Identification and Separation of the Signatures of Volcanic Forcing and Natural Climate Variability

Muhammad Mubashar Dogar[1,2], Masatomo Fujiwara[2], Ming Zhao[3], Masamichi Ohba[4], Yu Kosaka[5]
1. Global Change Impact Studies Centre, Ministry of Climate Change, Islamabad, Pakistan 2. Faculty of Environmental Earth Science, Hokkaido University, Sapporo, Japan
3. NOAA-GFDL, Princeton, New Jersey, USA 4. Central Research Institute of Electric Power Industry (CRIEPI), Abiko, Chiba, Japan 5. Research Center for Advanced Science and Technology (RCAST), The University of Tokyo, Tokyo, Japan

Introduction

Volcanic eruptions and large-scale circulation changes could occur concurrently making it difficult to separate the volcanic impacts from natural climate variability (Dogar et al. 2022). For example, North American and Eurasian warming have been observed during the first winter after the two major tropical eruptions of the last century (i.e., El Chichón and Pinatubo). Similarly, a strong cooling was observed in the Middle East and North Africa (MENA) region after both these eruptions (Dogar et al. 2017). Therefore, to better understand the effects of volcanism and natural variability, we delineated the climatic impacts of volcanism and natural variability in the MENA region.

Methodology

GFDL's global **HI**gh **R**esolution **A**tmospheric **M**odel (HIRAM) simulations and University of Delaware (UDEL) observations are used to analyze the climatic impact of El Chichón and Pinatubo eruptions in the MENA region. Multiple regression analysis is used to delineate the contribution of volcanism and internal variability (i.e., ENSO, NAO and Indian monsoon) during two post-volcanic winter seasons.

Total Temperature and Precipitation Response

A strong cooling and associated decreased precipitation in winter both in UDEL observations and HiRAM model following volcanism is seen over the MENA region.

