Re-evaluation of leaf wax hydrogen stable isotopic signal from a case study of model-proxy discrepancy in mid-Holocene northern Africa

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1. Introduction

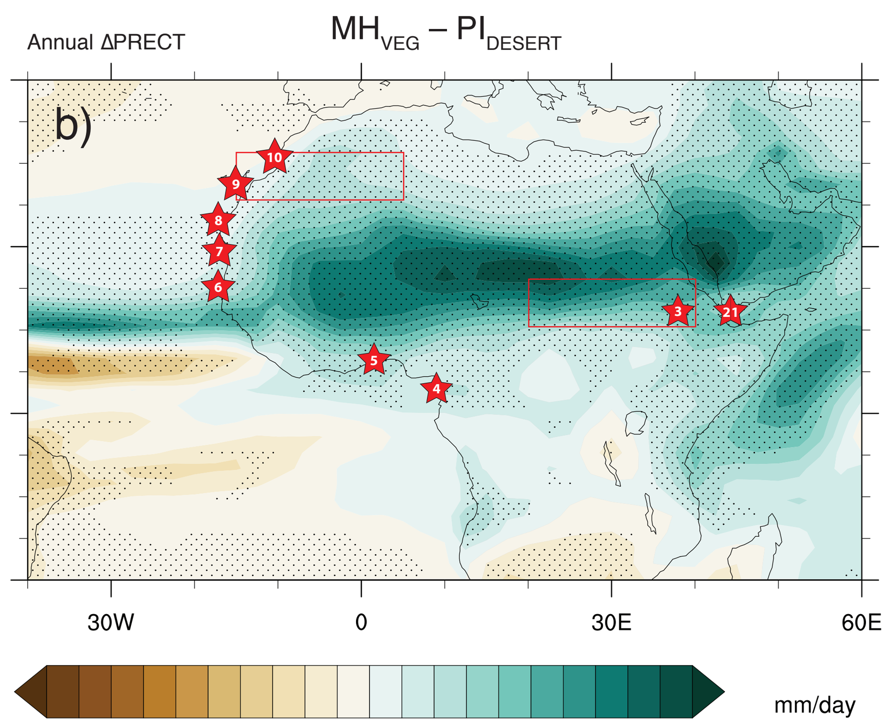
- Hydrogen stable isotopic composition of leaf wax *n*-alkanes (δD_{wax}) is an important tool for reconstructing past hydroclimate, which is done using the "amount effect"[1-7]
- "Amount Effect": mean annual rainfall (MAP) amount varies inversely with its δD[8]
- Past MAP is calculated from δD_{wax} by accounting for apparent fractionations under the assumption that the δD of rainfall (δD_P) is roughly equal to the δD of soil water (δD_S)[7]
  - Decoupling of δD_P and δD_S would complicate this calculation
- Case study for testing leaf waxes: Green Sahara of the mid-Holocene (MH, 6ka BP)
  - In the MH, the Sahara was wetter and greener relative to the Pre-industrial era (PI)
  - 10 leaf wax δD records report an average MH depletion of 12.8‰ relative to the PI
- Here we present the first comprehensive study of the Green Sahara, including a change in vegetation, using the water isotope-enabled Community Earth System Model[9]

2. Methods

- We perform experiments with the fully coupled water isotope-enabled iCESM[9]
  - Simulated tracers of water isotopes (i.e., δD) allow for direct comparison with δD_{wax}
  - Spin-up for 300 years (200 for PI) with climatology calculated from last 50 years
- PI_{DESERT}: Boundary conditions of Pre-industrial orbital (0ka) and modern Sahara desert
- MH_{VEG}: Boundary conditions of mid-Holocene orbital (6ka) and vegetated Sahara
  - Average PI land surface at zonal region over the Sahel (10°N) extended north to 35°N
- MH_{VEG}–PI_{DESERT}: climate differences due to altered orbital forcing and vegetation cover

a) Leaf wax δD records

#	MH–PI (‰)	Location	Ref. #
1	-13	Gulf of Aden	1
2	-7	Gulf of Aden	2
3	-10	Lake Tana	3
4	-13	Gulf of Guinea	4
5	-9	Lake Bosumtwi	5
6	-17	Western Margin	6
7	-13	Western Margin	7
8	-16	Western Margin	7
9	-19	Western Margin	7
10	-11	Western Margin	7



