Alternating mutual influence of El-Niño/Southern Oscillation and Indian monsoon

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Background

- Analysing the interdependence between ENSO and Indian monsoon
- Mutual Granger Causality Estimation (both linear and nonlinear) is being used to detect directional coupling characteristics
- Different versions of the Niño-3 and Niño-3.4 index are used to check robustness
- Climate processes in the Asia-Pacific region are mainly driven by ENSO and Indian monsoons phenomena
- Significant parts of the world population live in monsoon-related areas

El-Niño/Southern Oscillation

- Driven by the so-called Walker circulation
- Trade winds across equatorial Pacific blow from east to west
- These winds ascend in western Pacific, flowing back at hight altitudes
- Descend in easter Pacific
- Southern Oscillation causes upwelling of cooler ocean water
- The weaker the winds, the weaker the upwelling

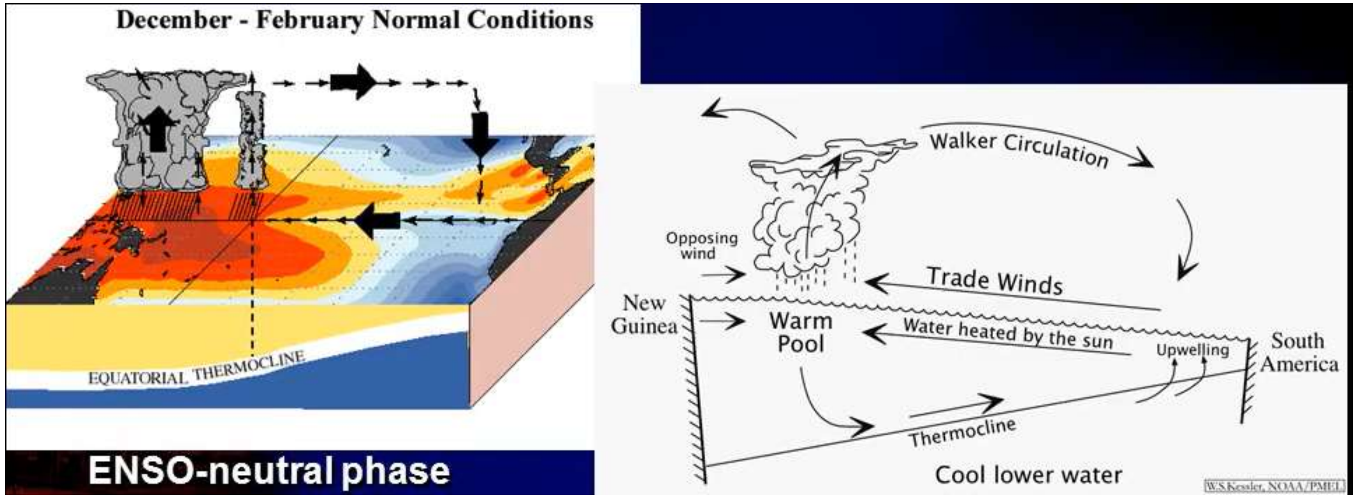

Figure 1

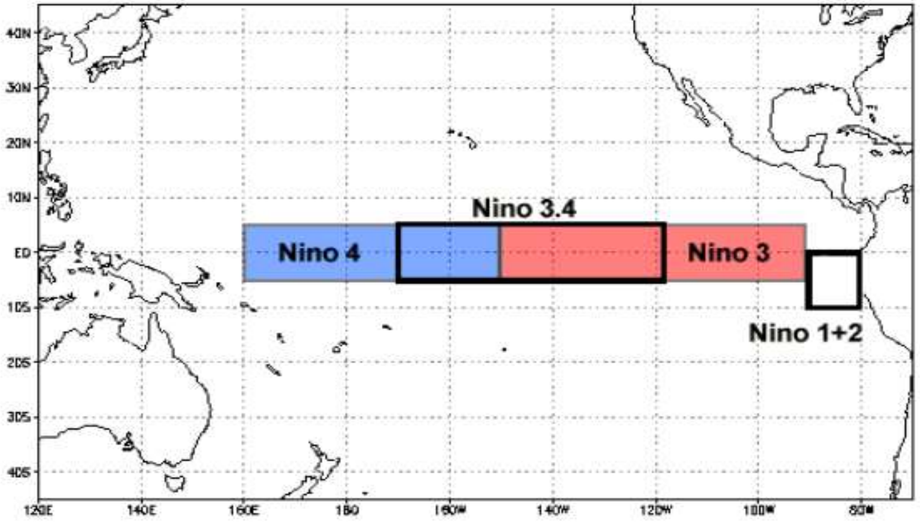

Figure 2

ENSO causes

- ENSO can be described as a positive feedback loop between the atmosphere and the ocean
- El Niño: Decreases trade winds lessen difference in SST across the Pacific

