The record-breaking weather of March 2016: synoptic analysis and characteristics

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Introduction

Surface ozone is hazardous to human health. Exposure to surface ozone can cause difficulty in breathing, aggravate asthma, and chest discomfort in individuals (Smith et al 2010). Surface ozone is the secondary product of pollution as it is created from the exposure of nitrogen oxide to sunlight (Smith et al 2010). In Mexico City, the problem of surface ozone is magnified due to the fact that the city has a population of 21 million, is located in a valley limiting dispersion of emissions, and the high altitude of the city (Barrett and Raga 2016). The problem of tropospheric ozone in Mexico City has been recognized by the Mexican government and international groups who have taken steps to understand the pollution levels. However, these programs while intensive last for only a short time. For example, the Megacity Initiative: Local and Global Research Observations (MILA-GRO) lasted only for only a month (Barrett and Raga 2016). These short studies fail to recognize and adequately address periods of peak tropospheric ozone such as the events during the first two weeks of March 2016.

Problem Statement: During the first two weeks of March 2016, Mexico City recorded a spike in surface ozone concentrations that were hazardous to the citizens of Mexico City. This spike caught the attention of meteorologists, as ozone had been decreasing for the past few years. Just days prior to the spike, one of the most extremely deep upper-tropospheric troughs of the last several decades moved across northern Mexico. All of these events occurred during an extreme El Niño and an active Madden Julian Oscillation (MJO).

Study Objective: The objective of this study was to analyze the high-ozone event from a synoptic-scale perspective and diagnose possible connections to both the extreme migratory upper and middle tropospheric trough as well as large scale modes of variability such as the El Niño Southern Oscillation and the MJO. Precipitation during the multi-day passage of the trough was also analyzed.

Data and Methods

Datasets used in this study include:

- SST anomalies in the Niño 1.2, 3, 3.4, and 4 boxes (Figure 1)
  - Source: NOAA Extended Reconstructed Sea Surface Temperature v4
  - Period: Monthly 1950-2016
- Geopotential Heights at 700, 500, and 300 hPa
  - Source: ECMWF ERA Interim
  - Period: Daily 1981-2016
  - Resolution: 1°x1°
- Surface ozone concentration at Pedregal Station in Mexico City
  - Period: Hourly from 0600 to 2000 local time 1986-2016
- Accumulated Precipitation.
  - Source: ECMWF ERA Interim
  - Period: Daily March 8-13, 2016.
  - Resolution: 0.125°x0.125°

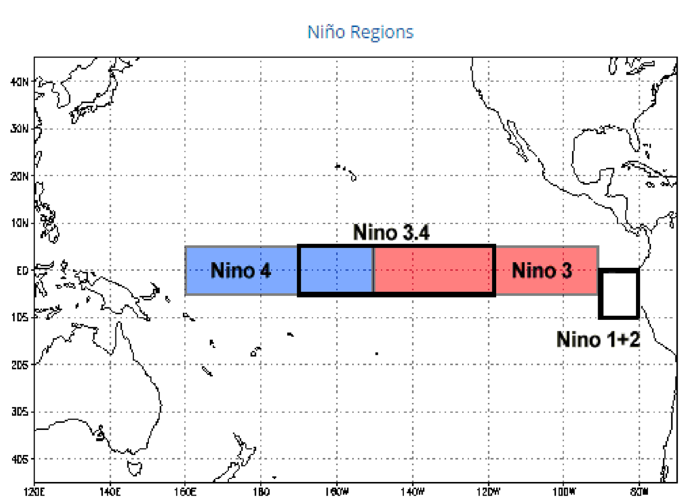

Figure 1. Shows the Niño boxes 1.2, 3, 4, and 3.4.

