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Interest of hydrogeological modelling in the interpretation of pollen proxies for palaeo-climate reconstitution: example from Senegalese niayes

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Purely climatic interpretation of pollen data may lead to important errors in palaeo-climate reconstruction.

1) Objectives and context

Niaye ecosystems shelter an azonal relic guinean vegetation under sahelian climate. Pollinic proxy records in cores (Fig. 1) show that a guinean closed forest installed at 10500BP* during the African Humid Period (AHP), and thrived under a somewhat degraded state until 2500 BP. Sub-surface water flow brings today the necessary water to these interdunal depressions, keeping some of them flooded, with a distribution linked to water stress (Fig. 5). But the equilibrium was different in the past between underground water availability, surface run-off, varying regional hydrogeology (Fig. 2), sea level (Fig. 4) and distance, and pluviometry (annual and seasonal). This study aims at:

- > explaining how gallery forest persisted through the mid-Holocene dry episode (7500-4000BP), though in a degraded state,
- > examining the dynamics of the end of the Tofolian humid pulsation (4000-3000BP), when vegetation turned to sahelian
- > weighting the relative strength of the different forcings, notably the transience of higher-scale hydrogeology (Fig. 2)
- > finally, examining the pertinence of a (sometimes assumed) distinctive relationship between observed pollens and regional climate.

