Records of Quaternary Climate in Turkey: A Review

Türkiye'de kuaterner iklim kayıtları: Holosen ve insan toplumlarıyla ilişkiler üzerine bir inceleme

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1. Introduction

Past climate curves are of three kinds: (1) on the global scales they are formed by results of analyses of ice cores in the poles (eg. Greenland cores) and in the ocean (eg. northern Atlantic ocean); (2) on the regional scale in seas (eg. cores in the Eastern Mediterranean Sea) and in continental (eg. Anatolia); (3) on the spot scale of a core at one site, considered as containing responses to the three other scaled records. The questions discussed below, concern records on scales nos 2 and 3, and can be stated as: "how much and which processes does the geographic scale intervene when comparing global and regional records"? Answer(s) to this intriguing question will be looked after herein in Anatolia and its regions.

Aim: Reconstruction of climatic curves in ANATOLIA, and then:

- looking for changes (investigating methods)
- dating the changes
- reconstructing the processes

Approach: Comparing Anatolia (regional and continental scale) and Greenland (global scale)

- Do the curves match? Where do they not match? Are there delays, discrepancies? ....
- Why do they match and how? Why do not they match and how?

Question 1 (introductory): How to consider the possible impacts of differences introduced by **Local/Regional Geomorphological Contexts and Environment Systems** in the past (and present!) climate change records?

Question 2 (final): When aiming at understanding these linking processes, **what role shall be given to Geography, ie to geography-born contrasts at the local and regional scales?**

2. Climate Contrasts Today In Turkey show

Relief and Climate Data Framing Palaeoclimate Records in Anatolia:

- Topographic profile and Precipitation profiles, NORTH-SOUTH
- Topographic profile and Humidity/Dryness map, WEST-EAST

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Climate Today: A High Geographic Variability Between

(1) Humid regions mostly located along the N and S coasts, and in the highest mountains in the SW and East of the peninsula;

(2) Dry regions, with one fourth of the land classed as semi-arid (ca < 380-400 mm/yr). The distribution of these dry areas occupy mostly the center of the peninsula, with in noticeable interruption caused by a **SE-NW humid path in the eastern highlands**

These regional contrasts a caused by the meeting of the location of the peninsula at the meeting place of different atmospheric circulations. These circulations are: (1) the "North Atlantic Oscillation" (western cyclonic depressions born in the Atlantic Ocean, which move W-E along the Mediterranean Sea, hurting western, south-western and southern Anatolia; (2) "Central European continental system" circulations hitting Anatolia from the Balkans; (3) the "Siberian Highs" originating from the Russian plains north of the Caspian sea; (4) waves of the tropic "Monsoon" from the Indian ocean.

Importance Of Scales (in space as well as time) in the High Variability of climate distribution in Anatolian, caused by, among other controls, the **regional distribution of relief** (highlands/lowlands) **vs origin of air masses.**

Two examples:

A figure (from Jex et al., 2011), illustrates the **variability of intensity and spatial distribution of Late autumn and Winter Precipitation** in NE Turkey (Gümüşhane) *vs* W Europe (between 1950-2004; 1932-2004; 1958-2004; 1948- 2004). The figure shows that recent trends of seasonal precipitation are highly variable at the same spot while stable at other spots, because of **relief control.**

Another figure (from Sarıkaya & Çiner, 2015) evidences that, since pre-LGM, the spatial and time distribution of glacial conditions in SW and S-central Turkey has responded to a **W-E Variability of precipitation (P) and temperature (T)** during the Upper Pleistocene Glacial phases. This relief control is illustrated by the differences in P *vs* T records when compared with the **orientation/distribution of relief barriers** combined with the **humidity amount of air masses.**

These examples show that the **spatial and time distribution of humidity changes** is strongly related to:

- the **geographic location** of the record

- the type of **geomorphologic context** of the record,

- the type of recording **environmental system.** This 3rd element impacting the "Geographic Variability" of climatic records in Anatolia, is strongly influenced by differences -through the peninsula- of:

- the **sensitivity** of environmental systems (= resilience) to climate change

- the **nature and processes of connections** between the environmental systems and their geomorphological, hydrological, biologic (etc) contexts**.**

Question:

In the past, did climate in Anatolia differ from global records? If yes: where and where not? Can differences be evidenced through the peninsula? Answering both sets of questions will make use of

- comparing Global/Anatolian past climate curves

- comparing, on the regional scale, the past climate curves reconstructed through Anatolia.

In case diachrony is evidenced, what is the role of the local/regional geographic context of the recording sites in producing the diachrony?

