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Holocene moisture variations in western arid central Asia inferred from loess records from NE Iran

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1. Introduction

Mid-latitude Asia can be divided into two distinct climatic regions: arid central Asia (ACA) ("westerlies Asia"), climatically controlled by the westerlies, and humid eastern and southern Asia ("monsoonal Asia"), controlled by the monsoon circulation (Fig. 1a; Huang et al., 2015; Chen et al., 2019). ACA is the main body of the mid-latitude inland arid region in the Northern Hemisphere and is composed of NW China and Central Asia (Chen et al., 2019). Further, Huang et al. (2015) defined the core area of the "westerlies-dominated climatic regime (WDCR)" (35° -53° N, 60° -90° E) during the instrumental period, and it ranges from the Xinjiang in the east to the Caspian Sea in the west. At present, water availability is crucial for sustainable development in ACA, where the location and intensity of westerlies mainly influence the precipitation. The arid environment, sparse vegetation and fragile ecosystems make it highly sensitive to climate change. Understanding its Holocene climate evolution is important for predicting the human living environment changes in the future. Holocene variations in precipitation in central and eastern ACA have been widely investigated, but the pattern in western ACA remains unclear.

Objectives:

(1) Based on loess sediments from NE Iran, western ACA, achieved a reliable proxy to reveal the paleoprecipitation variations; (2) quantitatively reconstruct Holocene paleoprecipitation changes in the western ACA to improve our understanding of its internal spatial pattern and possible physical mechanisms of the entire ACA.

2. Geographic setting

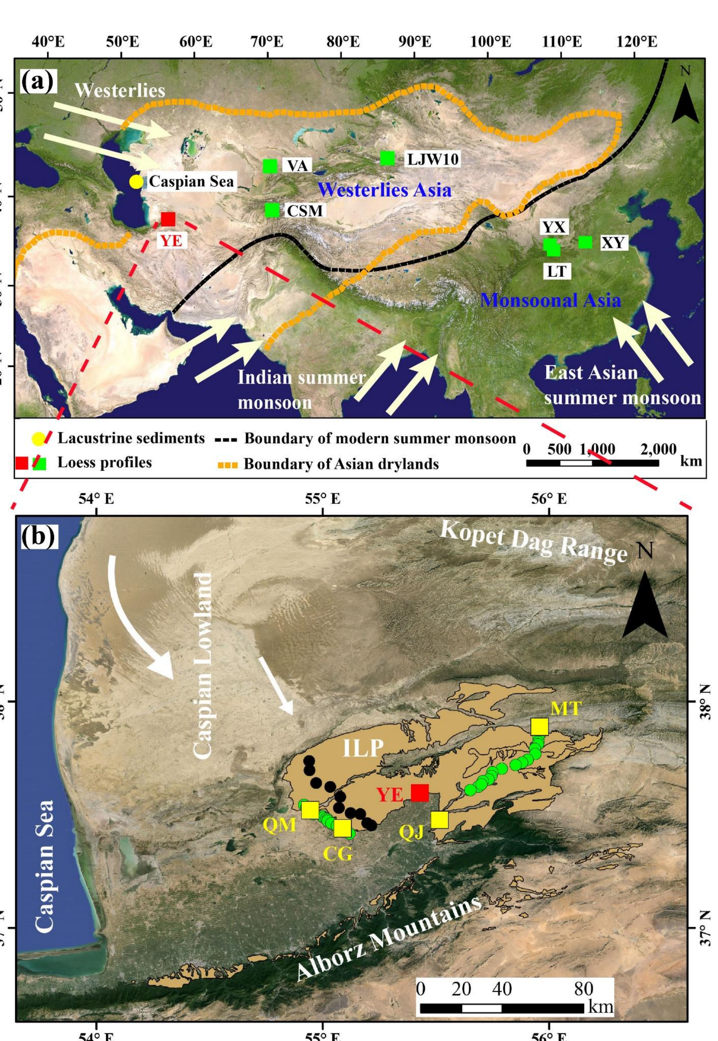

Fig. 1. (a) The dominated atmospheric circulation systems in mid-latitude Asia: the westerlies, Indian summer monsoon, and East Asian summer monsoon. The black dashed line indicates the modern limit of the summer monsoon (modified from Chen et al., 2019), and the area enclosed by the orange dashed line is arid Asia (modified from Huang et al., 2015; Chen et al., 2019). The red rectangle indicates the location of the Yellibadragh (YE) section, and the green rectangle indicates the location of referenced loess-paleosol sequences. The yellow dot indicates the Caspian Sea. (b) Location of the Iranian Loess Plateau and the studied area in NE Iran.