  The change further lessens the strength of the trade winds
- La Niña: Increased trade winds strengthen the difference in SST across the Pacific. The gradient in temperatures increases the strength of the trade winds

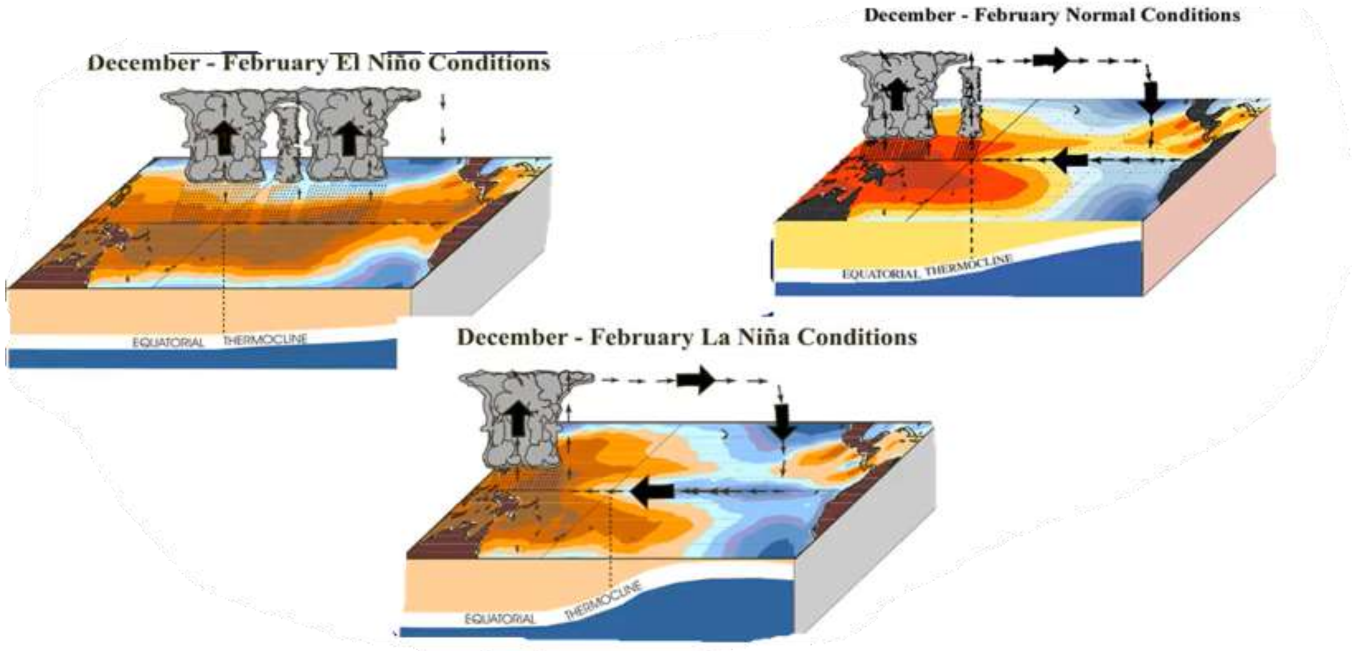

Figure 3

Indian Monsoon

- Primarily affects the Indian subcontinent
- Monsoon is a periodic seasonal wind
- Occurring every year from June to September
- Wind blows from sea to land in one season and reverses back in the next season
- Monsoon is derived from Arabic, which means season

