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

Benjamin Schmidt[1], Xun Wang[1], Sebastian Mutz[2], Svetlana Botsyun[2], Todd Ehlers[2], Dieter Scherer[1]

[1]Climatology Department, Technische Universität Berlin, Germany
[2]Dept. of Geosciences, Univ. of Tübingen, Germany

benjamin.schmidt@tu-berlin.de

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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 considered hyperarid.

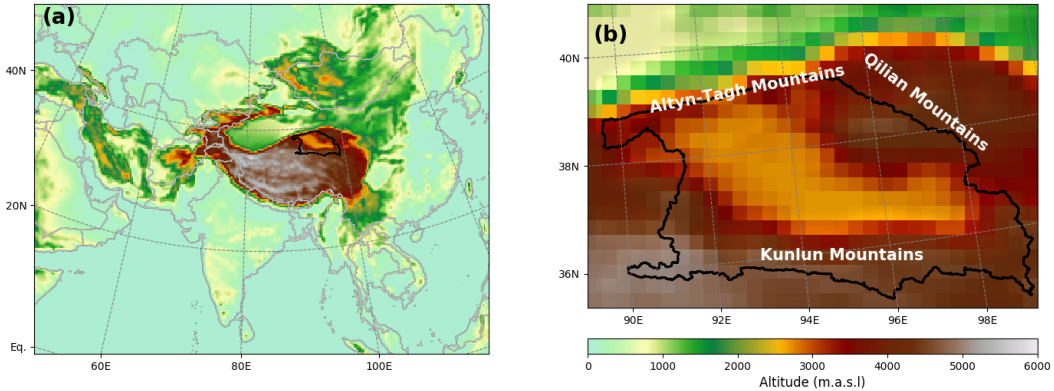

Figure 1: (a) Map of model domain d30km; (b) overview of Qaidam Basin.

Previous Work

Qaidam Mega-Lake System

- In mid-Pliocene ($\sim$3.3 Ma BP to $\sim$3.0 Ma BP) the Qaidam Basin contained a freshwater mega-lake system of 120.000 km^2 (Kezao and Bowler 1986; Mischke et al. 2010; Wang et al. 2012).
- Even though the basin and surrounding mountain areas experienced a general aridification process throughout the mid-Pliocene, the lake system was not affected (Miao et al. 2013; Rieser et al. 2009; Song et al. 2017).
- Only since the Late Pliocene ($\sim$2.5 Ma), the mega-lake began to shrink (Wang et al. 2012).

Previous Work

Water balance

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

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Research Questions

As we move towards a climate, analog of that of the mid-Pliocene, could the water balance become positive again?

- What are the large scale systems, that transport moisture into and away from the basin?
- How does the local climate of today differ, from that under mid-Pliocene conditions?
- How was the water balance during the mid-Holocene and Last Glacial Maximum?
- Could the mega lake system reappear in the future?

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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)
  - 15-year time slices representing the different climate situations

Experimental runs

Lateral boundary conditions set by climate conditions Modern day orographic forcing

Control run

All forcing data representing Present day climate

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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
- Pliocene driven with yearly cyclic SST

Regional Climate Model

- Weather Forecast and Research Model ARW v. 4.1.2 (Skamarock et al. 2019)
- Grid spacing of $\sim$30 km $\times$ $\sim$30 km
- 28 Eta-levels

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 mesoscale atmospheric features. It acts similar to nudging. A spin-up period needs to be simulated for every reinitialization.
- Developed and validated for the 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 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 $\Delta P = P - ET$

The water balance is calculated as $WB = \int \delta A \Delta P$, 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.

