Modelled ocean changes at the Plio-Pleistocene transition driven by Antarctic ice advance

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

The Earth underwent a major transition from the warm climates of the Pliocene to the Pleistocene ice ages between 3.2 and 2.6 million years ago. The intensification of Northern Hemisphere Glaciation is the most obvious result of the Plio-Pleistocene transition. However, recent data show that the ocean also underwent a significant change, with the convergence of deep water mass properties in the North Pacific and North Atlantic Ocean. We show that the lack of coastal ice in the Pacific sector of Antarctica leads to major reductions in Pacific Ocean overturning and the loss of the modern North Pacific Deep Water mass in climate models of the warmest periods of the Pliocene. These results potentially explain the convergence of global deep water mass properties at the Plio-Pleistocene transition, as Circumpolar Deep Water became the common source.

Mid to late Holocene transition Holocene simulation with the IPSL Earth System Model

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

The Holocene is characterized by long term changes in seasonality induced by insolation that is punctuated by several climatic events. How different feedbacks from the surface hydrology, vegetation or dust have shaped regional trend, seasonality, variability and abrupt events is not well understood. The poster will present the first results of a small multi complexity ensemble simulation with the IPSL model. The objective is to highlight common long term characteristics in seasonal trends depending on regions, the relationship between trend and variability in Indian and African monsoon regions, as well as teleconnections between the precipitation in these regions and the long term evolution of the ENSO phenomenon in the tropics. A particular focus will be put on vegetation changes and the role they play in trends and interannual to multidecadal variability.

Simulated Last Interglacial climates with the Norwegian Earth System Model

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:
Following PMIP3 protocols, we performed four 1000-year long time slices of the Last Interglacial (LIG) simulations (130, 125, 120, 115 ka BP) with a recently developed efficient version of the Norwegian Earth System Model (2-degree atmosphere; 1-degree ocean). We will present large-scale features of the simulated LIG climates, with more focus on the ocean and sea ice dynamics in the North Atlantic and Arctic region. Comparison of our model results with SST proxy data shows reasonable agreement. Early LIG (130 and 125 ka) feature a stonger AMOC and less Antarctic Bottom Water (AABW), whereas late LIG feature a weaker AMOC and more ABWW. Late LIG features more Arctic sea ice in the model, which rejects more salt and leads to a higher SSS in the Arctic. More sea ice also results in higher sea ice export through the Fram Strait and the Denmark Strait. Higher SSS in the Arctic can be exported to the Nordic Seas and the North Atlantic, which counteracts the effects that more sea ice export leads to a fresher sea surface. The net effect is a freshening pattern along the Greenland coast and more saline pattern in the Baffin Bay and the North Atlantic.

Underlying causes of Eurasian mid-continental aridity in simulations of mid-Holocene climate

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:
Climate-model simulations uniformly show drier and warmer summers in central Eurasia during the mid-Holocene, a regional signal which is not consistent with palaeoenvironmental observations. The simulated climate results from a reduction in the zonal temperature index, which weakens westerly flow and reduces moisture flux and precipitation in the mid-continent. As a result, evaporation and latent heating are reduced and sensible heating increased, resulting in substantial surface-driven atmospheric warming. Thus, the discrepancy with the palaeoenvironmental evidence arises initially from a problem in the simulated circulation and is exacerbated by land-surface feedback. Analyses show that this region is also drier and warmer than indicated by observations in the pre-industrial control simulations, and this bias arises in the same way: zonal flow and hence moisture flux into the mid-continent is too weak and land-surface feedback results in dry conditions and surface-driven warming. These analyses pinpoint the processes underlying discrepancies between simulated and observed central Eurasian climates and suggest the need to improve aspects of the model that affect the strength of westerly circulation.

Antarctic Last Interglacial Isotope Peak in Response to Sea Ice Retreat not Ice Sheet Collapse

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:
Several studies have suggested that the Antarctic Ice Sheet was the primary contributor to sea level rise during the last interglacial (LIG; 130,000 to 115,000 years ago), most of which is hypothesized to have come from the unstable West Antarctic Ice Sheet (WAIS). Collapse of the WAIS would contribute ~3.5 m to the 5-9 m sea level rise reconstructed for the LIG. The prevalent hypothesis is that WAIS loss coincided with the peak Antarctic temperature and stable water isotope values from 128,000 years ago (128 ka); very early in the last interglacial. Using Bayesian multivariate linear regression and a statistical model comparison to combine isotope-enabled climate model simulations with Antarctic ice core data, we show that WAIS loss is not consistent with the isotopic evidence at 128 ka. Instead, a 65 ± 7 % retreat of Antarctic winter sea ice area best explains the 128 ka ice core evidence. This finding of a dramatic retreat of the sea ice at 128 ka demonstrates the sensitivity of Antarctic sea ice extent to climate warming. These results may also provide supporting evidence for WAIS loss and sea ice build up later during the LIG.

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Decoupling of temperatures and ice volume in the Middle Miocene: A missing piece of the puzzle?