* all datations are calendar

2) Environmental context

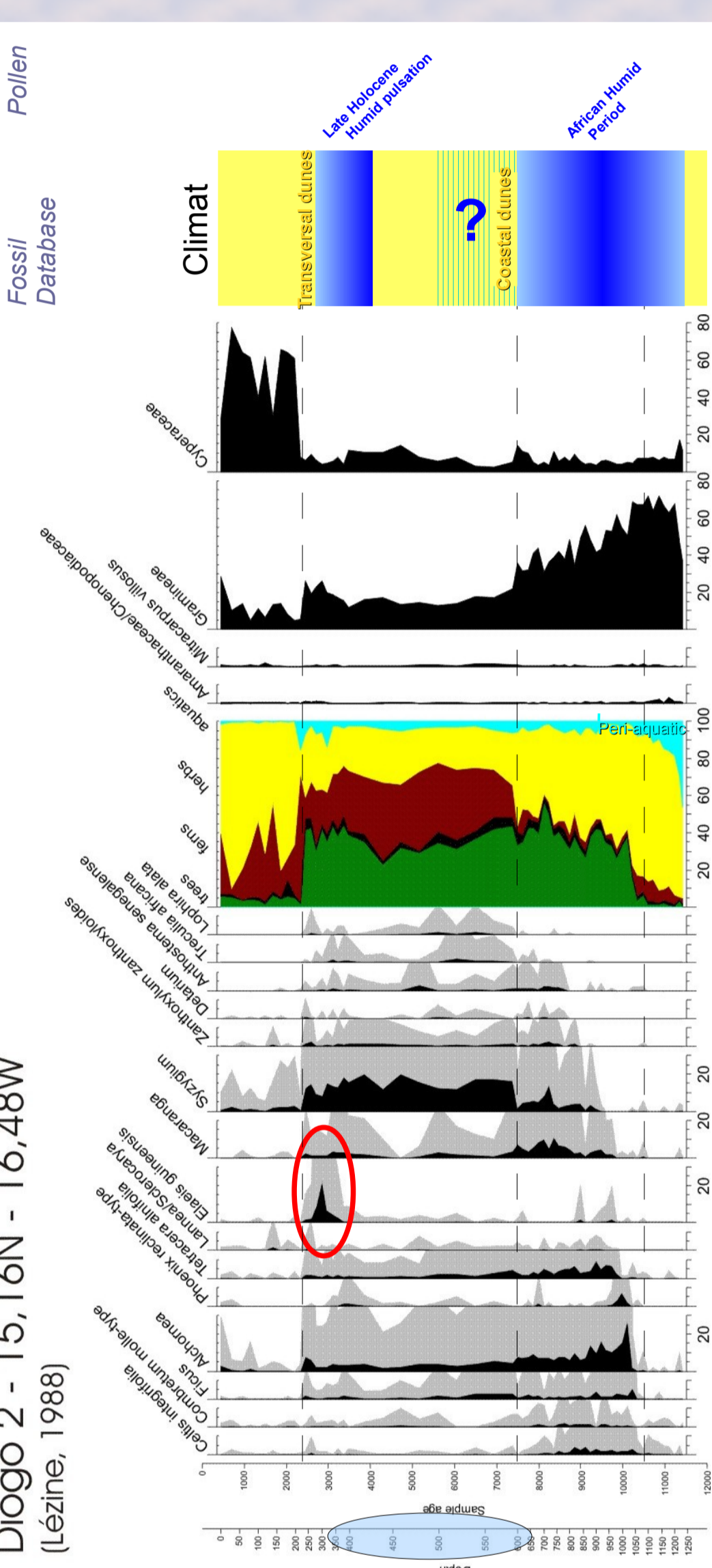


Fig. 1 : Synthesis of pollen analysis in core Diogo II with known badly-dated climatic events. Main features are (i) forest expansion from 10500BP; (ii) substantial degradation around 7500BP with fern expansion and high sedimentation rate; (iii) settlement of humidity-loving *Elais Guineensis* 3000-4000BP; then (iv) shift to sahelian types ca. 2500BP.

