J4.1 IMPACT OF THE MJO ON THE INITIATION OF MESOSCALE CONVECTIVE SYSTEMS OVER THE US CORN BELT

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Abstract

Mesoscale Convective Systems (MCSs) are prolific precipitation producers accounting for between 60 and 75 percent of the warm season precipitation in the United States. While this precipitation can be beneficial, it can also be destructive. To that end, determining what connections MCSs have to specific atmospheric conditions can make the prediction of time and location of initiation of these MCSs easier to achieve. The MCSs used in this analysis were determined using North American Regional Reanalysis (NARR). The NARR MCSs were compared to available satellite data to verify initiation. Once the MCSs were verified, Global Forecast System (GFS) data were downloaded to determine the velocity potential function over the area of the Indian Ocean where the Madden-Julian Oscillation (MJO) occurs. Once the potential function was determined for each day over the warm season in the Indian Ocean, a five day running average (to remove diurnal and synoptic variations) was taken to determine the 30 and 60 day modes of the MJO and how the MJO affects the weather in the Corn Belt region. The propagation of the MJO was observed through the Corn Belt region. The strength of the MJO when it reached potential initiation locations of MCSs was compared to the initiation times and locations of the satellite verified NARR MCSs and a correlation between MCS initiation in the Corn Belt and the strength of the MJO was determined. This study seeks to examine a possible connection between the MJO and the initiation time and location of MCSs within the Corn Belt region in the warm season in 2004 to 2013.

1. INTRODUCTION

The United States Corn Belt is a significant source of the world's corn supply, accounting for 45 percent (Kucharik and Ramankutty 2005), and we rely heavily on corn through our food and ethanol production. Variability in the precipitation would greatly affect the supply. Major precipitation events, such as Mesoscale Convective Systems (MCSs), will provide the majority of the precipitation over the Corn Belt. MCSs account for 60 to 75 percent of the precipitation within the United States, according to Peters and Schumacher (2014). These MCSs can produce copious amounts of precipitation giving rise to flash flooding events (Doswell et al. 1996, Schumacher and Johnson 2005), which can be a major source of damage. Determining any source of variability of these major precipitation events within the Corn Belt region would be beneficial to agriculture, transportation, and municipal waterways within this region.

An MCS has come to refer to a Mesoscale Convective Complex (MCC), a squall line, a bow echo, and any system that meets MCS criteria, but cannot be characterized as an MCC, a squall line, or a bow echo. In terms of MCS distribution in the United States, most of the MCSs initiate between the Rocky Mountains and the Appalachian Mountains (Velasco and Fritsch 1987, Ashley et al. 2003). MCSs are most likely to occur in May through July, according to Jirak et al. (2003), or in May through August, according to Ashley et al. (2003), hence the selection of observing MCSs during the Northern Hemisphere warm season (April through September).

The goal of this study is to determine if the Madden-Julian Oscillation, also known as the MJO, plays any possible role in the initiation of MCSs over the United States Corn Belt. To that end, the MJO is a teleconnection pattern located in the Indian Ocean on a 41-53 day cycle (Madden and Julian 1971, 1994). The MJO resides north of the equator during the boreal summer and south of the equator during the austral summer, typically following, but lagging behind, the patterns of greatest sea surface temperature (Zhang 2005). When the strong, deep convection associated with the MJO occurs, it propagates eastward at roughly 5 meters per second (Zhang 2005). The MJO continues to move eastward after it initiates in the tropics and its signal can be seen in the upper tropospheric zonal winds over the entire globe.

The MJO can be broken down into eight phases (Knutson and Weickmann 1987; shown in Figure 3 of Madden and Julian 1994) which correspond to the location of the MJO convection across the Indian and Pacific Oceans. To determine the current phase of the MJO, Wheeler and Hendon (2004) created an index of the MJO through the use of the 850 mb and 200 mb zonal winds and the satellite observed outgoing long wave radiation data. The Wheeler and Hendon (2004) index, also known as RMM1 and RMM2, was used in this analysis to determine the MCS initiation time relationship to the MJO phase. The index has continued to be calculated by Wheeler (2014).

