

AFRICA: PALEO-PERSPECTIVES ON WATER AND LAND COVER WITH EMPHASIS ON EASTERN AFRICA

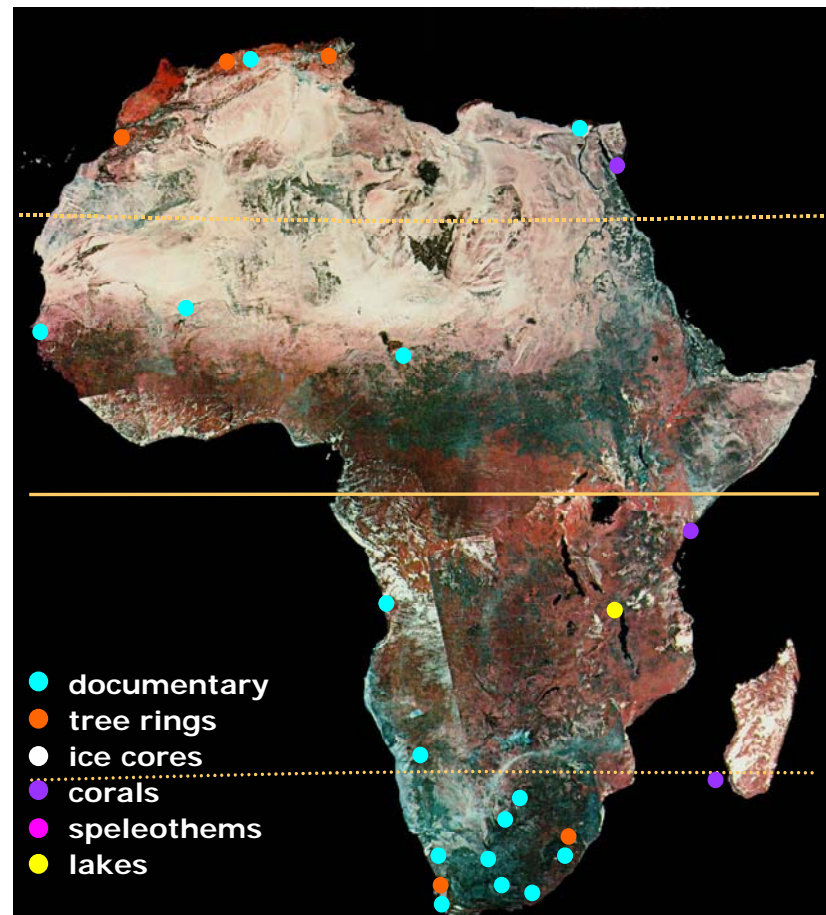
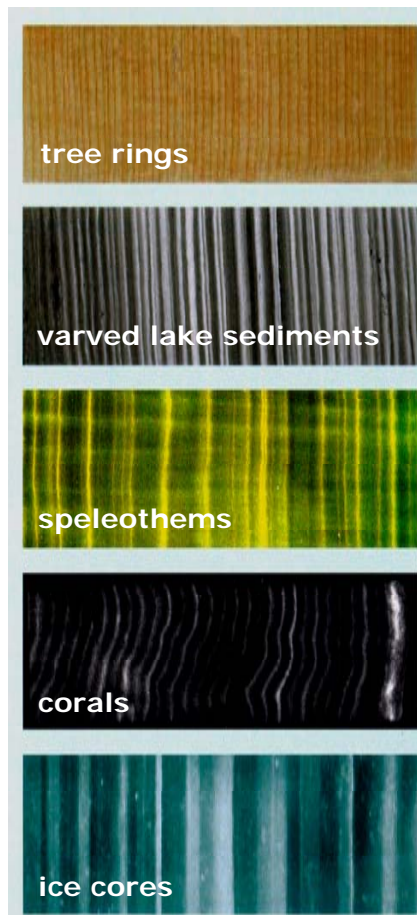
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Role and Significance of Palaeo-research in Africa

- ◆ Palaeo-environmental and palaeoclimatic research in Africa is of great importance for several reasons.
 - ➔ It provides a historical perspective on past variability due to natural and human causes, and thus provides a baseline for efficient long-term management of natural resources
 - ➔ Meteorological records and written observations are limited to the very recent past (often only the past few decades); thus data on longer term cyclical fluctuations is very limited, as is our understanding of how these impact on regional environments and human societies, or how these various components interact.
 - ➔ It is noted, for example, that during the late Holocene when natural forcings and boundary conditions were similar to today, climate variability often exceeded anything that is seen in modern instrumental records (Oldfield and Alverson 2003). Knowledge of long-term climate change, therefore, is necessary in order to assess the significance of historically documented, and modern-day climate change.
 - ➔ Palaeo-research also enables us to estimate better the range or 'envelope' of natural climate variability under boundary conditions similar to the present, and also to discriminate between natural and anthropogenic perturbations of the climate system.
 - ➔ It enables us to recognise locally and regionally significant human impacts, and is critical in the development and testing of models which can then be used to simulate future climate change and trends.

