Weather Regime-Dependent Predictability: Antecedent Environments Conducive to the Production of High-Impact Weather Events over the United States

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Project Motivation

- One or several extreme weather events (EWEs) during a single season can contribute disproportionately to temperature and precipitation anomaly statistics for a particular season.

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Project Motivation

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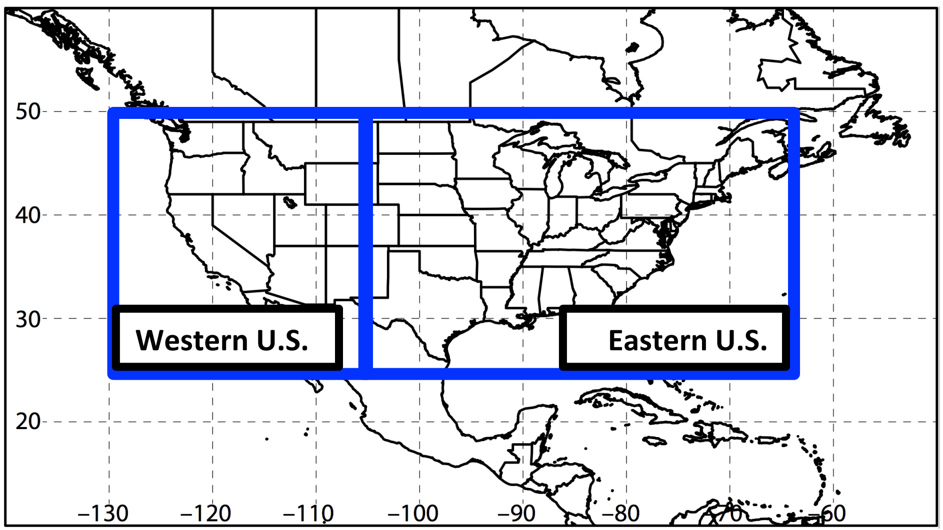
- The disproportionate contribution of EWEs to seasonal temperature and precipitation anomaly statistics suggests that EWEs need to be considered in understanding the dynamical and thermodynamic processes that operate at the weather–climate intersection.