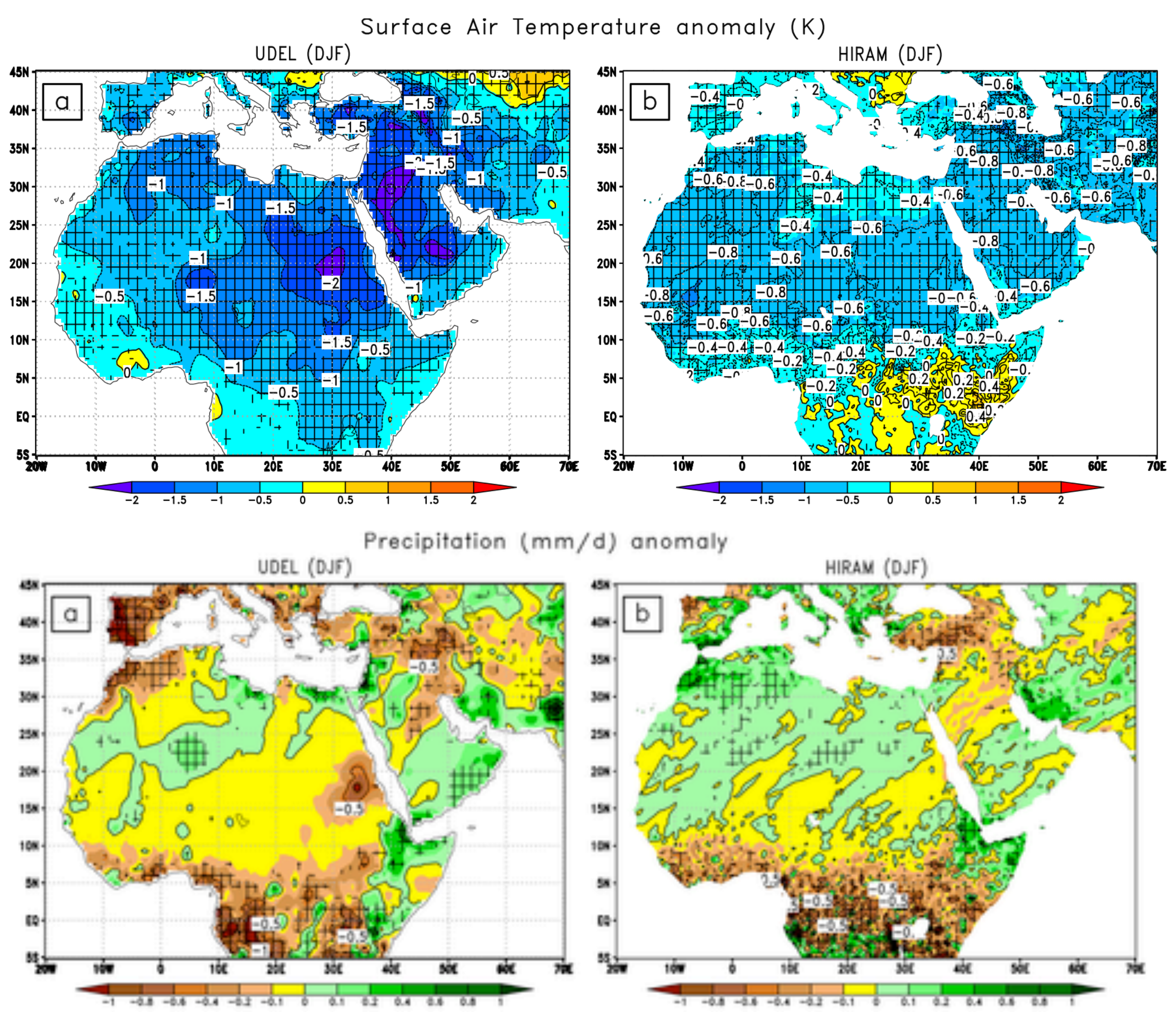

Fig. 1: Anomalies of Surface air temperature (K) and Precipitation (mm/day) following the El Chichón and Pinatubo eruptions, calculated for two winters using (a) UDEL observations, (b) HiRAM output. Hatching shows the statistically significant areas with at least 95% confidence level.

ENSO and NAO Response

Figures 2 and 3 show the regressed impact of ENSO and NAO on temperature in winter over the MENA region. The model underestimates the magnitude of ENSO and NAO-induced winter cooling compared to the observations, although their overall spatial patterns are coherent.