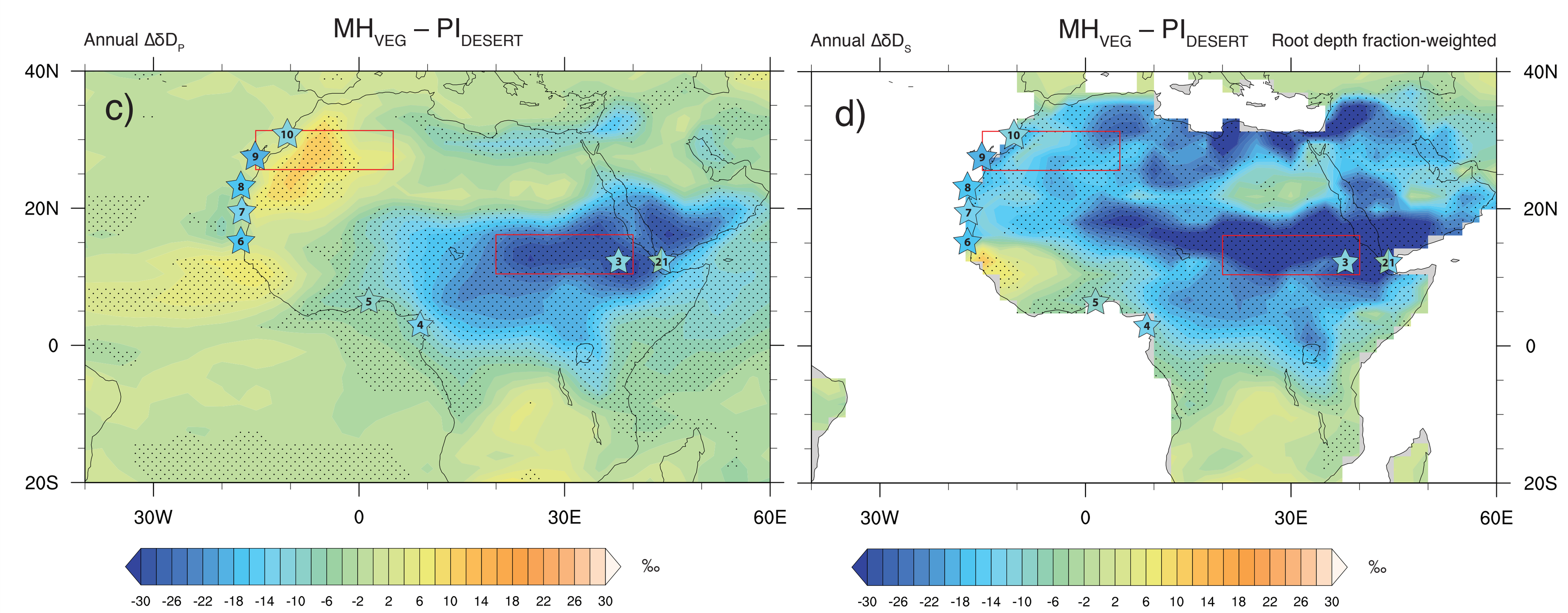


Figure 1. Annual MH–PI differences in a) leaf wax δD records throughout northern Africa, b) mean annual rainfall, c) rainfall amount-weighted isotopic composition of rainfall (δD_P), and d) root depth fraction-weighted isotopic composition of soil water (δD_S). Numbered stars in b), c), and d) correspond to the leaf wax δD records in a). Red boxes indicate the spatial extent of the northwestern and southeastern Sahara. Stippling shows statistically significant differences at the 95% confidence level.

