

Evolution of Extreme Madden-Julian Oscillation Events and their Impact on South America.

Mónica Minjares ¹, Marcelo Barreiro ², and Álvaro Corral ^{3,4,5}

¹Departament de Física, Facultat de Ciències, Universitat Autònoma de Barcelona, E-08193 Barcelona, Spain

²Departamento de Ciencias de la Atmósfera y Física de los Océanos, Facultad de Ciencias, Universidad de la República, Iguá 4225, 11400

Montevideo, Uruguay

³Departament de Matemàtiques, Facultat de Ciències, Universitat Autònoma de Barcelona, E-08193 Barcelona, Spain

⁴Complexity Science Hub Vienna, Josefstädter Strae 39, 1080 Vienna, Austria

⁵Centre de Recerca Matemàtica, Edifici C, Campus Bellaterra, E-08193 Barcelona, Spain

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1. INTRODUCTION

The Madden-Julian Oscillation is the leading mode of intraseasonal variability in the tropics, having large influence on the tropical circulation and precipitation within the time band of 30-60 days (Wheeler and Hendon, 2004; Kiladis et al., 2014) and is the most important source of predictability on subseasonal time scales (Ling et al., 2019). The influence of MJO is not limited to the tropics, it also impacts the extratropics through atmospheric teleconnection patterns. During austral summer the MJO influences the South American Dipole (SAD), a rainfall pattern characterized by opposite rainfall anomalies in the South Atlantic Convergence Zone (SACZ) and southeastern South America (SESA).

ENSO is the most important source of interannual climate variability, is originated in the equatorial Pacific but has a strong influence around the globe. In particular in South America during austral summer the El Niño phase influences the rainy season in the coast of Peru, northeastern Brazil, southeastern Brazil, Uruguay, Argentina and Chile (e.g. Ambrizzi et al. 2004; Barreiro 2010, Barreiro 2024). Both, MJO and ENSO are known to influence the SAD through different mechanisms.

In a recent work (Corral et al. 2023), we studied the statistics of the size and duration of MJO events and found that there is increased probability of extinction after about 27 days, roughly half the characteristic period. Moreover, this analysis allows us to distinguish between weak MJO and extreme MJO events, which would be expected to have different impacts worldwide and particularly over South America. Hence in this study we focus characterizing the evolution of extreme MJO events and their impact in tropical and extratropical South America depending on the initiation phase. Following our previous work (Corral et al. 2023), MJO events are considered extremes when they exceed a certain threshold, based on the distribution of events. We further analyze whether ENSO influences MJO and its impacts over South America.

2. METHODOLOGY

The evolution of MJO is analyzed by means of the Wheeler and Hendon (2004), Real-time Multivariate (RMM) index during the period of 1979-2021. It is constructed using the first and second empirical orthogonal functions (EOF) considering latitudinal averages (15°S–15°N) of outgoing long-wave radiation (OLR) and zonal winds at 200 hPa and 850 hPa. The index provides the amplitude, or intensity of the MJO given by $A = \sqrt{RMM_1^2 + RMM_2^2}$ and its phase given by $\varphi = \arctan2(RMM_2, RMM_1)$.

The index can be visualized in a phase diagram with RMM1 in the x-axis and RMM2 in the y-axis. It is divided in 8 phases which corresponds to geographical locations where the convection center is located. The western Hemisphere and Africa correspond to phases 8 and 1, the Indian Ocean to phases 2 and 3, the Maritime Continent (MC) to phases 4 and 5 and the western Pacific to phases 6 and 7. In our framework the MJO is active when the index amplitude is above or equal to 1. Therefore, the contiguous time periods with active MJO define an event. Given this, we define the duration of an event as the period in which the amplitude is larger than 1 and the size of the event (energy) as the sum of the amplitudes along the duration, i.e. $\sum A(t)$ as detailed in Corral et al. (2023). The winds were used to calculate the streamfunction (ψ) and velocity potential (χ) fields to describe the rotational and divergent components of the circulation, respectively.

To define extreme MJO events we apply the Clauset et al.'s method and the Deluca's method (Clauset et al., 2009; Deluca and Corral, 2013) to the event duration and size distributions. Both methods fit the tail of the distribution to a power-law by means of the maximum likelihood and goodness of fit by Kolmogorov-Smirnov test, using Montecarlo simulations. These methods allow to find a lower cut-off or threshold for extremes. Considering events during all year round we find for the duration that extreme events are the ones that exceed or equal 24 days and for the size extremes are the ones that exceed or equals a value of 39. In this study we use the threshold based on size to define extreme events.

By composite analysis we study the evolution of extreme MJO events during extended austral summer (NDJFM) depending on the phase of initiation and how they influence remote regions, particularly South America and the SAD. Here phases are grouped by pairs, i.e., 8-1, 2-3, 4-5, 6-7. We further separate the composites on events that coincide with the different ENSO phases: El Niño, La Niña and Neutral phase.

3. RESULTS

Figure 1a,b shows the composites of extreme MJO events (left column) and weak MJO events (right column). Each column shows the evolution of OLR and (a) eddy-streamfunction and (b) velocity potential for events starting in phases 2-3 where the center of enhanced convection is located in the Indian Ocean and the center of suppressed convection is to the east. Our results show that the centers of enhanced and suppressed convection during extreme MJO events are more intense and extend further east and south than those of weak MJO events. Over South America extreme MJO events present more intense rainfall and circulation anomalies and are larger in spatial extent. In particular, the SAD is well developed for extreme events during phase 2-3 and 4-5, while it has much smaller amplitude in weak events. Moreover, in extreme events the evolution of the MJO increases the SACZ activity during phases 8-1, while weak events do not last that long and thus show no significant anomalies. These differences arise because during extreme events tropical-extratropical teleconnections are strong while during weak events tropical-tropical teleconnections dominate.

