Changes in water balance of the Qaidam Basin from Pliocene to present day

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Qaidam Basin

The intermontane endorheic basin is located in the northeastern part of the Tibetan Plateau. The central lower altitude areas are hyperarid.

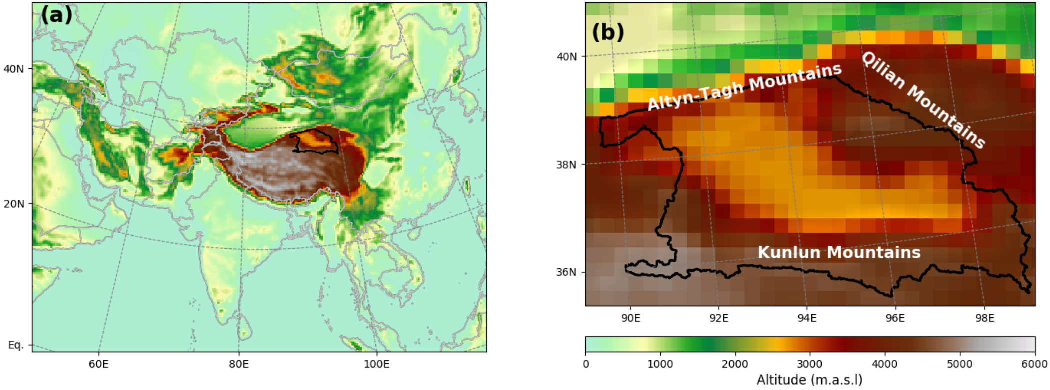

Figure 1: (a) Map of model domain d30km; (b) overview of Qaidam Basin.

Previous Work

Qaidam Mega-Lake System

- In mid-Pliocene (∼3.3 Ma BP to ∼3.0 Ma BP) the Qaidam Basin contained a freshwater mega-lake system of 120.000 km^2 (Kezao and Bowler 1986; Mischke et al. 2010; Wang et al. 2012).
- Even though the basin and surrounding mountain areas experienced a general aridification process throughout the mid-Pliocene, the lake system was not affected (Miao et al. 2013; Rieser et al. 2009; Song et al. 2017).
- Only since the early Pleistocene (∼2.6 Ma), the mega-lake began to shrink (Wang et al. 2012).

Previous Work

Water balance

- For the lake system to survive, the long-term water balance of the Qaidam drainage basin must have been non-negative in mid-Pliocene
- Scherer 2020 (In Revision) suggests that present-day water balance is close to zero
- The low altitude hyperarid regions are balanced by high altitude regions with positive net precipitation

Research Questions

- How do the climate and water balance in the Qaidam drainage basin of today differ from the past climate (mid-Holocene, Last Glacial Maximum. mid-Pliocene)?
- How could the lake system survive the continuous aridification process and maintain its stability throughout the Pliocene?
- What are the large scale systems, that transport moisture into and away from the basin?

Experiment Setup

- We simulate the Qaidam Basin's climate employing a model chain
  - General Circulation Model (GCM) for the large scale situation
  - Regional Climate Model (RCM) to resolve important meso scale processes
  - Model the "modern" Qaidam Basin under climate conditions of:
    - Mid-Holocene (MH)
    - Last Glacial Maximum (LGM)
    - Mid-Pliocene (PLIO)
    - Present-Day (PD, control run)
  - 15-year time slices representing the different climate situations

Model Chain

General Circulation Model

- Echam5-wiso atmospheric GCM (Roeckner et al. 2003)
- Ability to reproduce paleoclimates shown by Botsyun et al. 2020; Mutz et al. 2016
- T159 spectral resolution ($\sim$0.75° or $\sim$80 km $\times$ $\sim$80 km)
- L31 vertical Resoltuion (31 levels up to 10 hPa)
- Present Day driven with AMIP2 sea surface temperature (SST) and sea ice data from 1957 to 2014 Nakicenovic et al. 1990
- Other simulations driven with yearly cyclic SST

