

# Esercitazione N° 3: **The Greening of the Sahara**

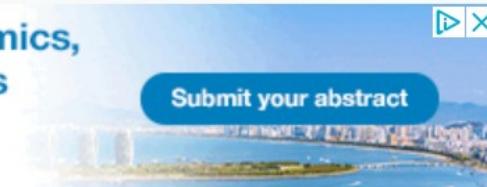
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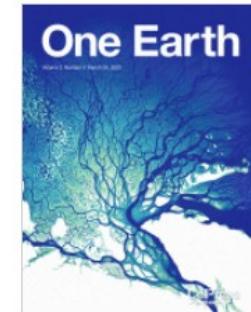
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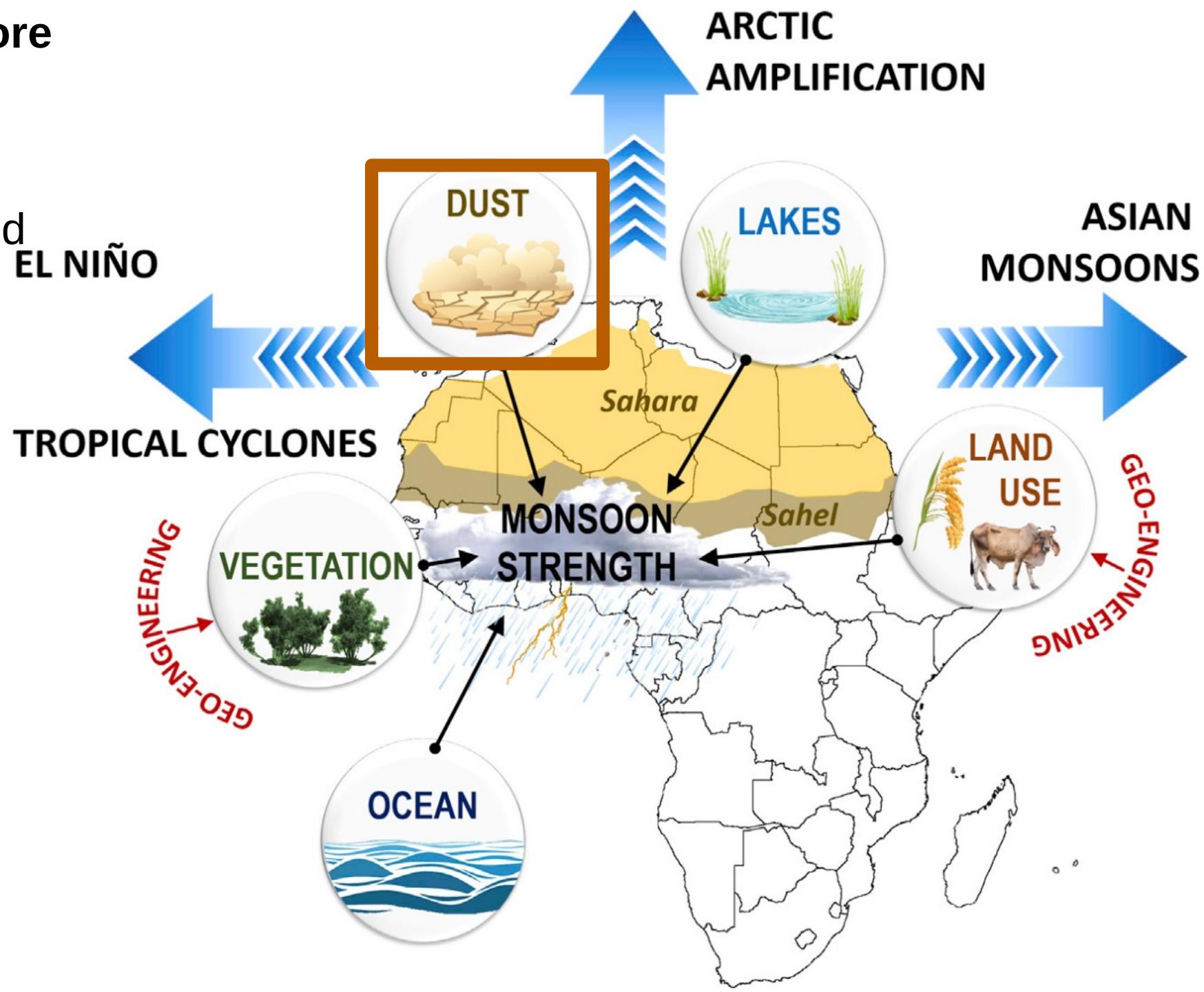
# The Greening of the Sahara: Past Changes and Future Implications

Francesco S.R. Pausata <sup>1</sup> · Marco Gaetani <sup>2</sup> · Gabriele Messori <sup>3,4</sup> · ... ·

Danielle Maia de Souza <sup>6</sup> · Rowan F. Sage <sup>7</sup> · Peter B. deMenocal <sup>8</sup> ... Show more

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Wetter conditions and more vegetation decrease dust emissions, whereas the converse happens for drier conditions and reduced vegetation cover



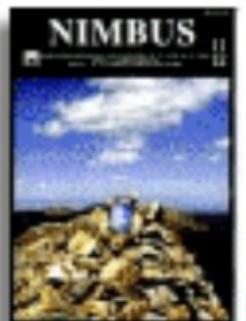
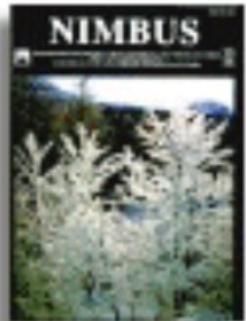
# The Greening of the Sahara

The harsh and hyperarid Sahara in northern Africa is the largest hot desert on Earth.

The Sahara Desert is currently the **largest source of airborne mineral dust on Earth**. Mineral dust is the most abundant atmospheric aerosol component and contributes to more than half of the total global aerosol mass burden.

