A solar variability driven monsoon see-saw: switching relationships of the Holocene East Asian-Australian summer monsoons

Could be a possible phase relationship existing between East Asian summer monsoon and Indonesian-Australian summer monsoon regimes in a region where billions of people's lives depend highly on monsoon-related rainfall? Here we show that our newly-developed non-linear time series analysis technique enables us to confidently identify monsoon regime changes at millennial to sub-centennial time scales and identify a see-saw relationship over some 9000 years – with wet and dry monsoon states essentially opposingly phased.

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Abstract

The East Asian-Indonesian-Australian monsoon is the predominant low latitude monsoon system, providing a major global scale heat source. Here we apply newly developed non-linear time series techniques on speleothem climate proxies from eastern China and northwestern Australia and establish relationships between the two summer monsoon regimes over the last ~9000 years. We identify significant variations in monsoonal activity, both dry and wet phases, at millennial to multi-centennial time scales and demonstrate for the first time the existence of a see-saw antiphase relationship between the two regional monsoon systems. Our analysis attributes this interhemispheric linkage to the solar variability that is effecting both monsoon systems (Eroglu et al. (2016)).

Techniques

There are challenges in the field of time series analysis such as,

- Cumulative or functional trends
- Irregularities in sampling

Geophysical time series, particularly paleo-climate ones, have such problems almost in all proxies. We have developed a novel approach to overcome these challenges without degenerating the quality of the data set by, e.g., interpolation.

TrAnsformation-Cost Time-Series (TACTS)

The basic idea of this method is a distance metric that provides information of how easily one data segment can be transformed into the following one with possible three elementary operations: (i) time shift, (ii) adjusting the amplitute, and (iii) adding or deleting. The cost (Ozken et al., 2015) associated with each transformation (Initial → Final) is given by:

$$p(c)=\sum_{(\alpha,\beta)\in C}\left\{\lambda_0|t_a(\alpha)-t_b(\beta)|+\frac{1}{m}\sum_{k=1}^{m}\lambda_k|L_{a,k}(\alpha)-L_{b,k}(\beta)|\right\}+\lambda_S(|I|+|J|-2|C|), \qquad (1)$$

where I and J are a set of indices of the events in starting set and the final set, respectively (Fig. 1).

The cost factors λ_0, λ_k are based on the time series:

$$\lambda_0=\frac{M}{\text{total time}};\qquad \lambda_k=\frac{M-1}{\sum_i^{M-1}|L_a-L_b|}, \qquad (2)$$

where M is the total number of events in the time series.

TACTS method produces a detrended and regularly sampled time series, and allows us to identify regime changes using analysis methods that require equal sampling.

