CLIMATE CHANGE: FROM THE GEOLOGICAL PAST TO THE UNCERTAIN FUTURE : A TRIBUTE TO ANDRE BERGER

PROVISIONAL ABSTRACT BOOK (AS ON 9th APRIL)

27 MAY 09:10 — Vegetation - Climate Feedbacks

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Not only the ocean, but also the land surface, particularly its vegetation coverage, plays an important role in the dynamics of the climate system. Commonly it is thought that vegetation moderates climate change "Gaian-like", but theoretical interpretation of palaeoclimatic evidence suggests that vegetation ? climate feedback might amplify climate change triggered by variations in external forcing. Examples are the Cambrian explosion where biotic enhancement of silicate weathering by complex life could have just triggered this explosion. In the recent geological past, the synergy between the sea-ice albedo feedback and the taiga-tundra feedback is suggested to amplify the orbitally forced climatic precession. This synergy could be particularly important in the Pliocene when large ice sheets — supposedly strong amplifier of glacial climate change — were absent in the Northern Hemisphere. A further example of strong vegetation ? climate feedback concerns the desert-albedo effect which presumably leads to fast changes of subtropical deserts. It is still not clear whether these fast, and in comparison with orbital forcing fairly abrupt desert changes emerge because of a bifurcation of the vegetation - climate system. In the presence of stochastic climate variation, climate and vegetation "jumps" occur with or without bifurcation. A final question concerns anthropogenic interference with the climate system. It seems possible that human could trigger strong vegetation-climate feedbacks not only directly via land use, but also indirectly by greenhouse-gas induced climate change.

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27 MAY 09:50 — Atmospheric CO2 and the Carbon Cycle:Key Components of the Earth System

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In 2007, humans are responsible for the release of almost 40,000,000,000,000,000 kg of CO2 into the atmosphere and atmospheric CO2 concentration is far above the natural range of the past million years. The life time of this carbon added to the atmosphere through human activities is comparable to the life time of radioactive waste. Consequently, global warming, and ocean acidification caused primarily by fossil fuel burning and the related release of carbon dioxide (CO2) and other agents that force Earth?s surface temperature to rise, will last for many thousands of years. This

highlights the need for stringent cuts in carbon emissions. Palaeoclimatic reconstructions offer the unique opportunities (i) to put magnitude and speed of the climate perturbation by humans in the context of past natural variability, and (ii) to improve our quantitative understanding of the Earth System and predictability of future changes. Here, different aspects of the carbon cycle are addressed in a paleoclimatic context. The rate of change of climate co-determines the global warming impacts on natural and socio-economic systems and their capabilities to adapt. Establishing past rates of climate change from temperature proxy data remains difficult. In contrast, past greenhouse gas forcing, causing climate to change, is well-known from ice cores. While today?s unusually high greenhouse gas concentrations are widely discussed, surprisingly little attention has been paid to the speed of change. A data analysis (Joos and Spahni 2008) shows that the 20th century increase in CO2 and its forcing occurred more than an order of magnitude faster than any sustained change during the past 22,000 years. In addition, the decadal-to-century scale rate of change in anthropogenic forcing is unusually high in the context of the natural forcing variations (solar and volcanoes) of the past millennium. The cause-effect change implies that global climate change, which is anthropogenic in origin, is progressing at a speed that is unprecedented at least during the last 22,000 years. Beside variations in orbital parameters (Berger 1977), the energy output of the sun regulates the spatio-temporal distribution of solar insolation on Earth. Tentative correlations with records of cosmogenic nuclei (10Be, 14C), sunspots, aurora histories in combination with the behaviour of solar-like stars have been used to estimate past solar irradiance (Muscheler et al. 2007). Solar activity over the Holocene is estimated from the tree ring radiocarbon isotope record by combining a model of radiocarbon production from cosmogenic particles and a carbon cycle model describing the distribution of radiocarbon in the Earth System. The results suggest that the recent activity of the sun was not unusual in the context of the last millennia, in contrast to recent claims. Different mechanisms to explain glacial-interglacial CO2 and climate change have been proposed. However, a quantitative attribution to the reconstructed CO2 changes remains difficult. The response of atmospheric CO2 to modifications in the strength and the position of Southern Hemisphere westerlies is examined with the Bern3D ocean model (Tschumi et al. 2008). To achieve major CO2 reductions the model has to be forced with windstress patterns that are not compatible with current reconstructions of the glacial winds. The results are in conflict with the hypothesis that Southern Hemisphere wind changes are responsible for the low glacial CO2 concentration. Selected References (pdf-files on http://www.climate.unibe.ch/~joos/publications.html) Berger, A. 1977. Long-Term Variations of Earths Orbital Elements. Celestial Mechanics 15:53-74. Joos, F., and R. Spahni. 2008. Rates of change in natural and anthropogenic radiative forcing over the past 20,000 years. Proceedings of the National Academy of Sciences of the United States of America 105:1425-1430. Muscheler, R., F. Joos, J. Beer, S. A. Müller, M. Vonmoos, and I. Snowball. 2007. Solar activity during the last 1000 yr inferred from radionuclide records. Quaternary Science Reviews 26:82-97. Tschumi, T., F. Joos, and P. Parekh. 2008. How important are Southern Hemisphere wind changes for low glacial carbon dioxide?: A model study. Paleoceanography, submitted 2008.

27 MAY 10:50 — Ice shet models

Huybrechts P.

27 MAY 11:30 — Glacial-interglacial pCO2 Variations and the Rain Ratio Hypothesis: Implications for Sedimentary Carbonate Preservation/Dissolution Processes

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A reduction of the carbonate-carbon to organic-carbon export rain ratio during glacial times has been for years one of the favourite hypotheses to explain the glacial?interglacial atmospheric CO2 variations. This hypothesis has been tested and implications for the dynamics of sedimentary carbonate preservation and dissolution explored with MBM, a ten-box model of the ocean carbon cycle, fully coupled to the transient early diagenesis model MEDUSA. With this coupled model, a peak reduction of the rain ratio by 40% at the Last Glacial Maximum (LGM) was found to produce a net atmospheric pCO2 reduction of about 40 ppm. Changing shelf carbonate accumulation rates and continental weathering inputs produced a 55?60 ppm reduction. The combination of the two mechanisms generates a 90-95 ppm pCO2 change, which compares well with the observation. However, the resulting model sedimentary record is at odds with actual sedimentary records. Changing carbonate accumulation rates on the continental shelf and variable weathering fluxes depress the calcite saturation horizon (CSH) by about 1 km at the LGM; rain ratio variations depress it by another km. In addition to this large amplitude for the CSH, the changing rain ratio also leads to transition zone changes in the model sedimentary record that are opposite in phase with data-based reconstructions.

27 MAY 12:00 — Antarctic ice-sheet response to orbital variations and atmospheric CO2 in the Middle Miocene

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Foraminiferal oxygen isotopes from deep-sea sediment cores suggest that a rapid expansion of the Antarctic ice sheet took place in the Middle Miocene around 13.9 million years ago. The origin for this transition is still not understood satisfactorily. Among the proposed causes are changes in atmospheric CO2 content and a shift in insolation from obliquity to eccentricity dominated frequencies that is associated with an

extended period of relatively small variations in summer insolation. We use an axially symmetric ice-sheet model with a specially developed energy and mass balance module to assess variations in ice-sheet volume induced by pCO2 and insolation forcing. The ice-sheet sensitivity to atmospheric CO2 is tested in several scenarios using constant pCO2 forcing or a regular decrease in pCO2. Small, ephemeral ice sheets exist under relatively high atmospheric CO2 conditions (between 400-480 ppm), whereas more stable, large ice sheets occur when pCO2 is smaller than 400 ppm. Transitions between the states are largely CO2 induced, but are enhanced by extremes in insolation. A well-timed decrease in pCO2 of only 50 ppm is sufficient to explain the Middle Miocene glaciation event. The shift in dominant frequencies within the oxygen isotope record could be the result of different ice-sheet sizes. Volume variations in small ice sheets are mostly dominated by obliquity. On the contrary, larger ice sheets show variations characteristic of precessional forcing.

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27 MAY 14:35 — Impact of insolation variations on the ocean behaviour during the last interglacial period

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Insolation variations over the high latitudes of the Northern Hemisphere triggered the behaviour of the ocean-atmosphere system during the last interglaciation (LIG). Oxygen isotope analysis of benthic foraminifera show that during the LIG, North Atlantic Deep Water (NADW) were about 0.4 ± 0.2 °C warmer than today. Model simulations show that the distribution of deep water temperatures may be explained as a response of the high latitude Ocean to the insolation forcing. In the North Atlantic, warm saline surface waters sank to form NADW warmer than today. This warming was transferred to the Circumpolar Deep Water by the deep thermohaline circulation, providing the additional heat needed to enhanced melting of deep ice-shelves around Antarctica and partial melting of the West Antarctic Ice Sheet. Land and marine records, together with GCM experiments, showed that the insolation changes at the end of the LIG lead to a winter surface warming and a summer cooling over the Northern Hemisphere. This configuration resulted in increased atmospheric moisture transport and provided optimal conditions for developing perennial snow cover over the Canadian archipelagos and northern Fennoscandia, which are both thought to be the nucleation sites of the ice sheets of the last glacial period.

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27 MAY 15:20 — A threshold in ice volume to reinforce the East Asian summer monsoon during a cool interglacial?

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The loess in northern China, a sedimentary core in the eastern Tibetan Plateau and the palaeosols in southern China, all record an extremely strong East Asian Summer Monsoon (EASM) during the interglacial Marine Isotope Stage (MIS) 13 (about 500 000 years ago), actually the most intense one over the whole Quaternary. This was surprising because on the one hand, deep-sea and Antarctica ice cores show that this interglacial is significantly more glaciated (and cooler) than the most recent interglacials, and on the other hand, ice sheets are generally assumed to weaken the summer monsoon through their subsequent cooling of the continents (at least at the Last Glacial Maximum). To understand this seeming paradox of a strong EASM occurring during a cool interglacial, we have investigated the climate system response to prescribed GHG concentration, astronomical and ice sheet forcings. Primary climate modeling experiments show that this very strong MIS 13 EASM results not only from the astronomical forcing but also from the ice sheets themselves. As it was expected, Northern Hemisphere summer occurring at perihelion like at 506 ka BP leads indeed to an EASM stronger than during the Pre-Industrial time, but at the same time, the ice sheets reinforce also the EASM. Analyses convinced us that this reinforcement is through the propagation of a perturbation wave which is induced by the Eurasian ice sheet and is probably phase-locked by the Tibetan Plateau. This unexpected role played by the Eurasian ice sheet invites us to revisit our current understanding of monsoon dynamics and in particular its interaction with the ice sheets. A series of sensitivity experiments have been done related to the size, location, topography and albedo of the Eurasian and North American ice sheets. Among all the parameters, the total ice volume seems to be significant for the existence of a possible threshold in the response of the EASM.

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27 MAY 15:50 — Validation of a regional climate model over the Antarctic plateau

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Links between global climate and local climate at antarctic drilling sites may be studied using regional climate models (RCM), which are (i) developed for simulating the extreme meteorological conditions prevailing over the antarctic plateau, and (ii) forced through their lateral boundaries with meteorological fields reconstructed from observations (meteorological analyses) or generated by general circulation models. The RCM MAR (Modèle Atmosphérique Régional) has been developed for simulating the climate over huge ice sheets. Here it is validated at Dome C by using observations from Automatic Weather Stations (AWS), radiometers and atmospheric soundings. MAR is set up over the whole antarctic ice sheet with an horizontal resolution of 80 km and is forced with ECMWF operational analyses for the period 2004 ? 2006. It is able to simulate the succession of cold and warm events at Dome C during winter. Warm events are simulated in conjunction with polar stratospheric clouds. MAR also simulates a strong

variability in time of the temperature inversion strength, which generally weakens at the beginning of warm events. Model sensitivity to the parameterization of cloud radiative properties is significant during warm events. In particular the very small effective radius of antarctic snow flakes must be taken into account in MAR radiative transfert scheme.