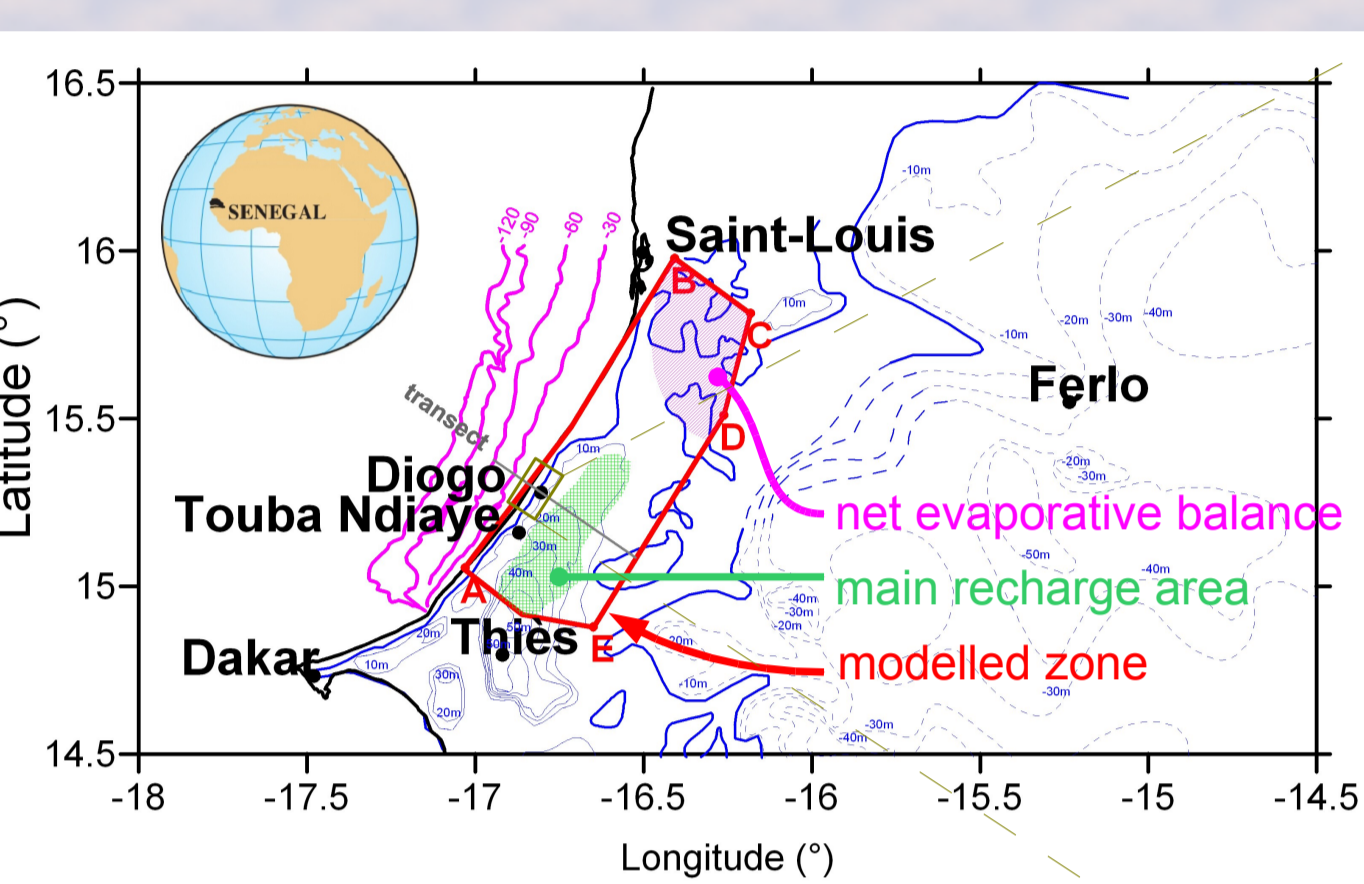


Fig. 2 : hydrological features of the studied area. (pink) bathymetry, (blue) regional piezometry (dashes stand for altitudes lower than present sea level).
Linguere depression, relic of last glacial maximum low sea level, diverts much water from the main recharge area situated on "Plateau de Thiès" the flanks. The regional hydrogeology is complicated by drainage from/to meastrichtian confined aquifer below, and by perched aquifers as well.

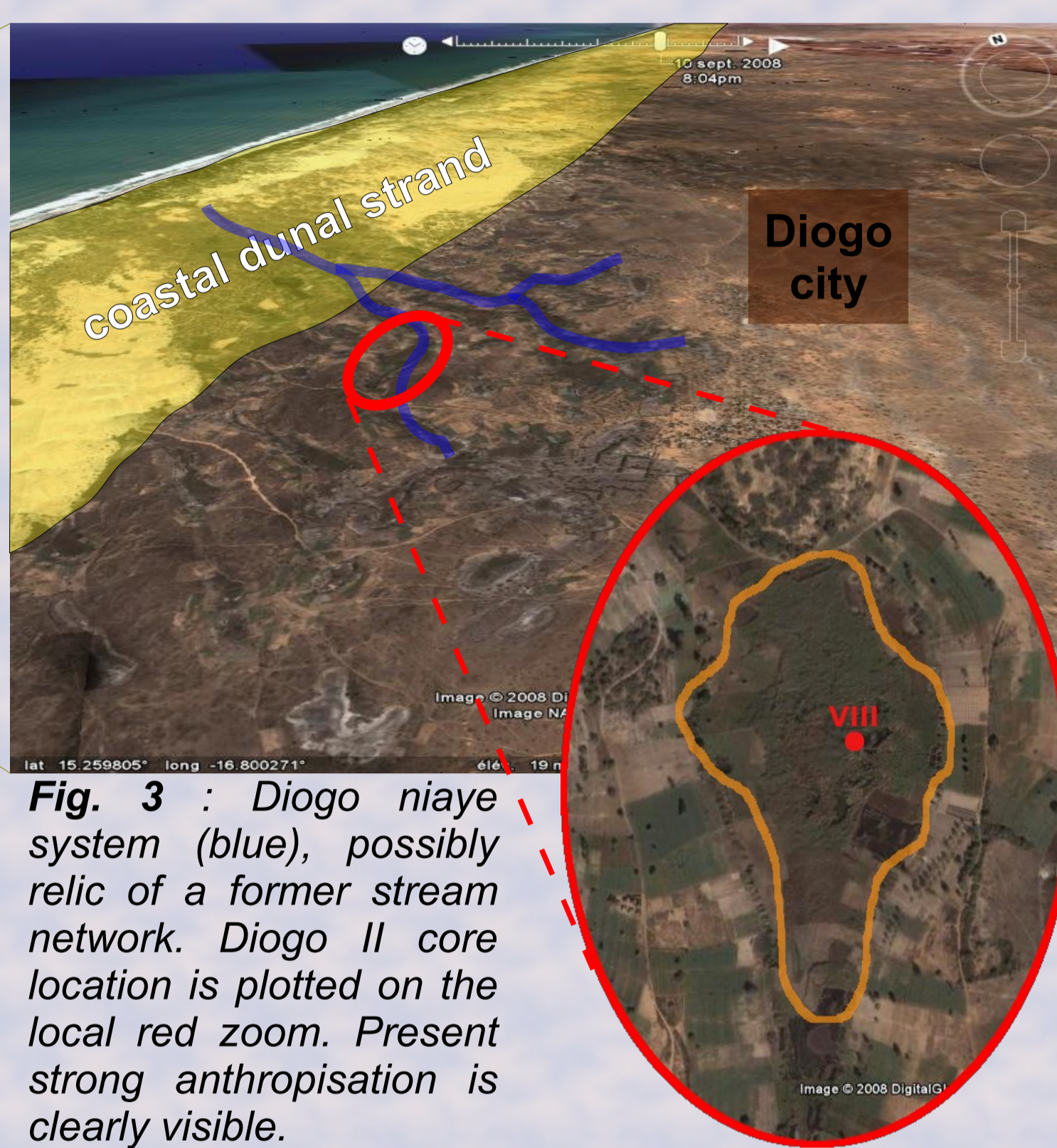


Fig. 3 : Diogo niaye system (blue), possibly relic of a former stream network. Diogo II core location is plotted on the local red zoom. Present strong anthropisation is clearly visible.

