UNIVERSITY OF BERGEN
Department of Earth Science
Tor Lien Mjell

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7th USSP: Past Global Change Reconstructions & Modelling Techniques (July 10-29)

My PhD project aspires to provide empirical constraints regarding the fundamental behavior of the lower limb (deep overflowing branches from the Nordic Seas) of the Atlantic Meridional Overturning Circulation (AMOC) and its relationship to climate on multidecadal to millennial timescales throughout the Holocene. A full understanding of the link between changes in climate and deep-ocean ventilation and vigor requires an in-depth knowledge about the multidisciplinary field of paleoclimatology, including an understanding of the interaction between climate, physical and chemical oceanography, and biochemical cycling. It is my belief that the 7th Urbino Summer School in Paleoclimatology, with its pool of international renowned scientists from a wide variety of fields within paleoclimatology, will provide me with this much needed knowledge.

"*The 7th summer school of the USSP consortium will focus on past climate dynamics with special emphasis on the analysis of the long-term Carbon cycling and its implications in the understanding of Present and Future climates.*" (USSP, 2010).

The course provided interactive lectures, fieldwork and exercises on the paleoclimatic evolution from the Cretaceous and until present, with special emphasis on Cretaceous Ocean Anoxic Events (OAEs), Paleocene/Eocene hyperthermals, greenhouse-icehouse transitions, Neogene and Quaternary climate dynamics, but also including millennial scale variability. Throughout the course we were familiarized with the different paleobiological and geochemical proxies used to reconstruct changes in climate and oceanography during the different geological periods, as well as deep time climate modelling.

Lecture outline:

10th July:

- Introduction to the Earth System (Anna von der Heydt): We were given a brief introduction to the different aspects of the Earth system (e.g. interactions between the different subsystem, forcing mechanisms, feedbacks, response time, etc.)
- Biochemical Cycles in the Present Ocean (Jack Middelburg): Middelburg lectured about the production rate of organic matter in the oceans and its preservation factor in the sediment record (e.g. photosynthesis Vs respiration, nutrient recycling, what does aging of the waters do to the nutrient content? Etc.)
- The Biology and Ecology of Planktonic Foraminifera (Howard Spero): Case study *Orbulina universa*; culturing, life cycle, ontogenetic calcite Vs gametogentic calcite, vital effects etc.
- An Introduction to Data Analysis (H. Dijkstra): During the lecture we learned about different ways of analyzing and interpreting data using statistical methods. Subjects included stationarity, pre-processing, Gaussian distribution, correlation analysis, statistical significance, white and red noise, principal component, non-stationary behavior, nonlinear response, lag determination, and recurrence plots.

11th July:

- Modern Carbon Cycle (Nicolas Gruber): Gruber lectured about how the modern carbon cycle functions and how it responds to the current continued increase of anthropogenic CO_2 into the atmosphere. One of the most important aspects of the carbon cycle is the oceans capacity to take up CO_2, which is closely related to the level of CO_2 in the atmosphere (i.e. increase of atmospheric CO_2 decreases the ocean uptake capacity). Gruber also highlighted that The *Southern Ocean window* is key to understanding the present, future, and past impact of the ocean carbon cycle on atmospheric CO_2.

- Mesozoic Paleoceanography: State of the art (R. Mark Leckie): Leckie lectured about the climate and oceanography of the Cretaceous. There is largely an agreement in the community that it was a warm world with CO_2 levels perhaps more than 1000 ppm, where some of the warmth can be explained by widespread volcanism (LIPs), which delivered a lot of CO_2 into the atmosphere. However, a lot of unanswered questions remain to be resolved (e.g. what triggered the Oceanic Anoxic Events? Evidence for glacial ice during a greenhouse world? How warm was it? Reduced meridional temperature gradients? Cold tropics and warm poles? Etc.).
- Cenozoic (Paleogene) Overview (R. Mark Leckie): Leckie lectured about the gradual, but highly variable, transition from a warm greenhouse world into a cold icehouse world. Periods that got special attention included: Paleocene-Eocene Thermal Maximum (PETM), Benthic Extinction Event (BEE), Middle Eocene Climatic Optimum (MECO), and the start of glaciations on Antarctica and in the Arctic.
- Quaternary Climate Variability: Patterns Vs Processes (Tom Cronin): Cronin lectured about the different processes that controls the Quaternary climate. Topics that were discussed were orbital scale climate changes (Milankovitch – Glacial-Interglacial transitions), millennial scale climate changes (Dansgaard-Oeshger Events, Heinrich Events), and abrupt climate changes (e.g. 8.2 K Event, Monsoon variability, sunspot cycles etc.).