- Consideration of EWEs may improve operational probabilistic temperature and precipitation forecasts in the 8–10 day time range.

Extreme Event Identification

Extreme Cold Events:

- Employed 1-h forecasts of 2-m temperature from the CFSR (0.5°× 0.5°) at 6-h intervals during 1979–2014 (Saha et al. 2014).

- Compiled times during which at least one grid point was characterized by a temperature < **1st percentile** within separate domains over the western and eastern U.S.



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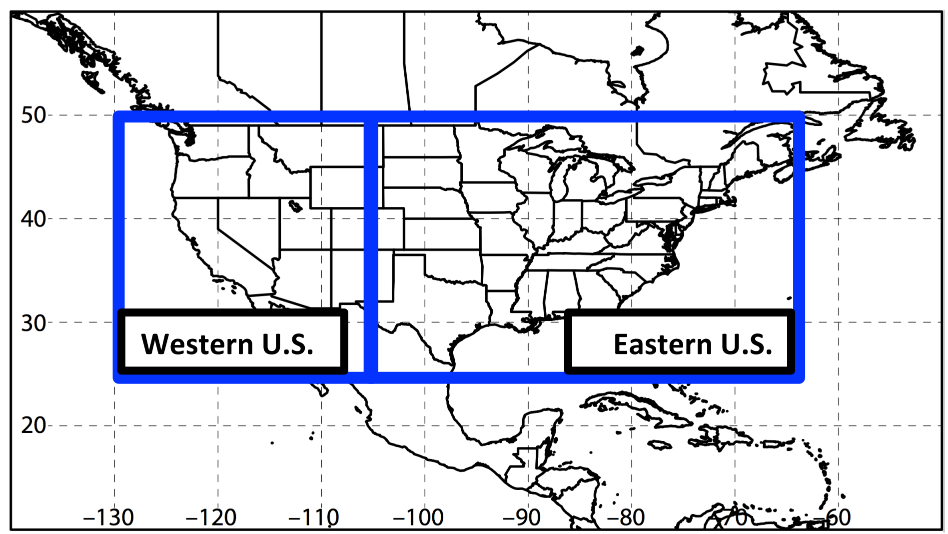
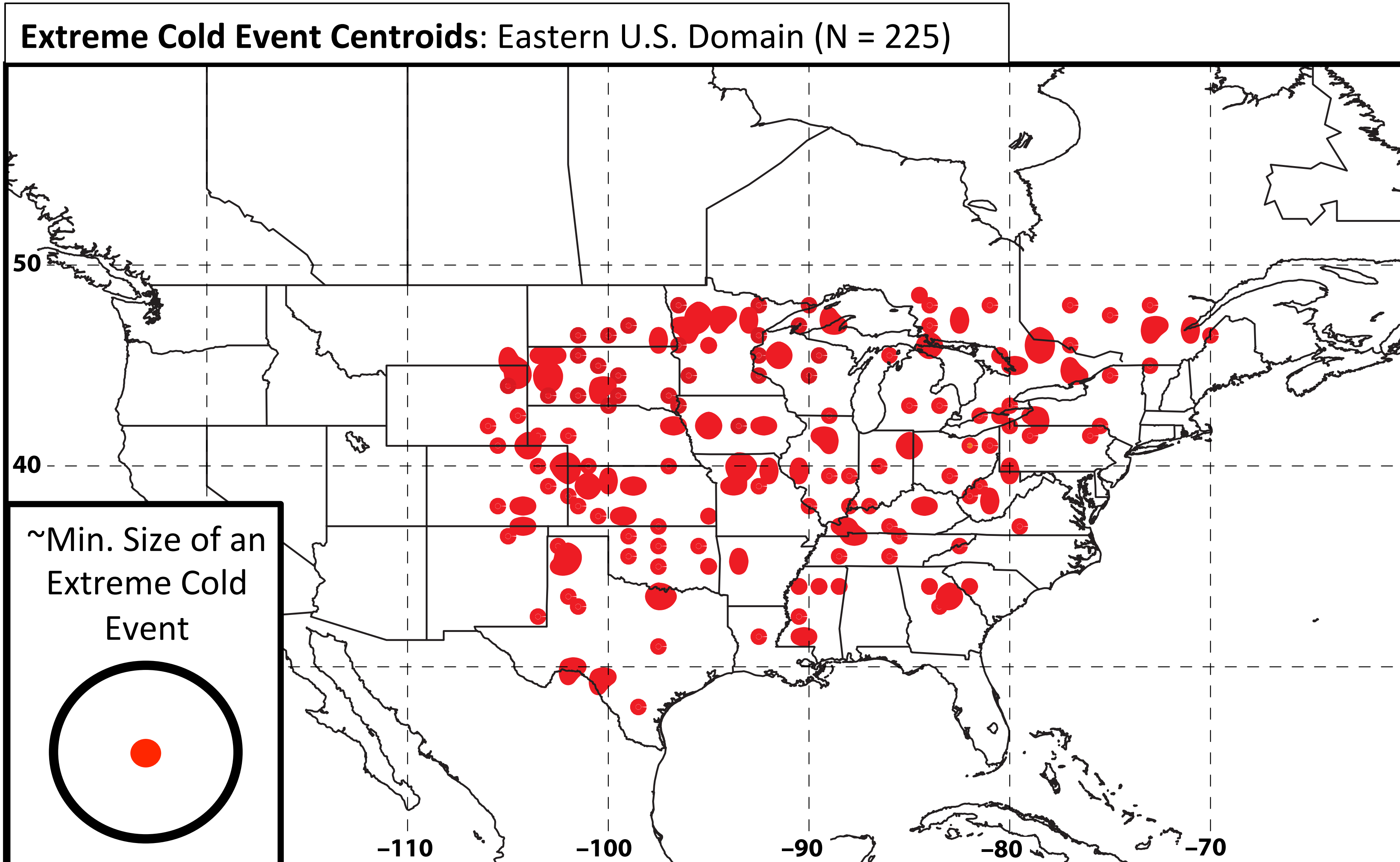
- Identified times that ranked in the **top 5%** in terms of the number of grid points < **1st percentile** as **extreme cold events** within each domain.

