UCRL-JC-150900-EXT-ABS

The Madden-Julian Oscillation in GCMs

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1. Introduction

The Madden-Julian Oscillation (MJO) dominates tropical variability on timescales of ~30-70 days (Madden and Julian 1971, 1972). It is manifested through large-scale circulation anomalies in conjunction with eastward propagating convective anomalies over the eastern hemisphere. Here we analyze intraseasonal variability in AMIP models and coupled ocean-atmosphere models to determine the extent to which the MJO is simulated, and the influence that air-sea interaction has on the representation of the MJO. All data are bandpassed with a 20-100 day Lanczos filter. The validation data include daily NCEP/NCAR reanalysis (Kalnay et al. 1996), and AVHRR OLR (Liebmann and Smith 1996).

2. The MJO and its Propagation

Sperber and Slingo (2003) identified seven years when the boreal winter MJO was notably active as a well-defined eastward propagating mode. Using these periods, the eastward propagation of convection was isolated via EOF analysis of filtered AVHRR OLR. In the present study, filtered OLR from satellite data and the models is projected onto the afore-mentioned EOF's. Thus, all models are evaluated relative to a common metric. The analysis is confined to the months November-March, for 1979/80-1994/95 for the observations and the AMIP II models, and for 9-19 winters from the coupled models.

Figure 1 shows the lag 0 regression of the PC time series on to the filtered OLR from observations and for the ECHAM4 AMIP II model, and the SINTEX coupled ocean-atmosphere model (which used ECHAM4 as the atmospheric component). The simulated and observed anomalies are consistent, reaching approximately +/-20Wm^{-2}. However, just north of the Maritime Continent the models have more enhanced convection in EOF-1, and in EOF-2 the reduced convection is stronger north of the equator just west of the dateline. Furthermore, the convective maximum north of the Maritime Continent extends further east in ECHAM4 relative to SINTEX.

The amplitude of the OLR perturbations are directly proportional to the standard deviations of the PC's (Table 1). For the AVHRR OLR data, the standard deviations of PC-1 and PC-2 are 211.3 and 205.6, respectively. The vast majority of models have much weaker MJO convective signals. Also given is the maximum positive correlation, R, between PC-2 and PC-1, and the time lag at which it occurred. For the AVHRR data, on average, PC-2 leads PC-1 by 12 days with a maximum positive correlation of 0.67. For all models, R is smaller than observed indicating that eastward propagation is not as coherent as observed. The characteristic timescale of propagation exhibits a wide-range of variability, with some models being incorrectly dominated by westward propagation (PC-1 leads PC-

