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Influence of the Stratosphere on MJO-AO Teleconnections in the Subseasonal to Seasonal (S2S) Models

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1. Introduction

There is increasing evidence that the Madden Julian Oscillation (MJO), the leading mode of intraseasonal variability in the tropics, may be a source of predictability for the extratropical Northern Hemisphere (NH) atmospheric circulation during the boreal winter. Several studies have linked variability in the MJO to the leading modes of Northern Hemisphere (NH) atmospheric variability including the North Atlantic Oscillation (NAO; Cassou 2008) and the Arctic Oscillation (AO; L'Heureux and Higgins 2008). Of particular interest is the extent to which the extratropical stratospheric circulation has a modulating influence on these MJO-AO teleconnections, which, in turn, influence temperature and precipitation over North America. This study examines the observed boreal winter relationships between the MJO and the AO during different phases of the stratospheric polar vortex and then evaluates how well these relationships are captured in subseasonal to seasonal prediction models.

2. Data and methods

The analysis focuses on the extended boreal winter (November- March) for the period 1979-2016. Daily MJO indices, obtained from the Bureau of Meteorology (BOM), are based off the method of Wheeler and Hendon (2004). MJO events are identified using the primary requirement that the amplitude of the leading two Real-time Multivariate MJO (RMM) series $[(RMM1^2+RMM2^2)^{1/2}]$ exceeds 1. The daily AO index is obtained from the NOAA/CPC website (http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/ao.shtml) and is calculated by projecting the ERA-Interim (Dee *et al.* 2011) daily z1000 anomalies onto the leading Empirical Orthogonal Function (EOF) of monthly z_{1000} anomalies over the region 20°N-90°N. The stratospheric polar vortex (SPV) is calculated the same way but for z_{050} height anomalies.

Reforecast data are used from prediction models that are part of the World Weather Research Program (WWRP)/ World Climate Research Program (WCRP) Subseasonal to Seasonal (S2S) Project database (Vitart *et al.* 2017). The analysis uses models from BOM, ECMWF, and NCEP. The simulated AO index is calculated for each model by projecting the leading EOF of observed z_{1000} height anomalies onto the simulated z_{1000} height anomalies for each forecast lead. Doing so ensures that the models are all showing how the same pattern evolves in time. The same method is used to calculate the SPV using z_{050} height anomalies. The simulated RMM indices are calculated using the method outlined in Vitart (2017) and are obtained from the S2S website (http://s2sprediction.net/).

3. Relationships between the MJO, AO and the SPV

Figure 1 shows the observed frequency of the AO events as a function of MJO phase. When the considering all states of the SPV (top left), the AO strongly favors the positive sign in MJO phases 2-5 and the negative sign in phases 7-8, consistent with L'Heureux and Higgins (2008). However, when the SPV is anomalously strong, (SPV>0.5, top right), the AO favors the positive polarity regardless of MJO phase. Conversely, the AO remains negative for all MJO phases when the SPV is anomalously weak (SPV<-0.5, bottom right). In the absence of strongly positive or negative polar vortex anomalies (*i.e.*, neutral conditions,

