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MJO Influence in Continental United States Temperatures

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MJO Influence in Continental United States Temperatures

An honors thesis presented to the
Department of Atmospheric Science,
University at Albany, State University Of New York
in partial fulfillment of the requirements
for graduation with Honors in Atmospheric Science
and
graduation from The Honors College.

Ernesto W. Findlay

Research Mentors: Nicholas Schiraldi, B.A and Philippe Pappin, M.A.

Research Advisors: Paul Roundy, Ph.D and Lance Bosart Ph.D

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Abstract

Heat and cold episodes in the continental United States (U.S.) affect millions of people each year. Severe episodes can cause crop damage, power failure, heat stress and hypothermia. The predictability of these extreme events decreases significantly after one week. It is, therefore, essential for scientists to discover new ways to forecast these events weeks in advance, which will provide society ample of prior warning to prepare. The Madden-Julian Oscillation (MJO) is one of the largest drivers of weather in the tropics (Madden and Julian 1971, 1994). Previous studies have found relationships between the MJO and midlatitude modes of climatic variability, such as the Pacific-North American mode (PNA), the Arctic Oscillation (AO), and the North Atlantic Oscillation (NAO) (Zhou and Miller 2005; L'Heureux and Higgins 2008). Little work has been done on the relationship between the magnitude of cold (warm) events and the MJO amplitude. This study will focus in looking into what type of MJO events lead to a strong cold (warm) events over the Continental United States.

Acknowledgment.

The images were provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at <http://www.esrl.noaa.gov/psd/>". Also, a special thanks to Philippe Pappin for his technical support in the use of NCL throughout this project. Finally, to Paul Roundy, Lance Bosart and Nicholas Schiraldi for their advisement and help in editing this thesis.

Introduction

Heat and cold episodes in the continental United States (U.S.) affect millions of people each year. Severe episodes can cause crop damage, power failure, heat stress and hypothermia. The predictability of these extreme events decreases significantly after one week. It is, therefore, essential for scientists to discover new ways to forecast these events weeks in advance, which will provide society ample of prior warning to prepare. The Madden-Julian Oscillation (MJO) is one of the largest drivers of weather in the tropics (Madden and Julian 1971, 1994). Previous studies have found a relationship between the MJO and midlatitude modes of climatic variability, such as the Pacific-North American mode (PNA), the Arctic Oscillation (AO), and the North Atlantic Oscillation (NAO) (Zhou and Miller 2005; L'Heureux and Higgins 2008). Tropical convection associated with the MJO affects circulation patterns in the midlatitudes because it redistributes mass, which results in large-scale overturning circulations and Rossby wave trains that extend eastward and poleward from the source convection (Sardeshmukh and Hoskins 1988). Thus, the MJO impacts the weather over the continental United States. Further studies by Zhou (2011) suggest that during phases 4, 5, 6, and 7, the MJO has a strong influence on above (below) normal temperatures and precipitation anomalies over the eastern (western) United States, while in phases 8 and 1 this pattern reverses. Conversely, two weeks after the MJO passes through phases 4, 5, and 6, there is a trough over the East Coast and anomalously cold temperatures. These patterns occur primarily during the winter months. During the summer there is not a significant signal between the location of active convection associated with the MJO and weather patterns in the United States. Therefore, understanding the structure and the evolution of the MJO can help to understand the variation of large temperature and precipitation

anomalies associated with floods, heat and cold events, and potentially forecast their onset weeks in advance. This study not only focuses on winter influence, but throughout all seasons.

Data and Methodology

This study breaks down into two parts, the first part focuses on how a strong phase 6 MJO event affects temperatures across the eastern United States. The second part focuses on identifying what type of MJO events (location, and strength) result in extreme cold (warm) temperatures anomalies across the United States.

Part I

This study applies the Wheeler and Hendon (2004) real time multivariate MJO (RMM) index to identify the 10 strongest MJO events during December through February. Although not a perfect tracer of the MJO, this index conveniently sorts the conditions on each day into values of amplitude in one of 8 phases that approximately represent the longitude range of MJO convection. An event is defined by selecting the top 10 the highest MJO amplitude events during the Real-Time Multivariate MJO (Wheeler and Hendon 2004) phase 6 (suggesting convection over the western Pacific basin), if the amplitude decreases and another maximum occurs within the same episode, it is counted as an event as long as it is at least four days apart from the previous maximum. After selecting all of the events, a composite of interpolated Outgoing Longwave Radiation (OLR) and 300 hPa streamfunction anomalies is constructed over the entire globe. The results are used to analyze the structure of the MJO and its associated streamfunction anomalies. The 300 hPa streamfunction anomalies are lagged forward to track the downstream response by Rossby wave propagation. When the wave train reaches the U.S., mean and anomaly composites are constructed for 500 hPa heights, 925 hPa temperatures, 300 hPa winds, and precipitation to analyze to climatological patterns related to the Rossby wave response to the

MJO. All composites are constructed using data archived from the Earth System Research Laboratory (ESRL), using the National Centers of Environmental Prediction /National Center for Atmospheric Research (NCEP/NCAR) reanalysis Dataset.

Part II

There are three geographical regions studied in this project: the Great Lakes and New England States (50N-32N, 70W-88W), Great plains (50N-32N, 88W-106W), Rocky mountains, and West coast (50N-32N, 106W-124W). The focus seasons are December, January, February (DJF), March, April, May (MAM), June, July, August (JJA) and September, October, November (SON). NCEP/NCAR daily temperature data from 1979-2010 are used in this project. The daily mean temperature are calculated will be subtracted from the daily climatology to create anomalies. This then will be divided by the daily standard deviation, finally, this will be averaged over all grid points confined in each box to create daily standardized anomalies over each box for each day of the year. A heat event will be defined as any standardized anomaly that exceeds + 1.5 for a period of two consecutive days, while a cold event will be defined as any event that is -1.5 for two consecutive days. These events separated to both warm and cold events, and plotted in a phase diagram for the entire year and the four different seasons.

Results

Part I

a. MJO and Streamfunction Anomalies at day Lag 0

This section will focus on the structure of the MJO during the composite day lag 0 and its associated streamfunction anomalies. The MJO is located east of Indonesia (Fig.1), which will be expected for a phase 6 MJO event. There is a strong negative anomaly of OLR associated with the active convection from the MJO. This anomalous active convection is enhancing a positive streamfunction anomaly to the north of the area of convection (Fig.2),

this is because of the rising motion from the convection is creating divergence aloft, this flow then gets torqued to the right by the Coriolis force, which turns the flow more anticyclonic, generating positive streamfunction in the Northern Hemisphere. Furthermore, notice that there is a streamfunction minimum to the north of the streamfunction maximum which enhances the streamfunction gradient, as a result an anomalously westerly jet is located along Japan.

b. Streamfunction Anomaly propagation response to the U.S.

This section will focus on the track of the streamfunction anomaly across the Pacific as it approaches the U.S.. Three days after the initial development of the positive streamfunction anomaly (Fig.3), the anomaly has intensified caused by the continuous intense convection from the MJO, which continues add anticyclonic flow, as a result enhances the anticyclonic rotation anomaly. This signal has propagated eastward as the mean flow is westerly. The streamfunction minimum to the north intensifies, which enhances the westerly jet across the central northern Pacific. At day 6 (Fig.4), the anomaly has propagated to Hawaii, the minimum to the north has intensified and the anomalous westerly jet continued to move closer to the U.S. Also, notice the split in the streamfunction positive anomaly, which at day 9 (Fig.5) has disappeared leaving behind the main anomaly. Finally, at day 12 (Fig.6) the streamfunction maximum has moved into the Pacific Northwest. Located to the northwest is the minimum in streamfunction anomaly, which brings the anomalous westerly jet into Alaska. Therefore, it takes approximately 12 days for the downstream response of the MJO to reach the U.S, in the next section the mean climatology of this response is analyzed.

c. Mean and Anomaly weather pattern related to MJO response.

Analyzing the mean and anomaly patterns of geopotential height at 500 hPa (Figs.7 and 8), results show that there is an anomalous trough (-100 m) over the eastern U.S., while there is anomalous ridging over the central plains. Furthermore, there is a maximum of positive anomalies just off the coast of the Pacific Northwest. This signals is associated with a positive streamfunction anomaly at the west coast and a negative streamfunction anomaly at the east coast (Fig. 6). Finally, there is an anomalous through or cutoff low in the southwestern parts of the U.S. (-40m). In relationship to temperatures (Figs.9 and 10), there are anomalously low 925hPa temperatures over the eastern U.S (-4 K). Anomalously warm temperatures are located over the southwestern parts of the U.S. Cold temperature anomalies are due to northwesterly flow (Fig.11) over the region; flow from this direction will bring in cold arctic air from Canada. This northwesterly flow is due to a strong negative height anomaly to the northeast and a positive height anomaly to the southwest shown in Fig.8. The warm temperature anomalies over the southwestern parts of the U.S. are caused by an easterly wind anomaly (Fig.11); wind from this direction brings in air from the Gulf of Mexico which is relatively warmer than their climatological southwesterly flow from the comparatively cooler waters of the Pacific Ocean.

Precipitation rate anomalies are shown in Fig. 12. Negative anomalies are located over the eastern parts of the U.S. and the Pacific Northwest. These anomalies result from anomalously northwesterly flow from Canada that brings in colder and drier air to the eastern parts of the U.S. As a result of this cold air, the atmosphere is not able to contain as much water vapor as

it would in higher temperatures. In addition, the Pacific Northwest is under anomalous ridging, which moves the Pacific jet farther north along with its weather disturbances and moisture. Furthermore, it brings in anomalous northeasterly flow from Canada which comes from a continental air mass. There are positive precipitation rate anomalies along southern Texas into the desert southwest. These anomalies are consistent with advection of warm moist air from over the Gulf of Mexico.

In general, the MJO response in the U.S. takes an average of 12 days. Positive and negative height anomalies caused by this response are tied in with negative and positive anomalies in the fields of 925 hPa temperatures and precipitation.

Part II

1. Eastern United States

a. Cold Events

Figure 13 suggests that cold events in the eastern U.S. tend to have weak (amplitude <1) RMM signals. Furthermore, these strong events that do occur are mainly located over phase 7, with a few events located over phases 8 and 1. It can be hypothesized that the strong events in phase 7 may have occurred outside the DJF period, since results from Zhou 2011 suggest that warm events occur during this phase across eastern U.S.

While analyzing the different seasons, it was observed there was not a clear pattern in terms of the location of the MJO as identified by RMM phase during the winter and summer months (Figs. 14 and 16). This result may imply that other factors contribute to these anomalies, which merit further study. Nevertheless during the winter months, there is a cluster of events with amplitude greater than one located over phases 3 and 4.

Conversely, there is a clearer pattern when the MJO is located mainly in phases 7, 8 and 1 during the transition months (Figs. 15 and 17).

b. Warm Events

In Figure.18, strong events tend to be located in phases 5 and 6. There is also a cluster of weaker events that occur between phases 2 and 3, which suggest that warm events occur in weaker MJO events.

When analyzing the different seasons, many of the strong events occurred in phase 5 during the winter months (Fig.19), with another cluster in phase 4 which all occurred in one event. During the spring (Fig.20), the pattern is more defined with a bimodal distribution of strong events occurring during phases 5, 6, 8 and 1. The summer and fall months were not plotted as there was a small sample size.

2. Central United States.

a. Cold events

In the yearly composite (Fig. 21), there is not a pattern in the location of MJO events with respect to cold events because there is an even distribution of strong and weak events over all phases. On the other hand, when examining the different seasons, a pattern becomes apparent. During the winter, spring, summer, and fall months, phases 7-2 (Fig. 22), 2-4 (Fig.23), 6-8 (Fig.24), and 4-6 (Fig.25) become more favorable for cold events, respectively. This is an interesting results in which cold outcomes tend to occur in different phases throughout the seasons.

b. Warm events

During these events phases 5 and 6 are the most favorable for warm outcomes (Fig.26). Many of these events only occur during the transition seasons as standard deviation is large during the winter and summer season in the upper Midwest. During the spring (Fig. 27) phases 5 and 6 is the most evident maximum, with another small maximum in phase 3. During the fall (Fig.28) the pattern is more define as almost all of the events occurred during phase 6.

3. Western United States.

a. *Cold events.*

The yearly composite (Fig. 29) suggests that there is not a significant pattern in MJO location with cold events in the Western United States but there tends to be a higher concentration of strong events in phases 1-3. Seasonal patterns, suggest a higher frequency of strong events in phases 7 and 1 during the winter season (Fig. 30). During the spring (Fig. 31) the MJO tends to be located in the left side of the RMM phase diagram (phases 7-2), in the fall (Fig.32) phases 7, 1 and 2 are the most frequent for these cold events.

b. *Warm events*

When analyzing the association between the RMM index and western US temperatures over the entire year (Fig. 33), there is not a significant pattern in MJO location, but there tends to be a higher concentration of strong events in phases 3, 5, 6 and 7. When examining the seasonal patterns, there tends to be a higher frequency of strong events in phases 6-8 during the winter season (Fig.34). During the spring (Fig. 35) the MJO does not show a pattern into where there is a higher frequency of events as a function of RMM phase, in the fall (Fig.36) phases 5-7 are the most frequent for

these cold events. This result suggests that events on the west coast are also driven by other factors not just the MJO.

Conclusion

In conclusion, the MJO is associated with substantial variability in continental U.S. temperatures and precipitation. This signal has been associated with a response to MJO convection in the atmospheric circulation that is expressed well in the streamfunction field. Results suggest that this signal takes about two weeks to reach the U.S.. Results suggest that eastern parts of the U.S are cold and dry during this period. In contrast, western parts of U.S. are warm, in addition to above normal precipitation in the southwestern parts of the U.S. and below normal precipitation in the northwest. Therefore, understanding the MJO response through the analysis of the anomaly fields of streamfunction or any other important anomaly fields can help forecast the onset of cold, warm, dry, and wet extreme events in the United States weeks in advance. In the eastern United States strong MJO events that are related to cold events tend to occur during the transitions season during phases 7, 8 and 1, strong events tend to be located in phases 5 and 6 in warm events. In the Central United States there is an event distribution of MJO events per phase for cold events, but cold events during specific seasons tend to be better associated with MJO events are more confined in specific regions in the phase diagram. Results suggest that warm events tend to occur in phase 5 and 6. Finally, in the Western United States there is not a clear pattern into which MJO events is more favorable during either warm or cold events. These results suggest that there are many other factors that are contributing to these events which will need to be studied further.