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28 MAY 09:20 — The LR04 benthic d18O stack and its implications for glacial cycle dynamics

Lisiecki, L. E., and M. E. Raymo
Boston University

We describe the evolution of climate system dynamics by examining the climate response to changes in obliquity and precession over the last 5.3 Myr. In particular, we measure changes in the shape of glacial cycles and the power of obliquity and precession response in LR04 benthic d18O stack. When the exponential trend in d18O variance is removed, its spectral power exhibits strong, proportional responses to amplitude modulations in orbital forcing over most of the Plio?Pleistocene. Precession responses correlate with modulations in forcing for the last 5 Myr, but 41-kyr response is sensitive to obliquity modulation only before 1.4 Myr. Where responses are sensitive to modulations in forcing, we demonstrate that glacial cycles are orbitally forced rather than being self-sustained or paced by orbital changes. The shapes of glacial cycles have several nonlinear properties, which may be indicative of glacial?interglacial differences in climate sensitivity or response time. The "saw-tooth" asymmetry of glacial cycles first appears shortly after the onset of major northern hemisphere glaciation, and the relative duration of interglacial stages decreases at 1.4 Myr. Collectively, trends in the shape of glacial cycles and the sensitivity of d18O to obliquity and precession are suggestive of major transitions in climate dynamics at approximately 2.5 and 1.4 Myr but show no significant change associated with the appearance of strong 100-kyr cycles during the mid-Pleistocene transition.

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28 MAY 10:00 — Pliocene changes in the North Atlantic leading to Quaternary-style climates

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The Middle Pliocene was marked by a paramount change in Earth history, the onset of major Northern-Hemisphere Glaciation (NHG) and Quaternary-style pronounced glacial-to-interglacial cycles that contrast with more uniform climates over most of the preceding Cenozoic and continue until today. To better understand the underlying causal links a highly demanding climate stratigraphy and orbital age control were establ-ished over the last 15 years. Since 3.15 Ma (cold MIS K2) the Atlantic and global climate

system were subject to severe deterioration culminating 2.72 Ma (MIS G6). Various models and data suggest complex ties of NHG to the closure of the Central American Seaways (CAS) through enhanced North Atlantic thermohaline circulation which strengthened the poleward transport of heat and salt and in turn, that of moisture. Enhanced precipitation and fluvial run-off in north Eurasia reduced sea surface salinity in the Arctic Ocean, finally promoting sea-ice formation, Northern Hemisphere albedo, and the build-up of major NHG. New sea surface temperature and salinity records with submillennial resolution from Labrador Sea IODP Site 1307 confirm an abrupt, irreversible cooling of the East Greenland Current by 7°C/5.5°C for glacials and interglacials as early as 3.15-3.05 Ma and imply a freshening of the East Green-land Current by ~1 psu, likewise in the Arctic Ocean (Moran et al., 2006). This event slightly lagged behind a first but still reversible closure of CAS near 3.15 Ma (Steph et al., 2006; based on rising salinity anomalies between Caribbean and East Pacific, 3 . 25- 2 . 65 M a). Records from the N o r t h A t l a n t i c Current show a coeval, likewise reversible 2°C warming of interglacial surface waters . This was a precursor to the long-term 2- 3 °C interglacial warming during the final onset of N H G, 2.95-2.82 Ma (MIS G17-G10) and final c losure of CAS , thus supporting the model of increased poleward salt and heat transpor t . Finally, the build - up of NHG ended with a great "climate crash" at glacial s t a g e G 6 . I n total , we find a t hree- s t e p closure of CAS as origin for t h e o n s e t o f major N H G and Quaternary-style glacial c y c l e s . Moran, K. et al., 2006, Nature, v. 411, 1600-1605. Steph, S.,et al., 2008, G3, v. 9/1.

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28 MAY 10:50 — Long Eccentricity Signal in Oceanic Carbon Reservoir

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With the quantitative paleoclimate records extending back from Pleistocene to Paleogene, the signal of long eccentricity becomes increasingly prominent in paleoceanographic time series (e.g., Zachos et al., 2001), particularly in ?13C records because of the long residence time of carbon in its oceanic reservoir (Cramer et al., 2003). Now the 400-kyr cycle is likened to the Earth's heartbeat in the Oligocene (Pälike et al., 2006), but its conspicuous absence in the Pleistocene ice-age records remains unexplained. To track down the Plio-Pleistocene change of long eccentricity signal, carbon isotope records from the various oceans over the past 5.0 Ma are compared. All records show maximum delta-13C values (delta-13Cmax) at eccentricity minima during the Pliocene, but this relationship obscured in the Pleistocene after 1.6 Ma (Wang et al., 2003, 2004). A remarkable exception is the Mediterranean surface water delta-13C record, which remained paced by the long-term eccentricity cycle throughout the Pliocene and Pleistocene (Wang et al., MS). The 400-kyr signal in the oceanic reservoir is proved to be of low-latitude climatic origin, most probably related to the global monsoon variations, and there is evidence to show that its Pleistocene obscuring was caused by reorganization of the ocean circulation. At 1.6 Ma, the deep-water ventilation

rate drastically decreased in the Southern Ocean (Hodell et al., 2006), and the east-west asymmetry in upper ocean established in the equatorial Pacific (Ravelo et al., 2006; Lawrence et al., 2006). Obviously, the waning of long-eccentricity cycles in the oceanic reservoir was associated with high-latitude cooling and rapid growth of the boreal ice-sheet. A similar change occurred in the Miocene at 13.9 Ma when the 400-kyr cyclicity in delta-13C records flattened out together with a drastic cooling and Antarctic ice-sheet expansion (e.g., Holbourn et al., 2006), again accompanied by rapid decrease of deep-water ventilation rate (Tian et al., MS). Therefore, the long eccentricity and delta-13Cmax events play a critical role in the long-term global climate changes. Hypothetically, we ascribe the signal of long eccentricity in oceanic carbon reservoir to periodic changes in chemical weathering rates of the continents and in rain ratio in the ocean, which in turn depends on monsoon intensity, but this "normal" response to eccentricity can be disturbed by rapid growth of ice-sheet. As now the Earth is again passing through an eccentricity minimum, it is crucial to understand the nature of the delta-13Cmax event and to find out the mechanism behind it.

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28 MAY 11:20 — Frequency Domain System Analysis of Isotopic Paleoclimatic Records in relation with Insolation Orbital Forcing.

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Five deep-sea cores covering three different time extents (1-2 My, 500 ky, 150 ky) have been selected to study the behavior of O18/O16 and C13/C12 in relation with the Insolation Orbital Forcing. A special emphasis is given to the frequency domain approach for its well known appropriateness in the astronomical theory of paleoclimates and its power in dynamical systems analysis. The chronology building is first discussed in terms of the underlying hypotheses and its implications on the spectral properties of the isotopic records. The spectral properties of the O18/O16 and C13/C12 isotopic records and the chosen insolation indexes are reviewed in terms of spectral peaks, tones combinations, noise background, spectral slopes, time evolution ... Finally, Dynamical System Identification is performed and analysed in the frequency domain by taking the insolation indices as input and the isotopic data as output. Since planktonic and benthic foraminifera O18/O16 records are available together with C13/C12 measurements, possible behavior of climate related variables like sea surface temperatures, ice volumes and ocean circulation will be investigated.

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28 MAY 12:00 — Temporal variability of the sedimentary magnetic properties off southeastern Mindanao.

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The southern Mindanao area is a key area for understanding past changes in the complex system of the oceanic circulation dominating in this area. This includes the surface Indonesian Throughflow transporting warm and low-salinity water from the Western Pacific Warm Pool to the eastern Indian Ocean and the Mindanao undercurrent transporting intermediate waters northward via recirculation of the Mindanao Eddy below 200m. This area is also affected by the Eastern Asian Monsoon and the seasonal changes in the position of the Inter-Tropical Convergence Zone (ITCZ). We present here a detailed study of the magnetic properties of core MD06-3067 taken during the IMAGES XIII-Marco Polo 2 cruise on board the R. V. Marion Dufresne (IPEV). This core is located along the main path of the Mindanao current and Mindano undercurrent, at the southeastern tip of Mindanao island (06°30.86'N; 126°29.86'E) at 1574 m water depth. Based on the oxygen isotope stratigraphy the bottom of this 15.53 m long core reaches Marine Isotopic Stage 6 (MIS6). Different experiments show that the dominant magnetic mineral is magnetite varying in concentration and grain size. The results show that the concentration in magnetic minerals is dominated by the precession orbital periodicity (23 kyr), illustrating monsoon related-run-off variations on the island of Mindanao. The magnetic grain size, remarkably consistent with the changes in the sortable silt is sensitive to the eccentricity (100 kyr) and precession (23 kyr). Together with the magnetic fabric, they illustrate changes in bottom current activity, probably related to the Mindanao undercurrent. Stronger currents are active during glacial periods than during interglacial periods. At sub-orbital scale, the continuous geomagnetic intensity profile is extremely similar to the master curve GLOPIS-75 between 28 and 50 kyr including a marked low associated with the Laschamp excursion. The Greenland age scale could therefore be transferred onto core MD07-3067, allowing us to refine at sub-millenial scale the isotopic age model for this time interval. At this scale, it appears that the short-term fine grain events, most likely illustrating weak bottom current activity, are coeval to cooling phases in Antarctica and also, according to the correlation based on atmospheric methane records with the warmest Greenland events (interstadials 8, 12 and 14). These magnetic results illustrate the sensitivity of oceanic bottom currents to the global climate changes and that will be discussed at the different time scale.

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28 MAY 14:15 — The loess series, from one climate state to another

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Among terrestrial records, eolian deposits represented by loess series constitute, when available, remarkable objects to study the impacts of the variations in the Earth orbit parameters all along the recent history of the Earth. This allows investigating the glacial-interglacial cycles as described in various regions worldwide and therefore under different climate regimes. Such analysis relies on accurate dating of the series, precise description, use of multiproxy approach, and characterizing similarities with global signals. However, detailed investigations of loess series also permit to study the climate variability at other periodicities, which are not necessarily related to the Earth orbit parameters, but at much higher frequency. Loess series again show then precise correlations with marine and ice-core records. Examples will be provided from Northern Hemisphere loess sequences showing the great potential of eolian deposits as a very sensitive record of past climate conditions at these different frequencies.

