The Impact of the Madden-Julian Oscillation (MJO) on Extreme Winter Weather

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Introduction

- Winter weather events have large societal impacts and are challenging to predict
  - Texas/Oklahoma winter storms Feb. 2021 caused 100+ deaths, billions of dollars of damage from power outages
- Subseasonal-to-seasonal (S2S) prediction of winter weather
  - MJO major source of S2S predictability (e.g., Tseng et al. 2017)
  - MJO has significant influence on eastern New England snowfall (Klotzbach et al. 2016) and impacts on 2009-10 winter over Mid-Atlantic U.S. (Moon et al. 2011)
  - Limited research on MJO impacts on winter weather over entire U.S.

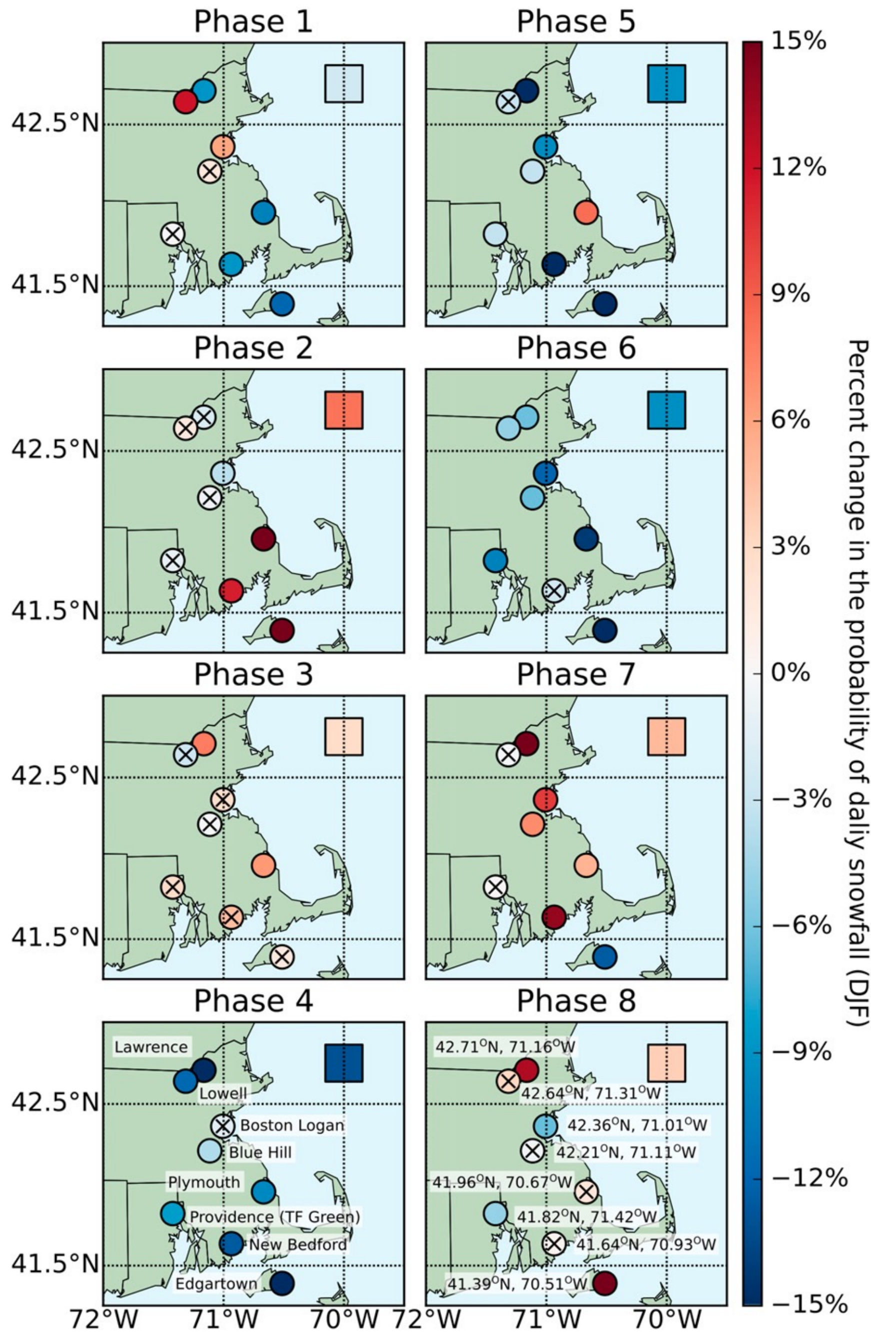


Figure source: Klotzbach et al. 2016

What is the Madden-Julian Oscillation?

- MJO is oscillation of pressure and wind values associated with convection propagating along Equator
- Typically divided into 8 phases based on location of convection
- Time scale of 30-90 days
- MJO affects global circulation
  - e.g., Sardeshmukh and Hoskins 1988, Garfinkel et al. 2014

