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Response of the North Atlantic Oscillation to the Madden-Julian Oscillation: Dependences on the QBO and ENSO

Lon Hood (1), Malori Redman (2), Thomas Galarneau, and Jr. (3)

(1) University of Arizona, Lunar and Planetary Laboratory, Tucson, Arizona, United States (lon@lpl.arizona.edu), (2) Dept. of Earth & Climate Science, San Francisco State University, San Francisco, California, United States, (3) Dept. of Hydrology & Atmospheric Science, University of Arizona, Tucson, Arizona United States

Although the Madden-Julian Oscillation (MJO), also known as the 30-60 day oscillation, is a tropical climate oscillation, it generates a Rossby wave train that produces significant effects on extratropical circulation and intraseasonal climate, including effects on the North Atlantic Oscillation (NAO) during northern winter [Cassou, Nature, 2008; Lin et al., J. Climate, 2009]. During the last 3 years, it has been established that the stratospheric quasi-biennial oscillation (QBO) influences the occurrence rate of strong MJO events during northern winter such that mean amplitudes are larger during the easterly phase (QBOE) than during the westerly phase (QBOW) [e.g., Yoo and Son, GRL, 2016; Hood, GRL, 2017]. Here, composite analyses of ERA-Interim sea level pressure, surface air temperature, and total precipitation data over the 1979-2016 period are conducted to show that the QBO, like ENSO, modulates the MJO-induced Rossby wave train with significant consequences for the NAO response to the MJO during northern winter. Specifically, during QBOE as monitored at 40 or 50 hPa, the wave train amplitude is enhanced resulting in a stronger NAO response and a stronger dependence on the phase of the MJO than during QBOW. A similar enhancement of the wave train amplitude occurs during the La Niña phase of ENSO [Moon et al., Clim. Dyn., 2011]. During the earliest part of an MJO cycle when tropical convection is centered over the western Indian Ocean (MJO phases 1 and 2), a strongly negative NAO tendency is produced during QBOE. The NAO-related low pressure anomaly over the North Atlantic results in a cooling tendency over eastern North America and a warming tendency over northern Eurasia via horizontal temperature advection. During the middle part of an MJO cycle (phases 5 and 6) when intense MJO convection shifts eastward to the western Pacific, a strongly positive NAO tendency is produced. This results in a strong warming tendency over eastern North America and a cooling tendency over northern Eurasia, opposite to the response during the early MJO phases. Precipitation tendencies over western Europe are positive during the early MJO phases and negative during the middle MJO phases. In contrast, during QBOW, the MJO-induced Rossby wave train is more subdued and the MJO modulation of the NAO is less pronounced. Weaker warming tendencies over eastern North America are present during MJO phases 3 to 7 and cooling tendencies are present over northern Eurasia during MJO phases 1 to 4. Further compositing for combined QBOE/La Niña conditions shows that the MJO-induced Rossby wave train amplitude and its effects on the NAO are stronger than for either QBOE or La Niña conditions alone, consistent with a linearly additive response.