# 6 febbraio 2021: polvere sahariana sulle Alpi

DOVE MI TROVO: [Nimbus Web](#) » [Eventi meteorologici](#) » **6 febbraio 2021, polvere desertica**



Nimbusweb

## 6 FEBBRAIO 2021: SCIROCCO, CALDO ANOMALO E POLVERE SAHARIANA SULLE ALPI

*Daniele Cat Berro, SMI / Redazione Nimbus*  
*6 febbraio 2021*

La depressione "Tristan" in avvicinamento dalla penisola iberica all'Italia ha richiamato davanti a sé correnti di **scirocco** che sabato 6 febbraio 2021 - oltre a determinare un episodio di caldo anomalo più marcato al Sud e sulle isole con punte prossime a 30 °C - hanno trasportato grandi quantità di **polvere sahariana** dall'entroterra algerino alle Alpi.

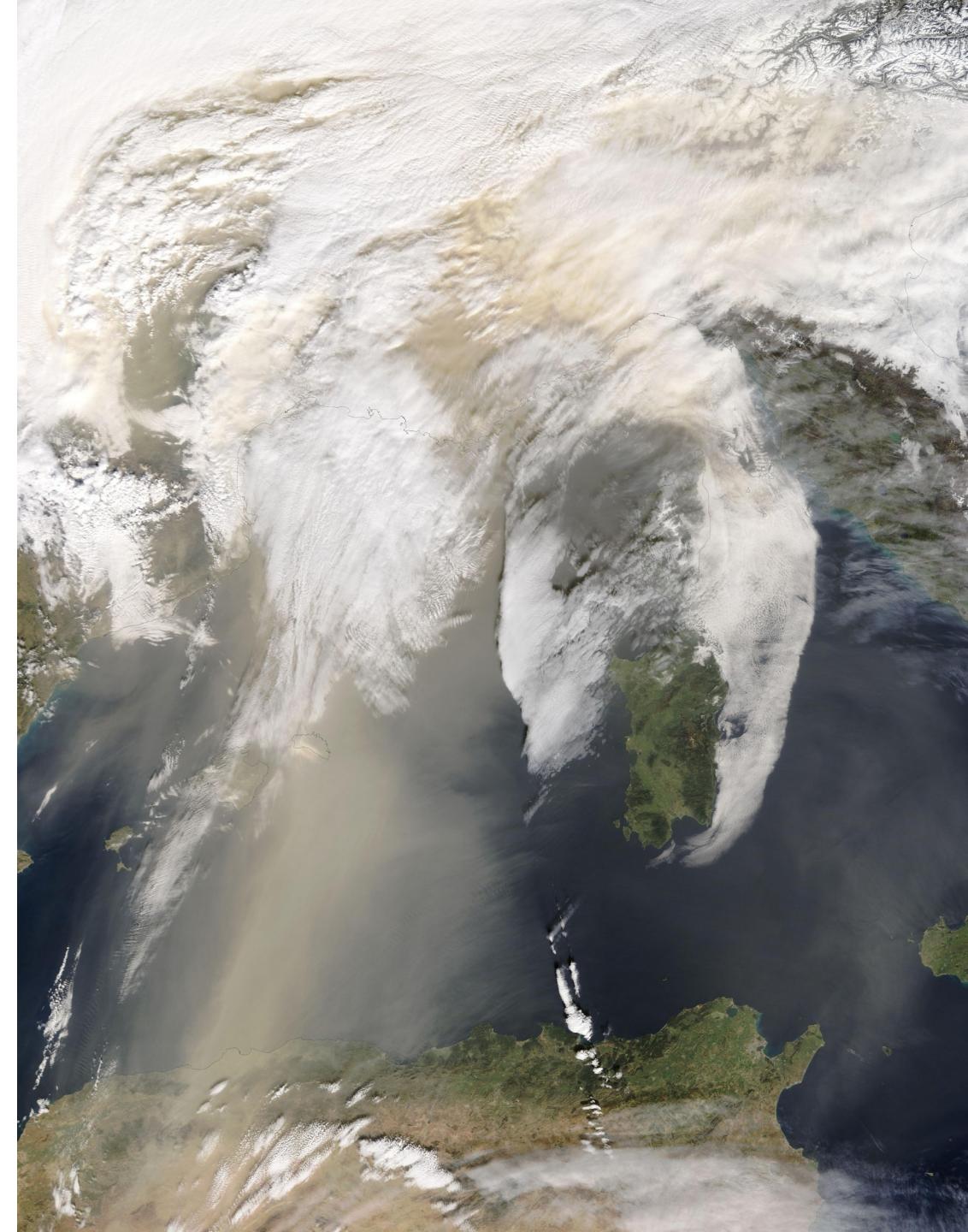
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# 6 febbraio 2021: polvere sahariana sulle Alpi

La depressione "Tristan" in avvicinamento dalla penisola iberica all'Italia ha richiamato davanti a sé correnti di scirocco che sabato 6 febbraio 2021, oltre a determinare un episodio di caldo anomalo più marcato al Sud e sulle isole con punte  $\sim 30$  °C, hanno trasportato grandi quantità di **polvere sahariana dall'entroterra algerino alle Alpi**.

[https://wvs.earthdata.nasa.gov/api/v1/snapshot?  
REQUEST=GetSnapshot&LAYERS=MODIS\\_Terra\\_CorrectedReflectance  
\\_TrueColor,Coastlines\\_15m&CRS=EPSG:4326&TIME=2021-02-  
06&WRAP=DAY,X&BBOX=34.9094,0.007,47.665,13.1131&FORMAT=image/  
jpeg&WIDTH=5965&HEIGHT=5805&AUTOSCALE=TRUE&ts=174323455  
1504](https://wvs.earthdata.nasa.gov/api/v1/snapshot?REQUEST=GetSnapshot&LAYERS=MODIS_Terra_CorrectedReflectance_TrueColor,Coastlines_15m&CRS=EPSG:4326&TIME=2021-02-06&WRAP=DAY,X&BBOX=34.9094,0.007,47.665,13.1131&FORMAT=image/jpeg&WIDTH=5965&HEIGHT=5805&AUTOSCALE=TRUE&ts=1743234551504)



