Daily rainfall δ^{18}O suggests Southern Thailand speleothem ^{18}O records controlled by extreme winter monsoon events

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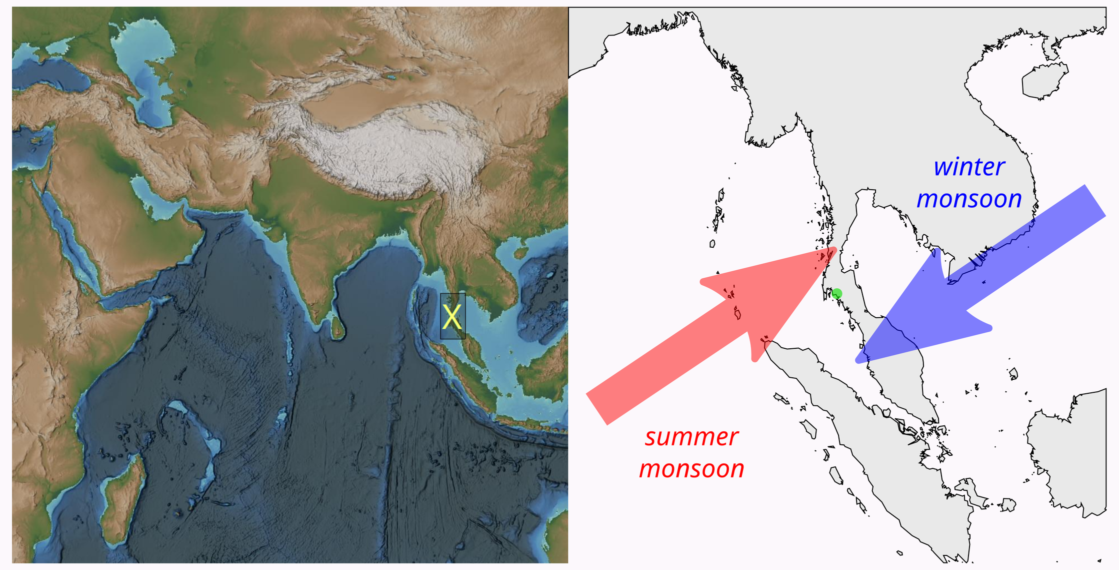
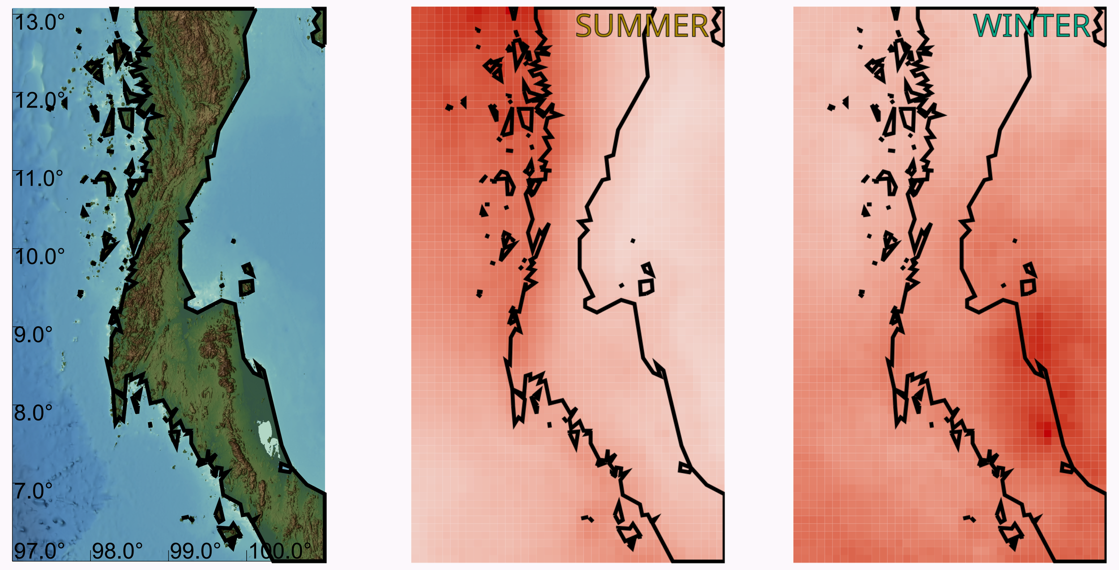
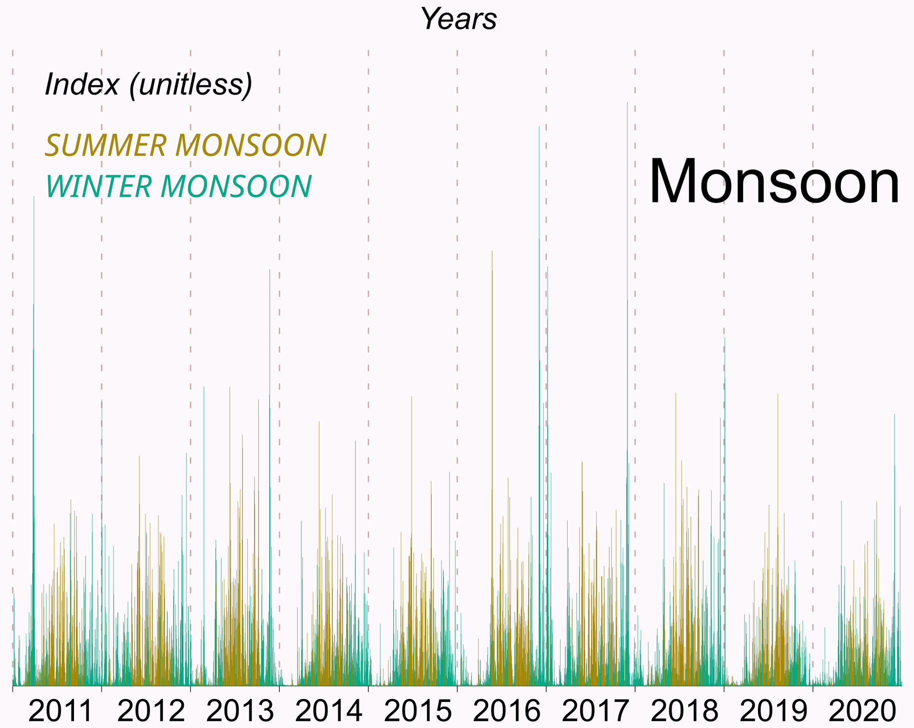
Regional Climate Setting