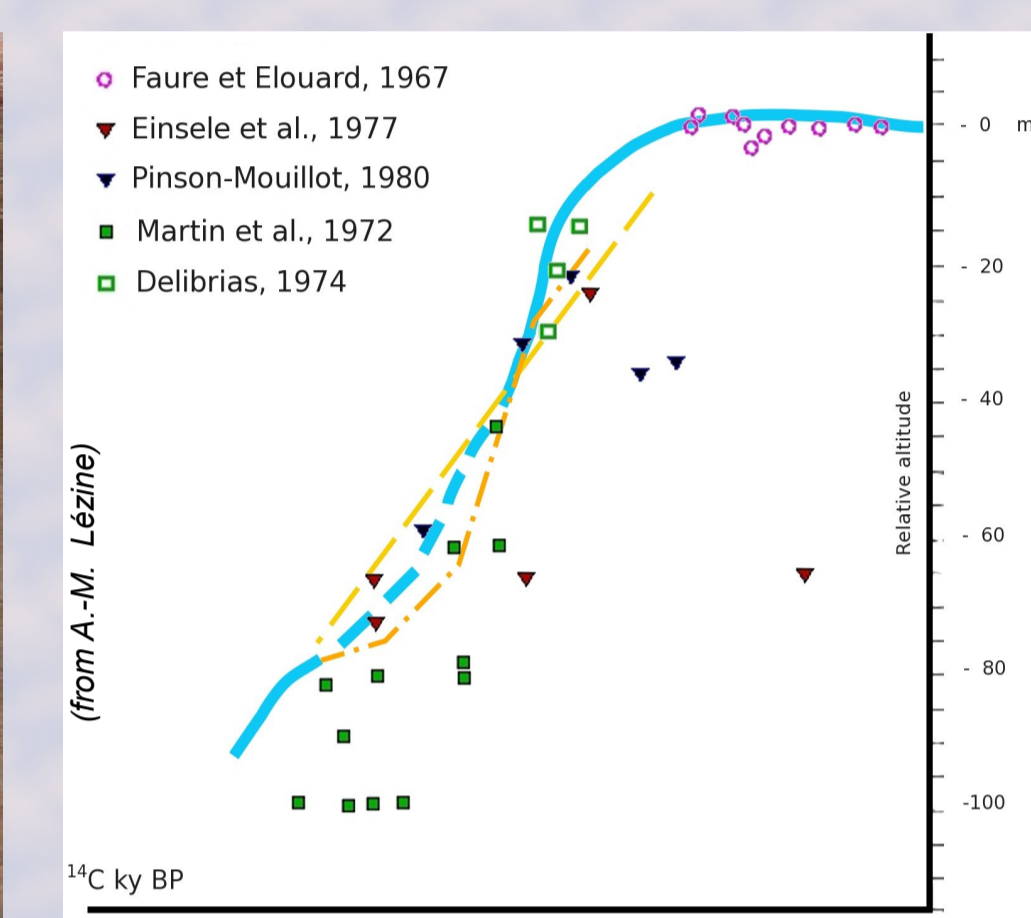


Fig. 4 : Relative sea level (without surrection correction) during quaternary. Ocean coastline was as low as 120m below present during Last Glacial Maximum. The measure points correspond to different places along west Africa coastline. Only Faure worked on Senegal. Datations are imprecise.