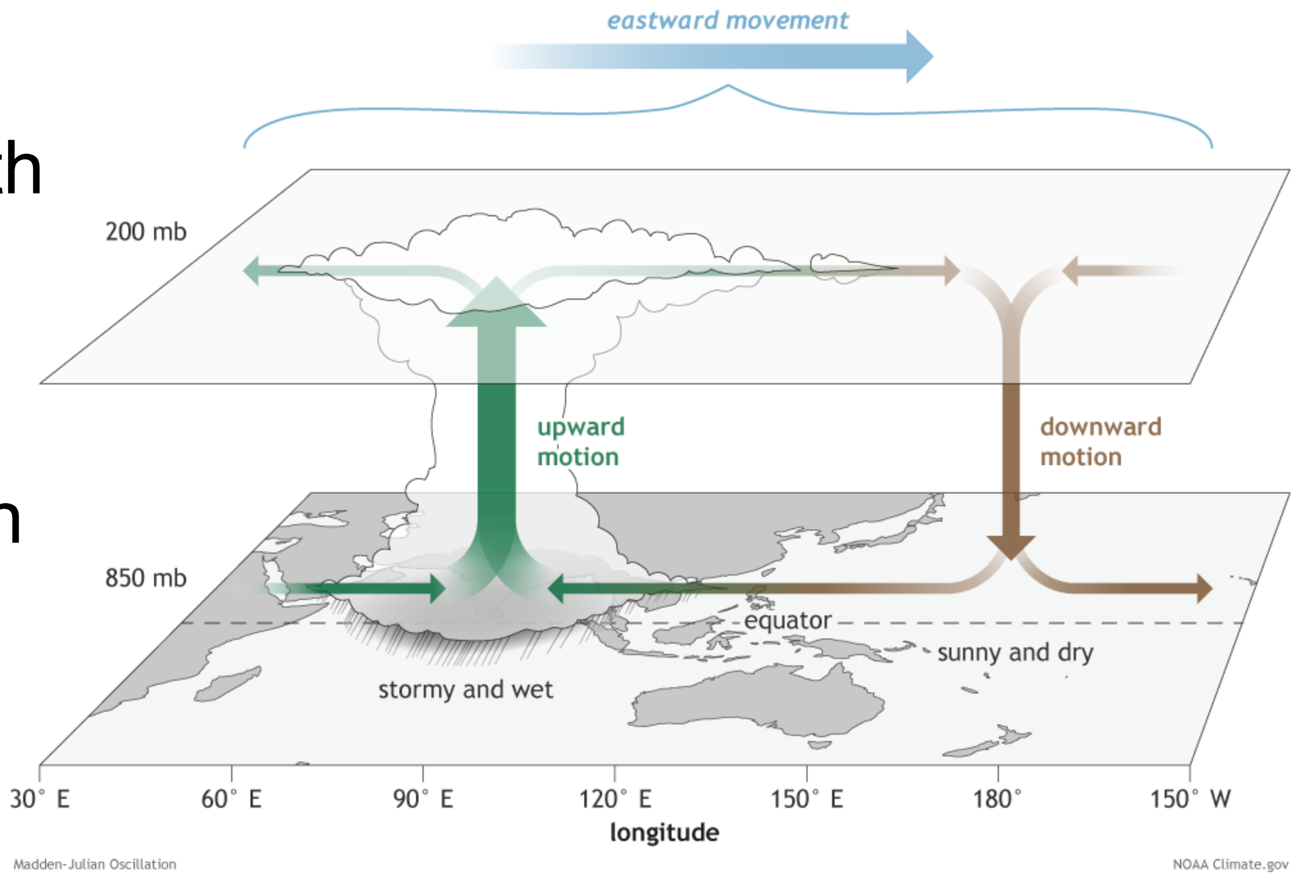


Figure source: NOAA Climate.gov

MJO and Subseasonal Predictability

- MJO has significant impacts on mid-level heights out to 14 days (S2S) (Tseng et al. 2017)
- Also has impact on North Atlantic Oscillation (e.g., Cassou 2008) and Pacific North America patten (e.g., Riddle et al. 2013)
- But these impacts have not been tied to winter weather frequency over the United States