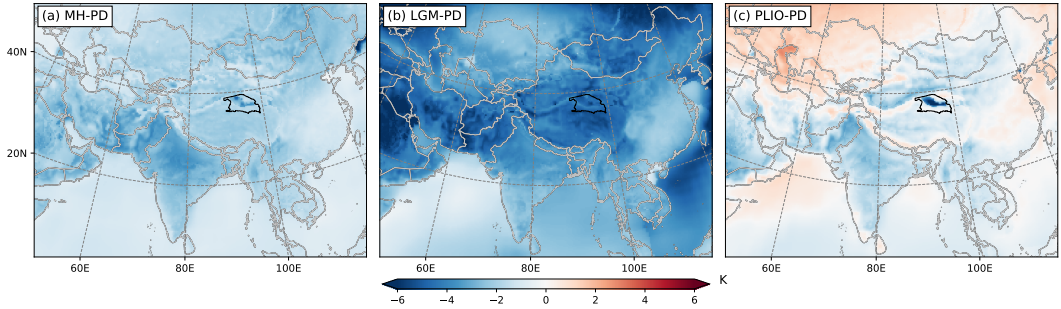

Figure 2: Average temperature (2 m) differences to Present day simulation for mid-Holocene (left), last glacial maximum (mid) and mid-Pliocene (right)

Specific humidity

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

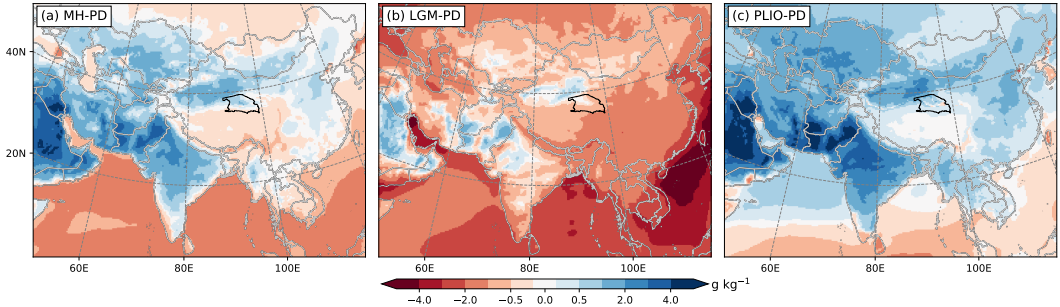

Figure 3: Average humidity (2 m) differences to Present day simulation for mid-Holocene (left), last glacial maximum (mid) and mid-Pliocene (right)

Precipitation

Local precipitation shows shifts in monsoon position and strength, with generally low intensity for LGM, fewer differences during MH and intensification during PLIO, especially for the Indian Summer Monsoon over the Indian Ocean, the East Asian Summer Monsoon (EASM) over eastern China and in the westwind zone.

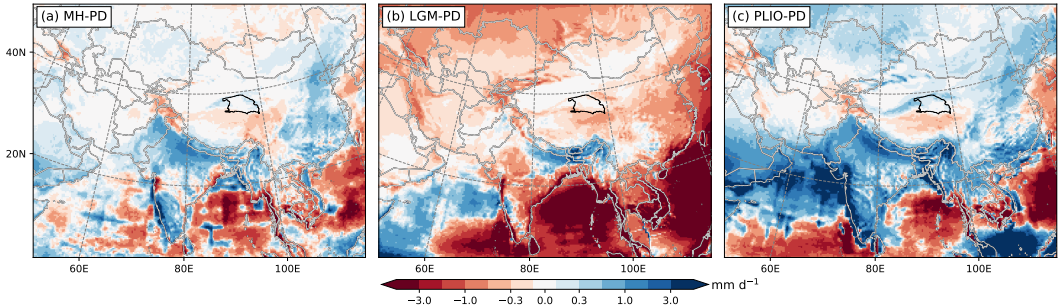

Figure 4: Average precipitation differences to Present day simulation for mid-Holocene (left), Last Glacial Maximum (mid) and mid-Pliocene (right)

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.

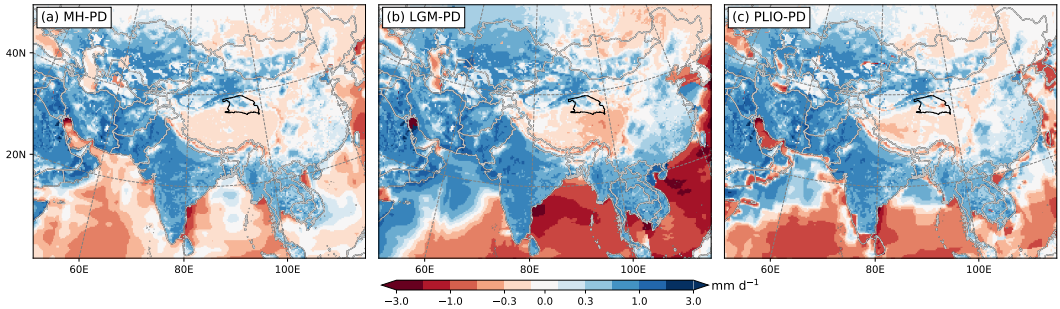

Figure 5: Average evapotranspiration differences to Present day simulation for mid-Holocene (left), last glacial maximum (mid) and mid-Pliocene (right)

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.