✓Northeastern Iran was located in the western ACA (Fig.1a; Huang et al., 2015; Chen et al., 2019), and was flanked by Kopet Dag Mountains to the north and Alborz Mountains to the south, Caspian Sea was in the west (Fig.1b). Loess is widely distributed on the so-called Iranian Loess Plateau (ILP) (Fig.1b), and is located between the rivers Atrek and Gorgan (Fig. 2a; Wang et al., 2019).

✓At present, the majority of the precipitation in this area falls during winter and spring with approximately more than ~85% in a year (Wang et al., 2016, 2019), which has the characters of Mediterranean-type climate: with hot, dry summers and mild, humid winters (Wang et al., 2019); totally different from monsoonal Asia which was influenced by Eastern Asian Summer Monsoon (EASM) and Indian Summer Monsoon (ISM) circulations with major precipitation in summer. The high-level westerlies can carry moisture from North Atlantic Ocean, Mediterranean, Black Sea and Caspian Sea to northeastern Iran. Because the pressure differences between the Caspian Sea and Central Iranian highlands, during summer, northeasterly to northwesterly winds are the dominated near-surface winds, with the opposite wind directions during in winter. (Fig.1b; Wang et al., 2016, 2019). Currently, mean annual temperature (MAT) only has the slight changes from ~15 °C in the south to ~18 °C in the north. Mean annual precipitation (MAP) shows significant gradient with latitude of more than ~800 mm in the south near Alborz Mountains and less than ~300 mm in the north of ILP near Kopet Dag Mountains over ~80 km from south to north (Fig.2; Wang et al., 2019).