500 hPa height anomalies associated with MJO phase

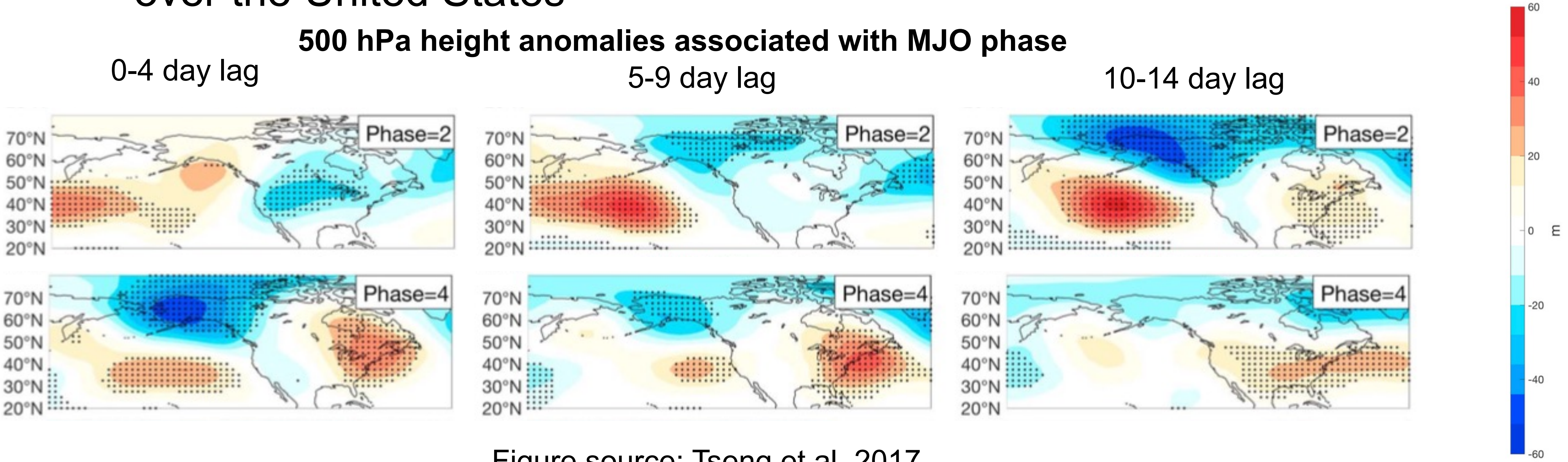
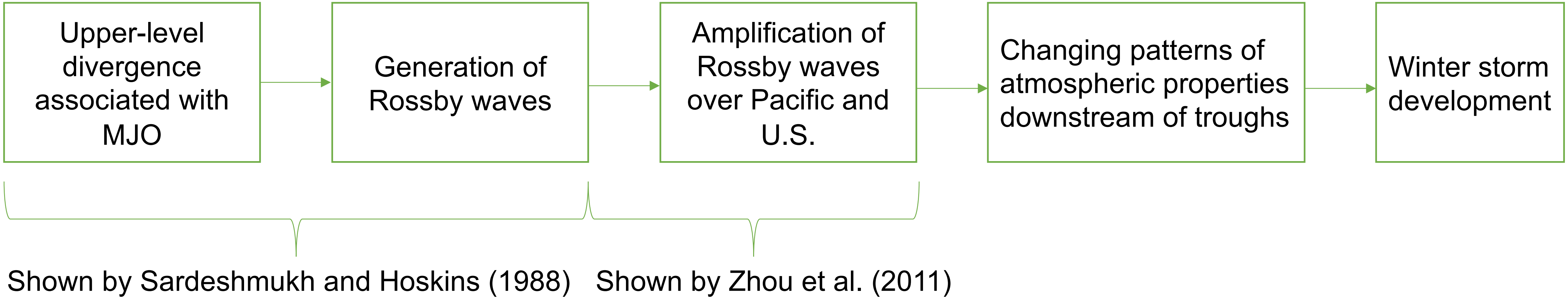


Figure source: Tseng et al. 2017

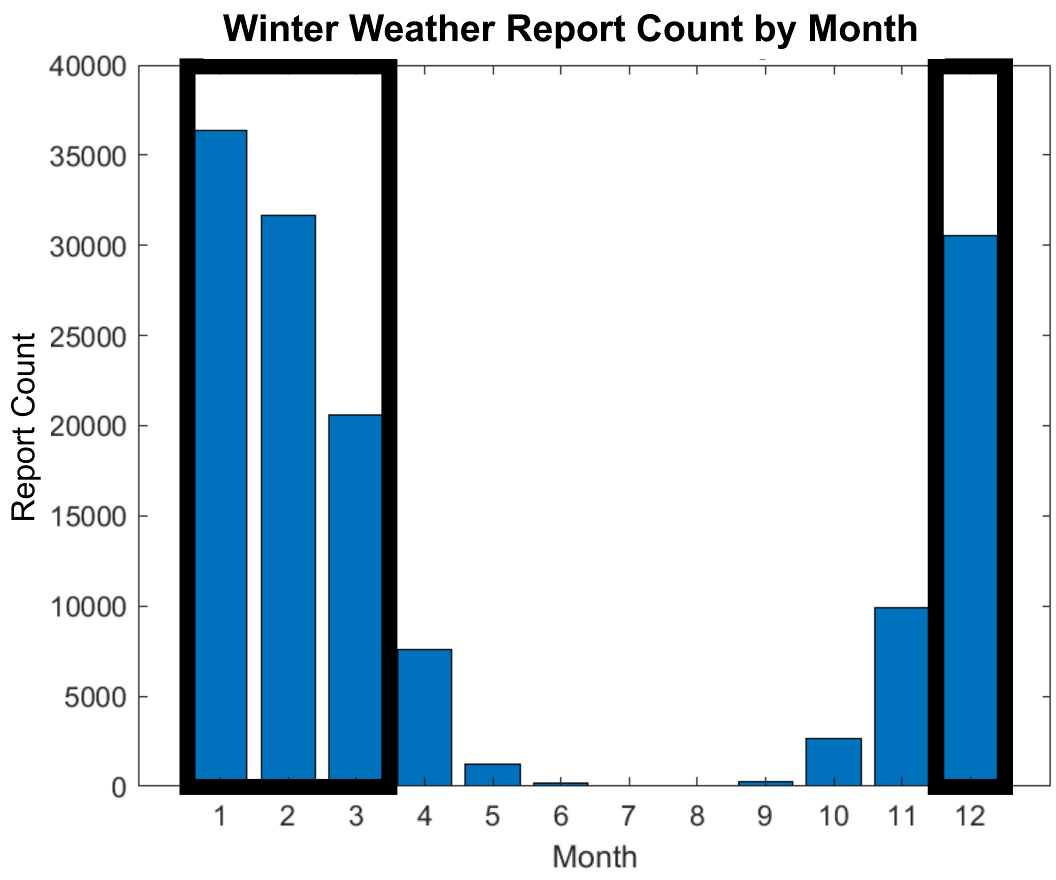
Research Goals

- **Research question:** How does the phase of the MJO impact the frequency of winter weather events over the United States?
- **Hypothesis:** Changes in winter weather frequency are caused by changes in the flow pattern influenced by MJO and its effect on temperature and precipitation.