Figure and tables

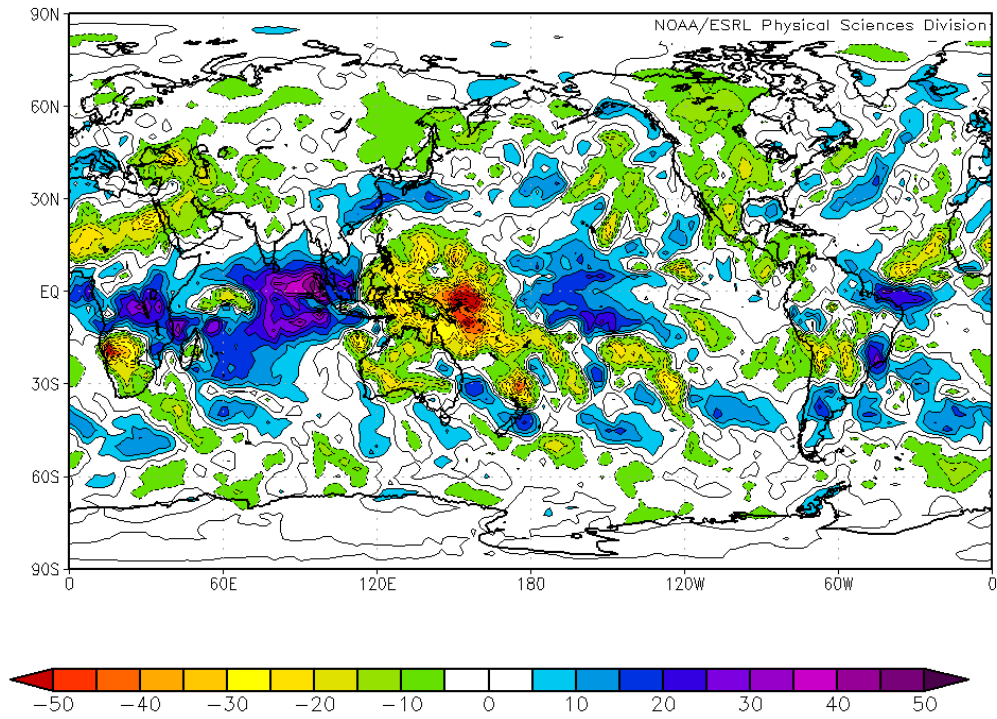


Fig.1 NOAA Composite interpolated OLR anomaly(K) for day lag 0. Negative anomalies correspond with active convection, while positive anomalies correspond with suppressed convection.