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:
The geological record documents a dynamic Antarctic ice sheet during the Middle Miocene (16 – 14 Ma) against a background of relatively low CO2. Recent bottom water temperature reconstructions indicate significant bottom water temperature changes during the Middle Miocene Climate Optimum (MMCO, 17-14.7 Ma), but no significant cooling over the major ice sheet growth of the Middle Miocene Climate Transition (MMCT, 14.7-12 Ma). This implies the increase in seawater oxygen isotopic composition at the MMCT represents growth of a larger-than-modern ice sheet. Our new modelling results indicate the mechanism by which this decoupling of temperatures and ice volume can be achieved. An ice-free Antarctic is warm and wet. Surface runoff from a very active hydrologic cycle forms a polar halocline preventing the freezing surface waters from ventilating the deep ocean. Ice sheet growth markedly reduces this precipitation and subsequent runoff, thereby making the near-freezing surface water around Antarctica saltier and able to form bottom water. Once the ice sheet has reached a continental scale, additional vertical growth does not further affect runoff significantly because precipitation has already reduced to a low level. Consequently, the polar salinity and temperatures are also little affected and hence neither is deep water production (which is in all cases produced in the south). Through orbitally paced scaling up and down of deep ocean ventilation, this mechanism is able to offer explanation for both the large amplitude variations in the MMCO benthic isotope records occurring whilst CO2 changes are no greater than 300ppm, and the lower amplitude isotopic variations following the MMCT (Holbourn et al., 2005, 2007, 2013; Kochhann et al., 2016 and references therein). Estimates of the Antarctic ice volume increase at the prior Eocene-Oligocene Transition (34-33 Ma) are equivalent to the modern ice sheet (Lear et al., 2008; Liu et al., 2009). Taken together, our new modelling results and the existing isotope, temperature, vegetation and CO2 reconstructions suggests this large Oligocene Antarctic ice sheet had collapsed by the MMCO. This implies that the dynamism during the Middle Miocene operated on a much smaller ice sheet than previously thought.

Using isotopic model emulation and ice cores to advance our understanding of Last Interglacial ice sheets

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

Far-field sea level records have provided evidence that parts of the Antarctic Ice Sheet and Greenland ice sheet were likely lost during the Last Interglacial (LIG) period, 116-129 thousand years ago. Reconstructing ice sheet changes within the LIG however remains a difficult problem. Sediment cores from beneath the West Antarctic Ice Sheet (WAIS) support the view that parts were lost within the last 1.3 million years (e.g. Scherer et al., 1998), but again the timing of the loss is unknown. And set against this, proximal ice-rafted debris evidence from marine sediment cores has been interpreted to suggest that there was no major loss of the WAIS in the last 250,000 years (e.g. O'Cofaigh et al., 2001) or last 1.8 million years (Hillenbrand et al., 2002). Near field marine and sub-ice sheet sediment core data has not provided conclusive evidence of LIG changes in the WAIS, or the wider Antarctic or Greenland ice sheets. The resultant lack of agreement and knowledge about the ice sheet changes, particularly the WAIS, during the LIG hampers our ability to calibrate models of potential ice sheet loss in the future. Ice cores provide amongst the best dated proximal evidence of LIG change across the Antarctica and Greenland (e.g. Masson-Delmotte et al., 2011; Capron et al., 2014), it is therefore very helpful if we can use ice core measurements to provide constraints on the rate and timing of ice sheet change throughout the LIG. Holloway et al. (2016) thus explored the ice core signal of WAIS change; we found that ice sheet meltwater and/or ice sheet morphology changes would be recorded in Antarctic and Greenland ice cores. Here we present our recent progress on reconstructing ice sheet changes, simulating how possible LIG ice sheet and sea ice changes would be imprinted on Antarctic and Greenland ice cores using isotopically enabled climate model simulations of the LIG. We present initial results from a novel statistical approach to this problem, using isotopic model output emulation, to test the interplay of ice sheet, meltwater, and sea ice changes on the ice core record.

The role of vegetation and dust reduction in altering the West African Monsoon and the climate worldwide during the mid-Holocene Green Sahara period

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

Understanding the West African monsoon (WAM) dynamics in the mid-Holocene (MH) is a crucial issue in climate modelling, because climate models typically fail to reproduce the extensive precipitation suggested by proxy evidence. We show that this discrepancy may be largely due to the assumption of both unrealistic land surface cover and airborne dust concentration, which strongly feed back into the WAM strength. However, the climate response associated to the greening of the Sahara are not limited to North Africa but affect the entire globe: the ENSO activity and mean state is significantly altered, the tropical cyclone activity is enhanced in both hemisphere in particular over the Caribbean Sea and Gulf of Mexico, the Indian Summer Monsoon is intensified, the East Asian Monsoon shifts northward and the extra-tropical is also altered. Compared to the case in which only orbital forcing are considered, all these climate responses under a green Sahara condition have better agreement with the mid-Holocene climate indicated by paleo-proxy records. Sensitivity experiments from a fully coupled ocean-atmosphere model EC-Earth show that the strengthening of the WAM induced by the orbital changes and amplified by the greening of the Sahara, shift and strengthen the Walker circulation, which triggers a chain of events that are responsible for the above-mentioned changes.