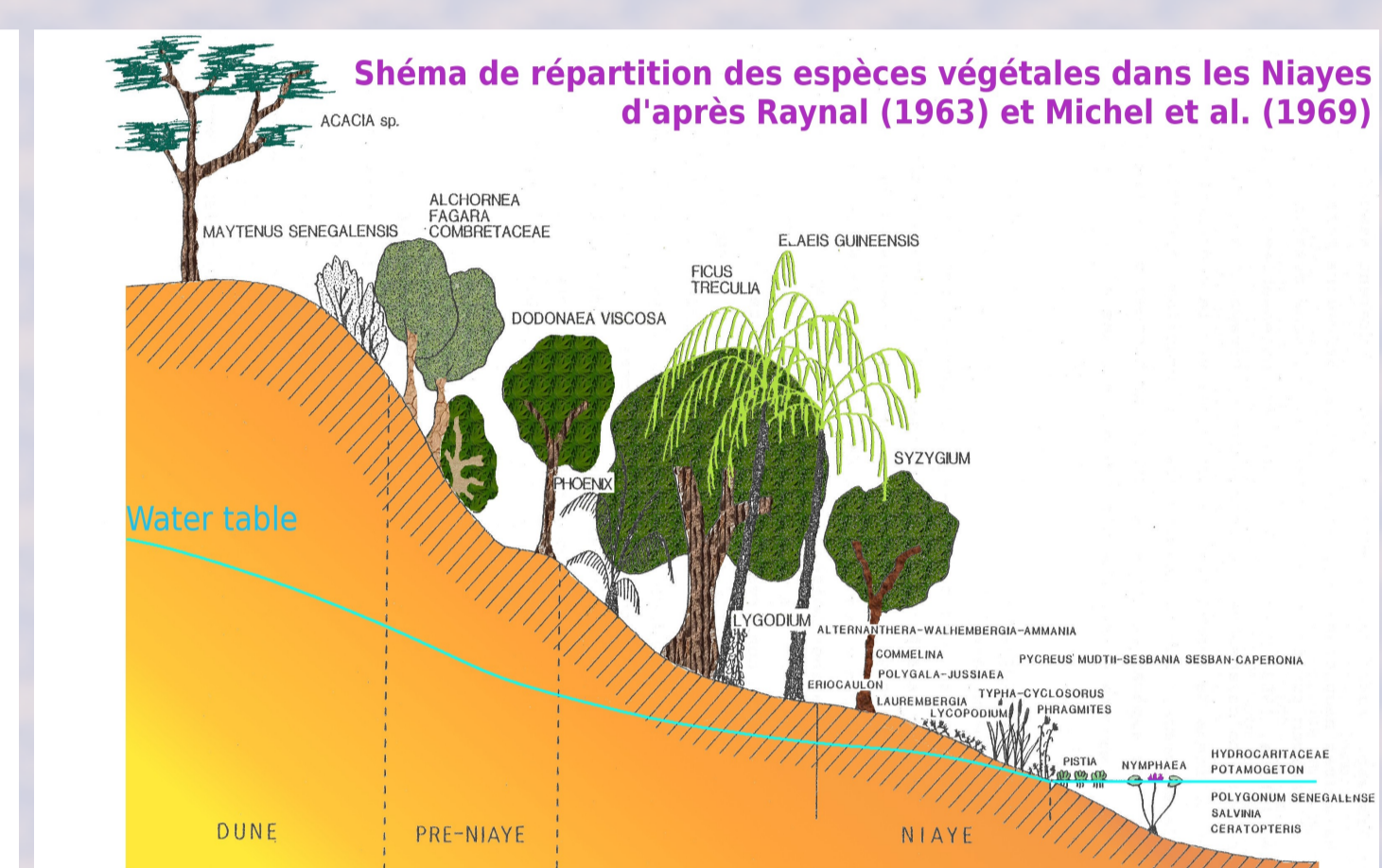
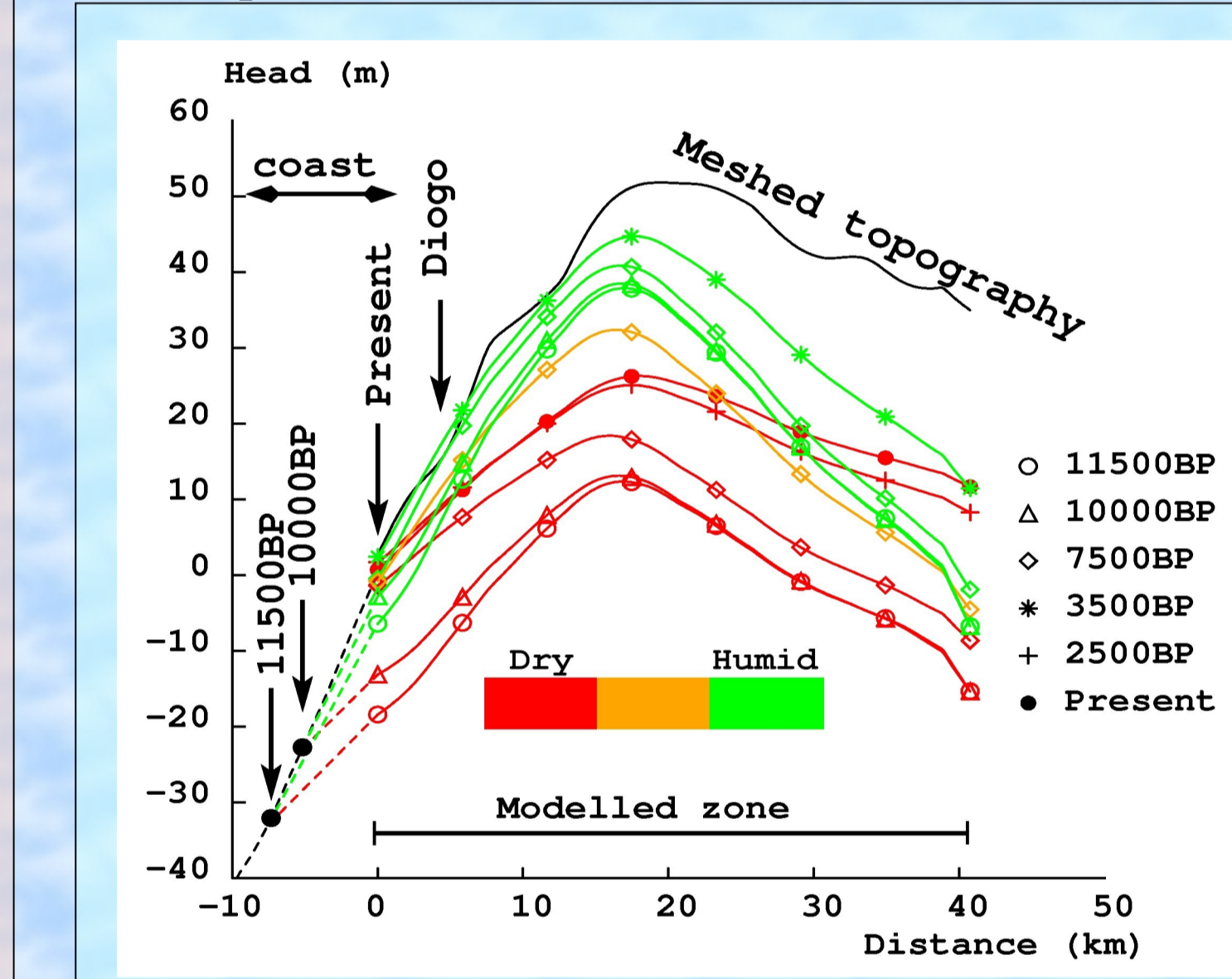