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28 MAY 14:55 — Neogene loess-soil sequences in northern China and Asian paleoclimate

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The loess-soil sequences of the last 2.6 Myr and the eolian Red-Clay (8-2.6 Myr) in northern China provided a huge amount of information on the climate changes in Asia from tectonic to millennial scales. In the recent years, this terrestrial record has been extended to 22 Myr ago by the widely spread Miocene and Pliocene loess-soil sequences in the western Loess Plateau. Up to date, a near continuous record with a high spatial correlativity of stratigraphy and proxies can be reconstructed based on the available sections for the interval from 22 to 3.5 Myr. This provides an opportunity to address the Neogene history of paleoclimates in Asia and their links with global tectonic/climate changes. At tectonic timescales, the onset of eolian deposition by 22 Myr ago is roughly consistent with a major reorganization of climate pattern in Asia. This attests the initiations of the monsoon-dominant climate and inland-type deserts in Asia by the early Miocene, which have been constantly maintained since then. Geological data and climate models suggest that uplift of the Himalayan-Tibetan complex and shrinkage of the Paratethys Sea would have played a joint role. The existence of sizeable inland deserts and typical monsoon climate in Asia provides an independent perspective that these tectonic conditions had evolved to a threshold scenario by 22 Myr ago to cause this major change of climate regime. The strong monsoonal seasonality, probably associated with a drop of the atmospheric CO2 level, also led to an earlier emergence of plants that use C4 photosynthesis in East Asia. Over the past 22 Myr, variations of the inland aridity and winter monsoon were closely coupled, with rather weak impacts of the ongoing global cooling during most of the Miocene, but reinforced effects since the latest Miocene. The effects of the summer monsoon in northern China show an overall declined trend during the Neogene. The more than three hundred pairs of loess and soil alternations evidence

orbital-forced monsoon changes, with typical orbital-related signals from million-year scale to the precessional scale.

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28 MAY 16:15 — The greenhouse gas and climate record from ice cores : leads and lags

Raynaud D. (1), Barnola J.M. (1), Chappellaz J. (1), Parrenin F., Petit J.-R. (1), Jouzel J. (2), Masson-Delmotte V. (2), Landais (2), Dreyfus G. (2)

The ice core records now covers the last 800,000 years in Antarctica and the last climatic cycle in Greenland. It contains a variety of proxies describing the changes in important climate properties, including greenhouse gases (mainly CO2 and CH4 measured in the air trapped in ice), gaseous isotopic composition (with the isotopic composition of the atmospheric oxygen trapped in the ice being affected by changes in sea level and biospheric productivity), Antarctic and Greenland temperatures and moisture origin (through the ice isotopic composition), dust and aerosols reaching the polar regions. Such records are used to evaluate the relative phase relationship between the climate and environmental changes and therefore to identify the sequence of events between different climate feedbacks..The chronological ice sequences can then be compared with the marine and continental records and used as a constraint for the modelling of past climate and carbon cycle dynamics. Any progress on the understanding of the air trapping processes is crucial as the uncertainties of the ice and gas chronologies limit the understanding of the sequence of events between climate and atmospheric composition. Finally until recently we had no tool for investigating the phase relationship between the external orbital forcing and the various feedbacks described above. Things are progressing now with the discovery of potential proxies of the local insolation (O2/N2 ratio of the air trapped in ice, total air content of ice) at the sites of ice formation. The aim of the presentation will be to give an overview of what we know and what are the remaining enigma in terms of leads and lags deduced from the ice core records.

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28 MAY 17:00 — The proximal cause of glacial terminations

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Approximately every 100 ka, Earth enters a period of exceptional warmth in both hemispheres, which is accompanied by deglaciation for the large northern ice sheets. The literature is almost unanimous in ascribing this change to orbital variations, but is much more fragmented in explaining the details of how this leads to the observed timing of warming. There are also conflicting discussions about whether warming is led from the north or the south. In fact warming of Antarctica and the Southern Ocean is not restricted to the terminations. It was recently shown that each Dansgaard-Oeschger (D-O) event has a southern counterpart, known as an Antarctic Isotopic Maximum (AIM).

The amplitude of the AIM appears to be related to the length of the cold part of the D-O cycle, and at least for the larger AIMs, the D-O warming occurs at the maximum of southern temperature (EPICA Community Members, 2006). This finding can be stated in a different way: there are numerous periods when the south is warming, and it appears to be the occurrence of a D-O warming that reverses the southern increase. At glacial terminations, warming in the south also commences at a very similar rate to that seen for AIM, and is accompanied by similar changes in other measured parameters. The difference is that no D-O event occurs, so warming of the south simply continues. In most terminations, it continues until full interglacial conditions are reached. In Termination I, the warming is reversed by the northern Bolling warming, but it is too late: amplifiers such as CO2 have already reached a level at which termination is inevitable. If this interpretation is correct, then the proximal ?cause? of deglaciation is the inability of the system to produce a D-O event. We can also start to understand why there is confusion about the roles of north and south, because the warming (as indeed each AIM warming) is led from the south, but it is most likely the conditions in the north that allow it to proceed unchecked.

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28 MAY 17:40 — Ice-core evidence of Environmental conditions during Greenland Ice-sheet inception and development

Souchez R.

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29 MAY 09:15 —

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The solar energy received by the Earth is the main source of energy for the climate system. It is now largely recognised that the long-term changes in the distribution in latitude and during the year of this energy is responsible for the observed climate changes at the geological time scale. For example, physically based climate models are forced by this insolation distribution to simulate the main features of the past climate. Past climate records have also been intensively compared with indices related with insolation changes. The energy available at any given latitude on the Earth and at any given time in the year (irradiance) is depending on three orbital parameters (eccentricity, obliquity and climatic precession) (Berger, 1978a). They describe the characteristics of the Earth?s orbit around the Sun and rotation. Their secular variations are due to the gravitational perturbations that the Sun, the other planets, and the Moon exert on the Earth?s orbit and on its axis of rotation. The values of these orbital parameters are now accurately computed over several million years in the past and in the future (e.g. Bretagnon, 1974; Berger, 1978a; Berger and Loutre, 1991; Laskar et al., 2004). The daily irradiation is dominated by the precession signal at all latitude and

time in the year, except for the high polar latitude during winter where obliquity is the dominant component. However, it must be underlined that the insolation is then very small. In order to understand the origin of the time variation recorded in proxies of past climate, several indices of insolation were derived in addition to the daily irradiation. For example, Milankovitch (1941) defined the caloric summer half year, which varies primarily with the precession but also contains some component in obliquity, especially in the high latitudes (Berger, 1978b). Annual and (astronomical) seasonal daily mean irradiation signal is dominated by the obliquity. It contains a weak eccentricity component but no precession component (Loutre et al., 2004). In addition to the precession component, many proxy records contain as very clear obliquity component, often stronger than the one in the insolation time series. Therefore indices with strong obliquity were looked for. In that line, elevation classes (Cerveny, 1991) and zenith classes (Berger et al., 1993) were defined. For example, the noon zenith class irradiation at the summer solstice is showing a very strong obliquity component. Huybers (2006) suggested that climate would only respond the sum of the insolation on days exceeding a given threshold. This index is indeed depending on both obliquity and precession. Recently, Berger et al (2006) and Ashkenazy and Gildor (2008) identified some key features of the insolation in the tropical regions. The annual maximum (and minimum) of daily equatorial irradiation has pronounced eccentricity periodicities as well as a pronounced half-precession periodicity. These insolation features will be discussed in detail. References: Ashkenazy Y. and H. Gildor (2008), Timing and significance of maximum and minimum equatorial insolation. Paleoceanography, 23, PA1206, doi:10.1029/2007PA001436. Berger A. (1978a), Long-term variations of daily insolation and Quaternary Climatic Changes. Journal of Atmospheric Science, 35(12), 2362-2367. Berger, A. (1978b), Long-term variations of daily insolation and Quaternary climate changes. J. Atmos. Sci., 35, 2362? 2367. Berger A. and M.F. Loutre (1991), Insolation values for the climate of the last 10 million years. Quaternary Science Reviews, 10, 297-317 Berger, A., M. F. Loutre and C. Tricot (1993), Insolation of Earth?s orbital periods. J. Geophys. Res., 98, 10,341-10,362. Berger A., M. F. Loutre and J. L. Mélice (2006), Equatorial insolation: from precession harmonics to eccentricity frequencies. Clim. Past, 2, 131-136. Bretagnon P. (1974), Termes à longues périodes dans le système solaire. Astronomy and Astrophysics, 30, 141-154. Cerveny R.S. (1991), Orbital signals in the diurnal cycle of radiation. J. Geophys. Res., 96(D9), 17,209-17,217. Huybers P. (2006), Early Pleistocene Glacial Cycles and the Integrated Summer Insolation Forcing. Science, 313, 508-511. Laskar J. , P. Robutel, F. Joutel, M. Gastineau, A.C.M. Correia and B. Levrard (2004), A long-term numerical solution for the insolation quantities of the Earth. Astronomy and Astrophysics, 428, 261?285, DOI: 10.10510004-6361:20041335. Loutre M.F., D. Paillard, F. Vimeux, E. Cortijo (2004), Does mean annual insolation have the potential to change the climate? Earth and Planetary Science Letters, 221, 1-14, doi:10.1016/S0012-821X(04)00108-6. Milankovitch M.M. (1941), Kanon der Erdbestrahlung und seine Anwendung auf des Eizeitenproblem. Beograd, köninglich Serbische Akademie, 484pp R. Serbian Acad. Spec. Publ. 132, Sect. Math. Nat. Sci., 33 (Canon of insolation and the ice-age problem, English translation by Israel Program for Scientific Translation,

Jerusalem, 1969 and Canon of insolation and the ice-age problem; Zavod za udzbenikb i nastavna sredstva, Beograd, 1998).

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29 MAY 09:45 —

Huybers, P.
Harvard University

Southern Hemisphere marine and ice-core climate proxies are coherent and nearly in-phase with Northern Hemisphere summer insolation at the obliquity (~1/41 Kyr) and precession (~1/22 Kyr) bands. Although such coherence is suggestive of Northern control of Southern climate, the physical mechanisms that would tie Southern climate to Northern insolation are unclear. Mercer called this situation ?a fly in the ointment of the Milankovitch theory?. I will present an alternative hypothesis that Southern climate responds primarily to changes in the duration of local summer. In this view, interhemispheric symmetry at the obliquity and precession time scales during the late Pleistocene arises from a Northern response to local summer intensity and a Southern response to local summer duration.

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29 MAY 10:45 — What is the role of sea ice in the climatic response to Milankovitch forcing?

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Cycles at Milankovitch frequencies have been argued to be present in paleoclimate records from ocean sediment cores for epochs such as the Pliocene when little or no ice was present on land. We have investigated the time-dependent response of a land ice-free climate to Milankovitch forcing using a coupled atmosphere-ocean-sea ice model. The ocean model component is a zonally averaged model of the circulation in 5 basins (Arctic, Atlantic, Indian, Pacific and Southern Oceans) . The sea-ice model component is purely thermodynamic and the atmosphere model component is a one-dimensional (latitudinal) energy balance model. The coupled model is used to conduct three different numerical experiments on the time-dependent response of climate to Milankovitch forcing for the time interval from 5 Myr to 3 Myr ago. The first experiment does not include the sea-ice model component. The second experiment includes the sea-ice model component but the effect of sea ice on ocean salinity is neglected. Finally, the third experiment includes the sea ice component and the effect of sea-ice cover on sea surface freshwater fluxes is incorporated. The first experiment (no sea-ice) confirms some results obtained in a previous study (Brickman et al., 1999): a) the annual mean surface air temperature linearly responds to changes in annual mean insolation at the obliquity and eccentricity frequencies, b) the response of deep ocean temperature to eccentricity is suppressed, and c) ocean convection rectifies the effect of precession on deep ocean

temperature. However, the inclusion of sea ice modifies significantly the climate responses to Milankovitch forcing: a) in both polar regions, sea ice is highly sensitive to changes in local summer insolation at the precession, obliquity and eccentricity frequencies , b) sea ice variations rectify the effect of precessional forcing on the annual mean surface air temperature at high latitudes, and c) the response of deep ocean temperature drastically changes when the effect of sea ice on salinity is incorporated in the model. At precessional frequencies, the temperature variations of deep ocean water of northern and southern origin are approximately in (out of) phase when sea-ice volume changes does (not) modify ocean salinity; this is a consequence of the strong effect of surface salt fluxes on the convective heat fluxes in the Southern Ocean. These numerical experiments suggest that sea ice plays an important role in the time-dependent response of the climate system to Milankovitch forcing and should provide a useful reference for future investigations based on more complete models.