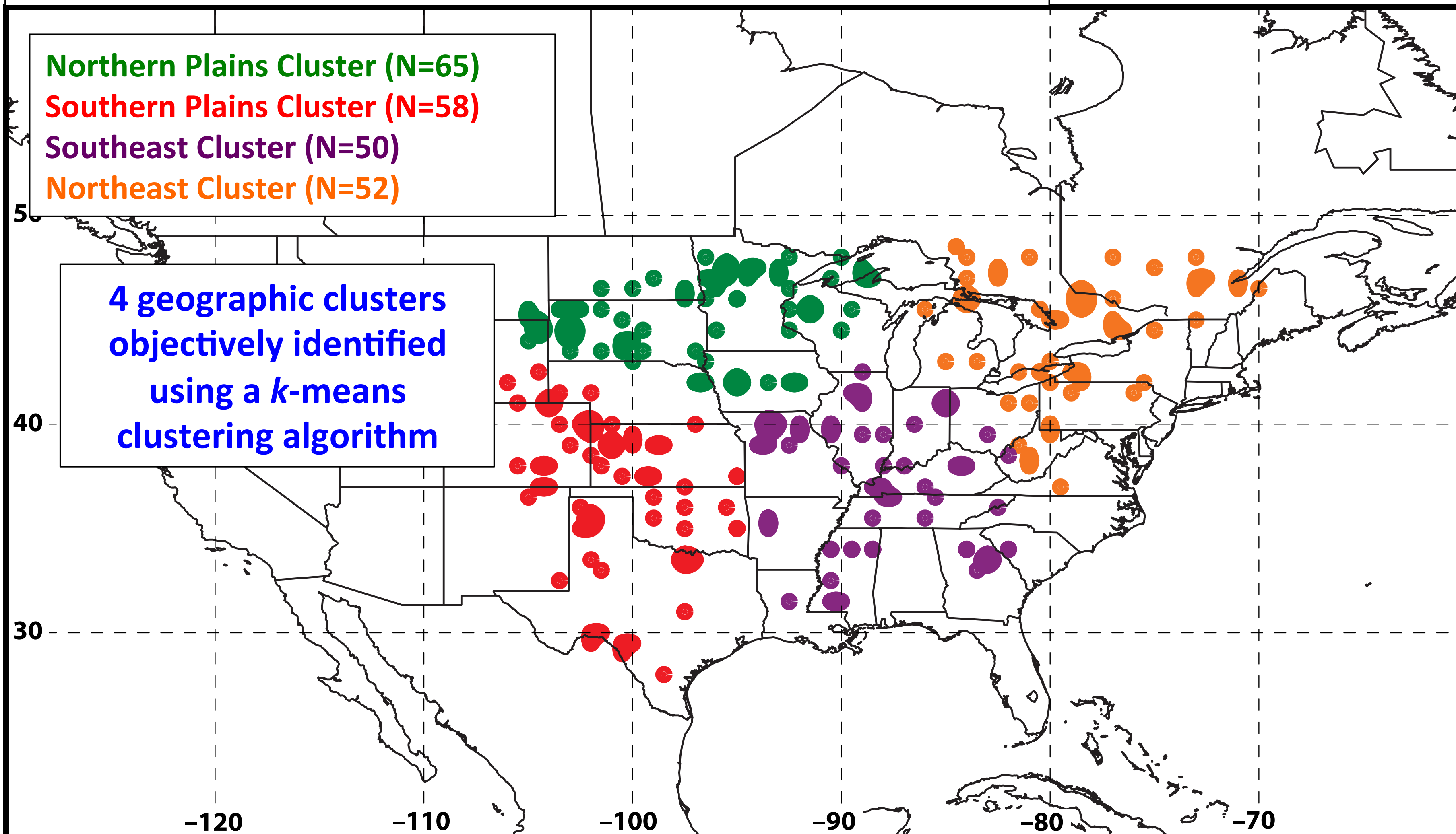


Extreme Event Identification



Extreme Event Identification

Extreme Cold Event Centroids: Eastern U.S. Domain (N = 225)



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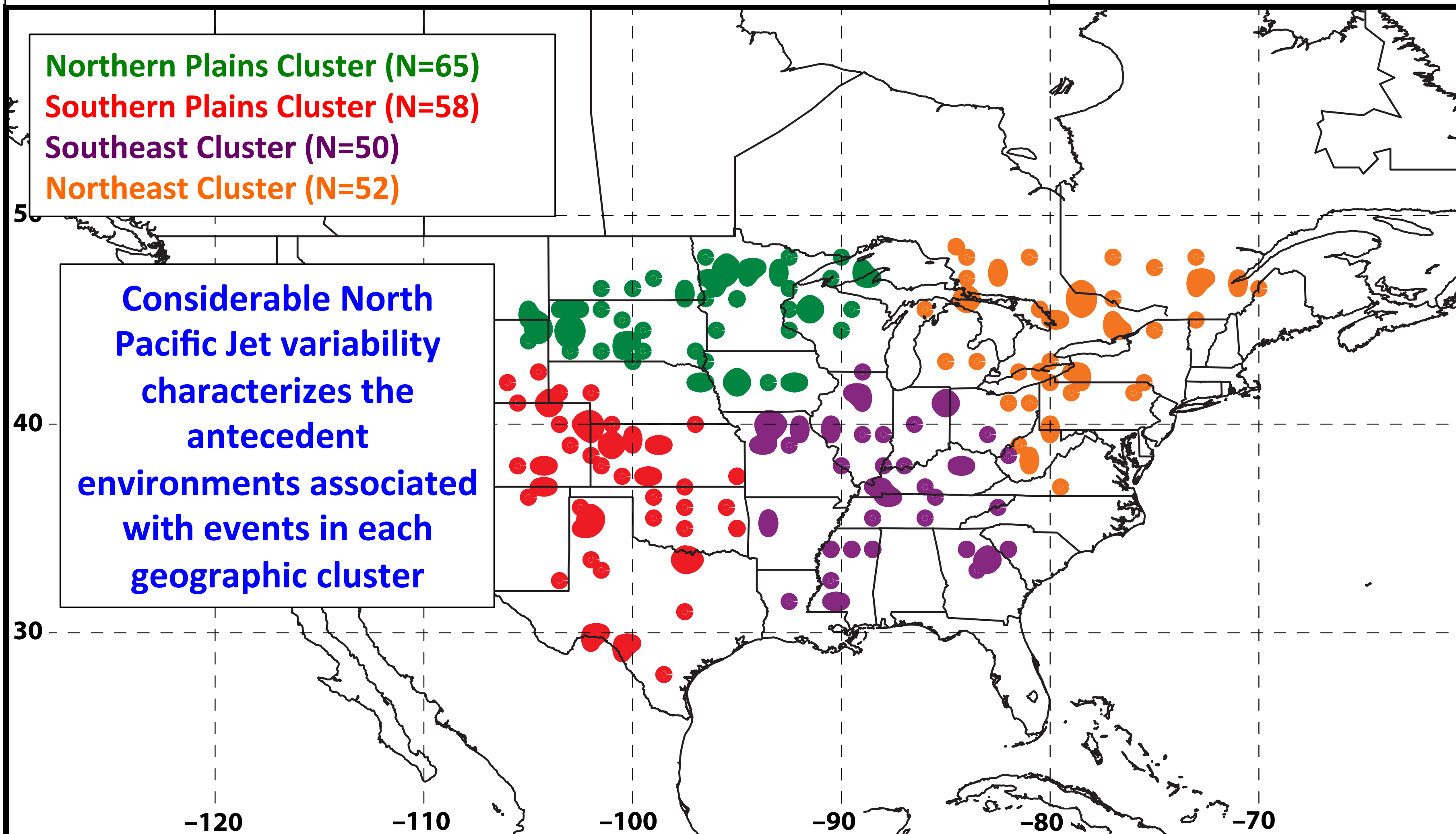


Antecedent Environments Associated with Cool-Season (Sept.–May) EWEs in the Context of North Pacific Jet Variability

