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MJO prediction skill, predictability, and teleconnection impacts in the Beijing Climate Center Atmospheric General Circulation Model

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ABSTRACT

This study evaluates performance of Madden–Julian oscillation (MJO) prediction in the Beijing Climate Center Atmospheric General Circulation Model (BCC_AGCM2.2). By using the real-time multivariate MJO (RMM) indices, it is shown that the MJO prediction skill of BCC_AGCM2.2 extends to about 16–17 days before the bivariate anomaly correlation coefficient drops to 0.5 and the root-mean-square error increases to the level of the climatological prediction. The prediction skill showed a seasonal dependence, with the highest skill occurring in boreal autumn, and a phase dependence with higher skill for predictions initiated from phases 2–4. The results of the MJO predictability analysis showed that the upper bounds of the prediction skill can be extended to 26 days by using a single-member estimate, and to 42 days by using the ensemble-mean estimate, which also exhibited an initial amplitude and phase dependence. The observed relationship between the MJO and the North Atlantic Oscillation was accurately reproduced by BCC_AGCM2.2 for most initial phases of the MJO, accompanied with the Rossby wave trains in the Northern Hemisphere extratropics driven by MJO convection forcing. Overall, BCC_AGCM2.2 displayed a significant ability to predict the MJO and its teleconnections without interacting with the ocean, which provided a useful tool for fully extracting the predictability source of subseasonal prediction.

1. Introduction

It is well known that the predictability limit of weather forecasts is between two and three weeks. Beyond that, the initial errors grow quickly and become so large that overwhelm the useful signals in the forecast. In contrast, for seasonal predictions, the predictability mostly comes from the lower boundary and some influences external to the atmosphere (Shukla et al., 2000), such as oceans, soil moisture, land use, and sea ice. Nowadays, the extended-range forecast, as the gap between the weather forecasts and seasonal predictions, has received increasing attention because of large needs of society (Waliser et al., 2006).

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The Madden–Julian oscillation (MJO) is the most prominent mode of intraseasonal variability in the tropics (Madden and Julian, 1971, 1972) and plays a critical role in bridging weather and climate (Zhang, 2013). The MJO is typically characterized by a spatial structure of zonal wavenumber one with large-scale signals in the atmospheric circulation, deep convection, and other variables propagating slowly eastwards (at approximately 5 m/s) from Indian to Pacific oceans (Zhang, 2005). The MJO modulates tropical cyclone (TC) genesis and activity (Vitart et al., 2010; Fu and Hsu, 2011), influences global weather and climate variability (Donald et al., 2006), impacts on extratropical teleconnections such as the Arctic Oscillation (AO) and North Atlantic Oscillation (NAO; Cassou, 2008), and also affects climate variability over longer timescales, such as the El Niño-Southern Oscillation (ENSO; Kessler and Kleeman, 2000; Wang et al., 2011). In addition, the MJO has an important impact on the onset and break of the summer monsoon and precipitation over East Asia via stimulating of anomalous meridional teleconnection between the tropics and middle latitudes, and changing the northward transportation of low-level moisture (Jeong et al., 2008; Jia et al., 2011; Jia and Liang, 2013; Qi and Zhang, 2015). Recently, lots of theoretical researches have advanced the fundamental dynamics of MJO (Li, 2014), such as its scale selection (Li and Zhou, 2009), initialization (Zhao et al., 2013; Li et al., 2015), and moisture asymmetry construction (Hsu and Li, 2012, 2014), increasing our knowledge and references in understanding the predictability of the MJO and intraseasonal variability.

