学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Study of the regional climatic impacts of tropical explosive volcanism in the Middle East and North Africa region

（熱帯の爆発的火山活動が中東および北アフリカの地域気候に与える影響に関する研究）

Explosive volcanism is considered as a strong climate forcing with profound global and regional scale direct and indirect radiative impacts. The direct radiative effects of volcanic eruptions resulting in solar dimming, surface cooling and reduction in rainfall are well documented. However, volcanic eruptions also cause indirect climatic impacts that are not well understood. For example, solar dimming induced by volcanic aerosols could cause changes to the updraft branch of Hadley circulation that in turn largely affect surface temperature, evaporation, and precipitation patterns especially in monsoon fed regions such as the Middle Eastern, African, and South Asian tropical rain belt regions. Therefore, understanding the sensitivity of Hadley circulation to volcanism and associated regional impacts is essential, as the Hadley circulation is directly related to the precipitation changes in the tropics and with other large-scale circulations. Likewise, volcanic-induced radiative perturbations potentially interact and modulate the leading teleconnection modes such as El Nino Southern Oscillation and North Atlantic Oscillation that strongly affect global and regional climate. Hence, quantification of magnitude and spatial pattern of these postvolcanic direct and indirect climatic responses is important for a better understanding of climate variability and changes, especially in the tropical rain belt regions.

In earlier literature it is noticed that the studies dealing with volcanism have matured in terms of their global climatic impacts; however, uncertainties remain in their regional impacts. Therefore, the main aim of this research is to improve our understanding of the regional climatic impacts driven by volcanism, especially in the Middle East and North Africa (MENA) region. This study focused on the MENA region, as this region appears to be very sensitive to the effects caused by explosive volcanism. For instance, the winter cooling in the MENA region following the 1991 Pinatubo eruption far exceeded the mean hemispheric temperature anomaly, even causing snowfall in most parts of the Arabian Peninsula region. Similarly, previous studies also reported that the strong volcanic eruptions diminished the solar radiation to such an extent that the resulting cooling caused crops to shrivel and produced famine in Africa and Egypt. Several earlier studies have documented this cooling anomaly over the Middle East after large eruptions with snowy conditions over the Gulf of Aqaba and pointed out that this cooling response is produced as a result of the direct radiative impact of volcanism. However, there is rarely any studies available that looked at the changes caused as a result of the dynamic response of post-eruption circulation changes over MENA, such as caused by post-eruption El Nino Southern Oscillation, North Atlantic Oscillation, and Indian monsoon changes, and therefore, this dissertation investigated both the volcanic direct radiative impacts and post-eruption circulation impacts (i.e., indirect response) over the MENA region.

A better understanding of volcanic eruption's impact on the global and regional climate allows scientists to better account for the relative contributions of natural and human-induced factors on the long-term warming trends. This suggests that for a better assessment of the climate variations, one needs to consider the contribution caused by major explosive eruptions in our climate system.

For this purpose, I choose the two strongest low-latitude tropical eruptions of the late 20th century, El Chichón of 1982 and Pinatubo of 1991 occurred in the satellite era, which have better observational records. Hence, to better understand MENA climate variability, the climate responses to the El Chichón and Pinatubo volcanic eruptions are analyzed using observations, reanalysis data, and output from the Geophysical Fluid Dynamics Laboratory's High-Resolution Atmospheric Model (HiRAM) with the effectively 50-km and 25-km horizontal grid spacing. This high-resolution modeling technique ensures ample grid resolution for regional climate analysis with the ability to better account for global and regional responses to volcanic direct radiative and circulation impacts. A multiple regression analysis both for the observations and the model output is performed on seasonal summer and winter composites to separate out the contributions from climate trends, El Niño Southern Oscillation (ENSO), North Atlantic Oscillation (NAO), Indian summer monsoon, and volcanic aerosols.

Strong regional temperature and precipitation responses over the MENA region are found in both winter and summer. This study shows that the Northern hemisphere tropical volcanism produces a significant reduction in rainfall and concomitant drought conditions over the Sahel region by weakening the land-sea thermal gradient in boreal summer. Post eruption changes of ENSO and Indian monsoon amplifies the rainfall deficit by shifting the ITCZ southward in the boreal summer. The model and the observations both show that the volcanic-induced positive phase of NAO amplifies post-eruption cooling over MENA in winter. The HiRAM results are consistent with observations in general, however, it underestimates post-eruption NAO and ENSO responses and associated climatic impacts over MENA in winter. This study confirms that the MENA and South Asian climate regime responds vigorously to direct and indirect (through circulation changes) impacts of explosive volcanism. The conducted analysis sheds light on the internal mechanisms of MENA climate variability and helps to selectively diagnose the model deficiencies.

This dissertation develops a sound understanding of the direct and indirect radiative impacts of tropical volcanic eruptions over the MENA region in the winter and summer seasons. In this study, a unified framework that combines the use of high-resolution modeling and multiple regression approach is developed. This study analyzes specifically designed climate model simulations to account for the regional impacts of El Chichon and Pinatubo eruptions. This framework illuminates the amplified cooling responses over the Arabian Peninsula in winter and volcanic-induced weakening of African monsoon and drought conditions over the tropical rain-belt regions of MENA in the summer season. It clarifies the gaps in earlier studies and answers why eruptions caused strong cooling anomalies in winter over the MENA region. Moreover, this study also sheds light on the shift of ITCZ in the summer season that significantly impacts monsoonal precipitation. This improved understanding is expected to advance climate model simulations to account for circulation impacts caused by strong tropical volcanic eruptions. It will help the climate community to better simulate the regional impacts of volcanism. Moreover, it could be very useful for studies dealing with solar radiation management and geoengineering applications.