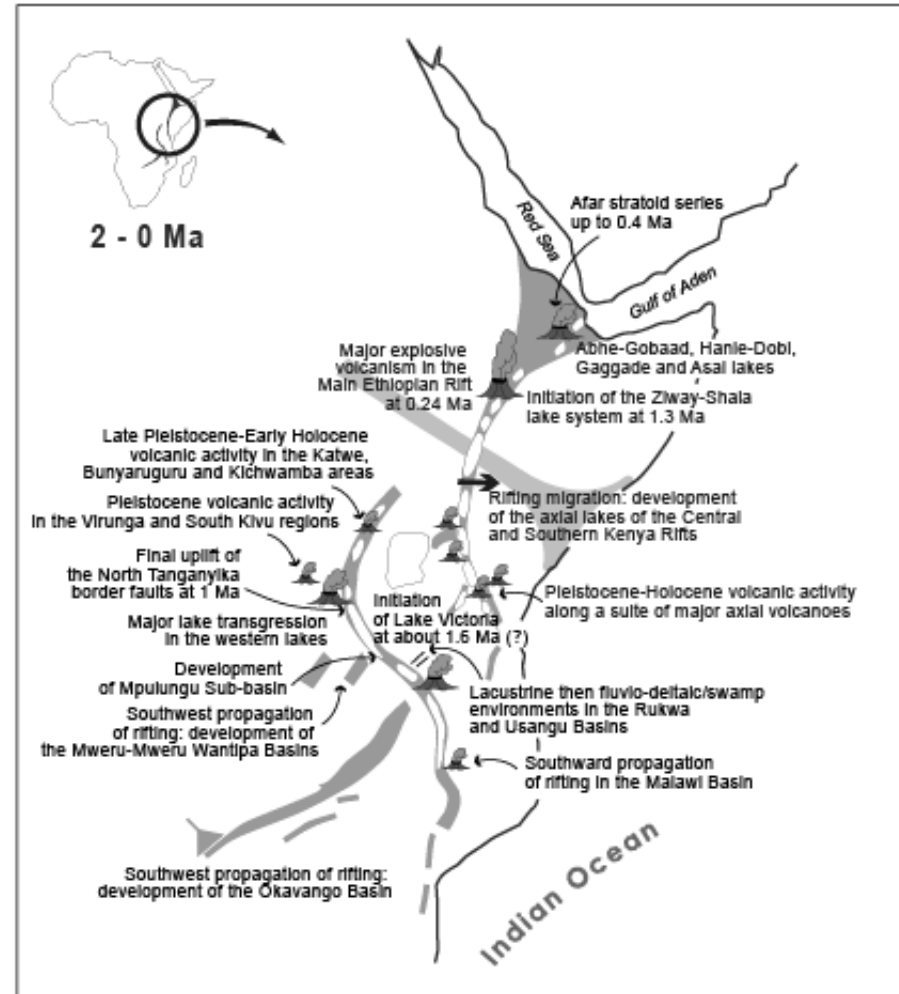
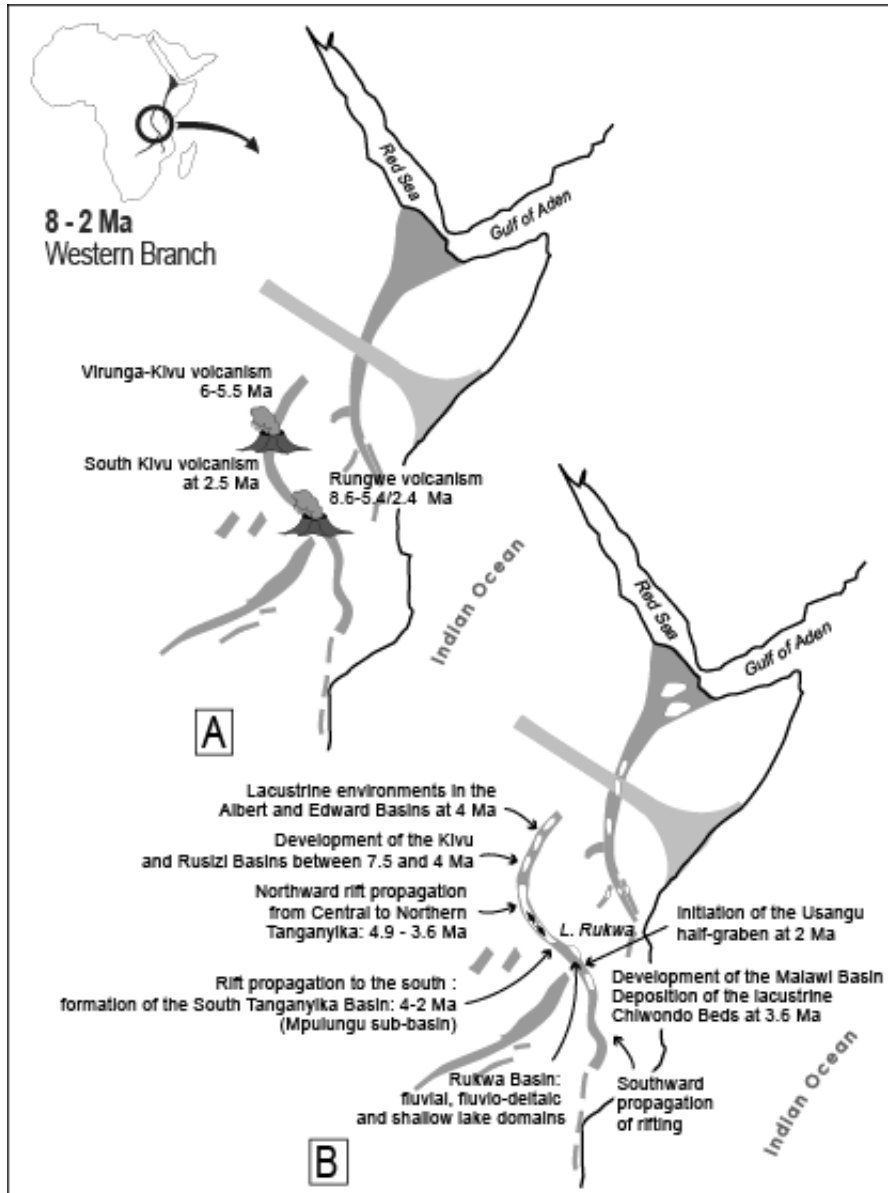
Palaeo-proxies in Africa

- ◆ Instrumental climate records (very short), Documentary (scarce), Marine sediments, Lake sediments, Peat, Groundwater, Corals, Speleothems, Tree rings, ice (glaciers)
- ◆ Proxies include pollen, diatoms, foraminifera, dinoflagellates, geochemistry, stable isotopes, alkenones etc.
- ◆ Information derived includes: precipitation, temperature, ecosystem dynamics, palaeoproductivity, SST, LST, salinity, ventilation, sediment provenance, dust deposition, etc.