To determine the MJO's influence over the MCSs initiating in the Corn Belt domain, the Velocity Potential Function was used for this analysis. The Velocity Potential Function was determined through a combination of the continuity equation and the vertical differentiation of the thermodynamic equation, which was derived in Chen and Yen (1991 a, b). An idea of the structure of the convergent/divergent circulation over the globe and Corn Belt can be given by the Velocity Potential Function.

Section 2 details the data and methods used in this analysis. Section 3 outlines results of the MJO phases and Velocity Potential Function in relation to the MCS initiations over the Corn Belt domain. Finally, in Section 4, conclusions concerning the Velocity Potential Function and its relation to the MJO and the MCSs are given.

2. DATA AND METHODS

The first portion of this analysis was to determine the MCS definition. The MCS definition was determined through a compilation of multiple sources including Maddox (1980), Zipser (1982), Bluestein and Jain (1985), Chappell (1986), Fritsch et al. (1986), Augustine and Howard (1988), Augustine and Howard (1991), Doswell et al. (1996), Glossary of Meteorology (American Meteorological Society, 2000), Parker and Johnson (2000), Fritsch and Forbes (2001), Ashley et al. (2003), Jirak et al. (2003), Houze (2004), Schumacher and Johnson (2005), Jirak and Cotton (2007), and Tucker and Li (2009). The MCSs were determined using North American Regional Reanalysis (NARR; Mesinger et al. 2006) model data as a starting source, while satellite and Global Forecast System (GFS) model data were used as verification data sources.

The MCSs were determined and defined as follows. The NARR variables used to determine the MCSs utilized in this analysis were the Categorical Rain and three hour average of the Convective Cloud Cover and were observed over the Corn Belt in the warm season (April through September) for 2004 through 2013. These variables were observed over the 10 state Corn Belt region defined as Kansas, Nebraska, South Dakota, North Dakota, Minnesota, Iowa, Missouri, Illinois, Indiana, and Ohio. The initiation time and location was the three hour NARR window, model run time to three hours after, and where the first convective clouds appeared that would eventually become the MCS. The exact initiation location was the place of maximum convective cloud cover. To complete the MCS definition, the convective cloud cover had to be below -30^{o}C for a minimum of six hours. Categorical rain had to be present, for the same system, in two consecutive frames in NARR with a maximum horizontal extent of at least 100 kilometers. The exact duration and initiation time of the MCS were determined using satellite data.

The Velocity Potential Function values were determined by running GFS (run every 6 hours) through a predetermined FORTRAN code. This FORTRAN code outputted the Velocity Potential Function values over the entire globe (Adams and Swarztrauber 1999). For this analysis, the Velocity Potential Function is (Chen and Yen 1991 a, b, Chen 2003):

$$\chi = \nabla^{-2}[\frac{\partial}{\partial p}(\frac{1}{\sigma c_p}\dot{Q})] - \nabla^{-2}\{\frac{\partial}{\partial p}[\frac{1}{\sigma}(\frac{\partial T}{\partial t} + \vec{v}\cdot\nabla \mathrm{T})]\} \quad (1)$$

From those values, the daily mean was determined. From the daily mean, a five day running mean was obtained for April 1 through September 30. The five day running mean was used to isolate wavenumbers 1 and 2. The five day running mean was run through a 30 to 60 day bandpass filter (Murakami 1979) to determine the MJO effect (and to isolate the MJO signal in the Velocity Potential Function) on the United States Corn Belt. Plots at 850 mb and 200 mb were obtained from the Velocity Potential Function for the entire globe and over the Corn Belt domain.

3. RESULTS

The Velocity Potential Function analysis was done for two years in the time period 2004-2013 and a phase analysis was done for the entire time period (2004-2013), with the phases being determined by Wheeler and Hendon (2004) and Wheeler (2014). The two years which were chosen represent the extremes – 2008, which was a flood/moist year for major portions of the United States Corn Belt region, and 2012, which was a drought/dry year for major portions of the United States Corn Belt region.

3.1 *2004-2013*

The MCS Corn Belt domain initiation locations are shown in Figure 1 with the different colored dots representing different years. Overall, the MCSs are more concentrated in the western and southern portion of the Corn Belt, more specifically, in Kansas, Nebraska, and South Dakota.