Changes in West African monsoon precipitation: the competition between large-scale dynamics and local thermodynamics

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

The changes in West Africa Monsoon (WAM) precipitation are studied by the convective regimes and energetic analyses on the basis of three simulations of mid-Holocene (MH), sstClim4xCO2 and abrupt4xCO2. The atmospheric only simulation of sstClim4xCO2 shows similar changes in the pattern of WAM precipitation as that in the MH. The large-scale dynamics is found to be the main contribution to the changes in WAM precipitation, although the external forcing is completely different in these two simulations. The analyses of the moist and dry static energy (MSE and DSE, respectively) are also similar in these two simulations, showing a northward shift of the MSE and DSE maxima. However, such changes are not conclusive through models in abrupt4xCO2 simulation. Interestingly, in the very a few years when the 4xCO2 is imposed, the pattern of precipitation change is similar to those of MH and sstClim4xCO2, but the pattern reversed when the coupled system reaches an equilibrium state. The warming in the ocean tends to reduce the land-sea thermal contrast that leads to a negative contribution of large-scale dynamics, while the increase of CO2 and water vapor in the atmosphere tends to enhance the local thermodynamics. The large model spread thus result in the completion between large-scale dynamics and local thermodynamics in the models.

Influence of cloud radiative effects on tropical rain belts in the mid-Holocene

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

Paleoenvironmental data, in particular vegetation and lake-status in Sahara shows that at mid-Holocene (6,000 years ago) African monsoon extended much further north than today. Much of this change results from the changes in insolation driven by precession of the Earth’s orbit, but in the state-of-the-art climate models, this factor alone is insufficient to explain the magnitude of the change. Previous studies showed that ocean and vegetation feedbacks affect the mid-Holocene monsoon and that the incorporation of these feedbacks in models improves the simulation of the hydrological cycle. However, it is not sufficient to reduce the discrepancies between simulated and reconstructed surface climates. In this study, we investigate the impacts of atmospheric cloud radiative effects (ACRE) on tropical rain belts during the mid-Holocene. This is done by running a general circulation model with and without cloud-radiation interactions using the IPSL model. The ACRE impacts include (1) a small northward shift of the tropical rain belts, (2) a decrease in tropical precipitation, (3) a narrowing and a strengthening of the ascending motions of the tropical overturning circulation, and (4) an intensification of the African easterly wave activity, but a contraction of tropical rain belts and decrease in precipitation over West Africa. Although the last impact in the mid-Holocene simulation is much larger than one in the control simulation, it is not enough to represent observed hydrological cycle over West Africa.

Mechanism of ENSO weakening during mid-Holocene

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

The mechanism of El Niño-Southern Oscillation (ENSO) amplitude change during the mid-Holocene (MH) is investigated by the Bjerknes stability (BJ) index through the model simulations from the Paleoclimate Modelling Intercomparison Project Phases (PMIP) 2 and 3. Results show that the weakening of thermocline (TH), zonal-advection (ZA) and Ekman (EK) feedback terms are the major drivers for the weakened ENSO amplitude in MH. And then we go one step further to discuss the key factors in regulating the above drivers and reveal that the weakening of TH, ZA, and EK terms are attributed to the weakened thermocline response to zonal wind stress anomaly in MH compared to PI. Such changes are due to the flattened meridional structure of ENSO-related interannual anomaly field (e.g, zonal wind stress anomaly field) in MH. The meridional structure change of ENSO-related anomaly field results from the strengthening of mean surface poleward meridional current (or mean subtropical cell). Quantitative diagnosis of PMIP simulations shows that the mean STC change might be a key factor, which plays an essential role in determining the changes of TH, ZA, and EK feedback terms, and thus the change of ENSO amplitude in MH.

Paleoclimatic constraints on monsoon precipitation extremes over South Asia

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:
Knowledge about past climatic variations is critical for making reliable assessments of future changes in global and regional monsoon hydrological cycle. Paucity of long-term climate observations, limited spatio-temporal coverage of climate proxy records and complexities in modelling multi-scale variations of monsoon precipitation, pose inherent challenges in comprehending the behaviour of monsoon precipitation extremes in the past. Historical climate records for the 19th and 20th centuries provide valuable information on teleconnection linkages of the Asian monsoon precipitation with tropical and extra-tropical modes of climate variability. This study presents analyses of paleo-climate simulations for the mid-Holocene (~ 6000 years BP) and Pre-Industrial conditions (late 19th century) using a global climate model having high-resolution (

MIROC4m experiments using state-of-the art boundary conditions for the Late Pliocene and for the pre-PETM to Early Eocene

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)
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Abstract:
Warm periods of the past offer the chance to test climate models, not just through comparisons with proxy data, but also through model intercomparisons. The idea of an analogue to future global climate change, albeit with caveats, has additionally created much interest in these past periods. Two intercomparison projects have been established to utilise up-to-date paleodata to reconstruct formal boundary conditions for climate simulations. The Pliocene Model Intercomparison Project (PlioMIP), now in its second phase, focuses on the late Pliocene, approximately 3 Ma, while the Deep-Time Model Intercomparison Project (DeepMIP) looks back further to the period between the latest Paleocene and the early Eocene, approximately 55-50 Ma. Here, we present some results using the mid-resolution MIROC4m coupled atmosphere-ocean general circulation model. These results will focus on the most basic experiments specified in the projects, adhering to the protocols and using the boundary conditions provided.

HadCM3 PlioMIP Phase 2 Contribution: Enhanced Boundary Condition Core Experiments.