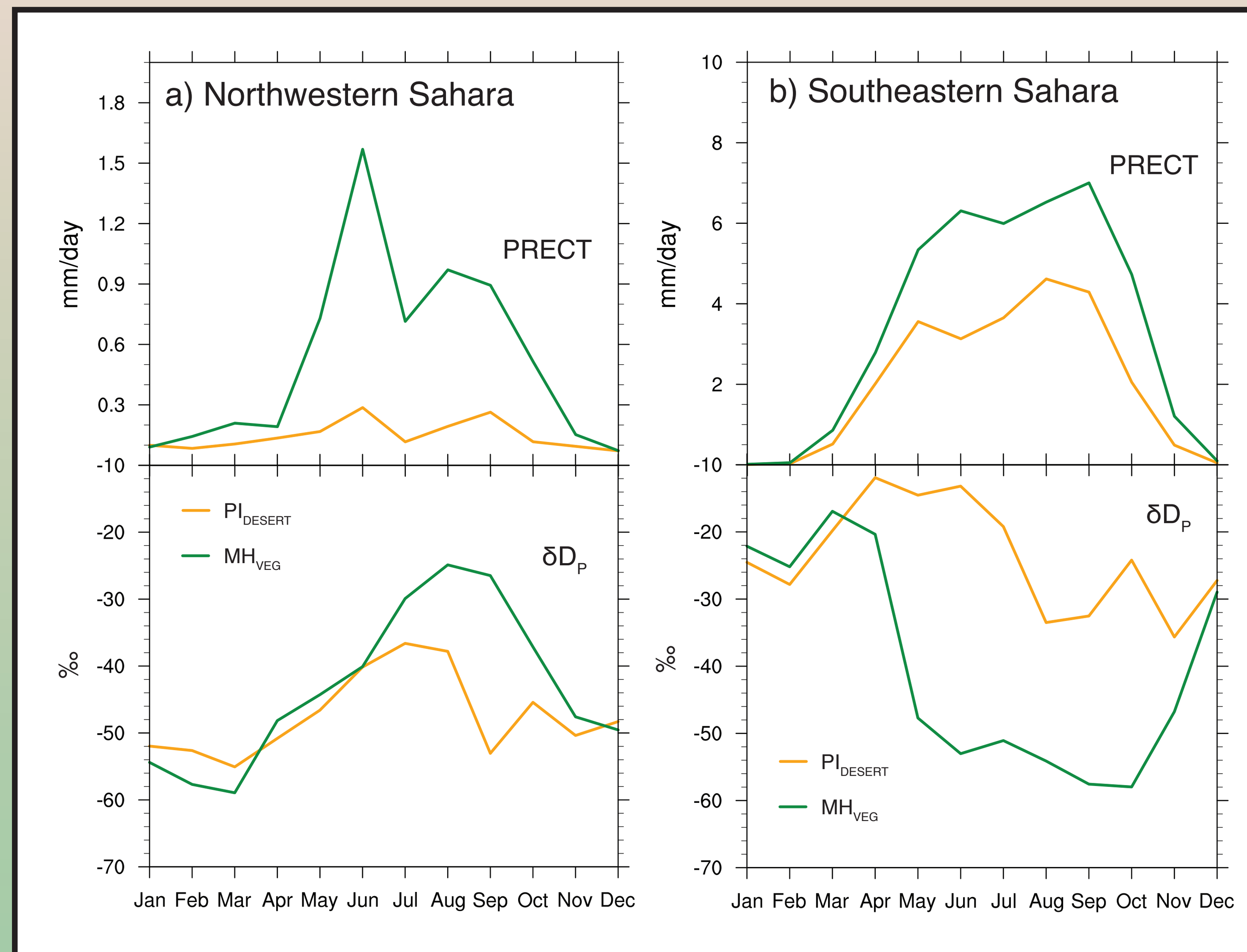
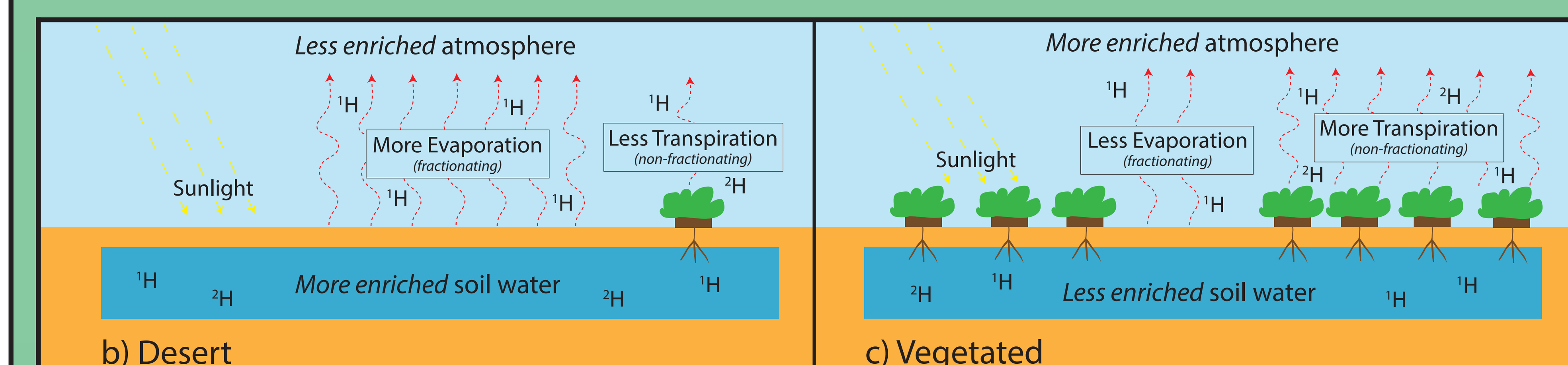


