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Conference on Milankovitch cycles over the past 5 million years

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Pliocene-Pleistocene Shifts in Tropical Atlantic Ocean-Atmosphere Coupling

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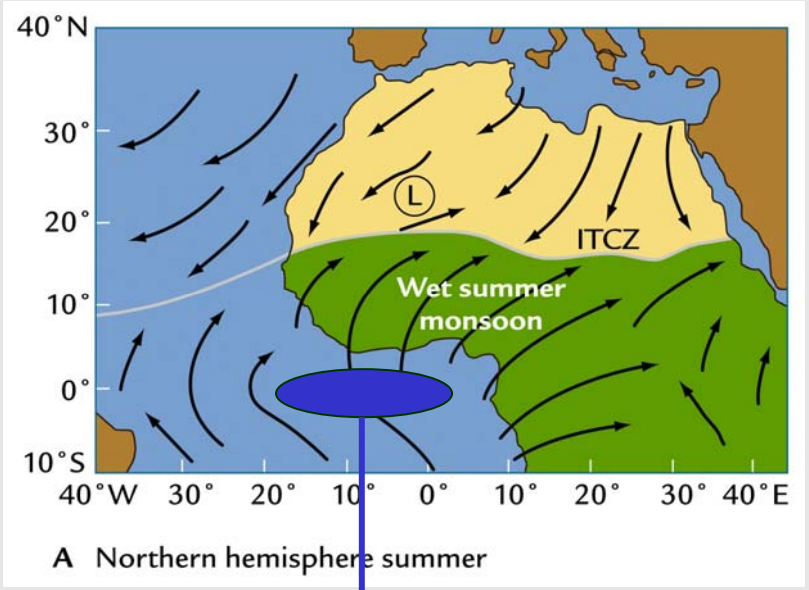
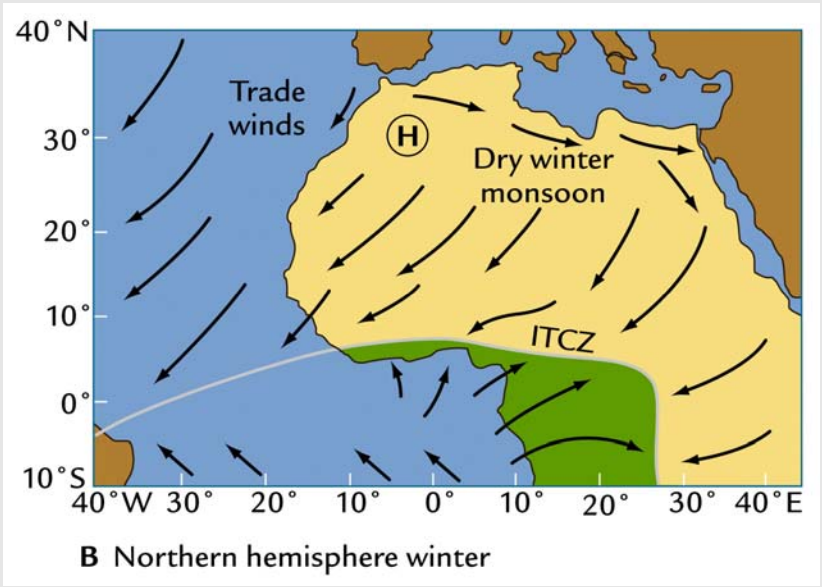
The African Monsoon and Tropical Atlantic Upwelling