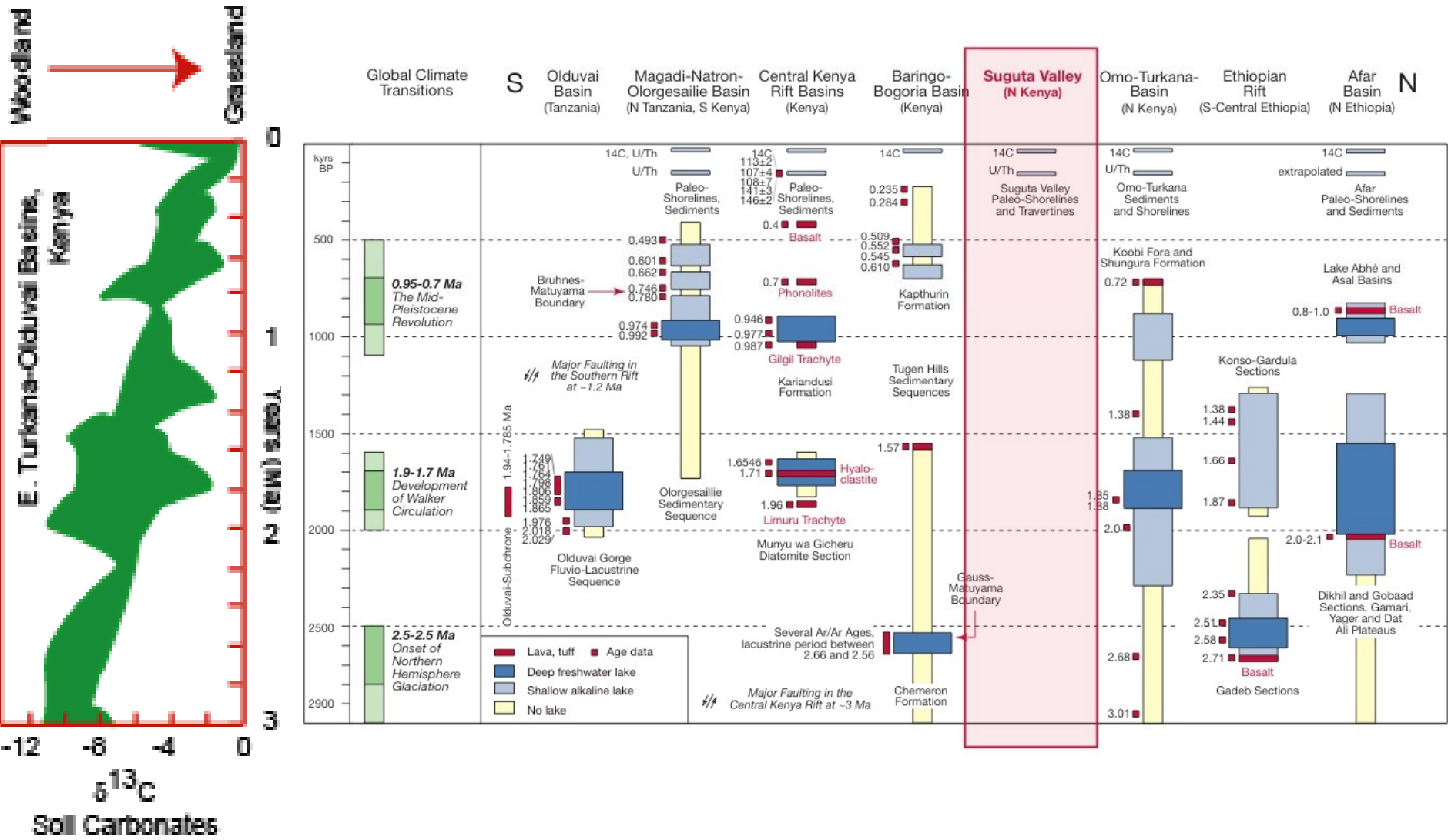
From
Verschuren
and
Eggermont

Lake Basin Initiation from 8 to 0 Ma



From Tiercelin and Lezzar, 2002

Water and land cover from 3 to 0 Ma

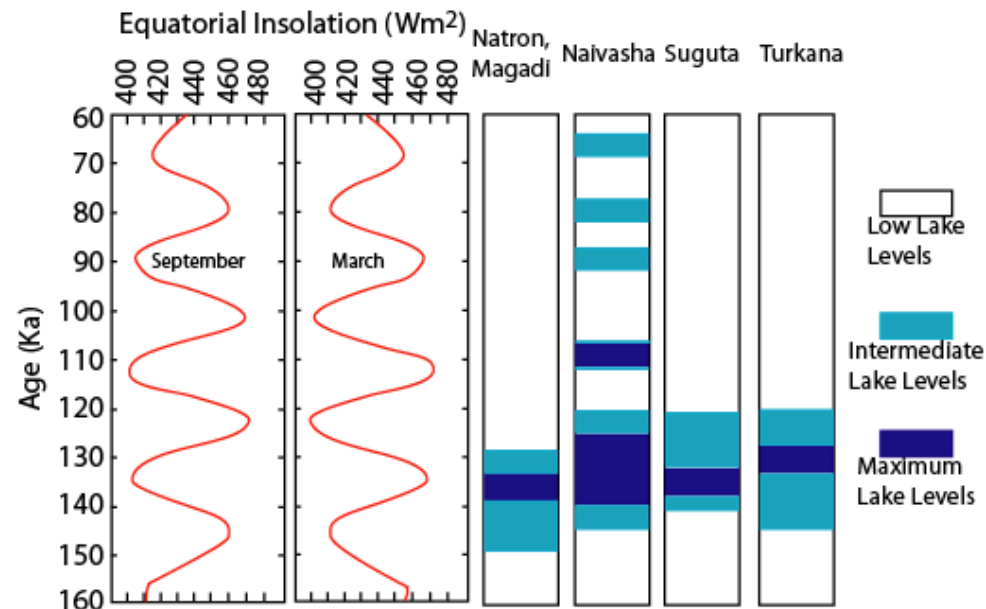


Gasse, 2005; Cerling, 1992;
Cerling and Hay, 1988

Trauth et al., 2005

Orbital Forcing of Climate Over the Past 3 Ma: Examples

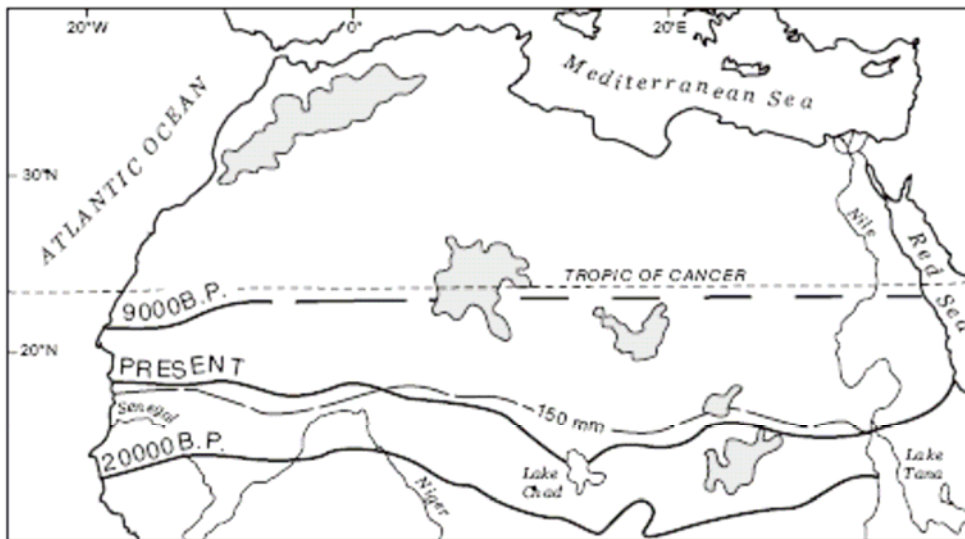
- ◆ Chemeron Formation, Central Kenya Rift – diatomite/fluviol cycles, reflect precession (ca. 2.66-2.55 Ma) (Deino et al. 2006)
- ◆ Palaeohydrological studies of Lake Naivasha show that high lake levels at 135,000, 110,000, 90,000 and 66,000 yr BP precisely match spring insolation at the equator without any significant lag (Trauth et al., 2001)
- ◆ Freshwater diatom species in equatorial Atlantic core (Prell, 1984) and stable carbon isotope variation in an equatorial maar lake (Olago et al., 2000) show that the precession cycle and its higher order harmonics influence winds and precipitation cycles