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29 MAY 11:20 — TBA

Abe-Ouchi A.

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29 MAY 12:00 — How to treat climate evolution in the assessment of the long-term safety of disposal facilities for radioactive waste : examples from Belgium

Van Geet, M. (1), De Craen, M. (2), Wouters, L. (1), Cool, W. (1) and Lalieux, Ph. (1)
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In order to protect man and the environment, long-term, passive solutions are needed for the different radioactive waste streams produced. In Belgium, three main categories of conditioned radioactive waste (termed A, B and C) are defined by radiological and thermal power criteria. It is expected that Category A waste ?low and intermediate level short-lived waste ? will be disposed in a near-surface facility, whereas Category B and C wastes ? high-level and other long-lived radioactive waste ? will be disposed in a deep geological repository. In both cases, long-term safety assessments are the means by which various lines of argument for the long-term safety of a given disposal facility are identified and critically evaluated. The time frames considered are, however, markedly different for category A and category B&C waste. Considering the decay of radioactivity, typical time frames of several centuries to millennia are evaluated for category A, while for category B&C time frames of several hundred thousands to one million years need to be considered. The central element of safety assessment is the development and analysis of scenarios and assessment cases that illustrate the range of possibilities for the evolution and performance of a disposal system without trying to predict its precise behaviour. In both cases the evolution of the climate will play a role in the derivation of

these scenarios. In the safety assessment of category A waste with time frames of several centuries to millennia, Ondraf/Niras is strongly relying on the conclusions of the IPCC, demonstrating that a global warming is nearly unavoidable. The consequences of such a global warming in the evolution of the surface repository are considered. Glaciations are not considered as climate evolution scenarios with natural variations in insulation and natural atmospheric carbon dioxide concentrations do not predict glaciation in the northern hemisphere before several 10 000's of years (BIOCLIM). For the long-term evolution of a geological repository (up to 1 million year), however, the uncertainty on climate modeling seems rather high (BIOCLIM). Consequently, Ondraf/Niras envisages not to rely on the precise description of climate evolution to be incorporated in the different scenarios. Contrary to that, the robustness of the geological disposal system towards the possible results of a spectrum of potential climate changes and their timing of occurrence will be evaluated. The results of climate modeling and knowledge of past climate changes will merely be used as guidance of the extremes of climate changes to be considered and their geological consequences. IPCC, Intergovernmental Panel on Climate Change, The physical science basis ? Contribution of working group I to the fourth assessment report of IPCC ? Chapter 10, Global Climate Predictions, 2007 BIOCLIM, Modelling Sequential Biosphere Systems under Climate change for Radioactive Waste Disposal, Final Report EC-contract FIKW-CT-2000-00024, November 2003

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29 MAY 14:00 — Modelling glacial-interglacial cycles

Ganopolski A.
Potsdam Institute for Climate Impact Research

Simulations of the last eight glacial cycles were performed using the coupled climate-ice sheet model of intermediate complexity CLIMBER-2 with and without time-dependent concentrations of the greenhouse gases. The model reproduces a number of important aspects of glacial climate variability both on orbital and millennial time scales, including dominating 100-kyr cycle and numerous abrupt climate changes resembling in temporal and spatial dynamics Dansgaard-Oeschger and Heinrich events. Overall, our modeling results suggest that a considerable portion of glacial climate variability arises from the direct and strongly nonlinear response of the northern hemisphere ice sheets to the variations in Earth?s orbital parameters amplified by a number of positive feedbacks and an intrinsic instability of the several components of the Earth system.

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29 MAY 14:40 — Quasi-100 ky glacial-interglacial cycles triggered by subglacial burial carbon release

Zeng, N
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A mechanism is proposed in which climate, carbon cycle and icesheets interact with each other to produce a feedback that can lead to quasi-100 ky glacial-interglacial cycles. A central process is the burial and preservation of organic carbon by icesheets which contributes to the observed glacial-interglacial CO2 change (the glacial burial hypothesis, Zeng, 2003). Allowing carbon cycle to interact with physical climate, here I further hypothesize that deglaciation can be triggered by the ejection of glacial burial carbon when a major icesheet grows to sufficiently large size after a prolonged glaciation so that subglacial transport becomes significant. Glacial inception may be initiated by CO2 drawdown due to a relaxation from a high but transient interglacial CO2 value as the land-originated CO2 invades into deep ocean via thermohaline circulation and CaCO3 compensation. Also important for glacial inception may be the CO2 uptake by vegetation and soil regrowth in the previously ice-covered regions. When tested in a fully coupled Earth system model with comprehensive carbon cycle components and semiempirical physical climate components, it produced under certain parameter regimes self-sustaining glacial-interglacial cycles with durations of 93 ky, CO2 changes of 90 ppmv, temperature changes of 6C. Since the 100 ky cycles can not be easily explained by the Milankovitch astronomical forcing alone, this carbon-climate-icesheet mechanism provides a strong feedback that could interact with external forcings to produce the major observed Quaternary climatic variations. It is speculated that some glacial terminations may be triggered by this internal feedback while others by orbital forcing. Some observable consequences are highlighted that may support or falsify the theory.

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29 MAY 15:10 — The carbon cycle during the Mid Pleistocene Transition: The Southern Ocean Decoupling Hypothesis

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We here use the global carbon cycle box model BICYCLE to investigate changes in the carbon cycle during the Mid Pleistocene Transition (MPT) covering the past 2,000,000 years (2 Myr). While there exist so far no ice core record of atmospheric CO2 beyond 800,000 years our simulated atmospheric carbon dioxide partial pressure across the MPT can only be compared with pCO2 calculated from new pH reconstructions based on boron isotopes measured in planktic foraminifer shells. We validate our results further by a comparison of simulated ?13C with paleo reconstructions of benthic ?13C in the deep Pacific Ocean. Our approach is based on regression analyses of various paleoclimatic proxies with the LR04 benthic ?18O stack, which are then used to extrapolate changing climatic boundary conditions over the whole 2 Myr time window. The focus of our investigation is on the changes in the glacial/interglacial (G/IG) amplitudes in climate (represented by LR04) and the carbon cycle (represented by

benthic ?13C) across the MPT. We ?nd that the G/IG amplitudes in LR04 increased by a factor of two across the MPT, those of benthic ?13C measured in cores in the deep Paci?c only by 40%. According to our model this difference in the dynamic of the climate system and the carbon cycle can be explained if we assume a different response to the applied forcings in the Southern Ocean prior and after the MPT. This behaviour is what we call the "Southern Ocean Decoupling Hypothesis" of the climate and carbon dynamics. We discuss how our ?ndings are related to the various hypotheses on the causes of the MPT published within the last years. This study is a temporal extension of the "EPICA challenge", which tried to estimate variations in atmospheric CO2 from published paleo reconstructions before new ice core measurements of CO2 were made public. We ?nally hypothesise that as consequence of our analysis the close relationship between Antarctic temperature and atmospheric CO2 found in ice cores breaks down prior to the MPT.

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29 MAY 15:40 — Half-precessional climate forcing, megadroughts, and high-latitude influences on the moisture-balance history of equatorial East Africa

Verschuren, D. (1), J. Moernaut (2), J. Sinninghe-Damsté (3), Isla Milne (4) and CHALLACEA project members
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The composite oxygen-isotope record of East Asian monsoon dynamics over the last two glacial-interglacial cycles, extracted from excellently dated stalagmite calcite in Chinese caves, is dominated by 23,000-year-long precessional cycles synchronous with summer insolation at 65° N, supporting the idea that on orbital timescales this subtropical monsoon responds predominantly to changes in Northern Hemisphere summer insolation. Long continental moisture-balance records from tropical Africa are also dominated by precession-scale cycles, but also highlight the possibly continent-wide occurrence of mega-droughts during MIS5, compared to which the iconic LGM drought was quite modest. Reflection-seismic data from Quaternary deposits in crater lake Challa near Mt. Kilimanjaro present a detailed continuous record of past lake-level fluctuations, and thus moisture-balance variation, in equatorial East Africa over the last 140 ka. There an MIS5 mega-drought occurred from ~115 to ~98 ka BP. Extreme aridity also occurred during peak penultimate glaciation (>130 ka BP), coeval with Heinrich event 11. Modest LGM aridity was preceded by ~75,000 years of stable and moist climate conditions interrupted only by eight short-lived dry spells, five of which match the timing of Heinrich events 2 to 6. At this time scale, climate history on the East African equator reflects the precessional forcing of monsoon rainfall modulated by orbital eccentricity, but compared to northern and southern tropical Africa the precession-driven moisture fluctuations were less extreme. This allowed a mostly moist climate to persist from ~98 to 21 ka BP, contrasting with the trend towards greater aridity after 75 ka BP, and especially after 35 ka BP, that developed in equatorial West Africa as

progressive expansion of the northern ice sheets slowed down Atlantic meridional overturning circulation. A detailed reconstruction of moisture-balance variations in equatorial East Africa over the past 25,000 years, based on multiple-proxy core data from Lake Challa, bears the clear signature of half-precessional insolation forcing of regional Indian Ocean monsoon dynamics, modified by high northern latitude influences at millennial and century time scales.

POSTER — Orbitally paced lake-level history in the Miocene Teruel Basin (NE Spain) revealed by lacustrine carbonate microfacies

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Results are presented of a detailed carbonate petrographic study of an Upper Miocene lacustrine mixed carbonate - siliciclastic succession in the Teruel Basin (Spain) with the aim to constrain lake level variability at different stratigraphic scales. Regular alternations of red to green mudstone and lacustrine limestone, termed the basic cycle, reflect lake level variations at the metre-scale. In an earlier study, the basic cycle was shown to be controlled by the climatic precession cycle. Petrographic analysis made it possible to distinguish two main carbonate microfacies groups characteristic of very shallow transient and shallow permanent lake environments, respectively. In addition to the basic cyclicity, the microfacies analysis also reveals lake-level variations on a larger scale. As a consequence, the astronomical forcing hypothesis of the cyclicity in the Cascante section is further explored. A climate modelling study of orbital extremes indicates that high lake levels could relate to enhanced net winter precipitation and runoff during precession minima, consistent with Mediterranean geological data. Using this phase relation, an astronomical tuning of the cycles is established starting from astronomical ages of magnetic reversal boundaries. Subsequently, successive basic cycles are correlated to precession minima. The tuning reveals an identical number of basic cycles in the Cascante section as precession-related sapropel cycles in the deep marine succession at Monte dei Corvi (Italy), corroborating the precessional control of the basic cycles at Cascante. Lake-level high-stands in the large scale cycle identified by the microfacies analysis relate to maxima in both the ca 100 and 405 kyr eccentricity cycles, again consistent with Mediterranean geological data. Subtraction of the identified astronomically related (lake-level) variations from the palaeoenvironmental record at Cascante indicates a shift to deeper and more permanent lacustrine environments in the upper half of the section. The cause of this shift remains unclear, but it may be linked to tectonics, non-astronomical climate, long-period astronomical cycles or autogenic processes.