Cool SSTs
Maximum upwelling
Steep thermocline slope

Orbital Precession and the Monsoon

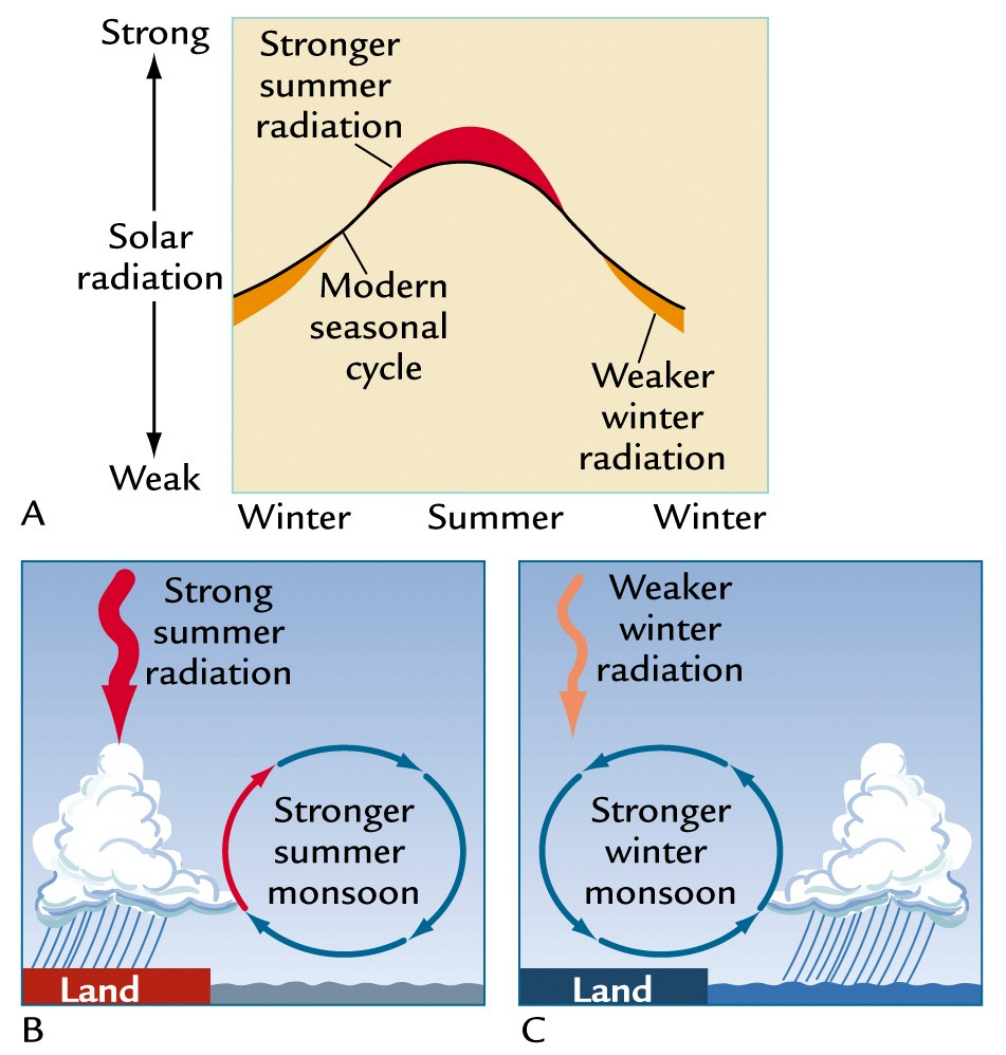
Kutzbach (1981)

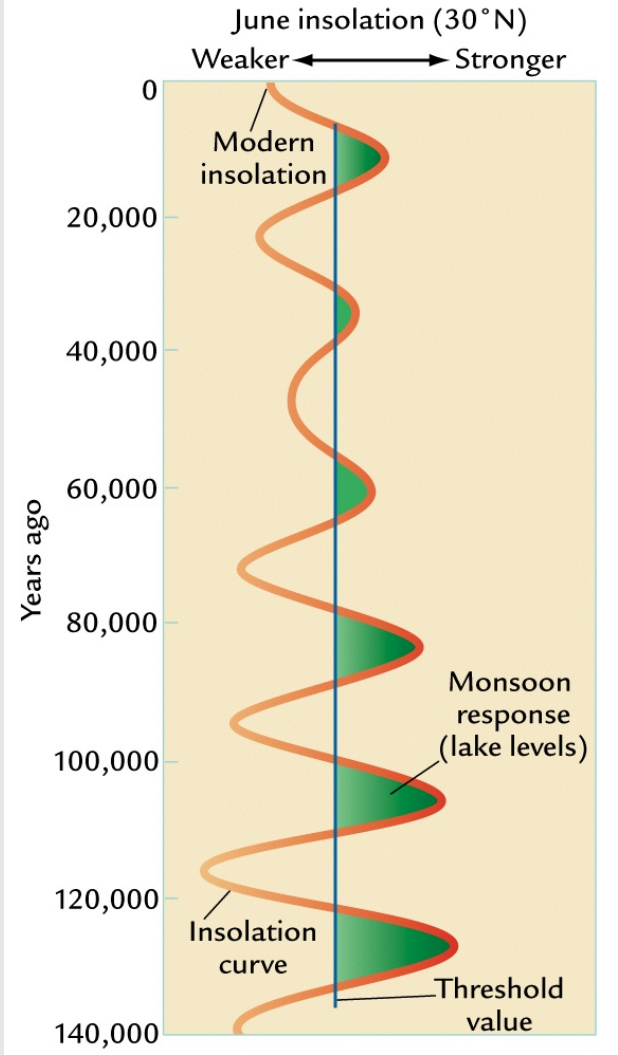
Monsoon Climate of the Early Holocene: Climate Experiment with the Earth's Orbital Parameters for 9000 Years Ago