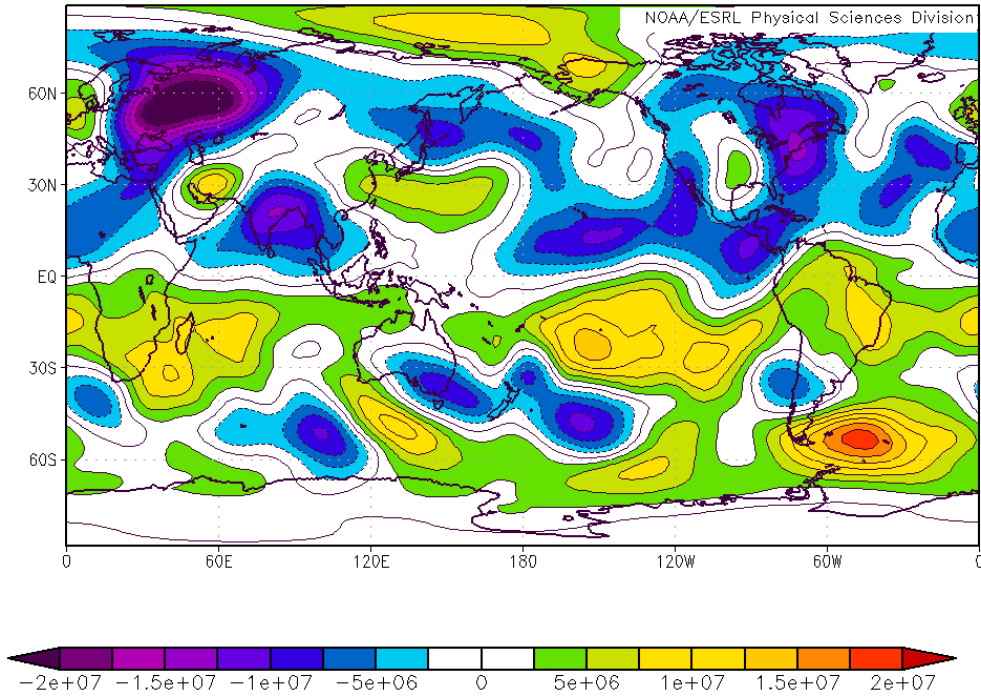


Fig.2 Composite of 300 hPa Streamfunction anomalies($m^2 s$) at day lag 0

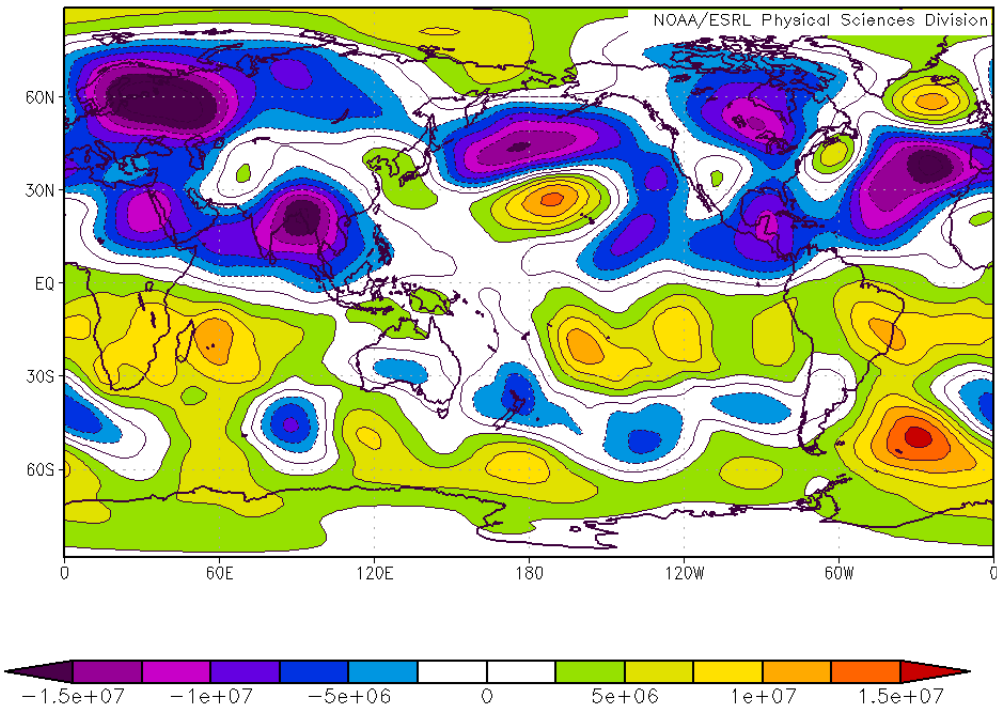


Fig.3 Composite of 300 hPa Streamfunction anomalies($m^2 s$) at day lag 3

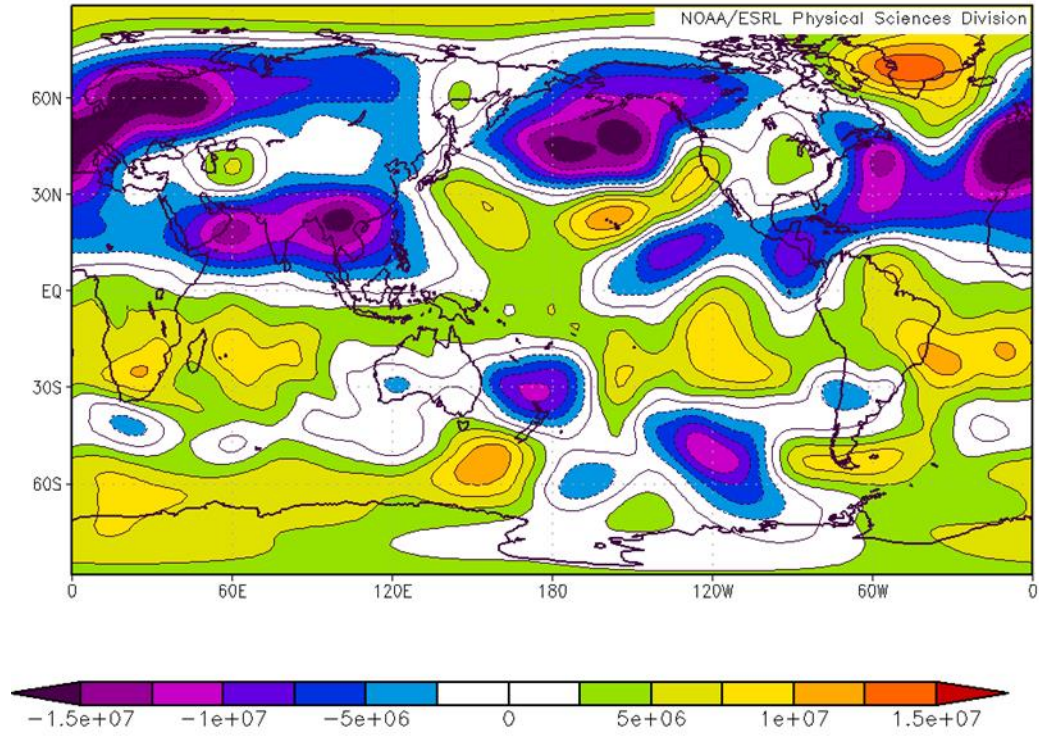


Fig.4 Composite of 300 hPa Streamfunction anomalies($m^2 s$) at day lag 6

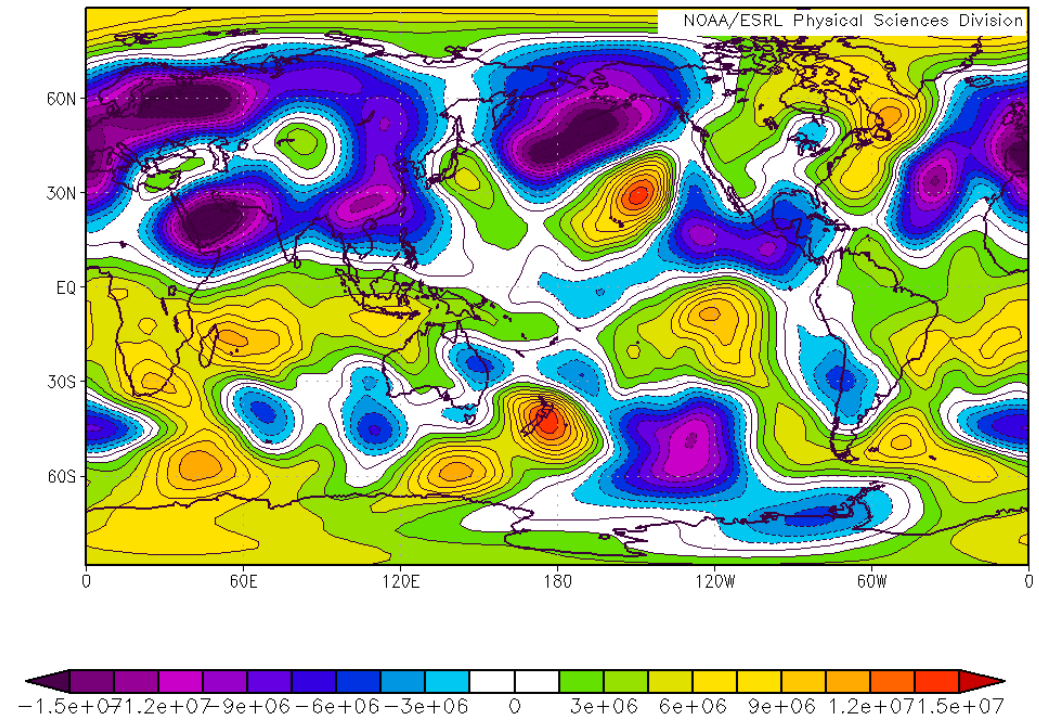


Fig.5 Composite of 300 hPa Streamfunction anomalies($m^2 s$) at day lag 9

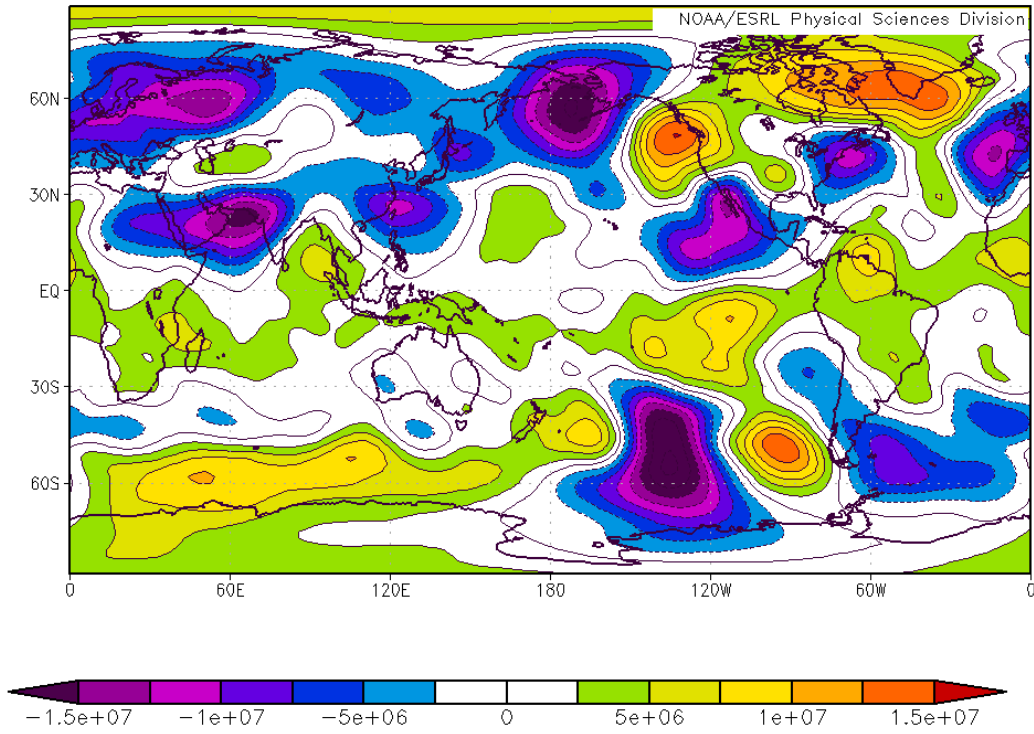


Fig.6 Composite of 300 hPa Streamfunction anomalies($m^2 s$) at day lag 12

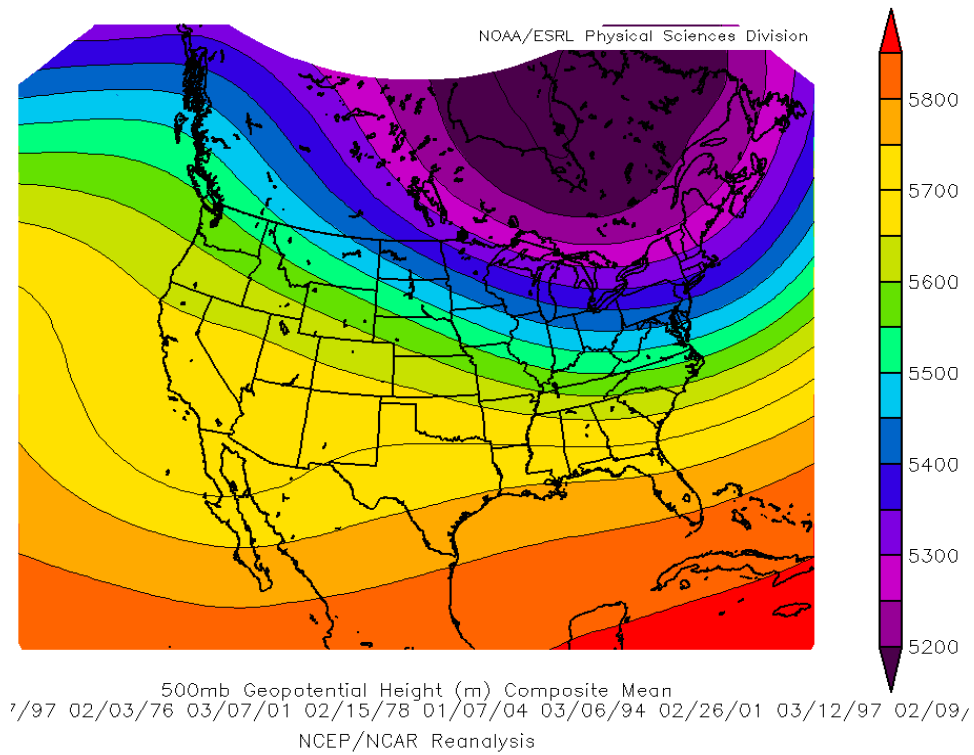


Fig.7 Composite of mean 500 hPa geopotential heights(m) day lag 12

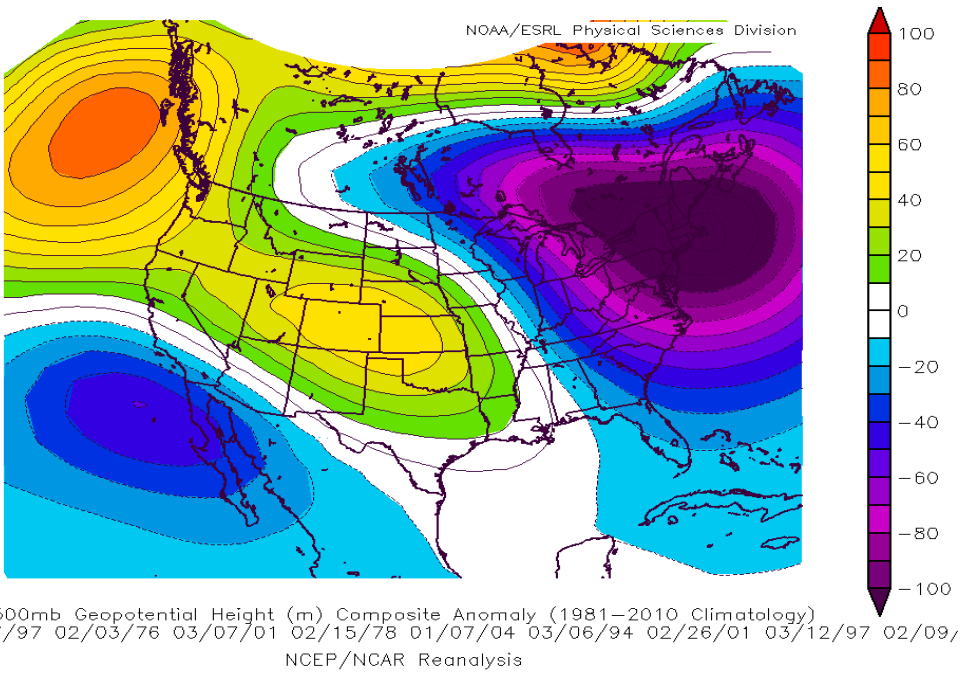


Fig.8 Composite of 500 hPa geopotential heights anomalies (m) at day lag 12

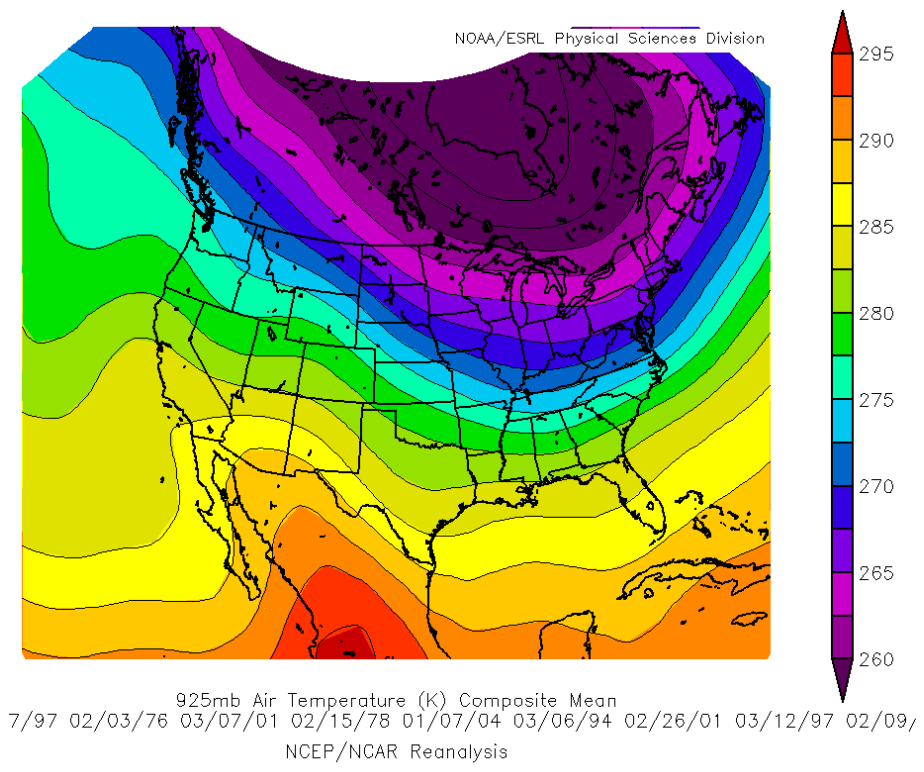


Fig.9 Composite of mean 925 hPa air temperatures(K) at day lag 12

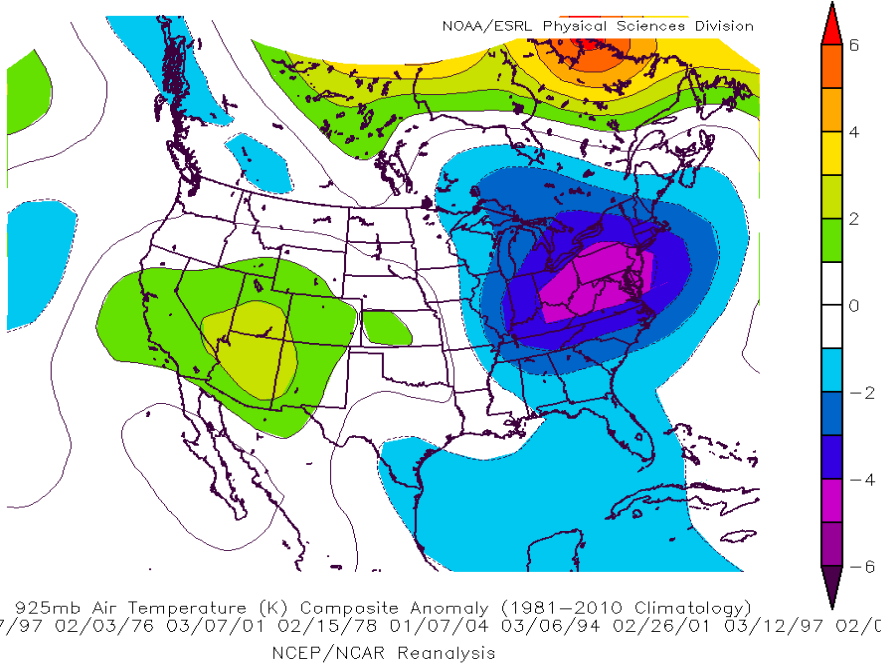


Fig.10 Composite of 925 hPa air temperatures anomalies(K) at day lag 12

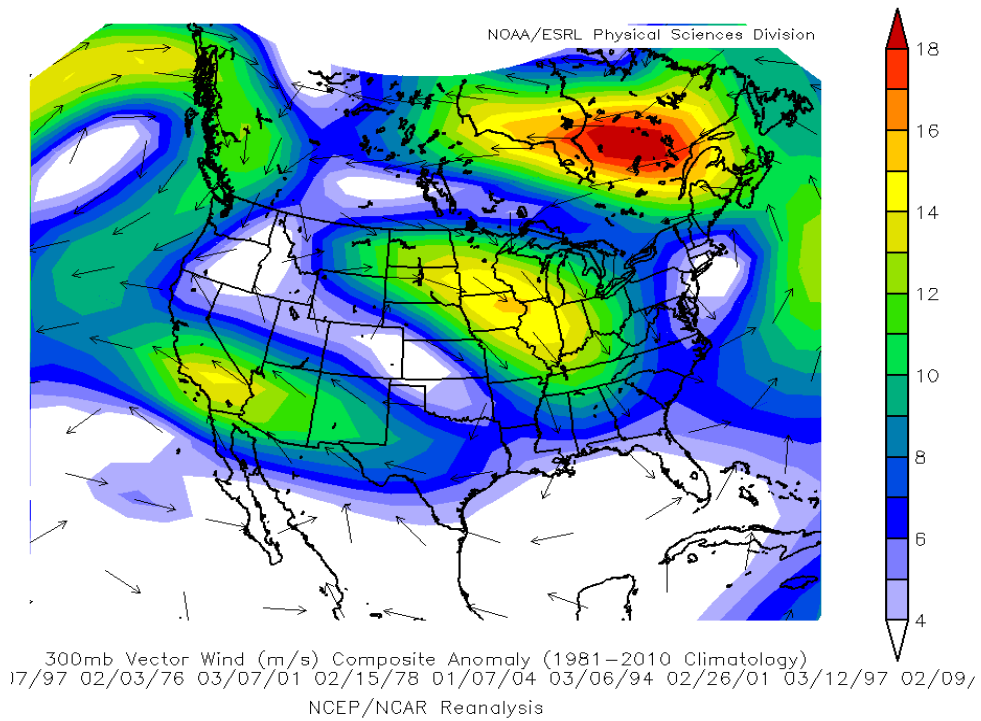
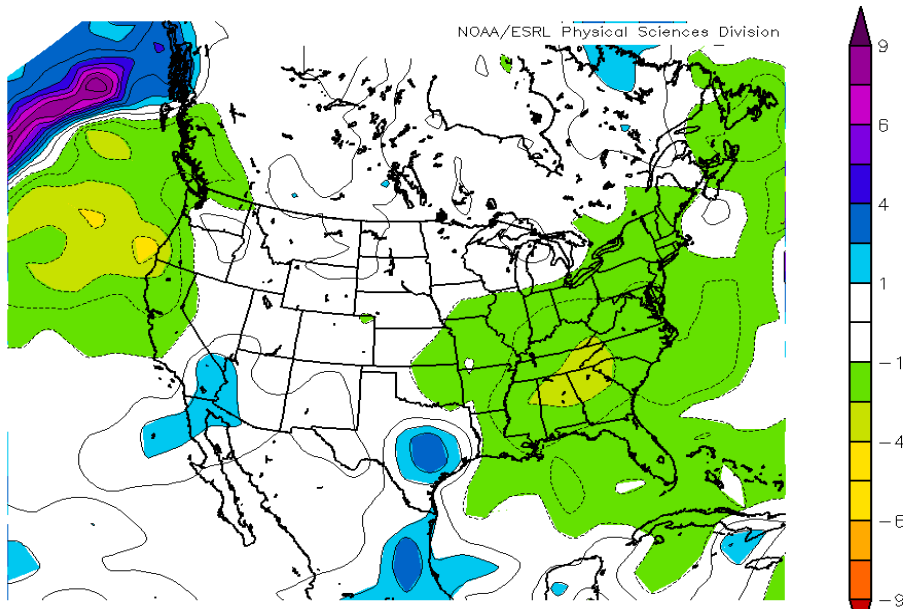


Fig.11 Composite of 300 hPa vector wind anomalies(m/s) at day lag 12



Surface Precipitation Rate (mm/day) Composite Anomaly (1981–2010 Climatology)
 /07/97 02/03/76 03/07/01 02/15/78 01/07/04 03/06/94 02/26/01 03/12/97 02/09/
 NCEP/NCAR Reanalysis

Fig.12 Composite of precipitation rate anomalies (mm/day) at day lag 12

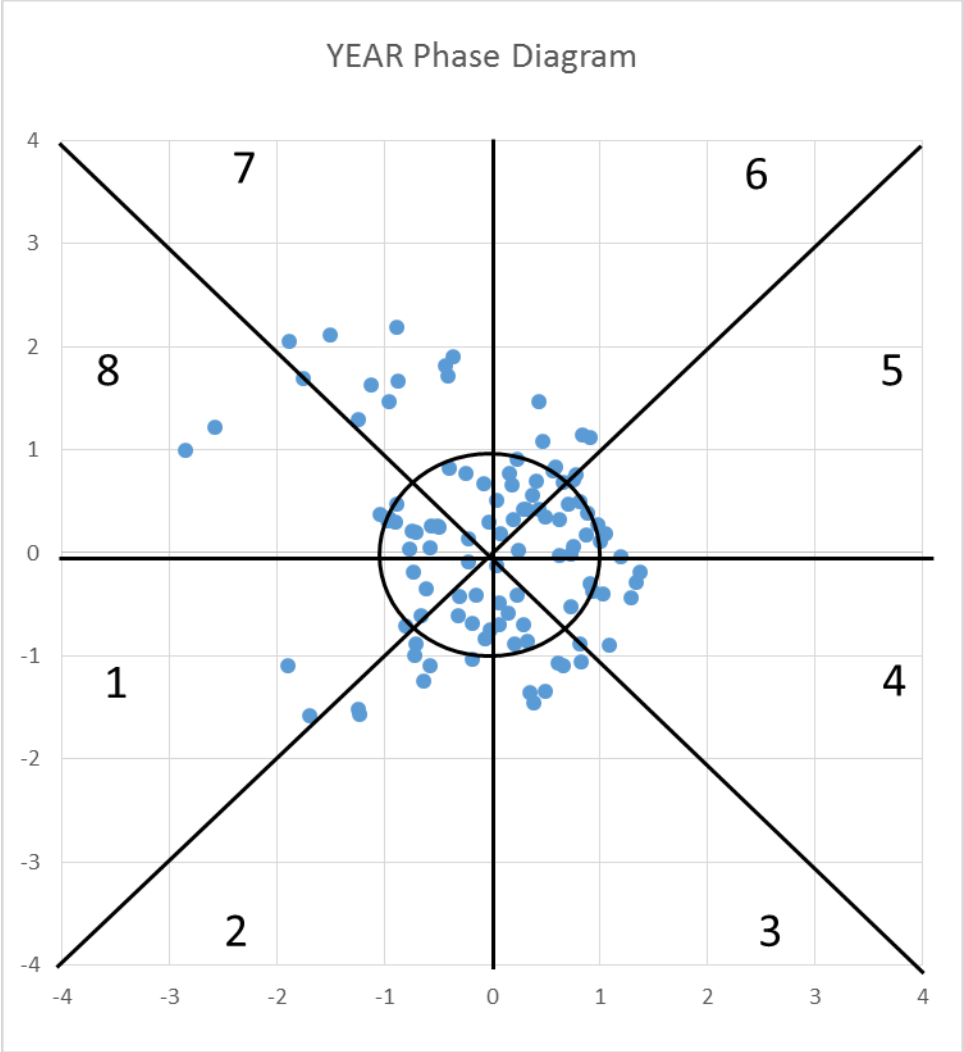


Fig.13 RMM Phase diagram of cold events in the Eastern United States for all seasons.