12th July:

- Past Global Carbon Cycling (Andy Ridgewell): Ridgewell lectured about how the global carbon cycle functions, and what role it played during the Mesozoic and Cenozoic. Ridgewell spent a lot of time talking about the curious case that atmospheric CO_2 was about 90 ppm lower during glacial periods compared with interglacials. According to Ridgewell, while our understanding of the global carbon cycle is increasing, there still remains about 20 ppm that we cannot explain with the transition from a glacial into an interglacial.
- Past Ocean Acidification (Andy Ridgewell): In this lecture Ridgewell talked about changing $\delta^{13}C$ gradients in the deep ocean before and after the mass extinction at the Cretaceous-Paleocene boundary (KT boundary). He concluded that the $\delta^{13}C$ gradients during the late Cretaceous were consistent with a warmer and a more stratified surface ocean, which, however, still enabled the occurrence of strong deepwater formation and ventilation in the North Pacific. Ridgewell explained the collapse in $\delta^{13}C$ gradients after the K/T boundary with a persistent biological pump and/or a shallower remineralization depth.
- Data Processing: Nonlinear time series analysis (H. Dijkstra): Djikstra walked us through some exercises on how to properly analyze nonlinear time series.
- Sediment & core description (Mark Leckie & Stephen Schellenberg): Leckie & Schellenberg gave us a brief introduction into marine sediments (e.g. Sedimentology, grain-sizes of different sediments, sediment distribution, erosional Vs depositional processes etc.). The rest of this day was used to go through an exercise designed to familiarize each student with marine sediments and how to work with them.

13th July:

- Time and Stratigraphy (Stephen Schellenberg): Schellenberg lectured about how the geological (stratigraphic) timetable we use today was created. Subjects lectured about were fossil biomarkers, biostratigraphic classification (concepts & methods), building a biomagnetostratigraphy, and shifting paradigms.
- Biomagnetostratigraphy (Leckie & Schellenberg): Leckie & Schellenberg had designed an exercise aimed to show how the combination of biostratigraphy, magnetobiostratigraphy, and orbital changes are used to ordinate marine sediment

cores in time. Our material came from ODP Leg 208 site 1262 & 1263, and the goal was to complete a Cenozoic age-depth plot based upon integration of biomagnetostratigraphic data. In addition, we were to propose a testable hypothesis for why there are stratigraphic differences between site 1262 & 1263. Thereafter we compiled an age model to constrain the timing of the ELMO and PETM hyperthermals.

- USSP 2010 Excursion – Furlo & Gubbio: The purpose of this excursion was to investigate the cyclostratigraphic nature of the marine sediments that are deposited in Furlo (lower Jurassic to upper Cretaceous) and Gubbio (uppermost Jurassic to Miocene) areas. The first stop was in Contessa Valley in the Gubbio area. Here we looked at the cyclostratigraphy of sediments aging from Hautervian (136-130 Ma) to latest Maastrictian (~65,5 Ma – KT boundary). Thereafter all the students were split into 4 groups, where each group were assigned to a specific time interval and the assignment was to log and sample the section one was assigned to in order the reveal its cyclostratigraphic history. My group was assigned to the Bonarelli section, which is a time interval spanning the global Cretaceous Oceanic Anoxic Event 2.

14th July:

- Orbital forcing and cyclostratigraphy (Lucas Lourens): Lourens lectured about how the changes from a glacial to an interglacial period is mainly caused by changes in the solar insolation that reaches the Earth surface, which is modulated by the interaction between the different orbital parameters precession, obliquity, and eccentricity. Lourens also went through several exercises on how to extract information about the cyclostratigraphy from a dataset, including frequency analysis, filtering, and spectral analysis. This was important information because later we would use these methods to analyze the data we collected out in the field (Bonarelli section).
- Lab work: My group compiled together the data we collected in the field and started to construct a stratigraphic column, which we later analyzed in terms of cyclostratigraphic variations.

