Sen trend estimator, significance of 90%). Increased blooms are shown in red, and decreased bloom magnitudes are shown in blue.

From this rough analysis it can be derived how complex and different the climate system is on the global scale and that a large number of factors are influencing the response of the phytoplankton community to global warming: phytoplankton abundance and photosynthesis rate can be both decreasing or increasing, depending on region and boundary conditions. A much more thorough analysis is needed to address a clear cause and effect chain to phytoplankton changes.

Summary

From the above information it is clear that ocean color sensors are very powerful and cost-effective tools that can be used to measure a number of important variables at the ocean's surface. For example the clear relationship of temperature and phytoplankton distribution, which indicate possible implications for future ecosystem dynamics.

Here lies the importance of change and trend detection in climate sciences. However, the detection of changes in the climate system can be quite complicated due to the variability of the climatic quantities and the complexity of the processes going on in the system.

Impact of Climate Change on Mediterranean Hydrate Thickness

What are Gas Hydrates?

Gas hydrate is a crystalline solid made up of gas molecules surrounded by a cage of water molecules, which looks very much like water ice (Fig. 17). The suitably sized 'guest' gas molecules are usually methane (CH_4) but sometimes can be propane, ethane or carbon dioxide (Fig. 18). Methane hydrates are believed to form by migration of gas from depth along geological faults, followed by precipitation, or crystallization, on contact of the rising gas stream with cold sea water. They normally form at about 300 m on continental shelves (Fig. 19) with a lot in the Arctic region.

Fig. 17: Structure of a gas hydrate block embedded in the sediment. Note the cavities where the gas is held.

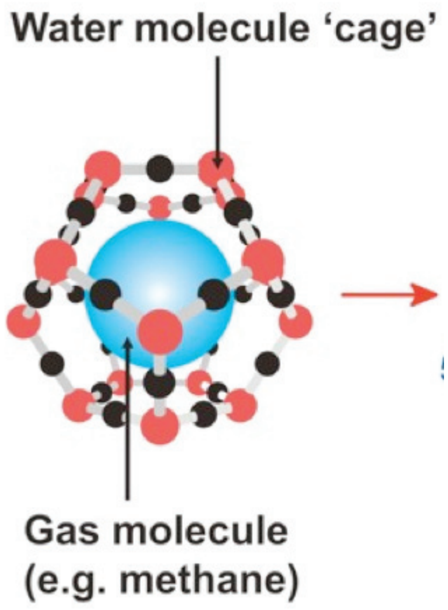

Fig. 18: The chemical structure of a gas hydrate.

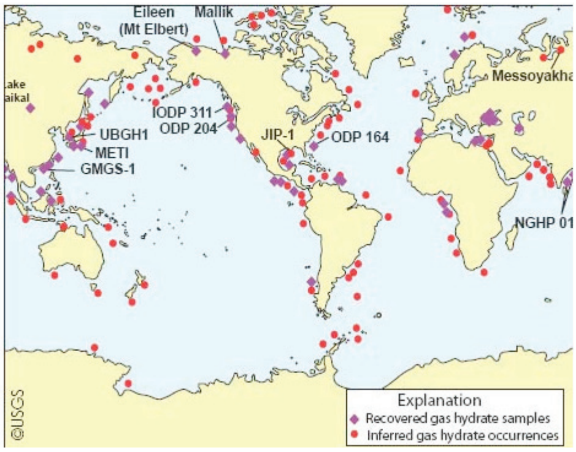

Fig. 19: The extent of gas hydrates across the globe. Note how they occur mainly around continental shelves.

Did you know?

1m³ gas hydrate can contain up to 164 m³ of gas!

Gas hydrates are very sensitive to both temperature and pressure. A rise in water temperature causes the hydrate to melt and so do falls in sea level. Temperature is expected to rise between 2-6 ˚C in the next century due to global warming which will cause many of the gas hydrates to melt and release methane. This will then oxidise to carbon dioxide and be released to the atmosphere, causing the global temperature to rise even more. The Arctic is most at danger from climate change and this is where most of the hydrates are stored. This makes it very important to understand how and when the hydrates will melt in the future and to avoid catastrophic climate change (Fig. 20).