Model Chain

Regional Climate Model

- Weather Research and Forecasting model ARW v. 4.1.2 (Skamarock et al. 2019)
- Grid spacing of 30 km $\times$ 30 km
- 28 Eta-levels
- Reinitialized every 24 hours (Maussion et al. 2011; Maussion et al. 2014)

Daily Reinitialization

Description

- This strategy keeps the circulation patterns simulated by WRF closely constrained by the forcing data, while concurrently allowing WRF to develop the meso scale atmospheric features. It acts similar to nudging. A spin-up period needs to be simulated for every reinitialization.
- Developed and validated for the High Asia region by Maussion et al. 2014

Specifications

- The Model is reinitialized every 24 h
- 36-hour runs
- The first 12 hours act as spin-up period for the model and are disregarded
- Last 24 hours are cropped and merged with neighboring days

Data Analysis

We examine modeled characteristics of the following variables in order to calculate the drainage basin's water balance and identify driving mechanisms

Variables

- 2 m air temperature T_{2m}
- 2 m specific humidity Q_{2m}
- Precipitation P
- Evapotranspiration ET
- Net Precipitation $\Delta S = P - ET$

The water balance is calculated as $WB = \int \delta A \Delta S$, with A as the area of the Qaidam Basin catchment area.

Temperature

We find relatively cooler temperatures for the whole domain in MH and LGM and strong cooling in the basin for PLIO.

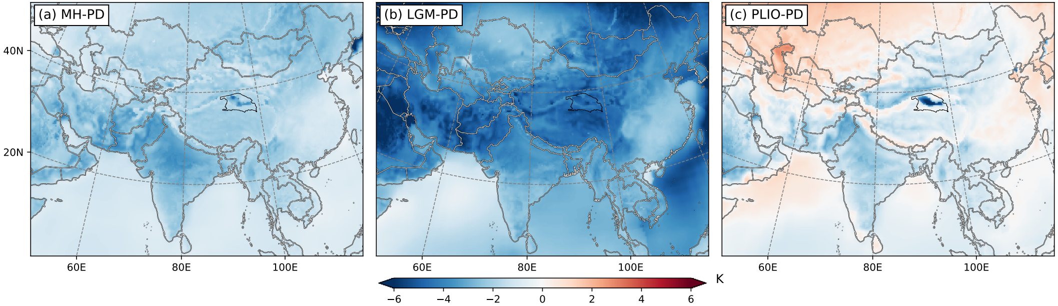

Figure 2: Average temperature (2 m a.g.) differences to Present day simulation for mid-Holocene (left), last glacial maximum (mid) and mid-Pliocene (right)

Specific humidity

While the LGM shows generally lower humidity, MH and especially PLIO simulations result higher values in large parts of the domain and in the basin.

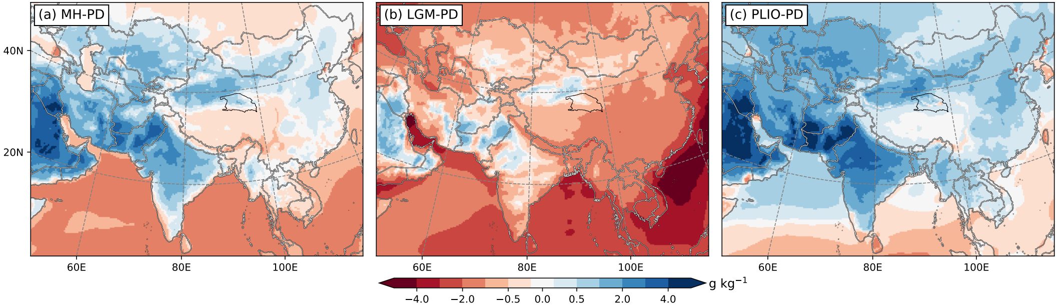

Figure 3: Average humidity (2 m a.g.) differences to Present day simulation for mid-Holocene (left), last glacial maximum (mid) and mid-Pliocene (right)

Precipitation

Areas of high precipitation vary with time slices. Generally, the simulations show less precipitation for large parts of the domain under LGM conditions, fewer differences for MH and intensification for PLIO. Especially the areas of the Indian Summer Monsoon, the East Asian Summer Monsoon (EASM) and in the west wind zone show higher values.