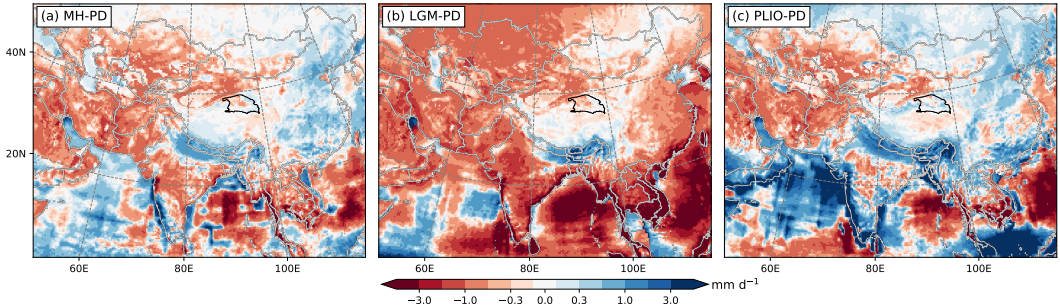

Figure 6: Average net precipitation differences to Present day simulation for mid-Holocene (left), last glacial maximum (mid) and mid-Pliocene (right)

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: Average differences for examined variables in the Qaidam Basin catchment area.

	ΔT 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

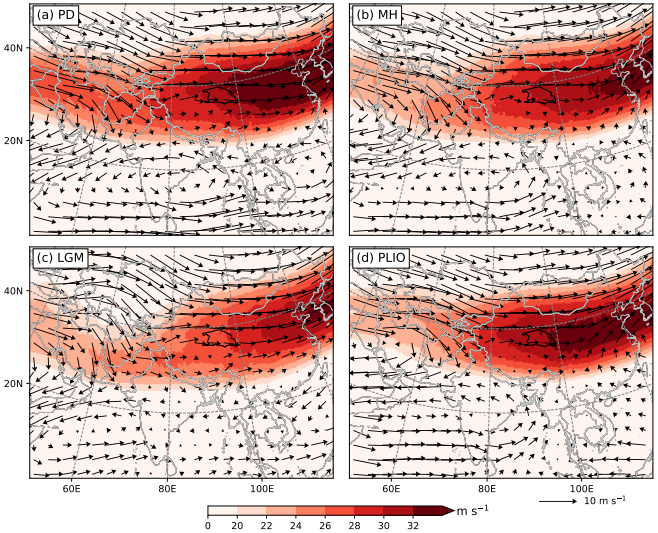

Figure 7: The 15-year average annual zonal wind speed at 200 hPa (shade), and the mean wind field of summer months at 500 hPa (arrows) for (a) PD; (b) MH; (c) LGM and (d) PLIO.

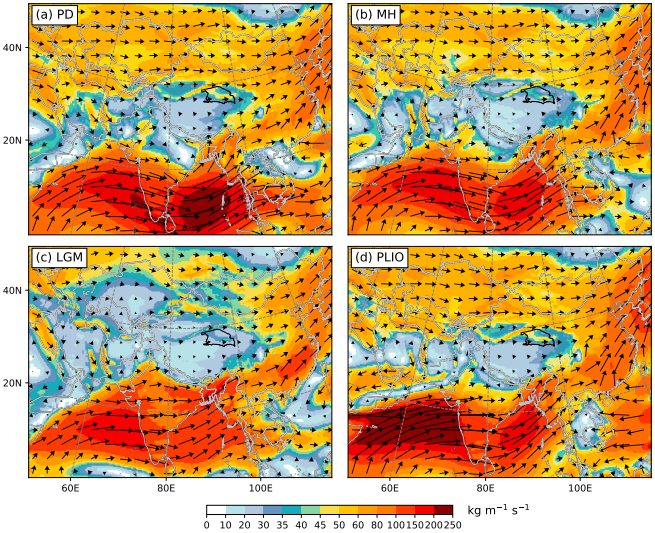

Figure 8: The 15-year mean vertically integrated atmospheric water transport (shade) and the wind field (arrows)

Large scale drivers

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

Westwind 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 Basin is strongest for PLIO and PD. 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 time periods.