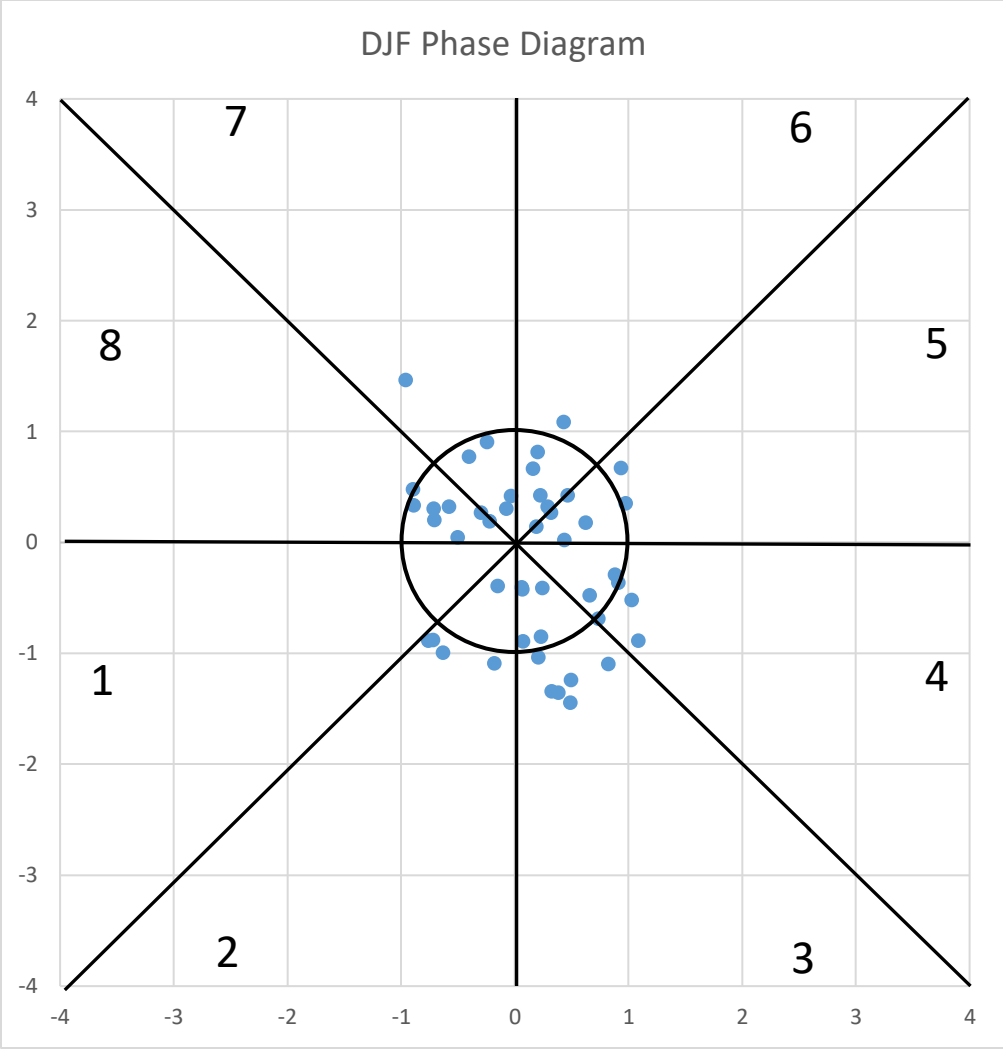


Fig.14 Same as Fig. 13, except winter season

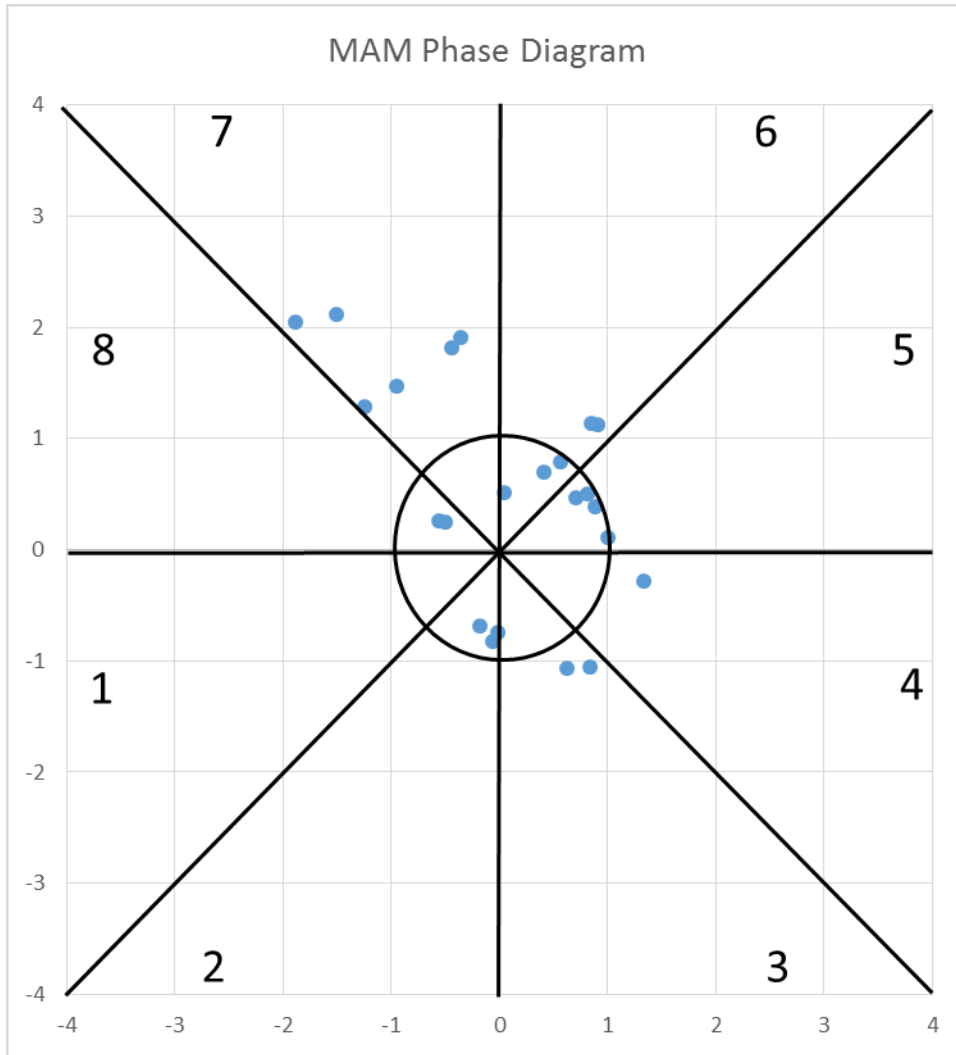


Fig.15 Same as Fig. 13, except for spring season.

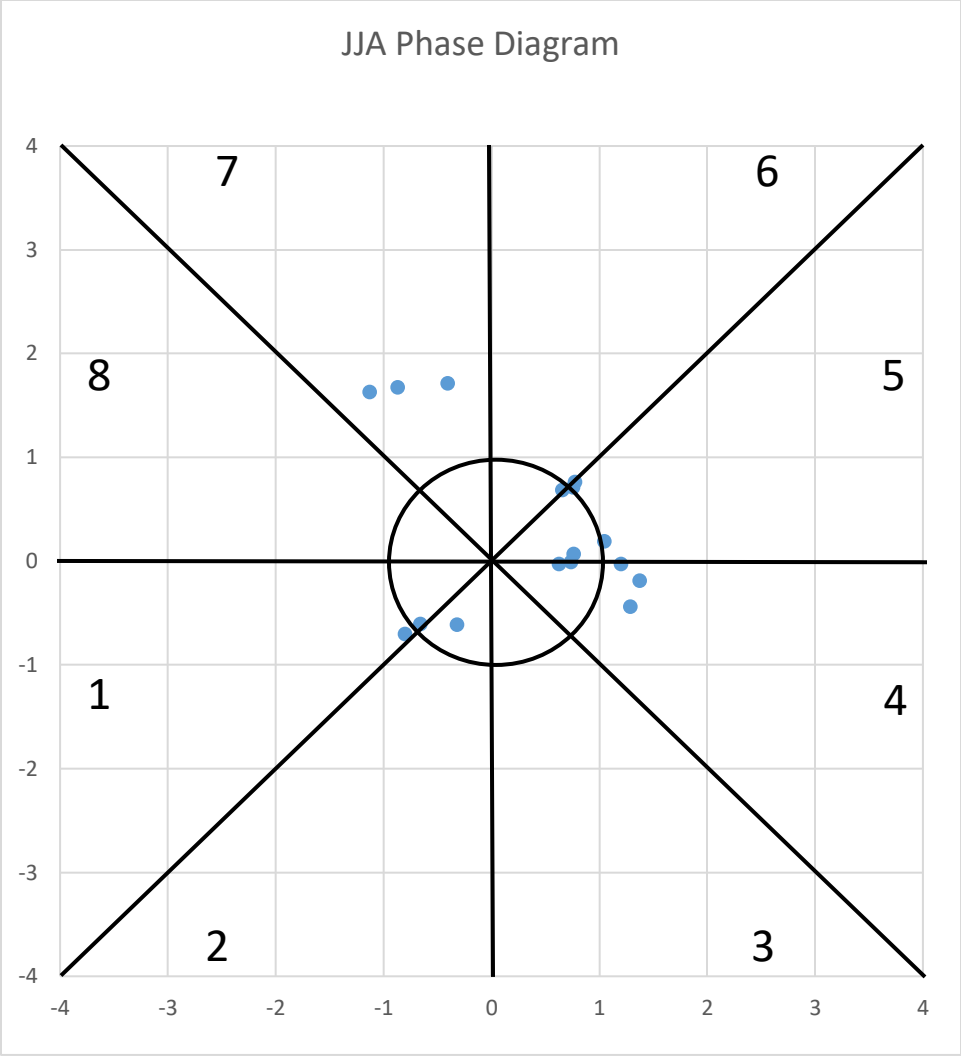


Fig. 16 Same as Fig. 13, except summer season.

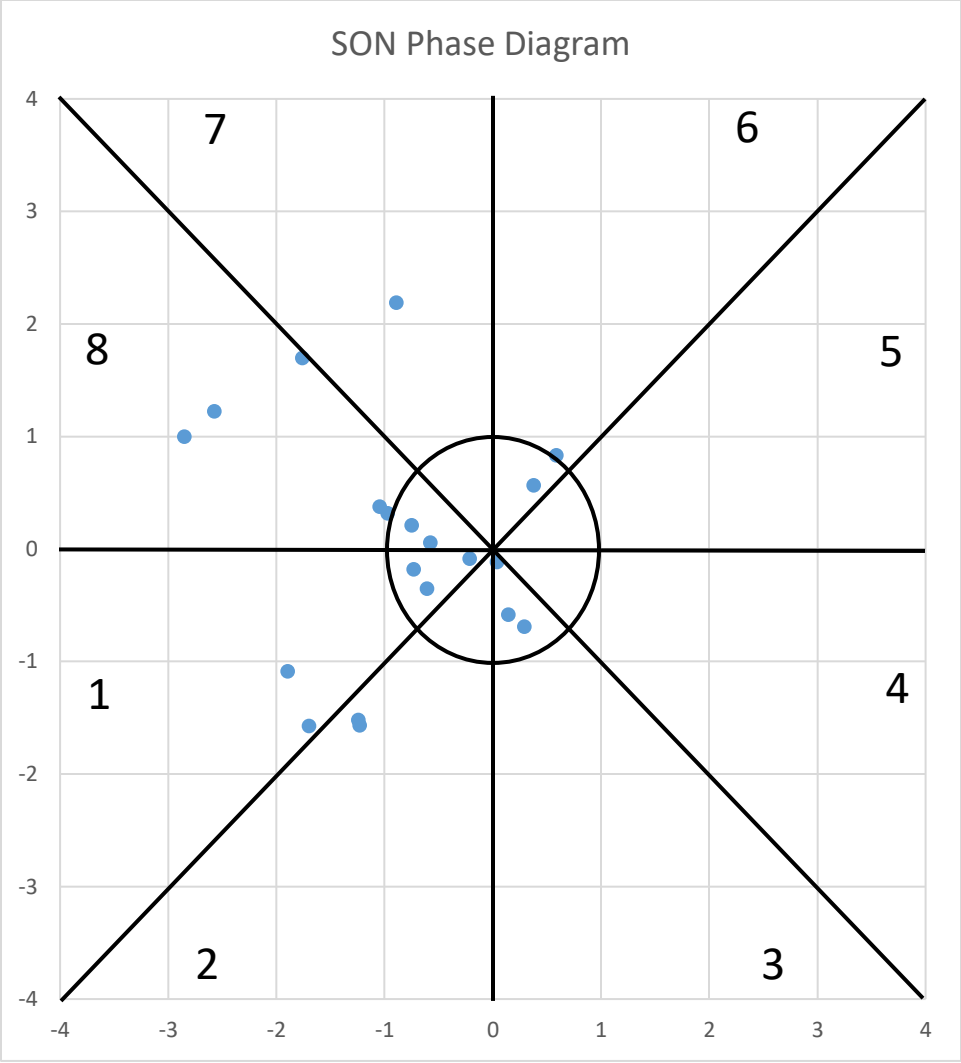


Fig.17 Same as Fig. 13, except fall season.

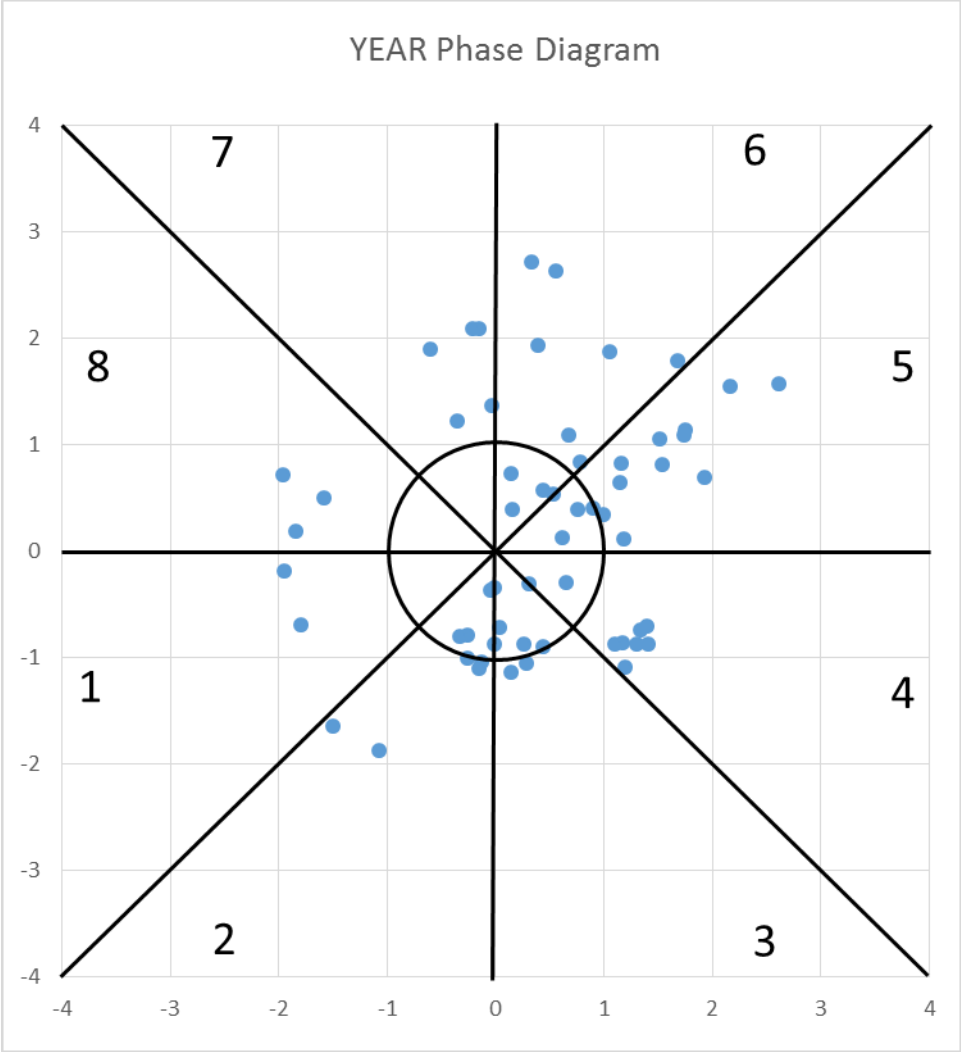


Fig. 18 Same as Fig.13 , except for warm events.

