NEW METHODS FOR QUANTIFYING CLIMATE VARIABILITY AROUND AFRICA OVER THE LAST 400 KA AND IMPLICATIONS FOR ANATOMICALLY MODERN HUMAN EVOLUTION AND DISPERSAL

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ABSTRACT

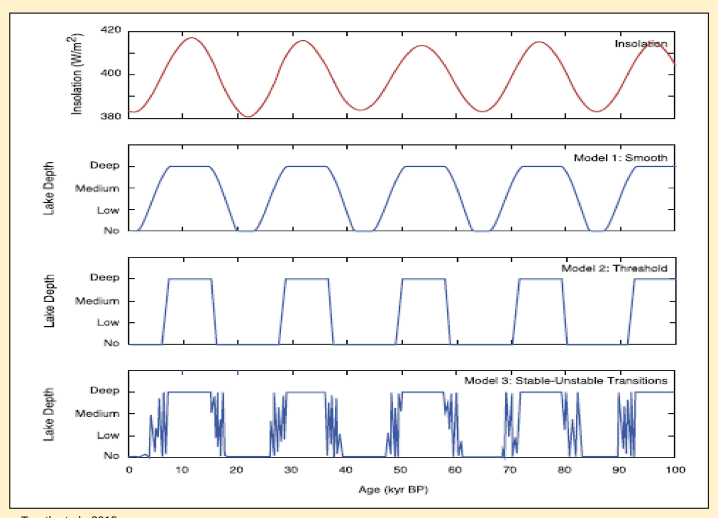
Numerous hypotheses have attempted to correlate key periods of human evolution and migration with climate and landscape changes. Many of these hypotheses operate within a unidirectional backdrop of decreasing tree cover and increasing aridity, trends evident in offshore dust flux, soil carbonate isotope and fossil faunal records. Others, like the variability selection hypothesis, focus on alternating climate extremes which would have required early humans to adapt to climatic variability and a changing mosaic of habitat types. The more recent accumulated plasticity hypothesis states that a species which experiences increased temporal variation within their environment is naturally selected to have more adaptive strategies while being less fit for any one particular type of environment. These adaptive strategies would equip a species for dispersal into new habitats.

Direct comparisons between climate variability and human evolution have been difficult due to the lack of well-dated, long-term, regionally specific climate records. Aside from generalized insolation variability, climate variability has not adequately been defined and quantified for paleo-records in any testable manner. We use two different methods to quantify and define climate variability through 31 climate/environmental records developed using different techniques and timescales. The new methods allow direct comparisons between different records offering insight into complex, multi-regional climate dynamics of the last 400,000 years. Furthermore, the records span the African continent as well as the Southern Levant and Southern Europe offering an unparalleled spatial understanding of how multiple regions relevant to the rise and expansion of *Homo sapiens* responded to global climatic events.

Our study shows that five separate climate regions experienced both periods of high and low climate variability, and that these periods are not synchronous across Africa and into Europe. Higher latitude regions are more susceptible to global climate forcing as is tropical Africa. East Africa has a dampened response to glacial/interglacial cycles except for the transition out of MIS 5 and into MIS 4 and 3, which is a period of high climate variability for the region. Furthermore, major human migrations occur after periods of increased climate variability in a least one of the regions, with the prolonged period of repeated migrations during MIS 5 occurring during a period of increased variability everywhere but East Africa. However, the migration of 60ka occurred after a period of extreme variability in East Africa.

HUMAN EVOLUTION AND CLIMATE VARIABILITY

Hypothetical Climate Models

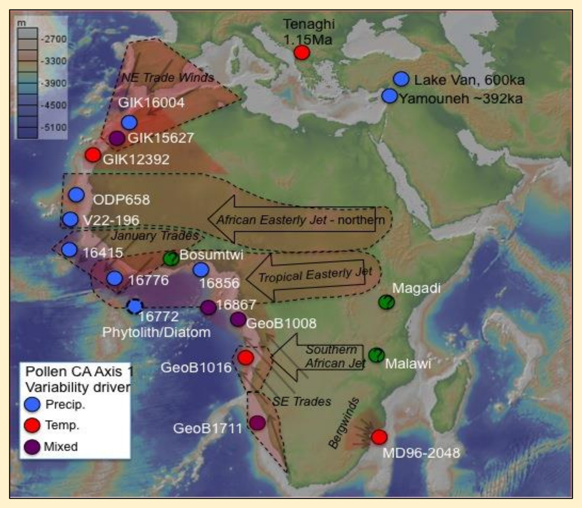


Trauth et al., 2015

- ***Pulse Turnover Hypothesis***: Variability causes pulses in extinction, speciation and replacement of species at particular climate thresholds. (Model 1)
- ***Variability Selection Hypothesis***: Hominin evolution was spurred by adaptations to increased climate variability (Model 2)
- ***Accumulated Plasticity Hypothesis:*** Hominins accumulate adaptive plasticity during periods of instable/high climatic variability occurring between periods of stable/low climatic variability (Model 3)