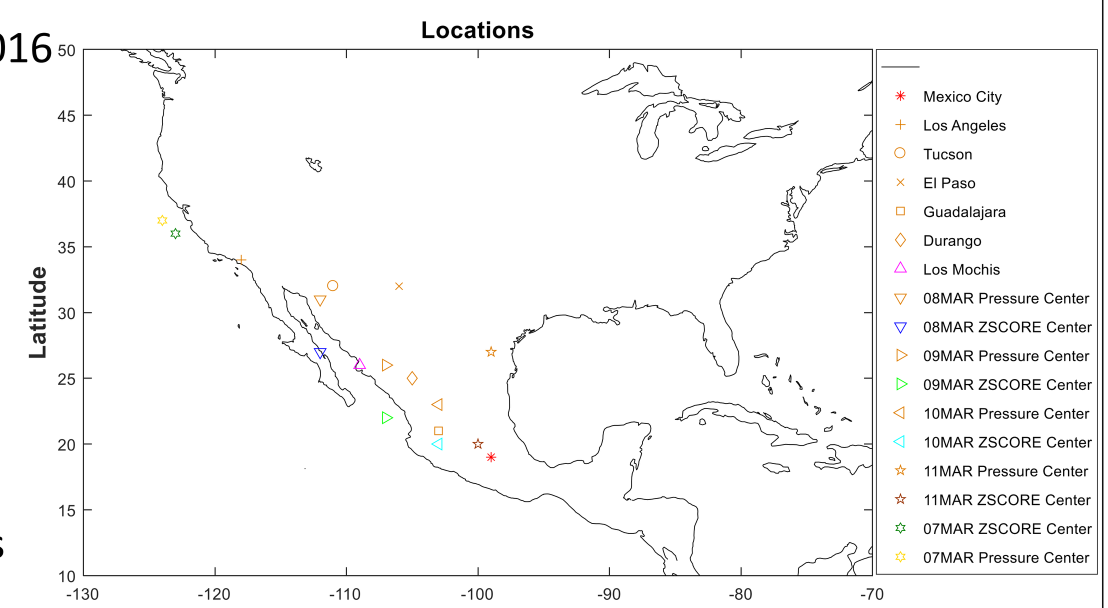

Figure 2. Map shows the locations of analysis performed.

Methodology used in the study were:

- Anomalies were calculated by subtracting the mean from individual values
- Anomalies were standardized (Zscore) by dividing the anomalies by standard deviation
- Locations were selected for comparison of geopotential heights (Figure 2) due to proximity of population centers and nearest grid point to height anomaly centers and Zscore centers

Result 1:

2015-2016 was a year of extremely warm sea surface temperatures in the equatorial Pacific Ocean. In the 1.2 Niño Box, the SST anomaly was the fourth highest recorded since 1950 (Figure 3). In Niño Box 3 and 3.4 the SST anomaly was the 2nd highest recorded (Figure 3). In Niño Box 4, the highest SST anomaly since 1950 was recorded during this time period (Figure 3).This indicates the presence of a strong El Niño event present during 2015 and 2016. In Niño Boxes 1.2, 3, and 3.4 the SST anomaly surpassed 2.5°C during 2016. In 1983 and 1997, Niño Box 1.2 recorded an anomaly beyond 2.5°C. In 1972, Niño Box 1.2 recorded an anomaly of 2.5°C.

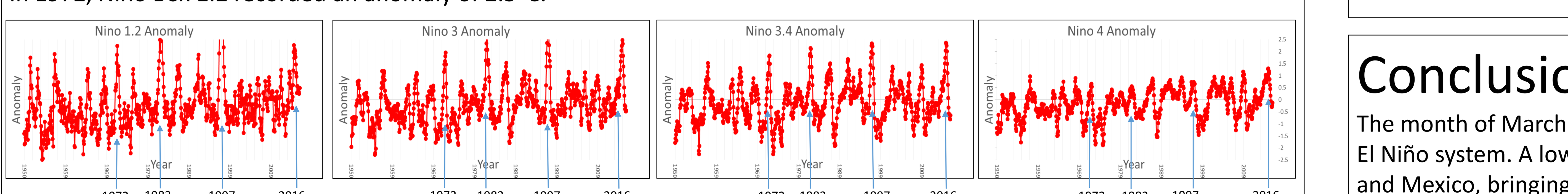

Figure 3. SST anomaly in Niño boxes 1.2, 3, 3.4, and 4.

References:

Barrett, B., Raga,G. (2016). *Variability of winter and summer surface ozone in Mexico City on the intraseasonal timescale.* Atmospheric Chemistry and Physics

Smith, K., Jerrett, M., Anderson, H., Burnett, R., Stone, V., Derwent, R., Atkinson, R., Cohen, A., Shonkoff, S., Krewski, D., Pope, C., Thun, M., Thurstand, G. (2010). *"Health and Climate Change 5: Public Health Benefits of Strategies to Reduce Greenhouse-Gas Emissions: Health Implications of Short-Lived Greenhouse Pollutants."* The Lancet

Result 2:

On March 5th and 6th, 300mb geopotential heights over the North Pacific Ocean resulted in fast zonal flow across the Pacific Ocean (Figure 4). This led to the formation of a 300mb wave on March 7th that would break along the California coast, creating troughs and ridges on March 8th (Figure 4).

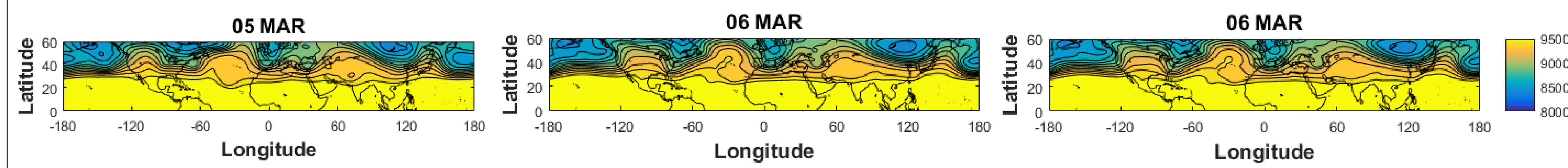

Figure 4. 300 mb geopotential heights on March 5,6,7 across a majority of the Northern Hemisphere.