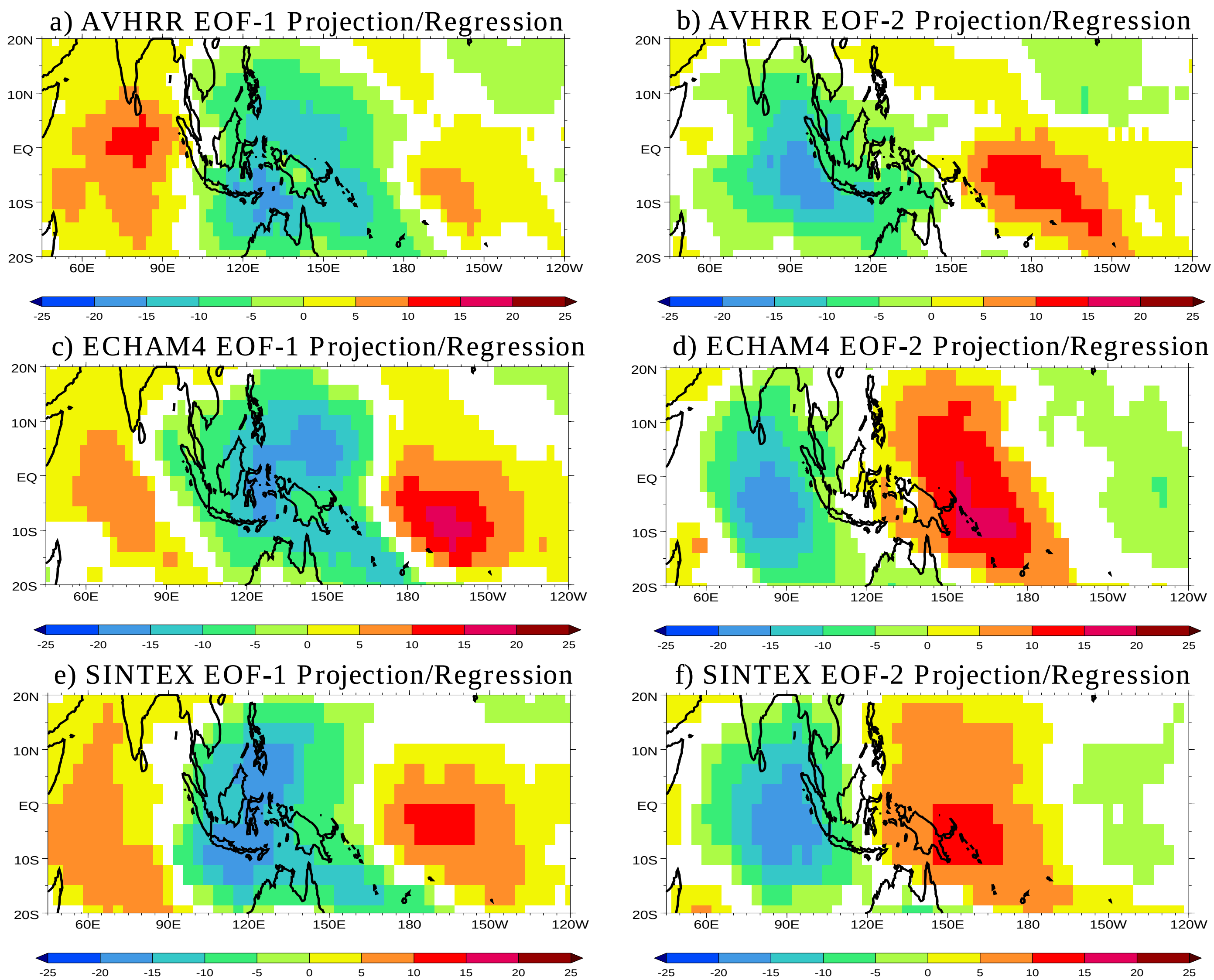

Figure 1. Linear regressions of PC-1 and PC-2 with filtered OLR for November-March: (a) and (b) 1979/80-1994/95 AVHRR OLR, (c) and (d) 1979/80-1994/95 ECHAM4 AMIP II integration, (e) and (f) years 21/22-39/40 from the SINTEX (ECHAM4+OPA8.1) coupled ocean-atmosphere model. The regressions have been scaled by a one standard deviation perturbation of the respective PC's. Negative values correspond to enhanced convection (Wm^{-2}).

2 as denoted by negative time lags). Comparing AMIP II and AMIP I we find that HADAM3 has a weaker MJO amplitude and less coherent eastward propagation compared to HADAM2. Importantly, air-sea interaction has a beneficial influence. Three of the coupled models have an AMIP II atmospheric component. In each case the coupled models have a larger R, indicating that the MJO convection has a more realistic propagating structure. That coupling to an ocean yields improvement to the representation of the MJO is consistent with Waliser et al. (1999) and Inness and Slingo (2003).