Figure 2. Seasonal cycle of total precipitation and the isotopic comp. of rainfall for PI_{DESERT} and MH_{VEG} for the a) northwestern Sahara (25.6-31.3°N, 15°W-5°E) and b) southeastern Sahara (10.4-16.1°N, 20-40°E). These seasonal cycle plots show that the MH enrichment (depletion) of δD_P relative to the PI occuring in the northwestern (southeastern) Sahara takes place during monsoon season, implying the processes that promote these changes also occur during the monsoon season.

3. Results

- Due to MH–PI difference in orbital forcing and vegetation cover (MH_{VEG}–PI_{DESERT}):
  - MAP increases throughout northern Africa (Figs. 1b and 2)
  - The isotopic composition of rainfall (δD_P) becomes...
    - ...depleted in the SE Sahara due to the continental effect (Figs. 1c and 2b)
    - ...enriched in the NW Sahara due to a combination of a stronger Saharan Heat Low and an enrichment in transpired water vapor δD (Figs. 1c, 2a, and 3)
  - δD_S becomes depleted throughout northern Africa due to increased vegetation cover and an increase in the transpiration-to-total ET ratio (Figs. 1d and 3)
- Root-mean-square error (RMSE) between the modeled results and leaf wax δD records is reduced year-round when comparing against δD_S instead of δD_P (Fig. 4)
  - Changes to δD_S better explain the five western leaf wax proxy sites, whereas changes to δD_P better explain the five eastern leaf wax δD sites (Fig. 4)