Abstract. *Values for the precession and obliquity of the earth 9000 years ago indicate that the global average solar radiation for July 9000 years ago was 7 percent greater than at present. When the estimated solar radiation values are used in a low-resolution climate model, the model simulates an intensified continent-scale monsoon circulation. This result agrees with paleoclimatic evidence from Africa, Arabia, and India that monsoon rains were stronger between 10,000 and 5000 years ago than they are today.*

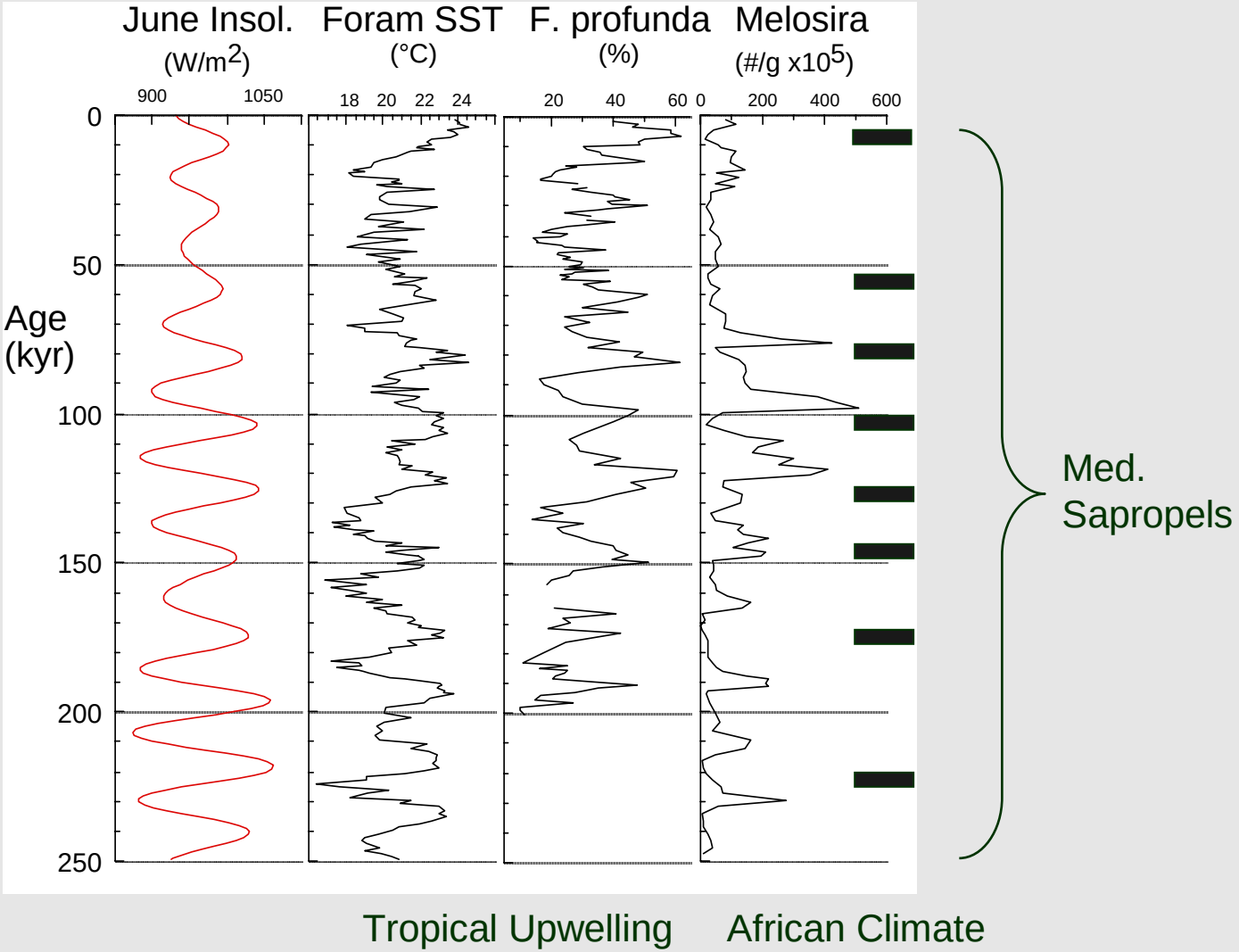
Orbital Precession and the Monsoon

Kutzbach (1981)