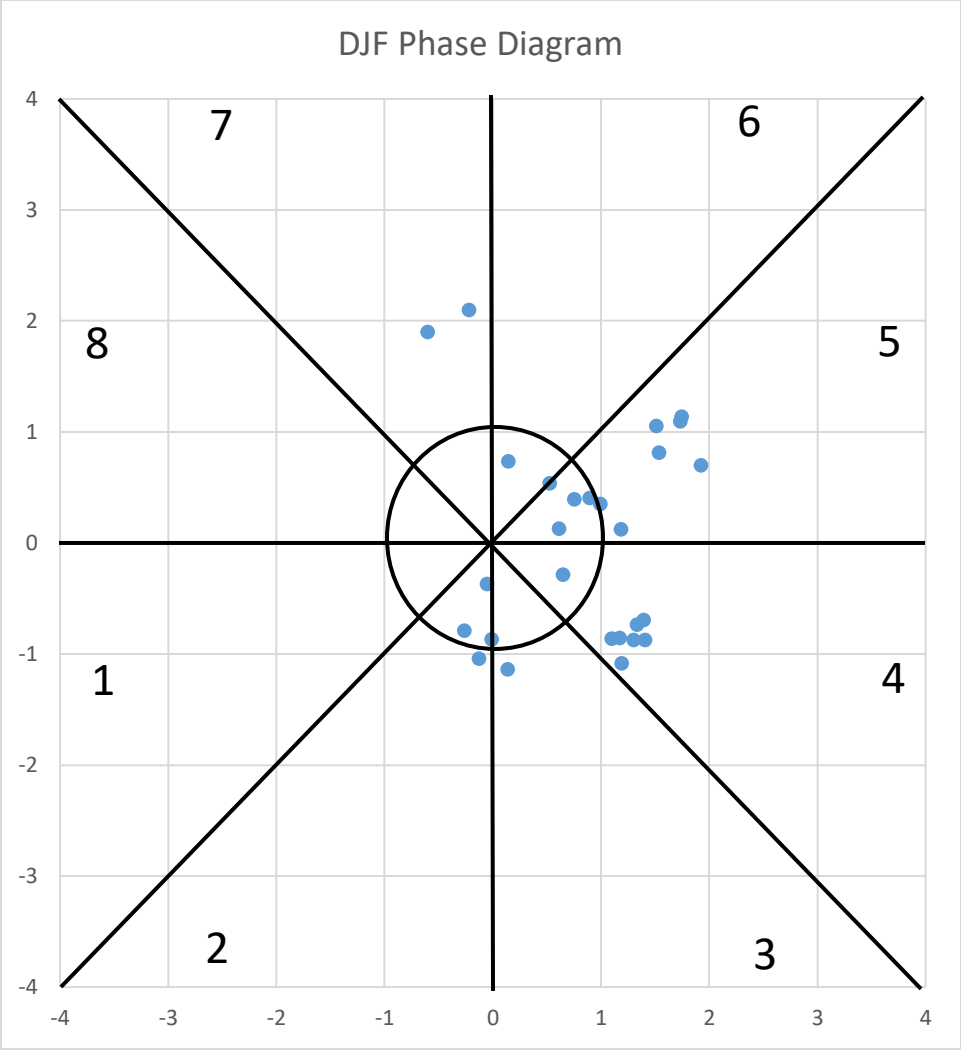


Fig.19 Same as Fig.18, except winter season.

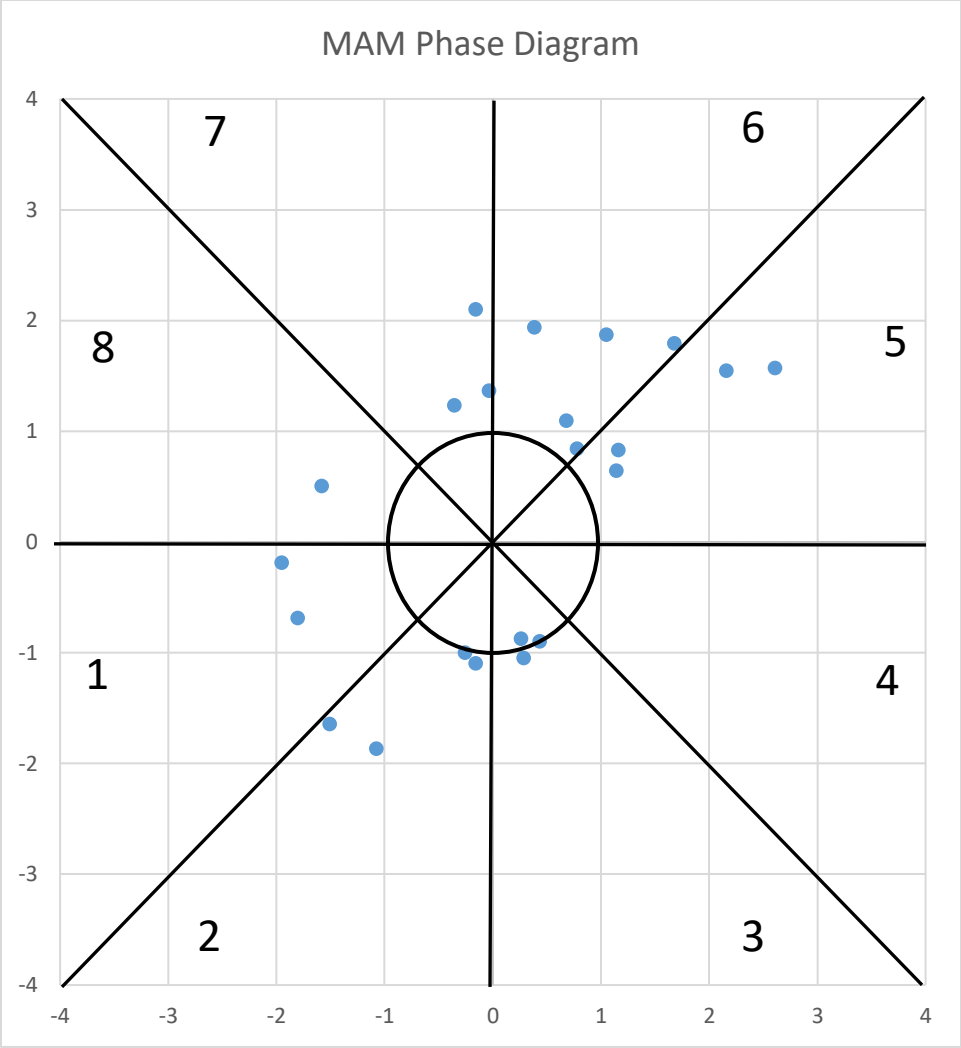


Fig. 20 Same as Fig.18 except spring season.

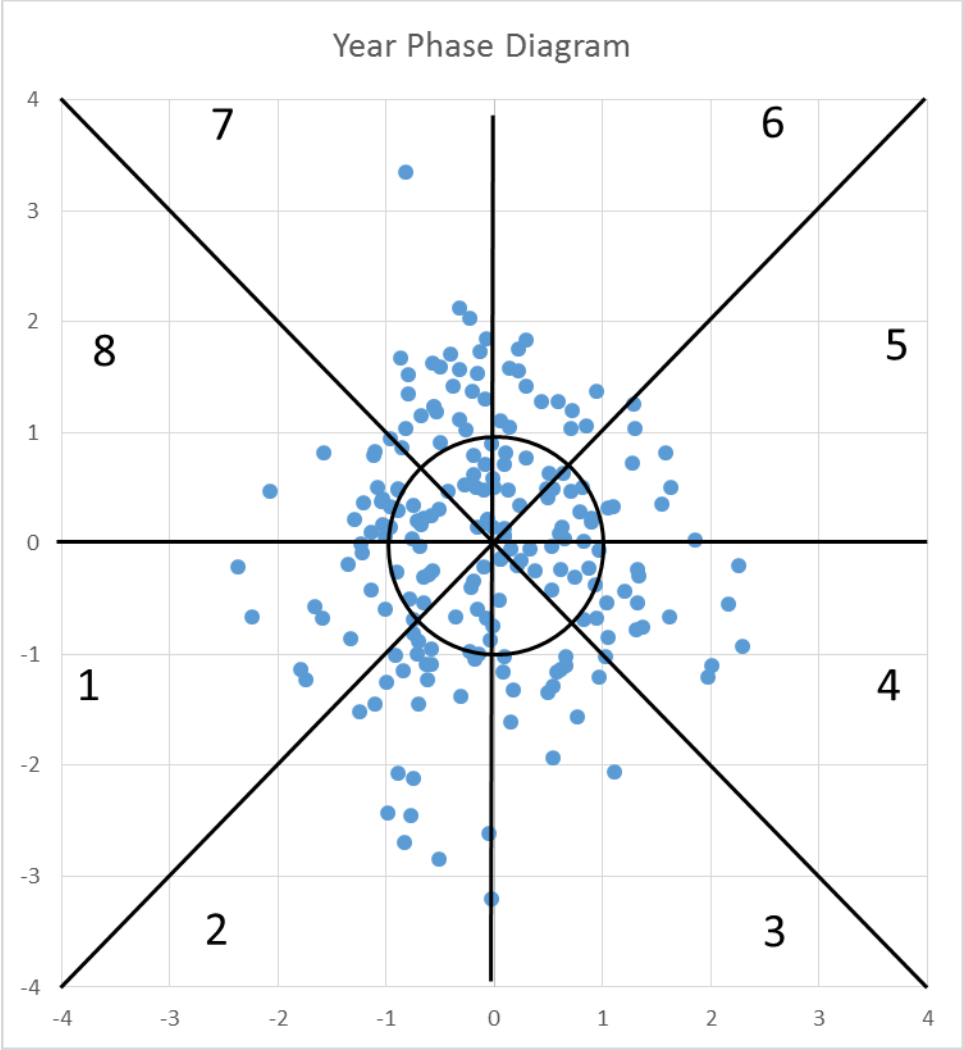


Fig.21 Same as Fig. 13, except for Central United States.

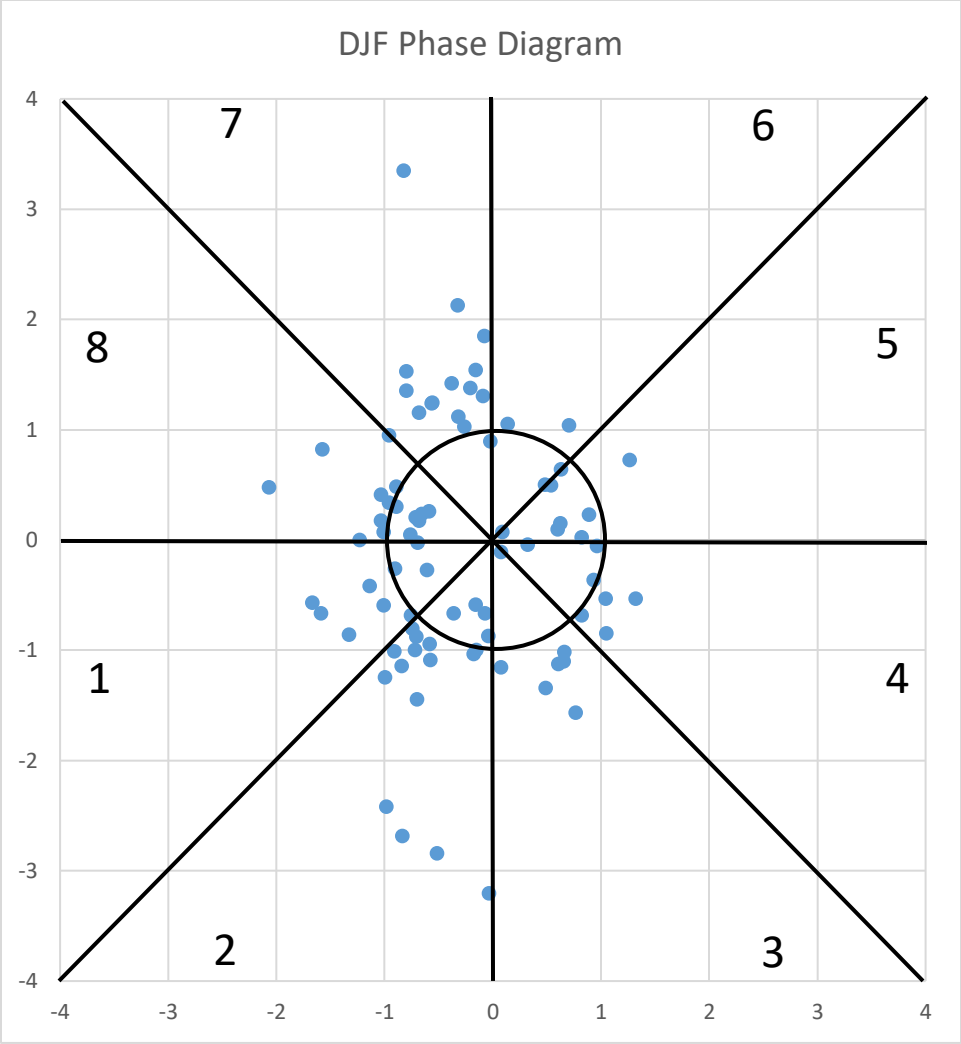


Fig.22 Same as Fig. 21, except winter season.