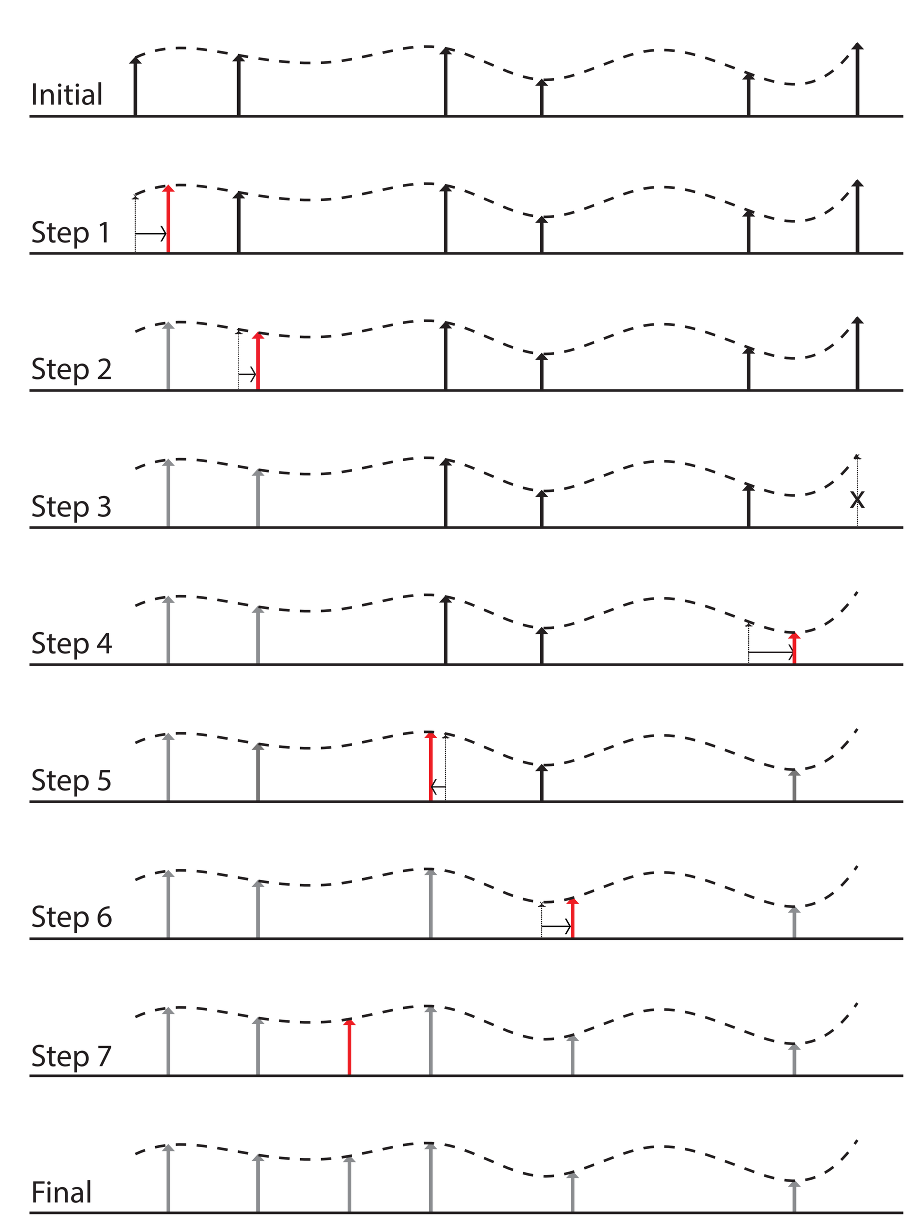

Fig. 1: Illustration of the transformation cost time series method. The initial time series segment (top) is transformed into the final time series segment (bottom) in seven steps. Note that after seven steps the segment is identical to the final target time series. The steps 1, 2, 4, 5, 6 are combinations of the elementary operations (i) time shift and (ii) adjusting the amplitude (first two terms in Eq. (1)) while in step 3 one event is deleted and therefore the last elementary operation (iii) was applied (last term in Eq. (1)).

Recurrence Plot and Quantification Analysis

Recurrence based approaches have taken an important place in dynamical systems analysis. (Marwan et al., 2007).

- Recurrence Plot(RP):

$$R_{i,j}(\epsilon)=\Theta(\epsilon-\|x_i-x_j\|),\ i,j=1,\dots,N, \qquad (3)$$

- Recurrence Quantification Analysis (RQA): There are many measures in RQA; in this work we used determinism (DET):

$$DET=\frac{\sum_{\ell=\ell_{\min}}^{N}\ell P(\ell)}{\sum_{\ell=1}^{N}\ell P(\ell)}, \qquad (4)$$

Data & Location

The high resolution speleothem paleoproxy records

- KNI-51 ($15.30°$S, $128.61°$E) from northwestern Australia
- Dongge Cave ($25.28°$N, $108.08°$E) from southern China