Winter Weather Data Sources

- National Centers for Environmental Information (NCEI) **Storm Event Database** contains impactful winter weather events across US
  - 1996-2018
  - Events that meet winter storm warning criteria
- December-March selected as study period based on storm report count
- Compared to Global Historical Climatology Network (**GHCN**) station data
  - Approx. 800 stations from 1979-2020

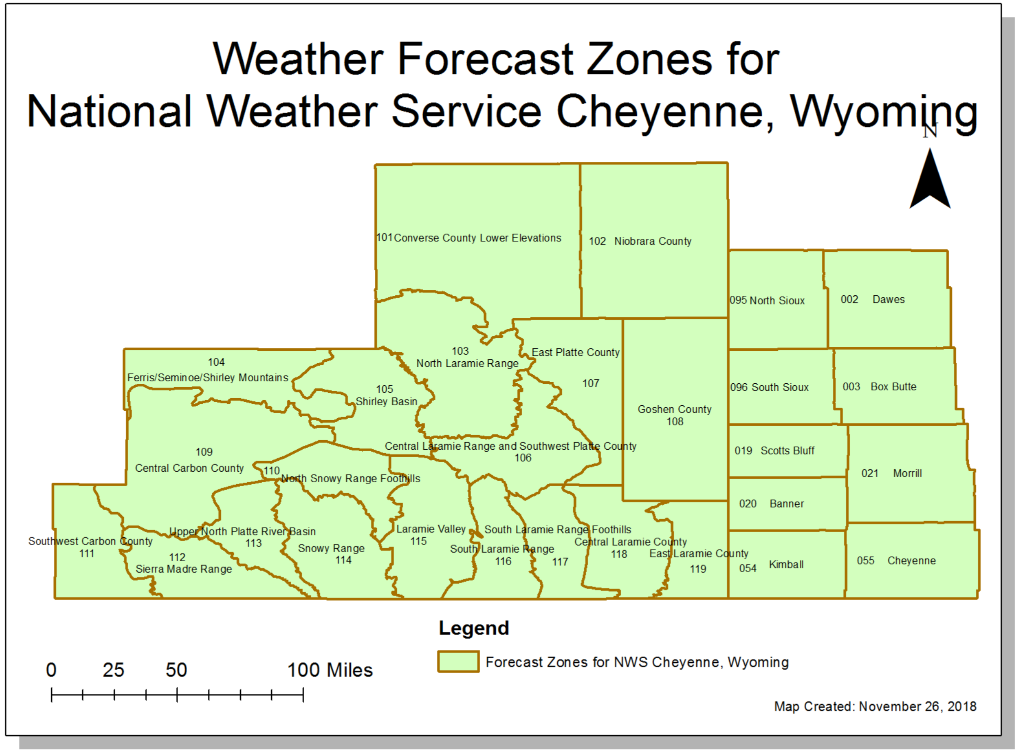


Definition of Frequency Ratio

$$\text{frequency of storms per MJO phase} = \frac{\text{number of reports in given phase}}{\text{number of zones in WFO} \times \text{number of days in given phase}}$$

$$\text{frequency ratio} = \frac{\text{frequency of storms per MJO phase}}{\text{daily climatological frequency}}$$

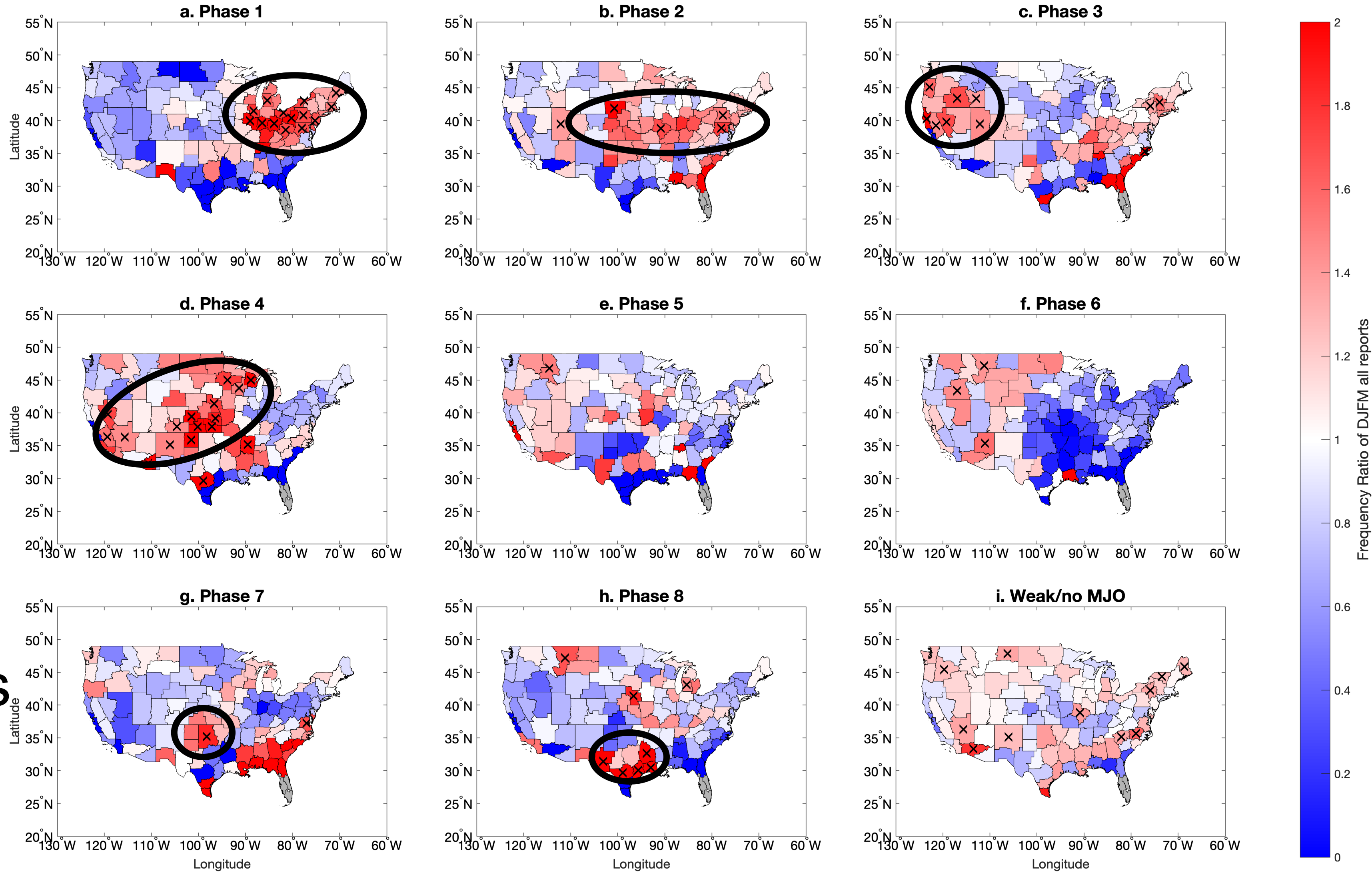
- Frequency ratio > 1 → winter weather more frequent than climatology
- Frequency ratio < 1 → winter weather less frequent than climatology