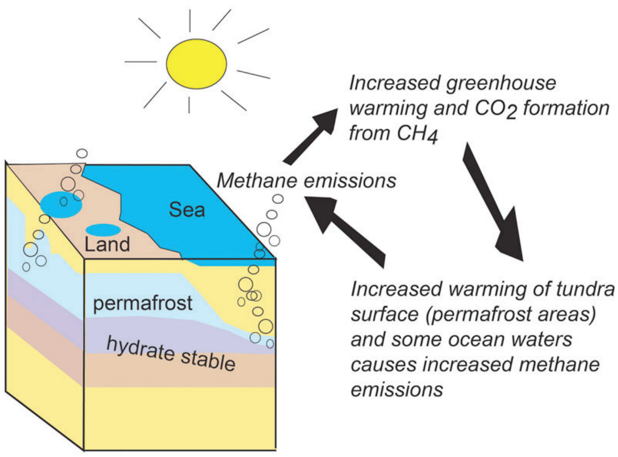

Fig. 20: When hydrate melts, it causes carbon dioxide and then temperature levels to rise.

Did you know?

Methane is twenty five times more powerful than carbon dioxide as a greenhouse gas!

Methane can be burned to create energy for our homes. There is so much methane stored in hydrates around the world that it will become an important energy resource in the future. It is important to know where the hydrates are so we can monitor how fast they melt and also investigate their potential as an energy source.

Did you know?

The gas hydrate reservoir is twice as big as the fossil fuels reservoir!

We find hydrates in areas of high pressure (lots of seawater above) and low temperatures. In order to detect the hydrates below the seabed, scientists use Bottom Simulating Reflectors (Fig. 21). The BSR is a seismic reflector with negative reflection coefficient. It arises at the interface of hydrate-bearing sediments to those with free methane gas. BSR structures extend along isotherms almost parallel to the seabed morphology and not follow the course of stratigraphic horizons. The reflector occurs at depths of up to several hundred meters below the seafloor, showing the lower limit of the zone of gas hydrate stability. Gas hydrates are therefore to be expected above the BSR, including existing free gas.

A typical picture of an offshore reflection sounding of the seabed is shown in Fig. 22. This is how the oil industry searches for oil and natural gas reservoirs.

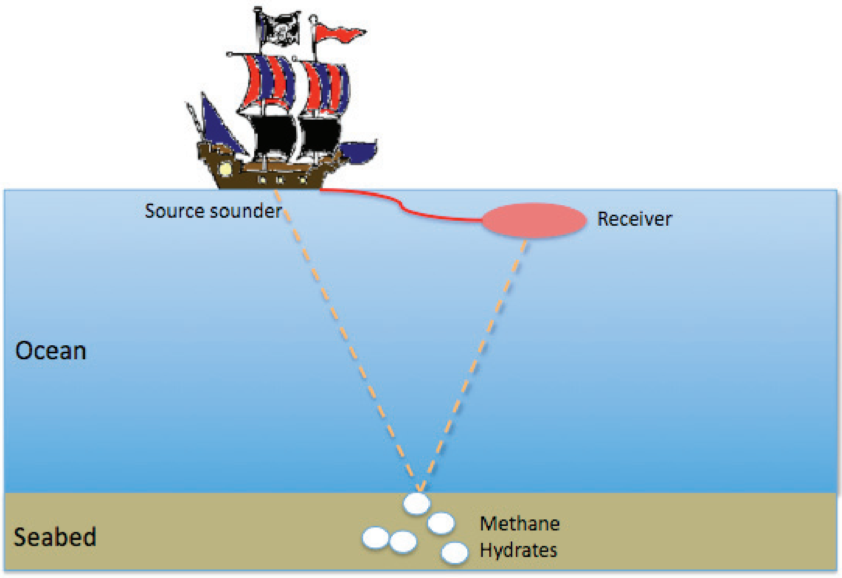

Fig. 21: Seismic reflection profiling sends an acustic signal down to the seafloor which penetrates into the ground and reflects from different structures, such as hydrate layer.