POSTER — The IRIS feedback over the tropical oceans: implications for global climate sensitivity in an extended model

Bates, J.R.
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Based on an analysis of geostationary satellite observations, Lindzen et al. (2001) have proposed that there exists a strong stabilizing (i.e., negative) cloud-area feedback (called the infrared IRIS feedback) on SST perturbations over the tropical oceans. Using a simple 3.5 box model of the global climate system, they show that this strong negative stability-altering feedback also necessarily acts as a strong negative sensitivity-altering feedback for global climate sensitivity to an external forcing (such as doubled CO2), and reduces the sensitivity to minimal values. In their model, the tropical and extratropical SST perturbations (T1 and T2) about equilibrium are forced to be equal.

The effects of the IRIS feedback are here examined in an improved 3.5 box model in which T1 and T2 are allowed to vary independently, a simple parameterization of the dynamical heat transport between tropics and extratropics is included, and the parameters determining the clear-sky outgoing longwave radiation are set to be in better accord with observation. In the new model it is shown that:

a) The stability criteria of the model are changed in such a way that the sensitivity to external forcing becomes much larger.

b) The sensitivity-altering feedback provided by the combined IRIS and dynamical heat transport effects becomes highly nonlinear (the model feedbacks are no longer additive).

c) The IRIS feedback, even if valid as a stabilizing feedback for the tropics, no longer necessarily diminishes global climate sensitivity (in accord with the results of Bates, 2007), though for the best estimates of the model parameters it still does so. However, it no longer reduces the global climate sensitivity to the minimal values suggested by Lindzen et al.

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Lindzen, R.S., Chou, M-D. and Hou, A. 2001. Does the earth have an adaptive infrared iris? Bull. Am. Met. Soc.,82, 417-432.

POSTER — Chemical characteristics of the annually active snow layer of Vestfonna ice cap (Svalbard) under warming conditions: first evidence of spatial variability.

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The glaciology of Vestfonna glacier (Nordaustlandet, Svalbard) is one part of IPY-Kinnvika project. Snow and an ice cores from such an island close to sea ice margin reflect, among other things, the variations of open waters distance. Snow pits sampled during the first of the three spring campaigns at two summits of Vestfonna ice cap (summit Ahlman and summit 95), showed that ions concentrations were spatially heterogeneous in spite of a rather similar accumulation rate for both sites. The snow pack on summit Ahlman shows higher average values of marine incoming species and a winter ice layer depleted in sulfate compared with other sea water ions. In addition, [SO42-/Na2+] is more than 3 times higher (0,92) in this layer than in sea water (0,25). This typical salinity in winter snow and the characteristic backscatter coefficient of 2006 sea ice at radar frequency are a clear signature of frost flowers formed on young sea ice when offshore winds predominate. Frost flowers are described as the dominant source of sea salt to aerosol and ice cores in coastal Antarctica but this is the first time their chemical signal has been deciphered in Svalbard snow or shallow ice core. When analyzing earlier ice, if we succeed in getting rid of melting disruptive effects and tell clearly frost flowers signal from post depositional effects, we would be in position to give an accurate chronological account of sea-ice production around Nordaustlandet Island.

POSTER — Vegetation and climate variability during termination I and Holocene in Central Asia

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Vegetation and climate dynamics over the last ca. 16 ky for the Central Asia hinterland stretching from the Russian Arctic tundra zone to the steppe zone in Northern Mongolia was reconstructed on the base of new high resolution, and fine dated my means of AMS 14C method pollen records obtained from the Lena River delta as well as from Lake Baikal and Lake Hovsgol catchment area (lake bottom sediments as well as peat bogs). In order to clarify possible effects of climatic variations upon the changes in vegetation pollen records were compared with independent paleoclimatic series such as GISP2 oxygen-isotope stratigraphy and mountain glaciers fluctuations, the latter ones occurring over the Holocene on a wide geographical scale.

POSTER — A unified approach to orbital, solar and lunar forcing based on the Latitudinal Insolation/Temperature Gradient

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Two fundamental problems in our understanding of the Earth?s climate relate to how variations in solar energy from the Sun drive climate change, and how evidence of cyclical changes in climate can be explained. This debate has typically been divided between orbital, solar and lunar forcing, which operate at glacial-interglacial, decadal to millennial and bi-decadal timescales respectively. An interesting property of the latitudinal insolation gradient is that it varies with all these forcings, whilst also causing differential solar heating that drives the climate system through the latitudinal temperature gradient. Conventionally, externally forced changes in the insolation gradient would be considered too weak to influence the climate system in comparison with its powerful internal dynamics, especially at decadal timescales. However, it has been proposed that these internal dynamics may be finely balanced to maximise entropy, in which case the temperature gradient may be hypersensitive to external changes in the insolation gradient. Here we investigate this hypothesis by comparing changes in the Earths temperature and insolation gradients over decadal to glacial-interglacial timescales, as well as the ability of climate models to respond to this forcing. We conclude that the sensitivity of the temperature gradient and climate system to insolation gradient forcing may have been underestimated.

POSTER — Contraction of the tropical ocean warm pool between 4 and 2Ma and the onset of Northern Hemisphere glaciation

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Using new proxy data, as well as results from previous studies, we reconstruct the latitudinal distribution of SST for a time interval during the early Pliocene, around 4 million years ago. We show that the meridional temperature gradient between the equator and the subtropics was greatly reduced then, which implies that the tropical ocean warm pool (confined at present mainly to the western equatorial Pacific) extended much farther poleward. Corroborating evidence comes from a high-resolution proxy record from the subtropics indicating that the meridional extent of the warm pool has been gradually decreasing over from 4 to 2Ma (the temperature contrast between 0 to 32ºN increased during this time from roughly 2 to 8ºC, Liu et al 2008). Using an atmospheric general circulation model forced with the new SST reconstruction, we demonstrate that the contraction of the ocean warm pool since 4Ma must have caused a significant intensification of the atmospheric Hadley circulation. Further, our calculations show that a transition from the early Pliocene to a colder modern-like latitudinal temperature distribution induces an up to 10ºC cooling of parts of North America in summer (up to 15ºC in winter) and a significant increase in winter snow cover. Roughly half of these effects can be attributed to colder SSTs in high latitudes, while the rest is due to the contraction of the tropical warm pool. This makes the reduction in the warm pool meridional extent since the early Pliocene an important factor in the onset of Northern Hemisphere glaciation.

POSTER — Eemian and Holocene Climate Variability in a Coupled Atmosphere-Ocean-Biosphere Model

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According to the Milankovic theory variations of the orbital parameters of the Earth's motion around the sun yield varying spatio-temporal insolation forcing and therefore changes in the amplitude of seasonal cycles. These changes are considered to be the leading forcing mechanism of glacial-interglacial cycles. Model simulations of pre industrial climate (150 years before present) characterized by relatively low summer insolation at high northern latitudes are compared with the Holocene optimum (6000 years before present) and the optimum of the last interglacial, the Eemian, (125000 years before present). The main difference between the Holocene optimum and the pre industrial stage on the one hand and the Eemian period on the other is an enlarged eccentricity of the earth's orbit in the latter leading to an enhanced seasonal cycle over the Northern Hemisphere as the perihelion was during boreal summer. The aim is to unravel the influence of natural forcing factors, i.e. orbital parameters, on climate variability and regional heterogeneity. In order to investigate variability up to decadal and multi-decadal scale we perform 1000 year long unperturbed equilibrium integration runs of a coupled atmosphere-ocean general circulation model (ECHAM5/MPIOM) including a dynamic land cover model. Greenhouse gas concentrations are fixed at pre industrial levels in all runs. We analyze changes in the large scale ocean circulation, deep water formation and the variability patterns North Atlantic Oscillation (NAO) and El Nino/Southern Oscillation (ENSO) and feedback mechanisms between thermohaline circulation changes and low-frequency variations of climate.

POSTER — Recent developments in investigating high-resolution continental archives: the example of varved sediments from the Canadian Arctic.

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Annually laminated (varved) sediments are one important focus of research because they potentially provide a robust chronology in calendar years and paleoenvironmental information at annual or even seasonal scale. Identification of the climatic and environmental signal recorded in the sediments is critical and is usually performed using direct comparison with instrumental data. However in remote areas, this comparison is not always achievable. In this paper, we report the use of a simple deterministic hydrological model to decipher the hydroclimatic signal contained in the

sediment. Moreover, investigation of these archives also proved to be time and labor intensive preventing a wide use of these records. We also present innovative high-resolution imaging and chemical techniques that allow fast and reliable ways to investigate varved sediments. First, image analysis of thin sections allows the direct link of the characteristics of discrete and sub-millimeter scale sedimentary facies with hydrological parameters. Second, a new generation of micro X-Ray fluorescence core scanners allows fast and non-destructive chemical analyses along sediment cores at an annual scale. Together, these techniques make multiple and repeated measurements possible, and hence the improvement of reconstruction's robustness. As an example, our record from the Canadian Arctic showed the recent warming but also regional climatic influences such as the Arctic Oscillation.

POSTER —

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Precipitation, snow sublimation and snow transport by the wind are the main processes responsible for snow net accumulation over a great part of the antarctic ice sheet. Snow melting plays also an important role over the antarctic Peninsula. MAR (Modèle Atmosphérique Régional) is a Regional Climate Model (RCM) which has been developed for simulating the climate of polar regions. It contains in particular a bulk cloud microphysical scheme and is coupled with a detailled snow model including a blowing snow model. Blown snow particles are treated as snow flakes by the microphysical scheme and may sublimate. The strong negative feedback of snow erosion by the wind on atmospheric turbulence is also taken into account. Here a simulation of the Antarctic Surface Mass Balance (ASMB) is analysed. The simulation is made by forcing MAR with 11 years of meteorological analyses (ERA-40, 1980 ? 1990). The horizontal resolution is 40 km. Model outputs compare favorably with recent ASMB reconstructions. Sensitivity of the simulated surface mass balance to clouds radiative properties is weak over the antarctic plateau, while that of simulated surface temperature is more significant. This suggests that establishing a link beween a simulated cold bias and an underestimated surface mass balance over the antarctic plateau is not straightforward.

POSTER —

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Recent implementation of a permanent station at Dome C, antarctic plateau, raises the question if that site should be a good astronomical observatory. Indeed Dome C is situated 3200 m above sea level, the atmosphere is very clean over the antarctic plateau, and cloudiness is low. Here we show preliminary simulations of optical turbulence made with the Regional Climate Model MAR. Turbulence is parameterized in MAR using an

E-e scheme containing prognostic equations for turbulent kinetic energy and its dissipation. The turbulence model allows to represent the complex vertical structure of the antarctic boundary layer. Surface turbulent fluxes are parameterized using Monin-Obukhov Similarity theory (MOS) and serve as boundary conditions for the E-e scheme. A non-zero low limit is assumed for these fluxes, in order to take into account the existence of a residual and probably non stationary turbulence. Model results reveal that optical turbulence is very strong during polar night over the antarctic plateau, but only over the lowest 20 ? 30 m of the atmosphere. This behaviour is due to the mechanical forcing of turbulence under very stable conditions.

POSTER — Information on the early Holocene climate constrains the summer sea ice projections for the 21st century.