Source: NWS Cheyenne

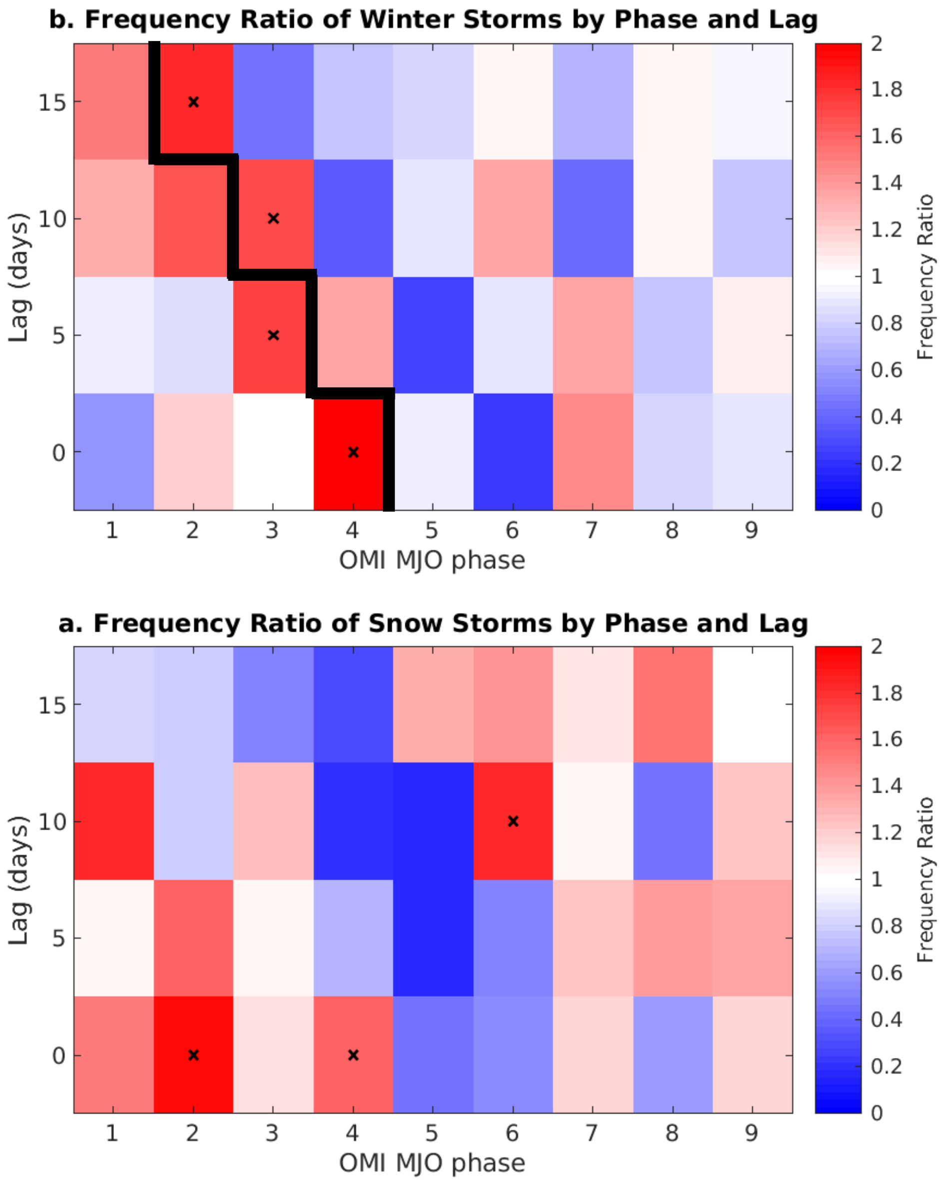
Frequency Ratio of Winter Weather

- High frequency ratios shift from east to west in phases 1-3
- High values across central/western US in phase 4
- Lower in phases 5-8 except in parts of the South