The MCS initiation times, as determined by NARR and satellite data, were compared to the phases calculated by Wheeler and Hendon (2004) and Wheeler (2014). Broken down by phase, the MCS counts for the entire time frame and for each year are listed in Table 1. The percentages of MCSs per phase for the entire time frame and for each year are listed in Table 2.

The phase corresponding to the most MCS initiations in 2004 to 2013 in the Corn Belt was Phase 1, but when this is broken down by year, Phase 1 was not always the phase with the most initiations. The dominant phase does vary from year to year.

3.2 *2008 (Flood Year)*

The MCS Corn Belt initiation locations for 2008, a flood year, are shown in Figure 2. The MCS Corn Belt initiation locations are concentrated more in the western portion of the Corn Belt. These Corn Belt MCSs had relatively large horizontal extents and 63 MCSs initiated in the warm season.

The Velocity Potential Function plots, not specific to a certain MJO phase, for the flood year were done at 850 mb (Figure 3) and 200 mb (Figure 4). At 850 mb, there is a relatively strong convergent circulation over the MJO initiation area and there is a convergent circulation present over the Corn Belt domain. This convergent circulation over the Corn Belt domain is larger near the Rocky Mountains where many thunderstorms and MCSs initiate in the early to late afternoon. The area of larger convergent circulation corresponds to the area where a significant portion of the MCS initiations occur over the Corn Belt.

At 200 mb, there is a divergent circulation present that roughly corresponds to the MJO initiation location in the Indian Ocean. The divergent circulation located in the United States Corn Belt domain is relatively weak. Within the Corn Belt itself, the divergent circulation is stronger towards the southern portion of the Corn Belt. A significant portion of the flood year, Corn Belt MCSs initiated within the area of larger divergent circulation at 200 mb.

Included in Tables 1 and 2 is the distribution of phases of the MCSs initiating in the flood year. The count and percentage for 2008 indicate that certain phases are more predominant than other phases. This dominance could indicate MCSs initiating in the Corn Belt, in a flood year, are more likely to initiate in Phase 1 of the MJO cycle, followed by Phase 5, then Phase 2.

3.3 *2012 (Drought Year)*

The MCS Corn Belt initiation locations for 2012, a drought year, are shown in Figure 5. The Corn Belt MCS initiation locations were less concentrated in the drought year than in the flood year and, in the 2012 warm season, there were relatively long periods of no precipitation. While 69 MCSs initiated in the Corn Belt warm season, these MCSs were small and short lived.

The Velocity Potential Function plots, not specific to a certain MJO phase, for the drought year were done at 850 mb (Figure 6) and 200 mb (Figure 7). At 850 mb, the convergent circulation over the MJO initiation area and over the Corn Belt is weaker than what was seen in the flood year. Also, the gradient over the Corn Belt, seen in the flood year, is not present in the drought year.

At 200 mb, the divergent circulation over the MJO initiation region and over the Corn Belt region is stronger than what was seen in the flood year. However, the gradient, present in the flood year over the Corn Belt, is not present in the drought year.

Included in Tables 1 and 2 is the distribution of phases of the MCSs initiating in the drought year. There are certain phases which are more predominant that other phases, as indicated by the count and percentage for each phase. For the drought year, MCSs were more likely to initiate in Phase 1, Phase 2, and Phase 4 of the MJO cycle.

4. CONCLUSION

At 850 mb, the gradient, over the Corn Belt, in the flood year convergent circulation could contribute to the increased precipitation over the Corn Belt. The gradient seen in the flood year is not present in the drought year. Also, the convergent circulation over the MJO initiation area is stronger in the flood year than in the drought year. While at 200 mb, the gradient, over the Corn Belt, in the flood year divergent circulation could contribute to the increased precipitation over the Corn Belt. This gradient is not present in the drought year.