Latest Pleistocene:
African Monsoon and Equatorial Upwelling

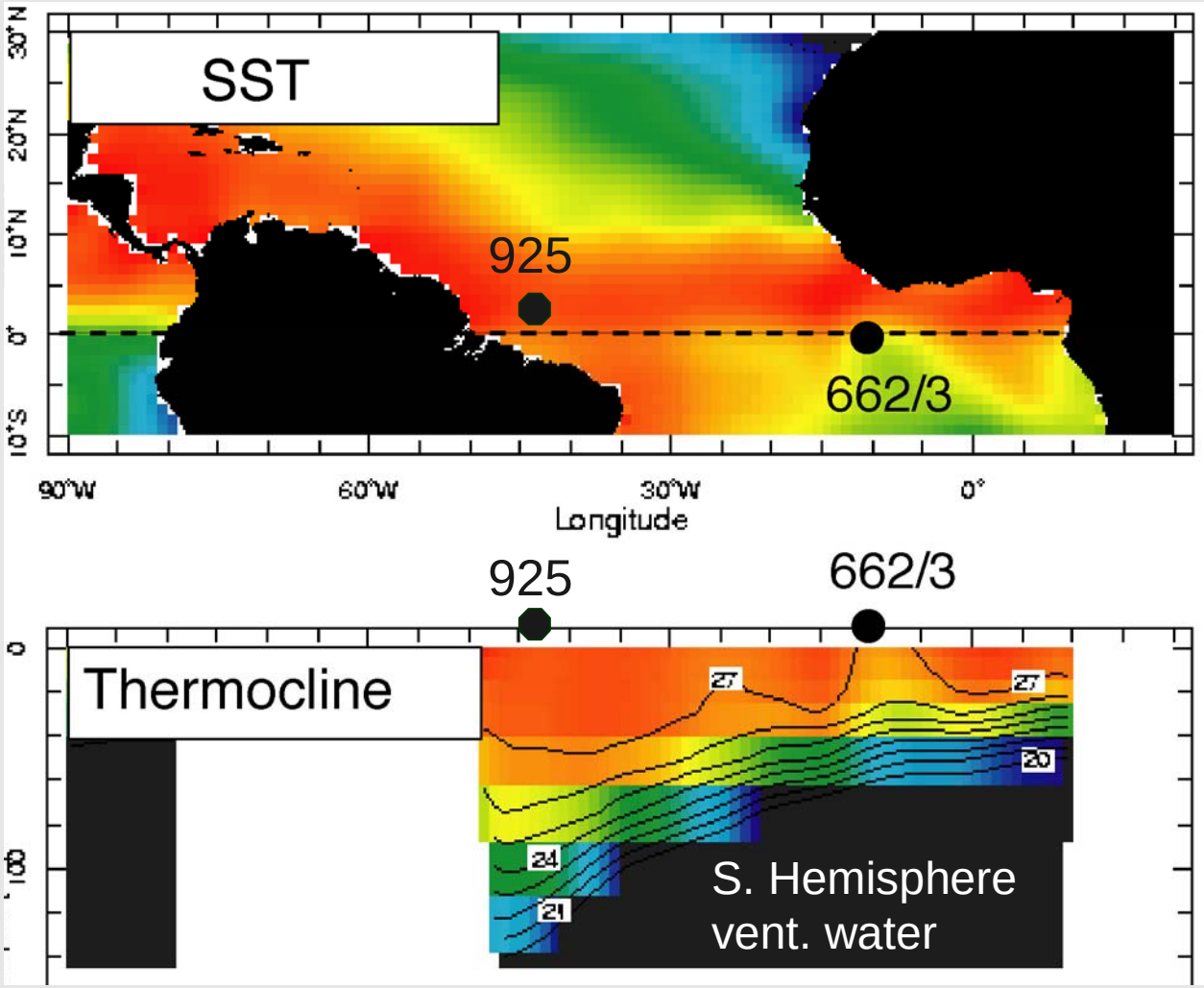


(McIntyre et al., 1989; Molfino and McIntyre, 1993; Pokras and Mix, 1985; Rossignol-Strick, 1983)

Precessional Monsoon Cycles Throughout the Neogene

Miocene Mediterranean Sapropels (Sicily; Frits Hilgen)

Has this close precessional coupling always been so?