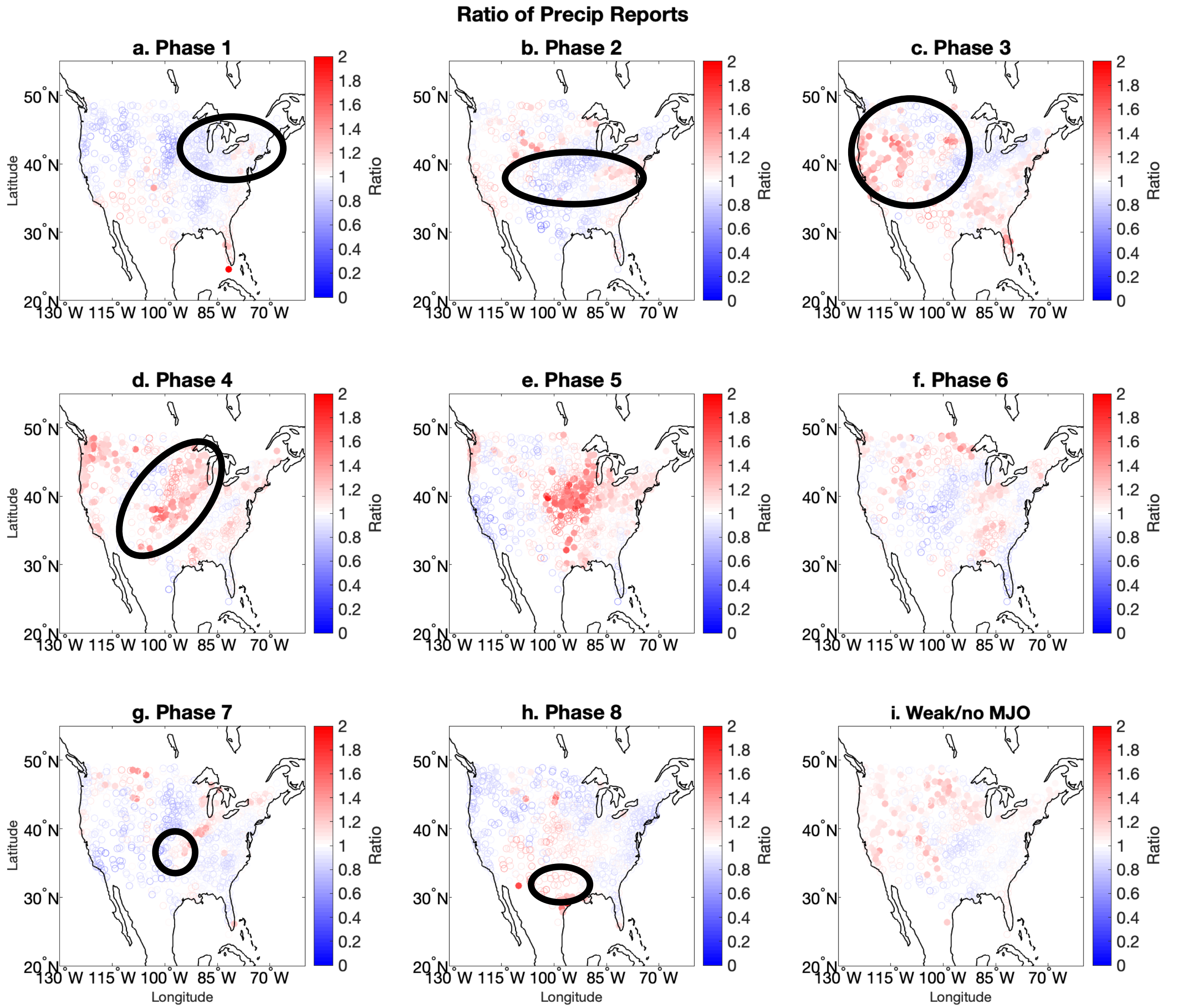
Lagged Frequency Ratio

- Frequency ratio of winter weather a given number of days after a phase of the MJO in the Southern Plains
- Snow and winter storms have stairstep pattern
  - Frequency in given phase similar to frequency in previous phase 5 days prior
- Pattern also present with low frequency ratios