3. State of The Art Of Pleistocene Climatic Archives In Turkey

Considered on the basis of their age, as well as on the basis of the available Pleistocene climatic records in Turkey, Pleistocene climatic archives are divided below in four main, overlapping, periods:

1) 1,8-0,6 Ma[1]: **Early Pleistocene to lower Middle Pleistocene** period, with the Early-Middle Pleistocene transition positioned ca 0.9 Ma;

2) 600 to 115 ka[2]: **Upper Middle Pleistocene** (from 600 to 125 ka ago) and the following **interglacial phase called MIS[3] 5e** (125-115 ka)

3) 125 to 11,4 ka: From **the Last Interglacial** (MIS 5e: 125-115 ka) to the **end of the Last Glacial** (MIS 5d to 5a; MIS 4, MIS 3; MIS 2)

4) 14,7 ka cal BP to today, ie the post-LGM[4] composed of **(a)** the **Late Glacial** (14,7 to 12,9 ka cal BP), **(b)** the **Younger Dryas** (12,9-11,6 ka cal BP), and **(c) the Holocene** (11,6 ka cal BP to today).

3.1 Early to Mid-Pleistocene Climate Records In Turkey (1.8 to 0.6 Myrs ago)

With the exception of the Acıgöl long sequence (Burdur and Çardak provinces) provided by DSI cores and studied by Akçer-Ön et al. (2016, 2017), and the Çiftlik (Niğde) sequences also provided by DSI cores (Güler, 2015) extracted from lakes, most climate records of this period in Turkey have been studied in fluvial archives. These old archives form terraces stepped downslope along the banks of deep valleys and canyons. Several reconstructions of the incision rate of the rivers eroding the valleys, have produced dates of terrace formation, either post-incision, or pre-incision.

While Akçer-Ön et al. (2016, 2017) and Güler (2017) have difficulties providing chronology along their sequences, Early to Mid-Pleistocene ages of climatically driven sediment accumulations or landforms, have been obtained by means of radioactive dating (ie. Ar-Ar and K-Ar of volcanic flows fossilizing the deposits or incised by the river) or by OSL dating of sediments (when younger than 0.2 ka ago). Results published by the articles related to such approaches, illustrate however a strong difficulty in identifying and measuring the respective roles of tectonic and climate in the stepping magnitude of the landforms fossilized or partly destroyed by geological processes through time.

Examples:

* In the central course of the Kızılırmak river near Avanos (Çiner et al., 2015) use both Terrestrial Cosmogenic nuclides from fluvial sediments topping terrace (1,36 to 0,34 Ma, and from 160 to 94.5 ka ago), and by K-Ar of basalt flow covers. At Ecemiş, Sarıkaya et al (2014) also use Terrestrial Cosmogenic nuclides to date from alluvial fans (from 136 ka to today).

* At Elazığ-Malatya (Upper Euphrates), Demir et al. (2009) discuss a terrace staircase formed before MIS 66, and fossilized by a basaltic flow K-Ar dated 1,82 Ma.

* In the lower section of the Euphrates basin, Sanlaville et al. (1988) dated Middle Pleistocene important terraces in the Sajur valley by using palaeolithic artefacts. In the same area and along the Euphrates trough, Kuzucuoğlu et al. (2004), Westaway et al. (2006) and Demir et al. (2009) studied Pleistocene terraces,

[1] Ma : Million years
[2] ka: thousand years
[3] MIS: Marine Isotopic Stage
[4] LGM = Last Glacial Maximum

producing a relative sequencing with no date, with the exception of comparison results from northern Syria (Demir et al., 2008).

* In a way similar to the approach developed in the Upper Euphrates (Demir et al., 2009), at Kula Westaway et al. (2004, 2005) and Maddy et al. (2005, 2015) dated major morphological changes in the Gediz basin (past river course, incision, capture, damming) using K-Ar dates of basalts fossilizing these morphologies.

* In the upper section of the Tigris river at Diyarbakır also, Westaway et al. (2008) and Demir et al. (2009) use K-Ar dates to establish a chronological frame for the incision of the river into Early Pleistocene coarse alluvial from 1,2 Ma ago on, and the formation of downslope distributed terraces between 1,2 Ma and 0,4 Ma ago.

3.2 Mid Pleistocene Climate Records In Turkey (600 To 115 Ka Ago)

Not only Mid-Pleistocene records become numerous when compared to the previous period, but regions and geomorphologic contexts concerned by these records increase in variety, covering all Turkey (except the Sakarya river basin?).