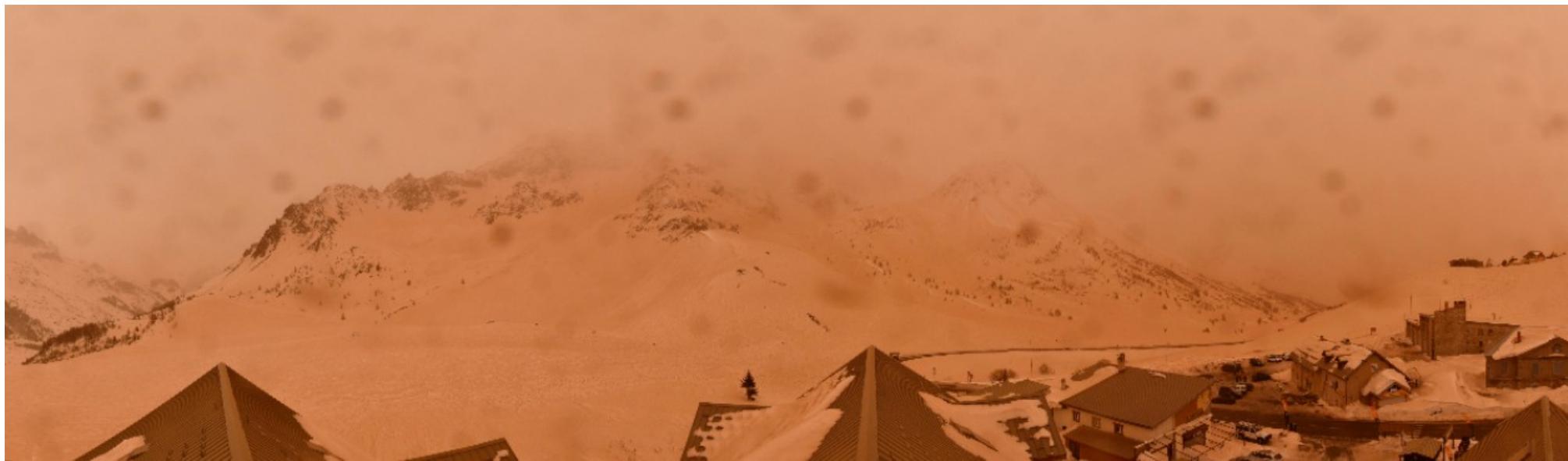
# **6 febbraio 2021: polvere sahariana sulle Alpi**

Fin dal mattino del 6 febbraio il cielo, coperto da estesa nuvolosità stratiforme da fronte caldo, ha mostrato surreali tinte giallo-arancio sulle Alpi. Qui vediamo la situazione presso Saint-Barthélémy, Valle d'Aosta (f. Rosa Antonella Barrel).