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The summer sea ice extent strongly decreased in the Arctic over the last decades. This decline is very likely to continue in the future but uncertainty on projections is very large. An ensemble of experiments with the climate model LOVECLIM using 5 different parameter sets has been performed to show that summer sea ice changes for the early Holocene and for the 21st century are strongly linked, allowing to reduce this uncertainty. Using the limited information presently available for the early Holocene, simulations presenting very large changes for the 21st century could reasonably be rejected. On the other hand, simulations displaying low to moderate changes during the second half of the 20th century are not consistent with recent observations. Using this evidence based on observations during both the early Holocene and the last decades, the most realistic projection indicates a nearly disappearance of the sea ice at the end of the 21st century for a moderate increase in atmospheric greenhouse gas concentrations. For a faster increase in those concentrations, the Arctic Ocean would become almost ice-free in summer as early as 2060 AD.

POSTER — Impacts of land surface properties on Last Glacial Maximum climate

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Climate models tend to overestimate surface temperatures and precipitations at the Last Glacial Maximum (21,000 BP). Changes in vegetation cover at that period may possibly represent a non negligible feedback to improve model-data agreement. At the Last Glacial Maximum (LGM), grassland and desert ecosystems were more widespread than they are today, mainly at the expense of forest ecosystems. In general, vegetation cover was less dense. Such a change is expected to lead to an increase of surface albedos and a

decrease of roughness lengths. Both effects may impinge on surface temperatures. In this work, we have analysed the implications of changing land surface properties on the climate at the LGM. The Planet Simulator, an Earth system model of intermediate complexity (Fraedrich et al., 2005, Meteorol. Z. 14: 299-304 and 305-314) was used to carry out a series of sixteen simulation experiments, where we have assessed the effects from differences in (1) the vegetation cover (via surface albedos and roughness lengths), (2) ice-sheet cover, (3) orography and (4) the effect of reduced atmospheric carbon dioxide between a pre-industrial state and the LGM. The sixteen simulation experiments consider all possible perturbations of a given control run configuration by prescribing changes of these four parameters individually and combined. The factor separation method of Stein and Alpert (U. Stein et P. Alpert, 1993, J. Atmos. Sci., vol. 50(14):2107-2115) was used to analyse the results from the sixteen simulation experiments in terms of the individual and combined contributions of the four applied modifications to the overall response of the climate system. Vegetation changes between the pre-industrial and the LGM have been obtained from simulation experiments carried out with the dynamic vegetation model CARAIB (Otto et al., 2002, Global Planet. Change, vol. 33:117-138). These changes were then translated into corresponding changes of surface albedos and roughness lengths, which are required as boundary conditions in the Planet Simulator. Our results witness of a global cooling due to the reduction of atmospheric CO2, a large and more localised cooling due to the ice cover change and of the strong influence of orography on atmospheric circulation and winds. They also emphasize the non negligible impact of vegetation cover change on climate. Indeed, we find that the vegetation cover change at the LGM leads to significant global cooling, with more pronounced local contrasts, together with a decrease in precipitations. Our analysis furthermore points out important non-linear effects when the combined effects are considered. The results from our simulation experiments emphasise that it is important to take the climate-vegetation interaction into account when using climate models to study past, present or future climate change.

POSTER —

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Sediments - Sediments from the Bogotá Basin (4°N, 74°W, 2550 m alt.) produced an unprecedented 540-m long pollen record. Core Funza-2 includes 2100-samples showing the complete series of ice-ages with c. 1.5 kyr resolution for the period of 3186-28 kyr BP (provisional ages). Downcore distributions of 2200 grain size samples shows the cyclic evolution of depositional environments. Downcore grain size distributions, carbon content values (LOI) and the aquatic vegetation-based record of lake-level changes showed 11 discrete sedimentary facies reflecting lacustrine, swamp, fluvial-lacustrine, and fluvial depositional environments. Several lithological discontinuities have been identified. Paleo-lake Bogotá evolved tectonically c. 1.6 Ma. Lake-levels fluctuated

constantly until the lake disappeared c. 28 ka also for tectonic reasons. Chronology - Eight fission-track ages span from c. 2.7-0.67 Ma. Visual curve matching of the temperature-dependant arboreal pollen record with composite ?18O record V1930-ODP677-ODP846, and astronomical tuning of the arboreal pollen record to the orbitally forced marine ?18O record dates the record from 3186-28 ka (provisional ages). CONISS-based cluster analysis on pollen taxa reflecting changes of the altitudinal distribution of the North Andean vegetation show 8 intervals with a characteristic vegetation association forming the basis of the late Pliocene and Pleistocene biostratigraphy. Vegetation - We used the ?downcore biomisation method? to support successive stadia in Pleistocene evolution of plant associations. Late Pliocene times show taxa such as Aragoa, Caryophyllaceae and Polylepis for the first time. From 3.186 Ma to c. 2.9 Ma warm late Tertiary conditions prevailed. Precursors of the modern Andean forest included Eugenia-Ilex-Miconia-Myrsine-Vallea-forest and Weinmannia-Melastomataceae-forest during cool episodes and Alchornea-dominated-forest and Podocarpaceae-Hedyosmum-forest during warm climate conditions. Between 3.0-2.5 Ma temperatures decreased and only Eugenia-Ilex-Miconia-Myrsine-Vallea-forest continued its presence. During late Pliocene time the páramo biome evolved from a species poor herbaceous protopáramo (with Borreria) into a lower shrub-dominated páramo and a higher grass-dominated paramo. The northern-hemisphere trees Alnus and Quercus migrated across the Panamanian Isthmus and arrived in the study area at 1.1 Ma and 0.29 Ma, respectively. Immigration events and evolution of climatic envelopes of the North Andean biomes prevent modern analogs from being used to arrive at quantitative temperature reconstructions over such long intervals of time. Climate Variability ? With support of L. Lourens (Utrecht) new age model is being developed including frequency analysis in the depth domain followed by astronomical tuning of records of selected taxa. We allow for a time lag between driving insolation forcing and the response of vegetation change. Ages mentiond are provisional and subject to change when we have completed the final age model. # Funza-team members: Andriessen, P.A.M. (VU Amsterdam), Berger, A. (UCL, Belgium), Hulshof, O. (IBED, Amsterdam), Lourens, L. (Utrecht), Mélice, J.L. (UCL, Belgium), Ran, E. (IBED, Amsterdam), Sarmiento, G. (UN, Bogotá, Colombia), Shackleton, N.J. (Cambridge, UK, deceased), Tzedakis, C. (Leeds, UK), Van der Hammen, T. (Chia, Colombia). Ref. (1) Torres, V., Vandenberghe, J., Hooghiemstra, H. (2005), An environmental reconstruction of the sediment infill of the Bogotá Basin (Colombia) during the last 3 million years from abiotic and biotic proxies. Palaeogeogr. Palaeoclimatol. Palaeoecol. 226, 127-148; (2) Torres, V. (2006), Pliocene-Pleistocene evolution of flora, vegetation and climate: a palynological and sedimentological study of a 586-m core from the Bogotá Basin, Colombia. Unpublished PhD thesis, University of Amsterdam; (3) five additional papers are ?in review? / ?in preparation?.

POSTER — Holocene climate variability and patterns of the North Atlantic: Orbital and non-orbital forcing

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The northern parts of the North Atlantic experienced major changes in Sea Surface temperature during the Holocene. A thermal optimum 8-6ka is ascribed to the seasonal forcing from the orbital parameters. However, the response of the forcing was mainly a direct radiative response, probably amplified by sea-ice/snow albedo feedbacks. The Holocene cooling trend that followed the decline in summer insolation is purely recorded by proxies sensitive to summer conditions at the sea surface, thus the thermal optimum was primarily not due to advective processes in the ocean. The last 4 ka is characterised by amplified variability at millennial and century time scales, the latter probably related to the Atlantic Multidecadal Oscillation. Comparisons of paleoclimate proxy data and model experiments using natural forcings during the past millennium indicate that volcanic and to a lesser extent solar forcing appears to have provided the most amplified changes, linking responses in the tropics with the high latitudes. It is unclear if resultant changes in the overturning circulation amplified these changes.

POSTER — A Holocene palaeoenvironmental reconstruction based on geochemical research (isotopes and trace elements) on three speleothems from Soqotra Island (Yemen).

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Certain geographical areas that play a key role in the elaboration of e.g. Global Circulation Models (GCM) are still insufficiently documented. The arid tropical island of Soqotra is situated in such an area that consists of the northwestern Indian Ocean, eastern North-Africa and the Middle-East. Here a bi-annual rainy season is active, due to the passing of the inter-tropical convergence zone (ITCZ) twice each year, known as the Indian Ocean Monsoon system. In order to contribute to a better knowledge of the palaeoclimatic evolution during the Holocene, we carried out a multi proxy study of three stalagmites from Soqotra together with an environmental study of the caves we sampled and a meteorological study of the island. Local meteorological data collected at 11 stations over 5 years lead to the conclusion that about 85% of the rainfall is related to the NE Monsoon, while only 15% is related to the SW Monsoon, the latter with an outspoken irregular geographical distribution over the island. Based on the differences in the oxygen isotope composition of meteoric waters versus groundwater and taking into account the observed amount driven seasonal fluctuations of rainwater oxygen isotopic composition, it appears that the karst aquifer recharge at the NE limestone plateau takes only place during the NE Monsoon rainy period when a rainfall threshold of 80-

90mm is exceeded, which explains why cave drip waters and groundwater are enriched in light isotopes compared to local meteoric waters. Two caves, Hoq and Casecas, 6 km apart, were studied. From the Hoq cave, two stalagmites 10 m apart, STM-1 and STM-6 were sampled, respectively 6 ka and 4.6 ka old at the base. A 1 ka old stalagmite STM-5 was sampled from Casecas Cave. These ages are based on U/Th-measurements and on the observation that the stalagmites were active when sampled in January 2003, 2006 and 2003, respectively. Stable isotope ratios of carbon and oxygen (?13C and ?18O) were analysed at high and low resolution in all three stalagmites, along with Mg/Ca and Sr/Ca ratios in STM-6 only. With some exceptions, there is a good agreement between high resolution and the low resolution stable isotope time series. Based on the strong correlation between ?13C and ?18O in the time series of all three stalagmites, the variations of the isotope ratios are interpreted as been driven primarily by changes in the amount of meteoric precipitation that are supposed to be related to changes in the position of the intertropical convergence zone. Untill about 0.5 ka (~500 BP, i.e. (~1500 CE), and in spite of local differences, the low resolution ?13C and ?18O time series of all three stalagmites are rather similar and reveal the occurrence of alternating wetter and dryer periods. The period from ~ 1200 a BP till ~ 500 a BP (or the period ~ 800 CE till ~ 1500 CE and encompassing the Medieval Warm Period, displays a clear evolution to dryer conditions in all three stalagmites. The observation of the Little Ice Age (~500 - ~150 a BP, or ~1500 CE till ~1850 CE) as a relatively wetter period in both STM-1 and STM-5 however is not confirmed in the time series of STM-6. Consequently, a comparison with the climatic evolution in eastern North Africa during the past ~1500 years, as based on lacustrine archieves, is not straightforward. Although the comparison of the ?13C and ?18O time series with that of the Mg/Ca and Sr/Ca ratios in STM-6 does not lead to meaningful conclusions, the low resolution Mg/Ca and Sr/Ca time series however show an overall evolution to dryer conditions. High resolution ?13C and ?18O analyses in STM-1 of up to 50 ?m, corresponding to a time resolution of up to one month demonstrate seasonal variations of 1 to 2 ? in ?13C and of 0.5 to 1 ? in ?18O, coinciding with the alternation of dark compact and white porous layers, presenting annual banding in the stalagmite. These observations suggest that the speleothem reliably registered variability in the Monsoon climate. We consider the presence of well preserved seasonal variations and the similarity of the isotopic records of the three speleothems as encouraging observations with respect to the reproducibility of the records.