Figure 2 shows the propagation of 5^{o}N-5^{o}S filtered OLR and 850hPa zonal wind. Both models exhibit difficulty in representing eastward propagation of enhanced convection into the central Pacific Ocean. SINTEX has more realistic convection anomalies over the Indian Ocean than does ECHAM4. However, SINTEX tends to have a standing oscillation in the central Pacific, and from day -5 to day 10 the enhanced convection does not extend as far east as for ECHAM4. The latter difference is related to systematic error of the mean state low-level winds. For the SINTEX model, the low-level near-equatorial westerlies do not extend as far eastward as for the ECHAM4 AMIPII integration. Rather the mean east-

Table 1: Observed and simulated MJO characteristics. The columns give the observation/ model designation (the last 4 entries are from the coupled models), the standard deviations of PC-1 and PC2, the maximum positive correlation, R, between PC1 and PC-2, and the time lag at which it occurred. Positive time lags correspond to eastward propagation. Shaded entries highlight models for which an AMIP II integration and a coupled ocean-atmosphere simulation using the same atmospheric model are available.

Model	PC-1	PC-2	R	Lag (days) PC-2 leads PC-1 (positive)
AVHRR	211.3	205.6	0.67	12
CCCMA-99a	100.3	107.0	0.26	11
CCSR-98a	106.4	91.7	0.30	13
CNRM-00a	155.1	143.3	0.42	14
COLA-00a	100.5	85.7	0.16	26
DNM-98a	63.0	67.1	0.16	25
ECMWF-98a	102.5	97.5	0.20	-11
ECMWF-98b	121.8	105.7	0.29	-13
GFDL/DERF-98a	159.0	182.1	0.36	12
GISS-98a	64.0	54.6	0.23	-7
GISS-02a	37.1	37.1	0.17	-15
HADAM2 (AMIP I; 1979/ 80-1987/88)	166.5	130.9	0.40	18
HADAM3 (L58) (UGAMP-98a)	117.1	102.8	0.28	14
JMA-98a	165.3	155.3	0.29	10
MPI-98a (ECHAM4)	222.2	215.8	0.35	12
MRI-98a	174.2	164.1	0.31	9
NCAR-98a (CCM3)	91.9	100.2	0.18	10
NCAR-02a (CAM2)	95.3	95.8	0.19	-24
NCEP-99a	108.9	108.6	0.24	12
NCEP-99b	104.1	98.4	0.22	24
HADCM3 (L30)	104.4	96.0	0.45	8
IAP/LASG GOALS	123.8	129.2	0.42	9
NCAR CCSM2	91.5	115.9	0.28	20
SINTEX (ECHAM4/OPA8.1)	231.2	201.5	0.44	12