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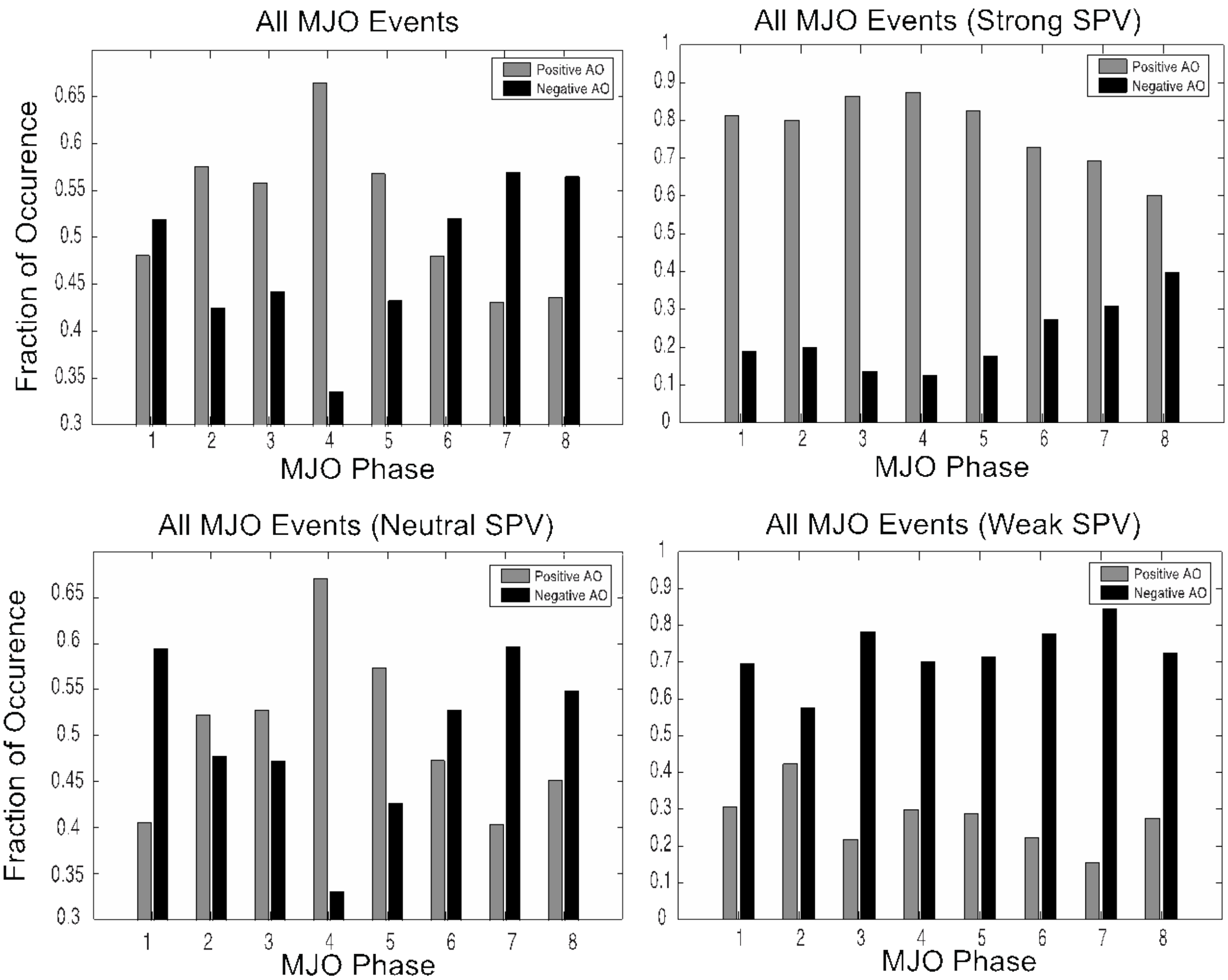

Fig. 1 Fraction of MJO days (as a function of phase) when the November-March AO is in the (grey bars) positive or (black bars) negative phase and the SPV is (top left) any amplitude, (top right) anomalously strong, (bottom right) anomalously weak, and (bottom left) neutral.

bottom left), the same relationships emerge as when all phases of the SPV are considered. These results suggest that the overall MJO-AO relationship in Fig. 1 primarily reflects a tropospheric link.

Figure 2 shows similar analysis using the three aforementioned S2S models and focuses on the MJO-AO relationship when all states of the SPV are considered. Note that the models each have distinct combinations of forecast periods and forecast frequencies, sampling different subsets of the observational period. Consequently, the models results are compared to observations that have been subsampled to match each those forecast periods/frequencies. The discussion highlights the relationships at MJO phases 4 and 7, which have been shown to be linked to the positive and negative phases of the AO, respectively.

Relative to the observations, ECMWF overestimates the fraction of positive AO days during phase 4 of the MJO. However, during phase 7, ECMWF is able to capture the high occurrence of negative AO days. The opposite is true in the NCEP S2S model in which the positive AO relationship with phase 4 of the MJO is well-simulated, but the negative AO relationship with phase 7 is overestimated. The best representation of the observations is evident in the BOM with the positive AO relationship slightly overestimated and the negative relationship in Phase 7 well-captured. Because these MJO-AO relationships in Fig. 2 are analyzed at lead 0, it is expected that these relationships would be well-captured in the models. While the anomaly correlations of the simulated winter AO demonstrate high skill at lead 0 ($r>0.95$; not shown), the anomaly correlations of the MJO amplitude are considerably lower ($r<0.8$; not shown), which may have an impact on the ability to capture MJO-AO relationships.