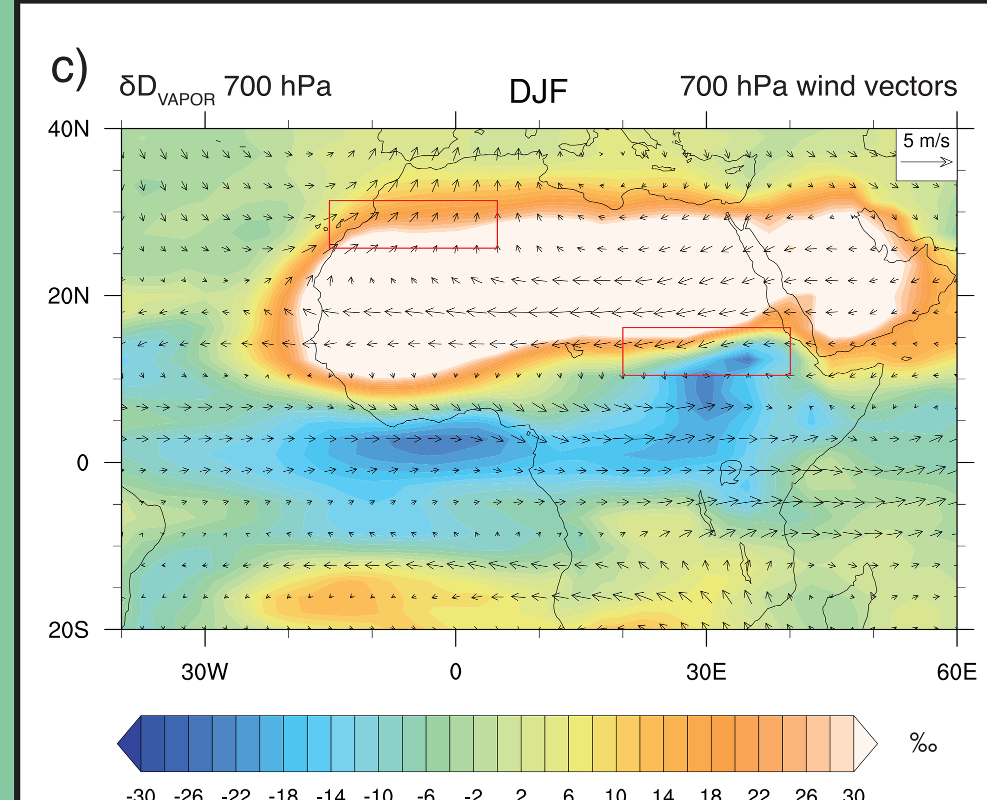
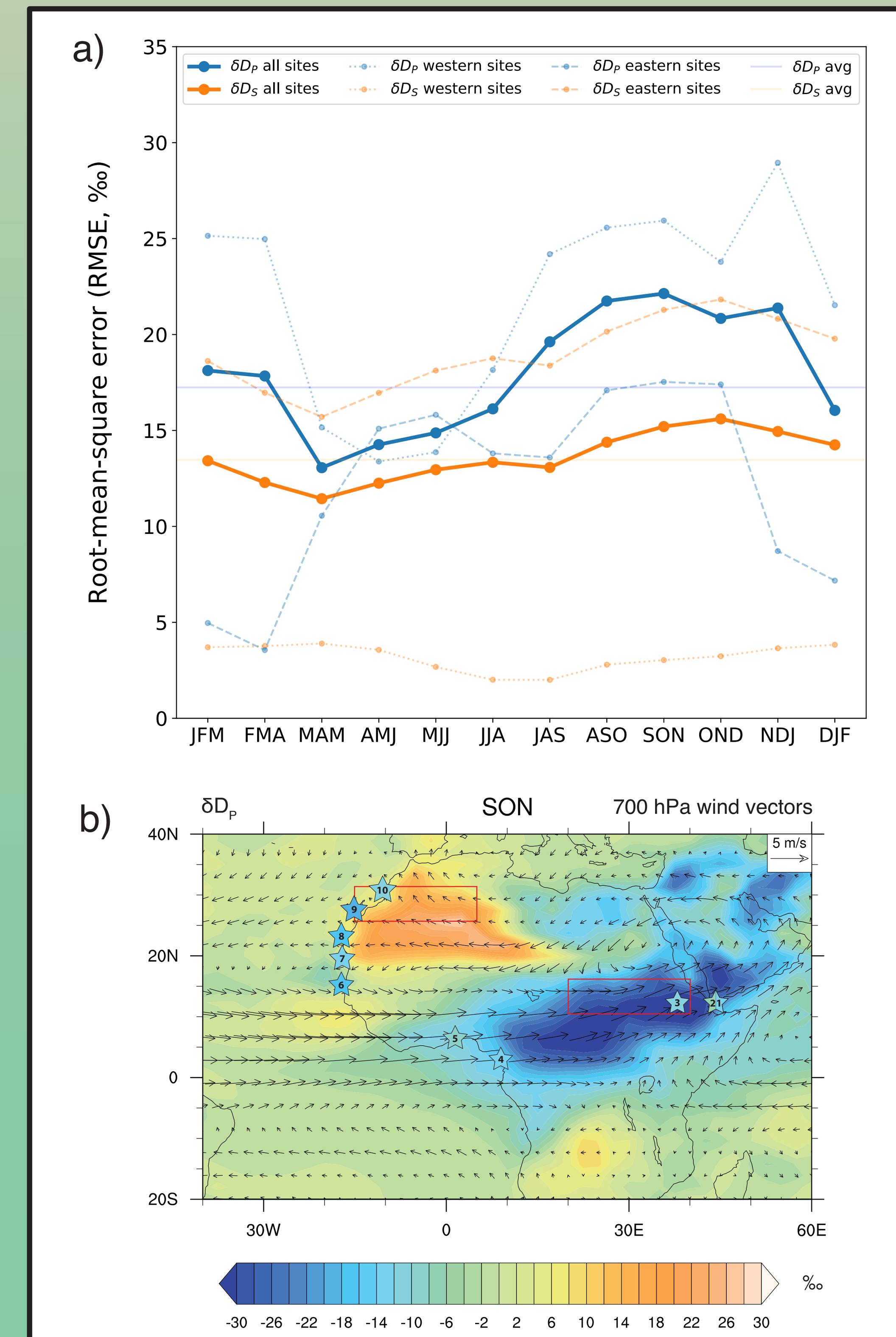


