Madden-Julian Oscillation (MJO) Teleconnections and their Impact on Precipitation in South America

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ABSTRACT

The Madden-Julian Oscillation (MJO) is a tropical planetary scale area of active and suppressed convection in the Indian and Pacific Oceans that impacts extratropical weather through teleconnections. Understanding MJO teleconnections is important because they are an important source of predictability on subseasonal timescales (30 to 90 days). There is a broad understanding of how MJO teleconnections impact the Northern Hemisphere, but there is less understanding of how they impact the Southern Hemisphere. This study will attempt to fill this gap by exploring the seasonality of MJO-induced precipitation in the Southern Hemisphere and seeing if any teleconnections lead to increased or decreased precipitation anomalies. The data sources that will be utilized include MJO tracking indexes, IMERG daily rainfall data, and ERA5 200 hPa height data. All three of these data sources will be used to create precipitation anomaly and 200 hPa height anomaly graphics for each phase of the MJO. We found that the MJO generates a Rossby wave train in the Southern Hemisphere during JJA and generates the height patterns over South America that are related to positive rainfall anomalies during MJO phases 1 and 2. However, we also found that height patterns from the Rossby wave train do not seem to explain MJO-associated rainfall anomalies during phase 8 of DJF. This information could be beneficial to forecasters in South America as it could give more lead time to prepare for extreme precipitation or drought episodes.

1. INTRODUCTION

Sub-seasonal forecasting is a recent frontier in tropical meteorology, and the MJO is the leading source of predictability at this time scale. The MJO is defined as a large-scale, eastward-moving disturbance that has global impacts (Woolnough 2019). These global impacts largely stem from MJO teleconnections.

Teleconnections refer to variabilities that link two different geographic regions. There is a broad understanding of how teleconnections work in the Northern Hemisphere. One such example is a connection between tornadoes in the Central Plains and certain MJO phases (Thompson and Roundy 2013). However, in the Southern Hemisphere, there is less understanding on how teleconnections work. With a greater knowledge on how teleconnections impact weather patterns in the Southern Hemisphere, meteorologists, for example, could be able to forecast extreme rainfall events at greater timescales (Schreck III 2021).

Based on works from a prior study, it appears that during certain phases of the MJO, an extreme rainfall event is more likely in South America. While in other phases of the MJO, the MJO has less impact on whether there will be an extreme rainfall event in South America (Alvarez et al. 2015). In addition to the relationship between extreme rainfall events and MJO phases, there is a seasonal dependence of MJO impacts on South American rainfall (Alvarez et al. 2015). There are certain clues as to why these differences exist in South America, one being the presence of an MJO-induced Rossby Wave Train, but understanding these through teleconnections is an area that still needs work.

To fill the gap in the literature surrounding the impacts of teleconnections on precipitation anomalies during different seasons and phases of the MJO, this paper will address the following questions.

1. Are there seasonally different precipitation anomalies during the same MJO phase over South America?
2. If there are different precipitation anomalies during the same MJO phase over South America, can the differences be explained by height patterns from an MJO-generated Rossby wave train?

To address the above questions, we will calculate rainfall statistics during each phase of the MJO during the December-January-February (DJF) and June-July-August (JJA) periods, and analyze geopotential height data to determine if a Rossby Wave

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Train exists. This will lead us to examine whether MJO-induced Rossby Wave Trains impact and modulate precipitation in the Southern Hemisphere.

2. DATA AND METHODS

The Madden-Julian Oscillation is identified through the Outgoing Longwave Radiation-based MJO index (OMI). This provides an advantage over the RMM index because it better captures the seasonality of the MJO than the Real-time Multivariate MJO index (RMM) that is commonly used to monitor the MJO. Thus, this will be used throughout the study.