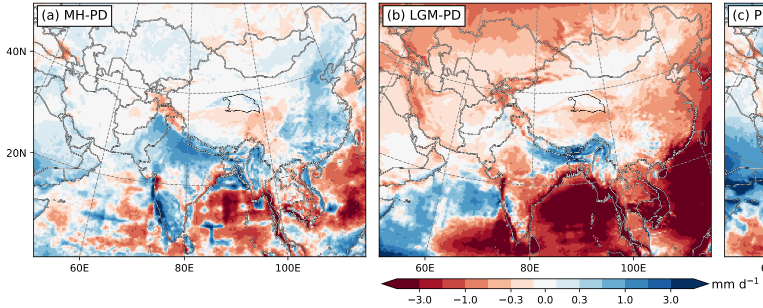

Figure 4: Average precipitation differences to Present day simulation for mid-Holocene (left), Last Glacial Maximum (mid) and mid-Pliocene (right)

Evapotranspiration

Evapotranspiration is increased for large parts of central Asia, India and south east Asia for all time slices. In the basin, evapotranspiration is higher for MH and LGM. Inside the basin evapotranspiration is increased for MH and LGM in the lower altitude central part with a mosaic patterns showing for PLIO.

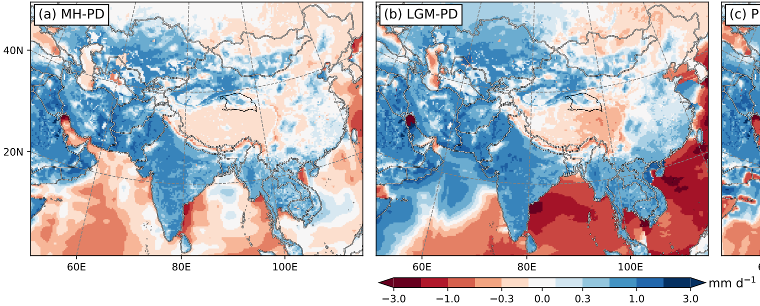

Figure 5: Average evapotranspiration differences to Present day simulation for mid-Holocene (left), last glacial maximum (mid) and mid-Pliocene (right)

Net Precipitation

Net precipitation is largely governed by Precipitation values. It shows drier conditions for the Qaidam Basin in MH and LGM, with only minor differences of positive and negative sign for PLIO.

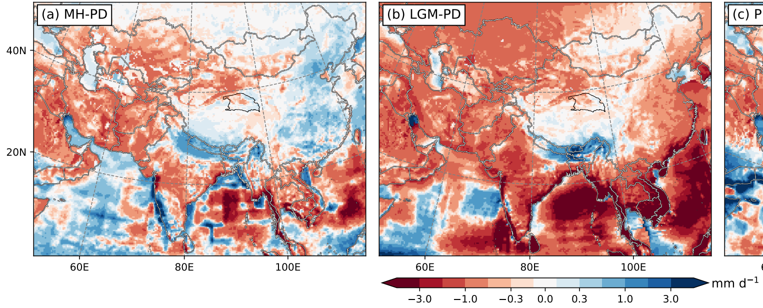

Figure 6: Average net precipitation differences to Present day simulation for mid-Holocene (left), last glacial maximum (mid) and mid-Pliocene (right)

Average Values

While each of the simulated time slices show a temperature drop for the area average, this is smallest for PLIO conditions. The humidity is increased for the mid-Holocene and PLIO. The same tendencies can be seen for Precipitation. Evapotranspiration is relatively larger for every time slice. This results in water balance being lower than PD's in MH and LGM, while it is higher in PLIO.