The relatively strong 850 mb convergent circulation and relatively weak 200 mb divergent circulation at the MJO initiation region and in the Corn Belt region, in the flood year, could lead to increased precipitation over the Corn Belt, leading to major flooding. The relatively weak 850 mb convergent circulation and relatively strong 200 mb divergent circulation at the MJO initiation region and in the Corn Belt domain, in the drought year, could be a hindrance to major precipitation events over the Corn Belt, leading to a drought. So, the MJO appears to have an impact on precipitation over the United States Corn Belt with the MJO enhancing the MCS activity (duration and horizontal extent) during the flood year, and the MJO suppressing the MCS activity (duration and horizontal extent) during the drought year.

Future works include determining the velocity potential for every warm season from 2004 to 2013, and, through the use of a different global model, observe the Velocity Potential Function in 1988, another significant drought year for the United States Corn Belt, and 1993, another significant flood year for the United States Corn Belt. Another future work would include an Empirical Orthogonal Function (EOF) analysis of the global and regional (centered on the Corn Belt) Velocity Potential Function. The EOF can be correlated with the flood year MCSs, the drought year MCSs, and the associated precipitation. Also, the precipitation efficiency can be calculated through the individual Velocity Potential Function terms and the entire Velocity Potential Function. To further prove that the MJO does have an effect on MCS activity in the Corn Belt, x-t diagrams of the entire Velocity Potential Function, the individual terms, and the precipitation efficiency would need to be determined.

5. REFERENCES

Adams, J.C., and P.N. Swarztrauber, 1999: SPHEREPACK 3.0: A Model Development Facility. *Mon. Wea. Rev.*, **127**, 1872-1878.

American Meteorological Society, 2000: *Glossary of Meteorology*, American Meteorological Society, 855 pp.

Ashley, W.S., T.L. Mote, P.G. Dixon, S.L. Trotter, E.J. Powell, J.D. Durkee, and A.J. Grundstein, 2003: Distribution of Mesoscale Convective Complex Rainfall in the United States. *Mon. Wea. Rev.*, **131**, 3003 – 3017.

Augustine, J.A., and K.W. Howard, 1988: Mesoscale Convective Complexes over the United States during 1985. *Mon. Wea. Rev.*, **116**, 685-701.

Augustine, J.A., and K.W. Howard, 1991: Mesoscale Convective Complexes over the United States during 1986 and 1987. *Mon. Wea. Rev*., **119**, 1575-1589.

Bluestein, H.B., and M.H. Jain, 1985: Formation of Mesoscale Lines of Precipitation: Severe Squall Lines in Oklahoma during the Spring. *J. Atmos. Sci.*, **42**, 1711-1732.

Chappell, C.F., 1986: Quasi-Stationary Convective Events. *Mesoscale Meteorology and Forecasting*, P.S. Ray, Ed., American Meteorology Society, 289-310.

Chen, T.-C., 2003: Maintenance of Summer Monsoon Circulations: A Planetary-Scale Perspective. *J. Climate*, **16**, 2022-2037.

Chen, T.-C., and M.-C. Yen, 1991a: A Study of the Diabatic Heating Associated with the Madden-Julian Oscillation. *J. Geophys. Res.*, **96**, 13,163-13,177.

Chen, T.-C., and M.-C. Yen, 1991b: Interaction Between Intraseasonal Oscillations of the Midlatitude Flow and Tropical Convection during 1979 Northern Summer: The Pacific Ocean. *J. Climate*, **4**, 653-671.

Doswell, C.A., III, H.E. Brooks, and R.A. Maddox, 1996: Flash Flood Forecasting: An Ingredients-Based Methodology. *Wea. Forecasting*, **11**, 560-581.

Fritsch, J.M., and G.S. Forbes, 2001: Mesoscale Convective Systems. *Severe Convective Storms*, *Meteor. Monogr.*, No. 50, Amer. Meteor. Soc., 323-358.

Fritsch, J.M., R.J. Kane, and C.R. Chelius, 1986: The Contribution of Mesoscale Convective Weather Systems to the Warm-Season Precipitation in the United States. *J. Climate Appl. Meteor.*, **25**, 1333-1345.

Houze, Jr., R.A., 2004: Mesoscale Convective Systems. *Rev. Geophys.*, **42**, doi: 10.1029/2004RG000150.

Jirak, I.L., and W.R. Cotton, 2007: Observational Analysis of the Predictability of Mesoscale Convective Systems. *Wea. Forecasting*, **22**, 813-838.