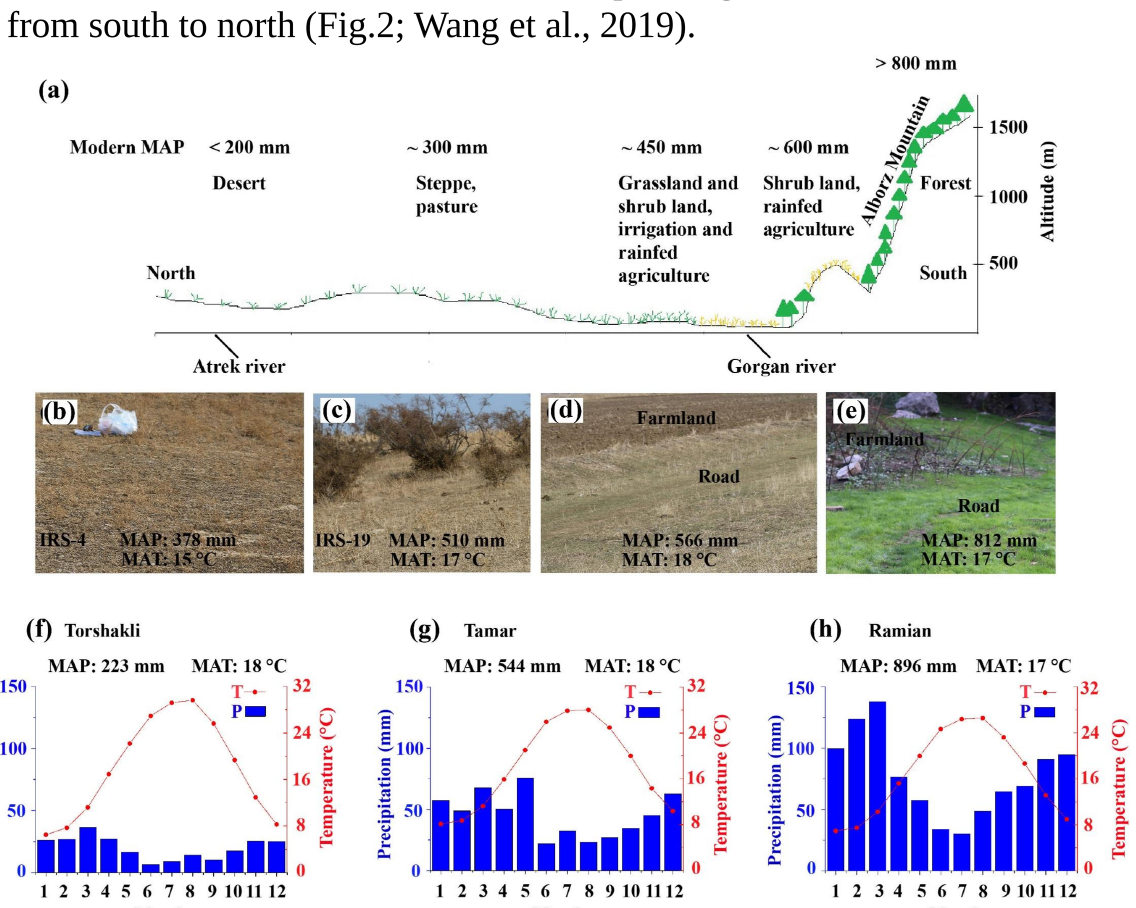

Fig. 2. (A) Modern MAP gradient from north to south and modern natural vegetation and land use in northeastern Iran. (b) and (c) are field photos of sampling sites IRS-4 and IRS-19, which are regarded as uninfluenced by human activity. (d) and (e) are likely influenced by human activity. (f), (g) and (h) show the monthly variation of precipitation/temperature (P/T) of meteorological stations Torshakli, Tamar and Ramian, from north to south.

3. Materials

- ***Sampling:*** 44 modern surface soil samples were collected, and total 182 bulk samples at 2-cm interval were collected from five sections for environmental proxy measurements (Fig.1b, 2, 3).
- ***Dating:*** Ten luminescence and five AMS^{14}C dating samples were collected from the YE profile for dating.