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

We present an overview of the UK's HadCM3 climate modelling contribution to the Pliocene Model Intercomparison Project Phase 2 (PlioMIP2) as part of PMIP4. We outline the process of setting up HadCM3 with the enhanced PRISM4 boundary conditions and discuss in detail the assumptions and choices made. In particular we focus on 1) efforts to maintain modelling consistency with previous PlioMIP HadCM3 modelling, 2) efforts to minimise potential sources of residual model drift, and 3) understanding the limitations of the model when simulating palaeogeographic changes. We then proceed to outline the process of HadCM3 and vegetation model spin-up and quantify the equilibrium state. We then present data from the final climatological mean state of the two core experiments - the Pre-industrial control (E280) and Pliocene control (Eoi400) - and compare PlioMIP2 against PlioMIP HadCM3.

From PLIOMIP to PMIP-"Quaternary" climate: a coupled climate /ice sheet simulation of the Pliocene-Pleistocene transition.

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)
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Abstract:
The early to mid-Pliocene was punctuated by cold and warm phases (5.3 to 3.3 Ma) [Lisiecki et al. 2005]. This period ended up with the major MIS M2 glaciation [Tan et al. 2017] and was followed by a warm and rather stable period called the mid Piacenzian warm period (mPWP, 3.3-3.0 Ma), which was the focus of the PLIOMIP1 project [Haywood et al. 2016]. Here, our purpose is to investigate the evolution of the Greenland ice sheet (GrIS) during the 3.0-2.5 Ma interval, which embraces the commonly accepted onset of perennial Greenland glaciation. We adapted and developed a specific tool that was first used to study the Eocene-Oligocene Antarctic glaciation (34 Ma) [Ladant et al. 2014]. This physically based method uses a matrix constructed from 56 IPSL simulations with various combinations of orbital forcing, CO2 concentration and GrIS configuration and creates a continuous climatic forcing based on the temporal evolution of the insolation, CO2 and ice sheet. This method allowed us to investigate the response of the GrIS to pCO2, in a first step by keeping the CO2 temporal evolution constant and in a second time, by using published pCO2 records from the literature. The constant CO2 simulations demonstrate the existence of a threshold for perennial GrIS onset: under 280 ppm it is possible to trigger and maintain the GrIS whereas above 320ppm the building of a large GrIS is not possible. These simulations also reveal the impact of the favorable insolation at 2.7 Ma in order to build the GrIS. Next, we force our model with recent pCO2 reconstructions from the literature [e.g., Martinez et al. 2015] to discuss the consistency between model results and available data, and also compare our simulated GrIS evolution with the recent model study of Willeit et al. 2015. Finally, we propose a CO2 scenario, which produces a GrIS evolution in good agreement with SST reconstructions and IRD records.

Mean climate and ENSO changes in three typical warm periods simulated by FGOALS-s2

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

We have analyzed the basic warming patterns among three typical periods - the mid- Holocene (MH), Medieval Warm Period (MWP), and the twentieth century warming (20CW) - and carried out a comprehensive heat budget analysis using four experiments simulated by FGOALS-s2. And we found that the model simulates similar spatial warming patterns in all three warm periods, e.g. stronger warming appears in the high latitudes. However, changes in surface air temperature (SAT) over the tropical regions are different: a significant warming occurs in the 20CW and MWP but a significant cooling in the MH. The heat budget analysis suggested that SAT changes are mainly induced by the heat flux. We further investigate how the ENSO change induced by the different external forcing in the three warm periods and found that the ENSO amplitude decrease in the MH but increase in the MWP. FGOALS-s2 simulated positive skewness in three warm periods, but underestimate the simulation of ENSO asymmetry.

Tracing changes in Neogene Antarctic hydrology using a data-model approach

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)
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Abstract:
With the advancement of both isotope-enabled climate models and our understanding of water isotope proxies, the hydrological cycle is becoming an increasingly important focus of paleoclimate studies. Of particular interest are periods of warmth and reduced ice cover such as the middle Miocene or the Pliocene, where exploring changes in hydrodynamics can constrain fundamental questions around the climate system. Here, we present a data-model approach to understanding changes to the hydrological cycle. Wood fossils and terrestrial sediments in the late Neogene (3-17 Ma) Sirius Group in the Transantarctic Mountains provide a unique insight into Antarctic palaeoclimate during a period of Antarctic ice sheet retreat. We use plant compound isotopes (?18O and ?2H) to reconstruct precipitation isotopes, suggesting that ancient precipitation was significantly enriched relatively to the modern (~12‰ and 100‰ for ?18O and ?2H, respectively). This result is consistent with reconstructed Antarctic summer paleotemperatures of 5 °C and implies increased moisture delivery to the continent with a shorter vapour transport pathway relative to the modern. We then present data from atmospheric tracer experiments using isotope-enabled general circulation model (HadCM3) to explore in detail changes in moisture source and atmospheric circulation during a vital period of Antarctic climate history.