- ◆ Eccentricity and precessional cycles also seen in granulometric analysis of sediments of the Tswaing impact crater lake in the northern part of south Africa (Partridge et al., 1997); Sedimentation rates off the coast of SW Africa (Gorgas and Wilkens, 2002).



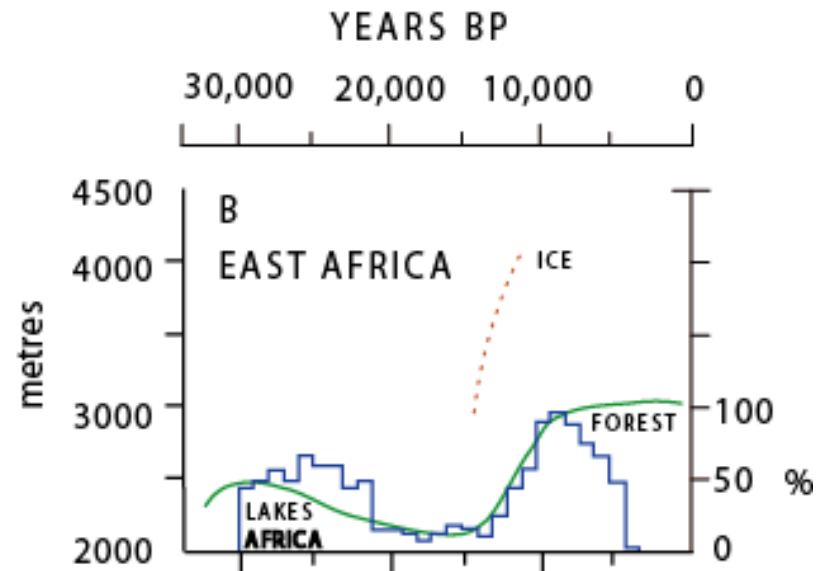
(Trauth et al., 2001)

The Last Glacial Maximum

- ◆ Climatic conditions were generally colder, drier and windier than present
- ◆ Many lake basins experienced drastically reduced water levels and/or desiccation and deflation
- ◆ Present Sahelian area and extensive dune building reached 300-400km south of the present Sahara-Sahel boundary; 60% less precipitation than today over the Kalahari region
- ◆ Expansion of C₄ grasses at the expense of montane forests as a consequence of lower temperatures, low glacial atmospheric CO₂ concentrations, and reduced precipitation
- ◆ In the lowlands, tropical forest cover appears to have been reduced and/or replaced by tropical seasonal forest; miombo forest and mangrove areas were considerably reduced



Petit-Maire, 1995



Hastenrath, 1991

Palaeoclimate during the Last Glacial Maximum in Africa

Tropical precipitation at the LGM (relative to present).