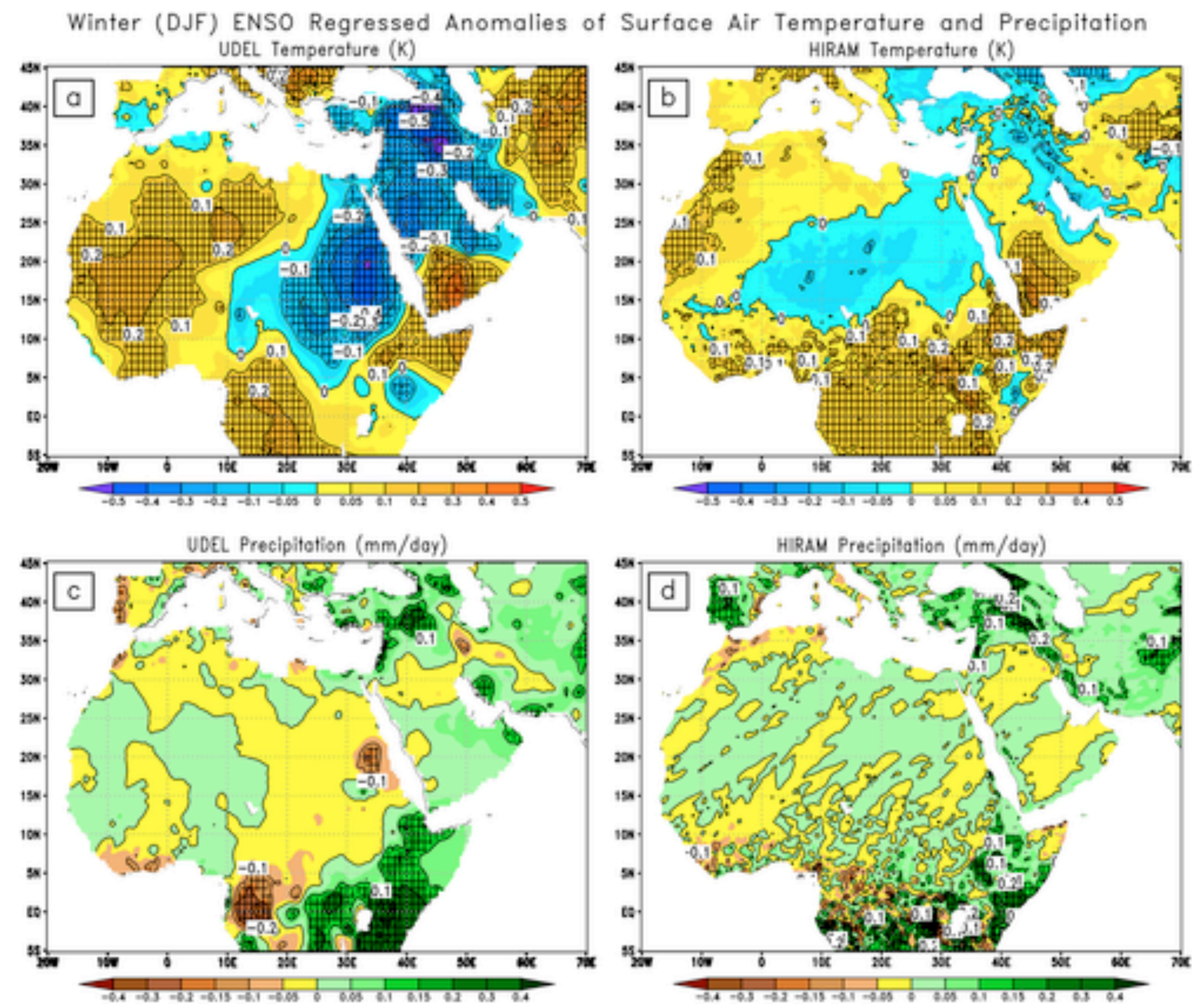

Fig.2: ENSO-regressed anomalies of surface air temperature (a, b) and precipitation (c, d) composited for two winters following the El Chichón & Pinatubo eruptions, calculated for temperature using (a) UDEL observations, (b) HiRAM output, and for precipitation using (c) UDEL observations, (d) HiRAM output. Hatching shows the statistically significant areas with at least 95% confidence level.