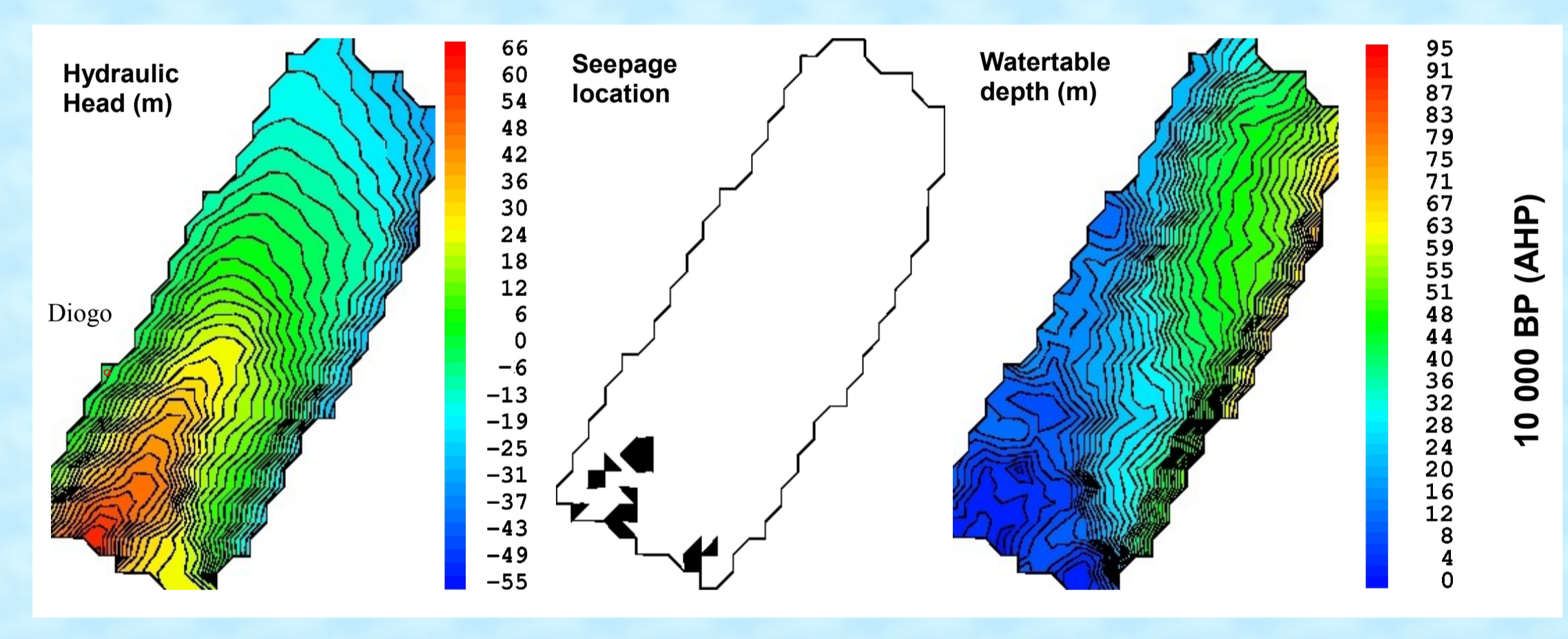
Fig. 5 : Repartition of vegetal species in the Niayes (Raynal 1963, Michel et al. 1969). Depth to water table is a primary forcing to its organisation.