DATA USED FOR ENVIRONMENTAL VARIABILITY

- **XRF**: X-ray fluorescence is an unitless count of relative abundance for an element in a sample. It is often displayed as a ratio of one element to another. This ratio records environmental processes. The interpretation relies on the system. Increased Zr/K and Ca/K are indicators of increased terrestrial input.
- **Pollen:** Pollen in marine cores is a composite of vegetation of the nearby continent. Contributions from trees, shrubs and grasses inform on landscape vegetation, temperature, and rainfall. See figure to the right for more about our pollen records.
- **TOC:** TOC is the percentage of total organic carbon in a sample. It is an indicator of biological contribution to the sediment and higher values are interpreted as wetter conditions.
- **bSi**: Biogenic silica is produced mainly by diatoms. It is a measure of primary productivity in an aquatic environment.
- **Dust**: Dust flux in marine cores is an indicator of increased terrestrial input. More dust would indicate that the nearby continent is arid.
- **Speleothem $\delta^{18}O$:** Depleted values in $\delta^{18}O$ are interpreted as increased precipitation
- **Bulk Geochemical:** Bulk geochemistry is a direct measurement of elements in a sample. Increased Na/Ca ratios indicate a more saline lake and arid environment.
- **$^{31}C/(^{31}C+^{29}C)$:** The ratio of particular carbon chains in leaf waxes. Higher values indicate more C_4 vegetation (grasses) and may point to more arid environments.



Pollen is a useful tool in climate reconstructions. However, transport distance and source area mixing influence pollen input and interpretation. Correspondence analysis (CA) analysis was performed on pollen records to determine the main climatic signal: precipitation, temperature or both. Variability was measured on the first axis of the CA. The figure above shows the main CA-derived climate signal and possible pollen source areas.

RECORDS USED IN THIS STUDY

Data Name	Latitude	Longitude	Data Type	Source
GIK16004	29.98	-10.65	Pollen	Hooghiemstra et al., 1992
GIK15627	29.16	-12.09	Pollen	Hooghiemstra et al., 1992
GIK12392	25.17	-16.85	Pollen	Dupont, 2011
ODP658	20.73	-18.58	Pollen	Dupont, 2011
V22-196	13.83	-18.97	Pollen	Lezine, 1991
GIK16415-2	9.57	-19.09	Pollen	Dupont, 2011
GIK16776-1	3.74	-11.39	Pollen	Dupont, 2011
GIK16856-2	4.81	3.40	Pollen	Dupont, 2011
GIK16867-2	-2.20	5.10	Pollen	Dupont, 2011
GeoB1008-3	-6.58	10.32	Pollen	Dupont, 2011
MD96-2048	-26.17	34.02	Pollen, $^{31}C/(^{31}C+^{29}C)$	Dupont, 2011; Castaneda and Dupont, 2016
Lake Yammouneh	36.02	34.13	Pollen, XRF	Gasse et al. 2015
Lake Van	38.63	42.82	Pollen, bSi, XRF, TOC	Stockhecke et al., 2014
Tenaghi Drill Core	40.97	24.22	Pollen	Tzedakis et al, 2006
Peqi'in Cave	32.58	35.19	Speleothem $\delta^{18}O$	Bar-Matthews et al., 2003
Soreq Cave	31.45	35.03	Speleothem $\delta^{18}O$	Grant et al., 2012
Lake Ohrid	41.00	20.75	XRF, TOC, bSi	Franke et al., 2016
Lake Malawi	-12.18	34.37	XRF	Johnson et al., 2016
ODP 659	18.07	-21.02	Dust	Trauth et al., 2009
ODP 967	34.07	32.72	Dust	Trauth et al., 2009
ODP 721/722	16.67	59.85	Dust	deMenocal, 2004

