Final Preport for Project **1023**

Project title: **Tipping Points of Lake Systems in the Arid Environments of Central Asia (Q-TiP)**

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The project Q-TiP (part on the CAME II project) aims to investigate the controls on water resources in Central Asia in order to improve our understanding of the mechanisms involved in the development of arid environments and their relevance for present-day and potential future climate change. In the frame of the Q-Tip project we conduct climate model experiment with ECHAM5-wiso, which is the 5$^{th}$ version of the General circulation model ECHAM with stable oxygen isotopes implementation. This numerical tool allows us to perform high-resolution simulations for different time slices corresponding to key periods through the Neogene. Addition WRF simulations nested in the ECHAM5-wiso model outputs (the nested WRF simulations are handled by collaborators from the Technische Universität Berlin) allow to test the hypothesis that mega lakes in Central Asia are able to sustain themselves through regional water recycling in spite of global trends in climate that would favour their disappearance. Furthermore, the ECHAM5-wiso is a unique tool for identification of potential global tipping points in the atmosphere that lead to the development of arid environments. ECHAM5-wiso's ability to simulate precipitation $\delta^{18}O$ ratios admits further evaluation of model performance and paleoclimate reconstructions via comparison with geochemical analyses conducted within the project. Finally, combined to the records from deep boreholes from the Qaidam Basin and Gaxun Nur Basin together with geomorphological work from Gaxun Nur and Orog-Nur Basin, the ECHAM5-wiso simulations allow us to answer the questions on the ability of lakes to sustain themselves in arid environments over long periods of time and on the tipping points leading to their disappearance.

During this project we conducted ECHAM5-iso simulations for the following time slices: present-day (AMIP-style, PD), pre-industrial (PI), Mid-Holocene, Last Glacial Maximum (LGM), Pliocene (PLIO), and Miocene (Mio). Note, that all numerical simulations were conducted in high spatial and temporal resolution (T159L31, ca. 0.8°x0.8° and 31 vertical levels, 6 hour output frequency). This outstanding numerical effort is necessary for successful nesting to the WRF model. With the Pliocene simulation we examine the Asian hydroclimate under higher greenhouse gas concentrations, warmer oceans and reduces ice sheets. In contrast, the LGM simulation explores the climate response to "cold" paleo boundary conditions: large ice sheets, cold oceans and lowered greenhouse gas concentrations. Finally, the Mid-Holocene experiment was designed to examine the climate response to a change in the seasonal and latitudinal distribution of incoming solar radiation (insolation) caused by orbital forcing.

Present-day (years from 1989 to 2016) high resolution (T159L31, ca. 0.8°x0.8° and 31 vertical levels, 6 hour output frequency) ECHAM5-wiso control simulation was conducted using PCMDI AMIP boundary conditions v1.1.3 (release 2018). This simulation has been validated by observational datasets including NCEP/NCAR and ERA40 re-analyses as well as by local observations of $\delta^{18}O$ from GNIP stations and published isotopic data and show good ability of ECHAM5-wiso to reproduce the hydrological cycle in the Central and High Asia. This simulation is the control experiment for all simulations to follow. Furthermore, a high resolution simulation was conducted for boundary conditions of pre-industrial times and the LGM. Pre-industrial (PI) ocean boundary conditions were taken from the AMIP2 data; boundary sea surface temperature and sea ice concentration were derived from a coupled atmosphere-ocean model ECHO-G (Lorenz and Lohmann, 2004) as described in Dietrich et al (2013). Vegetation conditions for the LGM simulation has been constructed from PMIP (http://pmip2.lsce.ipsl.fr) data (Braconnot et al. 2007) and interpolated using vegetation model outputs (Arnold et al.2009). Green house gas concentrations and orbital parameter during LGM and pre-industrial times are based on Dietrich et al. (2013) and Otto-Bliesner et al. (2006). Results from the LGM simulation show significant differences atmospheric dynamic, precipitation patterns and other variables relevant for understanding the onset in large-scale aridity in the Asian regions (and therewith addressing major questions of the Q-Tip project).

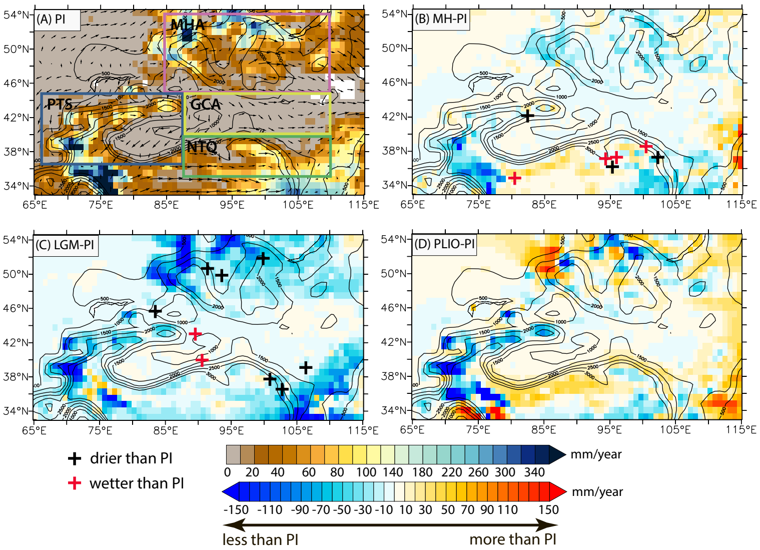


**Figure 1.** *ECHAM5 simulated annual mean effective moisture (precipitation – evaporation) for PI (A) and changes in effective moisture compared to PI for MH (B), LGM (C), and PLIO (D).*