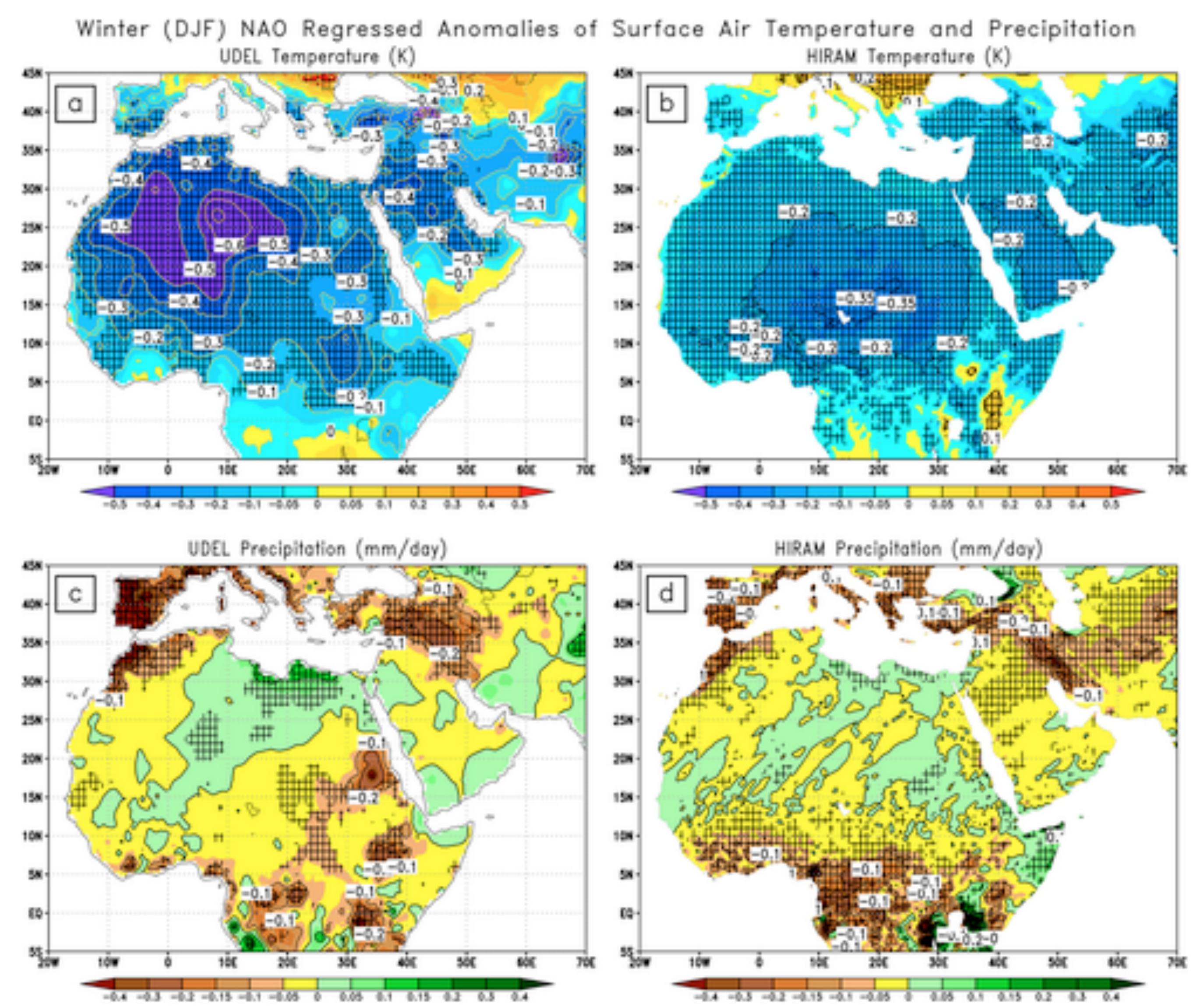

Fig. 3: Same as Figure 2, but for NAO contribution, that is two post-volcanic winters (DJF) NAO-regressed anomalies of surface air temperature (K) and precipitation (mm/day) composited for two winters following the El Chichón and Pinatubo eruptions.

Volcanic Radiative Cooling

Figures 4 shows the residual winter season anomalies of surface air temperature and precipitation, calculated by subtracting linear trend, ENSO, and NAO-regressed fields from the total anomaly. The direct radiative impact over MENA, especially in the Arabian peninsula is strong. Model underestimate this winter cooling signal, which could be attributed to other regional internal variability signals that are not considered in the multiple regression (e.g., East Asian/West Russian mode, signal caused by winter jet streams) and could be important.