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The PMIP4-CMIP6 Simulations for the Mid-Holocene and Last Interglacial with the Community Earth System Model

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)
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Abstract:
Two interglacial epochs are included in the suite of Paleoclimate Modeling Intercomparison Project (PMIP4) simulations in the Coupled Model Intercomparison Project (CMIP6). Experimental protocols have been established for the Tier 1 simulations of the mid-Holocene [midHolocene, 6000 years before present] and the Last Interglacial [lig127k, 127,000 years before present] (Otto-Bliesner et al., Geoscientific Model Development Discussions, 2016). These equilibrium simulations are designed to examine the impact of changes in orbital forcing at times when atmospheric greenhouse gas levels were similar to those of the preindustrial period and the continental configurations were almost identical to modern. The changes in insolation are characterized by enhanced seasonal contrast in the northern hemisphere (NH) (and reduced seasonal contrast in the southern hemisphere, SH), with these changes stronger in the lig127k experiment than the midHolocene experiment. Here, we report on the lig127k and midHolocene simulations with the Community Earth System Model, version 2 (CESM2), the same model and same resolution as is being used for the CMIP6 DECK, historical, and future projection simulations. The results will be compared to the CMIP5/PMIP3 simulations with the Community Climate System Model, version 4 (CCSM4). Otto-Bliesner, B.L. et al., 2016: The PMIP4 contribution to CMIP6 - Part 2: Two Interglacials, Scientific Objective and Experimental Design for Holocene and Last Interglacial Simulations. Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-279.

A 75-Year Long Absolute SST Reconstruction Reveals Last Interglacial Variability in the Tropical Atlantic Warm Pool: Comparison of Model and Coral-Based Reconstructions

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

The Last Interglacial (LIG), when sea level was ~6 m higher than today, serves as an analog for future climate scenarios yet only a few paleoclimatic reconstructions with seasonal to decadal resolution exist from this interval. Hispaniola, in the northern Caribbean Sea, is a desirable site for producing sea surface temperature (SST) reconstructions as it is located in the northern sector of the Atlantic Warm Pool (AWP), a primary moisture source region for precipitation in Central and North America, and this location has significant correlations with SST and precipitation anomalies for much of the region. Here we present an early LIG (128.6 ka) monthly-resolved coral Sr/Ca-SST reconstruction from a well-preserved Siderastrea siderea subfossil coral spanning 75 years from the northern coast of Hispaniola (19.913ºN, 70.925ºW), which is one of the longest subfossil coral reconstructions for any interval and the longest for this region. We compare our LIG SST reconstruction with three modern S. siderea microatolls, the longest spanning 84 years (1926–2010 CE), near Port-au Prince, Haiti (18.479070°N, 72.668659°W), as well as the CCSM3 125 ka LIG model simulation spanning 300 years. We find similar SST seasonal cycles (3.7ºC) in the LIG coral and simulation that are greater than those in the modern Haitian corals, observed SST (ERSSTv4.0 and HadISSTv1.1), and CCSM3 20th century simulations. This seasonal variability is consistent with the findings of other LIG coral reconstructions in the tropical Atlantic Ocean suggesting that orbital insolation changes are driving LIG SST seasonality in this region. Furthermore, our LIG reconstruction reveals larger multidecadal (2.8ºC, ~20–30 years/cycle) and interannual variability (3.0ºC, ~3–8 years/cycle) than the modern coral reconstructions and SST records in the AWP yet similar variability is present in the LIG model simulation. This interannual and decadal variability may reflect variations in the northern extent of the AWP on these time scales, which may covary with trade wind strength, westward moisture transport to the Americas, and precipitation in the Caribbean.

Solving the enigma of Arctic amplification during the Mid-Piacenzian Warm Period using the new Community Earth System Model

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

Polar amplification is key to understanding the stability of the cryosphere and sensitivity of the earth system to CO2 forcings. A potential analogue for estimating future Arctic warming is the Mid-Piacenzian Warm Period (3.264 – 3.025 Ma). During this time interval, the paleogeography and paleotopography were similar to present-day, except for a few gateway changes. The CO2 level was also similar to today, with a best estimate of 400 ppm. The MPWP shows strong Arctic amplification, which is epitomized by the existence of circum-Arctic boreal forests, a large reduction in Arctic sea ice, and absence of the western Greenland ice sheet. These findings suggest a precarious state of northern high latitude cryosphere at the 400 ppm CO2 level. However, earth system models that participated in phase one of the Pliocene Model Intercomparison Project (PlioMIP1) had limited success in simulating Arctic amplification during the MPWP, raising doubts about model sensitivity and the analogue nature of the MPWP. Since PlioMIP1, several improvements have been made to both the MPWP boundary conditions and the models' climate physics. These improvements allow us to simulate the northern high latitude warmth and Arctic low sea ice state that are broadly consistent with MPWP proxy records. Based on a series of sensitivity tests, we further identify that 1) the MPWP North Atlantic warmth is attributable to the closed Arctic Ocean gateways, 2) the Arctic low sea ice state is partly due to reduced cloud cover over circum-Arctic oceans under pristine atmospheric conditions, and 3) circum-Arctic terrestrial warming can largely be explained by a vegetation feedback from high density boreal forests. We argue that the latter two changes are relevant to future climate change at the centennial to millennial time scale. In this regard, the MPWP remains a potential analogue for the equilibrium climate state of the RCP2.6 world.