Large scale drivers

The west winds and the Indian Summer Monsoon (ISM) shw 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 ist 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 minor.

Large scale drivers

Further analysis shows the 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 during a short time period in the summer months. The atmospheric water transport across the eastern border of the basin shows influx from the east, against the governing west winds 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.

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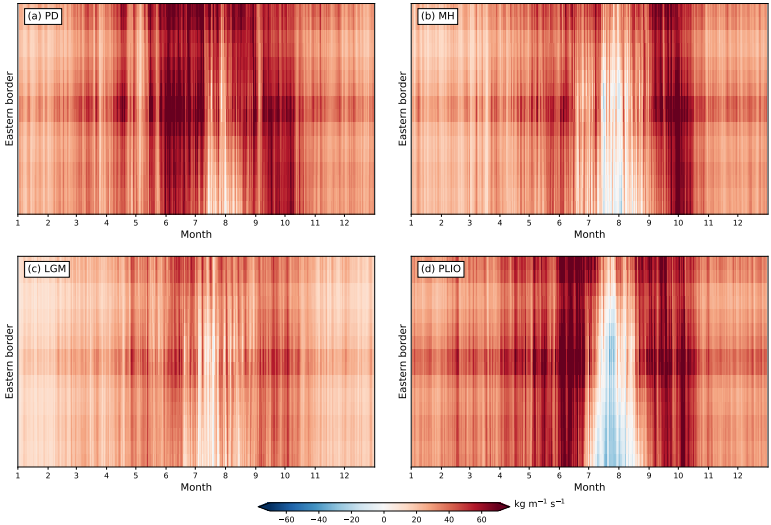

Figure 9: The 15-year mean vertically integrated atmospheric water transport across the eastern border of the Qaidam Basin. Red shading indicates eastward transport.

Conclusion

Question: 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 Basin. The influence of the ISM is limited by the mountain chains of High Asia. The influence of the EASM is weak today but was present in the Pliocene during July and August.

Question: How does the local climate of today differ, from that under mid-Pliocene conditions?

The strength and position of the system 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.

Conclusion

Question: How was the water balance during the mid-Holocene and Last Glacial Maximum?

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.

Could the mega lake system reappear in the future?

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 can cause the water balance to become positive. This would lead to aquifer recharge and could result in a reappearance of the lake system on a geological time scale.

Thank you!

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Botsyun, S., T.A. Ehlers, S.G. Mutz, K. Methner, E. Krsnik, and A. Mulch (Jan. 2020). "Opportunities and challenges for paleoaltimetry in "small" orogens: Insights from the European Alps". In: *Geophysical Research Letters*. ISSN: 0094-8276. URL: https://onlinelibrary.wiley.com/doi/abs/10.1029/2019GL086046.

Kezao, Chen and J. M. Bowler (May 1986). "Late pleistocene evolution of salt lakes in the Qaidam basin, Qinghai province, China". In: *Palaeogeography, Palaeoclimatology, Palaeoecology* 54.1-4, pp. 87–104. ISSN: 00310182. URL: https://linkinghub.elsevier.com/retrieve/pii/0031018286901197.

Maussion, F., D. Scherer, R. Finkelnburg, J. Richters, W. Yang, and T. Yao (2011). "WRF simulation of a precipitation event over the Tibetan Plateau, China - An assessment using remote sensing and ground observations". In: *Hydrology and Earth System Sciences* 15.6, pp. 1795–1817. ISSN: 10275606.

Maussion, Fabien, Dieter Scherer, Thomas Mölg, Emily Collier, Julia Curio, and Roman Finkelnburg (2014). "Precipitation seasonality and variability over the Tibetan Plateau as resolved by the high Asia reanalysis". In: *Journal of Climate* 27.5, pp. 1910–1927. ISSN: 08948755.