Table 1: Difference in the averages of spatial mean values for the Qaidam drainage Basin.

	ΔT_{2m} in K	ΔQ_{2m} in $g\,kg^{-1}$	ΔP in $mm\,a^{-1}$	ΔET in $mm\,a^{-1}$	ΔWB in $mm\,a^{-1}$
MH-PD	-2.2	0.3	27	61	-34
LGM-PD	-4.7	-0.6	-58	34	-91
PLIO-PD	-1.7	0.5	61	41	20

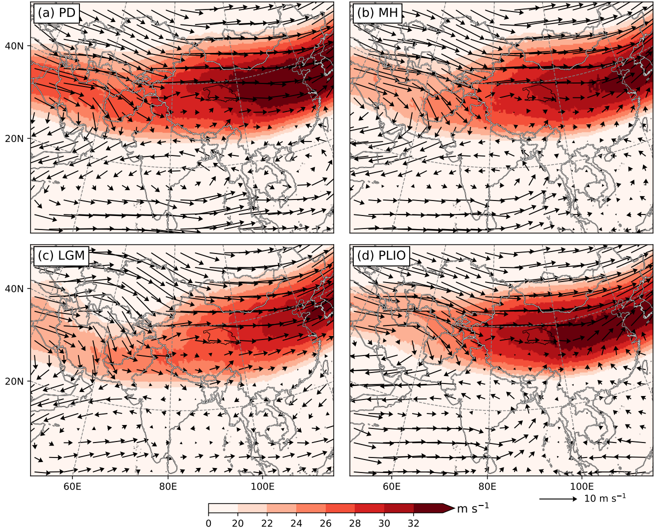

Figure 7: The 15-year average annual zonal wind speed at 200 hPa (shade), and the mean wind field of summer months at 500 hPa (arrows) for (a) PD; (b) MH; (c) LGM and (d) PLIO.

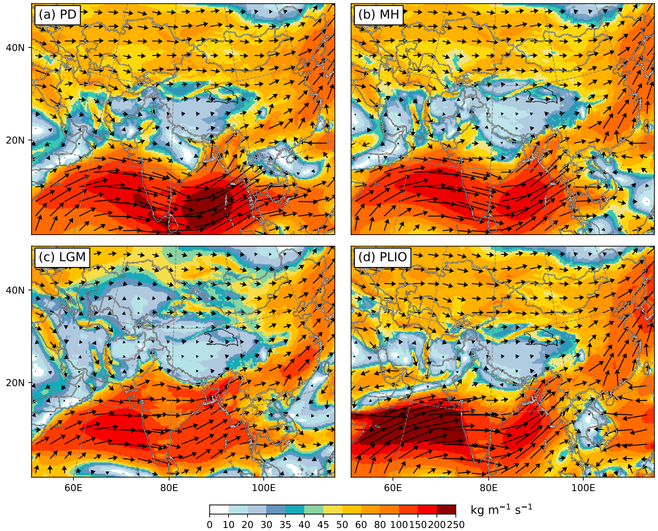

Figure 8: The 15-year mean vertically integrated atmospheric water transport (shade) and the wind field (arrows)

Large scale drivers

The west winds and the Indian Summer Monsoon (ISM) show to be the governing systems providing moisture to central Asia.

West wind system

The shading in fig. 7 indicates the jet stream position and intensity. This is an indicator for the average strength and position of the west wind system. We can see that the influence on the Qaidam drainage Basin is strongest for PLIO and PD conditions. Both situations show similar patterns, while the system differs in strength and position for MH and LGM. Consequently, the atmospheric water transport (Fig. 8) into and out of the basin are strongest for these PLIO and PD runs.