To get our precipitation data, we must first sort days into each of the phases of the MJO for the DJF and JJA time periods. Once we have a specific day attached to each phase of the MJO, we can analyze the precipitation data. To capture our precipitation data, an Integrated Multi-satelliE Retrievals for GPM (IMERG) daily rainfall dataset will be used to examine rainfall (Huffman et al. 2014). This data is daily and will span from 2001 to 2019, covering South America. We will calculate the average rainfall during the entire period stretching from 2001 to 2019, which represents climatological rainfall in each season. We will also find the average rainfall during each of the phases of the MJO. We then subtract the climatological rainfall from the average rainfall during each phase to find rainfall anomalies in each MJO phase. Coupling our precipitation anomalies with 200-hPa geopotential height data will better help us understand the roles that teleconnections play in creating these precipitation anomalies across South America.

The 200-hPa geopotential height data will be captured by using daily ECMWF-ERA5 reanalysis data and will be used to see MJO-induced Rossby wave trains (Hersbach et al. 2020). The reason why we are using this specific data is that the 200-hPa level is the level that the MJO impacts the atmosphere the most, specifically through the initiation of Rossby Wave Trains. The location of the Rossby Wave Train can lead to the formation of surface fronts, which can impact weather all across the globe This data will be utilized over the Indian and Pacific Oceans. Our work will examine if there is a teleconnection between the MJO-induced Rossby wave trains and extreme rainfall events in the Southern Hemisphere.

3. RESULTS

The following results will display ERA5 reanalysis data at the 200-hPa level and precipitation anomalies. Each figure will display data during each phase of the MJO and the DJF and JJA periods. We will examine the connections between the height patterns and precipitation anomalies in the two seasons during each MJO phase.

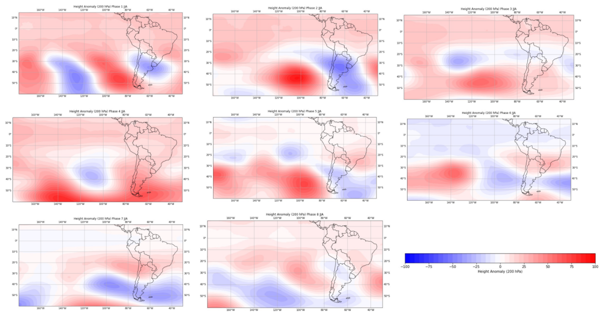

Figure 1. The subplot shows 200-hPa height anomalies during the eight phases of the MJO in the June-July-August period. The figure at the top left represents Phase 1 and each phase to the right represents the next phase. The colorbar represents the height anomaly per day measured in meters. Red colors represent height rises and blue colors represent height falls.

3.1 JJA

Figure 1 shows a strong, anomalous height pattern during Phase 1 in Southern South America. This strong pattern represents an MJO-induced Rossby Wave train, where in particular, we see a strong anomalous trough located in southern South America. With troughs, we typically expect to see more active weather because of surface-level convergence and the formation of surface fronts that are expected around troughs, so it is plausible that positive precipitation anomalies may exist in this region.

However, the same pattern does not appear in every phase. The phase that contrasts most with Phase 1 is Phase 4. During Phase 4 (Fig. 1), we see a large ridge across the entirety of South America. With this specific height pattern, we would expect to see less active weather because of surface-level divergence. Therefore, it is plausible to expect widespread anonymously dry conditions in South America during phase 4 JJA.

Phases 6 and 8 in JJA are examples of height patterns that are more neutral. There is no evidence of a strong ridge or trough across South America. With the lack of a strong height pattern, it appears that the MJO has less influence on the overall height pattern during these phases.