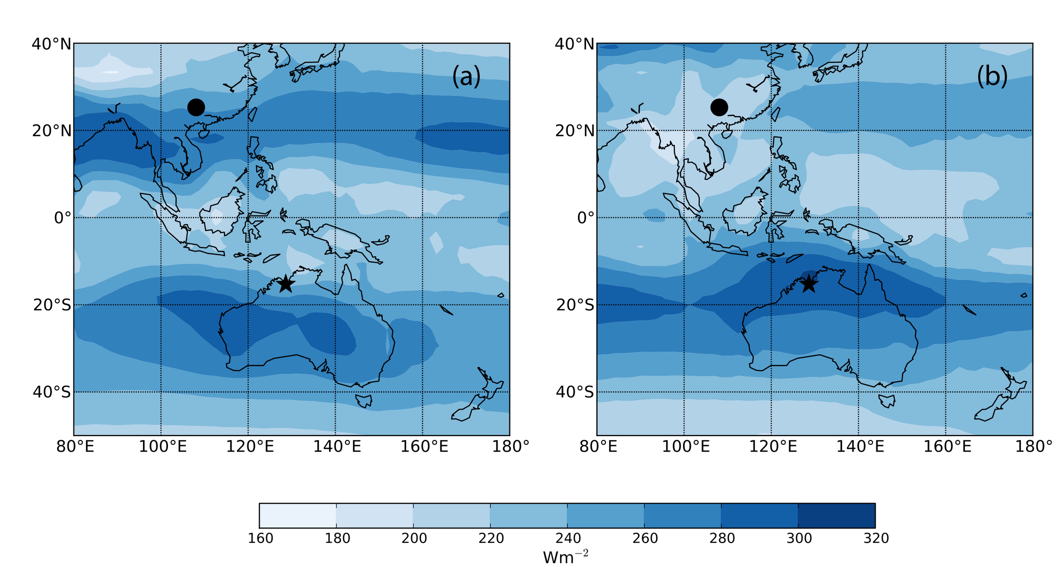

Fig. 2: Top of atmosphere outgoing long wave radiation delimiting the extent of: a) East Asian summer monsoon (JJA); and b) Indonesian Australian summer monsoon (DJF). Dongge Cave (dot) and KNI-51 (star).

Data and associated TACTS

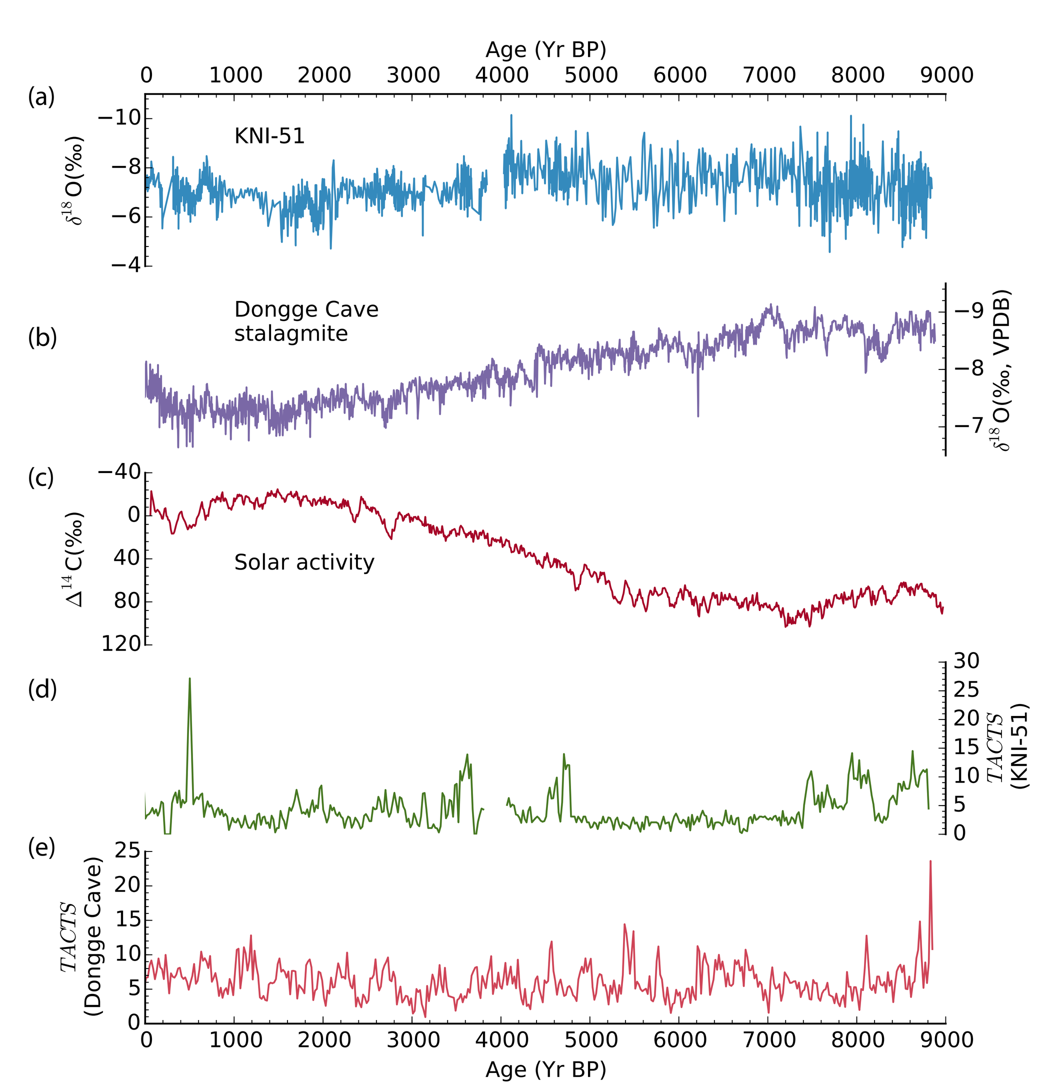

Fig. 3: δ^{18} O records of (a) KNI-51 and (b) Dongge Cave. (c) atmospheric $\Delta^{14}C$ record and the transformation cost time series of (d) KNI-51 and (e) Dongge Cave determined by application of Eq. (1) and (2).