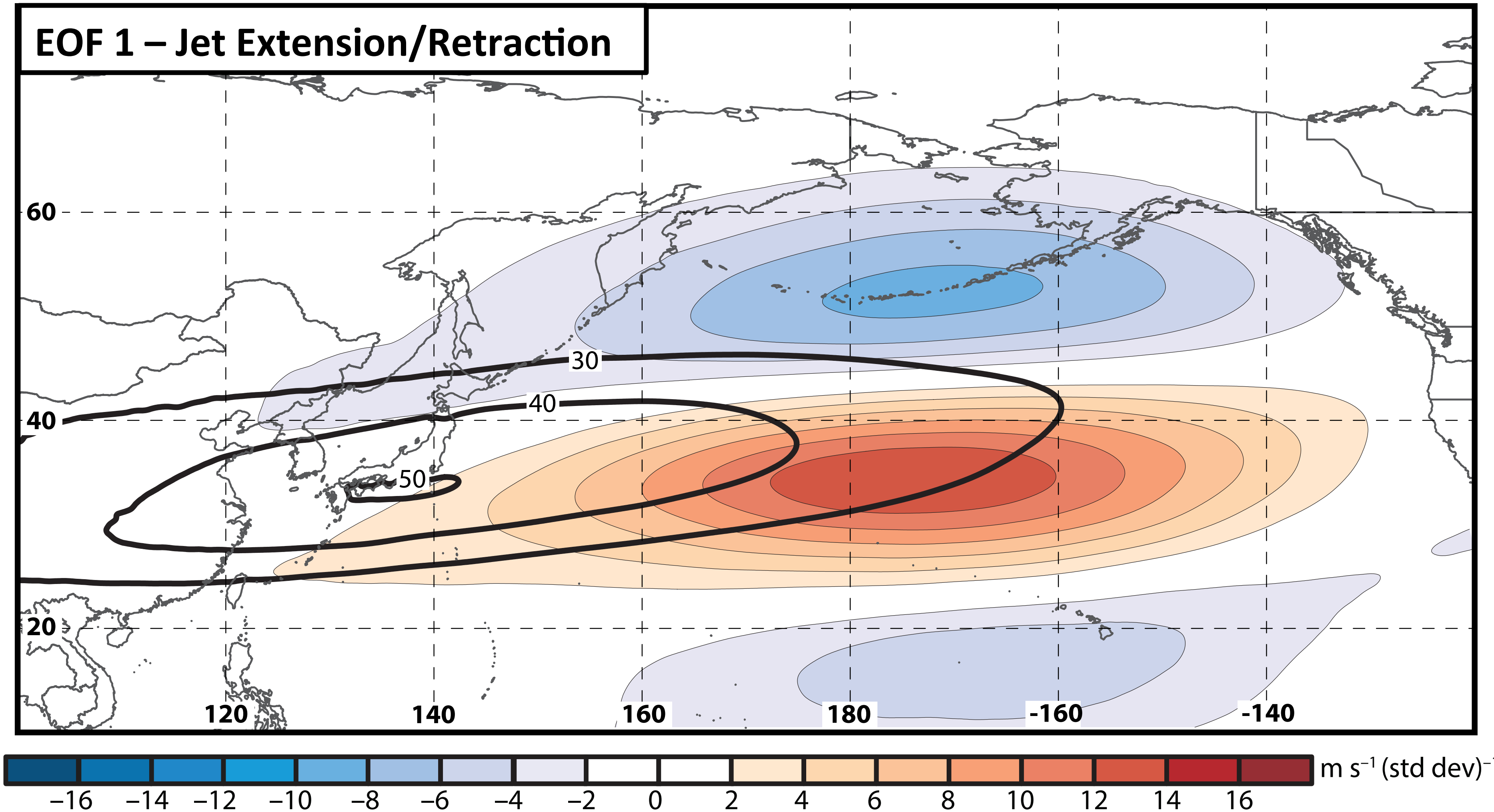
250-hPa North Pacific Zonal Wind Variability

- Removed the mean and the annual and diurnal cycles from 6-hourly, 250-hPa zonal wind data from the CFSR (1979–2014)
- Restricted data to the cool season (Sept.–May)
- Performed an EOF analysis on the zonal wind anomalies within the domain: 10–80°N ; 100°E–120°W

Analysis techniques and resultant EOF patterns are consistent with related work on the North Pacific Jet:

- Athanasiadis et al. (2010)
- Jaffe et al. (2011)
- Griffin and Martin (2016)