4) Results



Hydrology in Diogo area

Calculated water table altitude along the Diogo transect (smoothed). Infiltration appears to control the overall level of groundwater. However, sea level and coast distance are the dominant factors locally. The influence of the eastern boundary condition remains beyond the central piezometric ridge but its effect is greater under low infiltration rates. Head gradient (and thus sub-surface fluxes) increase with infiltration, of course, but are limited by seepage when the watertable reaches the surface.



Hydrology at Diogo site

Calculated depth in the cell containing Diogo site. The model overlooks local fluctuations induced, for instance, by local topography, so differential piezometry $H-H(0)$ and depression depth $Z-Z(0)$ are used instead.

Impact of infiltration rate is clear. Under dry conditions, non-climatic forcings have and increased effect. And when combined, they have the potential to override the climatic forcing.

The delayed onset of vegetation may stem from ecosystem dynamics. The vegetation transition ~ 8.2-7.5 ky BP may be explained by minored infiltration. All humid scenarios yield around 10m inundation higher than at present, while all dry ones have it under 3m. These coherent results illustrates the important role of the depression depth, but are not always consistent with the observed sedimentology

3) Scenarios & Numerical features

Period (ky BP)	Observation at Diogo			Scenarios				
	Sea ⁽¹⁾	Depression type ⁽²⁾	Z ⁽³⁾ (m)	Vegetation indication	Climate	Recharge ⁽⁴⁾ (mm/y)	H _{coast} ⁽⁵⁾ (m)	A, B ⁽⁶⁾ H _{land} C, D, E ⁽⁶⁾ (m)
11.5	-33 m	Palustrine	-12.4	Periaquatic	Dry	[-3; 6]	-20, -33	-40, -43, -36
	7 km	Channels			Very humid	[-5; 14]	-10, -28	
10	-23 m	Palustrine	-10.0	Tropical humid forest	Dry	[-3; 6]	-15, -23	-34, -34, -30
	5 km	Channels			Very humid	[-5; 14]	-7, -19	
7.5	-2 m	Lacustrine	-6.0	Idem more open	Dry	[-3; 6]	-2	-21, -23, -10
	?				Humid	[-4; 10]	-2	
					Very humid	[-5; 14]	-2	
3.5	+1 m	Lacustrine	-4.0	Forest expansion	Very humid	[-5; 14]	+1	-4, -2, +4
	- Ponds							
2.5	+1 m	Lacustrine	-2.8	Forest decline	Dry	[-3; 6]	+1	-3, +1, +5
	- Ponds							
0	+0 m	Palustrine	0	Periaquatic & sahelian	Dry	[-3; 6]	+0	+1, +3, +10
	- Ponds							

Table 1: Characteristics of the simulated periods. (1) sea level and distance to present-day coast in front of Diogo. (2) "lacustrine" corresponds to bottom inundation, "palustrine" to sporadic inundation or sub-surface groundwater, "channels" to active turbulent river, "meanders" to soft flow rivers with sedimentation, "ponds" to stagnant water. (3) Altitude of the niaye bottom relative to present at Diogo. (4) Min. and max. of inter-annual infiltration. (5,6) Prescribed head, linearly interpolated between the nodes A-E (Fig. 2). (7) Calculated head in the mesh containing Diogo. (8) Excess of groundwater level respective to present-day $H-H(0)$. (9) Difference in inundation depth $[H-Z] - [H(0)-Z(0)]$.