Results

See-Saw Dynamics between Northwestern Australia – Eastern China.

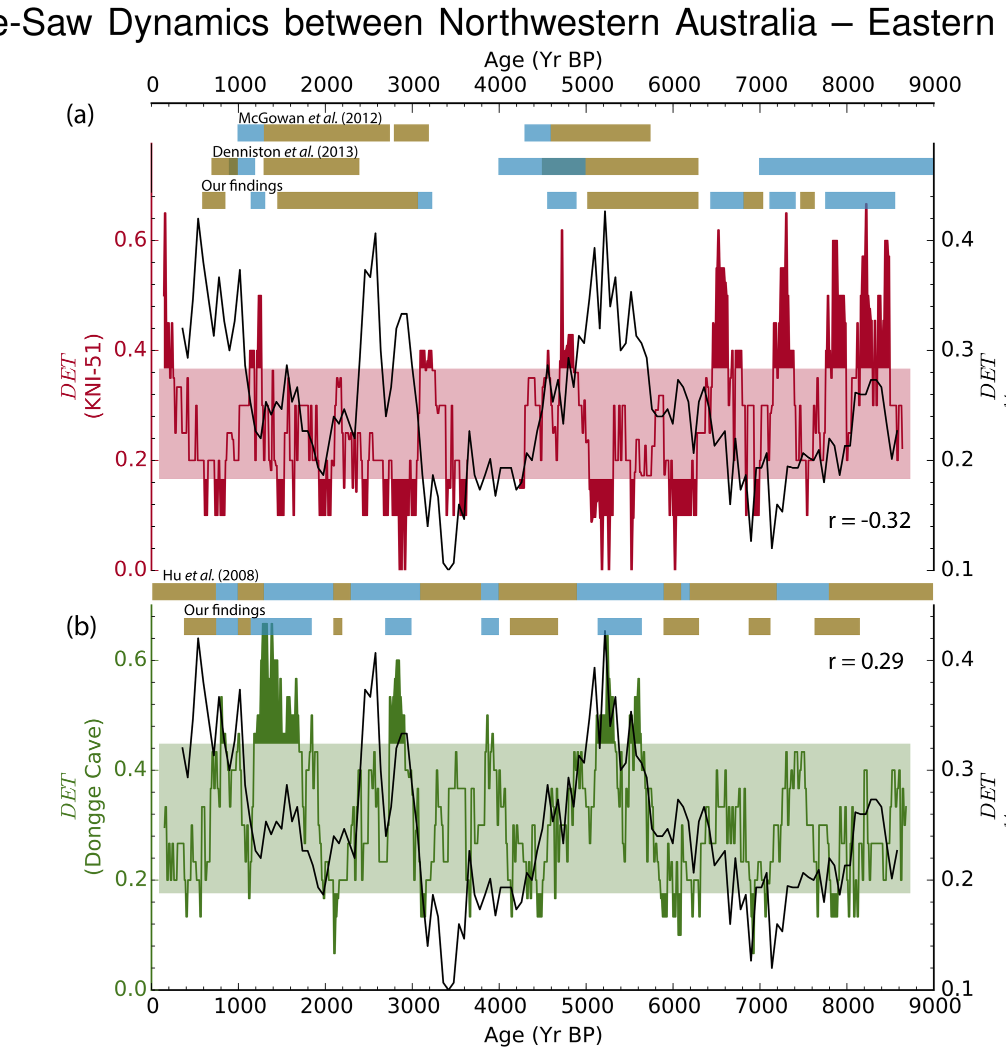

Fig. 4: Determinism of the two proxy records (a) (red) KNI-51 and (b) (green) Dongge Cave. The determinism is calculated from the corresponding TACTS and statistical significance is indicated by the two horizontal bands. High (low) determinism values correspond to wet (dry) monsoon regimes. The coloured bands (blue indicating wet regimes; brown, dry) provide a comparison of our findings with those of previous, qualitative studies. (black) Determinism of the solar activity proxy Δ^{14} C time series. Cross–correlation between the determinism of the solar activity proxy Δ^{14} C time series and KNI-51 time series is $r=-0.32$, and Dongge Cave time series is $r=0.29$.

Acknowledgments

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