NAO effect on winter precipitation in the Hindu-Kush Karakoram and its secular variations

Luca Filippi[1,2], Elisa Palazzi[1], Jost von Hardenberg[1], Antonello Provenzale[1]

[1] Institute of Atmospheric Sciences and Climate of the National Research Council (ISAC-CNR), Torino, Italy, l.filippi@isac.cnr.it
[2] Dipartimento di Ingegneria Meccanica e Aerospaziale, Politecnico di Torino, Torino, Italy

The Hindu-Kush Karakoram (HKK), encompassing parts of Afghanistan, Pakistan, India and China, constitutes the westernmost part of the Himalayan range. During the winter season, from December to March, it is strongly impacted by westerly perturbations (Western Weather Patterns, WWPs) originating from the Mediterranean and Atlantic regions. The dynamics of WWPs is affected by the North Atlantic Oscillation (NAO), which is the dominant pattern of atmospheric variability in the North Atlantic sector (Hurrell et al. 2003). As a consequence, above (below) than normal precipitation amounts are typically recorded in the HKK during the positive (negative) NAO phase (Archer and Fowler 2004; Syed et al. 2006). However, this relationship underwent secular variations during the 20th Century, showing an alternation of periods of strong and weaker influence of the NAO on precipitation in the HKK (Yadav et al. 2009).

In the present study, we further investigate the relationship between the NAO and precipitation in the HKK, and the mechanisms responsible for this link. We also address the secular variations that occurred in the NAO-precipitation signal and we show that these multi-decadal changes are associated with spatial shifts in the position of the NAO centers of action (COAs). To this end, we consider an ensemble of precipitation datasets, including three rain-gauge-based archives - the Asian Precipitation Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources (APHRODITE), the Global Precipitation Climatology Centre (GPCC) and the Climate Research Unit (CRU) data - and the ERA40 reanalysis. We also use another reanalysis product - the Twentieth Century Reanalysis (20CR) - extending further back in time, in order to study multi-decadal variations occurring in the NAO-precipitation relationship and to reconstruct the atmospheric variability from 1871 to the present.

All the considered datasets coherently exhibit enhanced precipitation over the HKK during the positive NAO phase. Some differences arise in the spatial distribution, intensity and significance of the NAO-associated precipitation anomalies, reflecting the difficulty of having reliable precipitation estimates over this region due to the complex orography, problems in detecting snowfall and the sparse coverage of stations (Palazzi et al., 2013).

The NAO exerts its control on precipitation in the HKK by regulating the intensity of westerly winds in the region of the Middle East jet stream, from North Africa to southeastern Asia. During the positive NAO phase, westerlies over this area are intensified from the upper-tropospheric jet to the lower levels. The strengthening of the jet intensifies the WWPs, while the anomaly in the middle-lower troposphere produces a faster transport of humidity towards the HKK. Our results indicate that evaporation from the Persian Gulf, the northern Arabian Sea and the Red Sea plays an important role. These basins, which constitute the main moisture sources for precipitation in the HKK, show enhanced evaporation during the positive NAO phase, mainly because of higher surface wind speed. The combination of enhanced humidity coming from evaporation and faster westerly winds results into an increased moisture transport towards the HKK. Wetter than normal conditions are experienced over northern Pakistan and northern India, and larger precipitation amounts occur as the WWPs reach this region.

The study of correlations between the NAO and precipitation in the HKK shows the multi-decadal variations that occurred in the NAO-precipitation relationship during the past century. The alternation of periods of strong and weaker control by the NAO is coherently reproduced by all the datasets. To investigate if these variations are associated with changes in the spatial structure of the NAO in the North

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Atlantic, we adopt the Angle Index metric introduced by Wang et al. (2012), a measure of the spatial displacements of the NAO COAs on decadal timescales. It is found that significant correlations between the NAO and precipitation mostly occur when the Angle Index is negative, that is, when the northern node of the NAO is shifted to the west and/or the southern node is shifted to the east. In the opposite configuration, the Angle Index is positive and the NAO-precipitation correlation is weaker. Shifts of the NAO COAs have significant implications for the circulation response to the NAO phase. Our analysis shows that, when the Angle Index is negative, the NAO has a strong control on the Middle East jet stream, and the mechanism of regulation of the HKK precipitation by the NAO is activated. Viceversa, when the Angle Index is positive, the NAO does not project – or projects weakly – onto the Middle East jet stream and the relationship between the NAO and winter precipitation in the HKK weakens.

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