Miao, Y. F., X. M. Fang, F. L. Wu, M. T. Cai, C. H. Song, Q. Q. Meng, and L. Xu (2013). "Late Cenozoic continuous aridification in the western Qaidam Basin: evidence from sporopollen records". In: *Climate of the Past* 9.4, pp. 1863–1877. ISSN: 1814-9332.

Mischke, Steffen, Zhencheng Sun, Ulrike Herzschuh, Zizhen Qiao, and Naida Sun (2010). "An ostracod-inferred large Middle Pleistocene freshwater lake in the presently hyper-arid Qaidam Basin (NW China)". In: *Quaternary International* 218.1-2, pp. 74–85. ISSN: 10406182.

Mutz, Sebastian G, Todd A Ehlers, Jingmin Li, Christian Steger, Heiko Paeth, Martin Werner, and Christopher J Poulsen (2016). "Precipitation ${\$}18*Overthehimalaya* - *tibetorogenfromECHAM5* - *wisosimulations* : *Statisticalanalysisoftemperature*, *topographyandprecipitation*". In: *Journal of Geophysical Research* 121.16, pp. 9278–9300. ISSN: 21562202.

Nakicenovic, Nebojsa, Joseph Alcamo, Gerald Davis, Bert De Vries, Joergen Fenhann, Stuart Gaffin, Kermeth Gregory, Amulf Griibler, Tae Yong Jung, Tom Kram, Emilio Lebre, La Rovere, Laurie Michaelis, Shunsuke Mori, Tsuneyuki Morita, William Pepper, Hugh Pitcher, Lynn Price, Keywan Riahi, Alexander Roehrl, Hans-Holger Rogner, Alexei Sankovski, Michael Schlesinger, Priyadarshi Shukla, Steven Smith, Robert Swart, Sascha Van Rooijen, Nadejda Victor, and Zhou Dadi (1990). *Special Report on Emissions Scenarios A Special Report of Working Group III of tiie Intergovernmental Panel on Climate Change*. Tech. rep., p. 599.

Rieser, Andrea B., Ana-Voica Bojar, Franz Neubauer, Johann Genser, Yongjiang Liu, Xiao-Hong Ge, and Gertrude Friedl (July 2009). "Monitoring Cenozoic climate evolution of northeastern Tibet: stable isotope constraints from the western Qaidam Basin, China". In: *International Journal of Earth Sciences* 98.5, pp. 1063–1075. ISSN: 1437-3254. URL: http://link.springer.com/10.1007/s00531-008-0304-5.

Roeckner, E, G Baeuml, L Bonaventura, R Brokopf, M Esch, M Giorgetta, S Hagemann, I Kirchner, L Kornblueh, E Manzini, A Rhodin, U Schlese, U Schulzweida, and A Tompkins (2003). *The general circulation model ECHAM5. Part I: Model description*. Tech. rep. URL: papers3://publication/uuid/54B29E7E-A721-4C90-9A14-61E6BA163B32.

Scherer, Dieter (2020). "Survival of the Qaidam Mega-Lake System under Mid-Pliocene Climates and its Restoration under Future Climates". In: *Hydrology and Earth System Sciences Discussions*, pp. 1–17. ISSN: 1027-5606.

Skamarock, W.C., J.B. Klemp, Jimy Dudhia, D.O. Gill, Liu Zhiquan, Judith Berner, Wei Wang, J.G. Powers, Michael G Duda, Dale M Barker, and Xiang-Yu Huang (2019). *A Description of the Advanced Research WRF Model Version 4 NCAR Technical Note*. Tech. rep. Boulder, Colorado: NCAR-UCAR, p. 145. URL: http://library.ucar.edu/research/publish-technote.

Song, Lulu, Qianlai Zhuang, Yunhe Yin, Xudong Zhu, and Shaohong Wu (2017). "Spatio-temporal dynamics of evapotranspiration on the Tibetan Plateau from 2000 to 2010". In: *Environmental Research Letters* 12.1. ISSN: 17489326.

Wang, J., X. Fang, E. Appel, and C. Song (2012). "Pliocene-Pleistocene Climate Change At the NE Tibetan Plateau Deduced From Lithofacies Variation In the Drill Core SG-1, Western Qaidam Basin, China". In: *Journal of Sedimentary Research* 82.12, pp. 933–952. ISSN: 1527-1404.