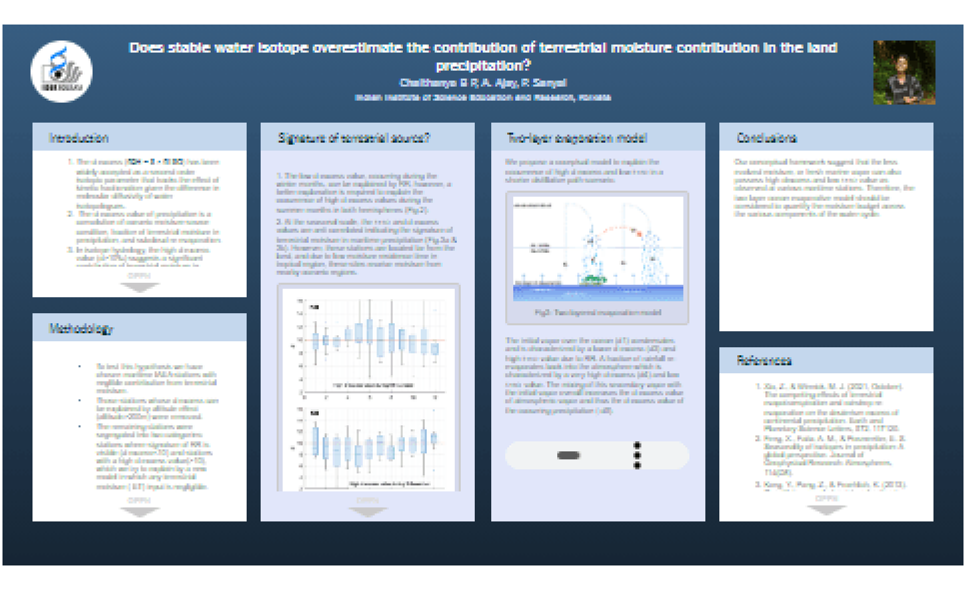
Does stable water isotope overestimate the contribution of terrestrial moisture contribution in the land precipitation?



Chaithanya B P, A. Ajay, P. Sanyal

Indian Institute of Science Education and Research, Kolkata

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INTRODUCTION

1. The d-excess (**δ2H − 8 × δ18O**) has been widely accepted as a second-order isotopic parameter that tracks the effect of kinetic fractionation given the difference in molecular diffusivity of water isotopologues.
2. The d-excess value of precipitation is a convolution of oceanic moisture source condition, fraction of terrestrial moisture in precipitation, and subcloud re-evaporation.
3. In isotope hydrology, the high d-excess value (d>10‰) suggests a significant contribution of terrestrial moisture in precipitation. Conversely, the d-excess value lower than 10‰ indicates sub-cloud re-evaporation during the rainfall, which mainly occurs in warm and dry regions (tropical regions).
4. Based on the δ18O and d-excess relationship, previous studies disentangle the competing effects of Evapotranspiration(ET) and Raindrop Reevaporation(RR). A **negative correlation** between d-excess and δ18O suggests a stronger ET effect while a **positive correlation** is related to a stronger RR effect as shown in Fig1.