Region: The Southern Thailand peninsula.
This region is of particular interest because it has precipitation from both a summer and winter monsoon system. Such wet winter monsoons are uncommon elsewhere.
Site: The reference speleothem record we will look at is from West coast of the peninsula (*green circle*) off the Phang Nga Bay.



Orography drives the spatial distribution of monsoonal rains
Summer rains predominantly rain on the Western Coast
and Winter rains on the Eastern Coast



A regional climate index classifies days as belonging to a summer or winter monsoon regime. The winter period will typically have a dry season around January

Classic Speleothem View

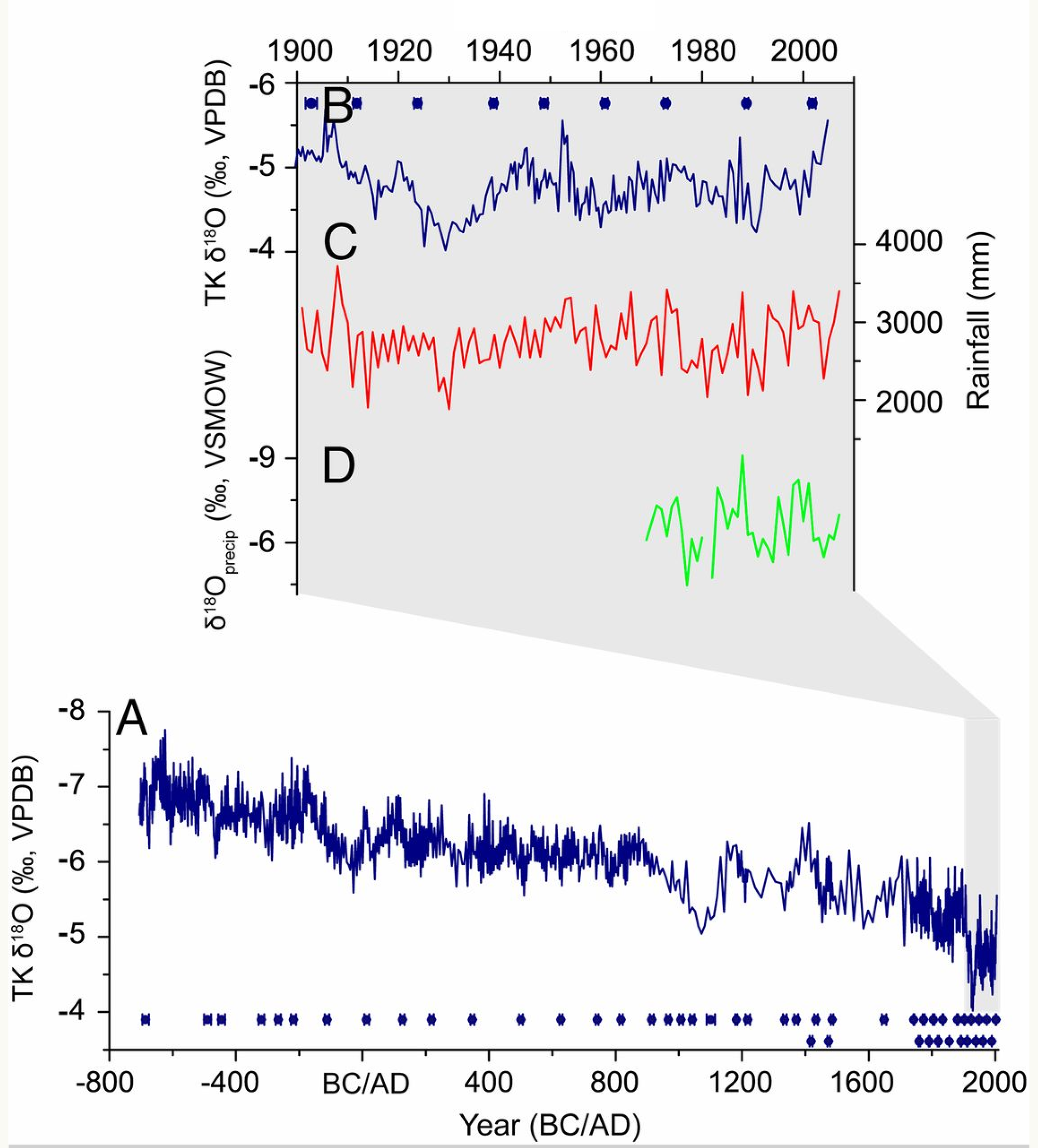
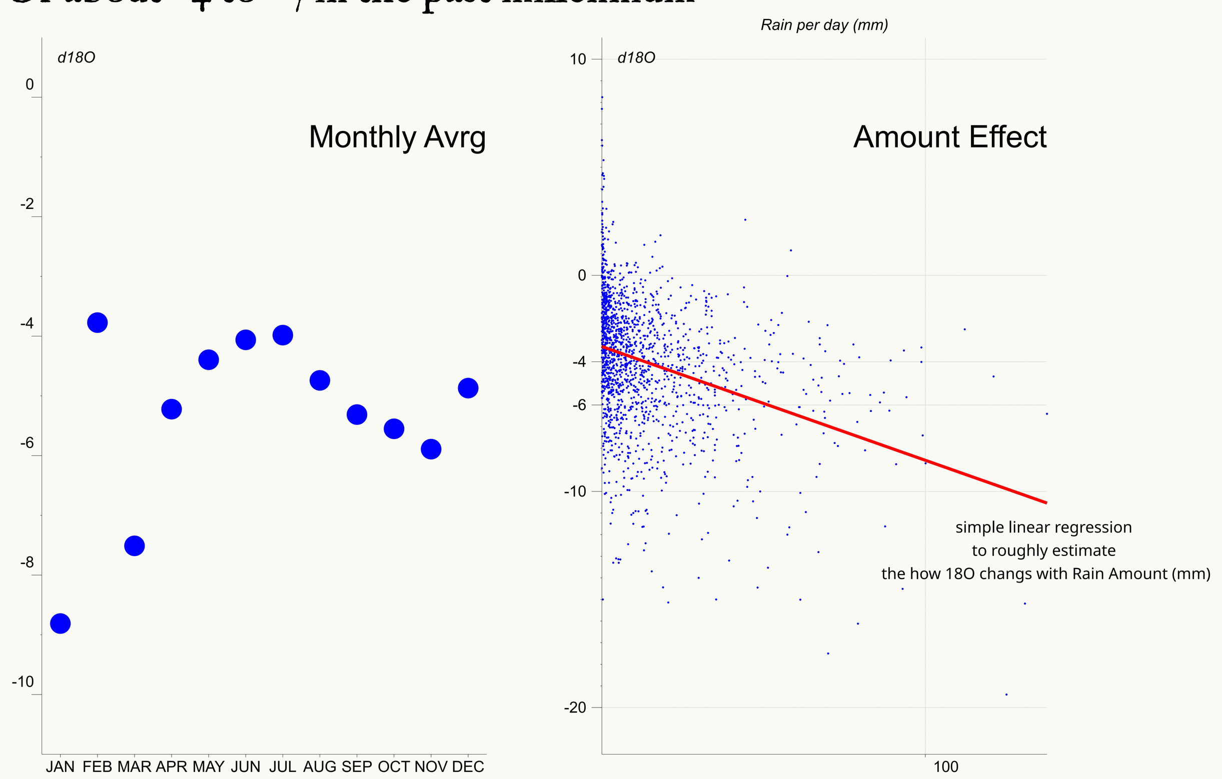