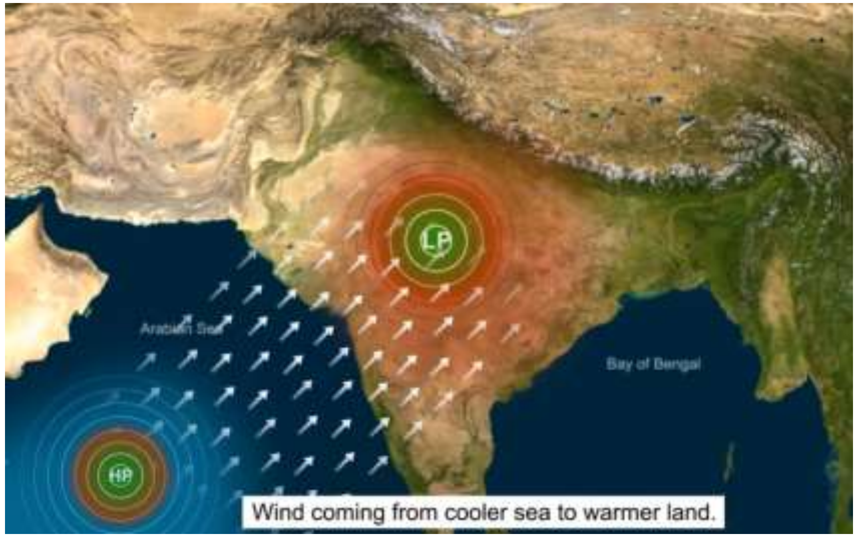

Figure 4

Figure 5

Method

- Monthly values of the ENSO and Indian monsoon indices for the period 1871-2006 were being analysed
- In this paper, Granger causality is being used
- Limitation: GC not necessarily true causality
- Given two or more time series, can we predict one variable based on what happens to other variables?
- In other words, is there an increase in R^2(explained variance) when using a bivariate autoregressive model compared to a univariate AR?

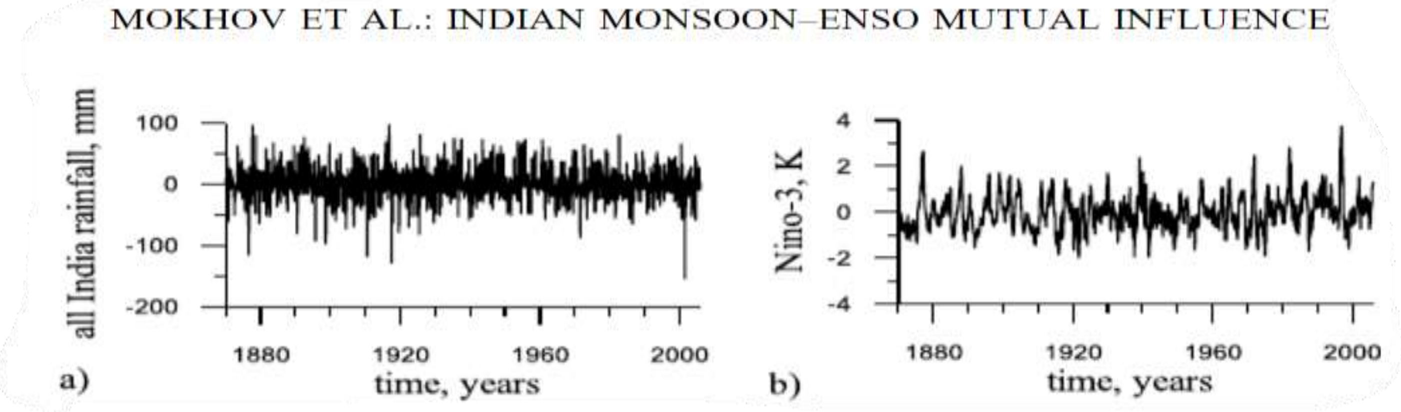
MOKHOV ET AL.: INDIAN MONSOON–ENSO MUTUAL INFLUENCE

Figure 6

Granger Causality

- Let x_1 be denoted as the monsoon index, and the ENSO index x_2
- Granger causality intents to reveal whether a process x_1 influences x_2 and vice versa
- A univariate model looks as follows: $x_k(t) = f_k(x_k(t-1), \ldots, x_k(t-d_k)) + \xi_k(t)$
- Where $k = 1, 2,$ d_k is a model dimension $\xi_k(t)$ Gaussian white noise, and f_k some function, f_k can be linear or not, authors use algebraic polynomials L_k
- Coefficients of f_k are determined via the least-squares method (one step-ahead), denoted σ_k^2
- A bivariate model looks as follows:

$$x_k(t) = f_{k|j}(x_k(t-1), \ldots, x_k(t-d_k), x_j(t-1), \ldots, x_j(t-d_{k|j})) + \eta_k(t)$$