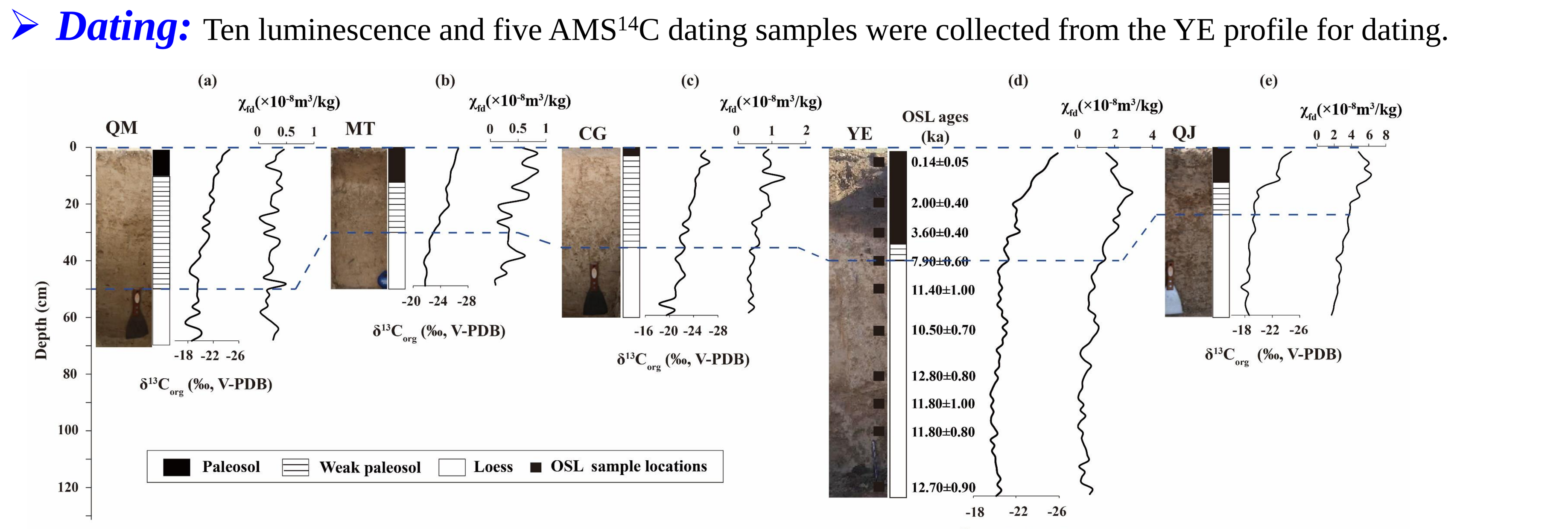

Fig. 3. Photographs, stratigraphy, chronology, $\delta^{13}C_{org}$ and χ_{fd} records of five loess profiles from NE Iran. Blue dashed lines show paleosol boundaries.

4. Results & discussion

Relationship between the $\delta^{13}C_{org}$ values of surface soils and MAP in northeastern Iran

✓The $\delta^{13}C_{org}$ values of all 44 surface soil samples range from –27.56 to –23.61‰, with an average of –25.77‰. Linear regression analysis was used to investigate the relationship between the surface soil $\delta^{13}C_{org}$ values and MAP. There is a significant negative relationship between $\delta^{13}C_{org}$ and MAP of the 44 surface soil samples (Fig. 4). The results for these samples show that for each 100 mm increase in MAP there is a 0.79‰ decrease in surface soil $\delta^{13}C_{org}$, which is expressed by the following empirical equation:

$$y = -0.0079x - 22.8418 \ (R^2 = 0.4419,\ n = 44,\ p < 0.001)$$

where y is the surface soil $\delta^{13}C_{org}$ g value and x is MAP.

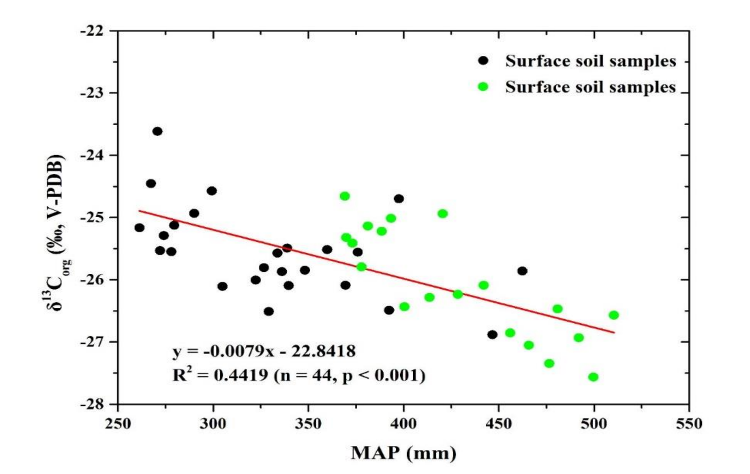

Fig. 4. Relationship between $\delta^{13}C_{org}$ values of 44 surface soil samples and MAP. Black and green dots indicate samples sampled along two transects (from northwest to southeast and from northeast to southwest).