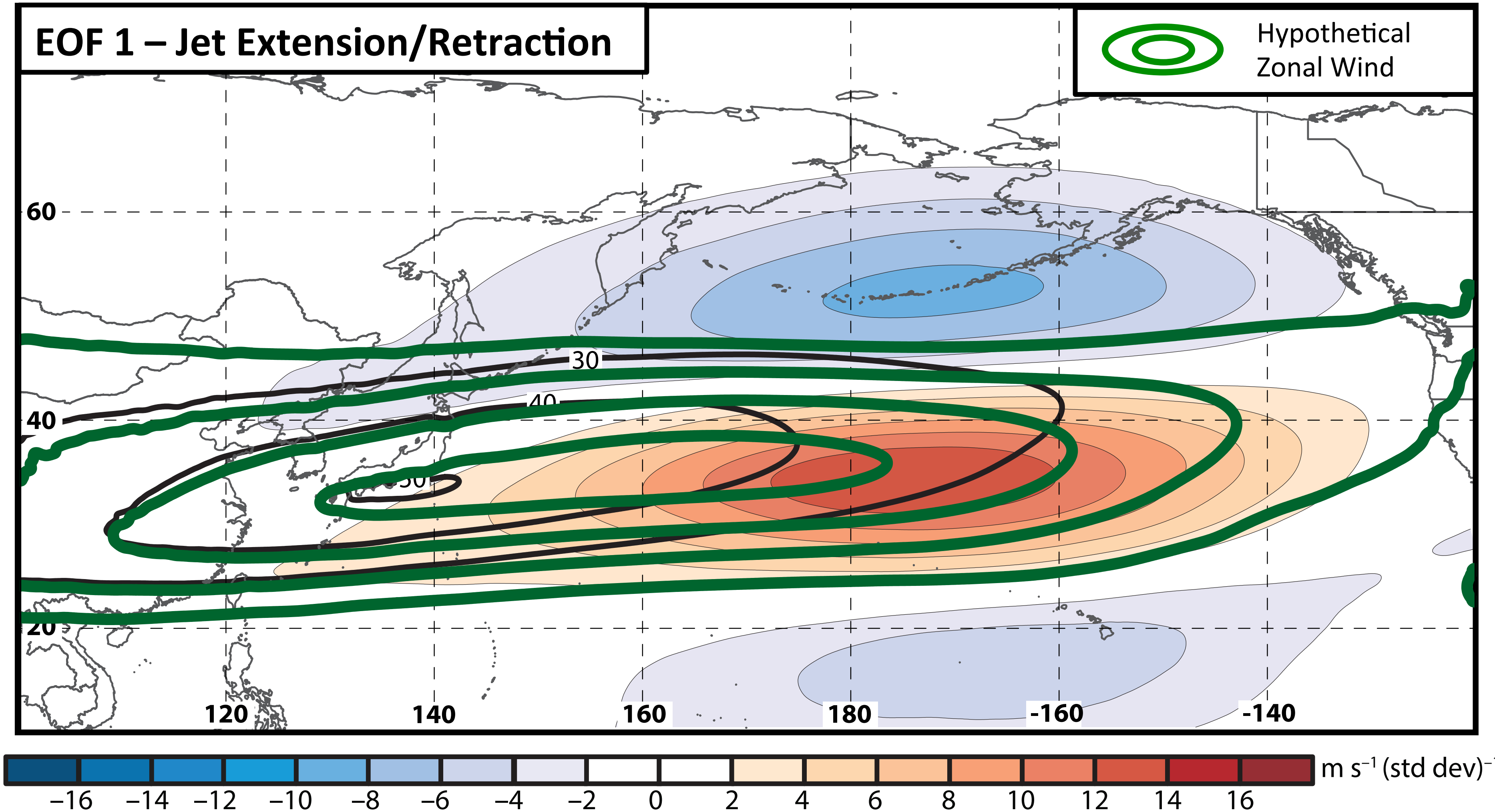
250-hPa North Pacific Zonal Wind Variability



Sept.–May mean 250-hPa zonal wind: black contours
Sept.–May 250-hPa zonal wind EOF 1 pattern: shading

+ EOF 1: Jet Extension
– EOF 1: Jet Retraction

250-hPa North Pacific Zonal Wind Variability



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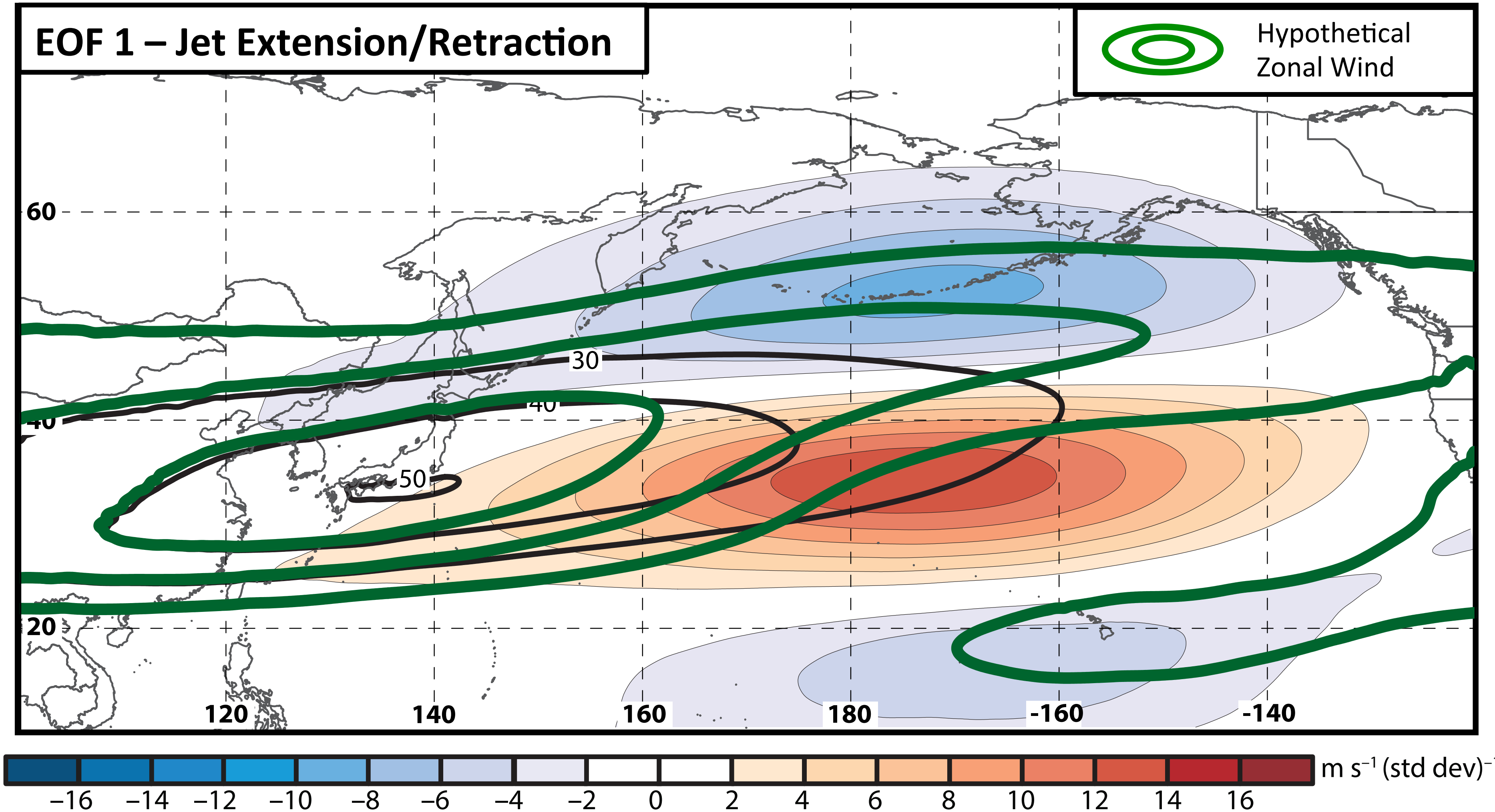