- Namely $d_{j \rightarrow k}$ is the number of x_j values directly influecing x_k

Granger Causality Results

- The so-called prediction improvement $PI_{j \rightarrow k} = \sigma_k^2 - \sigma_{k|j}^2$ measures the causality $j \rightarrow k$, later it‘s normalized values are plotted $PI_{j \rightarrow k}/\sigma_k^2$
- In addition, an F-test is used to validate statistical significances about $PI_{j \rightarrow k}$
- Only values $p < 0.05$ are considered
- Bivariate models for monsoon index: $d_1 = 1$, $d_{2 \rightarrow 1} = 1$ and $L_1 = 3$

  Bivariate models for ENSO index: $d_2 = 5$, $L_2 = 1$ and $d_{1 \rightarrow 2} = 3$

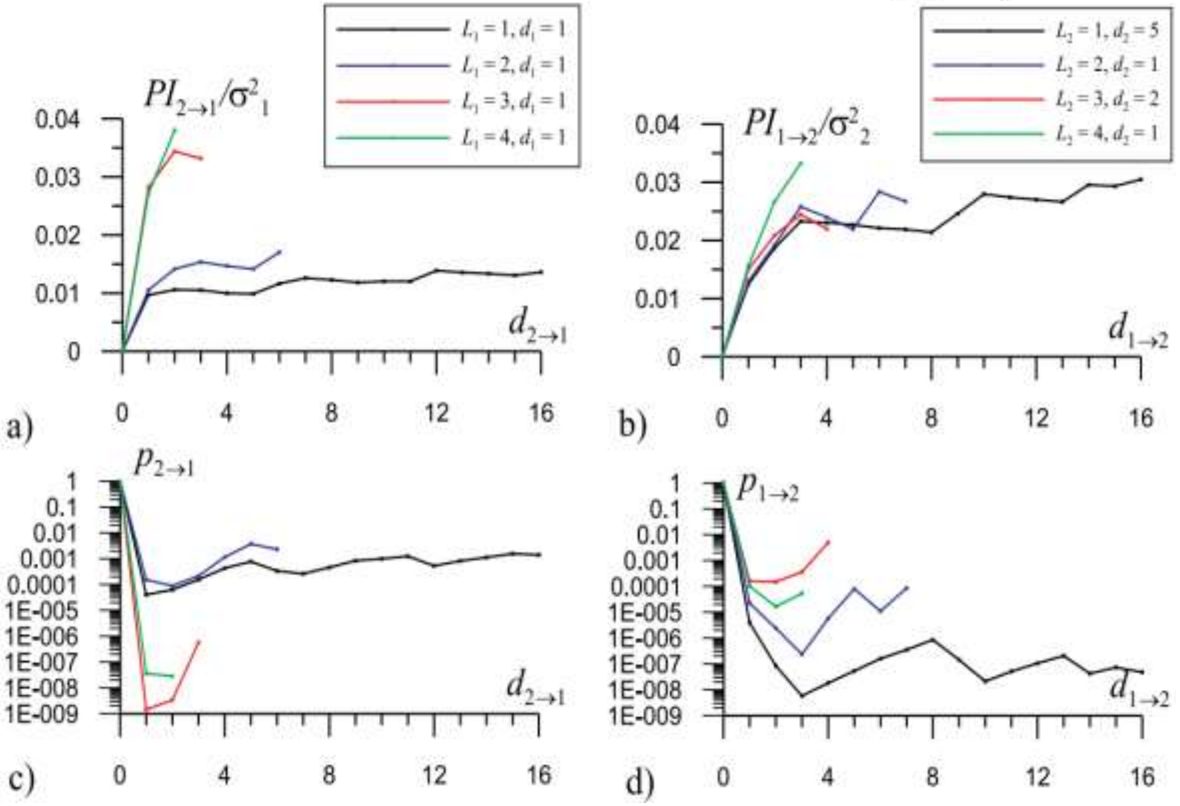

Figure 7

Granger Causality Results

Optimal bivariate monsoon index model:

$$x_1(t) = a_{1,1}x_1(t-1) + b_{1,1}x_2(t-1) + c_{1,1}x_1^2(t-1)x_2(t-1) + c_{1,2}x_2^3(t-1) + \eta_1(t)$$

where $\sigma_{\eta 1}^2 = 5.86 \cdot 10^2$ mm^2, coefficients and standard deviations of their estimates [*Seber*, 1977] $a_{1,1} = 0.071 \pm 0.037$, $b_{1,1} = -4.65 \pm 1.11$ mm$\cdot$ K^{-1}, $c_{1,1} = (-35.3 \pm 7.59) \cdot 10^{-4}$ mm$^{-1} \cdot$ K^{-1}, and $c_{1,2} = 1.53 \pm 0.38$ mm$\cdot$ K^{-3}