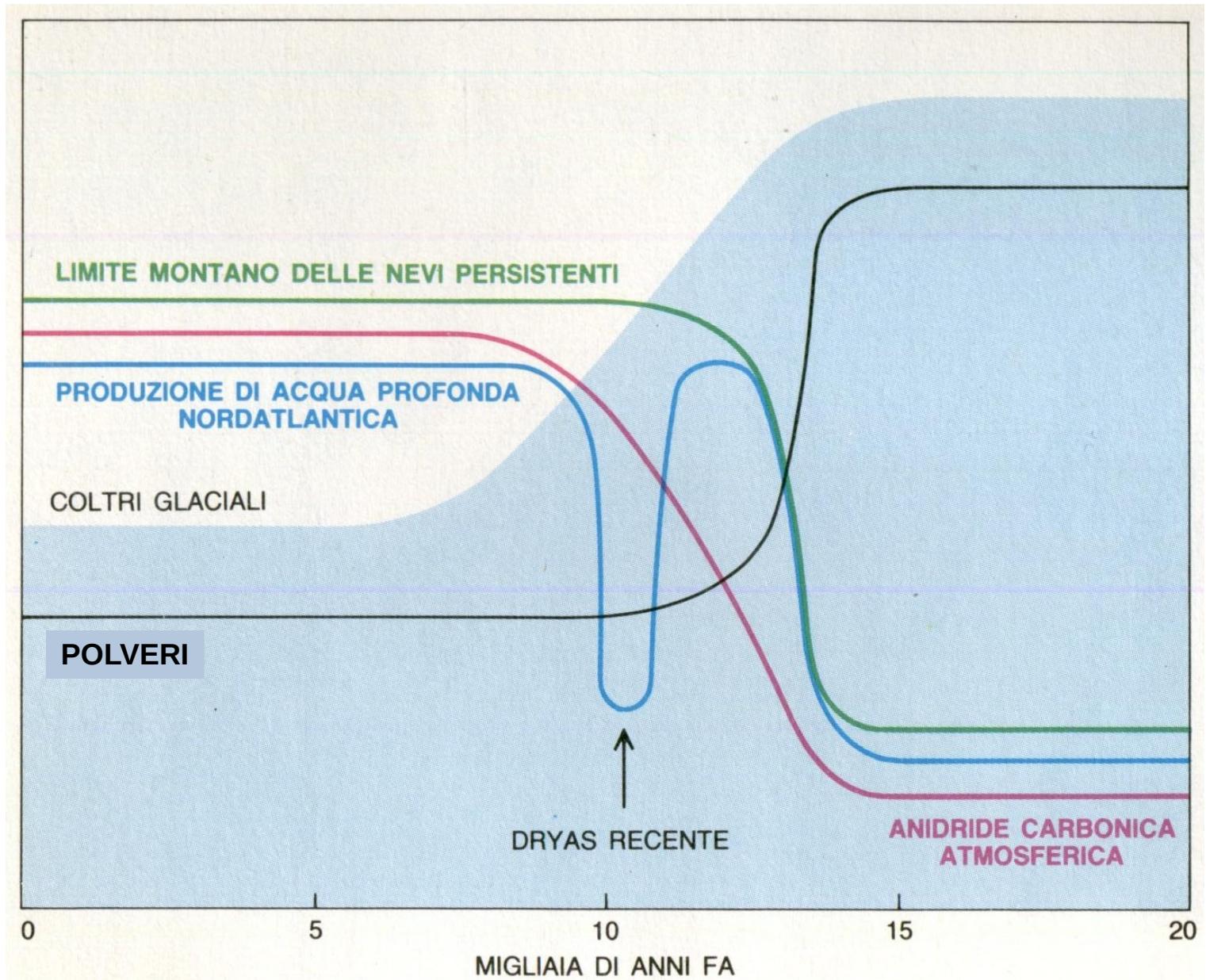


# **6 febbraio 2021: polvere sahariana sulle Alpi**

Ancora più appariscente il fenomeno appena oltre il confine italo-francese (qui al Colle del Lautaret, 2058 m, Hautes Alpes), dove già in tarda mattinata del 6 le pur modeste precipitazioni (inizialmente piovose fino a quote di 2000 m e oltre) hanno deposto la polvere desertica colorando vistosamente il manto nevoso  
(fonte: webcam comprensorio sciistico di Serre Chevalier).



Le polveri atmosferiche  
diminuirono drasticamente  
alla fine dell'ultima era  
glaciale



## TEMPERATURE CHANGES

EL NIÑO

TROPICAL CYCLONES

ARCTIC AMPLIFICATION

ASIAN MONSOONS

DUST



LAKES



LAND USE



Sahara

MONSOON STRENGTH

Sahel

VEGETATION

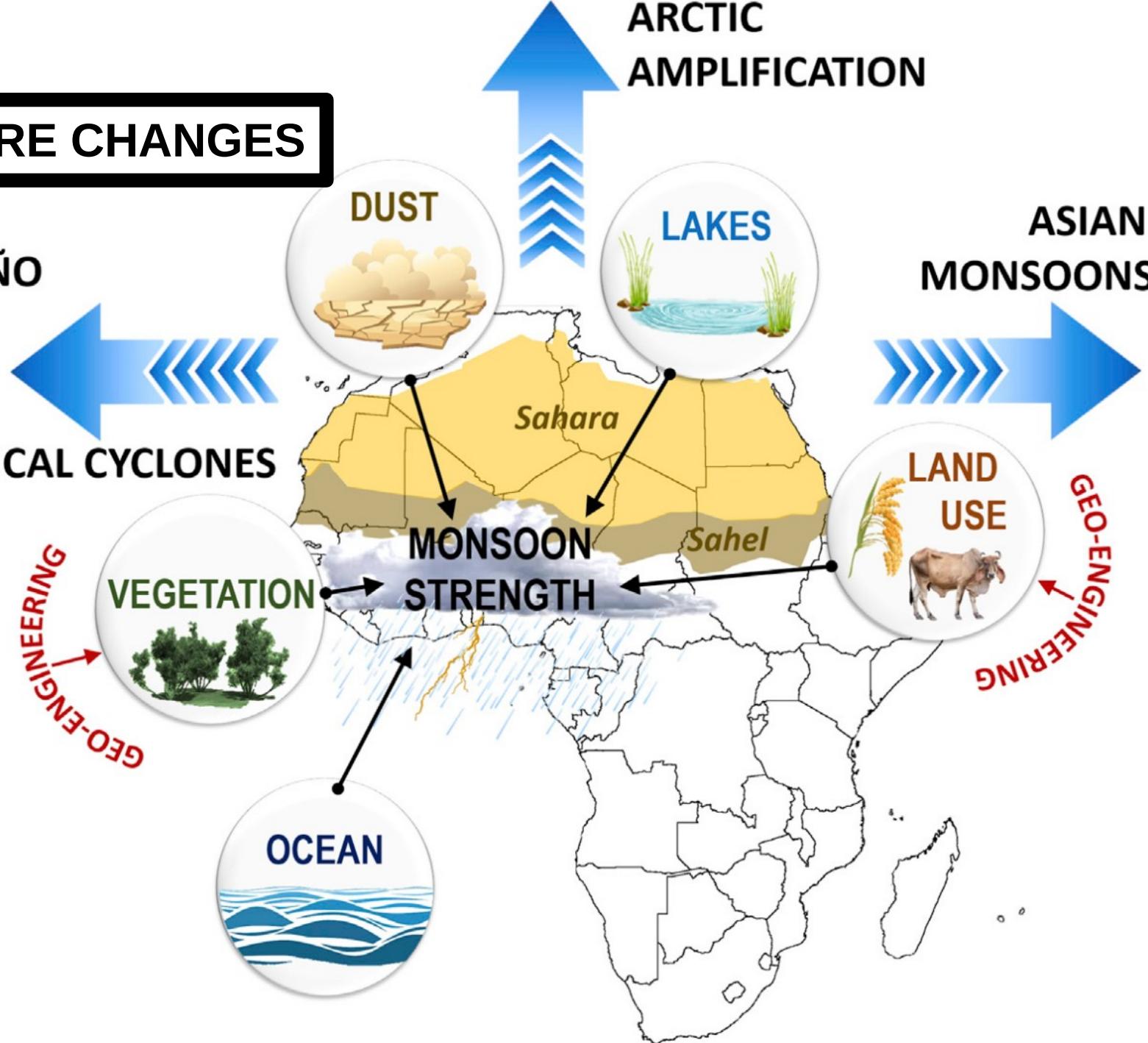


OCEAN



GEO-ENGINEERING

GEO-ENGINEERING



# A Reconstruction of Regional and Global Temperature for the Past 11,300 Years

SHAUN A. MARCOTT, JEREMY D. SHAKUN, PETER U. CLARK, AND ALAN C. MIX [Authors Info & Affiliations](#)

SCIENCE • 8 Mar 2013 • Vol 339, Issue 6124 • pp. 1198-1201 • DOI: 10.1126/science.1228026

 10.818  1332

## Exceptional Now

The climate has been warming since the industrial revolution, but how warm is climate now compared with the rest of the Holocene? **Marcott et al.** (p. 1198) constructed a record of global mean surface temperature for more than the last 11,000 years, using a variety of land- and marine-based proxy data from all around the world. The pattern of temperatures shows a rise as the world emerged from the last deglaciation, warm conditions until the middle of the Holocene, and a cooling trend over the next 5000 years that culminated around 200 years ago in the Little Ice Age. Temperatures have risen steadily since then, leaving us now with a global temperature higher than those during 90% of the entire Holocene.