Tropical paleoceanographic proxies

Upwelling & surface productivity

Florisphaera profunda (%), Biogenic opal flux

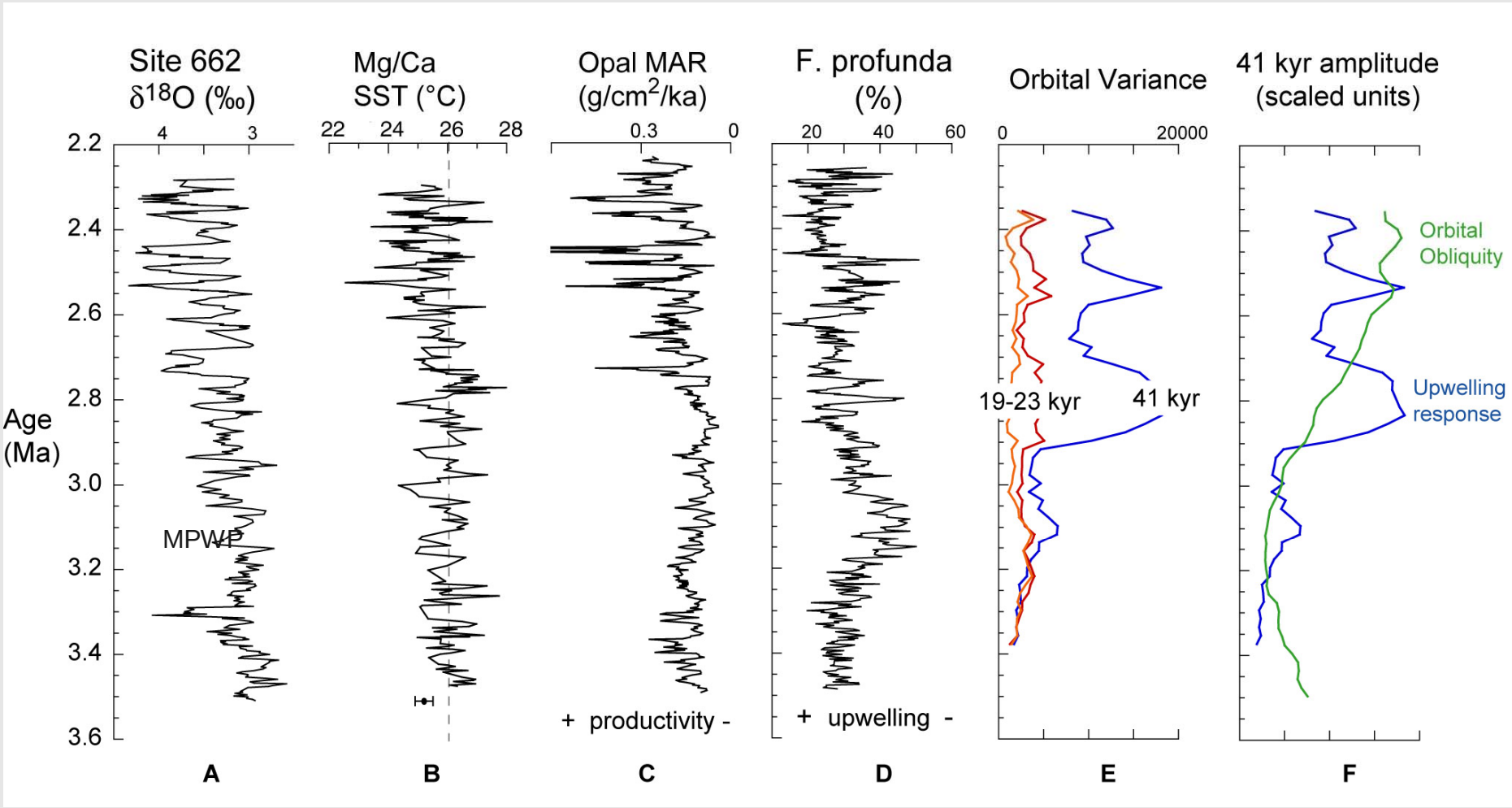
Photic zone thermal gradients

Multispecies planktonic $\delta^{18}O$

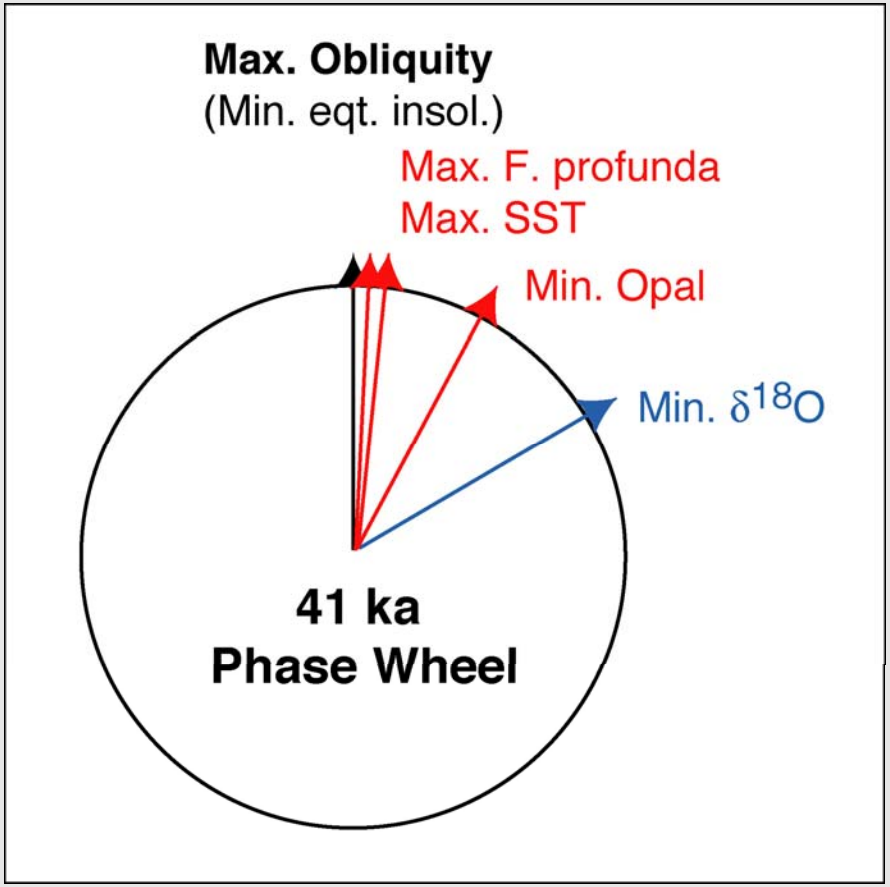
SSTs & zonal SST gradients