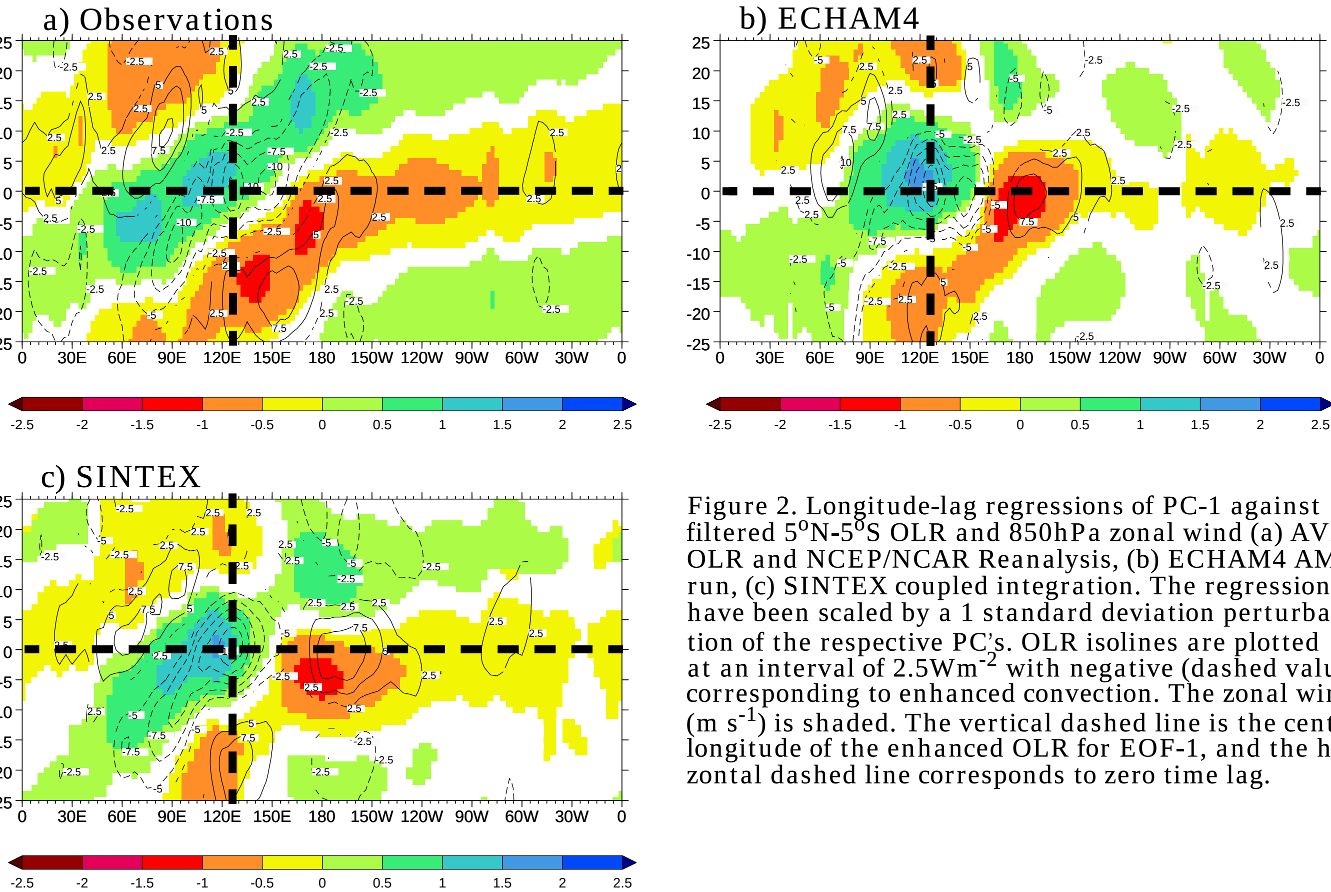

Figure 2. Longitude-lag regressions of PC-1 against filtered 5°N-5°S OLR and 850hPa zonal wind (a) AVHRR OLR and NCEP/NCAR Reanalysis, (b) ECHAM4 AMIP II run, (c) SINTEX coupled integration. The regressions have been scaled by a 1 standard deviation perturbation of the respective PC's. OLR isolines are plotted at an interval of $2.5 Wm^{-2}$ with negative (dashed values) corresponding to enhanced convection. The zonal wind ($m\ s^{-1}$) is shaded. The vertical dashed line is the central longitude of the enhanced OLR for EOF-1, and the horizontal dashed line corresponds to zero time lag.

erlies penetrate to 150°E (not shown), and inhibit further eastward propagation of the MJO convection. This link between the convection and systematic error of the mean state is consistent with Inness and Slingo (2003) and Inness et al. (2003) based on their study using HADAM3 and HADCM3. Over much of the eastern hemisphere, the 850hPa westerlies lag the leading edge of the convection more so in the observations.

3. Conclusions

The simulation of the MJO proves to be a critical test of a models ability to simulate the tropics. Additional regressions and examination of space-time spectra indicate that (1) the models typically fail to represent the intraseasonal dominance of the large-scale circulation, (2) within a family of models ocean-atmosphere coupling leads to an improved lag/lead MJO structure, and (3) eastward propagation is limited by systematic error of the mean state. Other variables are being analyzed to examine the mechanism of propagation in the models, and a more comprehensive peer-reviewed journal article will be prepared.

Acknowledgments. This work was performed under the auspices of the U.S. Department of Energy at the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

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