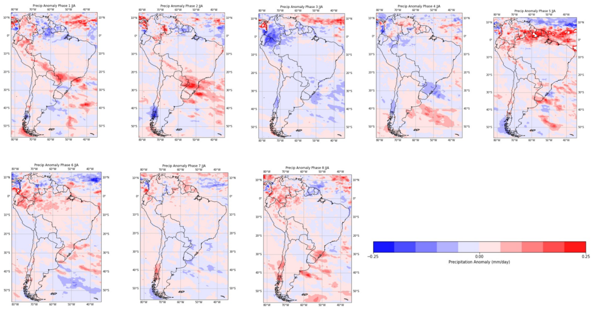

Figure 2. The subplot shows precipitation anomalies during the eight phases of the MJO in the June-July-August period. The figure at the top left represents Phase 1 and each phase to the right represents the next phase. The colorbar depicts precipitation anomalies, with red contours representing positive precipitation anomalies and blue contours representing negative precipitation anomalies

In Figure 1, we noted that there is a trough located in Southern South America which could potentially bring about positive precipitation anomalies during Phases 1-2. As we see with the first two subplots in Figure 2, there is an area of positive precipitation anomalies in central South America which is the same general location of the trough, which supports the claim that above-average precipitation anomalies will be located around troughs.

Additionally, we noted that during Phase 4 there was a large anomalous ridge (Fig.1) where we would expect there to be negative precipitation anomalies. In Fig. 2, we see evidence of negative precipitation anomalies across the continent, but they are not very strong. Instead, they are more neutral, which indicates that the MJO does not play a large role in modulating precipitation during this particular phase.

Lastly, during phases without a strong height pattern, like phases 6 and 8 (Fig. 1), we expected precipitation to be more neutral because of a lack of MJO-induced synoptic forcing. As we see with the precipitation anomaly subplots during phases 6 and 8, the precipitation pattern is generally neutral across South America.

3.2. DJF

Now, we want to see if there is seasonality in precipitation anomalies with the MJO, meaning is there a noticeable difference between the same MJO phase during different seasons. If there is seasonality, it may lead to findings that will help expand the literature on MJO teleconnections and their impact on precipitation in South America. The season that will now be examined is the DJF period and this will be compared to the prior JJA period

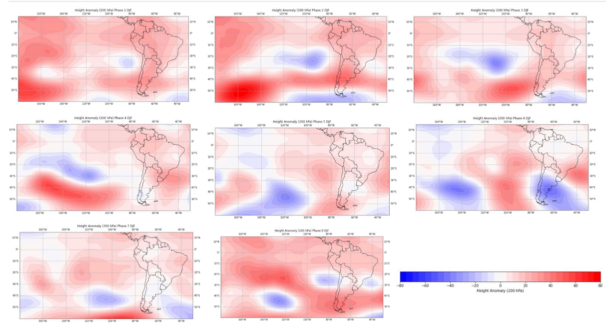

Figure 3. The subplot shows 200 hPa anomalies during the eight phases of the MJO in the December-January-February. The figure at the top left represents Phase 1 and each phase to the right represents the next phase. The colorbar represents the height anomaly per day measured in meters. Red colors represent height rises and blue colors represent height falls.

During the first five MJO phases, it is evident there is a broad area of anomalous ridge over South America, but their magnitudes differ from each other. The first three MJO phases appear to show a stronger ridge over South America, while phases 4 and 5 show a weaker ridge over South America. This almost exactly contrasts with the same phases in the JJA phases, with troughs in phases 1,2,3, and 5. Therefore, there is a distinct height pattern contrast within these specific phases.

Furthering this, troughs are indicated in both phases 6 and 8, with phase 6 having a much stronger magnitude. These phases do not contrast much between DJF and JJA, with both seasons showing troughs over the same area.

Therefore, when looking at height patterns for both seasons we see that there are key differences and similarities for the same MJO phases. For phases 1, 2, 3, and 5, during JJA, there was generally a trough located over South America. However, during the same phases in DJF, there was generally a ridge located over South America. Identifying the seasonal differences in the height patterns is important because it gives an idea as to how precipitation can be impacted by MJO teleconnections. Next, the precipitation anomaly will be shown for DJF to see if the differences in height patterns for differing seasons play a role in modulating precipitation.