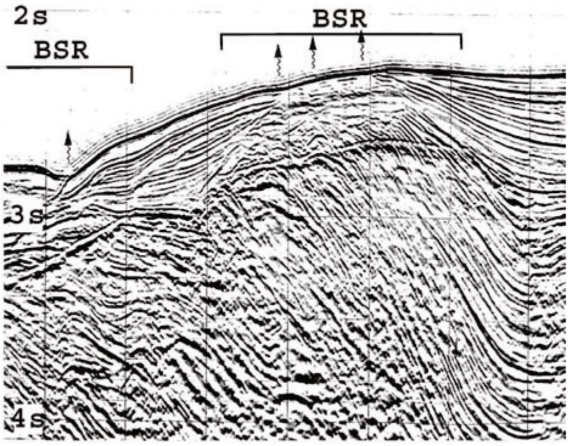

Fig. 22: A typical view of the sea floor indicating Bottom Simulating Reflectors (BSR). The arrows show where the methane gas is escaping.

Exercise 2: Gas Hydrates

In order to understand how and when gas hydrates in the seabed will melt and dissolve, scientists created a model, trying to predict what will happen when methane hydrates melt. As precondition the following information is needed:

- Location and areal distribution of methane hydrates
- Thickness of the hydrate layers
- Depth of hydrate layers in the seafloor

How will methane hydrates react to climate change? We expect to see more hydrates melting with a drop in sea level (thinner layer of hydrate).

Spot the Difference

Fig. 23 shows the result of a model simulation of the Mediterranean Sea before (Z0) and after (Zz) sea level has been dropped for 140 m If sea level goes down, the amont of water on top of the hydrates reduces and with it the pressure burden. This causes instability of the clathrates and melting of the hydrates so that the layer of gas hydrates gets thinner. This is confirmed by the model simulation:

When the sea level drops (Fig. 23, Zz), there is a much reduced thickness of hydrates existing in the seafloor compared to normal conditions (Fig. 23, Z0)

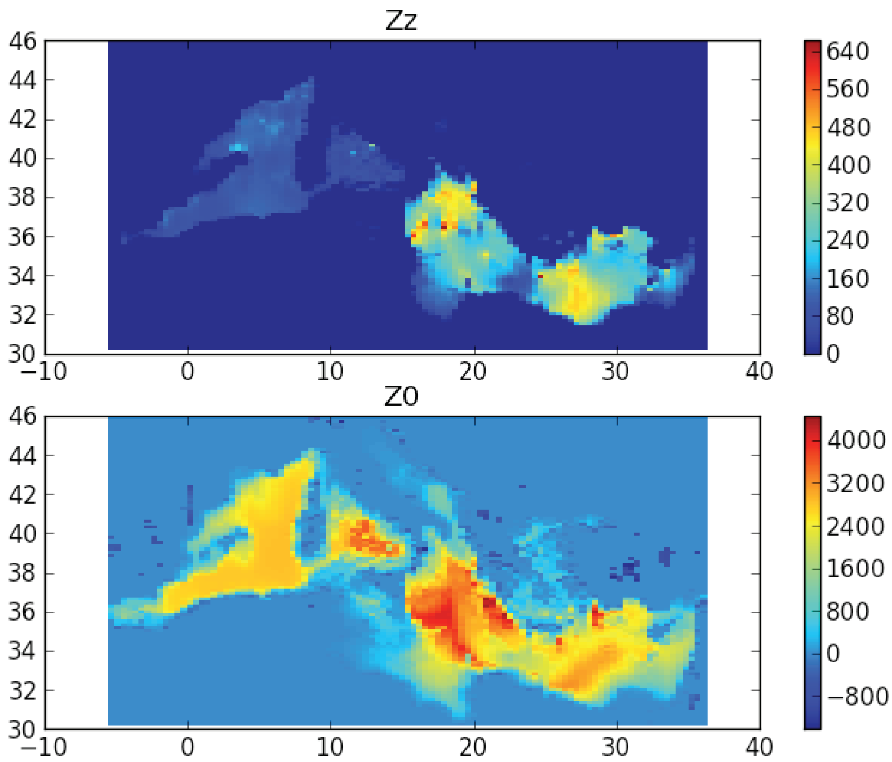

Fig. 23: The results of the model prediction. The colour shows the thickness of the hydrate layer. Bright red means the hydrate layers are thicker than dark blue. The scale of the thickness is shown on the color scale to the right hand side in metres. The Zz picture shows the gas hydrate thickness after sea level drops and Z0 shows the thickness before the drop. ***Can you spot the difference?***