METHODS FOR QUANTIFYING CLIMATE VARIABILITY

1. All data was detrended
2. Z-scores were calculated for each data set to allow for comparison between different proxies

$$z = (x-\mu)/\sigma$$

where x is the raw value at any given time-step, μ is the mean, σ is the standard deviation

3. Data was sectioned into 10ka bins, with a value linearly interpolated for the 10ka timestep
4. The mean, standard deviation and weighted rate-of-change were calculated for each 10 ka bin

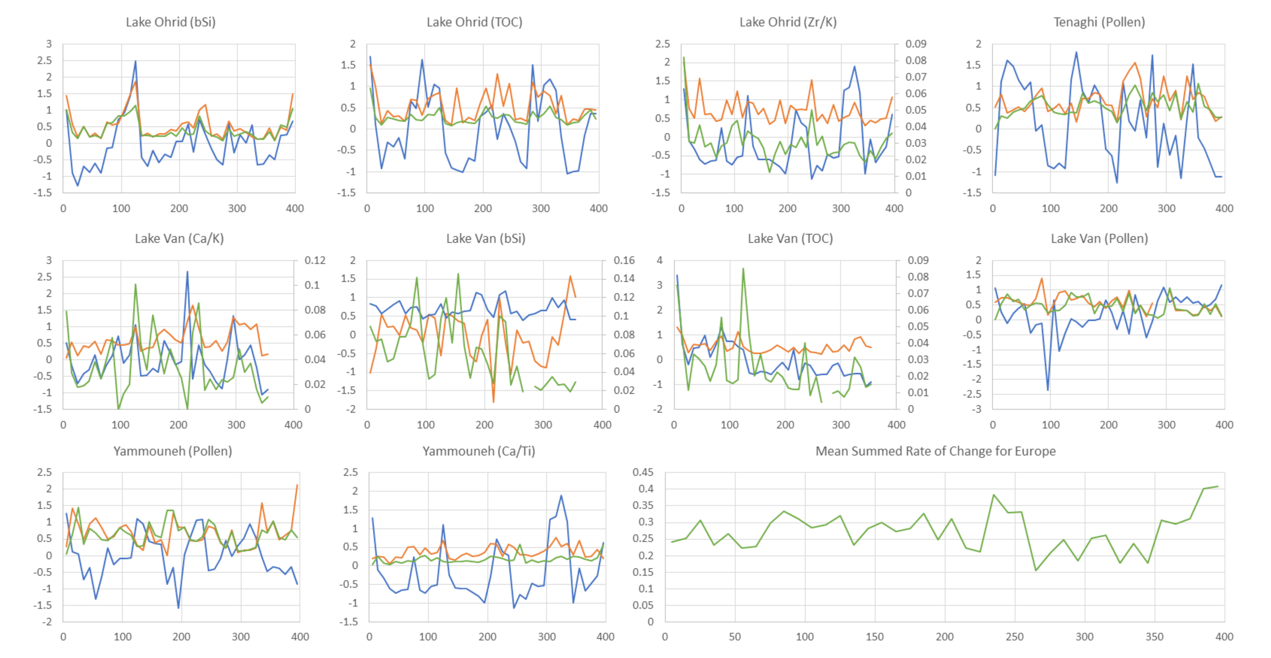
$$R_{change} = |(x_2-x_1) \times (y_2-y_1)/10)|$$

where x is the z-score for any given time step and y is the age in thousands of years

