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Identification of Global Drivers of Indian Summer Monsoon using Causal Inference and Interpretable AI

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Indian Summer Monsoon Rainfall (ISMR) is a complex phenomenon that depends on several climatic phenomena at different parts of the word through teleconnections. Each season is characterized by extended periods of wet and dry spells (which may cause floods or droughts) which contribute to intra-seasonal variability. Tropical and extra-tropical drivers jointly influence the intra-seasonal variability. Although El Nino and Southern Oscillation (ENSO) is known to be a driver of ISMR, researchers have also found its relation with Indian Ocean Dipole (IOD), North Atlantic Oscillations (NAO), Atlantic Multi-decadal Oscillation (AMO). In this work, we use ideas from Causality Theory and Explainable Machine Learning to quantify the influence of different climatic phenomena on the intraseasonal variation of ISMR.

To identify such causal relations, we applied two statistically sound causal inference approaches, i.e., PCMCI+ Algorithm (Conditional Independence based) and Granger Causal test (Regression-based). For the Granger causality test, we have examined separately for both linear and non-linear regression. In case of PCMCI+, conditional independence tests were used between pairs of variables at different "lag periods". It is worth pointing out that, till now "causality" is not properly quantified in the Climate Science community and only linear correlations are used as a basis to identify relationships like ENSO-ISMR and AMO-ISMR. We performed experiments on mean monthly rainfall anomaly data (during the monsoon months of June-September over India) along with six probable drivers (ENSO, AMO, North Atlantic Oscillation, Pacific Decadal Oscillation, Atlantic Nino, and Indian Ocean Dipole) for May, June, July, August, September months during the period 1861-2016. While the two approaches produced some contradictions, they also produced a common conclusion that ENSO and AMO are equally important and independent drivers of ISMR.

Additionally, we have studied the contribution of the drivers on annual extremes of ISMR (years of deficient and excess rainfall) using Shapley values based on the concept of Game Theory to quantify the contributions of different predictors in a model. In this work, we train a XGBoost model to predict the ISMR anomaly from any values of the predictor variables. The experiment is carried out in two approaches. One approach involves analyzing the contribution of each driver for each of the ISMR months of any year on the mean seasonal rainfall anomaly of that year. Another approach focuses on the contribution of the seasonal mean value of each driver on the same. In both approaches, we analyze the distribution of each driver's Shapley values for excess and

deficient monsoon years for contrast. We find that while ENSO is indeed the dominant driving factor for a majority of these years, AMO is another major factor which frequently contributes to such deficiencies, while Atlantic Nino and Indian Ocean Dipole too sometimes contribute. On the other hand, Indian Ocean Dipole seems to be a major contributor for several years of excess rainfall. As future work, we plan to carry out a robustness analysis of these results, and also examine the drivers of regional extremes.