15th July:

- Paleocene-Eocene Thermal Maximum (~55 Ma) (Stephen Schellenberg): Schellenberg lectured about the latest development in our understanding of the PETM. Currently, the most plausible explanation for the cause of the PETM is rapid emission of the greenhouse gas methane, which resulted in a sharp negative carbon isotope excursion (CIE). The cause of the methane outburst is probably dissociation of shallowly buried methane hydrate deposits from continental margins. Although, as Schellenberg points out, this is a compelling hypothesis there are several remaining uncertainties. For instance, the methane release needed to explain the CIE is not large enough to explain the large global warming signal recorded in the sediments, which means that there has to be a feedback mechanism that is still unknown. In addition, the community does not know where the methane was released, or what triggered it.
- Group presentation of fieldwork

16th July:

- Stable Isotopes in Paleoceanography and Ocean Biochemistry (Howard Spero): Spero lectured about the use of stable isotopes like oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) in paleoceanography. Topics discussed were temperature related fractionation on stable oxygen isotopes, Rayleigh distillation, relationship between precipitation and evaporation (salinity-$\delta^{18}O$ relationship), and the distribution of $\delta^{13}C$ in the ocean (gradients, inverse relationship with nutrients etc.).
- Stable (C&O) Isotopes: Paleocene Carbon Cycle Perturbations (James C. Zachos): Zachos lectured about how reconstructed changes in $\delta^{13}C$ and changes in $\delta^{13}C$ gradients between the surface and deep ocean during the Paleocene can give valuable information on changes in the global reservoir of dissolved inorganic carbon (DIC), ocean circulation changes, strength of the biological pump, and stratigraphic correlation.

- Stable (C&O) Isotopes: Paleocene Oxygen Cycle Perturbations (James C. Zachos): In this lecture Zachos talked about the relationship between changes in the $\delta^{18}O$, and how much that would correspond to in terms of temperature and/or ice volume changes. For instance, during the Middle Eocene Climatic Optimum (MECO) the global $\delta^{18}O$ value was reduced ~1 ‰. How much of this was related to a temperature increase, and how much to changes in global ice volume? Zachos believes that between 70-34 Ma the global ice volume was so low, or non-existing, that any $\delta^{18}O$ changes can only be explained by temperature.
- Stable Isotope exercise (Howard Spero): Spero had prepared several exercises for us so that we would grasp the concept of stable isotopes more easily. The exercises included calculating fractionation factors, derive a paleotemperature equation, Rayleigh fractionation etc.

17th July:

- Orbital time scale & cyclostratigraphic tools (Heiko Pälike): Pälike gave us a thoroughly explanation on cyclostratigraphy, in order to put orbital theory of climate change into a geological context. After the lecture we did some hands-on experiments including spectral analysis and "wiggle matching".
- Plio-Pleistocene ice volume, Antarctic climate and the global $\delta^{18}O$ record (Maureen E. Raymo): Raymo lectured about the different orbital parameters and the effect they have on climate. Raymo spent most of the time on the problem that, while orbital theory tells us that eccentricity should not have a great effect on climate and ice-sheet buildup, the $\delta^{18}O$ reconstructions tells us otherwise. She also talked about the shift from the 4 kyr world to the 100 kyr world, which happened from ~ 0,9 Ma ago, and what could have caused it.
- Trace element geochemistry and proxies 2010 (G. J. Reichart): Reichart lectured about the distribution of important marine trace elements as Manganese (Mn) and bromide (Br). Topic discussed was oceanic trace element distribution, bottom water oxygenation, and trace element incorporation in biogenic carbonates.
- Geochemical proxies (Yair Rosenthal): Rosenthal lectured about the different geochemical proxies that are available in biogenic carbonates (e.g. Mg, Mn, Ca, Zn, B, Cd etc.), with special emphasis on Mg/Ca ratios, and its application as a paleothermometer (i.e. its usefulness Vs difficulties).
- Bonarelli exercise (Stephen Schellenberg & Heiko Pälike): We did a cyclostratigraphic exercise with data from the Bonarelli section.