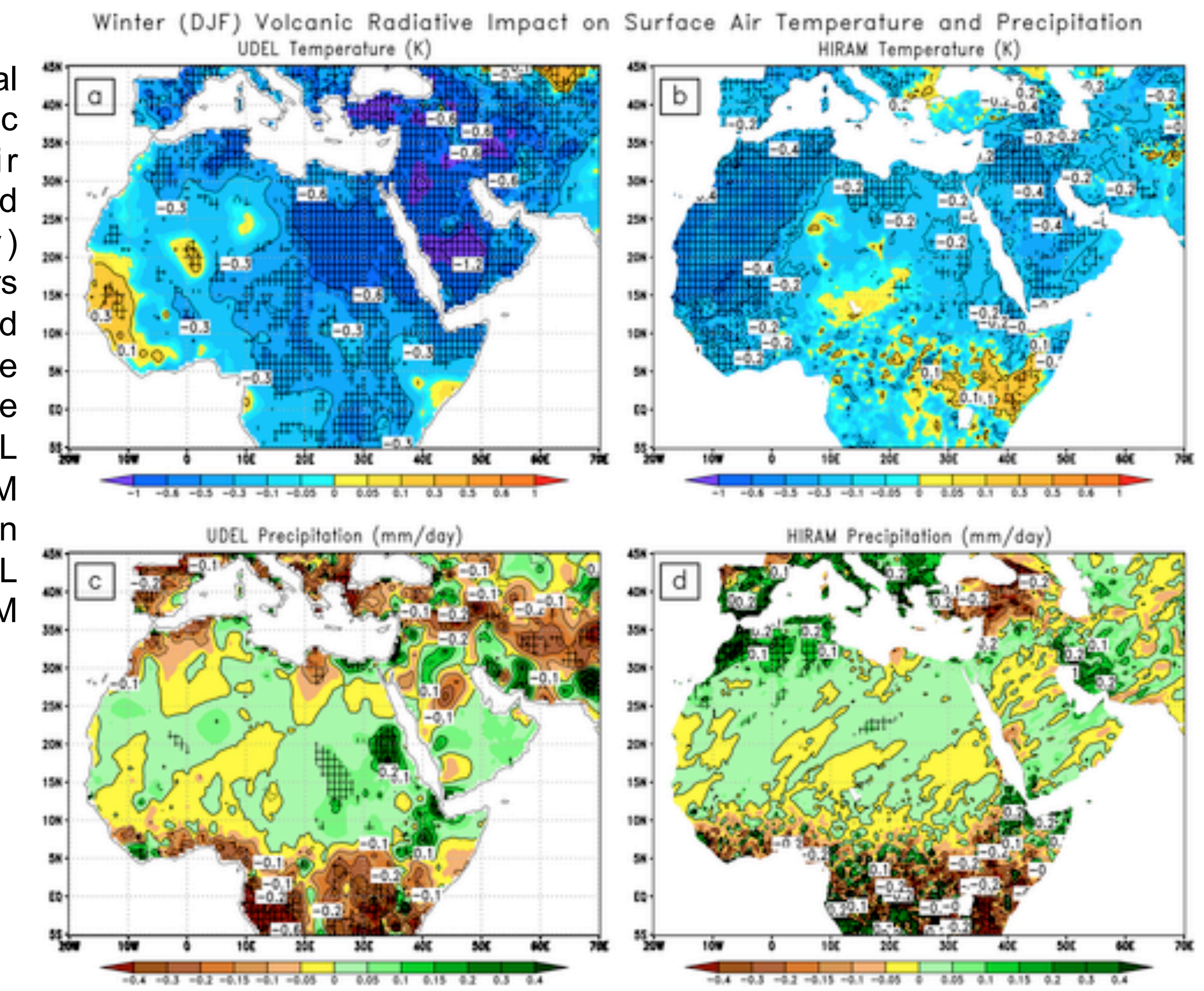

Fig. 4: Winter (DJF) residual anomalies (direct volcanic cooling) of surface air temperature (K) and precipitation (mm/day) composited for two winters following the El Chichón and Pinatubo eruptions. The temperature composites are calculated using (a) UDEL observations, (b) HiRAM output, and precipitation composites using (c) UDEL observations, (d) HiRAM output.

Summary and Conclusions

The strong large-scale global and regional circulation anomalies, along with direct volcanic aerosol radiative cooling, cause an enormously strong climate response over the MENA region in winter. Therefore, while analyzing volcanic signals, contribution due to concurrent large-scale circulation changes interfered by internal variability (e.g., ENSO, NAO) must be taken into account to better quantify the regional climatic impacts of volcanism and natural variability. The existing uncertainties in the simulated response to volcanism, that are mainly introduced by post-volcanic concurrent internal variability signal, are not well reflected in models. It is suggested that these uncertainties could be improved by considering synchronized modeling approach involving multimodal with large ensembles.

Bibliography

1. Dogar, M. M., Stenchikov, G., Osipov, S., Wyman, B., & Zhao, M. (2017). Sensitivity of the regional climate in the Middle East and North Africa to volcanic perturbations. Journal of Geophysical Research: Atmospheres, 122(15), 7922-7948.
2. Dogar, M. M., Hermanson, L., Scaife, A. A., Visioni, D., Zhao, M., Hoteit, I., ... & Fujiwara, M. (2022). A Review of El Niño Southern Oscillation Linkage to Strong Volcanic Eruptions and Post-Volcanic Winter Warming. Earth Systems and Environment, 1-28.