Lithology and chronology

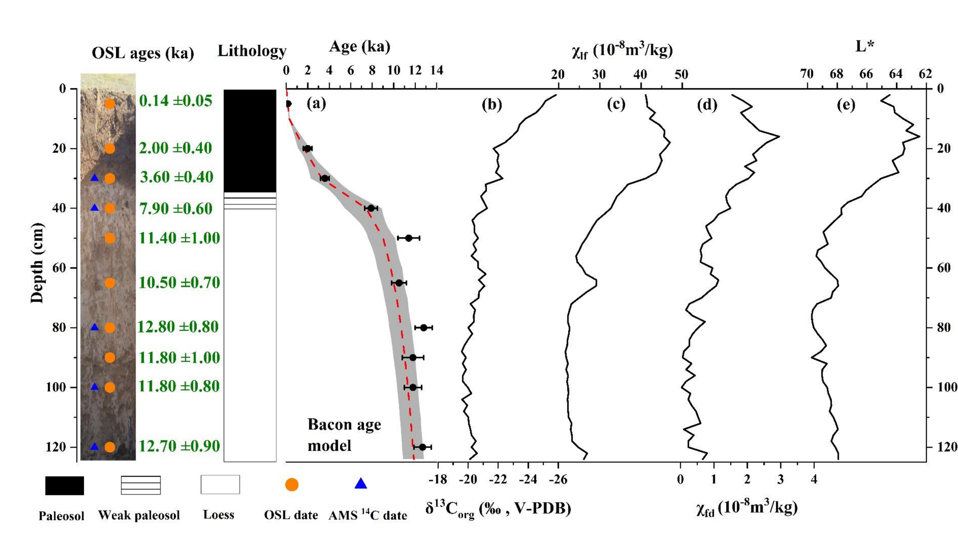

Fig. 5. Photographs, stratigraphy, and chronology of the YE profile. The orange dots in the photograph are the locations of samples for OSL dating. The locations of AMS 14C dates are shown by blue triangles. Green numbers adjacent to the profile are OSL ages (a). Depth profiles of $\delta^{13}C_{org}$ (b), χlf (c), χfd (d) and color index (L*) (e).

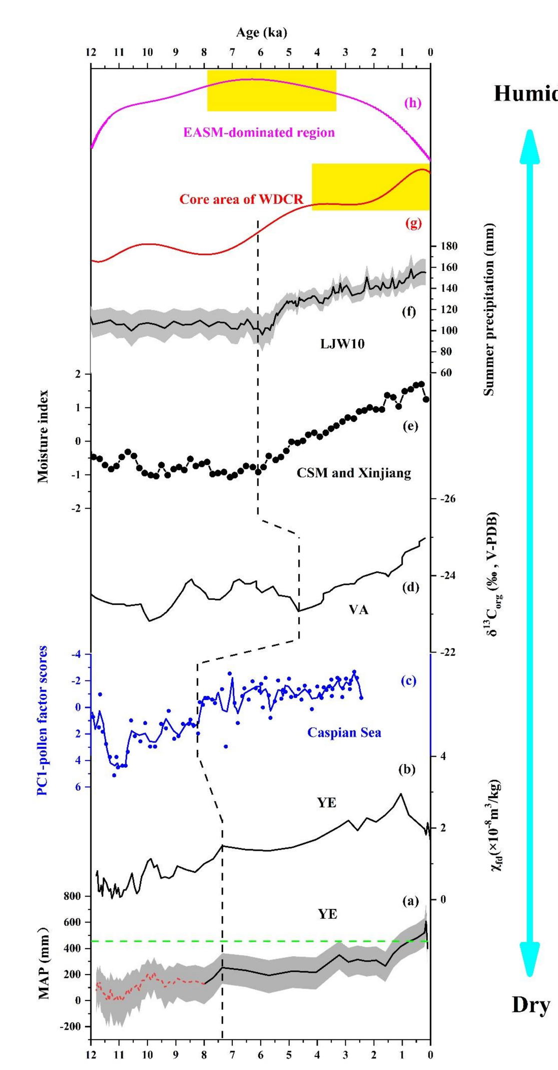

Fig. 6. Comparison of various Holocene moisture/precipitation records from mid-latitude Asia.

Holocene moisture/precipitation changes revealed by the variations in loess stratigraphy and environmental proxies in western ACA, and comparison with central and eastern ACA and monsoonal Asia