Jirak, I.L., W.R. Cotton, and R.L. McAnelly, 2003: Satellite and Radar Survey of Mesoscale Convective System Development. *Mon. Wea. Rev.*, **131**, 2428-2449.

Knutson, T.R., and K.M. Weickmann, 1987: 30-60 Day Atmospheric Oscillations: Composite Life Cycles of Convection and Circulation Anomalies. *Mon. Wea. Rev.*, **115**, 1407-1436.

Kucharik, C.J., and N. Ramankutty, 2005: Trends and Variability in U.S. Corn Yields over the Twentieth Century. *Earth Interact.*, **9**, 1-29.

Madden, R.A., and P.R. Julian, 1971: Detection of a 40-50 Day Oscillation in the Zonal Wind in the Tropical Pacific. *J. Atmos. Sci*., **28**, 702-708.

Madden, R.A., and P.R. Julian, 1994: Observations of the 40-50 Day Tropical Oscillation – A Review. *Mon. Wea. Rev.*, **122**, 814-837.

Maddox, R.A., 1980: Mesoscale Convective Complexes. *Bull. Amer. Meteor. Soc.*, **61**, 1374-1387.

Mesinger, F., G. DiMego, E. Kalnay, K. Mitchell, P.C. Shafran, W. Ebisuzaki, D. Jovic, J. Woollen, E. Rogers, E.H. Berbery, M.B. Ek, Y. Fan, R. Grumbine, W. Higgins, H. Li, Y. Lin, G. Manikin, D. Parrish, and W. Shi, 2006: North American Regional Reanalysis. *Bull. Amer. Meteor. Soc*., **87**, 343-360.

Murakami, M., 1979: Large-scale Aspects of Deep Convective Activity over the GATE Area. *Mon. Wea. Rev.*, **107**, 994-1013.

Parker, M.D., and R.H. Johnson, 2000: Organizational Modes of Midlatitude Mesoscale Convective Systems. *Mon. Wea. Rev.*, **128**, 3413-3435.

Peters, J.M., and R.S. Schumacher, 2014: Objective Categorization of Heavy-Rain-Producing MCS Synoptic Types by Rotated Principal Component Analysis. *Mon. Wea. Rev.*, **142**, 1716-1737.

Schumacher, R.S., and R.H. Johnson, 2005: Organization and Environmental Properties of Extreme-Rain-Producing Mesoscale Convective Systems. *Mon. Wea. Rev*., **133**, 961-976.

Tucker, D.F., and X. Li, 2009: Characteristics of Warm Season Precipitating Storms in the Arkansas-Red River Basin. *J. Geophys. Res.*, **114**, D13108, doi: 10.1029/2008JD011093.

Velasco, I., and J.M. Fritsch, 1987: Mesoscale Convective Complexes in the Americas. J. Geophys. Res., 92, 9591-9613.

Wheeler, M., cited 2014: An All-Season Real-Time Multivariate MJO Index. [Available online at: cawcr.gov.au/staff/mwheeler/maproom/RMM/.]

Wheeler, M.C., and H.H. Hendon, 2004: An All-Season Real-Time Multivariate MJO Index: Development of an Index for Monitoring and Prediction. *Mon. Wea. Rev.*, **132**, 1917-1932.

Zhang, C., 2005: Madden-Julian Oscillation. *Rev. Geophys.*, **43**, doi:10.1029/2004RG000158.

Zipser, E.J., 1982: Use of a Conceptual Model of the Life of Mesoscale Convective Systems to Improve Very-Short-Range Forecasts. *Nowcasting*. K. Browning, Ed., Academic Press, 191-204.

6. FIGURES AND TABLES

Phase	All	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
1	134	19	13	11	15	16	9	18	9	13	11
2	98	9	14	8	15	8	5	14	9	10	6
3	64	11	7	3	3	7	2	12	9	7	3
4	84	4	11	4	7	5	15	8	5	13	12
5	93	1	10	8	15	9	8	7	15	9	11
6	62	6	5	7	4	6	10	2	14	3	5
7	70	14	6	8	8	5	11	2	5	5	6
8	99	4	9	16	7	7	13	5	10	9	19

Table 1: Count for the MCSs present in each phase of the MJO for the time period 2004 to 2013.