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Early Last Interglacial climate over Europe: sensitivity experiments and model-data comparisons

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)
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Abstract:
Previous simulations (e.g. PMIP3) of the early Last Interglacial (LIG) were unable to reproduce the asynchrony in temperature response between northern and southern hemisphere suggested by ocean core reconstructions (Capron et al. 2014) when solely forced with known orbital and greenhouse gas forcings. More recent sensitivity experiments with realistic freshwater forcing representing melting of northern hemisphere ice sheets (Stone et al., 2016) provided a possible mechanism to account for a colder than present North Atlantic and warmer than present Southern Ocean. Such simulations have been primarily compared to available high latitude ice core and ocean data, partly due to sparsity of terrestrial palaeodata. Here, we expand these early LIG sensitivity simulations to consider orbital, greenhouse gas, freshwater hosing, modified ice sheets, and vegetation in their impact over Europe, and compare climate changes to terrestrial palaeodata including pollen-based climatic variables.

Pliocene Climate Modes of Variability Part I: Tropical modes based on SST

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)
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Abstract:
The dominant modes of large-scale climate variability, based on sea surface temperature (SST), extend over large areas of the globe. SST-based modes have direct influence over Tropical Variability. In this work we show preliminary results for the SST-based modes of climate variability for the WAIS-free Pliocene Atlantic, Pacific and Indian oceans relative to the Pre-Industrial climate and 20th century HADISST observations. The mid-Pliocene warmer climate has been attributed to elevated CO2 concentration in the atmosphere, which makes it a perfect analogue for studying the climate at the end of the 21st century. It is the last period of Earth's history with increased concentrations of atmospheric CO2 and global mean temperatures. Here we present the Pliocene modes of variability in the Pacific and Atlantic using a simulation of the mid-Pliocene Warm Period run with the Community Climate System Model version 4 developed at the National Center for Atmospheric Research (CCSM4-NCAR). The preliminary results show the possible changes in the variability modes in an ice-free WAIS world compares to the 20th C warming.

High sea level for the Last Interglacial: Contribution of the Antarctic ice sheet

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

Understanding the dynamics of warm climate states has gained increasing importance in the face of anthropogenic climate change. During the Last Interglacial (LIG, ~128 to 116 ka), greenhouse gas concentrations and high latitude insolation were higher than pre-industrial levels, causing a high-latitude warming (Turney and Jones, 2010; Pfeiffer and Lohmann, 2016). As a result of this modestly warmer climate, polar ice sheets were smaller and estimates report that the global mean sea level was 6-9 meters higher than today (Dutton et al., 2015). However, proxy reconstructions indicating a high-stand of LIG sea level are subject to uncertainties in timing and magnitude (Rovere et al. 2016). We present a suite of model results to evaluate the thresholds and feedbacks and will compare the simulations with paleoclimate reconstructions from high southern latitudes. Our atmosphere-ocean isotopic simulation of the LIG indicate that temporal and spatial gradients in ?18O do not match, adding uncertainty to the paleothermometer for past warm climates. A simulation using a reduced West Antarctic Ice Sheet (WAIS) is consistent with the isotopic signature found in ice core data (Masson-Delmotte et al., 2011). Ice sheet model simulations indicate that a pronounced subsurface oceanic warming can destabilize the WAIS, resulting in an oceanic gateway between the Ross and Weddell Seas (Sutter et al. 2016). We detect a threshold behaviour of the WAIS in the range of 2-3°C warming. A sensitivity study using the new oceanic gateway between the Atlantic and Pacific Oceans as bathymetrical boundary condition, indicates that this region would be covered by sea ice. Mixing due to sea-ice formation prevents a pronounced warming around the WAIS and would stabilize the WAIS. Thus, the sea level question of the LIG (Sutter et al. 2016; DeConto and Pollard, 2016) is uncertain. Past sea-level records located far from Antarctica and hence relatively unaffected by isostatic changes, show that it is possible that the end of the LIG was characterized by a sudden meltwater pulse (O’Leary et al., 2013), that made the sea level rise abruptly.

Impacts of boundary conditions on the simulated mid-Pliocene climate assessed using the full suite of PlioMIP2 experiments performed with the CCSM4 model

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)
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Abstract:
The Pliocene Model Intercomparison Project, Phase 2 (PlioMIP2) is an international collaboration to simulate the climate of the mid-Pliocene interglacial, marine isotope stage KM5c (3.205 Mya), using a wide selection of climate models with the objective of understanding the nature of the warming that is known to have occurred during the broader mid-Pliocene warm period. PlioMIP2 builds upon the successes of PlioMIP by shifting focus onto a specific interglacial and by using a revised set of geographic and orbital boundary conditions (BCs). Recently, we have shown [Chandan and Peltier, 2017] that with the revised BCs the CCSM4 model simulates a mid-Pliocene which is more than twice as warm as that with the BCs used for PlioMIP Phase 1. The warming is more enhanced near the high-latitudes which is where most of the changes to the PlioMIP2 BCs have been made. The elevated warming in the high-latitudes leads to a better match of the simulated climatology to proxy based reconstructions than what was possible with the previous version of BCs. We have recently completed additional PlioMIP2 sensitivity experiments using the CCSM4 model. Altogether, the nine experiments we have completed for PlioMIP2 constitute simulated model years at resolution. This is very likely the most extensive effort at any single institution, to date, to understand a specific time period of the past. Here, we present results obtained from applying a factorization methodology, that has been successfully used to understand the climate of past warm periods [Heinemann et al., 2009, Lunt et al., 2012], to investigate the impact of changes to the individual BCs (compared to present-day) in PlioMIP2 on the simulated mid-Pliocene climate. In addition to the PlioMIP2 simulations, we are currently performing simulations with an alternative set of BCs for the mid-Pliocene that we have reconstructed ourselves. These simulations allow us to assess the sensitivity of the mid-Pliocene climate to changes in global bathymetry and topography, which would not have been possible with only the PlioMIP2 experiments. References: Chandan, D. and Peltier, W. R., Clim. Past, in revision, 2017 Heinemann et al., Clim. Past, 2009 Lunt et al., EPSL, 2012