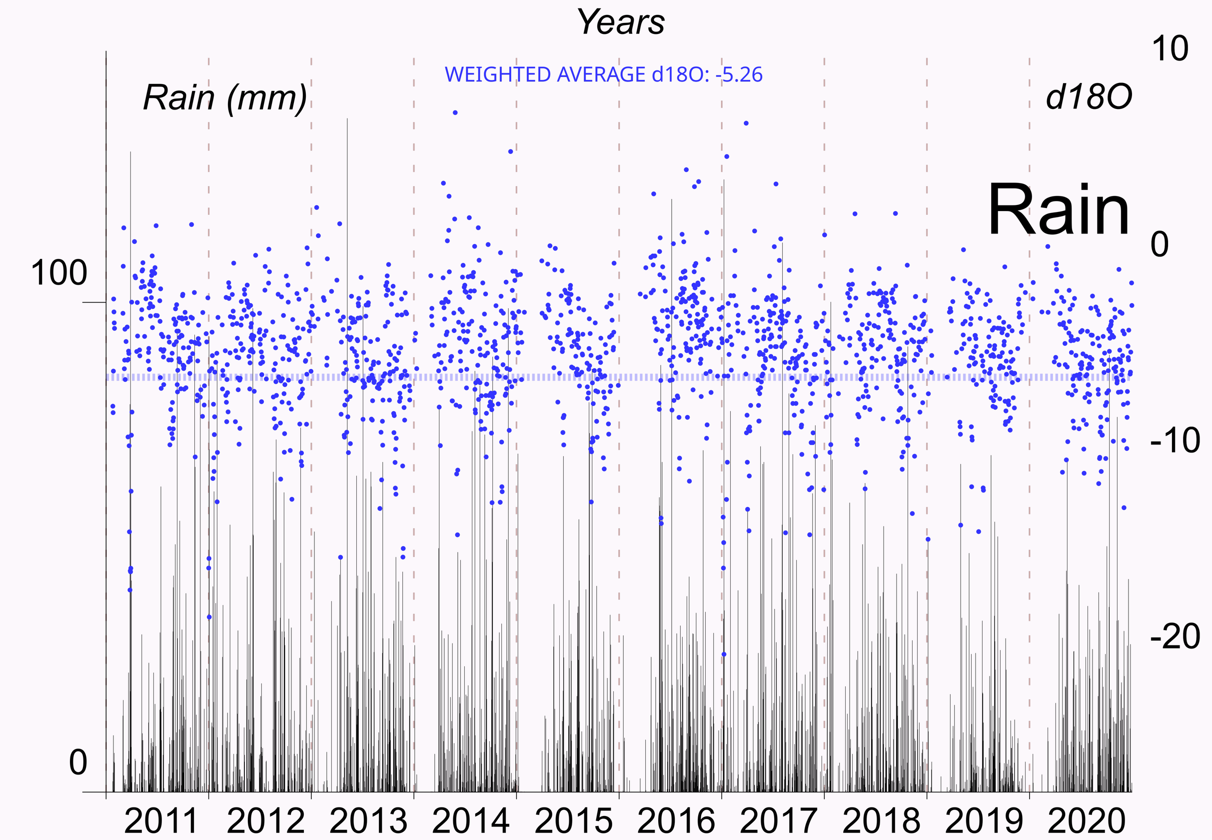
Figure from **Tan et al 2019** - doi.org/10.1073/pnas.1903167116
Rainfall variations in central Indo-Pacific over the past 2,700 y