General Conclusions

In conclusion, this module showed how observing the ocean through new technology and innovative methodologies represents the biggest challenge for marine and climate scientists nowadays. As the Earth's climate enters a new era, where it is forced by human activities, it is critically important to maintain an observing system capable of detecting and documenting global climate change. Policy makers and the general public require climate observations to assess the present state of the ocean, atmosphere and land, and place them in context with the past. To be of large-scale societal and scientific value, these observations must be carried out over many decades and remain of the highest quality. Climate observations are needed to initialise and evaluate climate models and to improve predictions of future climate change. Such assessments are essential for guiding national and international policies that govern climate-related resources, and agreements aimed at mitigating long-term climate change. In addition, heat and water are the fundamental elements of the climate system and the ocean is the dominant reservoir for both. To understand the oceanic branch of the system, we must observe on a global basis the storage and transport of heat, freshwater, and carbon in the ocean, and their exchange between the ocean and atmosphere. These are the reasons the use of the most up-to-date techniques has become a priority in the complex task of observing the ocean and understanding its role in the climate system of our planet.

Further Reading

This report was produced using material taken from Module 4 lectures during the AWI Climate Change in the Marine Realm Summer School 2012.

Websites:

Argo portal: www.argo.net

General information: www.argo.ucsd.edu

Windows Image Viewer: WIM/WAM software: www.Wimsoft.com

NEPTUNE Canada: www.neptunecanada.com

Wally information: www.jacobs.university.de

Literature

Kahru and Mitchell (2008) Ocean colour reveals increased blooms in various parts of the World. EOS, Trans. AGU, Vol. 89, No 18, p. 170.

Kahru, et al., (2009) Trends in primary production in the Californian Current detected with satellite data, J. Geophys. Res., Vol. 114, C02004.

Miles (1995) Potential distribution of methane hydrate beneath the European continental margins. Geophys. Research Letters. Vol 22, No. 23, p. 3179.

MODULE 5
CLIMATE SERVICE – DEFINITION AND FUNCTION

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Within the last 50 years the global population has risen from two to seven billion people (UN World Population Prospects, 2011). This growth will continue in the future, resulting in environmental and social challenges that we are already starting to encounter. Currently 600 million people do not have access to clean drinking water (WHO and WMO 2012). Health is currently a key issue in some developing nations, where e.g., incidences of malaria are increasing due to changes in weather patterns and temperatures. Millions of acres of land are degraded, reducing the yield of crops and leading to issues of hunger and malnutrition. Overfishing of oceans has led to serious concerns about the numbers of particular fish species and people feeding on them as wel as for the ecosystems themselves (FAO 2005). Pollution concerns from fossil fuel burning, the use of agricultural chemicals and industrial waste are often key local issues and can impact as well as people worldwide. Accompanying the growth of population in general by the year 2100 about 80 per cent of the world's population will live in urban areas (Grubler *et al.* 2007). Most of the megacities worldwide are sited in coastal areas with even increasing pressure in these areas. The burning of fossil fuels from industry and other sources and the resulting emission of greenhouse gases (CO_2, N_2O, CH_4, etc.) cause global temperature to rise, leading to complex and drastic changes in the Earth's climate system. Decreasing Arctic sea ice, rising sea level and changing weather patterns for example will all most likely feature in our future climate. Since the Earth system is a highly complex and interacting system, all these changes are (to some extent) coupled. The most prominent example is the interaction between the atmosphere and the oceans, which constantly tries to reach an equilibrium state. Therefore, the emission of carbon dioxide (CO_2) to the atmosphere also results in an increase in CO_2 in the oceans, which lowers the pH of the water. However, the consequences of ocean acidification on marine organisms and ecosystems are difficult to predict and it is likely that some species will be more adversely affected than others as shown in Module 1. Research suggests that corals have a high extinction risk, along with other species that generate calcium carbonate shells. This could have severe impacts for marine biodiversity, food webs and the function of the oceans as a sink for CO_2.