Phase	All	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
1	19.0	27.9	17.3	16.9	20.3	25.4	12.3	26.5	11.8	18.8	15.1
2	13.9	13.2	18.7	12.3	20.3	12.7	6.8	20.6	11.8	14.5	8.2
3	9.1	16.2	9.3	4.6	4.1	11.1	2.7	17.6	11.8	10.1	4.1
4	11.9	5.9	14.7	6.2	9.5	7.9	20.5	11.8	6.6	18.8	16.4
5	13.2	1.5	13.3	12.3	20.3	14.3	11.0	10.3	19.7	13.0	15.1
6	8.8	8.8	6.7	10.8	5.4	9.5	13.7	2.9	18.4	4.3	6.8
7	9.9	20.6	8.0	12.3	10.8	7.9	15.1	2.9	6.6	7.2	8.2
8	14.1	5.9	12.0	24.6	9.5	11.1	17.8	7.4	13.2	13.0	26.0

Table 2: Percentage for the MCSs present in each phase of the MJO for the time period 2004 to 2013.

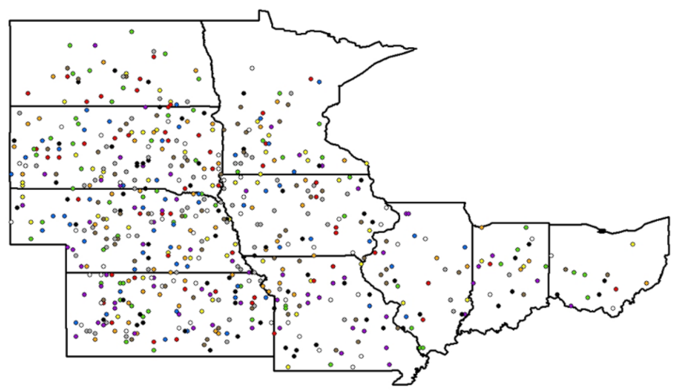

Figure 1: Map of all MCSs initiating in the 2004-2013 time frame. The different dot colors correspond to different years.

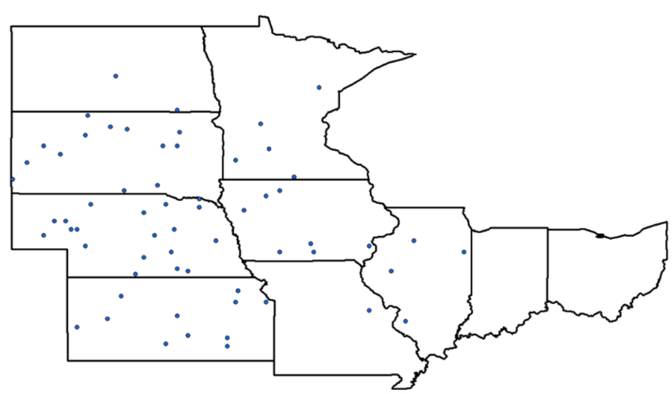

Figure 2: Map of MCSs initiating in 2008.