Therefore, as the MJO has a significant influence on the climate and weather events, the effective prediction of the MJO could fill in the predictability gap between weather forecasts and seasonal predictions. Over the last decade, there has been a significant improvement in MJO prediction skill and the potential predictability of dynamical models (Ren et al., 2015). Seo et al. (2009) evaluated the MJO forecasts from the National Centers for Environmental Prediction (NCEP) Climate Forecast System (CFS) and showed that this system has useful MJO prediction skill out to 10–15 days. Wang et al. (2014) further found that such a useful MJO prediction skill could be extended to 20 days by using CFS version 2. Rashid et al. (2011) examined the performance of the Predictive Ocean–Atmosphere Model for Australia (POAMA) and showed that the useful MJO forecast can extend to 21 days. More recently, Hudson et al. (2013) found that the POAMA-2 multi-week forecast system had further improved MJO prediction skill (out to 23 days) by applying a coupled-breeding initialization approach. Meanwhile, Kang and Kim (2009) and Kang et al. (2014) showed that by using an empirical singular vector (ESV) perturbation method, the MJO prediction limit of the Seoul National University coupled general circulation model (SNU CGCM) could be increased from 20 to 22 days. Fu et al. (2013) showed that the forecasting skills of MJO major modes can reach 13, 25, and 28 days in the GFS (Global Forecast System) atmosphere-only model, the CFSv2, and UH (University of Hawaii) coupled models, respectively, during the DYNAMO (Dynamics of the MJO) period. Also, major progress had been made by the European Center for Medium-Range Weather Forecasts (ECMWF) since 2002, with an evident increase in prediction skill (of about 1 day per year) to 30 days by 2012 (Vitart et al., 2007; Vitart and Molteni 2010; Vitart, 2014).

Recently, several studies have focused on characterizing the predictability of the MJO using contemporary general circulation models. Pegion and Kirtman (2008) showed that the predictability of the MJO could be extended beyond 45 days by estimating the predictability of the NCEP CFS hindcast data. Furthermore, Neena et al. (2014) made two estimates of MJO predictability based on the single-member and ensemble-mean methods, which showed the predictability limit of MJO to be around 20–30 days and 35–45 days, respectively. This study indicated that more skillful MJO forecasts could be generated from improvements in the dynamical models and ensemble prediction systems. These studies were almost all based on CGCMs that included air–sea coupling processes which may positively contribute to better simulations of both the MJO dynamics and propagation (Fu et al., 2013). However, whether the introduction of air–sea coupling can significantly improve MJO prediction skill remains controversial (Hendon 2000; Chou and Hsueh 2010), despite it being much more expensive to run a full CGCM than its atmospheric component in an operational system.

In this study, we focus on an atmospheric GCM rather than the CGCM to examine its performance in predicting the MJO. We also evaluate the predictability of the MJO using a unique daily-initialized hindcasts dataset generated by the Beijing Climate Center Atmospheric General Circulation Model version 2.2 (BCC_AGCM2.2), which has been applied to the Dynamical Extended-Range Forecasting (DERF) in the BCC operational prediction system. This AGCM has shown a much-improved performance in monthly predictions of the surface air temperature and precipitation over China, and also in the simulations of the MJO and AO, when compared with the earlier version of the model (Wu et al., 2010; He et al., 2014; Zhao et al., 2014, 2015; Zuo et al., 2016). This study also aims to increase our understanding of the MJO impacts through extratropical teleconnections, which provide an important reference when making predictions over subseasonal timescales. The remainder of the paper is organized as follows. Section 2 describes the datasets and methodology used. The overall prediction skill of the MJO is evaluated in Section 3, and the detailed analysis of the amplitude and propagation characteristics of the MJO is given in Section 4. Then, evaluations of the predictability in the model are presented in Section 5, and Section 6 analyzes the lagged relationship between the MJO and Northern Hemisphere teleconnection. Finally, conclusions and discussions are presented in Section 7.

2. Data and methodology

2.1. The hindcast data

Our analysis is based on the hindcasts from the BCC_AGCM2.2 model with triangular 106 (T106) horizontal resolution and 26 vertical levels (T106L26). The initialization scheme of hindcasts is nudging the atmosphere condition towards the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis-1 data