These are only examples of the impact of climate change on the Earth system. Some other likely impacts include increased aridity in already dry regions of the world, leading to the spreading of deserts and increasing drought events that already impact millions of people. Decreases in the amount of precipitation are likely in most sub-tropical land regions (IPCC AR4, Summary for Policy-makers

2007). As a result, agricultural productivity will also decline in some areas of the world (IPCC AR4, Summary for Policy-makers 2007). Areas that already get a considerable amount of rain are likely to encounter even more rainfalls as a result of climate change, hence increasing flood risks in many areas (Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability, 3.4.3 Floods and droughts). Extreme weather events are also becoming more frequent and causing more damage than ever before (IPCC AR4, Summary for Policy-makers, 2007). People have been deforesting areas for decades constantly increasing the pressure on these habitats. Global deforestation continues at an alarming rate - 13 million hectares of forest are destroyed annually, equal to the size of Portugal (UNEP). Tropical rainforests are some of the most severely impacted areas, but they are crucial for delivering rainfall to vast areas of some continents, exacerbating the local impact of climate change as a result and decreasing tropical biodiversity.

All those topics are big challenges not only for our generation but also for the generations to come. However, mankind has also already achieved great progress in a variety of global issues. The use and production of substances that deplete the ozone layer have been almost eliminated and there is almost no more lead in today's petrol due to the implementation of the Kyoto protocol in national jurisdiction. We have decreased the production and use of persistent organic pollutants (POPs), reduced world poverty from more than 50% in 1981 to about 20% in 2009 (Geneva Convention on Long-Range Transboundary Air Pollution 1979 and ratification of the 1998 Aarhus Protocol on Persistent Organic Pollutants) and have started the first steps in a decarbonisation process in order to reduce CO_2 emissions, e.g. by the investment in and increase of renewable energy technologies (wind, sun, etc.).

Within the last decade, the number of multi-national climate agreements such as for example the Kyoto protocol has increased dramatically. But does it really help tackling the problems related to climate change? Why do the results of scientific research fail to reach policy makers and decision takers and the general public? Why does the key scientific message become distorted along the way? Why is it so difficult to agree on measures to counteract climate change and its impacts? Why do people nut trust science? One of the biggest problems in science communication is to communicate uncertainties as scientists aim to be as precise as possible when translating or simplifying their results for the general public and policy makers. Climate change science is a particularly important area that everyone should be aware of and understand. However, there are a number of reasons why scientists have not been successful in better convincing society to act against climate change. Sometimes it is difficult for scientists to translate the scientific results in a comprehensible language in order to explain them to non-specialists, journalists, governmental representatives and the general public. Stakeholders, who use science output, may not have a scientific background. This can make it challenging to take appropriate decisions about climate change policy. Journalists can sensationalise science, which in turn can make it difficult for the public to understand that there are uncertainties and assumptions in the different projections for the future climate. It is not always easy the public to recognise that they can 'trust' scientists, as research will sometimes yield conflicting results in different studies so that reports seesaw from one view to another. However, it is also important that society tries to put aside preconceived ideas and misunderstandings and tries to approach science with an open mind. Science is always an on-going process that is changing with new findings and developments. The message may not always be clear or the same as what has been communicated at some time prior, but attempting to understand 'why' is just as important as the 'end result'.

In order to move science communication forward for the benefit of all parties involved, it is important that any communication is accessible for the intended audience and that any disagreements are discussed respectfully. It is also crucial for scientists to increase outreach and public engagement activities. The transfer of scientific knowledge should be a self-evident part of their work, interacting with all sectors of society and educating people about their research and how it relates to the 'big picture' of climate change research. A useful contribution could be to increase a target related communication through popular media as television, social media and the internet.

To close the gap between science and society, and given that the awareness of the importance of climate with regard to many sectors of society (agriculture, food security, water, health, energy, tourism etc.) is growing a new concept called 'climate services' has been conceived. Its fundamental objective is to help society (business, public service) to cope with climate risks and opportunities, strengthening the cooperation between (climate change) sciences and different interested parties that rely on climatic and scientific information. For example, economists need current and future climate information to make sound investments as it helps to better assess risks associated with different decisions. Thus all segments of society will benefit from climate services – governments, industry, economy, businesses as e.g. insurance companies (risk evaluation), the media, educators and the general public – and all will be affected in some way by future climate changes.