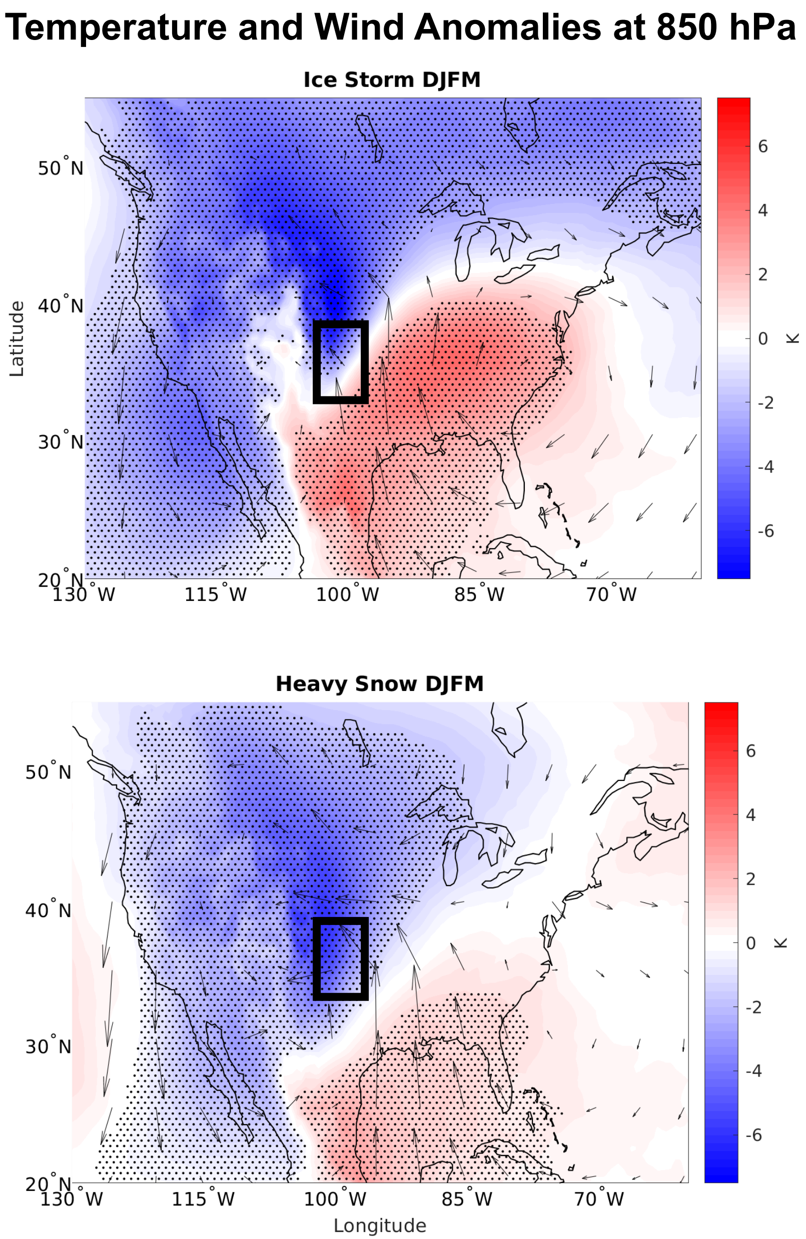
GHCN Precipitation Accumulation Ratios

- Higher precipitation in areas of higher frequency ratio for phases 3-4
- But phases 1 and 2 had above normal precip. and below normal snow
- So precipitation could be responsible for some but not all variation in snowfall



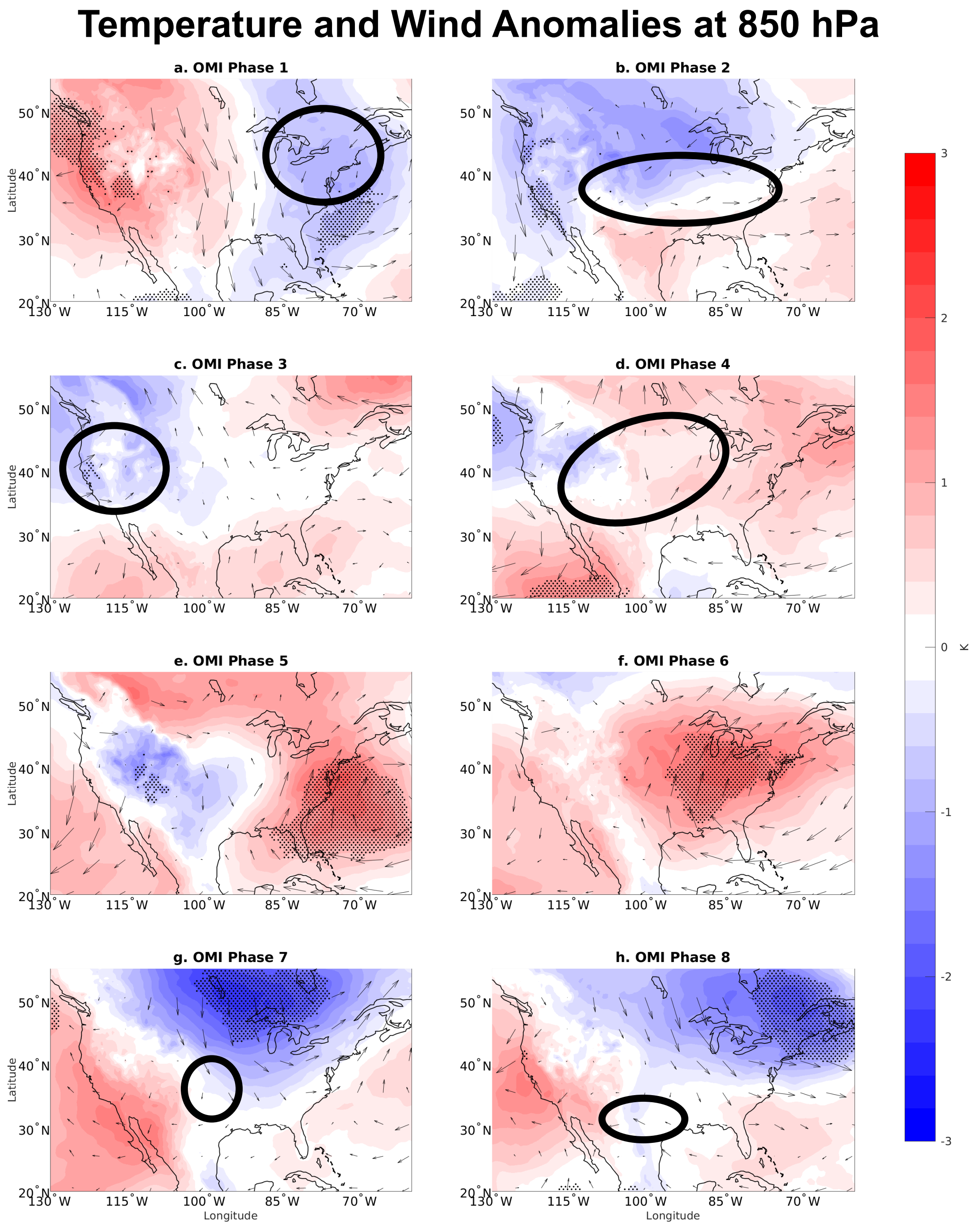
850 hPa Temperature – Southern Plains Storm Days