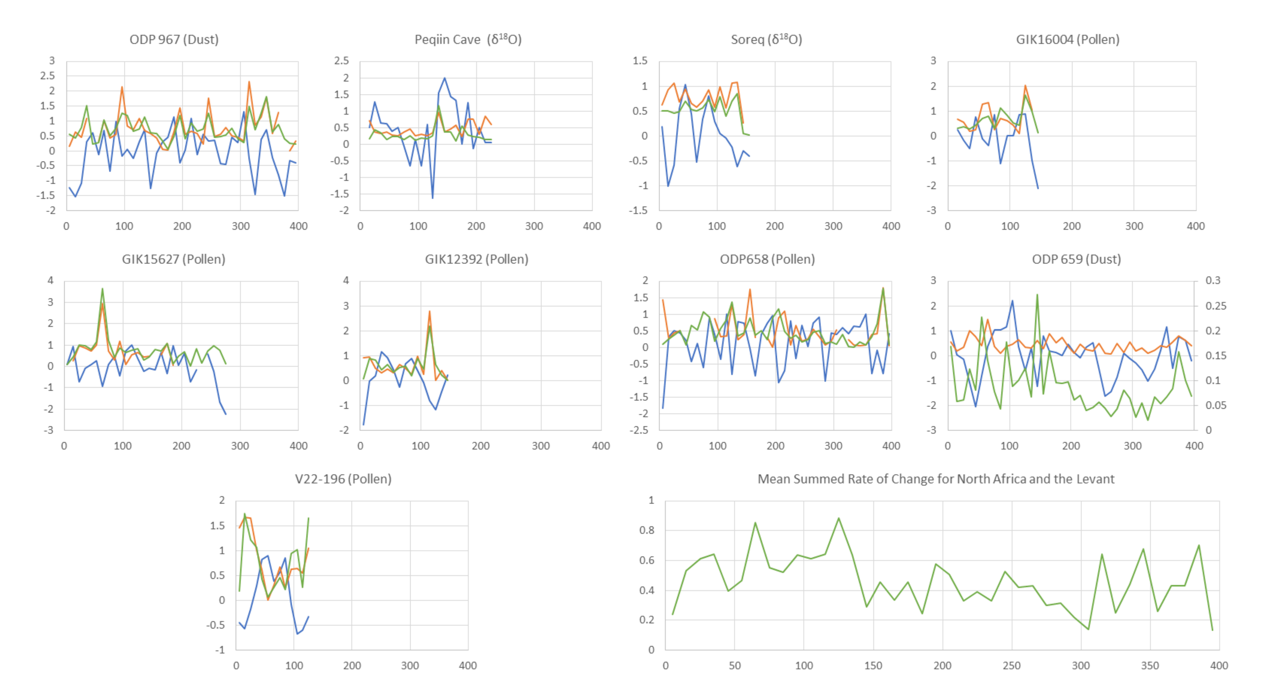
5. The average summed rate-of-change for each of the five regions was calculated for each 10ka time bin to determine regional climate variability