## Summary

Supplementary Text

Figs. S1 to S26

References

## Resources

File (marcott.sm.database.s1.xlsx)

2.01 MB



File (marcott.sm.pdf)

4.20 MB



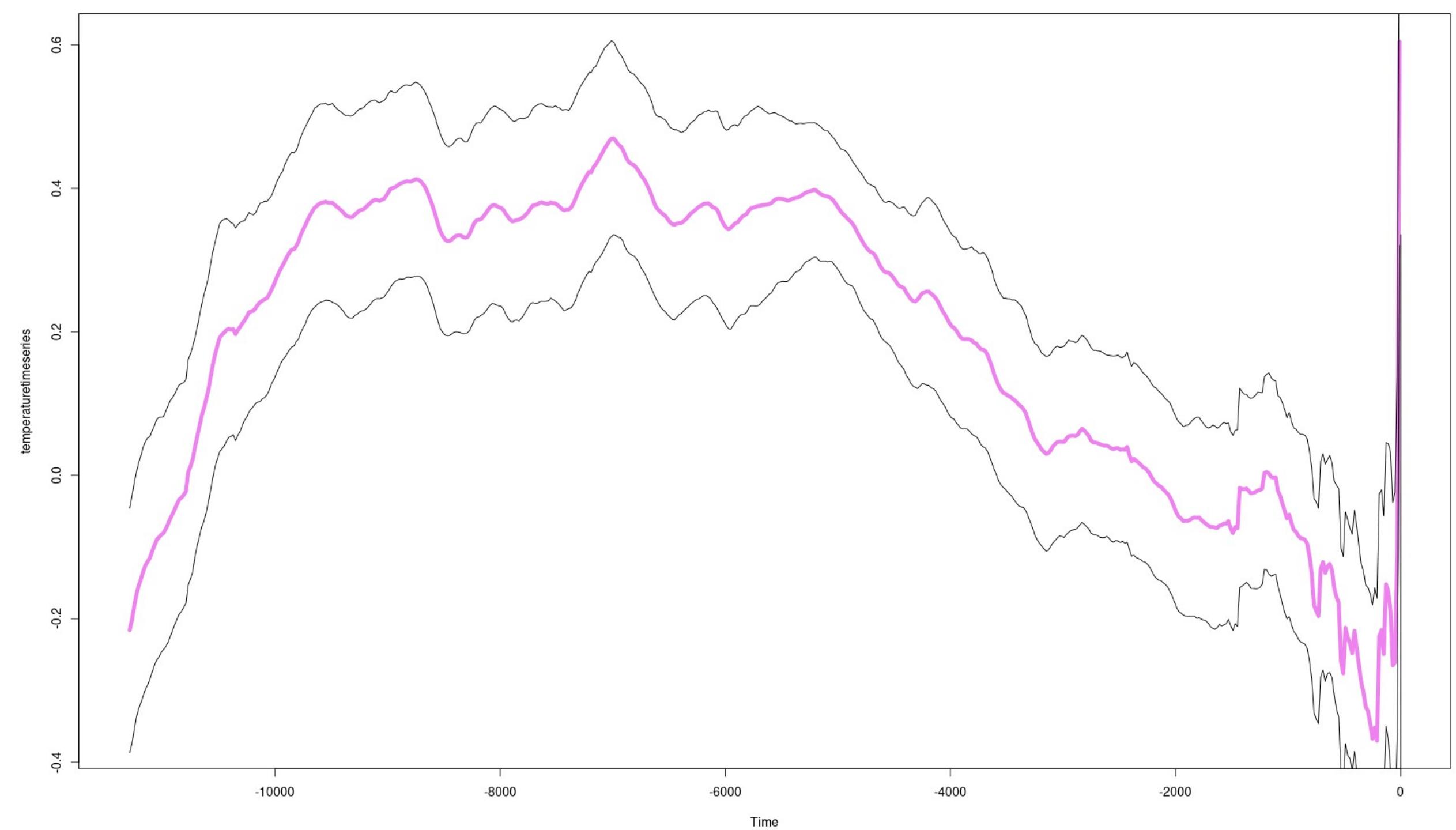
## References and Notes

- 1 E. Jansen *et al.*, in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon *et al.*, Eds. (Cambridge Univ. Press, Cambridge, 2007), pp. 433–497.



```
piero@piero-XPS-9320:~$ R
> library(readxl)
>
setwd('~/MATERIALE DIDATTICO A.S. 2025-2026/ESERCITAZIONI/EARLY_HOLOCENE_SAHLARA_GREENING/')
> Temperature_anomaly = read_excel('Temperature_anomaly.xlsx')
> Temperature_anomaly
# A tibble: 565 × 5
   YEARS_BP Global_Temp_C uncertainty plus_sigma minus_sigma
   <dbl>      <dbl>       <dbl>      <dbl>       <dbl>
1     10       0.604      0.284     0.321      0.888
2     30      -0.102      0.255    -0.358      0.153
3     50      -0.261      0.237    -0.497     -0.0242
4     70      -0.265      0.227    -0.492     -0.0379
5     90      -0.189      0.221    -0.411      0.0323
6    110      -0.162      0.206    -0.368      0.0443
7    130      -0.152      0.198    -0.350      0.0455
8    150      -0.249      0.193    -0.442     -0.0565
9    170      -0.216      0.196    -0.411     -0.0201
10   190      -0.225      0.199    -0.423     -0.0260
# 555 more rows
# Use `print(n = ...)` to see more rows
>
```