Numerical modelling with Cast3M Finite Element Code.
Generalized darcy law, 3D EFMH, Picard algorithm.
BRGM and SRTM data.
Parameter fitting on stationary head data (1975).

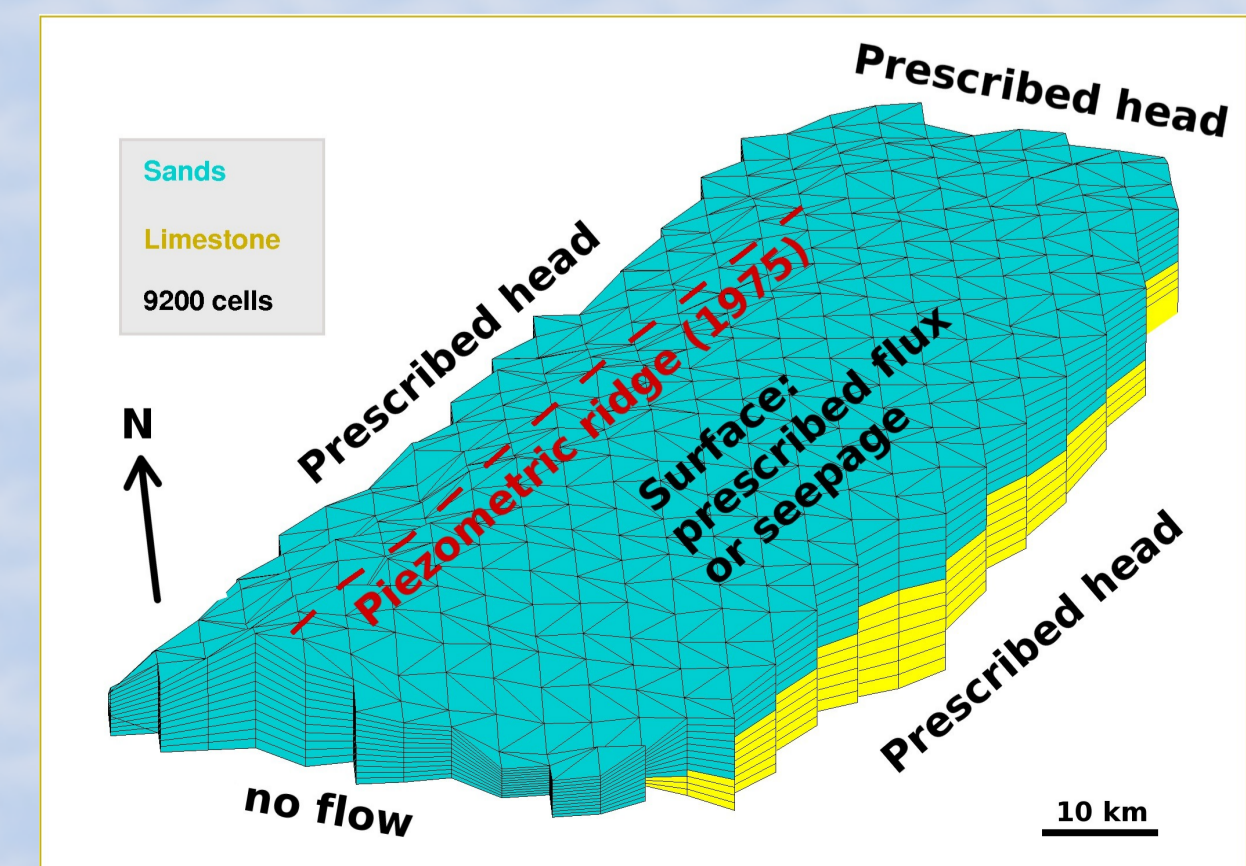


Fig. 6: Numerical mesh and boundary conditions

Qualitative forcing:

Dry periods present P & ETR
Very dry P/2, ETR/2
very humid P*2, ETR*1.9

5) Conclusions :

- > Complex trade-off exist between infiltration and sea level forcings. but watertable level at Diogo is mainly controlled by recharge after 7.5 ky BP. Depression depth, altitude and filling rate are local issues.
- > The ~3.5 ky BP forest expansion expresses a climatic bonification, out of phase compared to the rest of the sahelian Africa.
- > The 8.2 ky BP dry event left no sign in Diogo niaye, but did in another one, thus suggesting local specificities that need to be further investigated.