Large scale drivers

The west winds and the Indian Summer Monsoon (ISM) show to be the governing systems providing moisture to the Asia.

Indian Summer Monsoon

The arrows in fig. 7 show the average wind field during monsoon season. The associated moisture transport can be seen in fig. 8. The ISM is stronger during PD and PLIO and the center shifted westwards for the PLIO. This results in increased moisture transport east and respectively west of India. The influence on the Qaidam Basin is minor, since most of the moisture in blocked by the High Asia Mountains. The transport through the Brahmaputra channel and over the Pamir region is relatively low.

Large scale drivers

Further analysis shows an influence of the East Asian Summer Monsoon (EASM)

East Asian Summer Monsoon

During Pliocene we detected the influence of the EASM on the moisture transport into the Qaidam Basin area during a short time period in the summer months. The atmospheric water transport across the eastern border of the drainage basin shows influx from the east, against the governing westerlies during some days in July and August (Fig. 9). This pattern can be seen during other time periods as well but is much weaker there.

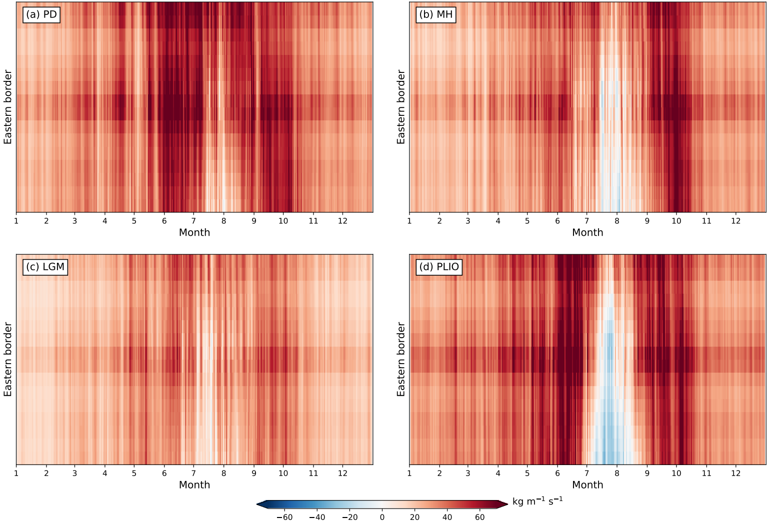

Figure 9: The 15-year mean vertically integrated atmospheric water transport across the eastern border of the Qaidam drainage basin. Red shading indicates eastward transport.

Conclusion

How could the lake system survive the continuous aridification process and maintain its stability throughout the Pliocene?

Scherer 2020 (In Revision) suggests that the water balance might be close to zero if we regard the whole catchment area. We conclude that strengthening of the west winds and enhanced influence of the EASM in summer months could have caused the water balance to stay positive, while surrounding areas showed continuous aridification.

Conclusion

What are the large scale systems, that transport moisture into and away from the basin?

We find that the west wind system is the dominant driver of atmospheric water transport into the Qaidam drainage basin. Most moisture transport of the ISM is blocked by the mountain chains of High Asia. The influence of the EASM is weak today but is more prominent for the PLIO run for July and August.

Conclusion

How do the climate and water balance in the Qaidam drainage basin of today differ from those under past climate conditions (mid-Holocene, Last Glacial Maximum. mid-Pliocene)?

The strength and position of the large scale drivers in PLIO and PD are quite similar. The temperature in the low-altitude regions of the basin were much lower. This can be due to increased soil moisture values under Pliocene conditions. The influence of the EASM in summer was stronger under Pliocene conditions. MH and LGM show generally lower values for the temperature 2 m ag. Monsoon and west winds are weaker and transport less moisture into the basin. This results in much lower values for the basin's water balance. while we see increased evapotranspiration, net precipitation is lower than in PD and specific humidity is lower for LGM climate conditions.

Thank you!

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