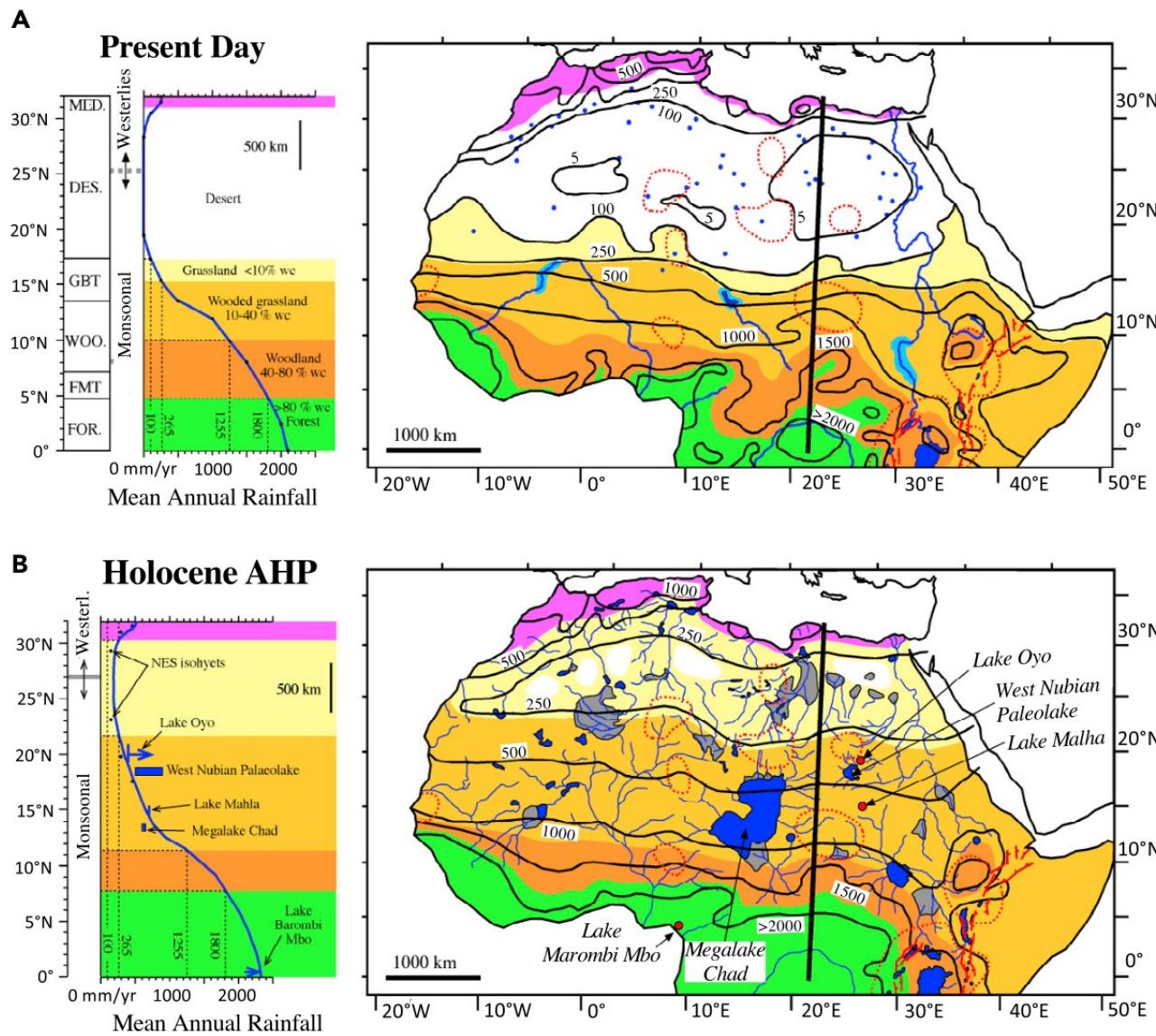
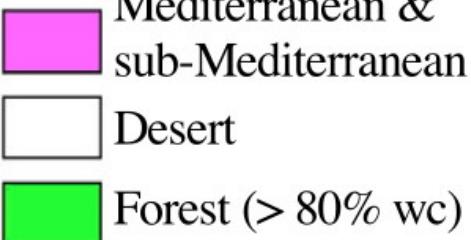
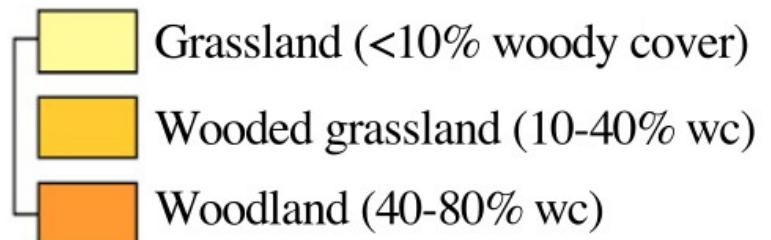
```
> temperaturetimeseries = ts(rev(Temperature_anomaly$Global_Temp_C), frequency=0.05,  
start=-11290)  
> temperaturetimeseries  
Time Series:  
Start = -11290  
End = -10  
Frequency = 0.05  
[1] -0.215960809 -0.201752346 -0.183237076 -0.166251530 -0.154023487  
[6] -0.144864157 -0.134380692 -0.125475303 -0.120158578 -0.115082330  
[11] -0.105969518 -0.097874648 -0.089912521 -0.086402164 -0.083051081  
...  
> plussigmatimeseries = ts(rev(Temperature_anomaly$plus_sigma), frequency=0.05, start=-  
11290)  
> minussigmatimeseries = ts(rev(Temperature_anomaly$minus_sigma), frequency=0.05,  
start=-11290)  
> plot(temperaturetimeseries, col='violet', lwd=5)  
> lines(plussigmatimeseries)  
> lines(minussigmatimeseries)  
>
```



The Sahara Desert has periodically experienced wet periods, often termed African humid periods (AHPs), with a more vegetated landscape.

The most recent AHP, the Holocene AHP, dates from the early and middle Holocene (EH and MH, respectively; 12,000–5,000 years BP), starting around 15,000 years BP and **peaking between 9,000 and 6,000 years BP**.