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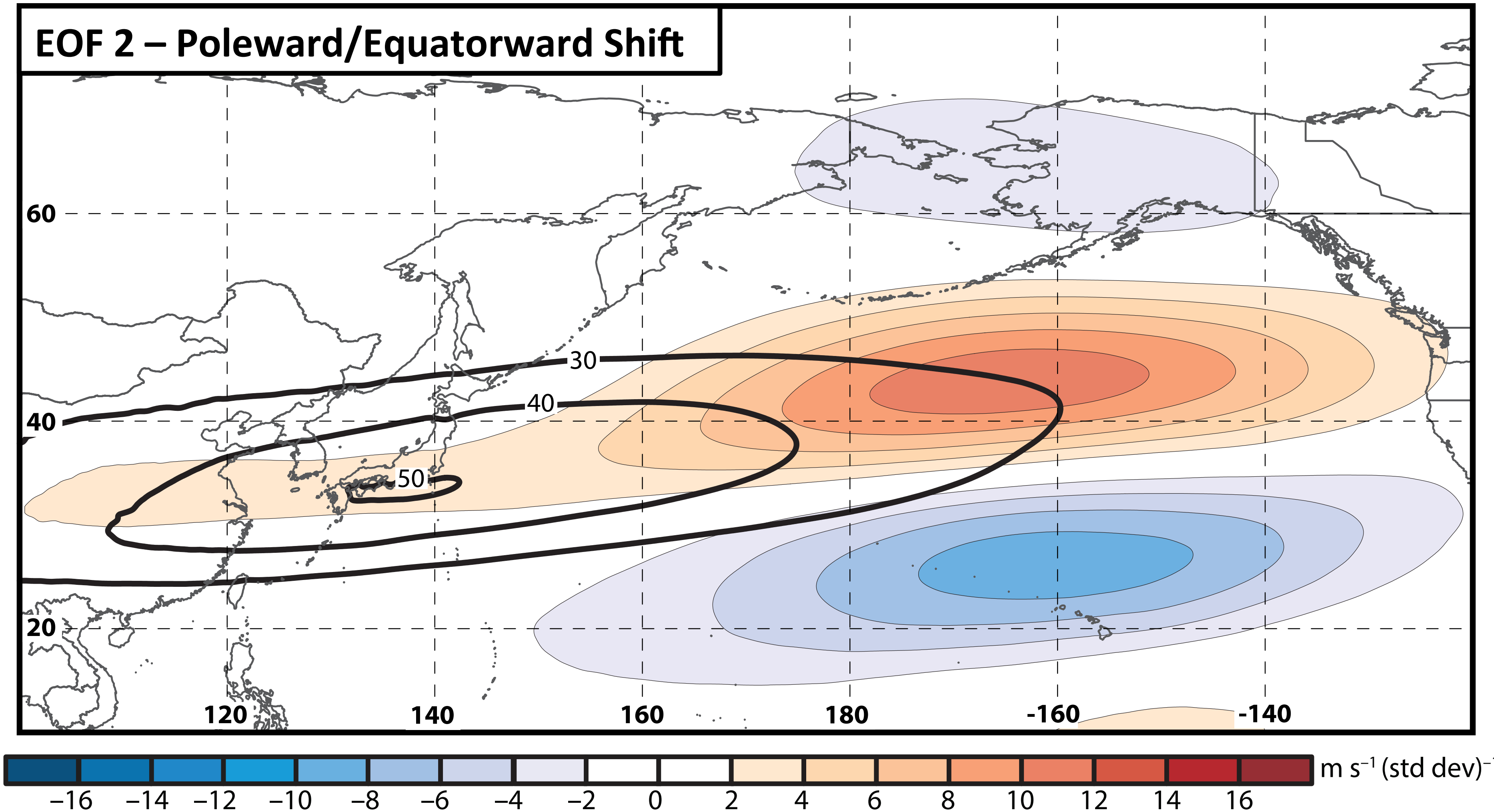
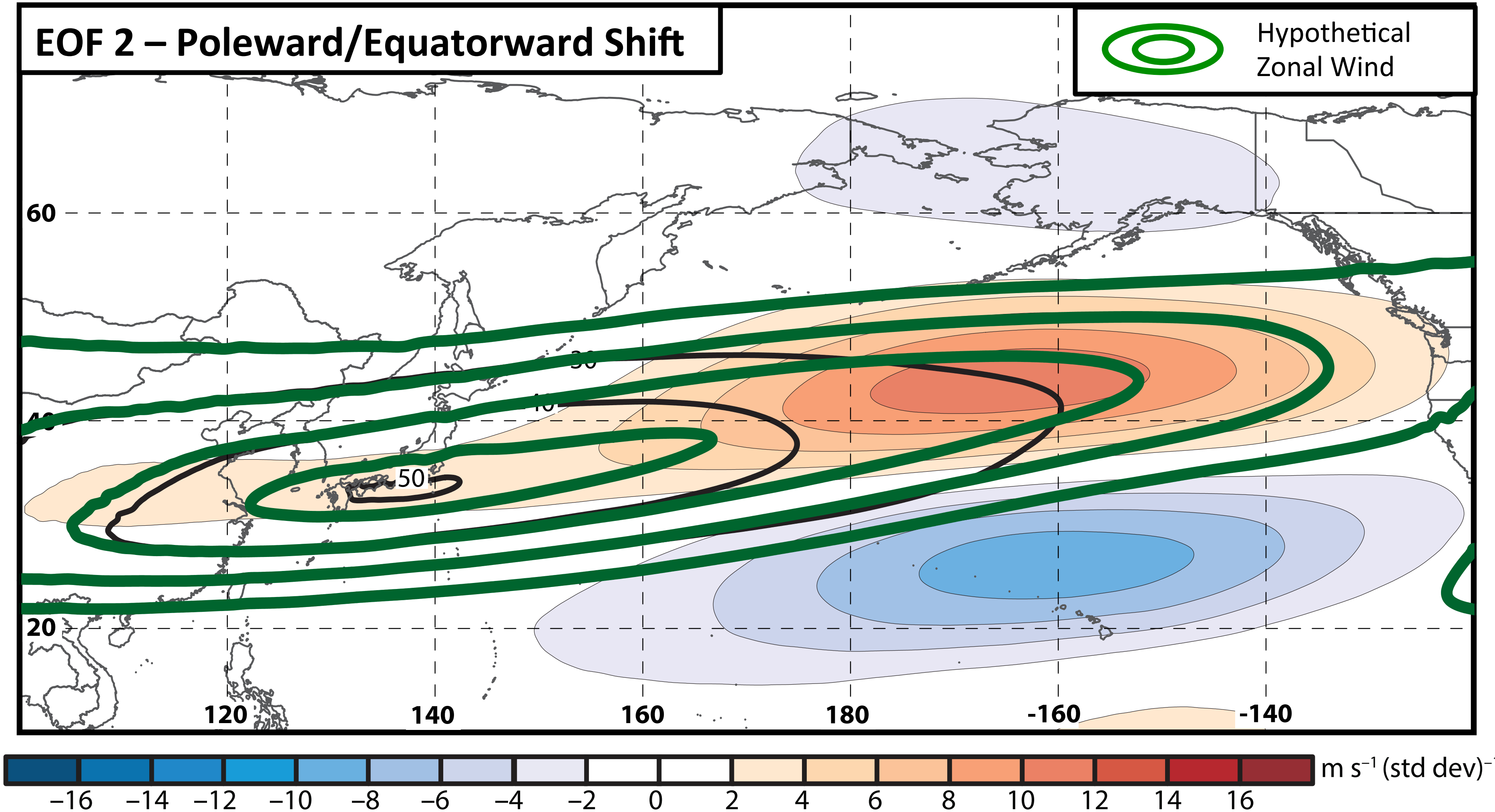