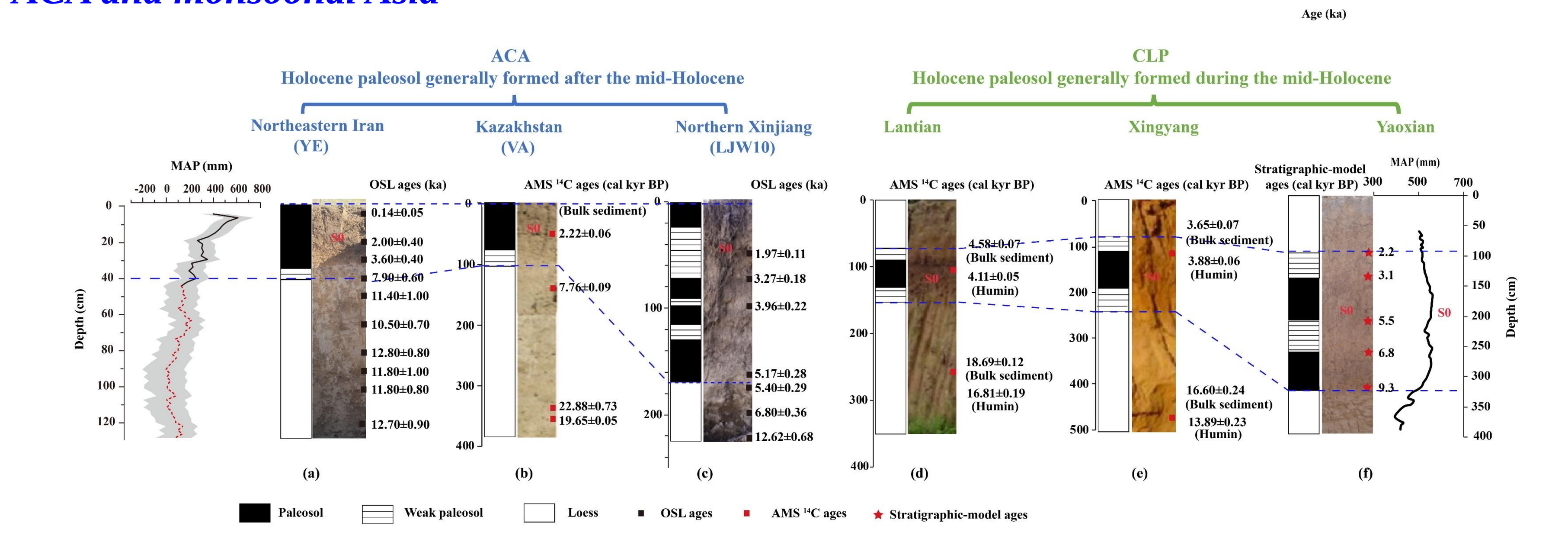

Fig. 7. Photograph, stratigraphy and chronology of six loess-paleosol sequences from mid-latitude Asia. YE (a, from NE Iran, this study; the red dashed line represents the reconstructed MAP with uncertainties), VA (b, from Kazakhstan) and LJW10 (c, from northern Xinjiang) are from ACA; LT (d), XY (e) and YX (f) are from the Chinese Loess Plateau in monsoonal Asia. Blue dashed lines denote the boundary of Holocene paleosol layers.

5. Conclusion

- Loess $\delta^{13}C_{org}$ values can be used as a useful proxy to reveal the paleoprecipitation variations in NE Iran. The resulting transfer function is valid for paleoclimatic reconstruction in western ACA where the hydroclimate is dominated by the westerlies and the natural ecosystem is dominated by C_3 plants.
- Our quantitatively reconstructed Holocene MAP results show the nearly constant MAP (~93 mm) before ~7.4 ka, followed by a persistent wetting trend, with the wettest period occurring in the late Holocene (4.0-0.0 ka, ~390 mm). Stratigraphic features, environmental proxies ($\delta^{13}C_{org}$, magnetic susceptibility and color) support this quantitative MAP reconstruction. Four additional short loess profiles show similar stratigraphic features and trends of environmental proxies. A dry early Holocene and a persistent wetting trend since the mid-Holocene in NE Iran are consistent with sand dunes and lake sediment records from western ACA. Comparison of these results with loess records from central and eastern ACA and monsoonal Asia supports the concept of a WDCR which was proposed based mainly on lake sediment records.
- The possible forcing mechanisms of the persistent wetting trend during the Holocene in the western ACA, on the sub-orbital timescale, can be attributed to changes in solar insolation.

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Acknowledgments

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