## Savannah



- River
- Isoyet (mm/yr)
- Lake
- Volcanism & uplift
- Alluvial fan/plain
- East African Rift System

# The Holocene African Humid Period

More intense summer rainfall led to an expansion of the northern African lakes and wetlands, as well as to an extension of Sahelian vegetation into areas that are now desert, giving origin to the so-called “**Green Sahara**”.

**These ecosystems supported animal life and human settlements of hunter-gatherers**, which are well documented from archeological evidence such as **rock paintings**.

# **Optimum termico olocenico: arte rupestre sahariana**

**Saharan rock art** is a significant area of archaeological study focusing on artwork carved or painted on the natural rocks of the central Sahara desert. The rock art dates from numerous periods starting c. 12,000 years ago, and is significant because it shows the culture of ancient African societies.

Il riscaldamento non causa un'espansione delle aree desertiche ma, al contrario, le trasforma in parte in savane alberate, grazie all'aumento della piovosità.

# Optimum termico olocenico: arte rupestre sahariana



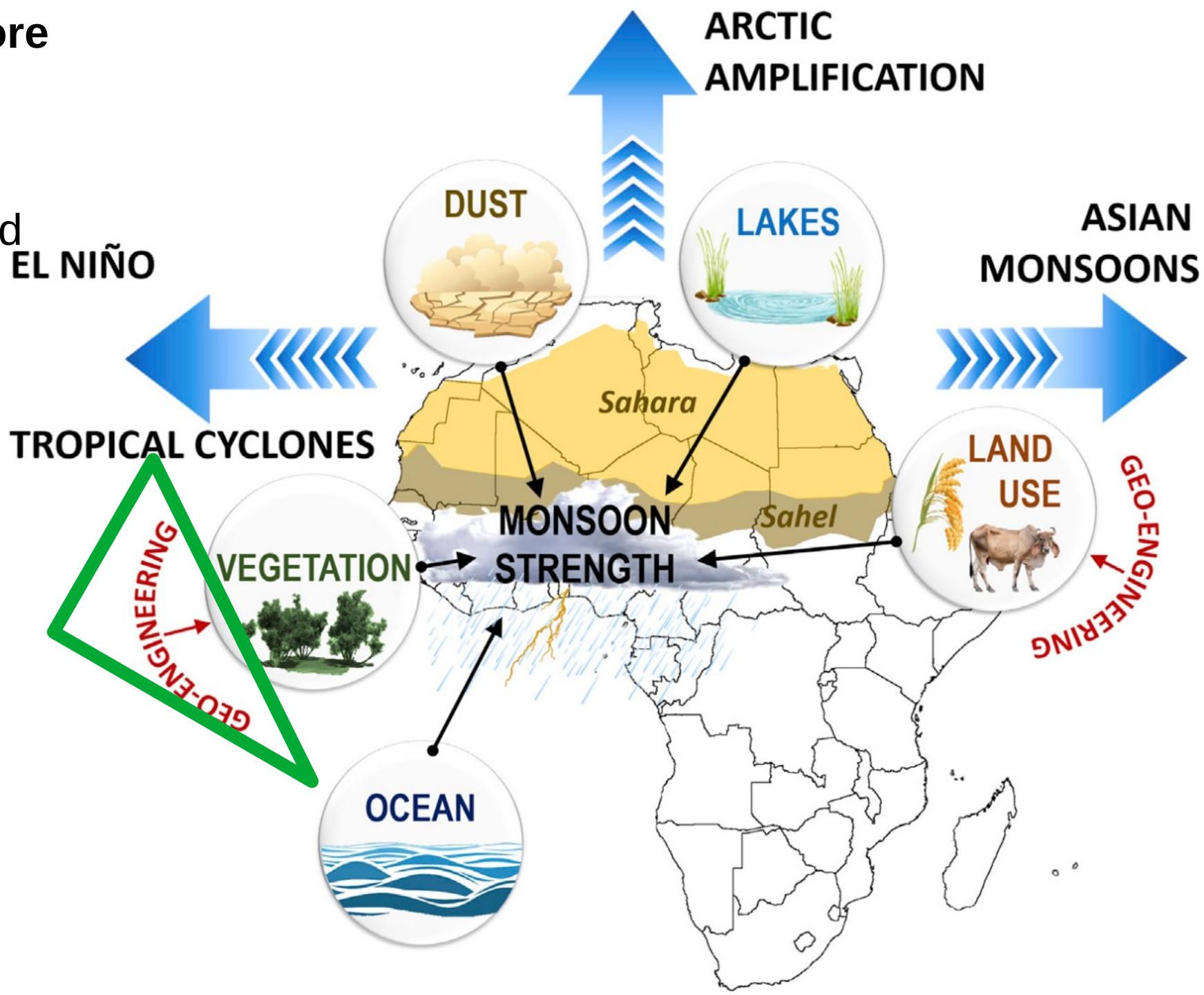
# Optimum termico olocenico: arte rupestre sahariana

Manda Guéli Cave  
in the Ennedi  
Mountains,  
northeastern Chad





Wetter conditions and more vegetation decrease dust emissions, whereas the converse happens for drier conditions and reduced vegetation cover



# The Great Green Wall



**THE GREAT GREEN WALL**

The Great Green Wall of the Sahara and the Sahel is Africa's Flagship programme including a mosaic of land-based initiatives leveraging the land-water-energy Nexus.

## GROWING A WORLD WONDER

The Great Green Wall is an African-led movement with an epic ambition to grow an 8,000km natural wonder of the world across the entire width of Africa.

A decade in and roughly 15% underway, the initiative is already bringing life back to Africa's degraded landscapes at an unprecedented scale, providing food security, jobs and a reason to stay for the millions who live along its path.

The Wall promises to be a compelling solution to the many urgent threats not only facing the African Continent, but the global community as a whole – notably climate change, drought, famine, conflict and migration.

Once complete, the Great Green Wall will be the largest living structure on the planet, 3 times the size of the Great Barrier Reef.