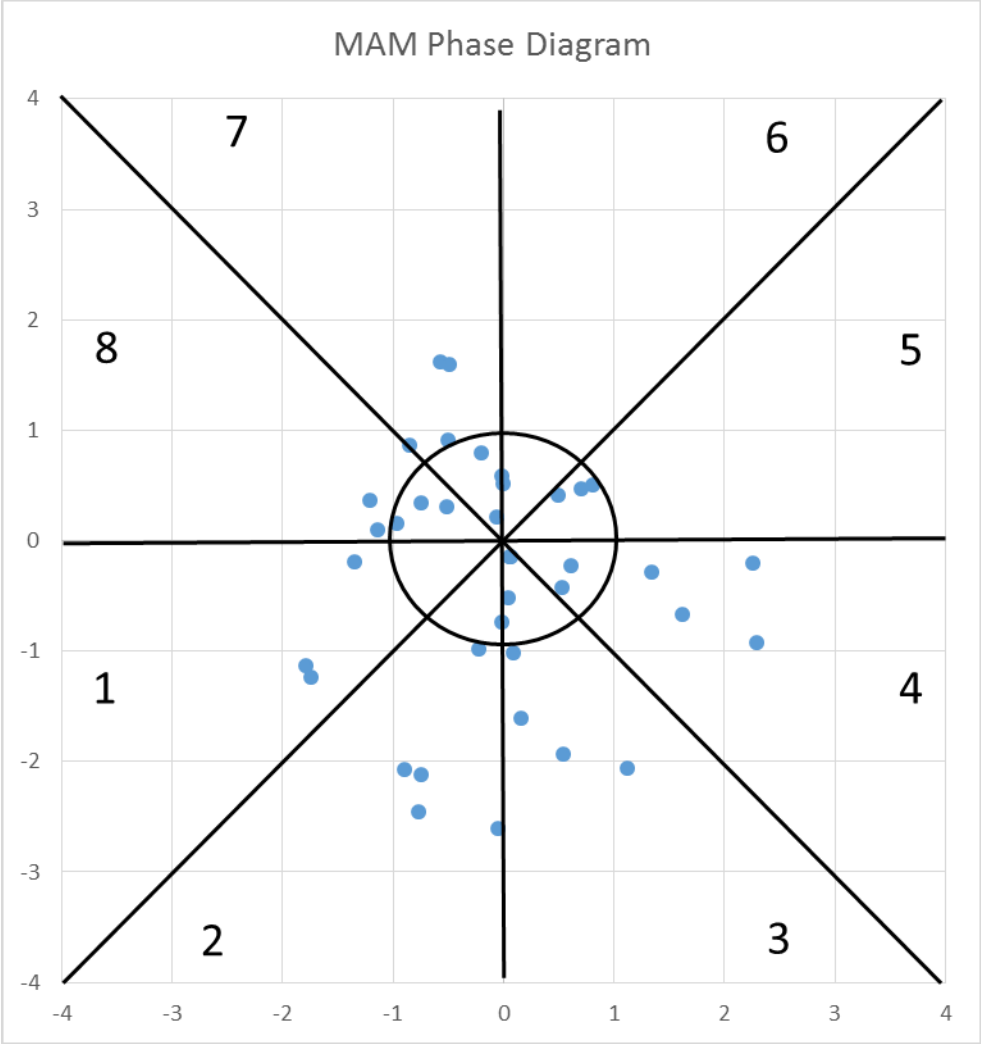


Fig.23 Same as Fig.21, except spring season.

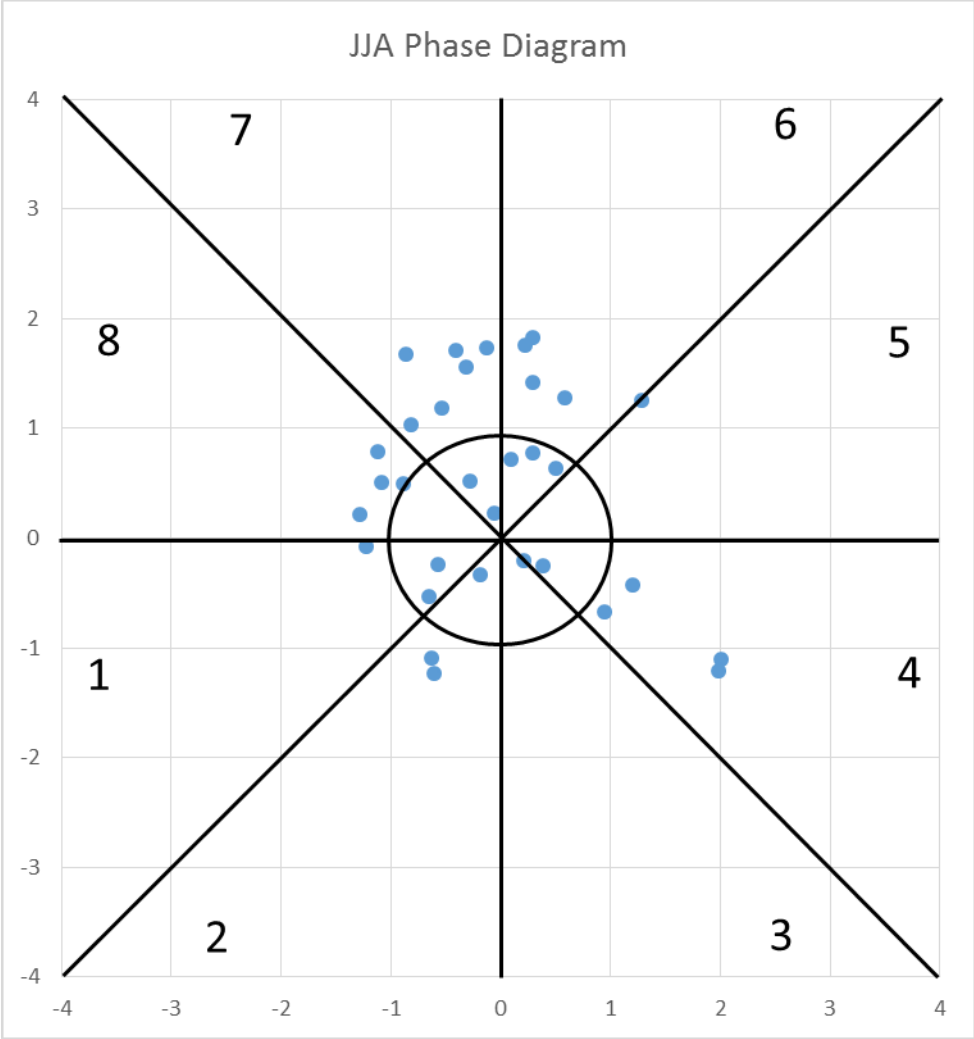


Fig.24 Same as Fig. 21, except summer season.

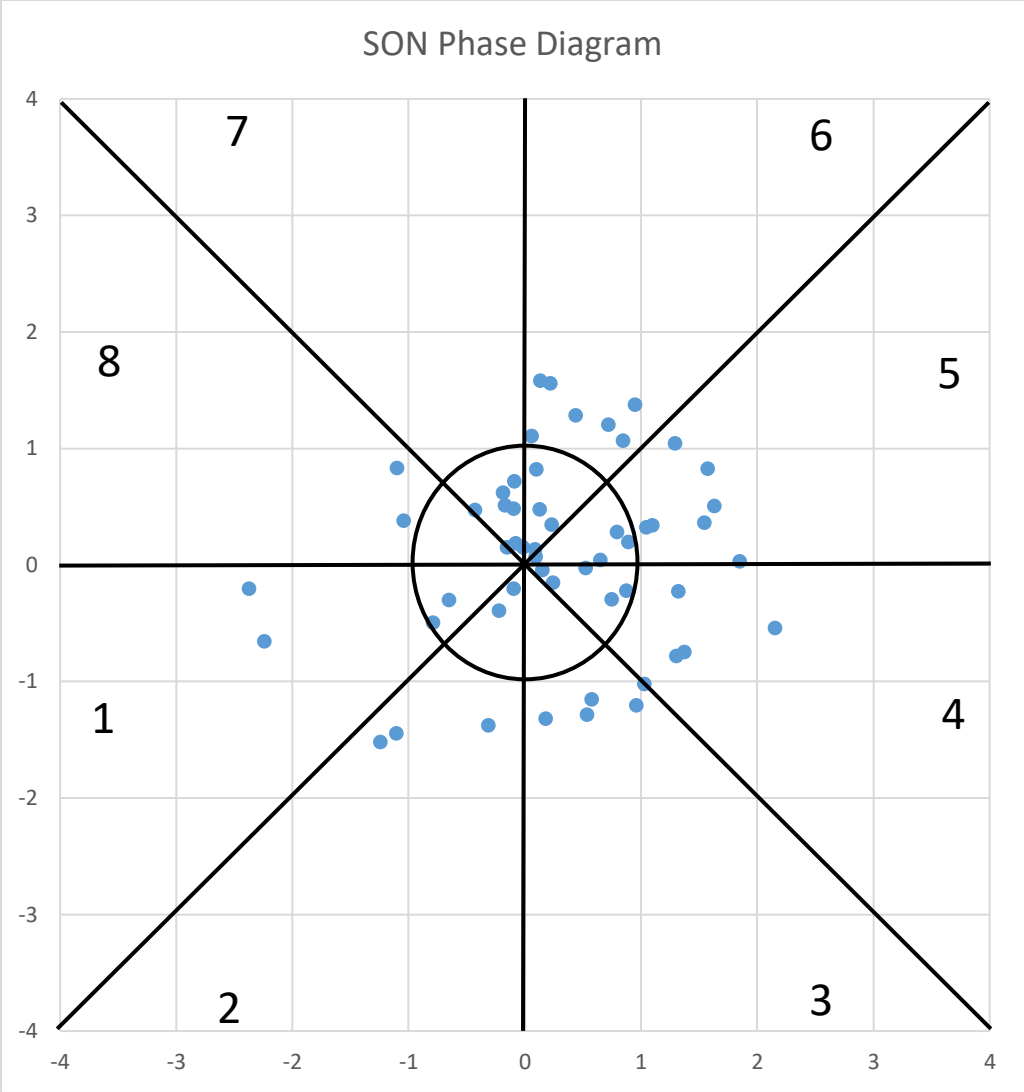


Fig.25 same as Fig. 21, except fall season.

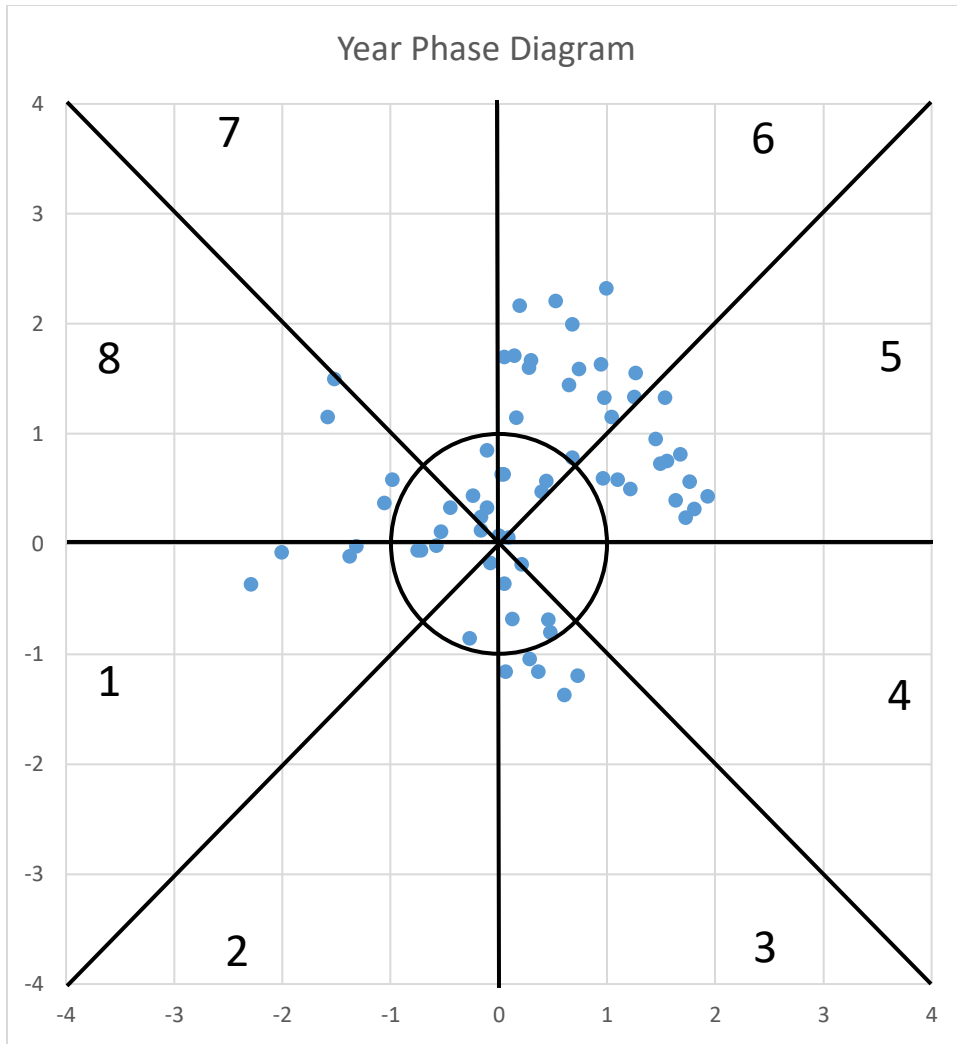


Fig 26. Same as Fig. 21, except for warm events.

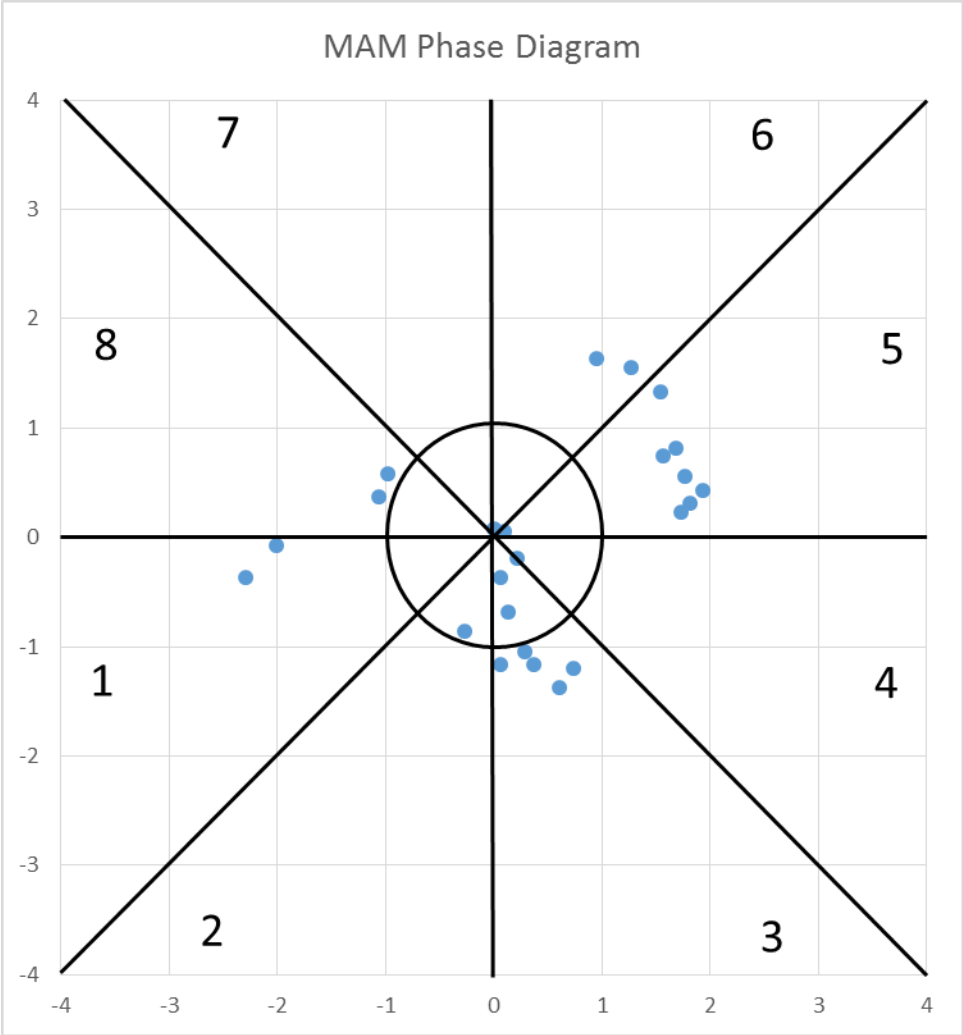


Fig.27 Same as Fig. 26, except spring season.