Based on performed paleoclimate simulations (MH, LGM, and Pliocene) water balance over the Central Asia region has been estimated. Today, inner regions of Central Asia (Fig. 1, GCA region), including Tarim Basin, Taklimakan Desert, Gobi desert are characterized by extremely arid conditions. Our modeling results for the PI experiment are in agreement with observed patterns: ECHAM5 simulates extremely low annual mean effective moisture (precipitation – evaporation) due to both low precipitation (lower than 20 mm/year over these regions) and high evaporation rates. Simulated changes of effective moisture over these regions for all selected time slices are minimal, within +-30 mm/year compared to PI however, statistically significant according to the t-test. Performed simulations allowed us detailed investigation of effective moisture pattern distribution over the Central and High Asia.

Our further analysis was performed in order to study the local and global driving forces responsible for effective moisture change in our selected region. Using the ECHAM5 outputs we calculate the vertically integrated moisture transport. LGM meridional and zonal moisture transport over the Indian Ocean and India is less than during the PD, MH and PLIO, whereas MH and PLIO zonal moisture transport is similar to PD, and PLIO meridional moisture transport is enhanced in the Arabian Sea, the Bay of Bengal and eastern China. In the regions of the aforementioned basins north of the Tibetan Plateau, modelled MH precipitation and precipitation seasonality are similar to PD conditions, whereas the LGM simulation estimates lower (ca. 8 mm/a) and the PLIO simulation higher (ca. 5 mm/a) precipitation values than PD.

Furthermore, precipitation seasonality is weakened in the LGM simulation, which estimates lower precipitation esp. in summer; PLIO precipitation seasonality is enhanced by higher precipitation values especially in spring and summer.

Model results reveal that variations in hydroclimate during the months of maximum precipitation (April-October) are shaped by both mid-latitudes dynamics and onset of Asian summer monsoons. In particular, the position and strength of the westerlies jet stream are highly correlated to local precipitation conditions in CHA for all studied paleoclimate periods. During warm periods (e.g. Pliocene or interglacial) the jet stream migrates to northern CHA and locally increases precipitation. During cooler periods (e.g. LGM) the jet stream moves southward, thereby resulting in a drying of CHA. Furthermore, we find that the changes in the jet stream position (Fig. 2) are closely linked to changes in the northern hemisphere pressure systems. These results portray how late-Pleistocene atmospheric circulation and moisture distribution in this region responded to global changes.

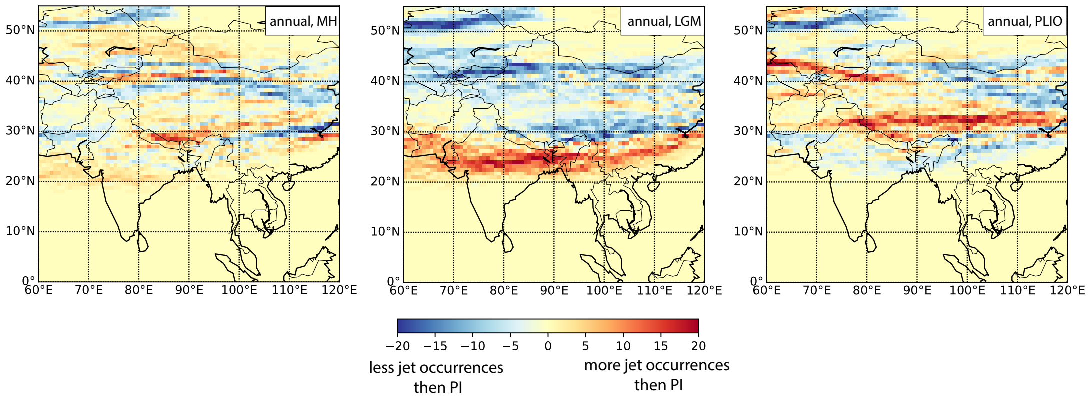


***Figure 2.*** *Annual averaged differences in jet counts calculated according to Schiemann et al., 2008 compared to pre-industrial simulation (PI).*

Finally, based on our paleoclimate simulations we investigate the spatial and temporal variation of the Northern Hemisphere pressure systems, the empirical orthogonal function (EOF) analysis (Björnsson and Venegas, 1997), which is considered to be a powerful tool for understanding the global drivers of local climate changes. The EOF analysis is a statistical technique that simplifies an original spatialetemporal data set by transforming it into spatial patterns of variability and temporal projections of the patterns. The spatial patterns are the EOFs as basic functions in terms of variance. This final EOF analysis will be complementing for our publication in preparation "Extreme global climate drivers contribution to the central and high Asia climate cycle" planed for a submission on early spring 2020.

Publication in preparation:

Botsyun S., T.A. Ehlers, S. G. Mutz, D. Scherer. Extreme global climate drivers contribution to the central and high Asia climate cycle. In preparation for *Quaternary Science Reviews.*