Red - Monthly rain (mm) ***Green*** - Rain δ^{18}O ***Blue*** - Speleo δ^{18}O
δ18O values that vary from around -4 to -6 in the past century.
Or about -4 to -7 in the past millennium

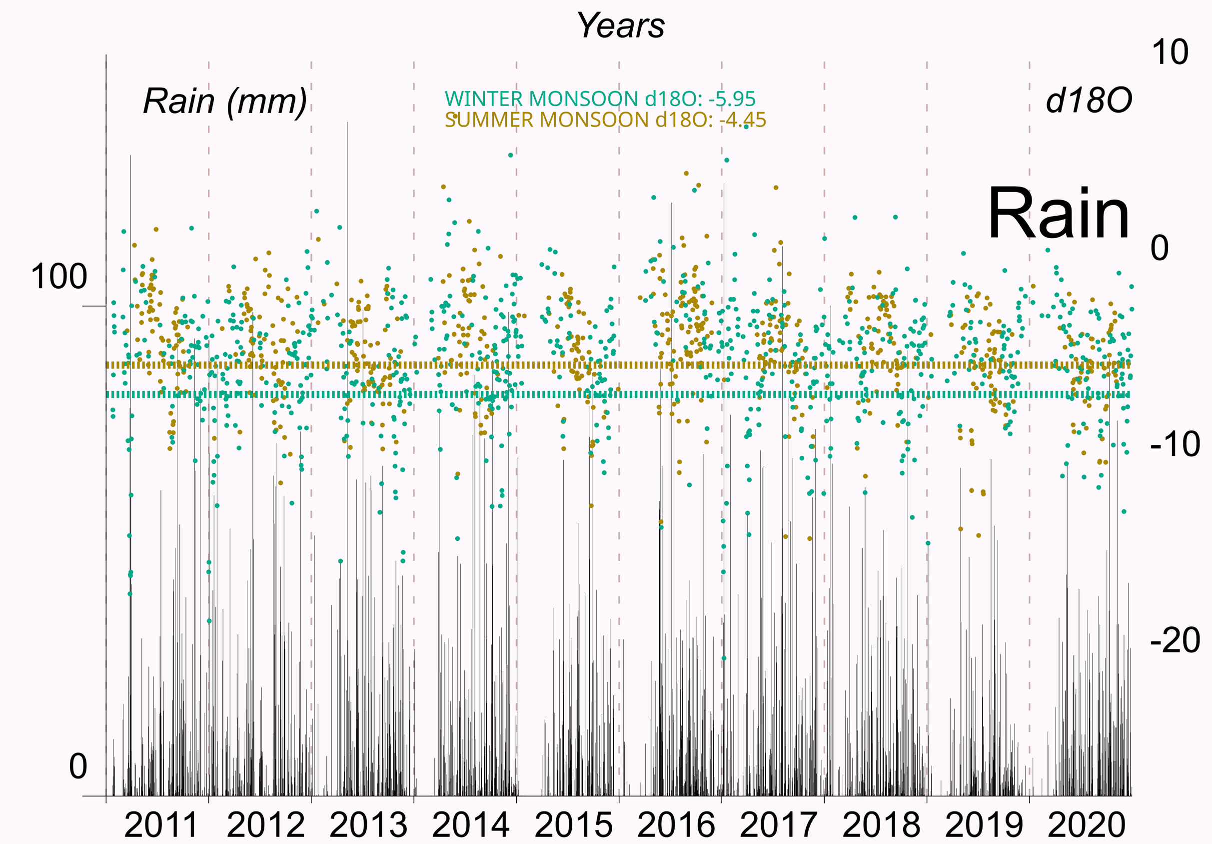


To explain the observed changes in δ^{18}O, two common mechanisms that drive ^{18}O suggest unlikely changes in climate:
- *Seasonal Effect*: ie. Seasons' ^{18}O signatures mix at some ratio
  Implies: Extreme change in the summer (~4) winter (~8) ratio
- *Amount Effect*: ie. The more it rains the more ^{18}O is depleted
  Implies: Extreme increase in rain (red intercept @ -4 vs -6)

