Using a causal discovery approach to analyse linkages among ENSO, circulation fields, and summer monsoon precipitation over the Himalayas

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Introduction

- The Himalayas are the main water source for major river systems in South Asia (e.g., the Ganges and Brahmaputra), providing crucial fresh water for irrigation and hydropower generation.
- Summer Monsoon Himalayan Precipitation (SMHP) predominantly supplies these river systems, which is also variable and influenced by large-scale atmospheric circulation patterns and anomalies.
- Sea Surface Temperatures (SSTs) over the tropical Pacific ocean associated with El Niño-Southern Oscillation (ENSO) strongly influence the variability in ISM precipitation via complex interactions between the Regional Walker Circulation (RWC) and the Monsoon Hadley Circulation (MHC) [1].
- We use a causal discovery approach based on Causal Effect Networks (CENs) to test and to analyse the causal relationships and possible pathways between ENSO and SMHP at intraseasonal timescales, involving the interactions between RWC and MHC (see Fig. 1).

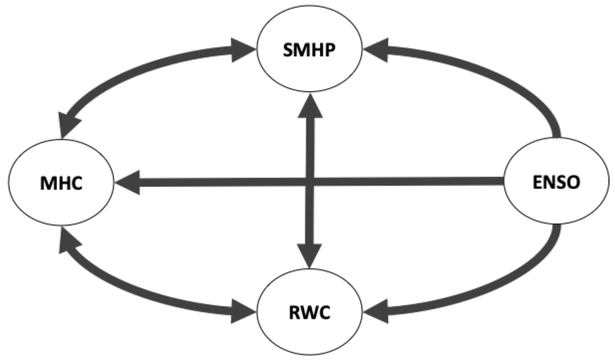

Fig. 1. A diagram illustrating the analysed one-way and two-way cause-effect interactions between ENSO, SMHP, RWC, and MHC.

Data and Methodology

- We analyse the causal relationships for an extended summer monsoon season from May to September from 1940 to 2022.
- We use monthly averaged ERA5 data to calculate indices representing SMHP, RWC, MHC [2,3,4] (shown in Fig. 2):
  - SMHP index: total precipitation averaged over 78-93°E, 25-32°N,
  - RWC index: U200 averaged over 78-93°E, 25-32°N,
  - MHC index: wind shear U850 and U200 averaged over 70-110°E, 10-30°N.
- We use an existing ENSO index based observational SSTs data in the Niño 3.4 region (i.e., 5°N-5°S, 170-120°W).
- We apply the Peter and Clark momentary conditional independence algorithm [5] to the indices to build CENs for:
  - finding causal links for 1-month time lag/delay and statistically significant at the significance level of 0.05,
  - measuring the strength of causal links as the path coefficient of the standardised linear regression.

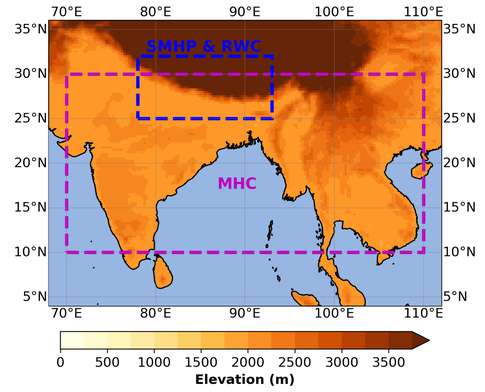

Fig. 2. Map showing a region used for calculating SMHP and RWC indices (represented by the blue box) and MHC index (represented by the magenta box). The orography elevation from ERA5 is also shown in meters (m).

Results

Causal Link	*Path Coefficient*
ENSO→SMHP	-0.23
ENSO→RWC	0.14
RWC→MHC	-0.16
MHC→RWC	-0.14
RWC→SMHP	-0.26
MHC→SMHP	0.27
SMHP→MHC	-0.12

Table 1. Causal links between ENSO, SMHP, RWC, and MHC and associated path coefficients for the CEN shown in Fig. 3. The links and coefficients are only shown for those cause-effect relationships that were found statistically significant (i.e., p-value < 0.05) for the 1-month time lag.

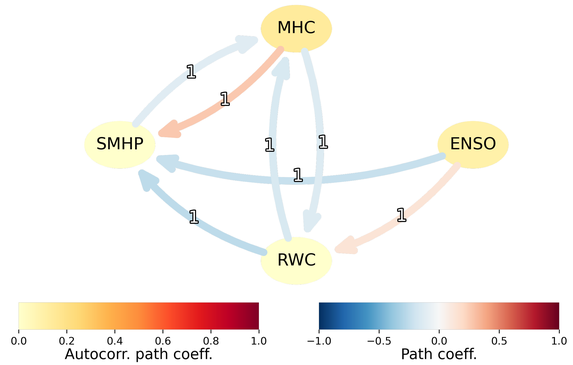

Fig. 3. The constructed CEN shows the causal links between four indices, involving one-way and two-way interactions. The colour of the arrows showing the strength/path coefficient of the causal links (see Table 1). The colour of the node corresponds to the autocorrelation path coefficient, which represents the causal influence of an actor on itself. The time lag (i.e., 1-month) is displayed over the arrows.

Discussion

- We test the influence of ENSO on SMHP mediated by RWC and MHC and demonstrate that it can be identified by the CEN approach at intraseasonal timescales.
- Our CEN results show the quantified strength of causal links as the path coefficients with 1-month time delay (see Table 1).
- Our findings also show a positive feedback loop between RWC and MHC. Also, we can observe a negative feedback loop between MHC and SMHP (see Fig. 3).
- Improving our understanding of drivers of SMHP and relevant regulatory mechanisms (i.e., RWC and MHC) plays an important role in the Himalayan hydrological budget, however; it is still an unexplored area compared to the vast amount of research focused on all India rainfall.
- Future work will investigate more complex sub-seasonal influence of ENSO on SMHP via the considered RWC and MHC dynamics, including other drivers of SMHP.

References

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