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MAGIC-DML: Combining climate and ice sheet modelling with field-based data to reconstruct the long-term glacial history of East Antarctica

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

Repeated build-up and retreat events across different sectors of the Antarctic ice sheet (AIS) were tightly linked to global climate variations over glacial-interglacial cycles. However, the long-term changes in the volume of the East Antarctic ice sheet (EAIS) and its contribution to the sea-level variations remain poorly understood. The international research project MAGIC-DML aims to constrain the past vertical extents and volumes of the EAIS and shed light on the regional long-term climate evolution using a combination of direct evidence from field-based reconstructions and numerical ice-sheet and climate simulations. As part of this, we will focus on the ice sheet history since the mid-Pliocene warm period, while zooming in on the past warm interglacial intervals to provide insights into the responses of the EAIS to warmer-than-present climate and ocean conditions. In these numerical reconstructions we will employ climate fields from our in-house simulations with the Community Climate/Earth System Model and outputs of general circulation models provided by the PMIP 2-4 to drive the Antarctic ice sheet simulations. We will build upon the approach presented in our recent study where the performance of several present-day climate data sets from CMIP5 has been evaluated during the initialization of an AIS model. This initialization utilizes the observed ice elevation and thickness to derive heterogeneities in the basal sliding parameters for the grounded ice sheet sectors and melting and freezing rates under ice shelves. We have evaluated different sets of the inferred sub-glacial parameters and compared the resulting dynamical states of the AIS with observations to demonstrate that this approach can be used to identify biases in the climate model outputs across the Antarctic continent. Our results indicate that similar methods can be adopted to evaluate the skill of paleoclimate model reconstructions of the periods for which only fragmentary data on ice geometry are available.

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Characterizing the mid-Holocene tropical atmospheric hydrologic cycle using simulated water isotopes in iCAM5

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)
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Abstract:
Despite successes in evaluating variability in precipitation patterns over the Holocene, significant uncertainties remain in interpretations of rain intensity, domain, and frequency from the diverse proxy records available. To reconcile point-wise proxies with spatially constrained circulation in the tropics, we used an AMIP-style run of the isotope-enabled Community Earth System Model (iCESM) to study the atmosphere and land components of the mid-Holocene (6.2 ka) hydrological cycle. We forced the simulation with SST and sea ice data from a fully-coupled simulation of the mid-Holocene using CCSM4, the predecessor to iCESM. All other forcings, including orbital parameters and greenhouse gas concentrations, were prescribed in accordance with PMIP4 specifications. Here, we present findings from the mid-Holocene simulation with respect to a control simulation of the pre-industrial period (PI). In agreement with previous studies, our simulation produced a wetter Sahara and Arabian Peninsula during the mid-Holocene. Using simulated water isotopes as a tracer of atmospheric transport processes, we found evidence that increased convergence of Atlantic evaporation was the primary source of increased moisture availability over the Sahara. In the maritime continent, precipitation stable isotope ratios were depleted relative to the PI, especially over land masses such as the Malaysian Peninsula, Sumatra, and Borneo. These depletions spatially correspond with lower troposphere water vapor isotope ratios more accurately than with precipitation rate. This provides evidence that moisture source was a more important factor for precipitation stable isotope ratios than, for instance, convection strength or precipitation amount. The results of this study allow for interpretations of proxy data in the context of the regional atmospheric hydrologic cycle rather than local first order variables such as precipitation amount and highlight the value of using direct simulation of isotope ratios when evaluating model performance.

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Coupled Long-Term Evolution of Climate and the Greenland Ice Sheet During Past Warm Periods: A Comparison for the Last Interglacial and the Late Pliocene

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

The Greenland Ice Sheet is expected to contribute increasingly to global sea level rise by the end of this century, and potentially several meters in this millennium, but still with considerable uncertainty. The rate of Greenland melt will impact on regional sea levels. To understand the response of the Greenland ice sheet to future warming, we are studying two warm periods in the past, from which there are relatively abundant and well-dated proxy records: e.g. the last interglacial (LIG) warm period and the late Pliocene, as potential process analogues for centuries to come. The LIG warming is primarily attributed to high boreal summer insolation. The late Pliocene is thought to represent the long-term climate response to near-current concentrations of CO2, though the North Atlantic region may also have been influenced by altered ocean heat transports in response to closed Arctic gateways. Here we examine the transient climate system response to the late Pliocene high CO2 and LIG high boreal summer insolation in two parallel multi-millennial experiments. We use the Community Earth System Model, version 2 (CESM2) fully coupled to the Community Ice Sheet Model, version 2 (CISM2), simulating the GrIS as an interactive component of the coupled climate system. The main focus of the analysis is on how the GrIS responds to differences in the imposed radiative forcing. Results will highlight the transient evolution of the ice sheet and how the surface mass balance (patterns of ablation and accumulation) and mass loss compare to data-based reconstructions of past climate states. We also discuss how these well studied past climate states may be informative in order to constrain the future evolution of the ice sheet.