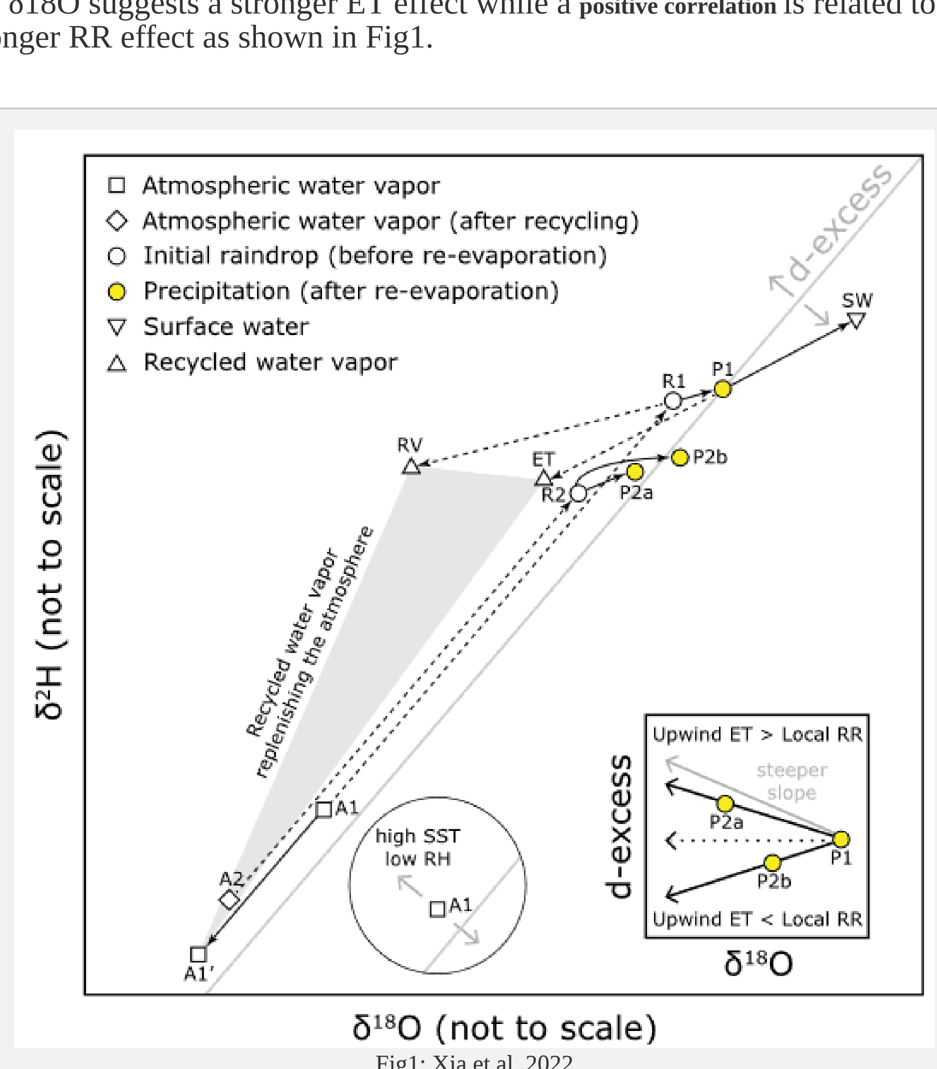

Fig1: Xia et al.,2022

METHODOLOGY

- To test this hypothesis we have chosen maritime IAEA stations with neglible contribution from terrestrial moisture.
- Those stations whose d-excess can be explained by altitude effect (altitude>200m) were removed.
- The remaining stations were segregated into two categories: stations where signature of RR is visible (d-excess<10) and stations with a high d-excess value(>10), which we try to explain by a new model in which any terrestrial moisture (ET) input is negligible.

SIGNATURE OF TERRESTRIAL SOURCE?

1. The low d-excess value, occurring during the winter months, can be explained by RR, however, a better explanation is required to explain the occurrence of high d-excess values during the summer months in both hemispheres (Fig.2).

2. At the seasonal scale, the δ18O and d-excess values are anti-correlated indicating the signature of terrestrial moisture in maritime precipitation (Fig.3a & 3b). However, these stations are located far from the land, and due to low moisture residence time in tropical region, these sites receive moisture from nearby oceanic regions.