Sept.–May mean 250-hPa zonal wind: black contours
Sept.–May 250-hPa zonal wind EOF 2 pattern: shading

+ EOF 2: Poleward Shift
– EOF 2: Equatorward Shift

250-hPa North Pacific Zonal Wind Variability



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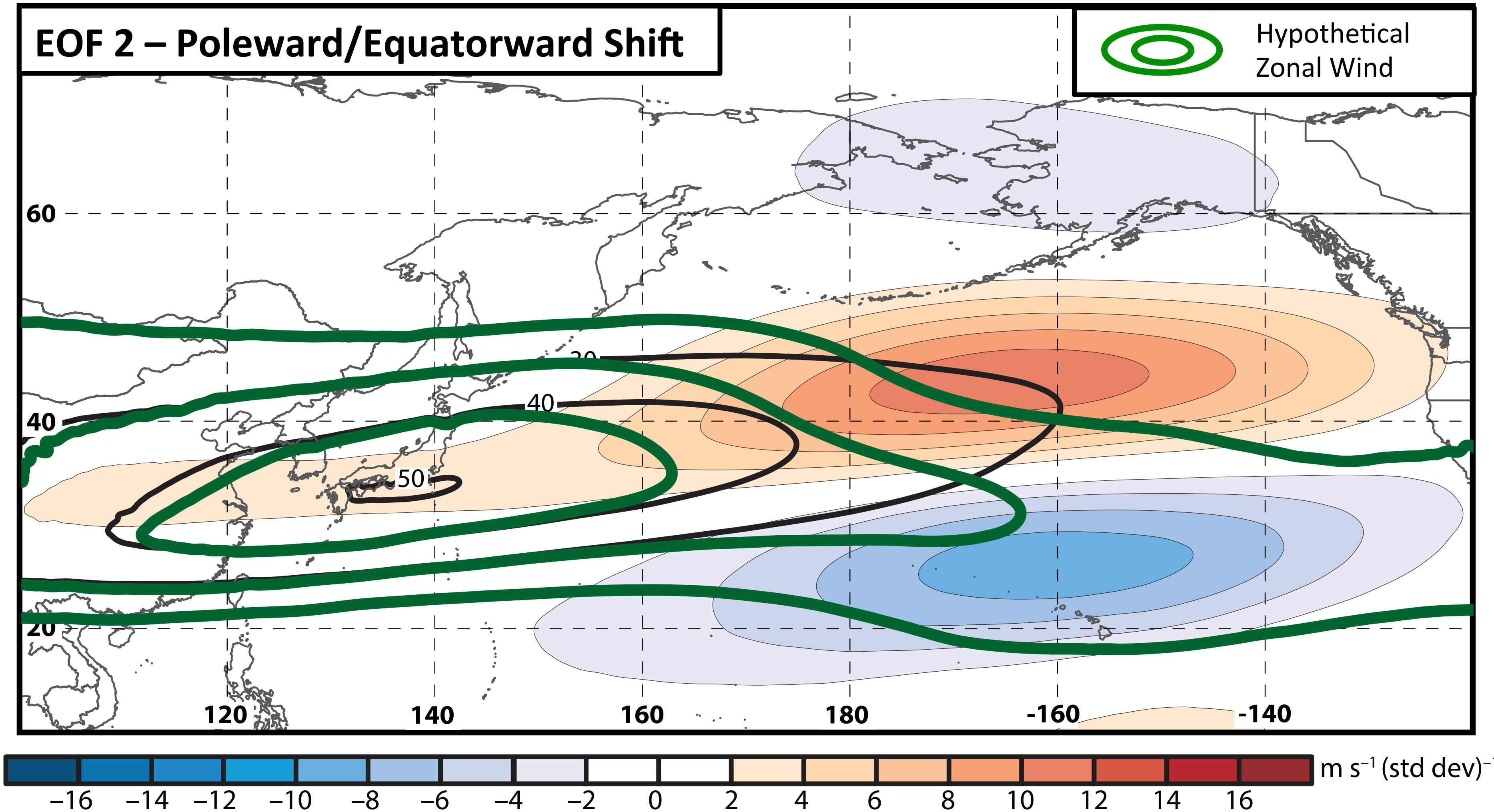