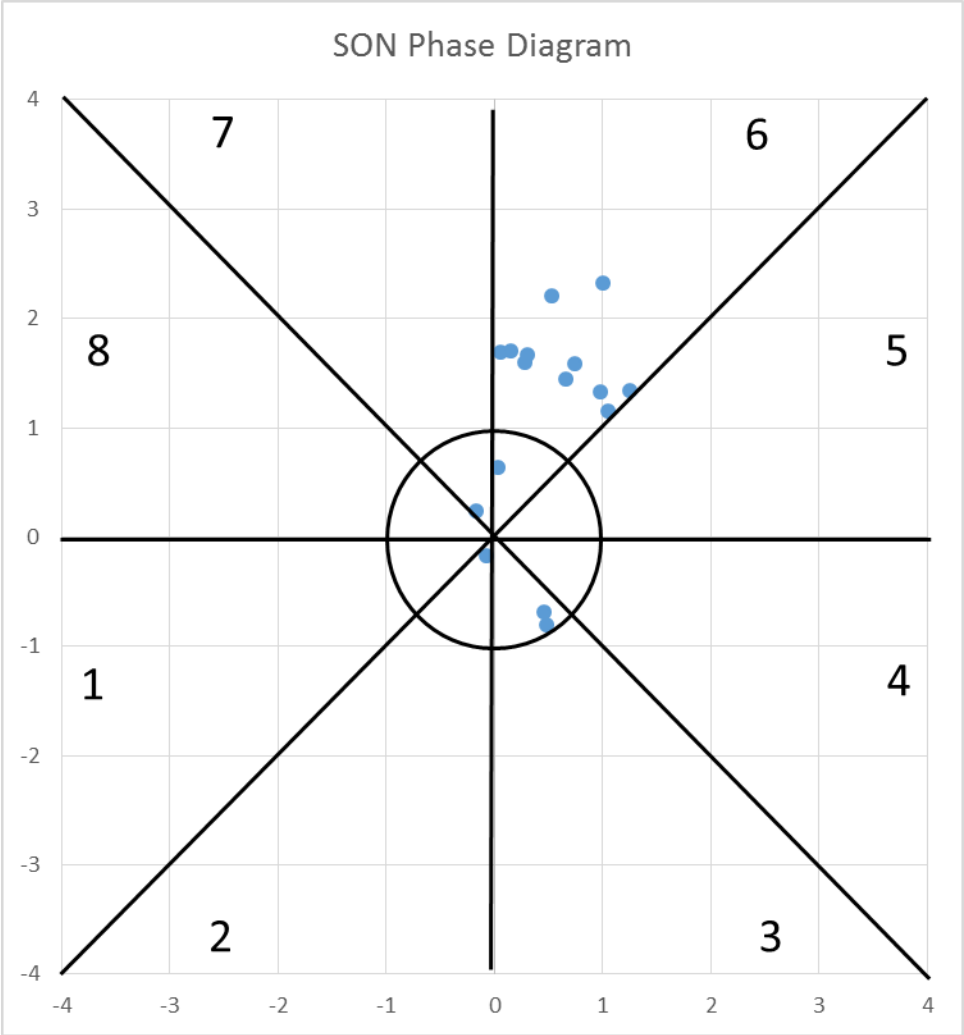


Fig.28 Same as Fig.26, except fall season.

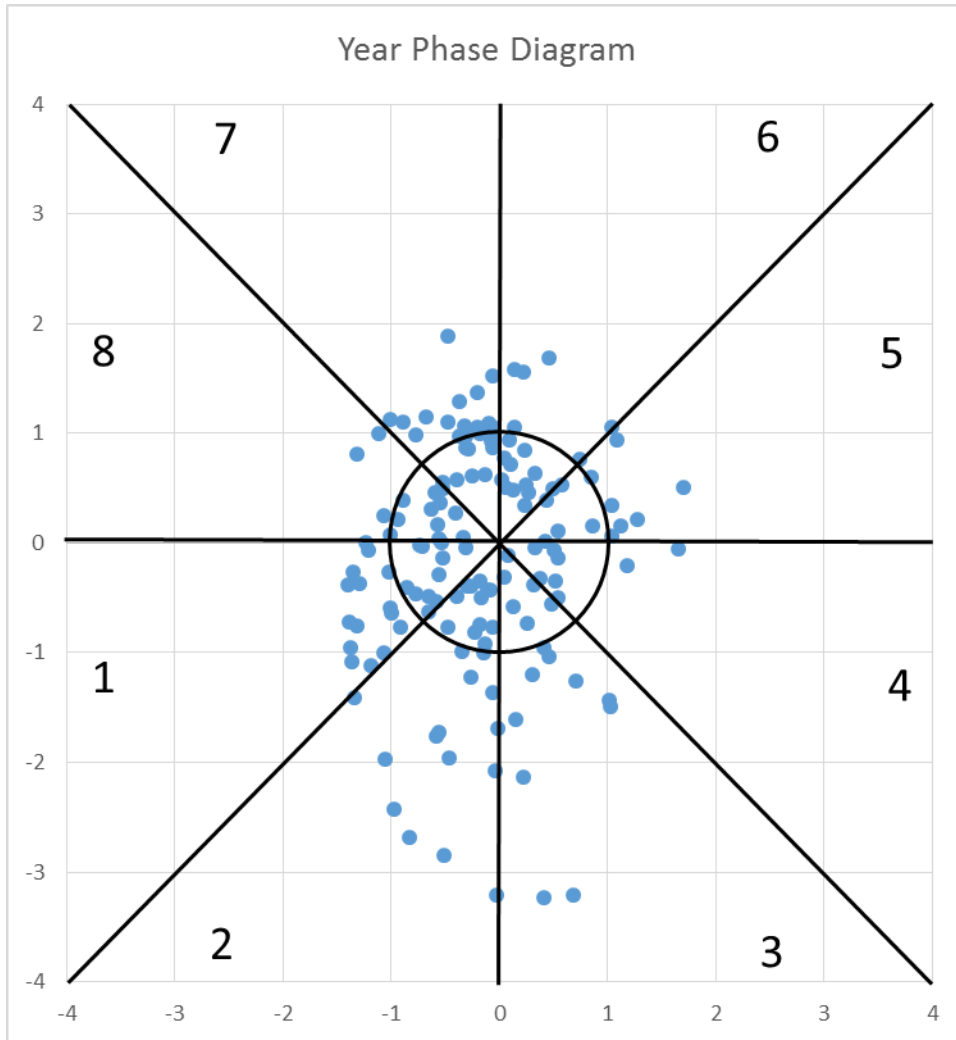


Fig. 29 Same as Fig. 21 except for Western United States.

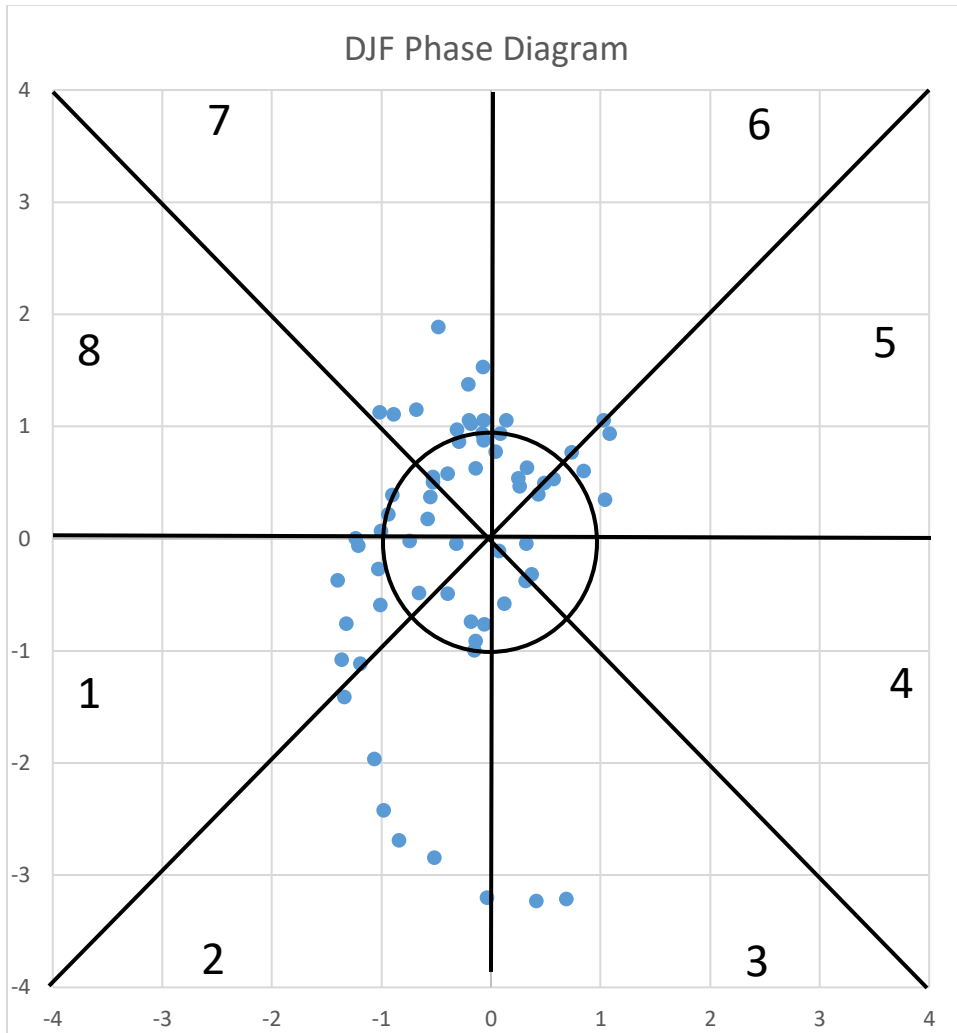


Fig. 30 Same as Fig. 29, except winter season.

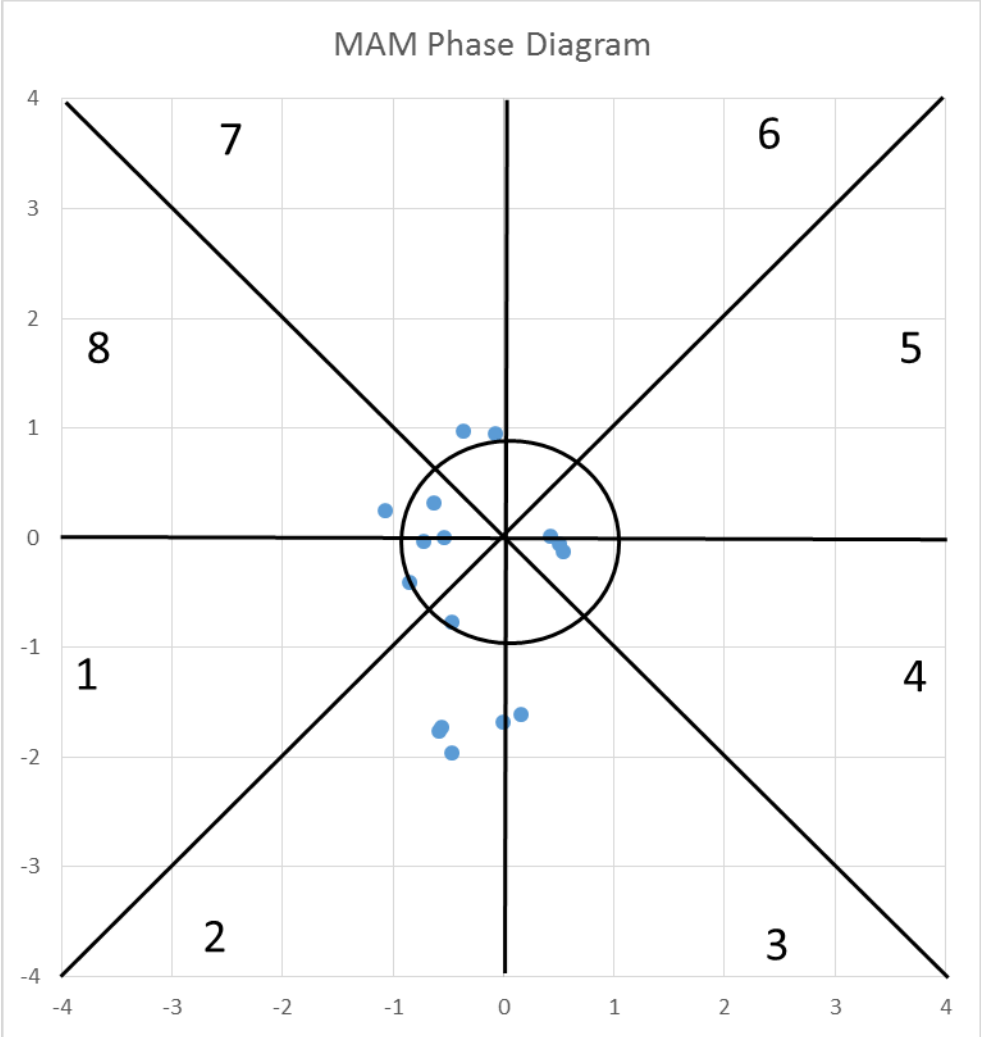


Fig.31 Same as Fig. 29, except spring season.