Area	% Rainfall	Source
Ziway-Shala Basin, Ethiopia (7° to 8°30'N)	-9 to -32	Street, 1979
Southern Africa	+150 to +200	Lancaster, 1979; Shaw, 1986
East and Central Africa (between 4°S to 12°N and 28°E to 42°E)	-30	Bonnefille <i>et al.</i> , 1990
Lake Tanganyika, Tanzania	-15	Vincens <i>et al.</i> , 1993

Tropical temperature lowering at the LGM (relative to present).

Area	Temperature		Source
	(°C)	Proxy	
Eastern Colombian Andes, South America	-6 to -7	Pollen	Van Der Hammen, 1974
Wonderkrater, South Africa	-5 to -6	Pollen	Scott, 1990
Sacred Lake, Mount Kenya	-5 to -8	Pollen	Coetzee, 1967
New Guinea	-7 to -11	Pollen	Flenley, 1979a
Muchoya Swamp, Uganda	-5 to -8	Pollen	Morrison, 1968
Lake Tanganyika, north basin, Tanzania	-5 to -6	Pollen	Vincens, 1989a
East and Central Africa (between 4°S to 12°N and 28°E to 42°E)	-4±2	Pollen	Bonnefille <i>et al.</i> , 1990
Lake Tanganyika, Tanzania	-4.2 ±3.6	Pollen	Vincens <i>et al.</i> , 1993
Mount Elgon, Kenya	-3.5	ELA	Hamilton and Perrott, 1979
High Semyen, Ethiopia	-7	ELA	Hurni, 1981
Mount Kenya, Kenya	-5	ELA	Osmaston, 1975
Ehiopian Mountains	-7	ELA	Hurni, 1981
South America	-7 to -9	ELA	Weingarten <i>et al.</i> , 1991
Cascade Ranges, North America	-4	ELA	Porter <i>et al.</i> , 1986
Global average (glaciers)	-4.2 to -6.5	ELA	Broecker and Denton, 1990

Deglaciation and the Younger Dryas

- ◆ Considerable amplification of the seasonal cycle in the Northern Hemisphere occurred between 15,000 and 6,000 yr B.P. due to changes in both perihelion and axial tilt.
 - Step-wise changes (lakes) towards wetter conditions in response to both insolation forcing and feedback processes with changes in oceanic circulation and sea surface conditions in Western Africa
 - The abrupt and spectacular lake level rise in intertropical Africa at about 15ka BP is thought to have been triggered by insolation changes, reaching 4.2% above modern values that produced a non-linear hydrological response
 - In southern Africa, geomorphological, pollen and stable isotope studies suggest a rapid increase of temperature towards present day values from about 18-17.5ka BP – thus the deglacial warming in the southernmost part of Africa begun about 3000 years earlier than in the northern hemisphere
 - Rapid retreat of tropical mountain glaciers at a rate of about 200m per 1000 years from about 15,000 yr BP
 - Gradual resurgence of vegetation to conditions existing today
 - A dry interlude corresponding to the Younger Dryas event is evident in some lakes at about 11.5ka BP and was associated with a temperature drop of 2°C in Lake Malawi

The Early Holocene

- ◆ Seasonal contrasts (radiation) between 11 and 10 Ka BP were about 7% greater during the summer and 7% less during the winter as compared to today across the low and middle latitudes of both hemispheres, and increased heating of the land surface
- ◆ Nearly all lakes from equatorial region to Sahara/Sahel were high: 9,000 and 4,500 yr B.P, saw the advent of the Green Sahara
- ◆ Rapid expansion and reconstitution of lowland forest and rise of treeline in montane areas
 - ➔ These changes coincided with the acceleration in global warming, and reflected increased atmospheric water vapour and precipitation due to higher SSTs and evaporation over land and sea
- ◆ Southern hemisphere of Africa was dry compared to the rest of Africa: wetter at ca.5000 yr BP.

Tropical precipitation during the Holocene (relative to present) (modified from Odada and Olago, 2005).

Area	Time Period (yr BP)	Rainfall		Source
		mm/yr	%	
Ziway-Shala Basin, Ethiopia	9,400 to 8,000	-	+25	Street, 1979; Gillespie <i>et al.</i> , 1983
Turkana basin	10,000 to 7,000	+80 to +140	+10 to +19	Hastenrath and Kutzbach, 1983
Lake Turkana, Kenya	10,000 to 4,000	+200	+27	Vincens, 1989
Nakuru-Elmenteita basin	10,000 to 8,000	+260 to +300	+29 to +33	Hastenrath and Kutzbach, 1983
Nakuru-Elmenteita basin	10,000 to 8,000	+260 to +300	+45#	Dühnforth <i>et al.</i> , 2006
Naivasha basin	9,200 to 5,650	+90 to +155	+10 to +17	Hastenrath and Kutzbach, 1983
Naivasha basin	9,000	-	+11 to +16*	Bergner <i>et al.</i> , 2003

- ◆ Maximum temperatures were at least about 2°C higher than present over Lake Malawi, consistent with temperatures of +1 to above +2°C derived from pollen data for the East Africa region.

#The authors propose a significant subsurface flow of water from the early Holocene Lake Naivasha in the south towards the Nakuru- Elmenteita basin to compensate the extremely negative hydrological budget of this basin.

*If the adaptation and migration of vegetation and subsequent higher transpiration were introduced into the model, the hydroclimatic conditions in the catchment would be characterized by a 28–32% increase in mean annual precipitation.

The Holocene

- ◆ Several post-glacial short-term anomalies occur during a state of apparent stability of external boundary conditions \Rightarrow tropical climate is very sensitive to subtle changes in/of its forcing mechanisms, e.g.