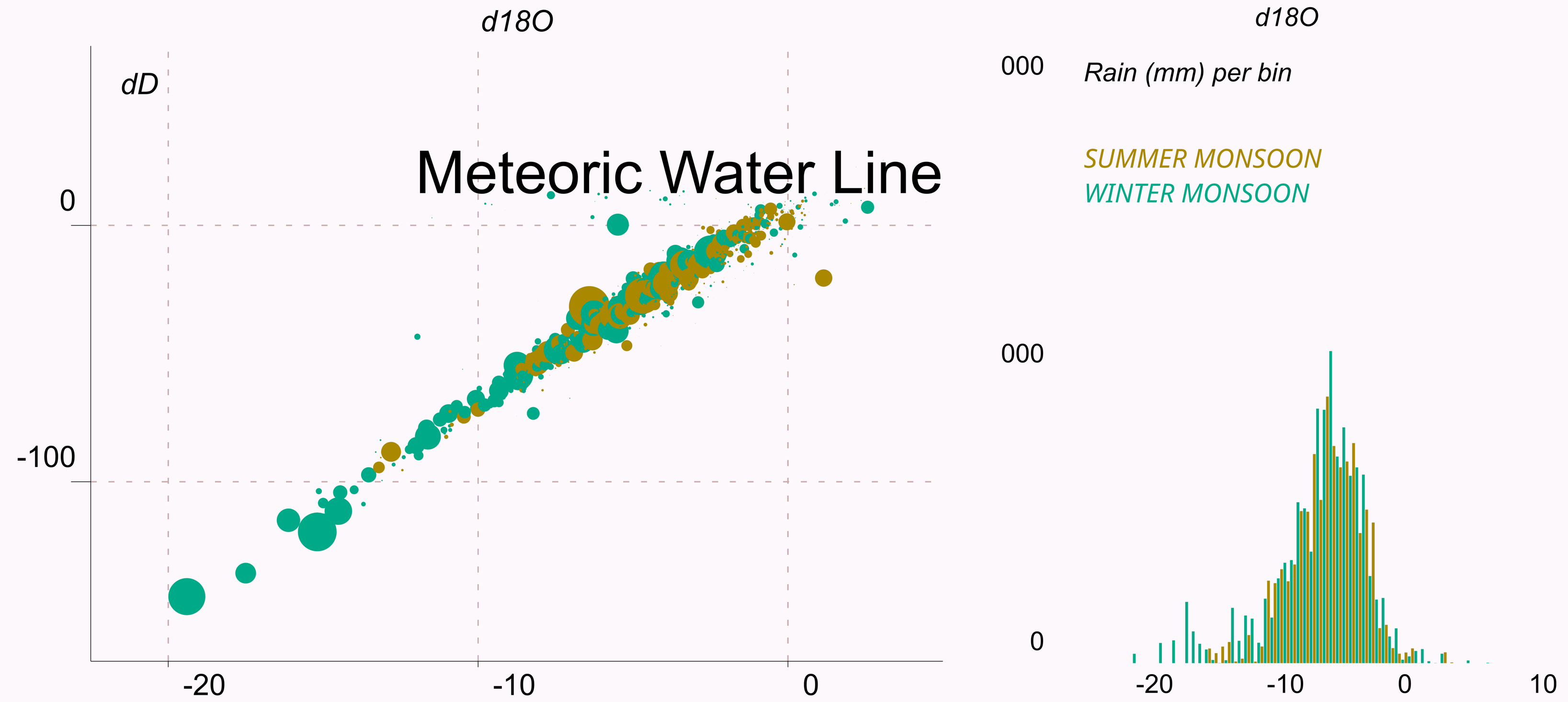
Insights from a Daily Precipitation Record