Planktonic (*G. ruber*) Mg/Ca

Tropical Atlantic during the mid-late Pliocene



Tropical Atlantic SSTs lead ice volume

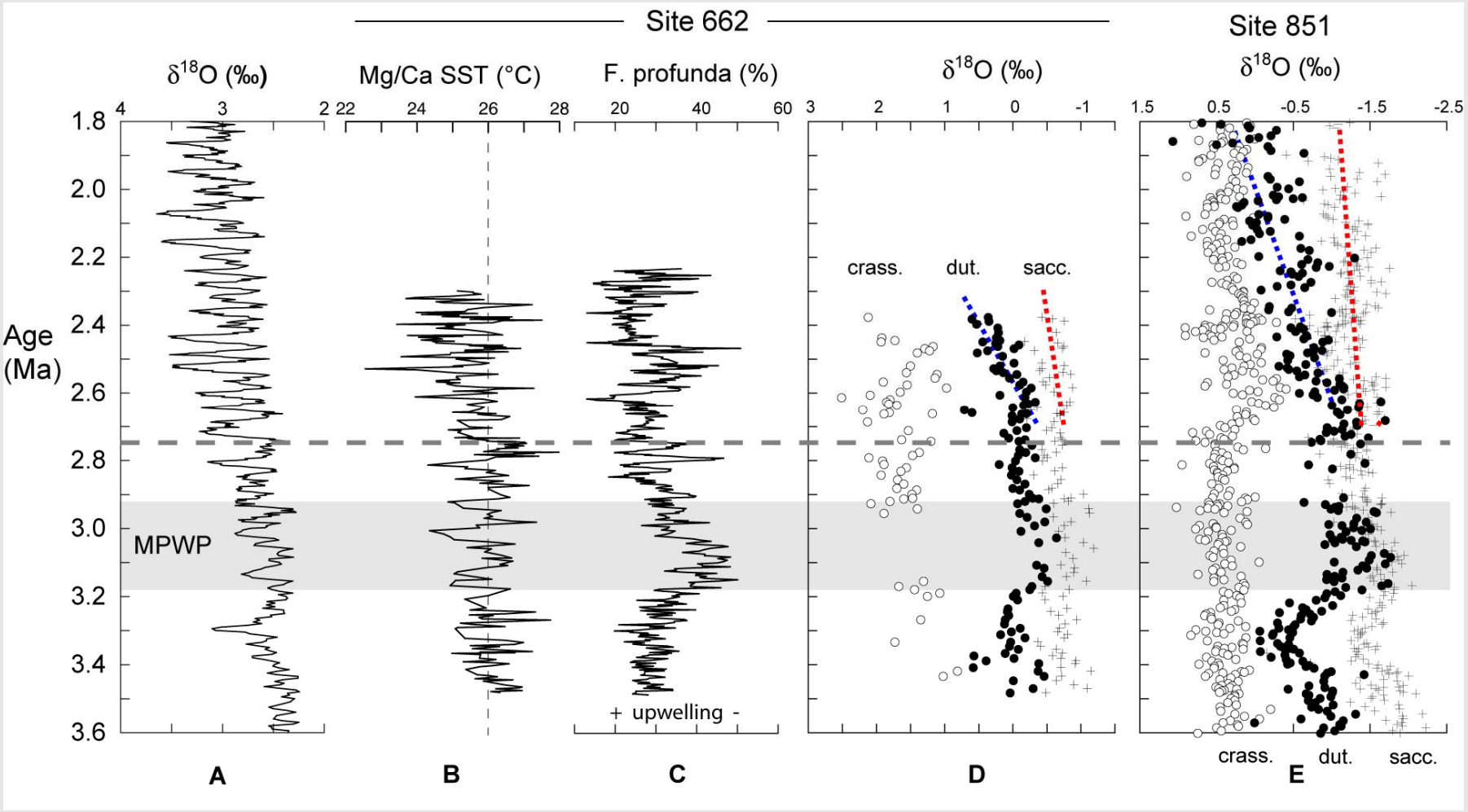


Also true for tropical Pacific.
(Liu and Herbert, 2004; Lawrence et al., 2006; Ravelo, 2006)

Phasing is such that SSTs not due to local radiation forcing.