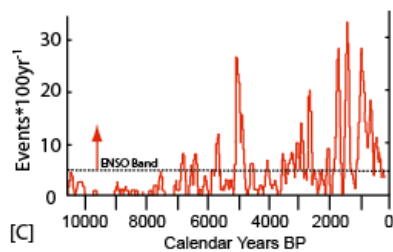
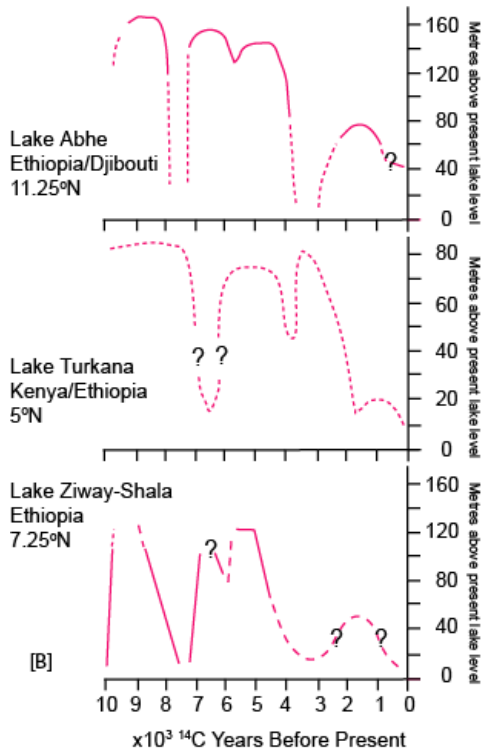
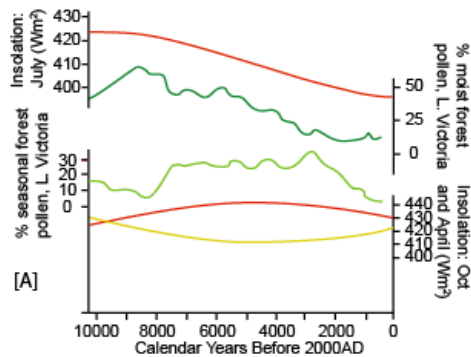
- ➔ SSTs, cross-equatorial heat transport by ocean surface currents that affect monsoonal climate domains.
- ➔ Abrupt dry periods in the Holocene also coincide with the broad period of enhanced seasonal contrasts and weak El Niño conditions.

- ◆ Reasons for the abrupt desiccation event between 8-7Ka are not well understood, and this is the general case for other Holocene events. It coincides with:

- ➔ a cooling and salinity lowering event in the north Atlantic
- ➔ strong interhemispheric contrasts in Atlantic SSTs related to less efficient export of heat from the south to the north

- ◆ Drier conditions were established *ca.* 5,000 yr BP. This dry phase in the tropics has been partly related to

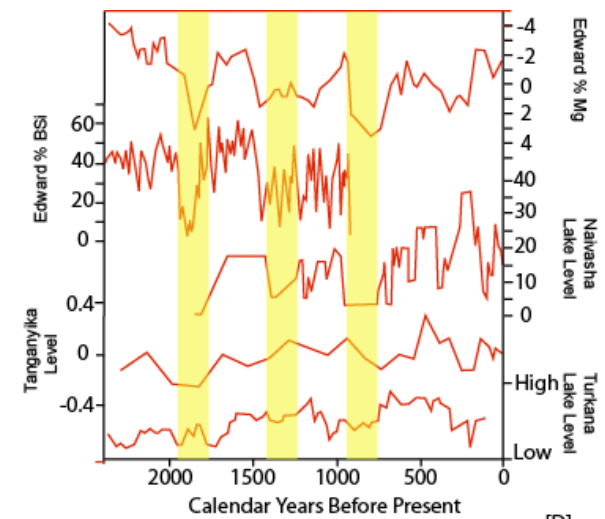
- ➔ orbital variations as the solar radiation peak at 9,000 yr BP returned to near modern values by 5,000 yr BP
- ➔ a low salinity event in the northeast Atlantic
- ➔ changes in Pacific Ocean sea-surface temperature regime, and the establishment of El Niño conditions at this time
- ➔ ENSO connections with tropical Atlantic SST
- ➔ Above coupling with large changes in Africa's land surface conditions (e.g. vegetation cover)



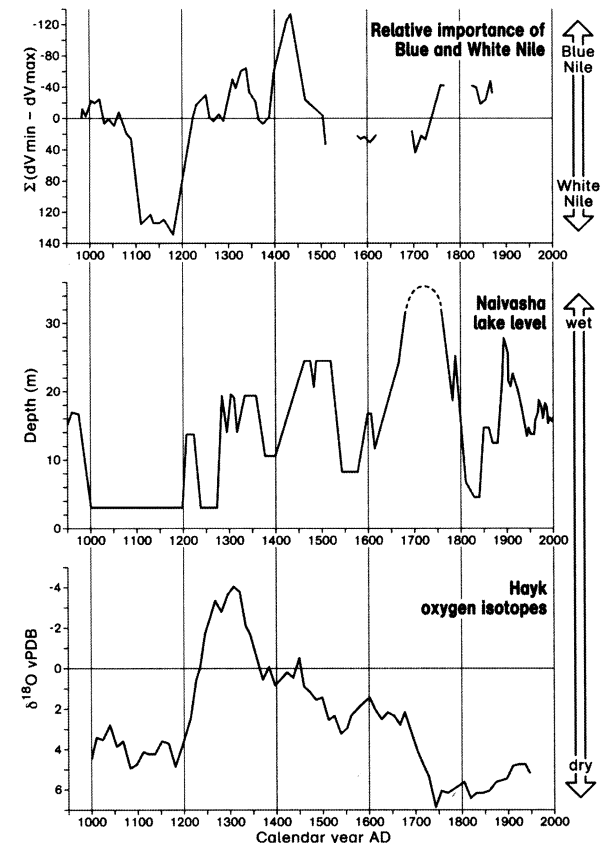
[A] Stager et al. 2003 [B] Gasse 2003; [C] Moy et al. 2002