POSTER — The astronomical forcing and mathmatical theory of glacial-interglacial cycles

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There are three important features of a proxy time-series recorded during the Pleistocene. They are: 1) 100000 years cycle as the dominant control of global glacial-interglacials through the late Quaternary, 2) fluctuations with the periods nearby 40 and

20 thousand years (their contribution to dispersion is no more than 15%). 3) ?Red noisily? behavior of the time-series. Although all processes can be explained by independent rhythms, their relationships and interaction are not fully understood. Development of the theory explaining named features is required. On the basis of the equation of the budget of heat the equation describing dynamics of the temperature of the zone, located between equator and the certain circle of latitude is developed. Various combinations of terms of this equation are discussed. These are a contribution of Milankovitc? periodicity, the Langeven stochastic equation, the equation of delay oscillator, the stochastical equation of climate bifurcation, the equation of a stochastic resonance. Direct influence of the radiation, created by fluctuations of the eccentricity, is too poorly to cause observed 100-thousand-year fluctuations of a climate. Therefore others various mechanisms of such rhythm are offered. They are realized due to interaction of elements of climate system with different inertia. Different aspects of this effect are depicted by different mathematical models (delay oscillator, the Brown movement, the stochastical resonance). Simultaneously, the Brown movement explains the ?Red noise? conditions of climate dynamic. Orbitally-induced changes of the solar energy flux received by the Earth play an important role as mechanism starting process of climate changes which is supported and intensified by different feedbacks within the climate system. Only in rare cases when for example inclination of Earth axis of rotation increases and, simultaneously, perihelion takes place during the summer time (for Northern hemisphere for one), arising anomalies of solar radiation serve as the real mechanism causing reorganization of a climate. The results of the Paleoclimate Modelling Intercomparison Project allow to investigate details of such process.

POSTER — The seasonal cycle as template for climate variability on orbital timescales

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Depending on the region, the earth's present day seasonal cycle of surface temperature is more sensitive on either, winter or summer insolation, or shows a linear response. Comparing surface temperature and the insolation forcing, we globally derive local transfer functions. These transfer functions can then be clustered into well defined regions in which the nonlinear part of the response is dominated by different physical processes (e.g. sea ice, Monsoon) Applying this transfer function to long time insolation time series we derive the idealized spatially resolved temperature response on long time scale. We test our approach using paleo time slice experiments from a coupled AOGCM and show that despite its simplicity the proposed method explains most of the modeled temperature response on insolation changes. We therefore propose this template method as new tool for the interpretation of paleo records.

POSTER — Climate spectrum estimation, aliasing and timescale errors: Algorithms and application to stalagmite and ice core records

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A power spectrum of a climate process is a powerful tool because it allows to separate short-term from long-term variations and to distinguish between cyclical forcing mechanisms of the climate system and broad-band resonances. This means that spectral analysis permits to learn about the physics of the sampled climate system. However, when having instead of a perfect knowledge only a handful of data contaminated with measurement and proxy errors, the task is to estimate, namely the spectrum. This paper gives a short overview of spectrum estimation methods for noisy, perhaps unevenly sampled climate time series. Two extra points are treated in more depth: aliasing and the influence of timescale errors. Estimation. The periodogram is not a suitable estimator of climate spectra because these are not pure harmonic but rather a combination of harmonic signals and a continuous background (i.e., mixed), and the periodogram has 100% (200% at the frequency borders) estimation error for such data. Instead, spectral smoothing has to be applied. The optimal smoothing technique, in a least-squares sense, is Thomson's (1982) multitaper method. The apparently only drawback of this method today is the unavailability of an implementation for series unevenly sampled in time. Such records are today best analysed using the Lomb?Scargle periodogram combined with Welch's Overlapped Segment Averaging procedure. An implementation (REDFIT) of this method together with bias correction and a hypothesis test of the AR(1) red-noise alternative was presented by Schulz and Mudelsee (2002). Aliasing occurs when a process with a high-frequency (f') component has been sampled at insufficient temporal resolution. This is the case when (even spacing) f' > fNy

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POSTER — A progressive transition from dry to wet conditions during sapropel events in the Eastern Mediterranean Sea

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To better understand the hydrological conditions conducing to the establishment of anoxic conditions in the eastern Mediterranean Sea during sapropel events, we have performed a detailed isotopic and micropaleontogical analyses along two cores covering the last four climatic cycles and recovered in the Levantine basin (MD84-641: 33°02' N;

33°38'E) and in Tyrrhenian Sea (DED87-08: 39°42' N; 13°34'E). Before the apparition of each sapropel, the succession of benthic foraminifera assemblages indicates that the decrease in the deep water dissolved oxygen content in the Eastern Mediterranean was gradual whereas the surface salinity decrease associated to the enhanced precipitation on the Mediterranean region was abrupt and synchronous with the beginning of organic matter preservation and the deposition of sapropel layer. It?s now well established that the organic matter preservation on the bottom of the Eastern Mediterranean Sea and the establishment of anoxic conditions were linked to the stratification of the water column in the Eastern basin and the slowing of the deep Mediterranean circulation. This can only be possible when the Mediterranean Sea received an enhanced freshwater supply which was able to equilibrate the water loss by evaporation transforming the Mediterranean Sea into a non concentration basin. However, benthic data seems to indicate that the transition from dry to wet conditions was rather progressive. On the other hand, hydrological conditions responsible for organic matter preservation events seem to be different from sapropel to another. While bottom conditions were totally anoxic for sapropels S1, S3, S5 and S7, fauna apparition during sapropels S10, S8, S6 and S4 indicates an episodic enrichment of bottom water with dissolved oxygen which can be explained by an activation of deep water convection probably linked to the instability of humid periods. Keywords : Mediterranean Sea, Humid periods, Sapropel, Benthic Foraminifera * E-mail address : melki_tarek@yahoo.fr

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POSTER — Feedback analysis of mid-Holocene winter warming

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The Arctic is very susceptible to climate change. In this region, feedbacks between atmosphere, ocean, sea ice, and vegetation may enhance or dampen an initial forcing. One well known example of climate change is the winter warming over Northern Europe during the mid-Holocene, which has been detected by observation based reconstructions. Up to now it is not clear, however, whether this winter warming is predominantly caused by stronger-than-present westerly winds or by feedbacks, especially by the synergy between the taiga-tundra feedback and the sea-ice albedo feedback. To quantify the impact of feedbacks and their synergy effects on the high northern latitude climate we use a comprehensive Earth system model consisting of an atmosphere/ocean general circulation model (ECHAM5/MPIOM) coupled to a recently developed dynamic land cover model. Simulations are performed with present and mid-Holocene (6000 years BP) orbital forcing implying a distinct difference in the seasonal and regional distribution of solar insolation. We determine the contribution of each dynamic Earth system component to the total climate signal. We will show our first results which reveal significant changes in the simulated mid-Holocene climate, which comprise seasonal

changes in temperature and a reduction in meridional overturning. Furthermore, we observe that the boreal forest expands northward, which is in general agreement with proxy data and previous studies.

POSTER — The ocean circulation during the Last Glacial Maximum: a model-proxy data comparison

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The meridional overturning circulation of the Atlantic Ocean (AMOC) is intimately coupled to the transport of sensible and latent heat by the atmosphere and ocean. The possibility that it may change in the future is the main motivation to understand how it may have differed in the past. To this end, we generated an ensemble of six simulations of the ocean circulation during the Last Glacial Maximum (LGM), using the University of Victoria Earth-System Climate Model (UVic ESCM) and changes in the wind and wind-stress fields that were obtained from fully-coupled Paleoclimate Modelling Intercomparison Project Phase II (PMIP 2) simulations. The UVic ESCM contains a marine bio-geochemical component as well as land-surface and vegetation components. The changes in the wind and wind-stress fields caused significant changes in the spatial anomaly patterns and a strengthening of the AMOC. To check to what degree our LGM simulations are consistent with the available paleo-proxy data, we carried out a quantitative comparison against sea-surface temperature proxies, nutrient-like proxies (stable carbon isotope and cadmium/calcium ratios) and a proxy for ocean ventilation (radiocarbon). Our results support the common paleoceanographic view of a shallower and slightly (~30%) weaker circulation than at present.

POSTER — A modelling study of Northern Hemisphere atmospheric variability across different climate states

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Diagnosing the stability of fundamental modes of climate variability across a wide range of mean climate states is likely to provide insight into fundamental features of the atmospheric circulation. Observed extratropical climate variability is dominated by fundamental modes, most notably the North Atlantic Oscillation (NAO)/Arctic Oscillation (AO) pattern for the Northern Hermisphere. We investigate the nature of past extratropical Northern Hemisphere atmospheric variability, in particular in the Atlantic sector, and to determine whether the main atmospheric patterns in today's climate are as important in fundamentally different climate states. We analyze the sea

level pressure (SLP) field in a cold climate (Last Glacial Maximum; LGM, 21 ka), a warm climate (mid Holocene; MH, 6 ka) and the present day climate (PD) as simulated by four different coupled climate models (CCSM, IPSL, MIROC3.2, HadCM3M2) belonging to the Paleoclimate Modelling Intercomparison Project Phase II (PMIP2). The models produce several robust changes between the LGM and PD mean state, such as a southward shift of the Aleutian and Icelandic lows (up to 10º of latitude) and the development of thermal anticyclones on the Eurasian and North American ice sheets throughout the year. In the MH simulations, the major SLP features are very similar to those in the PD simulations. In three out of four models, there is less (up to 35%) interannual variance in SLP in the LGM simulations than in the PD and MH simulations. The SLP variance peaks during the winter months in all the climates, but the seasonal cycle is damped in the LGM climate relative to the PD or MH climates. An NAO-like feature is the dominant pattern of climate variability in all three climates, although it explains less of the total variance during the LGM. There is no complete agreement on how the structure of this pattern changes between climates. Quantifying changes in internal variability in such past climates is essential to understanding how sensitive the climate system may be to external forcings such as solar radiation, greenhouse gases and aerosols. A dynamical interpretation of these consistent changes in variability could not only enhance our understanding of the atmospheric circulation's sensitivity, but also help discriminate between natural and human-induced change.

POSTER — On the influence of the solar activity on the climate

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The solar activity has an irregular cycle of 11 years that clearly influences the space environment of the Earth. It can also possibly influence the lower atmosphere and the climate. The long period of solar minimum activity called Maunder minimum from 1645 up to 1715 was associated to a cold period on Earth and is often interpreted as a sign of this influence. In the present work, it is shown how the solar activity of the Sun influences the space environment of the Earth and especially different regions of the magnetosphere and the upper atmosphere. The indices of solar activity (sunspot number, 10.7 cm solar radio flux F10.7, solar wind velocities, densities?) from the past 50 years are correlated to the geomagnetic activity illustrated by various indices like Kp, Dst, ? and compared to the temperature on the surface of the Earth. A summary of different scenarios that were suggested in the past for Sun?climate interactions will be presented. These scenarios include the effects of the solar irradiance variations, the modulation of the cosmic rays, the influence on cloud formation, and the ozone climate forcing.