Extratropical forcing of tropics likely.

Atlantic and Pacific Thermocline Changes

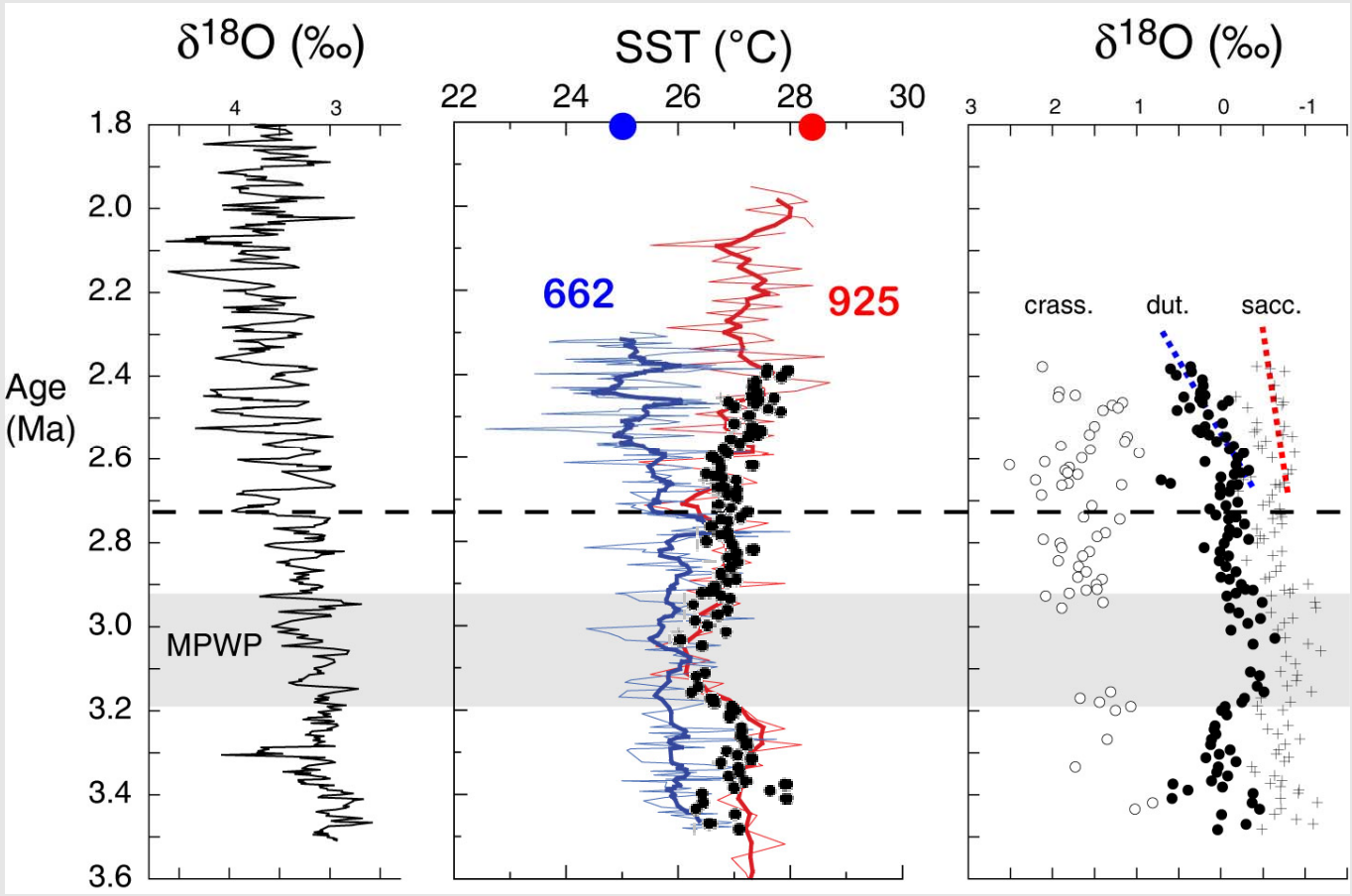


SST

Thermocline T-gradient

Cannariato and Ravelo, 1997

Zonal SST Gradient increases after 2.7 Ma



Eastern thermocline cooled as west SST warmed

Summary

"El Niño-like" tropical oceans during the warm mid-Pliocene

Tropical Atlantic sensitive to obliquity forcing after 2.8-2.7 Ma.