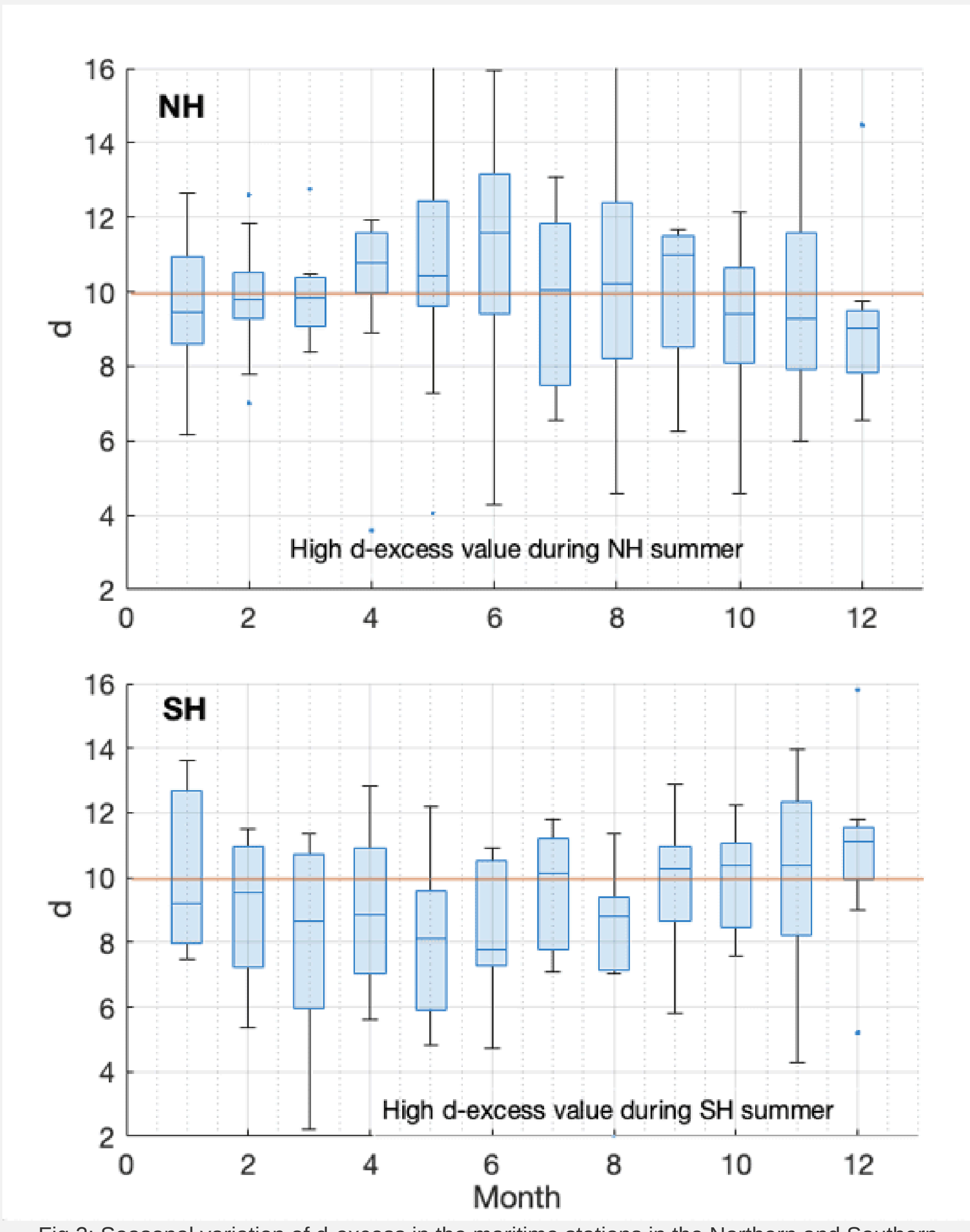

Fig.2: Seasonal variation of d-excess in the maritime stations in the Northern and Southern Hemisphere.

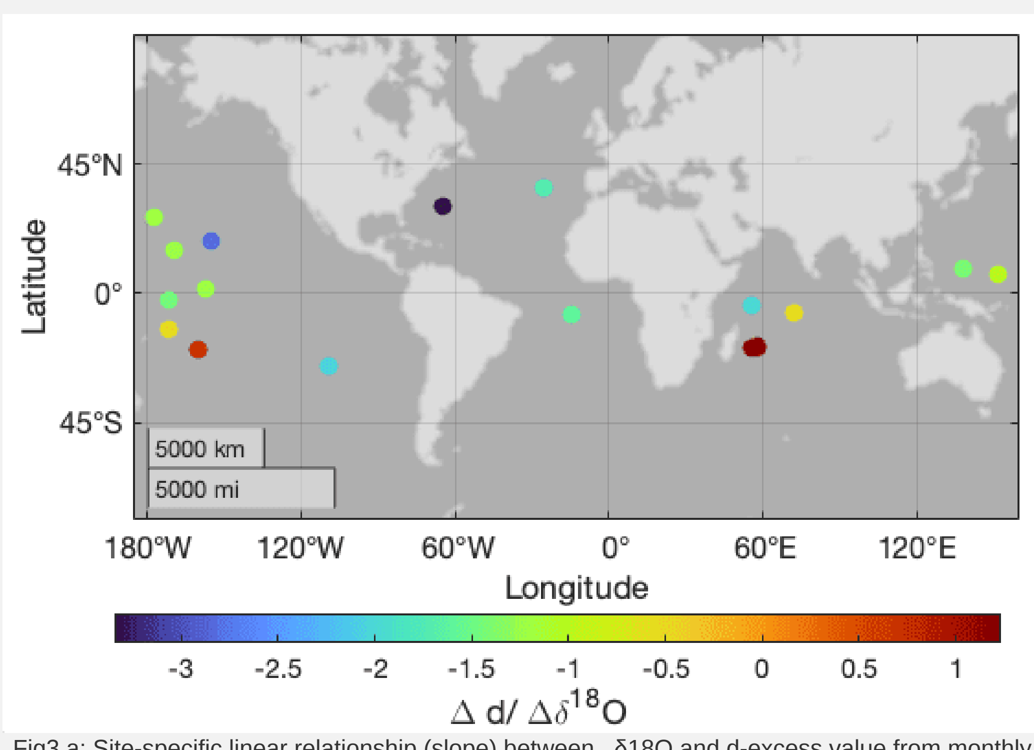

Fig3.a: Site-specific linear relationship (slope) between δ18O and d-excess value from monthly scale data.