# The Great Green Wall



# The Great Green Wall





**Growing gender equity,  
empowering women with  
new opportunities.**

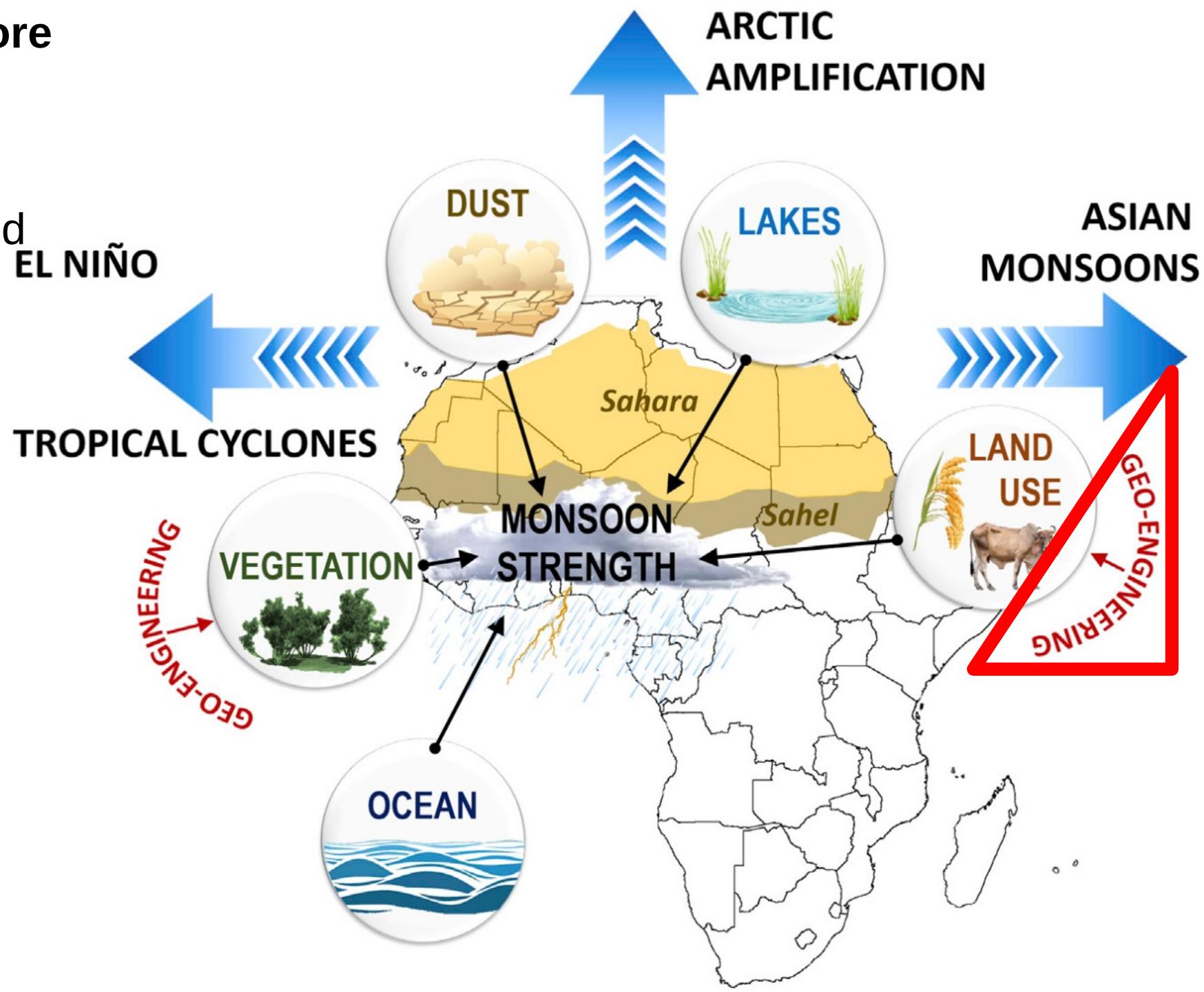


**Growing economic  
opportunities to boost  
small business and  
commercial enterprise.**

**Growing a reason to stay  
to help break the cycle of  
migration.**

**Growing sustainable  
consumption patterns,  
to protect the natural  
capital of the Sahel.**

Wetter conditions and more vegetation decrease dust emissions, whereas the converse happens for drier conditions and reduced vegetation cover



RESEARCH ARTICLE | EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES |



# Early Holocene greening of the Sahara requires Mediterranean winter rainfall

Rachid Cheddadi , Matthieu Carré , Majda Nourelbait , , and Enno Schefuß [Authors Info & Affiliations](#)

Edited by Francesco S. R. Pausata, University of Quebec in Montreal, Montreal, Canada, and accepted by Editorial Board Member Donald R. Ort

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May 31, 2021 | 118 (23) e2024898118 | <https://doi.org/10.1073/pnas.2024898118>

THIS ARTICLE HAS BEEN UPDATED

# The African Humid Period

The greening of the Sahara, associated with the African Humid Period (AHP) between ca. 14,500 and 5,000 y ago, is arguably the largest climate-induced environmental change in the Holocene.



<b>Location</b>	Haut Atlas Oriental National Park, Morocco
<b>Coordinates</b>	32°11'N 5°38'W
<b>Lake type</b>	Meromictic lake
<b>Basin countries</b>	Morocco
<b>Surface area</b>	1.3 km <sup>2</sup> (0.50 sq mi) <a href="#">[1]</a>
<b>Average depth</b>	16 m (52 ft) <a href="#">[1]</a>
<b>Surface elevation</b>	2,119 m (6,952 ft)
<b>Ramsar Wetland</b>	
<b>Official name</b>	Lacs Isly-Tislite
<b>Designated</b>	15 January 2005
<b>Reference no.</b>	1480 <sup>[2]</sup>



## Il lago Tislit in Marocco

Lake Tislit is a lake located in Morocco's Haut Atlas Oriental National Park, in the administrative division of Imlilchil. This is an "agdal" (which means "proprietary grazing field" in the Berber language) where **the tribes of Ayt Hdiddu lead their flocks during the summer**. The lake has been designated as a protected Ramsar site since 2005.

# La tecnica di datazione del C14

#