19th July:

- Principle of Organic Geochemistry-Organic Production (Mark Pagani): Pagani lectured about photosynthesis in plants, including the functions of chlorophyll, cartenoids, and phycobilins. Furthermore, we were familiarized wilt the ATP synthase complex, the Calvin Cycle, and respiration. Pagani ended this lecture by talking about the organic production variations on a global scale.
- Principle of Organic Geochemistry-Chemical Composition of Organic Matter (Mark Pagani): Pagani gave a brief introduction to the chemical composition of organic matter with examples from several different functional groups. Ranging from hydroxyl, carbonyl, carboxyl group, ether, amine, and amide.
- Organic Geochemical Proxies III (Richard Pancost): Pancost lectured about the advantages and problems with the alkenone CO_2 proxy. For instance, one assumes that the proportion of "active" to "passive" carbon uptake is constant through time, which may not be the case. Furthermore, the organisms are sensitive to light, especially when CO_2 levels are low, and there is possibly a problem with ontogenic effects, which currently one does not know how to counteract by changing the CO_2 values. Pancost also talked about the climate sensitivity related to changing CO_2 values (i.e. alkenone-CO_2 method Vs boron-isotope method).
- Terrestrial Geochemical Proxies (Neil J. Tabor): Tabor lectured about the benefits and problems of using terrestrial proxies for paleoenvironmental reconstructions, with special emphasis on paleosols.

- Science Party Assignment & Meeting: We were divided into different groups based upon our knowledge about different geological periods, and was asked to prepare a 20 minute presentation about the current development in that field. My group was assigned to the Holocene.

20th July:

- Long Term Carbon Cycle (Richard E. Zeebe): Zeebe lectured about silicate weathering and how change in the weathering rate controls the long-term carbon cycle. Topics discussed were CO_2 changes in different geological timescales (0,01-50 Ma), and long-term carbon modelling (e.g. Conceptual models, mass balance models, box models, intermediate complexity models, general circulation models (GCMs), and earth simulator).
- What do we know about the CCD (Heiko Pälike): Pälike lectured about the Carbonate Compensation Depth (CCD), and what is known about its evolvement through time.
- Marine Biota and Biotic Proxies (Stephen Schellenberg): Through the lecture Schellenberg gave a very brief overview over the major skeletonized marine clades that live today, and how they are useful in a paleoclimatological perspective. Clades introduced were calcareous nannoplankton (Coccolithophores), Foraminifers (planktonic & benthonic), Diatoms, Radiolarians, and Dinoflagellates.
- Science Party Meetings: Our group continued the work on preparing a 20 minutes presentation about the Holocene.

21st July:

- Terrestrial biotic proxies (Timme H. Donders): Donders gave a brief overview over the different terrestrial biotic proxies that are available today, and some of their applications. Topics covered were plant evolutionary trends, fossil and taphony (macrofossils & pollen), plant-climate relationships (temperature, humidity, CO_2), and applications (reconstructions methods, land-sea correlation).
- **Parallel Session**
  - Planktonic foraminifera (Isabella Premoli Silva): Silva gave a thorough lecture about the evolution of planktonic foraminifera, including; speciation, depth habitat, latitudinal distribution (temperature & salinity - density preferences), life cycle (reproduction), relationship to nutrients, symbiont bearing species Vs non-symbiont bearing species, spinose Vs non-spinose.
  - The Indonesian Throughflow (ITF)-The Great Indo-Pacific Communicator (Yair Rosenthal): Rosenthal lectured about the importance of the ITF as a transport mechanism of warm water from the Pacific to the Indian Ocean (~0,5 PW a year), and as an important part of the world thermohaline circulation (~10-15 Sv per year). Thereafter, Rosenthal lectured about transport changes through the ITF through time, and we calculated temperature changes in the surface and thermocline waters for the past 15 kyr based upon Mg/Ca data.
  - Siliceous microfossils I & II: Introduction to diatoms (David Hardwood & Catherine Stickley): Harwood and Stickley gave a thorough introduction lecture about the siliceous microfossil diatoms, including their role as a primary producer (produces 25-35 % of the world's oxygen), classification scheme, life cycle (reproduction), ecology and habitat (lives aquatic and marine), and their geological record and evolution.
  - Siliceous microfossils I & II: Cretaceous records of diatom evolution, radiation, and expansion (David Hardwood & Catherine Stickley): During this lecture we learned about the morphology of the oldest diatom, and then compared it with modern taxa. Furthermore, likely places for its origination were discussed, and we investigated its evolutionary history. Finally, since these protists can live in both aquatic and marine environments, migration patterns were also considered (i.e. migration from marine to non-marine and vice versa).