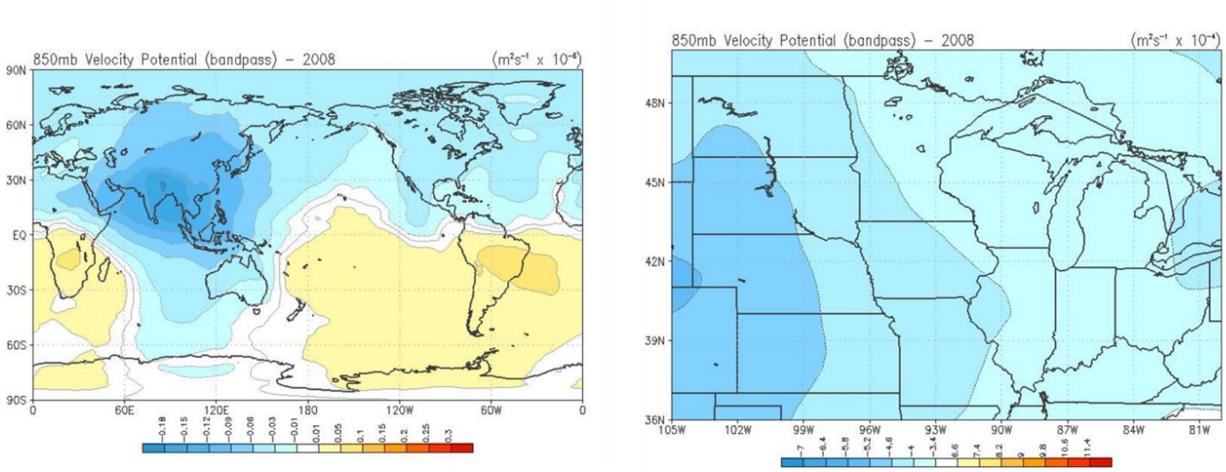

Figure 3: 850 mb Velocity Potential Function in 2008 over the entire globe (left) and centered over the United States Corn Belt domain (right). Blues indicate convergence and oranges indicate divergence. The scales of the two maps do not match.

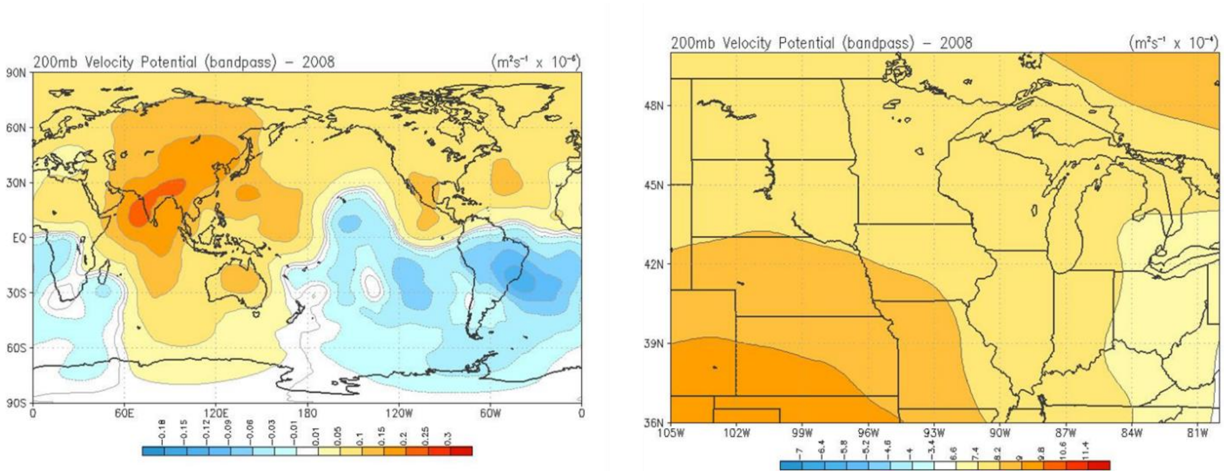

Figure 4: 200 mb Velocity Potential Function in 2008 over the entire globe (left) and centered over the United States Corn Belt domain (right). Blues indicate convergence and oranges indicate divergence. The scales of the two maps do not match.

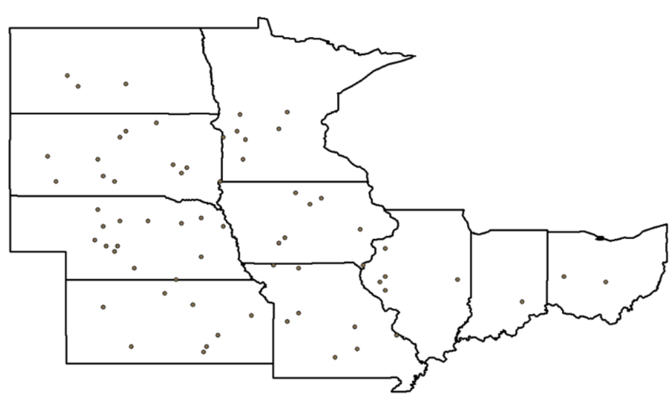

Figure 5: Map of MCSs initiating in 2012.