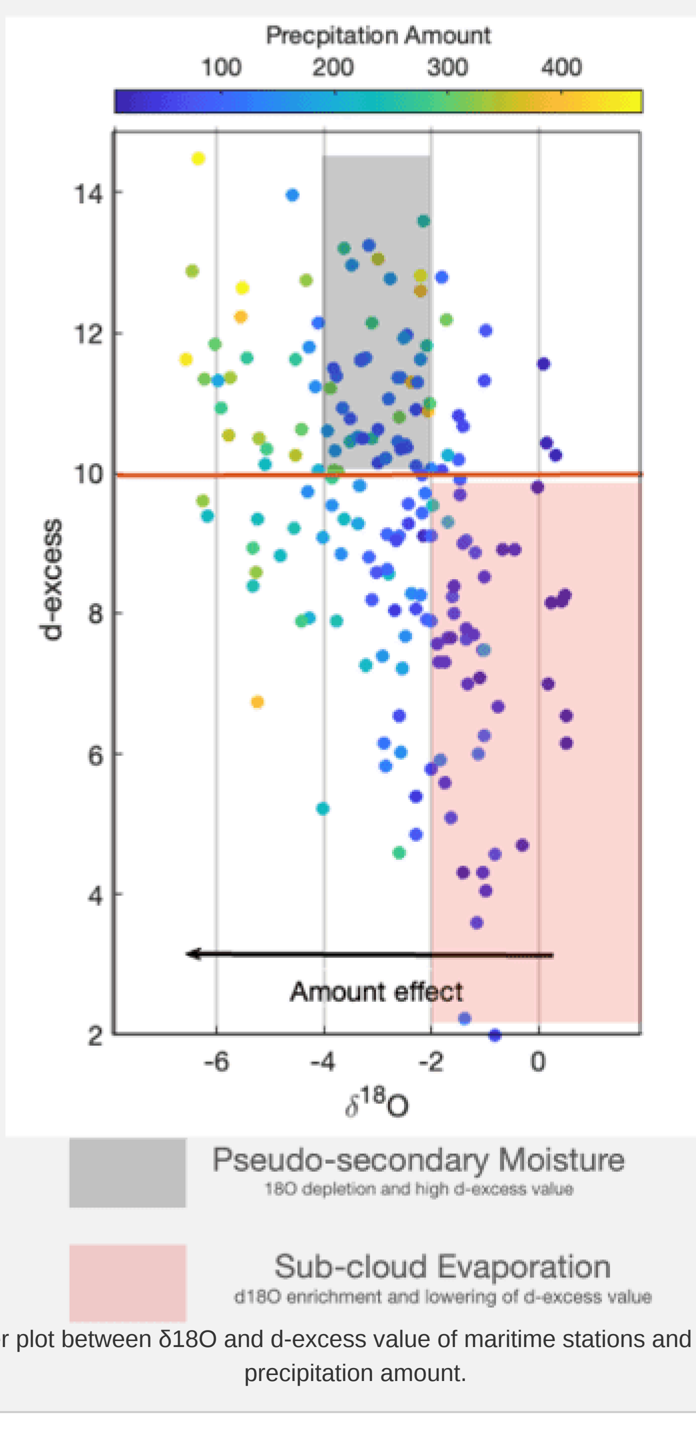

Fig3.b: Scatter plot between δ18O and d-excess value of maritime stations and its relation with precipitation amount.

3. The occurrence of a low δ18O value with a high d-excess value (Fig. 3b), more particularly during the summer months, suggests a longer moisture distillation path (old moisture). However, again the moisture residence time in the zones of the maritime station is very short (< 2 days).

TWO-LAYER EVAPORATION MODEL

We propose a coceptual model to explain the occurrence of high d-excess and low δ18O in a shorter distillation path scenario.