22nd July:

- **Parallel session**

- The Holocene (Ulysses Ninnemann): Ninnemann gave a thorough introduction to the Holocene interglacial period. Topics discussed involved changes in orbital parameters, total solar irradiance, volcanic eruptions, the role of the Atlantic Meridional Overturning Circulation (AMOC) in modulating the Holocene climate, 8.2 K event, did changes in the AMOC cause the Mediaeval Warm Period (MWP) and the Little Ice (LIA)? What about the Atlantic Multidecadal Oscillation (AMO) and the North Atlantic Oscillation (NAO) are these phenomenon related to changes in the AMOC?
- Benthonic microfossils: Ostracods (Stephen Schellenberg): During this lecture Schellenberg gave a thorough introduction to ostracods, including their growth and form, logistics and analysis, "core top" studies, Cenozoic trends, epochal case-studies, and unanswered questions.
- Understanding modern terrestrial carbon isotopes for paleo-research (Darren R. Gröcke): Gröcke lectured about the difference and distribution between modern C4 and C3 plants, and how their carbon isotopic values vary. Thereafter, Gröcke talked about the environmental parameters that controls carbon isotopes in plants, soils, and animals, and how carbon isotopic values varies on a regional to global scale.
- Using terrestrial carbon-isotope stratigraphy in understanding climates and environments (Darren R. Gröcke): During this lecture Gröcke talked about the global carbon-isotope control on plants and soils, and how we use first principles for constructing terrestrial isotope stratigraphies. Thereafter, Gröcke showed us examples of how to use carbon isotopes for correlation purposes, and made us aware of that there is intra-and-inter variations in the values between components, and that one should be careful with scaling a paleoenvironmental analysis into a global interpretation because there is relatively large isotopic differences in even one leaf.

- Cioppino Poster Session

23rd July:

- Cioppino 2010: Transient Changes in Past Warm Climates: This was an unique opportunity for us students to acquire new knowledge, because the idea behind the Cioppino is to invite some of the leading scientists in the field the Cippino focuses on that year to come and present their newest data, much of which is yet to be published.

25th July:

- Earth System Modelling (Paul Valdes): The thought behind this lecture was to introduce the concept of climate modelling, answer why modelling past climate can be useful, and give examples of different kinds of models. Valdes believes that climate modelling is important, because it gives us the opportunity to test our current knowledge about the climate system, and compare the results with real data. Finally, if these two uncertainties have good constraints, models can be used to give realistic prognosis of future climate change. Through the lecture Valdes went through conceptual models, empirical models (most models), box models, Energy Balance Models (EBM), Earth System Models of Intermediate Complexity (EMIC), and General Circulation Models (GCM).
- Examining uncertainties in climate simulations from the past: Examples from the Late Cretaceous (Paul Valdes): In this lecture Valdes showed us how to adapt Earth System Models (ESM) for paleoclimate simulations by showing examples from a coupled atmosphere-ocean-vegetation simulation during the Maastrictian. Valdes also showed model-data comparisons and talked about the uncertainties. According to Valdes, in order to give realistic paleo-simulations one need a model that can represent the effect of a wide range of diverse forcing factors, hence, the minimum requirement is a coupled atmosphere-ocean-vegetation models. Even though a lot still needs to be done, models have some success when compared to data (except for high latitude problems), but there is still a continued need for more quantitative model data comparisons. According to Valdes, one can quantify some of the uncertainties in the models, but this depends on which variables in the Earth System.