We present here a new record of daily precipitation δ^{18}O/δD record.
It will serve to introduce a new potential driver of the speleothem record.
Here we see:
- Rain has highly irregular intensity
- The `Dry Season` creates gaps near the start of the calendar year
- Amount-weighted average of -5.26 closely matches speleothem top (-5.5)



Using the climate index to classify rain days and their associated isotope samples allows for a weighted averages of each climate system.
Summer Monsoon: -4.45
Winter Monsoon: -5.95
The resulting spread of δ^{18}O values is narrow. For a seasonal contrast to explain the past century of speleothem δ18O would require complete shutdowns of both monsoons in different time periods

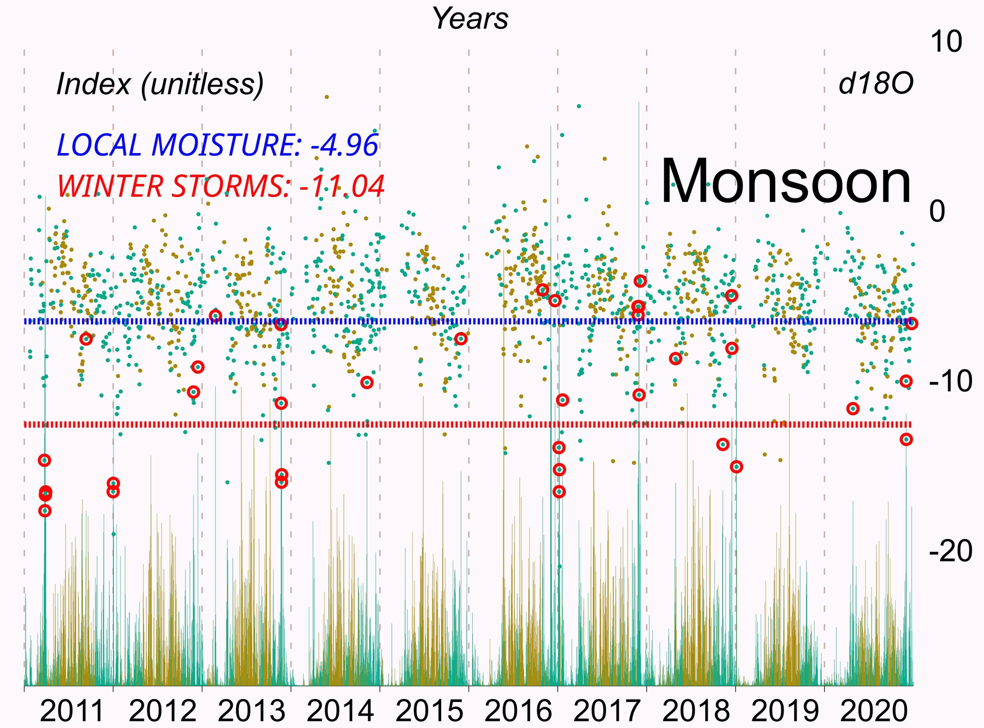


When daily precipitation is plotted as δ^{18}O vs δD (circle size is realtive to rain amount) we see several features:
- Both seasons lie on the same meteoric water line, suggesting a shared moisture source.
- Some very large winter rains lie separate in the bottom left (depleted), suggesting a secondary process
- These rain events drive the lower monthly winter averages. They have extremely low values (-17) individually, but are diluted by smaller rain events.
- Plotted as an amount-weighted histogram of δ^{18}O, we can see these rain events form a separate cluster away from the main distribution. Suggesting a bimodal system
- The main distribution/cluster is identical during both seasons.

Not only are these depleted winter rain events associated with high precipitation, but they show an even better correlation with large spikes in the monsoon index.

Treating high-winter-monsoon days (red circles) as a separate category, we can calculate new averages that are much more in-line with the speleothem record.

Winter Storms: -11.04
Remainder: -4.96



A more robust, less ad hoc characterization of these rains is still needed.
Note that there are only 1-3 depleted days a year, but they can in-effect account for the whole winter isotope shift. Because of their extremely depleted signal. A change in climate to 4-6 depleted winter storms could cause the observed shift in speleothem isotopes without drastic climate reconfiguration.This suggests a regional model with two end-members:
- Local Phang Nga Bay moisture-derived rain
- Extreme winter monsoon rains

With the former likely stable, while the latter highly variable year-to-year - serving to explain the speleothems' highly erratic record