RESULTS

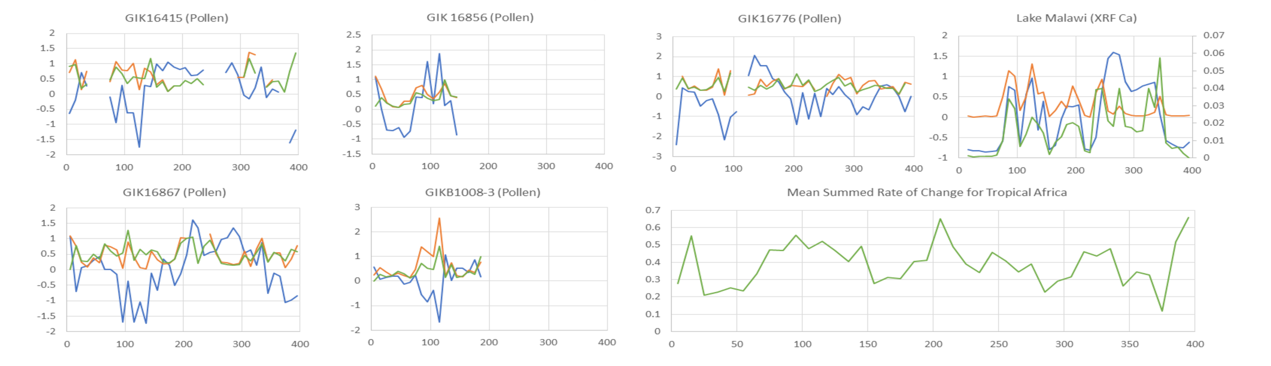
Southern Europe and Southwest Asia

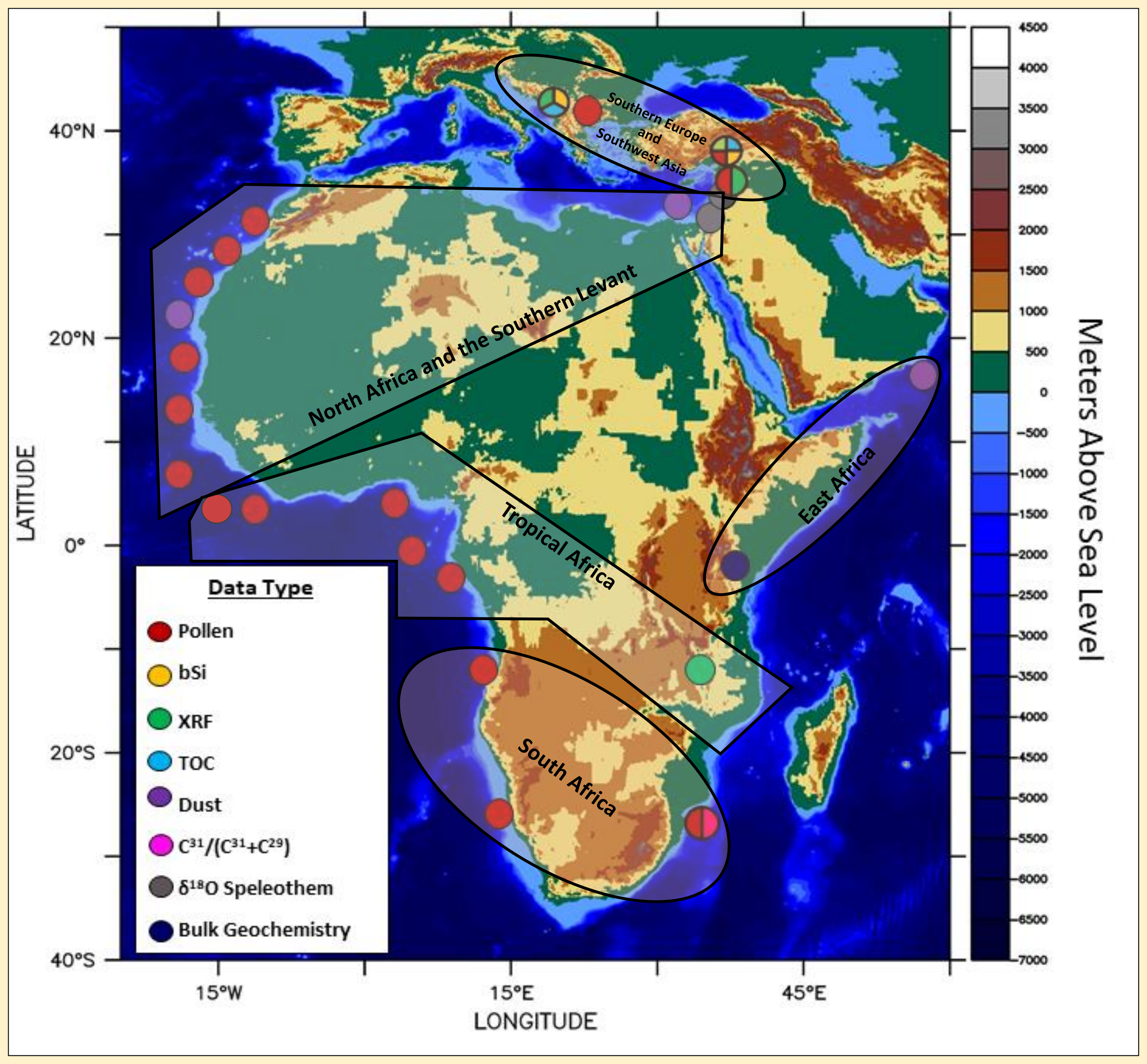


North Africa and the Southern Levant

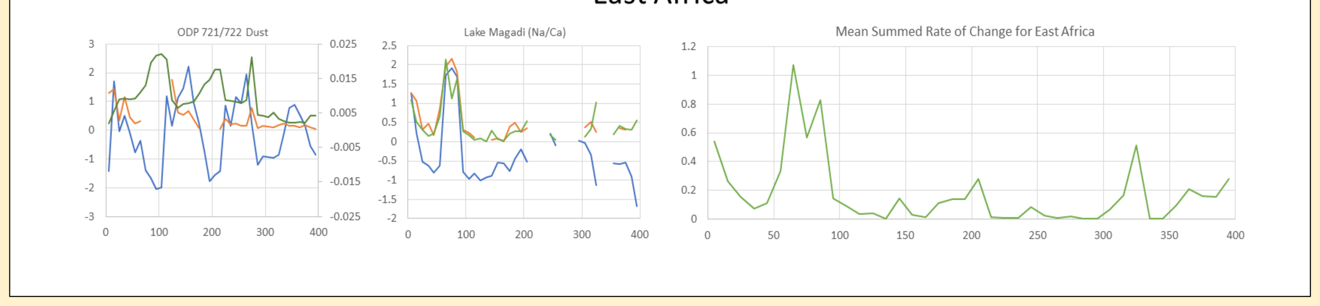


Tropical Africa

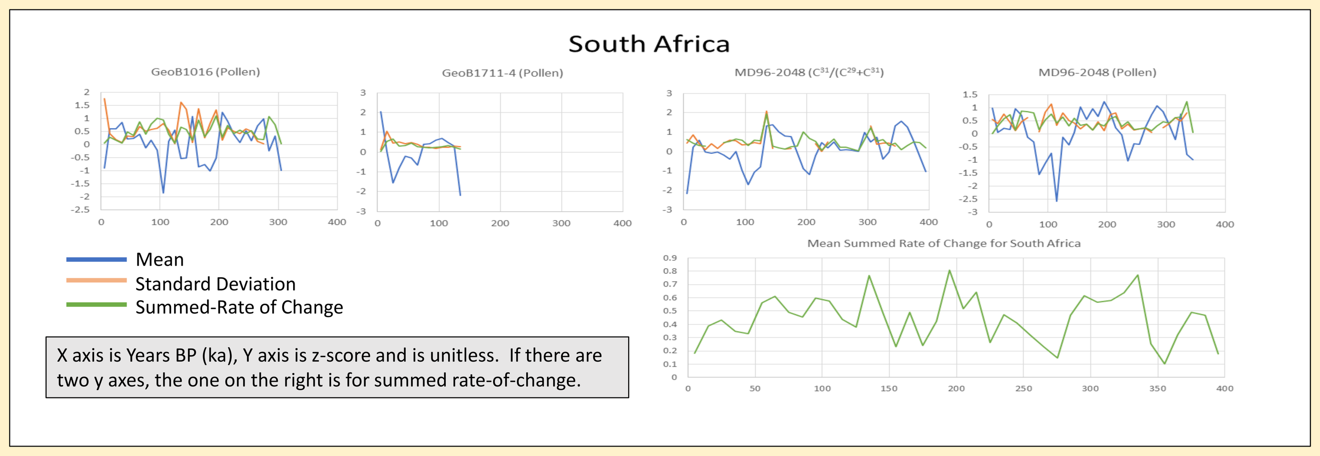




East Africa



South Africa

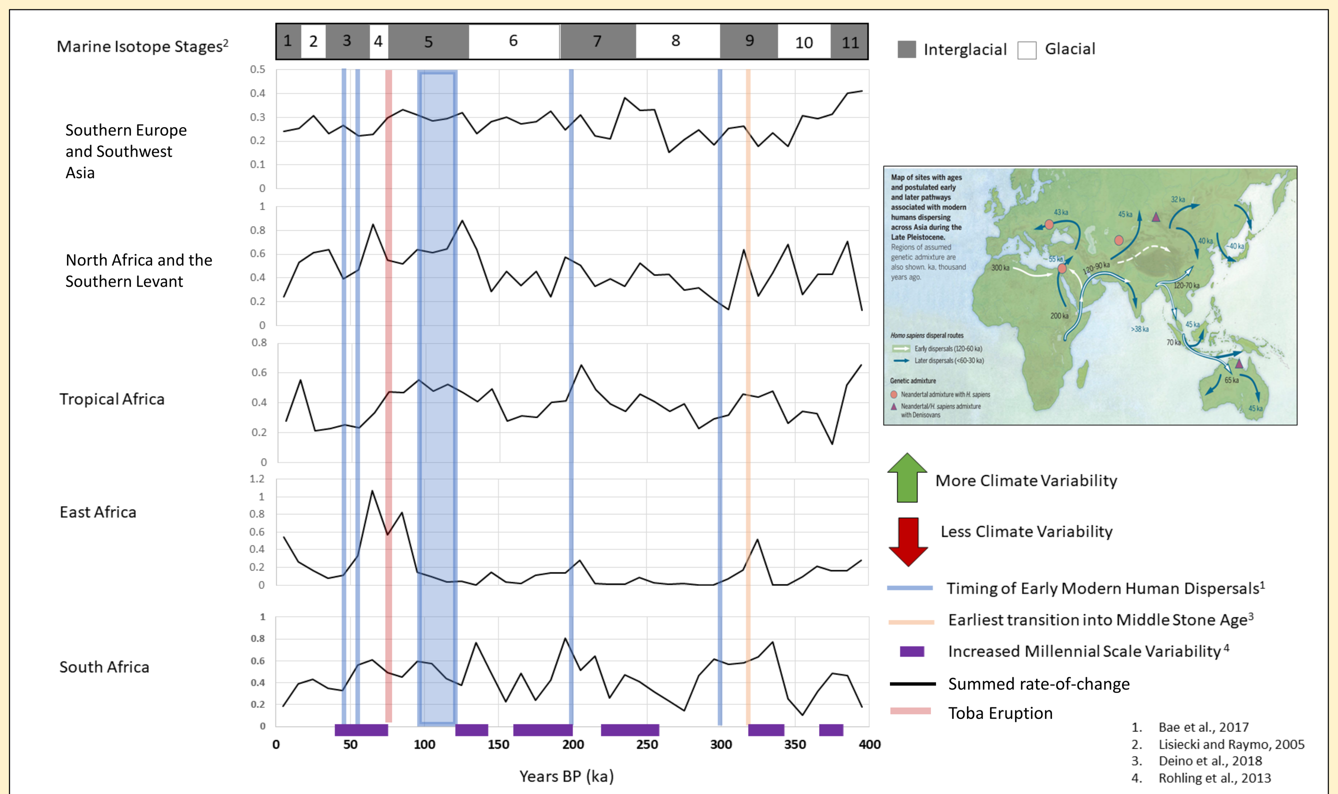


X axis is Years BP (ka), Y axis is z-score and is unitless. If there are two y axes, the one on the right is for summed rate-of-change.

- **31 separate environmental records** were delineated into **5 different climate regions**. Regions were decided based on geographical areas which repeatedly show similar climate behavior.
- We performed calculations for mean (blue), standard deviation (orange) and weighted rate-of-change (green) in segments of 10,000 years on each record. The data was plotted in the center of each 10,000-year bin. For example, the values for the 20ka-30ka timeframe are plotted at 25ka.
- Each data set records a different type of environmental signal (i.e. terrestrial input, temperature or precipitation).

- The **mean** tracks the general trend of the environmental signal. For example, a higher dust flux mean indicates a trend towards drier conditions. In marine core ODP 721/722, off East Africa, the high mean at 155ka represents overall dry conditions for the period 150ka-160ka while the lower mean at 105ka represents wetter conditions for 100ka-110ka.