Figure 3. Schematic illustrating differences in the evapotranspiration (ET) flux between a) deserted and b) vegetated environments and the resulting impacts on the isotopic composition of the soil water pool and atmosphere. c) Dec., Jan., Feb. (DJF) difference between MH_{VEG} and PI_{DESERT} for specific humidity-weighted isotopic composition of water vapor (δD_{VAPOR}) at 700 hPa overlain by 700 hPa winds. The strong MH enrichment that occurs where vegetation cover has been increased exemplifies the ET flux changes in vegetated environments (i.e., Green Sahara), as shown by b). Red boxes indicate the spatial extent of the northwestern and southeastern Sahara.

Figure 4. a) Root-mean-square error (RMSE) for comparing the 10 leaf wax δD records in Figure 1 to seasonal averages of the isotopic composition of rainfall (δD_P, blue) and to the isotopic composition of soil water (δD_S, orange). Dashed and dotted lines show RMSE calculations for records # 1-5 and 6-10, respectively. Faded solid lines show annual average RMSE for all records. b) Sept., Oct., Nov. (SON) average difference (MH_{VEG}–PI_{DESERT}) of δD_P and 700 hPa winds. SON has large RMSE between δD_P and the leaf wax δD records. As shown in b), easterly winds over the NW Sahara are accompanied by relative MH enrichment while monsoonal westerlies are accompanied by depletion.



4. Conclusions

- Amount effect *can* explain SE Saharan leaf wax records
- Amount effect *cannot* explain NW Saharan records
  - δD_S, rather than δD_P, agrees with these records
- Regional atmospheric and land surface dynamics must be considered to reconstruct rainfall from leaf waxes
- Leaf wax δD records capture integrated signal from both soil water pool and mean annual rainfall
  - Local changes in the presence or absence of vegetation can overprint the δD_P signal from the amount effect

5. References

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