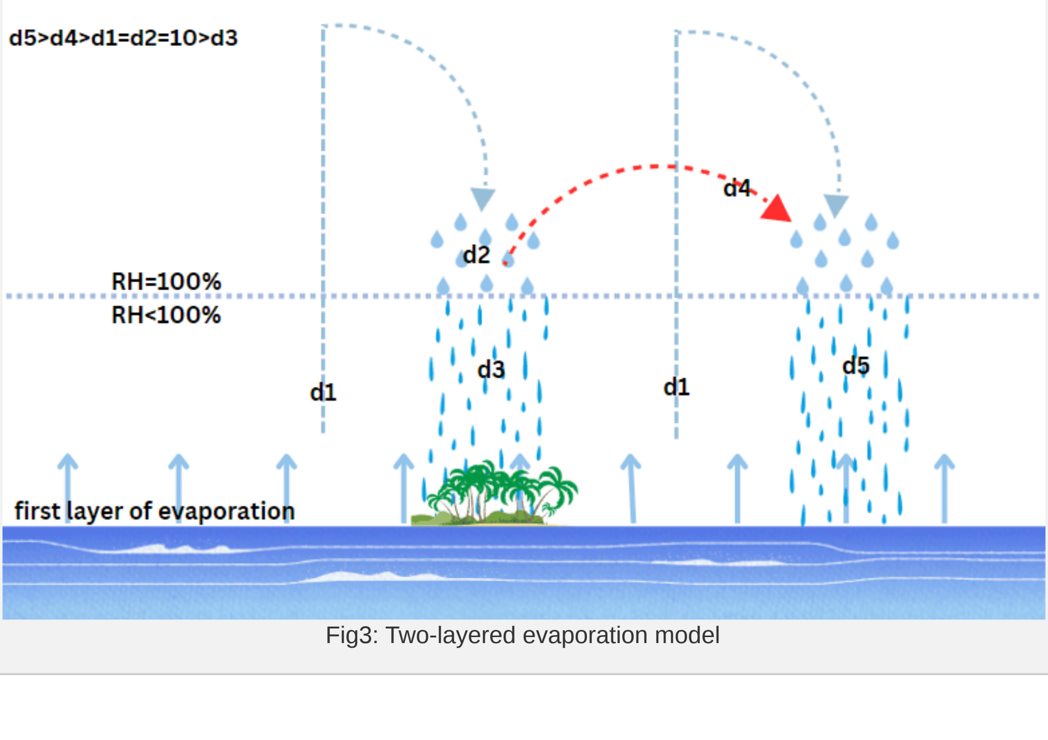

Fig3: Two-layered evaporation model

The initial vapor over the ocean (d1) condensates and is characterized by a lower d-excess (d3) and high δ18O value due to RR. A fraction of rainfall re-evaporates back into the atmosphere which is characterized by a very high d-excess (d4) and low δ18O value. The mixing of this secondary vapor with the initial vapor overall increases the d-excess value of atmospheric vapor and thus the d-excess value of the occurring precipitation (d5).

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CONCLUSIONS

Our conceptual framework suggest that the less evolved moisture, or fresh marine vapor can also possess high-dexcess and low δ18O value as observed at various maritime stations. Therefore, the two-layer ocean evaporative model should be considered to quantify the moisture budget across the various components of the water cycle.

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TRANSCRIPT

ABSTRACT

In the current context of climate change, accurately quantifying various components of the hydrological cycle is vital to understand the availability of freshwater. Stable water isotopes have proven to be valuable tools in estimating the budget of multiple components in the hydrological cycle. However, a discrepancy often arises when attempting to quantify these components using other methods, such as land surface and moisture diagnostic models.

Our research focuses on the d-excess value, a moisture source proxy, analyzed at 27 tropical and extratropical maritime stations maintained by IAEA. In tropical regions, a d-excess value greater than 10 usually suggests the presence of terrestrial moisture in precipitation, such as lake and soil moisture. Interestingly, we observed a high d-excess value (d > 12‰) in precipitation at 13 sites, all located in the southern extratropical regions, despite a negligible contribution from terrestrial sources. A slightly positive correlation between δ18O and the d-excess value is observed, suggesting a significant effect of raindrop evaporation. Consequently, the mixing of primary oceanic vapor and secondary raindrop re-evaporated vapor results in the high d-excess value of evaporative vapor flux over the extratropical region. Although the moisture source is purely oceanic, it exhibits a signature resembling terrestrial sources due to significant recycling over the ocean. Thus, studies based solely on isotope methodology may have inadvertently overestimated the contribution of recycled moisture in total precipitation over land, particularly in regions receiving moisture from extratropical areas.