POSTER — Lacustrine evidence for the Antarctic Oscillation in southernmost South America over the last three centuries

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The last decade has shown a substantial increase in high resolution records of environmental change in the Southern Hemisphere. There is, however, an urgent need to obtain high resolution archives in southernmost Patagonia that can be compared with their Antarctic and marine counterparts. Lately, tree-ring-based reconstructions further north indicate that climate in this area is highly sensitive to temporal and spatial changes in extra-tropical atmospheric circulation patterns such as the Antarctic Oscillation (AAO). Hence, Tierra del Fuego is a key site in the Southern Hemisphere to test the magnitude and extent of different forcing mechanisms of climate change that can be compared with other sites further located to the North. Here we present the geophysical, sedimentological and geochemical record of Lago Fagnano at 54°S in Tierra del Fuego (Argentina, Chile). The lake occupies a tectonic depression along the Magallanes-Fagnano fault system. A 160 cm long sedimentary core contains a laminated sequence covering the last ~200 years. These regularly laminated deposits comprise amorphous organic matter-rich dark laminae with a high content of diatom frustules alternating with dominantly clastic light laminae. This regularly laminated sequence is occasionally interrupted by turbidites of variable thickness. Physical properties and bulk geochemical data using XRF point towards relatively stable conditions during the studied time interval. Variations in the laminae thickness obtained by image analyses, however, indicate dominant interdecadal frequencies associated to precipitation and wind changes that can be related to extratropical forcing such as the Antarctic Oscillation (AAO).

POSTER — Plio-Pleistocene record of terrigenous sediment delivered into the eastern tropical and subtropical Pacific, ODP sites 1237 and 1239.

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One of the fundamental missing links in understanding the Neogene climate evolution is the interaction and variability between SE trade wind strength, SE Pacific upwelling intensity, dust transport and continental climate evolution of South America. Moreover, they are currently significant issues with regard to global warming and their impact on long-term El Nino behavior. Our project therefore aims at the reconstruction of these variables at the tropical and subtropical equatorial Pacific (ODP sites 1239 and 1237) on millennial and orbital time scales. We are particularly focussing on periods of pronounced re-organizations in global climate and oceanography such as the Pliocene warm period prior to 4.2 Ma, the interval of NHG intensification between ~3.5 and 2.7 Ma, the mid-Pleistocene climate revolution (MPR) from ~1.3-0.7 Ma, and the pronounced

glacial/interglacial climate variability of the last 500 kyr. Site 1237 (16°S) is located 140 km off the coast of Peru at 3212 m water depth on the eastern flank of Nazca Ridge. The area is characterized by high biological productivity, connected to upwelling, and lies underneath the modern path of eolian dust transport from the Atacama Desert. Site 1239 was drilled further north; on the Carnegie Ridge at 1414 m water depth, 120 km off the coast of Ecuador. At this latitude, the continental climate and its vegetation are marked by a strong change. Arid conditions expand from the Atacama to southernmost Ecuador at ~3°S (Golfo de Guayaquil). Further north, the coastal regions are under the influence of tropical rainfall related to the ITCZ. The site 1239 presumably contains signals of fluvial sediment discharge from the Guayas River, the largest river of tropical South America discharging into the Pacific. We present element concentrations, ratios and accumulation rates from X-ray fluorescence (XRF) scanning on the ODP cores in combination with published temperature proxy data from the Eastern Equatorial Pacific old Tongue EEPCT (ODP site 846; Lawrence et al. 2006), as a first approach to assess changes in terrigenous input. The history of eolian deposition in the subtropical southeast Pacific is best recorded at site 1237 as it underlies the path of modern dust transport from the Atacama Desert. Thus, we interpret the changes in siliciclastic element concentration and accumulation rates in his site to reflect predominantly changes in continental aridity and trade wind strength. Much of the sea surface temperatures (SST) variability correlated with siliciclastic concentration suggest a close relationship between long and short-term changes in wind strength, wind-induced upwelling intensity, and upwelling ?induced SSTs during the last 5 Ma. In general, SST minima during cold stages correspond to maxima in the Fe/siliciclastic ratios that can be interpreted in terms of enhanced eolian input most likely related to stronger trade winds. The long-term increases in Fe/siliciclastic since 4.2 Ma are paralleled by decreases in SST of about 5°C and also correspond to marked amplifications in the SST gradient between the West Pacific Warm Pool and the EEPCT. At equatorial ODP site 1239, the long-term variability of the siliciclastic is remarked by relatively high values between 5 and 3.5 Ma culminating into a pronounced maximum from 3.5 to 2.7 Ma leading to a level of distinctly lower AR during the late Pliocene and Pleistocene. This variability deviates from that observed at the more southern site 1237, suggesting that the mechanism controlling siliciclastic input is different in both sites. Despite the long-term similarity in compositional changes between both sites, the short-term variability on glacial-interglacial cycles is opposite to each other, meaning that at site 1239 minima in siliciclastic sediment deposition correspond to glacials. We interpret this pattern to reflect change sin the latitudinal position of the Intertropical Convergence Zone (ITCZ) on orbital time-scales. Southward shifts of the ITCZ during glacials favored humid conditions to penetrate southward into Peru, thereby reducing the eolian transport to site 1239 due to enhanced vegetation cover. Our results also document the potential for reconstructing long-term shifts in the latitudinal position of the ITCZ over the last 5 Ma for time-intervals that are marked by major reorganizations of the climate system.

POSTER — Glacial terminations as seen in the EPICA Dome C ice core records

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The climate system underwent several glacial-interglacial transitions during the Pleistocene, nine of which were recorded in the European Project for Ice Coring in Antarctcia (EPICA) Dome C ice core. However, there are large differences between these nine terminations. Over some terminations, the temperature changed only moderately from glacial to interglacial conditions. For others, huge initial warmings were observed, but these warm stages were only sustained over relatively short periods and followed by long moderately warm intervals. In this paper, we look into the sequence of events for all terminations, and check whether the same sequence applied to all terminations despite their different characteristics. In particular, we investigate the phasing between South American dust, a sea ice proxy and Antarctic temperature changes. The onset of a glacial termination is synchronous in Antarctic temperature and South American dust, while the sea ice proxy shows a lagged response, setting in once Antarctic temperature has reached a particular threshold. However, this is most likely an effect of the proxy's response rather than the result of true changes in sea ice. On the other hand, the end of each termination is synchronous in Antarctic temperature and sea ice, but dust tends to reach interglacial levels earlier, again depending on a particular threshold in Antarctic temperature.

POSTER — Constraining future climate warming based on LGM ensemble simulations

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Reducing the uncertainty range of climate sensitivity is a key challenge of climate research and a lot of approaches had been followed to constrain this range. One way of deducing the sensitivity of the climate system to changes in CO2 is to focus on the geologic record that contains information on how sensitively the climate system has responded in the past to a radiative perturbation. In our study we have focused on the LGM climate and used the pronounced glacial temperature anomaly for constraining climate sensitivity. For this purpose we have generated a large model ensemble (based on the CLIMBER-2 model) with different realizations of climate sensitivity. The spread in sensitivities resulted from differences in simulated feedback strengths through a

different choice of model parameters. The simulation design was chosen such that it accounts for the key LGM climate forcings: Northern hemisphere ice sheets, CO2 concentration, vegetation distribution, dust content and orbital constellation. Our simulations showed a rather strong link between the simulated warming due to doubling of CO2 (i.e. climate sensitivity) and the simulated regional LGM cooling. We then used proxy-data from tropical SST regions and from Antarctica to sort out those models that yielded a LGM temperature response inconsistent with the data. Our analysis favours a best-guess sensitivity closed to 3°C while the uncertainty in this estimate covers a range closed to the estimate of the IPCC. By having accounted for uncertainty in the proxy-data, and in the glacial forcing, we could quantify their impact on our estimates of climate sensitivity. The impact of structural model uncertainty is much harder to capture and will be discussed, e.g. the issue that different climate models differ in simulating the dependency of climate feedbacks from the climate state.

POSTER — Polyphony of the multiscale climatic variations during the Pliocene/Pleistocene

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It is well known that climatic variations are of very complex shapes. They are multiscale, apparently chaotic, and integrally nonstationary in the scale of the overall length of almost every paleoclimatic record being considered. Moreover a general trend seems to be existing in the largest scales of many Millions years. This trend probably is induced by the general evolution of the Earth planet and the Solar system as a whole. According to the modern mathematical nonlinear dynamical systems theory one can suppose that shortest-term (the interannual and interdecadal) climatic variations reveal themselves as essentially nonlinear and apparently chaotic responses of the global climate system to different external forces. Lower-frequency (the centennial and millennial) variations can be of a quasi-linear character like oceanic and atmospheric tides. Usually they are of neutral stability, and so nonchaotic in principle. At last, climatic variations of the supra-long scales seem to be more or less direct responses to slowly varying external forces like the famous Milankovitch?s orbital cycles. Studying such complex climatic variations is a great challenge for the international community of climatologists. A new technique of the wavelet and cross-wavelet analysis has been developed in order to clear up the essence of multiscale nonstationary climatic variations. This technique is applied to many proxy (oceanic bottom and ice cores? Tree-rings etc.) climatic records covering the Pliocene/Pleistocene/Holocene time period. As results, many evidences of nonlinearity and fingerprint of different external force effects were obtained such as amplitude and frequency modulations of paleoclimatic variations within a very wide range of time scales. In particular, the phenomenon of a central symmetry of the 8 Late Pleistocene glacial cycles in respect of the Marine Isotope Stage 11 was recognized at the first time. Equatorial insolation over the eccentricity range of time scales (the insolation data by courtesy of M.-F. Loutre) looks to be responsible for this phenomenon. Besides, nonlinear

responses of the global climate system to insolation variations within the precession and obliquity range of time scales such as the period doubling and tripling also seem to be essential to change these cycle length between 80 and 120 kyr, and to turn the well-known saw-tooth shape of these cycles at the moment of the Stage 11.

POSTER — Global kaolinite influx as reliable paleoclimate proxy? No evidence from the Paleocene-Eocene Thermal Maximum.

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The Paleocene-Eocene Thermal Maximum event (PETM at ~55.8 Ma) is regarded as a geological analogue of the currently ongoing climate change due to its worldwide, rapid and intense warming. This major warming has strongly affected the biosphere, particularly the evolution of microbiota (foraminifera and calcareous nannofossils) and the global distribution of mammals. The PETM is defined chemostratigraphically by the onset of global carbon and oxygen isotope excursions recognized in marine and continental depositional settings. Previous authors have suggested that a kaolinite influx witnesses global warming and increased humidity at the PETM. Here we focus on the clay mineralogical (< 2µm) content of five sections, ranging from open marine to terrestrial depositional settings: 1) Dababiya (Egypt, international GSSP of the Paleocene-Eocene boundary, distal platform), 2) Sidi-Nasseur (Tunisia, proximal platform), 3) Doel (Belgium, lagoonal environment), 4) Ailly (France, terrestrial to lagoonal), and 5) Polecat Bench (Wyoming, U.S.A., terrestrial). Carbon isotope analyses have been performed on all these sections, allowing precise correlation of the PETM. The R0 illite-smectite mixed-layers and illite represent the most abundant clay mineral phases within the PETM interval (generally > 80 % of the clay assemblage). Kaolinite contents are poor (usually < 10%) and no systematic influx is recognized. Precise calibration between the clay mineralogy and the chemostratigraphical data shows no direct relation between the PETM and potential kaolinite influxes (appearance or increase of kaolinite). The latter is generally related to chlorite and illite increases, and most probably reflects input of reworked detrital minerals into the deposition areas, in response to sea-level changes and/or tectonic uplift. The kaolinite is inherited from thick kaolinitic saprolites, which have been formed (much) earlier. The time between the formation and the reworking of kaolinite may be long. In conclusion, kaolinite influxes seem not to have any causal relationship with the PETM and should, therefore, not be regarded as a paleoclimatic proxy.