- General Circulation Models (GCMs) – Climate Sensitivity (Matthew Huber): Huber gave a lecture about climate sensitivity (i.e. determine how different processes interact with other parts of the climate system) and feedback mechanism (i.e. positive Vs negative feedback, determining the strength and sign of the feedback mechanism). Huber's main point was that it is important to have a reasonable estimate for climate sensitivity when modelling, for instance, there is a big difference between the modeled PETM CO_2 level if the sensitivity to a doubling of CO_2 is 2,5°C rather than 5°C. Another important aspect of CO_2 sensitivity that Huber emphasized is that the temperature response to a CO_2 increase is much larger in a low CO_2 world than a high CO_2 world.
- Science Party Meetings: Our group continued the work on preparing a 20 minutes presentation about the Holocene.

26th July:

- Cause of Mid Pliocene warmth and Intensification of Northern hemisphere Glaciations (A. Haywood, D. Lunt, and P. Valdes): From the literature four mechanisms are proposed to explain the Mid Pliocene warmth (~3,21 °C warmer than today), trace gases (increased CO_2), ocean heat transport, paleogeography, and Enso dynamics. According to the models about 40 % (~1,26 °C) of this warming be related to increasing CO_2 values. For the cause of the Northern Hemisphere glaciations 5 hypothesis are proposed: The closure of the Panama gateway, tectonic uplift, termination of a permanent El Nino, decrease in CO_2, and orbital variations. According to the models the closing of the Panama gateway is essential to achieve the thermohaline circulation pattern we have today. A decrease of atmospheric CO_2 content will, according to the models, not make a substantial effect on the Greenland glaciation because the Greenland ice-sheet had been waxing and waning on orbital timescales prior to 3 Ma. Tectonic uplift and ENSO forcing cannot explain the glaciations, and although some measurements suggest a permanent ENSO like state during the Pliocene- which could potentially trigger a Northern Hemisphere glaciation, the climate models cannot simulate such changes. Thus, according to the models, closing of the Panama gateway was apparently very important for the onset of the Northern Hemisphere glaciation.
- Eocene Greenhouse (GCM) General Climatic Characteristics (Matthew Huber): According to Huber the models that are trying to model the Greenhouse world of the early Paleogene all have to low polar amplification, and not enough tropical thermostating, and has done so for 30 years. Huber said that there is 4 main hypothesis for why models predict that the meridional temperature gradient during the early Paleogene was low: (1) The atmospheric heat gradient was less due to a permanent El Nino (Huber: this effect is to miniscule to cause such a low gradient), (2) an enhanced poleward latent heat flux caused the poles to be warmer and cooled the tropics (Huber: Cannot be, the effect actually goes in the other direction.), (3) polar stratospheric clouds maintained a strong polar greenhouse effect, which warmed the poles (Huber: The effect is too small and it does not explain why the interiors of continents warmed up.), and (4) the ocean heat transport was higher and several latitudinal gateways where closed. As of 2004: There is no evidence indicating an increased ocean heat transport, even with closed gateways. To get the proposed reduced equator-pole gradient the ocean heat transport has to be tripled.

  Current findings of The Community Climate System Models (CCSM):
  - The CCSMs sensitivity to a doubling of CO_2 is now around 2°C, which is very likely to low.
  - When the models scale up the sensitivity (pCO_2) the polar amplification seems to fit very well.
  - The models sensitivity increases when you increase pCO_2/MAT, in agreement with the proxies, but not enough.
  - For most of the Eocene neither data nor models support a strict thermostat.

- One possibility is that the CCSM is missing a mechanism that would thermostat the temperatures of the tropics, but this should only matter in the high upper range of the tropical temperatures.
- All of these findings also hold for the Pliocene, Miocene, and the Cretaceous.

- Ice Sheet Models, Hysteresis, and a Few Thoughts on the Miocene (Robert DeConto): Deconto lectured about hysteresis on the East Antarctica Ice Sheet (EAIS), where the newest modelling tells us that to melt down a full-grown ice sheet on East Antarctica the snowline has to be raised above 2200 m.a.s.l. On the other hand to build up an ice sheet the snowline has to be lowered to less than 0 m.a.s.l. During the early Miocene (23-17 Ma) DeConto said that EAIS ice volume ranged from 50-125 % of the modern value, while during the mid Miocene (17-16 Ma) the ice volume was only between 25-70 % of the modern.
- Science Party Meetings: Our group continued the work on preparing a 20 minutes presentation about the Holocene.