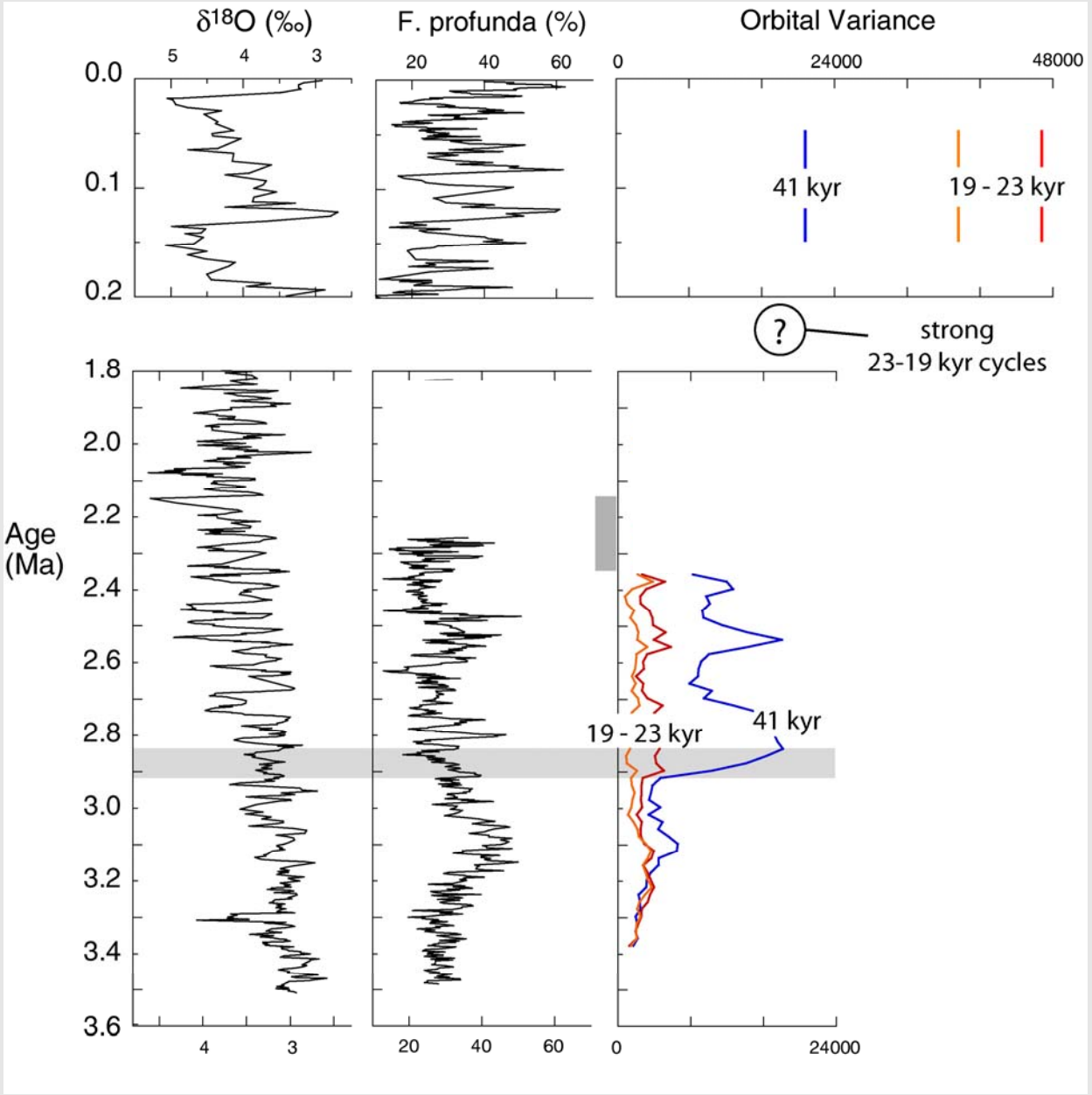
- Thermocline shoaled, greater upwelling
- SSTs cooled & more variable
- Enhanced zonal SST gradient
- Phasing suggests extratropical origin

When did the tropical Atlantic become sensitive to precessional forcing?

Near the base of the Pleistocene?

Late Pleistocene ocean was even more variable.

Very sensitive to seasonal (precessional) monsoon forcing.



Key Feature of the Modern Tropics: Shallow tropical thermocline