The Past 2000 Years

- ◆ The palaeoclimate records of north and east Africa, and the Americas, indicate with high confidence that droughts lasting decades or longer were a recurrent feature of climate over the last two millennia, and that under gradual climate forcings (e.g. orbital), the climate system can change abruptly
- ◆ Decadal scale droughts and intervening wet periods in Lake Naivasha are attributed to high and low phases of solar radiation, respectively (Verschuren et al., 2000).
- ◆ A similar record has been documented at Lobi Plain (between Lakes Baringo and Bogoria), where abrupt wetland formation is related to a climate shift from drier conditions associated with the mid-Holocene and Medieval Warm Period (~AD 800–1270), to wetter conditions associated with the Little Ice Age (~AD 1270–1850) (Driese et al., 2004).
- ◆ Further northeast in Ethiopia, similar conditions prevailed (Lamb et al., 2007).
- ◆ Contrasting (out-of-phase) data from western Uganda during this period highlights the strongly regional nature of century scale climate dynamics on the African continent (Russell et al., 2007).



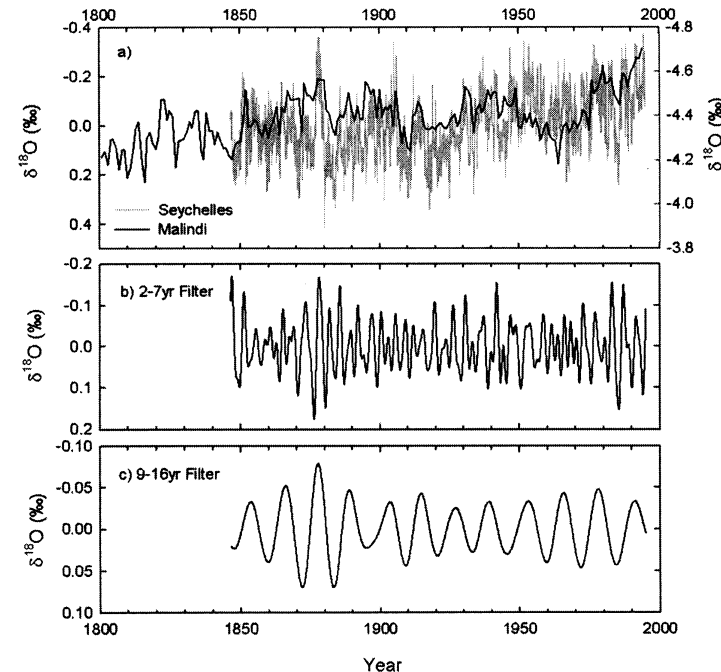
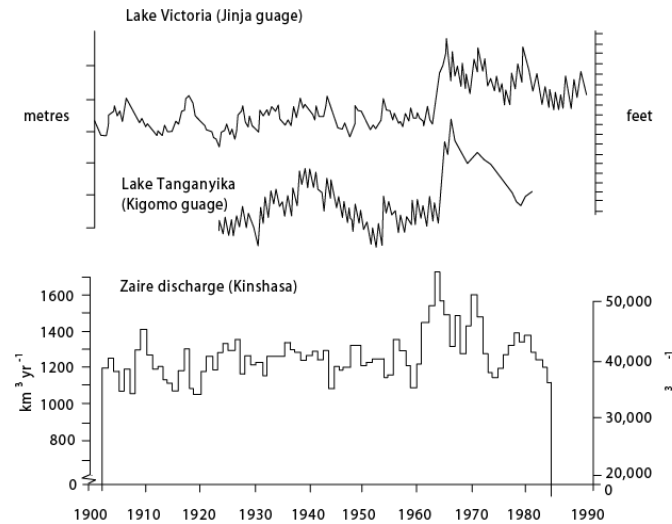
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Recent Times: Hydrology

- ◆ High levels: in Lakes Turkana and Naivasha in the 1890s; in Lakes Victoria, Turkana, Naivasha, Elementeita, Nakuru, Edward, Albert, and Lake Tanganyika in the early 1960s
- ◆ Lake Naivasha level decline in intervening period was attributed to a decreasing rainfall trend averaging about 5 mm yr^{-1} over the basin (1920-49) and increasing human consumption from river influents and borehole pumping
- ◆ While there are indications that the Indian monsoon rainfall has been decreasing over the past century and that its variation over the past century is not outside of the range of the past 800 years (Burns et al., 2002), strong correlations are observed between the Coral Dipole Index (CDI) for the Indian Ocean and Niño 3.4 index between 1860 and 1895, and after 1960 (Charles et al., 2003), coinciding with the high lake levels periods in east Africa.
- ◆ This suggests that the observed decadal scale rainfall variability both spatially and in terms of amount in the east Africa region may be related to variations in the strengths and to the degree and phase of interaction between ENSO, Indian Ocean Dipole, deep westerly airstreams from the Atlantic, and the Congo air mass.
- ◆ To a lesser and more subdued extent, the large water bodies (e.g. Lake Victoria), sharp topographic divides and land cover changes may modulate the signal interaction of these climate modes and systems, and contribute to mean trends over long (centennial to millennial) timescales.