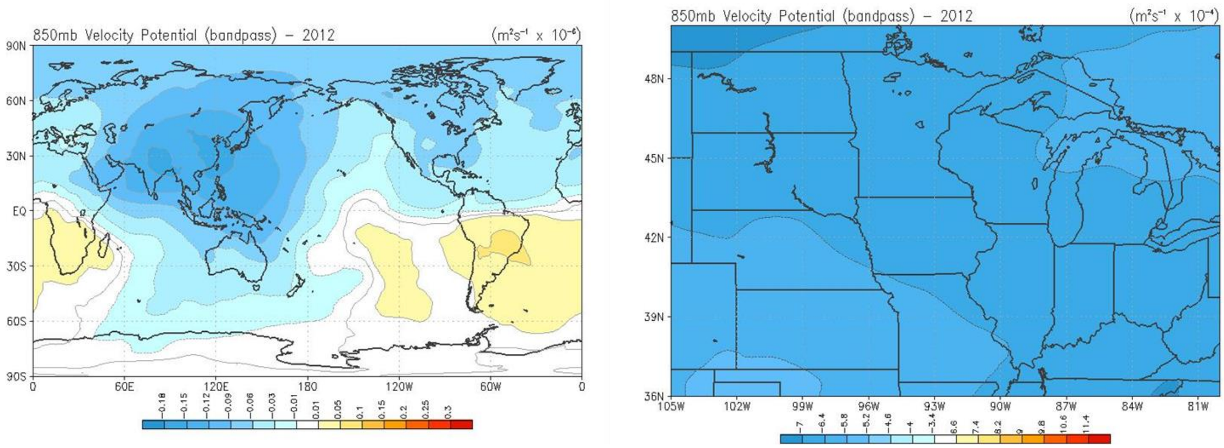

Figure 6: 850 mb Velocity Potential Function in 2012 over the entire globe (left) and centered over the United States Corn Belt domain (right). Blues indicate convergence and oranges indicate divergence. The scales of the two maps do not match.

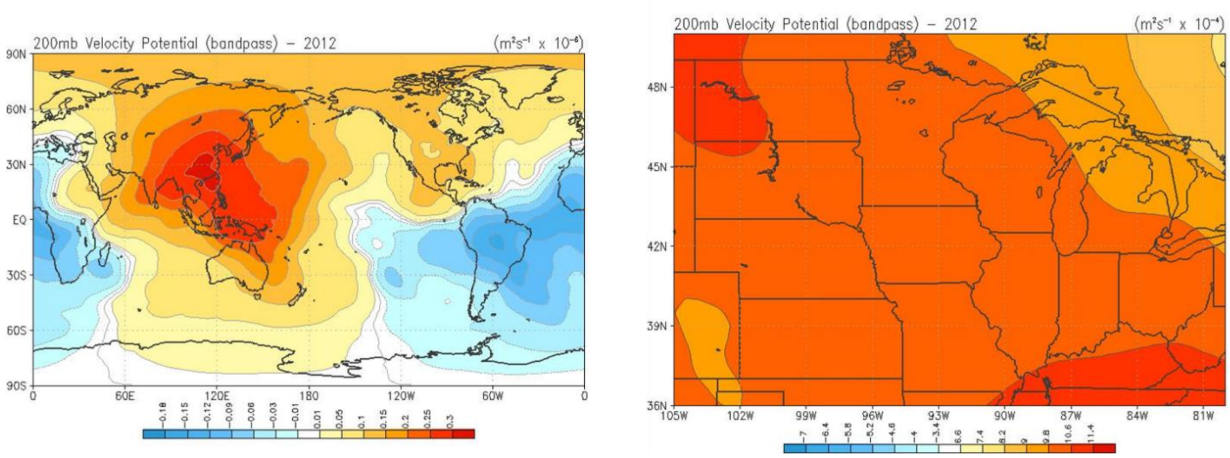

Figure 7: 200 mb Velocity Potential Function in 2012 over the entire globe (left) and centered over the United States Corn Belt domain (right). Blues indicate convergence and oranges indicate divergence. The scales of the two maps do not match.