27th July:

- Long-term feedback of the terrestrial biota on CO_2 and climate (David Beerling): Beerling lectured about the climate-weathering feedback mechanism that controls the atmospheric CO_2 content, and furthermore, that this mechanism is ultimately governed by the rise and fall of plants (i.e. more plants-more weathering-stronger drawdown of CO_2). Beerling however, means that this plant centric view of the feedback mechanism is not entirely true, because it misses the co-evolution of roots and fungi, which forms a symbiotic partnership called mycorrhiza. Hence, Beerling suggests a rethink of the "plants and weathering" paradigm: *"Rates of biotic weathering are fundamentally controlled by the biomass, surface area of contact, and the capacity of roots and mycorrhiza to interact physically with minerals". "These activities are ultimately controlled by rates of carbon-energy supply from photosynthetic organisms".*
- Ecosystem-climate system in "ancient" greenhouse worlds (David Beerling): According to Beerling one can from our current 3D Earth System Model simulations now simulate unrealized elevated levels of CH_4, H_2O_{strat}, O_3, and N_2O for the warm climates of the Cretaceous and the Eocene. Unlike previous simulations these simulations are robust, even when taking into account high CO_2 levels and suppression of isoprene emissions from leaves. The collective feedback of trace (GHG) feedbacks is significant, amounting to more than 5°C in the high latitudes and 2-3 °C globally over land, which is a warming effect the previous models has not picked up on, and thus neglected it. This increased feedback on trace (GHG) increase the sensitivity of the Earth system to a doubling of CO_2, amounting to a warming of about 1 °C
- Quaternary Climate Modelling (Paul Valdes): Valdes lectured about the current development of Quaternary climate models and told us that even though there are a lot of difficulties, the models are moving in the right direction. Valdes explained that today's climate models can now simulate a transient glacial-interglacial climate with reasonable spatial resolution, and capture orbital scale changes, even though its magnitude is still underestimated. The models cannot yet capture the millennial scale changes over the last deglaciation. With respect to greenhouse gases the models can now capture the main (orbital induced) EPICA patterns of methane emission variability over the last interglacial cycle, but underestimates the amplitude. Unfortunately, the models cannot yet capture the CO_2 variations.
- Science Party Meetings: Our group continued the work on preparing a 20 minutes presentation about the Holocene.

28th July:

- Non-linearity in the Quaternary climate system (Luke Skinner): Skinner lectured about our understanding of non-linear responses in the Quaternary climate system on orbital and abrupt timescales. Skinner summed it up in two paragraphs: On orbital timescales: "*Regionally restricted changes in seasonality (equivalent to tiny global* *radiative imbalances) operate via albedo and carbon-cycle feedbacks to effect global climate change. These feedbacks appear to have been triggered by state dependent thresholds (which remain poorly constrained).*" On abrupt timescales: " *The 'canonical theory': local/regional perturbations to freshwater balance act to destabilize the AMOC (depending on background climate state) again via state dependent thresholds, affecting the Atlantic meridional cross-equatorial heat transport. Either this process is the start of the causal loop (which has yet to be closed), or it is merely a 'lubricant' in an alternative mechanism (e.g. internal oscillations, stochastic resonance)...*"