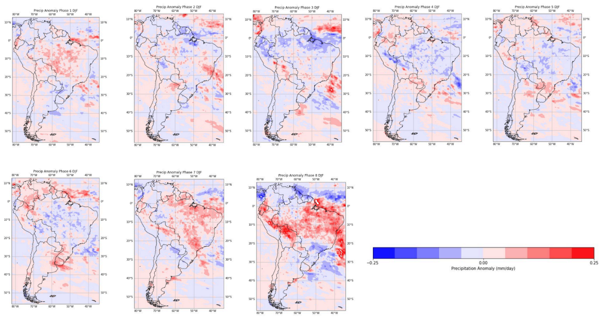

Figure 4. The subplot shows precipitation anomalies during the eight phases of the MJO in the December-January-February period. The figure at the top left represents Phase 1 and each phase to the right represents the next phase. The colorbar depicts precipitation anomalies, with red contours representing positive precipitation anomalies and blue contours representing negative precipitation anomalies

Figure 4 shows that only phase 8 had broad strong positive precipitation anomalies. The rest of the phases are more neutral, but there are some areas with slightly negative precipitation anomalies or slightly positive precipitation anomalies. These results are somewhat similar to the JJA precipitation anomalies, but there were some differences. For example, during phase 6 DJF there was an area of positive precipitation anomalies in Uruguay, but looking at phase 6 JJA that same area had more neutral precipitation anomalies.

When coupling the height pattern with the precipitation anomalies, there is a key trend that appears. Troughs is generally associated with positive precipitation anomalies across South America, while ridges seem to be associated with negative precipitation anomalies across South America. For the phases that had strong troughs, positive precipitation anomalies were present in the general areas where the troughs were located. One example of this in DJF was during phase 6 where a strong trough was located in Southern South America, and positive precipitation anomalies were situated in Uruguay. However, when strong ridges were present, there was typically not a strong negative precipitation anomaly. Instead, precipitation was more neutral with weakly positive and negative precipitation anomalies.

However, there are some exceptions. One example of this is an area of negative height anomalies in South America during phase 8 DJF (Fig 3) but broad areas of positive precipitation anomalies exist across Northern South America (Fig 4).

4. CONCLUSIONS

Analysis of the anomalous 200-hPa geopotential heights and precipitation anomalies during MJO phases shows that there is strong seasonality in MJO-induced precipitation over South America. During phases 1 and 2 of JJA, there was an area of strong positive precipitation anomalies situated on the east side of the trough, which would be expected. However, during phases 1 and 2 of DJF, there was not a trough located over South America, instead a ridge was situated over the continent. However, instead of seeing strongly negative precipitation anomalies, the results showed little anomaly.

The overall results show that MJO-induced troughs in a Rossby Wave Train have a larger impact on precipitation anomalies than MJO-induced ridges. The height patterns can generally explain precipitation anomalies in South America during the JJA period. For example, there were broad areas of positive precipitation anomalies associated with a trough over Central South America during JJA phases 1 and 2. However, as previously noted, there were areas of negative height anomalies in South America during phase 8 DJF (Fig 3) but broad areas of positive precipitation anomalies exist across Northern South America.

One potential explanation as to why MJO-initiated height patterns seem to not play a large role in modulating precipitation during DJF phase 8 could be from the biomes in South America. The broad area of positive precipitation anomalies exist in tropical areas of the continent. In addition, the DJF phase in the Southern Hemisphere would be the summer season. This could result in heavy rainfall events that do not rely as heavily on height patterns. However, future analysis on why some phases have precipitation anomalies that do not match their height patterns would further help understand how the MJO influences precipitation through its teleconnections.

In all, the results help to further our collective understanding on how MJO teleconnections impact precipitation in South America and will help improve forecasters' ability to forecast on an S2S timescale. Knowing what MJO phases can contribute to the synoptic conditions favored for extreme precipitation can help weather forecasters and community leaders to better plan for adverse impacts that stem from precipitation extremes

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