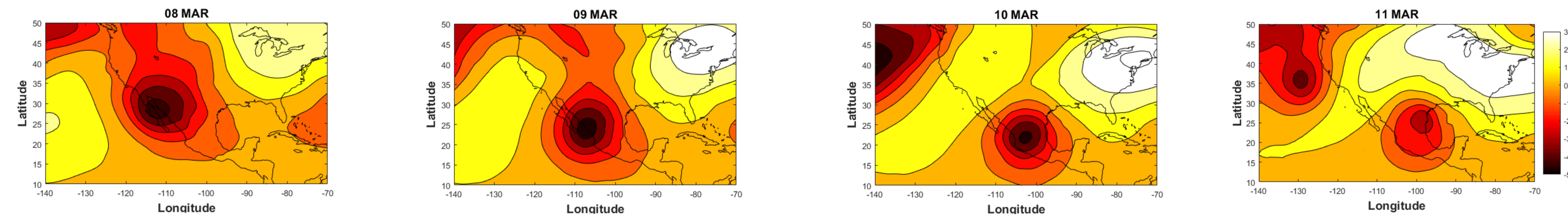

Figure 5. 300 mb anomalies on March 8,9,10,11 while focused on the North American continent.

An extremely deep trough, with heights that had not been observed since before 1981, then traveled across Mexico and the southwest United States (Figures 5,6,7) reaching a low value of 9388.2m in Mexico City. Los Mochis, where the storm came ashore, recorded a low value of 9082.9m on March 9th. The Zscore centers showed a gradual weakening of the system from 9016.7m on March 8th to 9291.9m on March 11th.

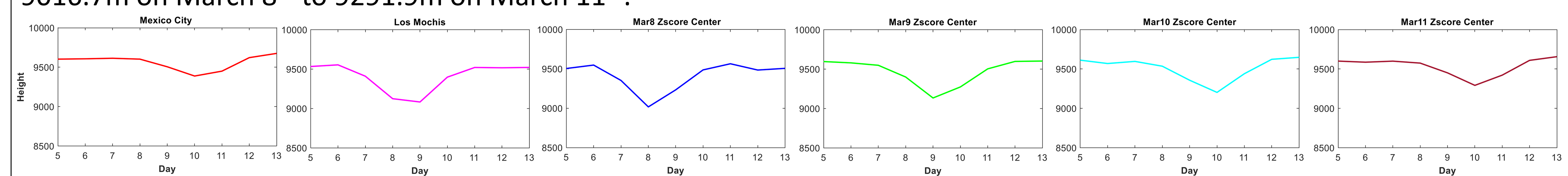

Figure 6. The height at different locations from March 5-13.

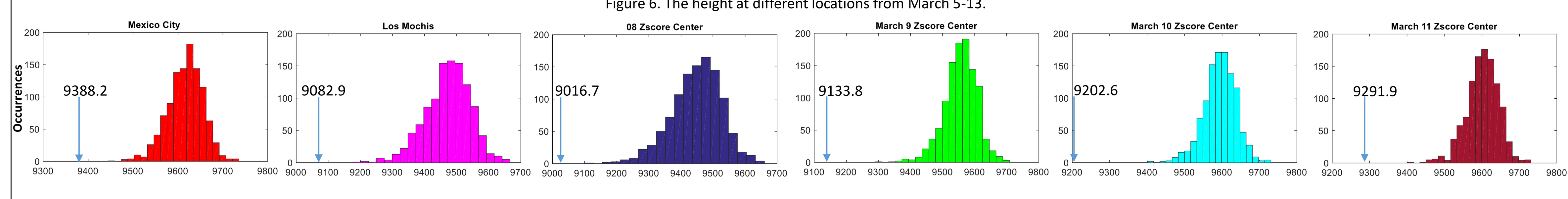

Figure 7. Distribution of heights for location since 1981. Lowest height recorded from March 5-13, 2016 indicated by arrow and value.

Result 3:

Surface ozone concentrations reached extreme levels following the passage of the upper tropospheric trough. Ozone concentrations peaked on March 13, 2016 at 1800 local time. At Pedregal Station ozone concentrations were recorded at 171. That value was among the highest recorded during February-April since 168 in February 2012 and 196 in February 2009.