- <u>The Pliocene onset of major glaciations and glacial/interglacial cycles (Gerald H. Haug)</u>: Haug lectured about what triggered the onset of the Northern Hemisphere glaciation for 2,73 Ma ago. Closing of the Panama gateway has been hypothesized to be the triggering mechanism, but according to Haug, the closure of the Panama gateway occurred already 4,6 Ma ago, which means that the timing of the glaciation is off by 1 Ma or more. Thus, there has to have been other factors involved. One possibility is that the Northern Pacific Ocean developed a permanent halocline, which enhanced the seasonal SST contrast and resulted in higher SST during autumn, which resulted in more evaporation, and that this source of moisture blew across North America and fell down as snow, which ultimately lay the foundation for a permanent ice-sheet. This is not completely proven yet, but Haug believes it to be a likely candidate. Haug thereafter talked about the glacial-interglacial cycles and what is known about them in terms if forcing mechanism (i.e. orbital forcing, 100 kyr problem, D/O events, Heinrich events etc.)
- <u>Glacial/Interglacial Changes (Ulysses Ninnemann):</u> Ninnemann talked about ocean circulation changes during glacial and interglacial cycles with special emphasis on the role of the Atlantic Meridional Overturning Circulation (AMOC) in regulating local and global climate (i.e. AMOC variability, bipolar seesaw, deepwater formation sites and their sensitivity to changes, etc.)
- <u>Sea level variability during the last 500,000 years (Eelco Rohling):</u> Rholing explained that there exists today continuous relative sea-level (RSL) records over the past 0,5 Ma, with 200 years resolution. According to Rohling, it has been suggested through comparison with ice-core data that, to reach "equilibrium sea level" with the current atmospheric CO_2 level would require melting ice equivalent to 15-25 m of sea level, which is similar to the mid Pliocene. Furthermore, Rohling explained that typical sea-level rises are about 1-2 m/century, but can reach as high as 5 m/century during deglaciations, and that the last time sea-level exceeded today's level by several meters, it occurred with rates of 1-2 m/century.
- <u>The past as a key to the Future? Sea level change (Bert Vermeersen):</u> Vermeersen lectured about sea level changes on regional and local scales. Vermeersen explained that even though it is true that the global sea level during the Last Glacial Maximum (LGM) was ~130 m below the current level, it is not the global sea level, but local sea level that is important in the context of global warming and melting icecaps. The reason for this, says Vermeersen, is that the combination of eustatic sea level change, the effect of self-gravitation, and the effect of solid-earth deformation all work together and changes the sea level regionally. Thus, even though the global sea level would rise 6 m if all of the Greenland ice-sheet melts, the regional variability would be much greater; some places would even feel a sea-level drop. Hence, Vermeersen believes that the focus on global warming and sea level rise should be shifted to regional sea level changes, because it is the regional changes we will notice and that will have an effect on human settlements.

29th July:

- <u>The past as a key to the Future? Ocean Acidification (Ken Caldeira):</u> Caldeira lectured about what we know about past events of ocean acidification, and how it relates to the current development of more acid waters due to continued increase of CO_2 in the atmosphere. From his work, Caldeira has found that with the current development we will during the coming centuries reach ocean acidification levels that has been unprecedented for the past 300 Ma, with perhaps devastating effects on marine biota.

- The past as a key to the Future? Global Warming (Matthew Huber): Huber talked about global warming in the context of human adaptability, and painted a grim future for the human population. In the recent years the focus has been on restricting global warming to 2 °C in the year 2100 by reducing and stabilizing our emissions of CO_2. However, as Huber explains, a doubling of CO_2 is expected to produce 1,9-4,5 °C of warming at equilibrium, but it could also be higher. This means, according to Huber, that with "business as usual" scenario a warming of 10 °C by 2100 is not very unlikely. This could have devastating effects to the human population explains Huber, because human heat adaptation is regulated by the wet-bulb temperature T_w, and a T_w above 35 °C would induce hypothermia in humans. While this never occurs today, it will occur in some regions of the world with a temperature increase of 7 °C says Huber, which would make the regions uninhabitable. With a bigger increase than 7 °C more places would become uninhabitable etc. Thus, according to Huber, if we do not start reducing our emissions of CO_2 into the atmosphere the human population faces a fearful future.
- Student presentation: We presented our work on the Holocene period, were we focused on climate change on regional versus global resolution (i.e. the Little Ice Age), fine resolution records (i.e. solar irradiance), and high frequency events (i.e. ENSO).
- USSP 2010 Wrap Up

I am very grateful that I got the opportunity to participate in the USSP 2010. Through these intense three weeks I have learned a great deal about the workings of the climate system, and how it has varied through time, which I am convinced will help me reach the goals of my PhD project. Although not everything that was taught during this summer school is directly related to my specific research, I believe that acquiring the knowledge this summer school presents enables me to see the bigger picture of climate change, and makes me more conscious and critically aware of my own research, its pitfalls and possibilities. In addition, discussing and collaborating with PhD student from across the globe, not only gives you possible future collaboration partners, but also gives you another perspective on how to tackle scientific obstacles and how to counteract them. In other words, participating in the summer school will eventually make me a better scientist, and is an experience I would recommend to all PhD students working with climate change.