- **Standard deviation** and **summed weighted rate-of-change** track fluctuations in the record, often with both calculations paralleling each other. In ODP 721/722, the higher summed weighted rate-of-change at 95ka, 105ka and 115ka, indicate that there were multiple changes in the dust flux off the coast of East Africa between 90ka-120ka. This accumulated change would indicate a period of **high variability**.
- The **mean summed rate-of-change** is the average rate-of-change of all records for that region. The analysis shows that **each region experienced** periods of **both high variability** and **low variability**, and these periods are not always synchronous through all the regions.

DISCUSSION AND CONCLUSION



- Climate variability in Southern Europe and Southwest Asia, North Africa and the Southern Levant, Tropical Africa and South Africa is influenced by global climate shifts such as glacial/interglacial transitions and the intensification of the cross-equatorial temperature gradient in the Atlantic (Rohling et al., 2013).
- East Africa is less influenced by global climate shifts with increases in variability occurring at the transitions into MIS 9 and MIS 6, but most notably into MIS 4 and 3. This may be due to a weakening in the Walker circulation during the last glacial maximum which would have allowed for more local convection and increased rainfall to occur (Dinezio et al., 2016).
- Regional differences in variability indicate that local environmental feedbacks and thresholds may have been more impactful for early humans than generalized orbital parameters. Orbital parameters as an index of environmental variability do not capture the full range of environmental variability experienced by African hominins over the last 400ka.
- Major human migrations over the last 400ka occur after periods of increased variability in at least one region studied. The prolonged period of repeated migrations between 120-90ka (MIS 5) occurred during a period of higher variability in Southern Europe and Southwest Asia, North Africa and the Southern Levant, Tropical Africa and South Africa.
- The last two major out of Africa migrations of modern humans occurred after periods of increased variability in East Africa and North Africa and the Levant.
- The recent discover of MSA tools at Olorgesailie Basin, Kenya dates to a period of high variability in the region (Deino et al., 2018).
- This new method offers an approach to linking climate variability as actually experienced by hominins to evolutionary and dispersal events in hominin history. More high resolution records are needed to narrow down regional differences in climate variability.

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