Table 1. Characteristics of Optimal AR-Models for the Entire Period 1871–2006 and Different Versions of the Niño-3 Index

Data	d_2	$\frac{\hat{\sigma}_2^2}{\mathrm{var}[x_2]}$	$d_{1\to2}$	L_2	$\frac{PI_{1\to2}}{\hat{\sigma}_2^2}$	$d_{2\to1}$	L_1	$\frac{PI_{2\to1}}{\hat{\sigma}_1^2}$
GISST	5	0.18	3	1	0.023	1	3	0.028
Kaplan	5	0.12	2	1	0.021	1	3	0.023
HADISST	6	0.15	2	1	0.022	2	3	0.030
ERSST	5	0.10	2	1	0.016	1	3	0.022

Optimal bivariate ENSO index model:

$$x_2(t) = a_{2,1}x_2(t-1) + a_{2,5}x_2(t-5) + b_{2,1}x_1(t-1) + b_{2,2}x_1(t-2) + b_{2,3}x_1(t-3) + \eta_2(t)$$

where $\sigma_{\eta 2}^2 = 0.11$ K^2, $a_{2,1} = 0.92 \pm 0.025$, $a_{2,5} = -0.083 \pm 0.025$, $b_{2,1} = (-1.44 \pm 0.34) \cdot 10^{-3}$ mm^{-1} K, $b_{2,2} = (-1.04 \pm 0.34) \cdot 10^{-3}$ mm^{-1} K, and $b_{2,3} = (-1.01 \pm 0.35) \cdot 10^{-3}$ mm^{-1} K

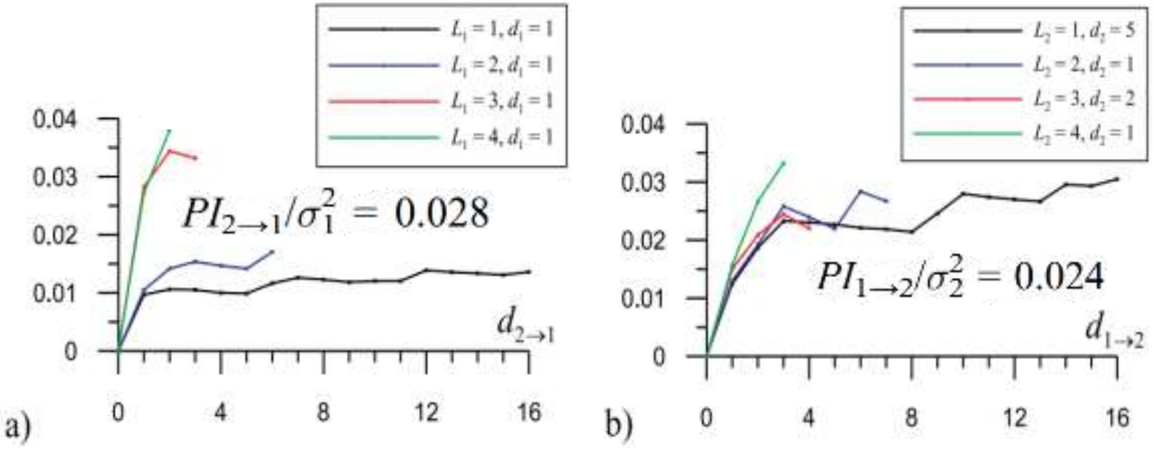

Figure 8

Moving Window Coupling Analysis

- Moving window $W = 30$ to trace variations in coupling over time with intervals $[T - W, T]$
- Bonferroni correction applied

  $\mathrm{p_c} = \frac{0.05}{\frac{N}{W}}$ (dashed line)
- Different colours represent different Niño-3 indices
- Observed fluctuations of Granger causality are statistically significant at $p < 0.05$