- Temperature and wind anomalies on days with a given type of winter weather event (storm days)
- Strong temperature gradient across the region
- Colder heavy snow days as compared to ice storm days
- Anomalous warm air advection, especially for ice storms
- Pattern most similar to phases 2 and 7, with cold to north, warmth to south



850 hPa Temperature and Wind – MJO Effects

- Colder weather generally associated with heavy snow in phases 1-3
- Not the case in phase 4
- Warmer temperatures and less winter weather in phases 5-6
- Phases 7-8 had heavy snow in the Deep South, with cold air to the north



Conclusion

- MJO has significant effects on frequency of winter weather
- Sometimes increased winter weather is collocated with below-normal temperature, sometimes with above-normal precipitation
- In Southern Great Plains, phases 2 and 7 have frequent winter weather and favorable 850 hPa temperatures

Favorability of patterns for winter weather in the Southern Great Plains

	Phase 2	Phase 3	Phase 4	Phase 7
Enhanced winter weather?	Yes	No	Yes	Yes
Favorable temperatures	Yes	Yes	Neutral	Yes
Favorable precipitation	No	No	Yes	Neutral

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Past Research on Extratropical and S2S Impacts of MJO

- The MJO can affect:
  - Temperature over Arctic and Mid-Latitudes (e.g., Vecchi and Bond, 2004, Matsueda and Takaya 2015)
  - Precipitation over Asia (Jeong et al. 2008)
  - Blocking patterns such as the North Atlantic Oscillation (e.g., Cassou 2008)
- MJO and stratosphere combined can have impacts on height field (e.g., Green and Furtado 2019)

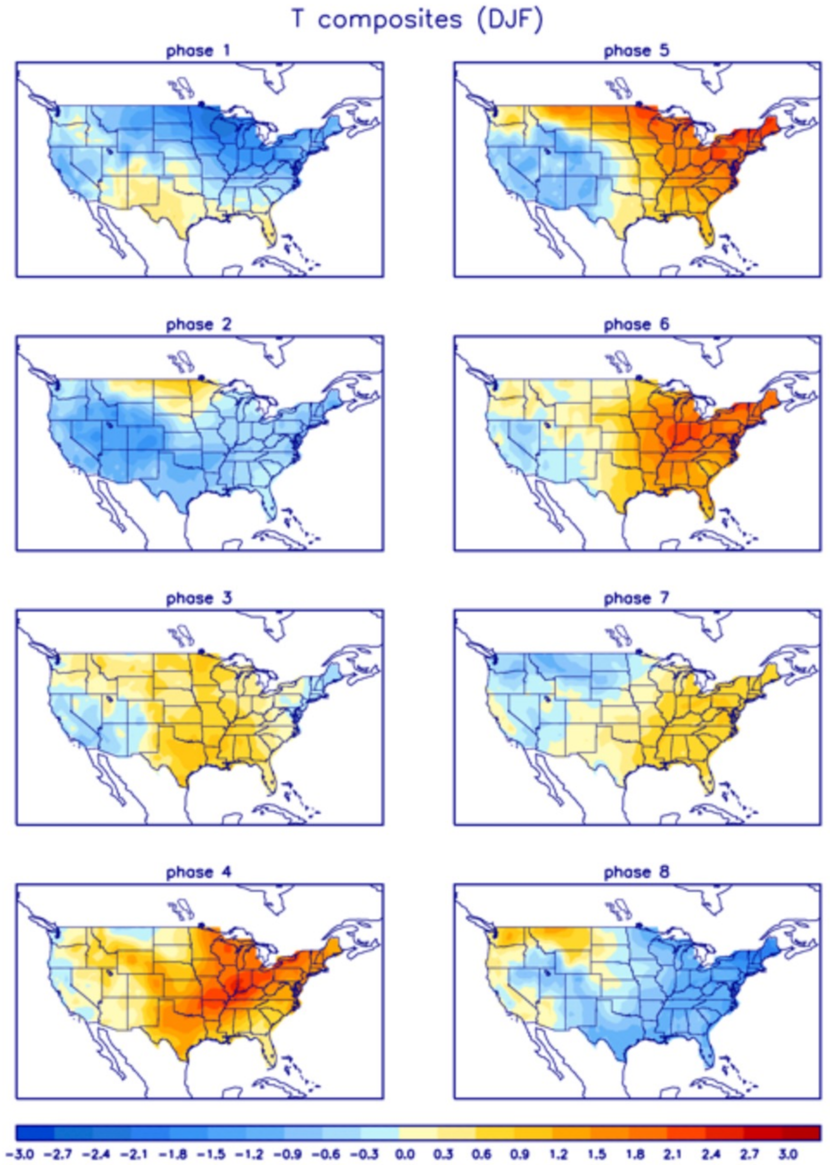

Figure source: Zhou et al. 2012

Color represents temperature anomalies in °C

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- Strong temperature gradient across the region
- Colder for heavy snow as compared to ice storms
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