In the same regions as above (Early Pleistocene to Mid-Pleistocene), the same authors also produced data concerning the upper part of the Mid-Pleistocene in:

* **river valleys** (the Gediz river at Kula; the Kızılırmak at Avanos, the Euphrates valley south of the Keban dam, the Tigris valley upstream and in the surroundings of Diyarbakır), and

* **lakes** such as the Acıgöl Pleistocene DSI cores (Akçer-Ön et al., 2016, 2017)

Additional river and lake sequences delivering information on Mid-Pleistocene records in Anatolia are

* **river terraces** in NW Anatolia (Dumoulin, 2013; Kazancı et al., 2014), and east-central Anatolia with the Aladağlar (et al. 2014a at Ecemiş) and Cappadocian fairy chimneys (Sarıkaya et al. 2014b; Çiner in press).

* **deep lake and coastal fan sediments** in the Konya plain (Kuzucuoğlu et al., 1999, 2010) and of Lake Van (Kuzucuoğlu et al., 2010, in press; Litt et al., 2014).

Meantime, two new types of mid-Pleistocene to MIS5e-dated climatic archives are now available:

* **travertines**, in western and Mediterranean Anatolia (Altunel et al., from 1993 to in press; Koşun et al. 2012; Glover and Robertson, 2013), and in east-central Anatolia near Sivas (Mesçi et al., 2018)

- **speleothems** in northern Anatolia (Fleitmann et al., 2009; Rowe et al., 2012), south-western (Poekover et al., 2015) and Mediterranean Anatolia (Ünal et al., 2008), central Anatolia in the Aladağlar (Ulusoy et al., 2014: MIS 5e record).

This richer set of sequences shows that:

(1) climatic cycles are comparable to the global ones (GISP 2)

(2) some signals are clearly local (eg. impacted by volcanic eruptions interrupting the records in Lake Van)

(3) some environments however respond to regional climate specificities distinct throughout Anatolia , for example when comparing northern and central Anatolia.

Chronological uncertainties however, as well as suspicion of tectonic impact on the records, keep from providing such curves as to start a discussion on possible impacts of relief, variations in spatial penetration of different atmospheric systems into the highlands and the mountain-shadowed plateaus of Anatolia.

3.3 From The Last Interglacial (Mis5e: 125-115 Ka Ago) To The End of Last Glacial (Late Glacial: 14.7-12.4 Ka Ago)

Regarding climate records of this period, two additional archive types (moraines, marine terraces) are to be added to the preceding ones (river terraces, lakes, speleothems, travertines).

Among new sequences:

* some are very important as they provide multi-proxy data (eg. İznik Lake: Roesler et al., 2012), while Konya Plain delivers a detailed MIS 5e (Kuzucuoğlu et al., 1999) and MIS 2to Late Glacial (Fontugne et al., 1999; Karabıyıkoğlu et al., 1999; Roberts et al., 1999) comparable with Lake Van record for the Last Glacial (Christol et al. 2010, 2013; Kuzucuoğlu et al. 2010; Picarski et al. 2013; Litt et al., 2014).

* a new speleothem record (80-0 Ka) is delivered by Dim Cave in the Mediterranean region (Ünal-İmer et al., 2015). At Sofular, Göktürk et al. (2011) focus on 50-0 ka ago; at Karaca Cave, Fowe et al. (2012) focus on 80-6 Ka. Several other records are being analyzed and about to be published soon.

* new dated river terraces are located in the Kızılırmak drainage area (at Amasya: Erturaç, 2006), in the Upper Büyük Menderes (Aksu et al., 1980, Kazancı and Gürbüz, 2011), and in the Tigris river at Diyarbakır (Karadoğan and Kuzucuoğlu, 2017)

Comparisons between these records show that, in all Anatolia, the Last Glacial is composed of wet-dry alternations. These alternations parallel the global records when the proxy used is pollen (Roesler et al., 2012; Litt et al. 2014) and, in a less striking way, charcoal (Pickarski et al., 2013). But dry/phases defined on the basis of vegetation (pollen, charcoal) match only partly those defined on the basis of the water balance (dry/wet) as in the lake level records.

In addition, the duration of climate stages and sub-stages vary between regions. This variety reflects the more or less sensitivity of the different areas of records to dryness (eg. central Anatolia *vs* the Taurus barrier), or to the penetration of air circulations from unusual origin (eg. monsoon influence in eastern Anatolia (eg. Kuzucuoğlu et al., 2009; Roberts et al., 2011).