Quantification of process contribution to Arctic amplification during the mid-Pliocene in EC-Earth simulation

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:
Arctic amplification is becoming one of the most highlighted issues while the record of global warming and Arctic sea-ice extent minimum have been refreshed frequently over the last decade. As a potential analogue of future climate projection, the Arctic amplification in mid-Pliocene is of special interest as its magnitude is significantly greater than that of present, though the carbon dioxide concentration is comparable during the two periods. Strong Arctic amplification that comparable with PRISM reconstructions is identified in a mid-Pliocene simulation with EC-Earth. A quantification of process contribution using the Climate Feedback and Response Analysis Method (CFRAM) shows that the largest contributor to Arctic amplification is sea-ice albedo feedback and cloud feedback plays a secondary role, whereas the latent and sensible heat fluxes largely offset Arctic amplification through a negative feedback. Significant sea-ice melting is found during summer months from June to October. The large area of open-water facilitates oceanic dynamical process to store large amount of heat content in the ocean. The stored energy is discharged in winter to sea surface, heats the overlying atmosphere through turbulent heat fluxes, and thus maintains the more pronounced Arctic amplification in winter in spite of no incoming solar radiation during polar night.

Quantifying albedo and insulation effects of Arctic sea ice in the Pliocene simulation

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)
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Abstract:
Arctic sea-ice extent minimum have been refreshed frequently over the last decade. As the sea ice retreats, its reflectivity and insulation decrease. This leads to the changes in surface heat budget directly or indirectly through overlying cloud and water vapour. In this work, the Pliocene simulation with EC-Earth climate model is performed as an analogue for future climate projections. The EC-Earth Pliocene simulation shows a strong Arctic amplification featured by pronounced warming SST over North Atlantic in particular over Greenland Sea and Baffin Bays, which is comparable with geological SST reconstructions documented in Dowsett et al. (2012). In order to reveal underlying physical processes, the air-sea heat flux variation in response to Arctic sea ice change is quantitatively assessed by a climate feedback and response analysis method (CFRAM) and an equilibrium feedback assessment (EFA)-like approach. Our analyses show that the albedo effect is dominant in summer, a 1% decrease in sea ice concentration could lead to an approximate 2 Wm-2 increase in short wave solar radiation through open sea surface. The insulation effect is attributed mainly to turbulent heat flux, which releases heat from the ocean to atmosphere prominently in winter. The sea ice decline accelerates the turbulent exchange between the ocean and atmosphere. We found that insulation effect in winter is slightly stronger than albedo effect in summer, thus explains the stronger warming amplification in winter than in summer.

Understanding the enhanced aridity in Eocene Asian inland: the roles of global cooling and early Tibetan Plateau uplift

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)
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Abstract:
Evolution of the aridity in the Asian inland is now a hot topic in the study of the Cenozoic climate in Asia. Recent geological evidence has pushed the earliest Cenozoic Asian inland aridification back to the Eocene. This enhanced Eocene aridity in the Asian inland is related to combined impacts from global cooling, topography uplift and land–sea reorganization. It was widely believed that global cooling led to this aridification. Here, we carry out climate simulations to demonstrate that the early uplift of Tibetan Plateau is also important in the enhanced Asian inland aridity during Eocene. Our simulations support the observed enhanced Asian inland aridity during Eocene observed from geological evidence. Both the early uplift of Tibetan Plateau global cooling induced by decrease in atmospheric CO2 concentration contribute to the enhanced Asian inland aridity, while changes in land–sea distribution do not. The early uplift of the Tibetan Plateau contributed to the long-term Asian inland aridification during the Eocene, whilst the variations in the atmospheric CO2 concentration are more important in modulating the regional aridity on short timescale.

Modelling the onset of North Atlantic Deep Water formation across the Eocene-Oligocene Transition

Session: Warm Climates (Mid-Holocene, Last interglacial, Deep-time, Pliocene)

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Abstract:

Geological evidence suggests that North Atlantic Deep Water (NADW) first formed around the Eocene-Oligocene Transition (EOT; 34 Ma), coinciding with the large-scale glaciation of Antarctica. In earlier periods, deep water is thought to have formed in the Southern Ocean and possibly the North Pacific. Here we investigate possible causes of this reorganization of the deep circulation. We present novel EOT simulations using the coupled climate model GFDL CM2.1 adapted to late Eocene paleogeography. Using this paleogeography, we find that the North Atlantic becomes very fresh, which prevents NADW formation. Instead sinking occurs in the North Pacific and Southern Ocean in agreement with Eocene circulation proxies. We test the role of greenhouse forcing by varying the CO2 to values of 400, 800 and 1600 ppmv, but the cooling alone does not substantially alter the preferred sinking regions. We further test the effect of closing the Arctic-Atlantic gateway, in light of recent evidence that the Arctic Ocean became isolated at the EOT. The gateway closure shuts off freshwater export from the Arctic to the Atlantic. This change enables a strong salinification of the North Atlantic that triggers the onset of NADW production.