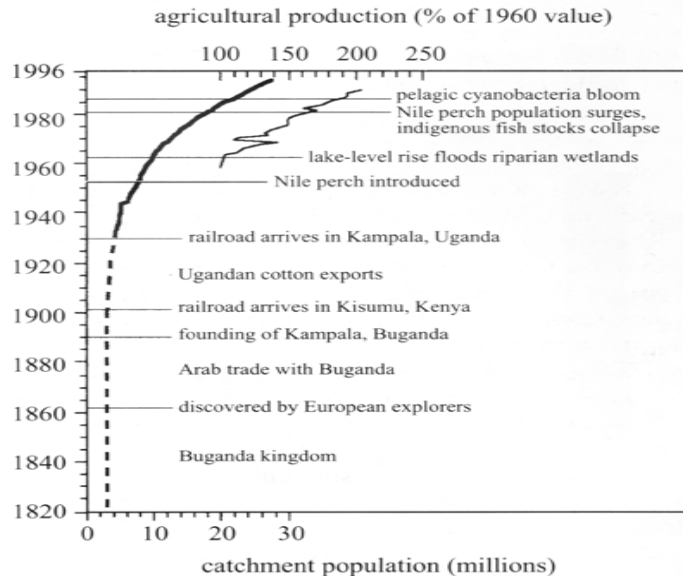
Grove et al., 1996



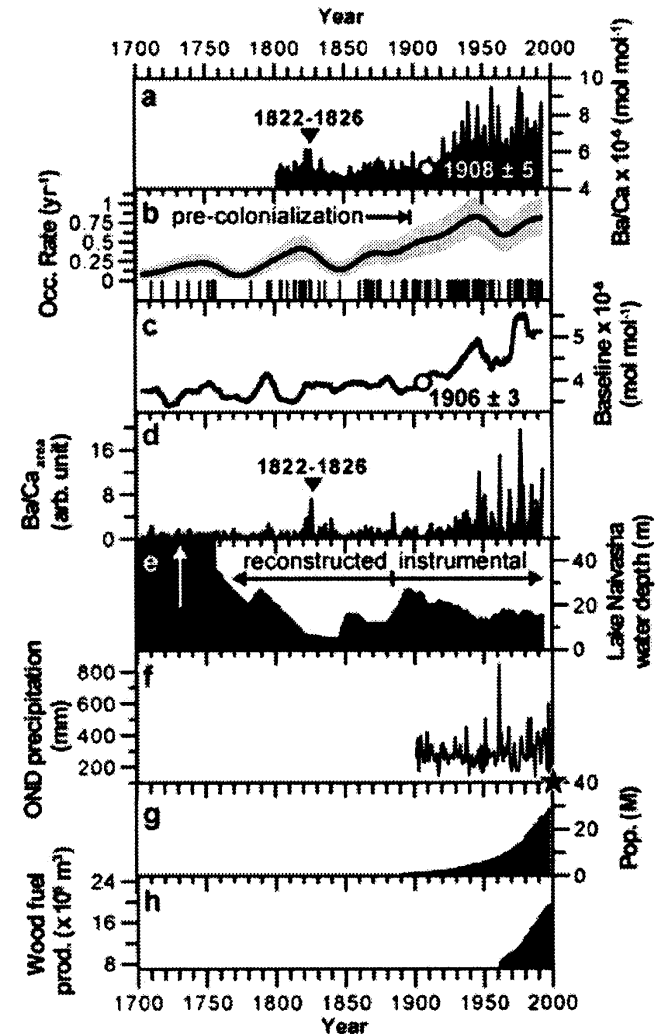
Charles et al., 2003

Recent Times: Land Cover

- ◆ Anthropogenic land cover changes are proceeding at a rate unprecedented in the past
- ◆ Most of the impacts of land cover change are archived in coastal and marine sediments
- ◆ The examples from Lake Victoria (below) and Indian Ocean sediments off the coast of Malindi, Kenya, indicate that these impacts began to be felt from about 1900 AD
- ◆ The earth's land cover and soil characteristics are now in a constant state of erosive dynamic flux. What does this mean for the delicately balanced climate system??



Verschuren et al., 2000



Fleitmann et al. 2007

Thresholds and Tipping Points

- ◆ In central and eastern Africa, the end of the Holocene humid phase occurred at about 5,500 cal yr BP when **gradually declining boreal summer insolation crossed a threshold value of 4.2% greater than present**, a similar insolation threshold that coincided with abrupt tropical lake level rises during the early deglacial warming
- ◆ In the **mid-Holocene, maximum temperatures were at least about 2°C higher than present** over Lake Malawi at about 5,000 yr BP; consistent with temperatures of +1 to above +2°C derived from pollen data for the East Africa region.
- ◆ The general aridification trend for the northern hemisphere of Africa is attributed to **strongly non-linear sea surface temperatures, vegetation, and albedo feedbacks** in relation to the gradually declining insolation trend (e.g. Claussen *et al.* 1999; Umer *et al.* 2004).
- ◆ In southern Africa, the **southward spreading of the summer-rain moisture related to the ITCZ during the middle and late Holocene was characterized by strong centennial scale variability** over different regions of the interior (Scott and Lee-Thorpe 2004).
- ◆ Apparently **small changes in precipitation, if persistent in a positive or negative mode, can result in large hydrological responses**, affecting environment and human civilisations
- ◆ Accelerated, **anthropogenically driven land cover changes may significantly alter the dynamic balance of the climate feedback factors** and thereby also induce non-linear and surprising climate system changes

Conclusion: Palaeoperspectives on Future Change in Africa

- ◆ More high-resolution proxy records with wide spatial coverage are required in order to differentiate between local and regional impacts, and between human-induced and natural change, and to better understand the decadal and longer timescales of climate behaviour in order to be better prepared for future climate change (Olago and Odada 2004).
- ◆ There is strong circumstantial link between climate change and human migration/evolution over long timescales that needs to be better constrained and explained
- ◆ Climate change/human society link is a pertinent today, given the huge and rapid anthropogenic impacts on water land cover plus feedback effects
- ◆ Need to explore more the issues of thresholds/tipping points to help constrain the range of 'surprise' climate scenarios
- ◆ The sustainable development and protection of food security will require agricultural management strategies adjusted to major long-term variation in water-resource availability (and land cover), irrespective of any future effects of anthropogenic climate change on the hydrological cycle (cf. Verschuren *et al.* 2000).
- ◆ Palaeo-data needed for generation of more robust predictive (regional) models that can be used for analysis and formulation of long-term sustainable development options in areas such as food security and land management (Olago and Odada 2004).