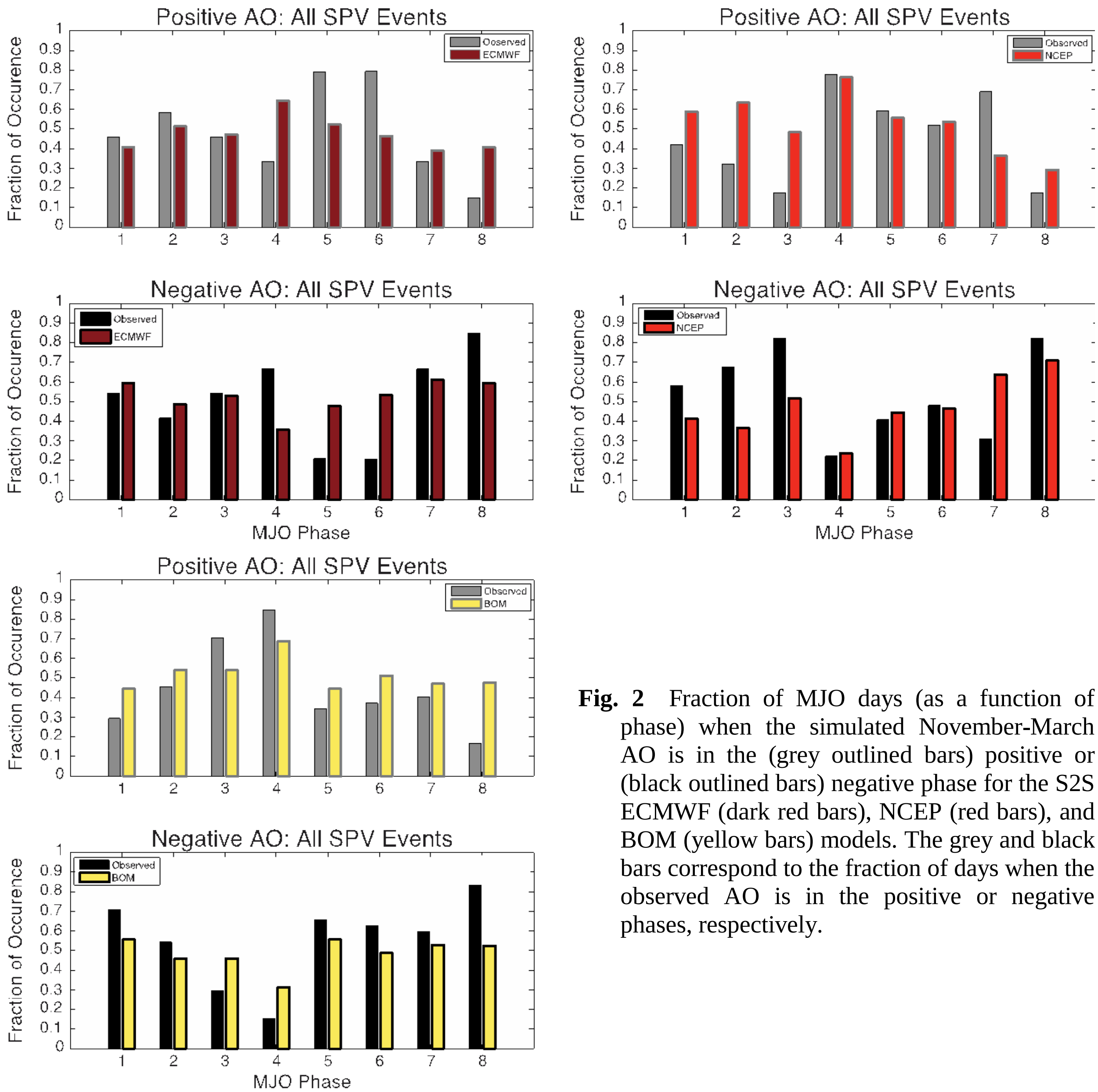

Fig. 2 Fraction of MJO days (as a function of phase) when the simulated November-March AO is in the (grey outlined bars) positive or (black outlined bars) negative phase for the S2S ECMWF (dark red bars), NCEP (red bars), and BOM (yellow bars) models. The grey and black bars correspond to the fraction of days when the observed AO is in the positive or negative phases, respectively.

4. Future work

The results of this analysis suggest that models have difficulty reproducing the boreal winter MJO-AO relationships. Because the tropospheric MJO-AO relationship is poorly captured in some of the models, the evaluation of the modulating effect of the stratosphere in the models could be further complicated. A possible explanation is that the inability to capture the MJO-AO relationship might be related to the MJO, which are not as well reproduced in the models as the AO. Future work will further examine how the representation of the MJO in the models influences the overall MJO-AO relationship. This analysis will also be extended to the other models in the S2S database.

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