Comparisons between Central Anatolia (eg. lake levels and evaporation intensity in the Konya plain) and eastern Anatolia (pollen composition in Lake Van sediments (Wick et al., 2003; Pickarski et al., 2013; Litt et al., 2014) show that:

- the last interglacial (MIS 5e lasts 15 ka instead of 10 ka in the global record (125-115 ka);

- the period 100-87 ka (2nd phase of MIS 4, which is increasingly cold in the ice core) is parted in

* a very dry/humid alternation in Konya, where the humid peak parallels a similar peak in GISP 2;

* while the whole phase remains humid in Van (*Quercus* forest patches with *Artemisia* spots)

A very striking difference concerns the period 28-18 ka ago, the coldest phase in the ice core (LGM). In Anatolia, it corresponds to several lake level occurrences in the Konya plain and lake rises in other lakes in the Lake District and Eastern Anatolia (Erinç, 1978). These occurrences and growth of lakes have been interpreted by Erol (1978, 1999) in the Konya and Sultansazlığı plains as responding to a globally humid phase, also recorded at Akşehir (Kazancı et al.,1997), Van (Christol et al., 2010; Kuzucuoğlu et al., 2010) and the Tuz Gölü (Kashima, 2002; Özsayın et al., in press) etc. Meantime, speleothems at Sofular (Fleitmann et al., 2009; Göktürk et al., 2011) record alternations which parallel lake level changes in the Konya plain (Roberts, 1983; Fontugne et al., 1999; Kuzucuoğlu et al., 1999, in press).

On the contrary, pollen in Lake Van records drought (steppe areas: Litt et al., 2014), as also in all other Anatolian lake sequences in which LGM has been reached by cores (eg. Bottema, 1984; Bottema et al., 1984, 1994; Kuzucuoğlu and Roberts, 1997; Emery-Barbier, 2002).

3.4 From The LGM (28-14.7 Ka Ago) To The End Of The Late Glacial (14.7-12.4 Ka Ago) And The Early Holocene (12.4-8.0 Ka Ago)

Climatic records of this time slice (from the LGM to the early Holocene) are available in the six geomorphological regions of Anatolia (Kuzucuoğlu et al., in press): NW, NE, eastern Taurus between Lake Hazar and Lake Van, the central Taurus from Geyikdağ to Aladağlar, the western Taurus from the Akdağ to the Dedegöldağ[5]. As shown by this list, the climate-recording sites are mostly located in highlands or high plateaus, or in sea-facing relief barriers. At these locations, they are provided by (1) moraines (2) lake sediments, whether the lake still exists, or is dry, or is masked by younger deposits fossilizing the records, and (3) speleothems.

The map presented by the oral paper classifies the archive types according to the three time slices of (1) the Late Glacial Warming, (2) the Younger Dryas, (3) the Early Holocene. This classification and the comparison between maps allow some interesting observation about time and space variability of the records. For example, regarding moraines reporting on extension *vs* retreat of past glaciers: (i) glaciers in the western Taurus extended last during the Late Glacial; (ii) glaciers in the central Taurus highlands facing the sea also extended during the Younger Dryas; while (iii) Early Holocene glacier extent is only recorded in the Erciyes and the eastern extremity of the central Taurus.

4. Conclusion

An attempt to compare

- (1) the pollen from Lake İznik in western Anatolia (Miebach et al., 2016), Çora maar in central Anatolia (Gauthier et al., 2014 and in prep.) and Lake Van in Eastern Anatolia (Wick et al., 2003; Litt et al., 2014; Pickarski et al., 2016), and

- (2) glacier extents and lake level records

show that:

➔ Lake level changes and glacier extent changes are comparable from MIS3 end to the Late Glacial

➔ The chronology of climatic phases (humidity reconstructed from pollen or from wetlands) are comparable all through Anatolia

➔ But the humidity context indicated by (i) plant associations or (ii) humid/dry hydrology, shows differences between the lands oriented toward the humidity-sources (highlands facing the marine air masses) and the lands enclosed within the mountain barriers like the Konya Plain in the central Anatolian plateaus and the Lake Van in eastern Anatolia.

These differences are due:

- (1) to the higher sensitivity of central Anatolian areas to changes in humidity, a sensitivity which leads to more frequent occurrences of dry phases through the Holocene, and

- (2) to a displacement eastward of the onset of humidity from west (11.8 ka ago in Lake İznik) to east (between 10.3 and 9.7 ka in the Konya Plain; 9.5 ka ago in Van), and

[5] There are so many references concerning this period (from LGM to Early Holocene) that they are not listed in the text (nor in the reference list used for writing the present article).

- (3) a scaled complexity of the 4.5-3.2 ka ago climatic phase (a 1.5 millennium years-long phase ending the mid-Holocene transitional phase) produced by increasing

* intensity and rapidity of onset/end of changes, and

* number of wet/dry alternations during the phase.

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