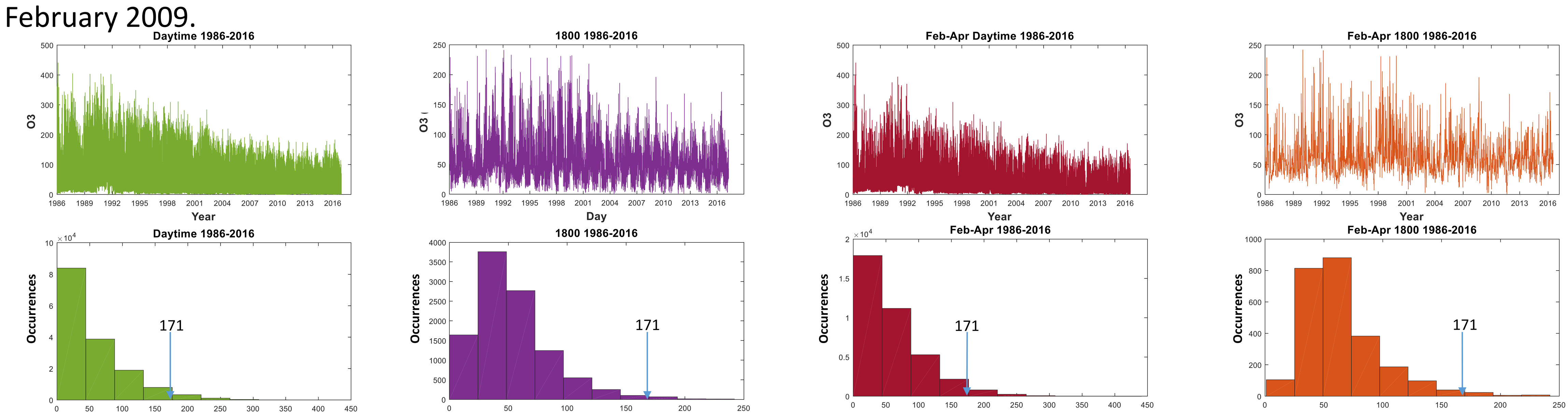

Figure 8. Ozone time series with a histogram indicating the maximum value reached during the event located below. First column on right displays ozone during the daytime for all days since 1986. The second column displays ozone at 1800 for all days since 1986. The third column displays ozone during the daytime for February through April since 1986. The fourth column displays ozone at 1800 for February through April since 1986.

Result 4:

Heavy precipitation also occurred during the passage of the upper-troposphere trough across the Southwestern United States and North Mexico. Areas in the Southeast United States, Gulf of Mexico, and the West Coast of the United States observed over 80 mm.

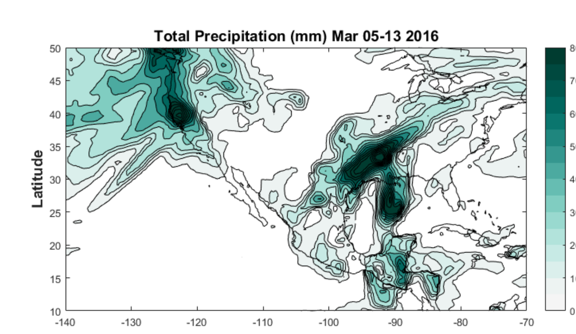

Figure 9. Accumulated precipitation values observed from March 5-13, 2016.

Conclusions

The month of March experienced many extremes in several measures. March 2016 saw a strong El Niño system. A low pressure event developed and traveled across the American Southwest and Mexico, bringing potentially record low geopotential heights. This low pressure event resulted In significant precipitation in the southeast and West Coast of the United States. An active MJO event occurred simultaneously during February and March (Figure 10). These factors together likely resulted in favorable conditions for ozone creation. With a reduced amount of atmosphere due to the low pressure and relatively clear skies free of precipitation, ultraviolet radiation was able to react with nitrogen oxide in Mexico City, and thus result in elevated ozone concentrations.

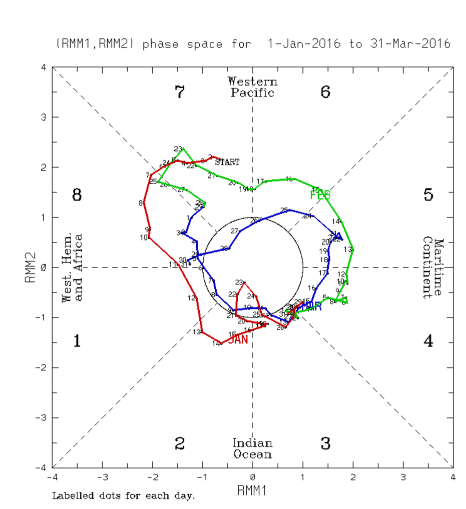

Figure 10. Madden-Julian Oscillation during the months of January, February, and March 2016. Courtesy of the Australian Bureau of Meteorology.