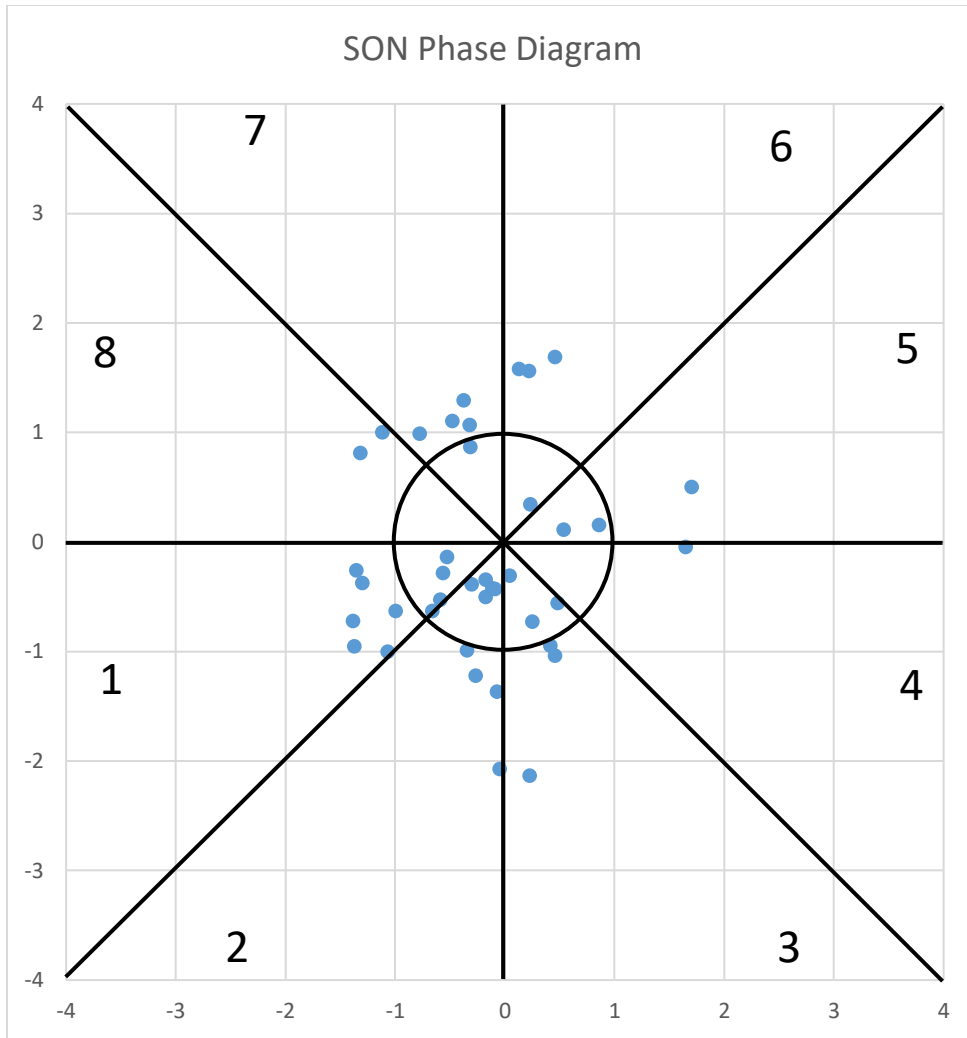


Fig. 32. Same as Fig. 29, except for fall season.

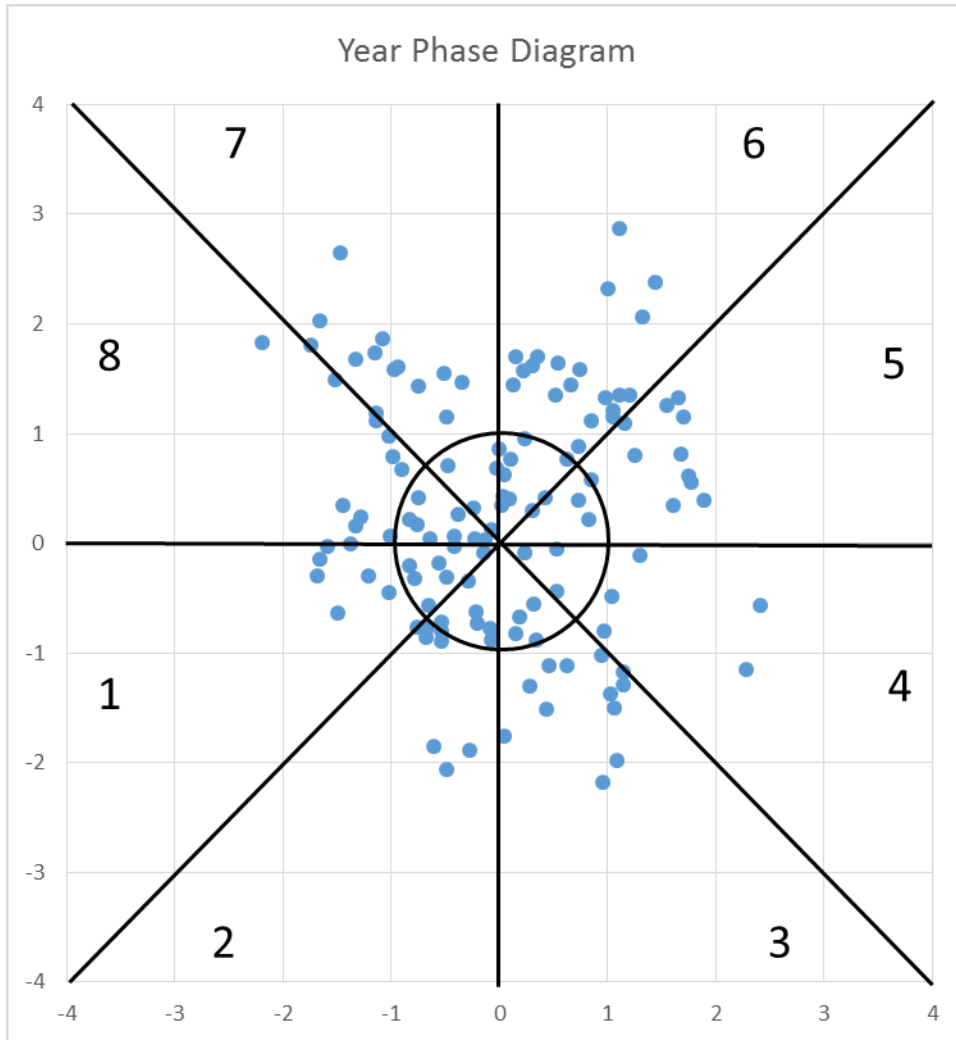


Fig. 33. Same as Figure 29, except for warm events.

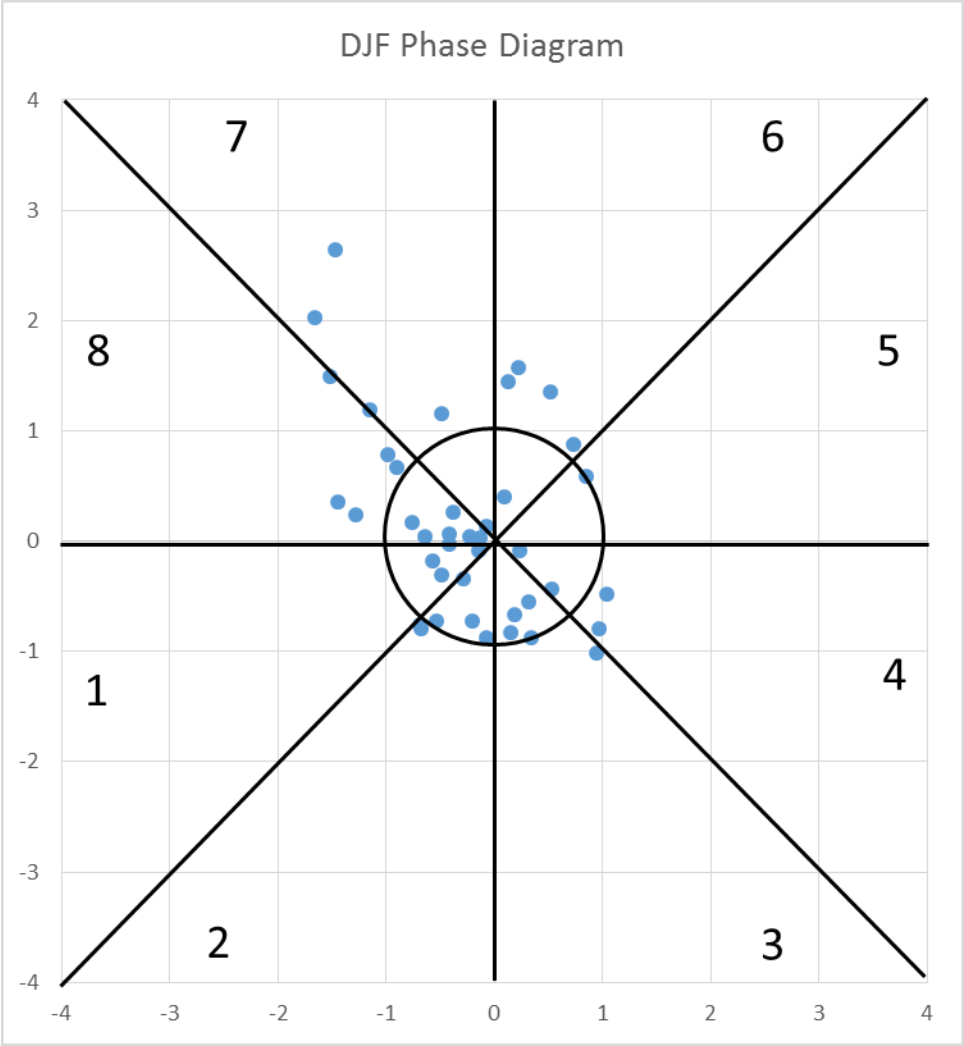


Fig.34. Same as Fig. 33, except for winter season.

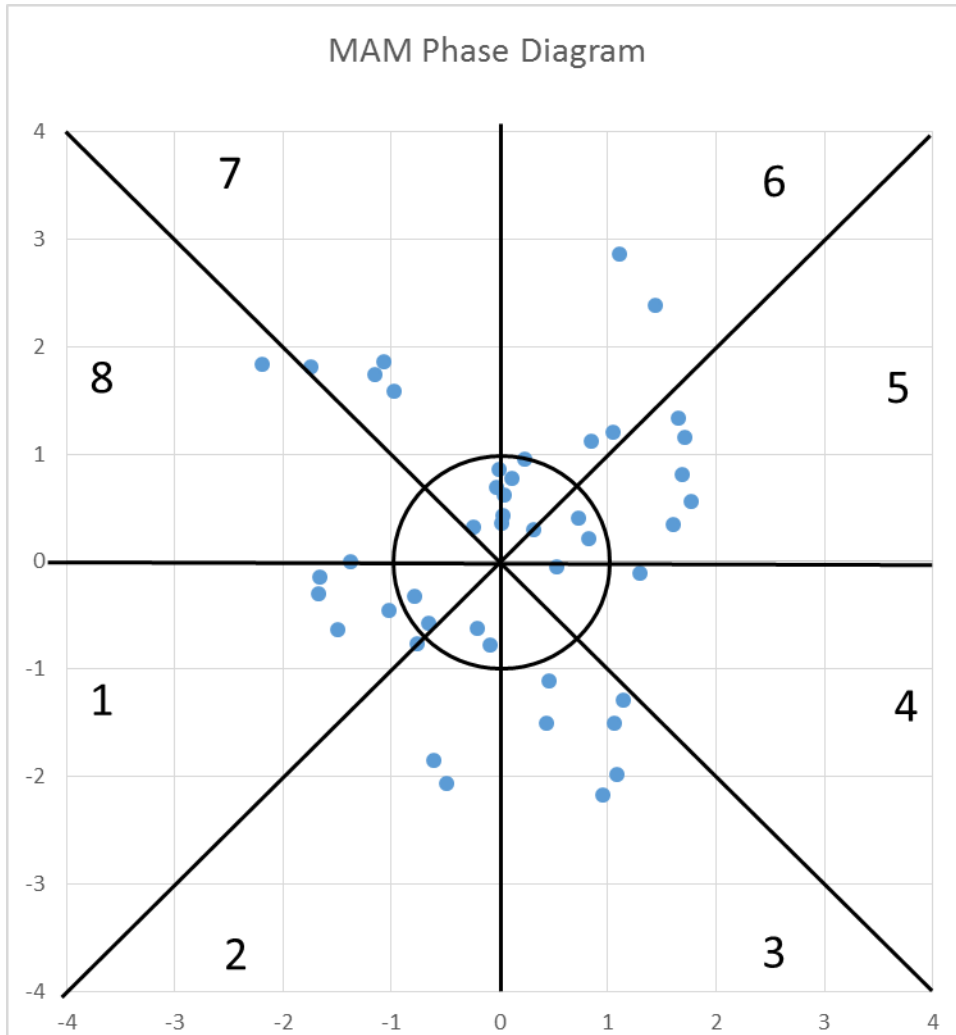


Fig. 35 Same as Fig. 33, except spring season.

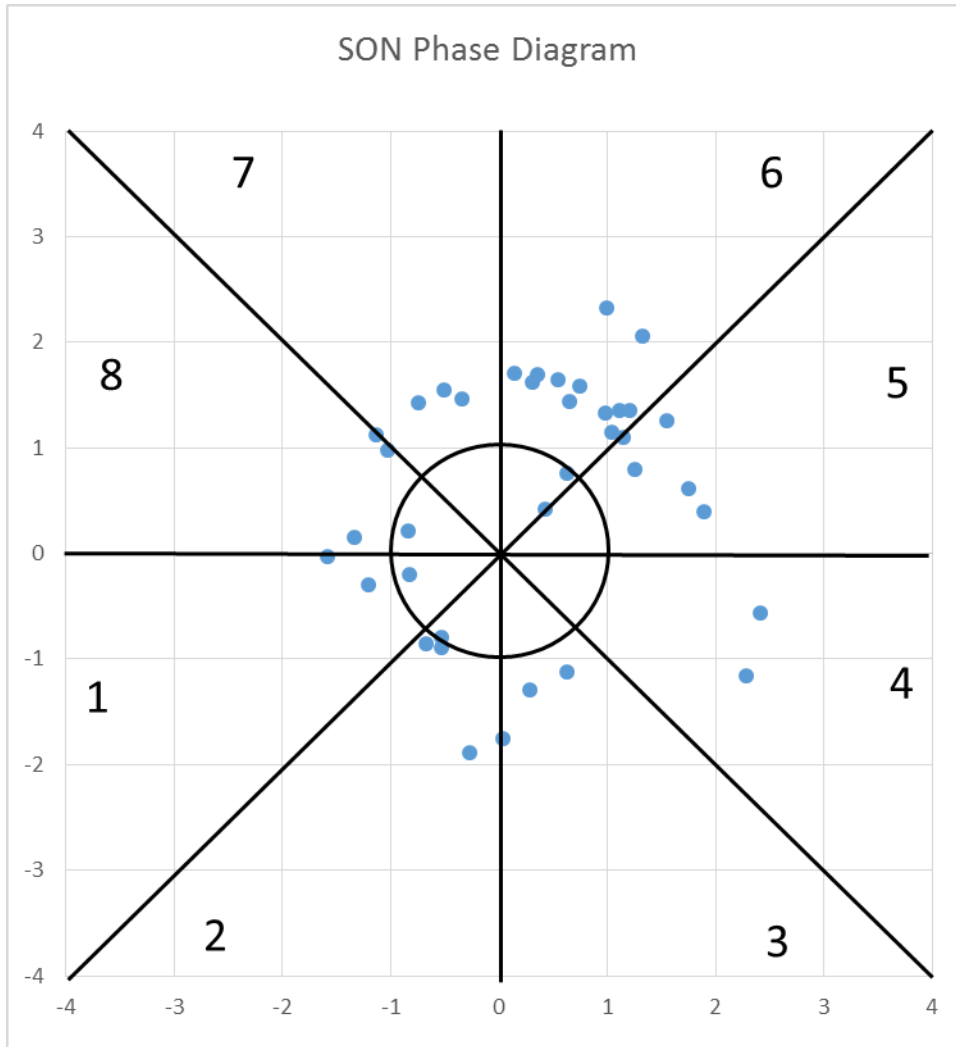


Fig.36 Same as Fig. 33, except for fall season.

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