Even though the relevance of managing climate risks is an increasingly important consideration to many entities, the concept of climate services is still evolving. Climate service investigates the need of society for advice regarding questions related to climate change. Climate service links climate researchers and climate advisors, integrates research data from natural and social sciences on the climate system and prepares them for the needs of clients. Climate service provides information to customers via products, which are sector specific and tailored to suit the clients' needs. And finally climate service also coordinates feedback from practitioners to science.

Climate services first and foremost must meet the users' needs to transfer scientific knowledge target-oriented. Climate communication is one important aspect and should include provision of choices and solutions that people can employ in their daily activities.

The main challenges of climate services will be to provide balanced, credible, cutting-edge scientific and technical information and to engage a diversity of users to express their needs in order to be able to act as real service providers.. Climate services must serve to strengthen scientific standards and improve local and regional projections of climate change so that the most appropriate decisions can be made to minimise adverse future climate impacts and risks. The key purpose of climate services is to reduce society's vulnerability to climate change impacts and to maintain – and if possible improve – the adaptability of natural, societal and economic systems to any future changes.

In summary, the future climate of our planet is uncertain due to its complexity. However, we observe rise in global mean temperature with different extent crucially depending on the geographical region. We expect further increase in global temperature rise and there will be a range of influences on ecosystems at all levels impacting on society through food provision, health, economic security and water availability – many of which are already daily challenges for millions of people around the world. Pressure on environmental resources will increase in severity with the projected increase in population in the next 50–100 years. Inequality between the rich and poor, those who consume few resources and those who consume many is not decreasing, and as many nations aspire to further improve their development, it is a time-sensitive issue for future generations to develop management strategies for reducing carbon emissions. Climate services will help to form productive relationships between scientists and those who use science, such as economists, governments, media and society leading to make informed decisions that benefit all of the society.

But what can you do? Science is something that we are all taught in school and we all learn about science through the media and our daily lives as well, although at times you may not realise it. However - how much do you think about what you learn? Science by its nature is unbiased and objective, but newspapers, television or the internet may not be. Next time you read or hear something about science, take a minute to think about it, and not just accept it as fact. After all, that is what scientists do every day! Where has the information come from? Who has written it and for what purpose? How does it relate to you or where you live? Asking questions like this will mean that you start to really understand the information that you pick up all the time. Misconceptions in climate change science are easy to form if you are not aware of the origin of the information and – as the next generation – it will be you who must live with the consequences of our changing climate. Understanding some of the science now and sharing it with those around you, asking questions and getting involved whenever you can – at school or in the community – will make you a better equipped member of our future society.

References

Climate Change (2007) Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [M.L. Parry et al. (eds.)]. Cambridge University Press.

FAO (2005) Review of the state of world marine fishery resources.

Grubler A., O'Neill B., Riahi K., Chirkov V., Goujon A., Kolp P., Prommer I., Scherbov S., Slentoe E. (2007) Regional, national, and spatially explicit scenarios of demographic and economic change based on sres. Technological forecasting and social change 74:980–1029.

IPCC (2007) AR4, "Summary for Policymakers: C. Current knowledge about future impacts".

The Geneva Convention on Long-Range Transboundary Air Pollution (1979).

The Aarhus Protocol on Persistent Organic Pollutants (POPs) (1998). Guidance document on best available techniques for reducing emissions of POPs from major stationary sources adopted on 18 December 2009.

United Nations (1993) Agenda 21: Combating Deforestation (Ch.11). 300pp. ISBN 978-92-1-100509-7.

United Nations, Department of Economic and Social Affairs, Population Division (2011) World Population Prospects: The 2010 Revision, Highlights and Advance Tables Working Paper No. ESA/P/WP.220.

World Health Organization and World Meteorological Organization (2012) Atlas on health and climate. 68 pp. ISBN 978 92 4 156452 6.

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