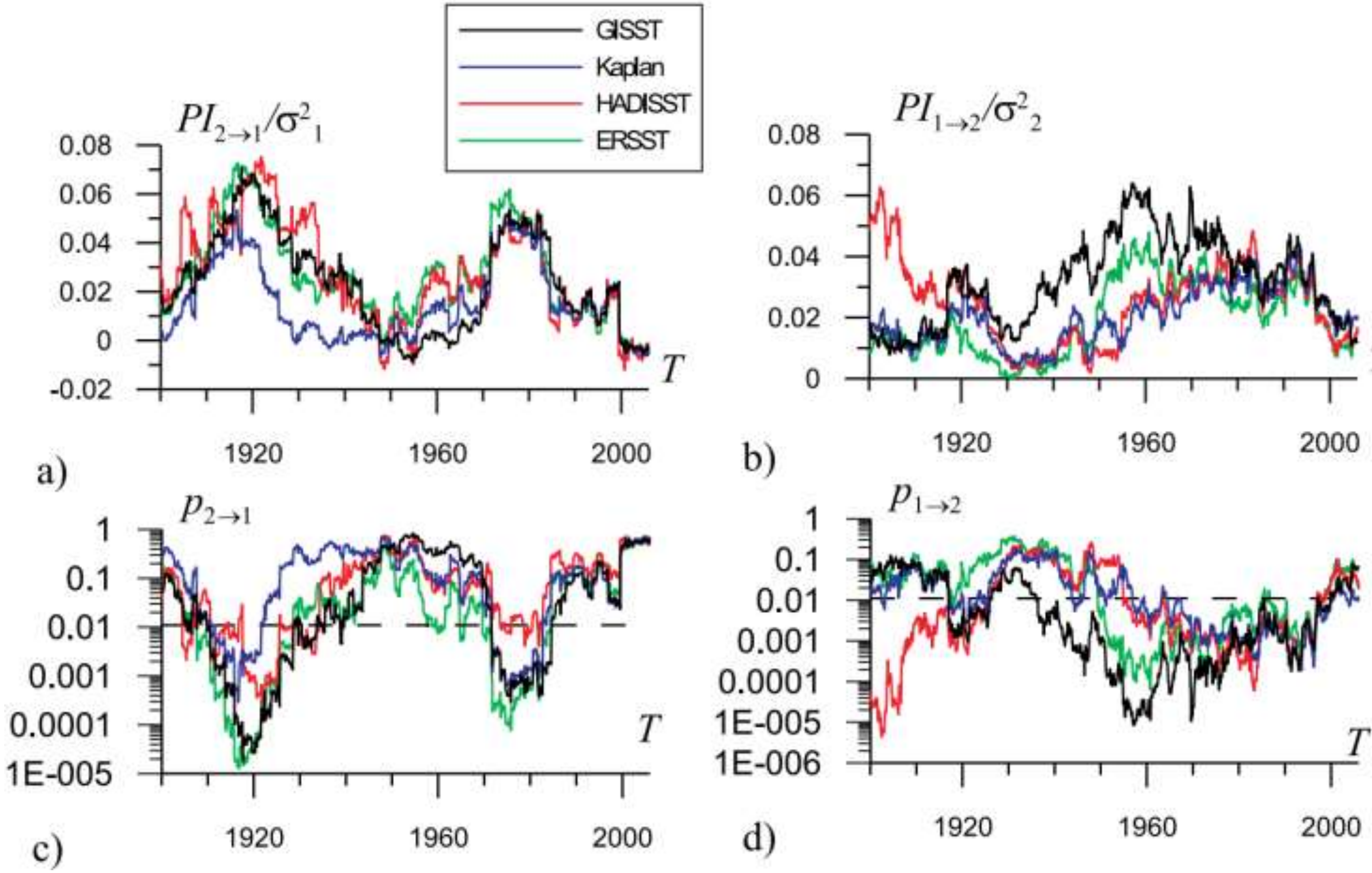

Figure 9

Conclusions

- Results complement previously known results about ENSO and Indian monsoon anti-correlation
- The ENSO-to-monsoon influence is inertialless and nonlinear
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- Moving window analysis shows alternation in the coupling
- ENSO-to-monsoon influence strongest 1890-1920 and 1950-1980
- ENSO-to-monsoon influence not present in 1920-1950 and after 1980
- Possible geophysical interpretation: Monsoon system can influence trade winds an therefore affect ENSO

Citations

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