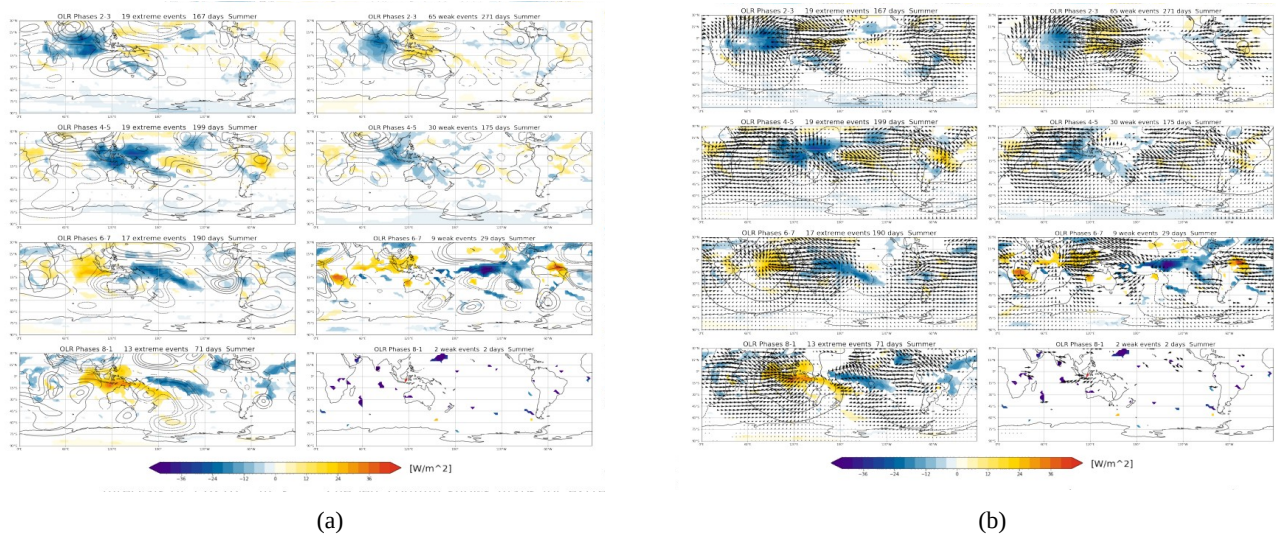


Figure 1. Composite maps of OLR anomalies and 200 hPa contours of eddy-streamfunction (a) and velocity potential (b) with intervals of $2.0 \times 10^{-6} \text{ m}^2 \text{ s}^{-1}$. The left column shows maps for extreme events, while the right column shows maps for weak events. Rows depict the composite maps of events starting in phases 2-3 (top) till they reach phases 8-1 (bottom). Positive streamfunction values (solid lines) represent a cyclonic gyre and negative values (dashed lines) represent anticyclonic gyre in the southern hemisphere. Each column shows the evolution of events starting in phases 2-3 (top) until they reach phases 8-1 (bottom). Only values significant at the 90% confidence level are displayed.

Regarding the Influence of ENSO on MJO our findings reveal that during the austral summer, extreme MJO events last longer during Neutral (NT) years. For events starting in phases 4-5 and 8-1, La Niña dominates in both duration and frequency relative to El Niño and NT. For MJO events starting in phases 2-3, the SAD appears more intense for phases 4-5 for the three ENSO states but the intensity and extent varies (Figure 2): OLR anomalies are strongest during El Niño years accompanied by well defined circulation anomalies. The SAD is also seen in phases 2-3 during El Niño and La Niña years, but not in NT years. However, in the latter MJO events tend to last longer and the SAD appears with anomalies of opposite sign from those in phases 4-5.

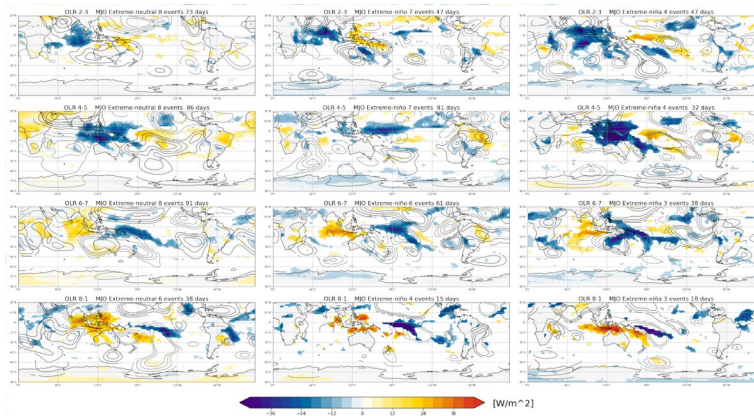


Figure 2: Evolution of austral summer extreme MJO events that start in phases 2-3, during (left column) Neutral ENSO phase, (middle column) El Niño phase and (right column) La Niña phase.

4. CONCLUSIONS

Overall, our results show that the impacts of the MJO over South America will depend not only on the particular phase in which the MJO is, but on its previous evolution, in particular where it initiates. The impact of the MJO is notably modulated by ENSO, with the strength and spatial patterns of anomalies varying according to the phase of initiation of MJO. When MJO is in phase with either EN or LN, these anomalies can be considerably amplified or diminished.

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