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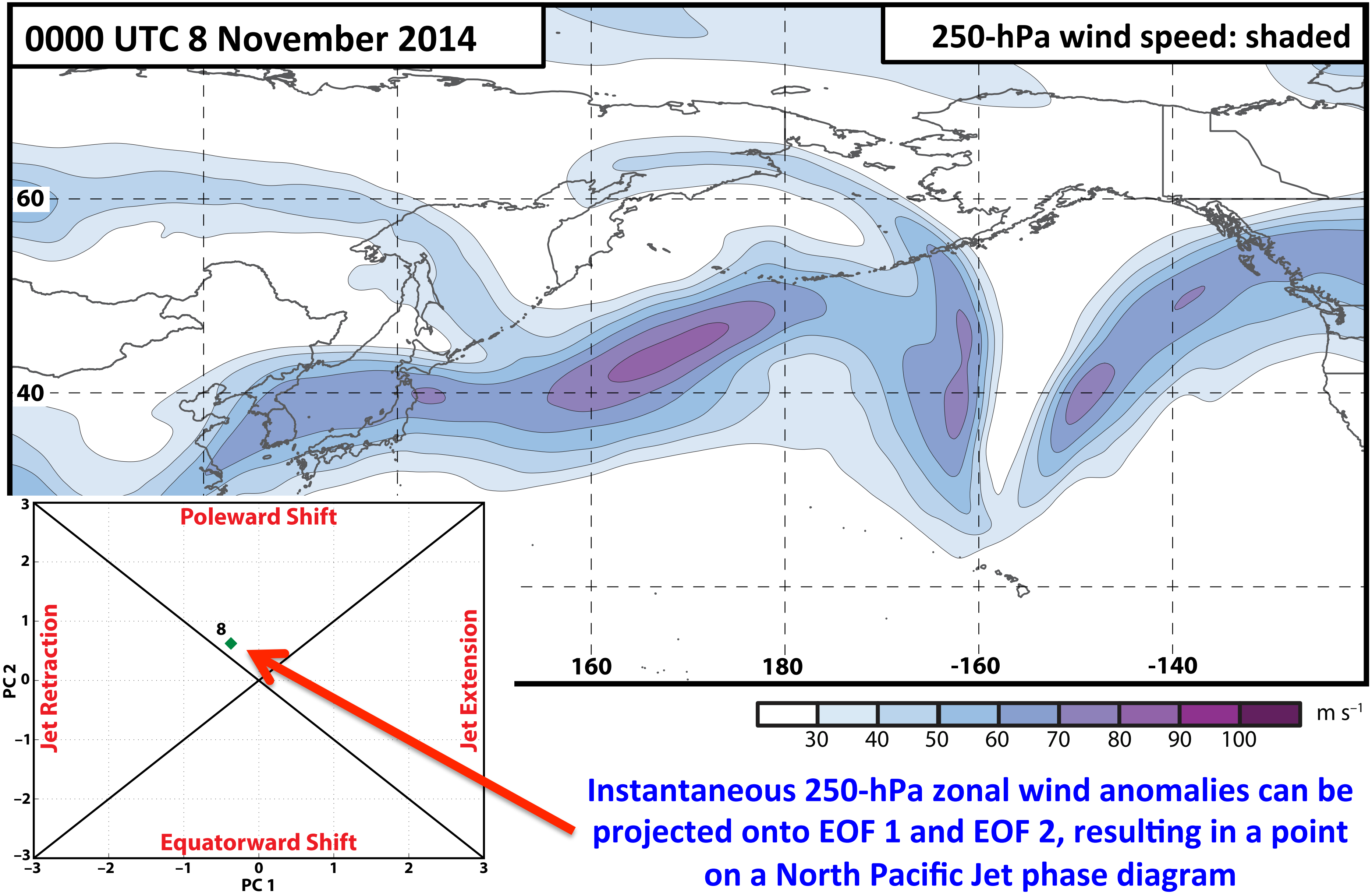
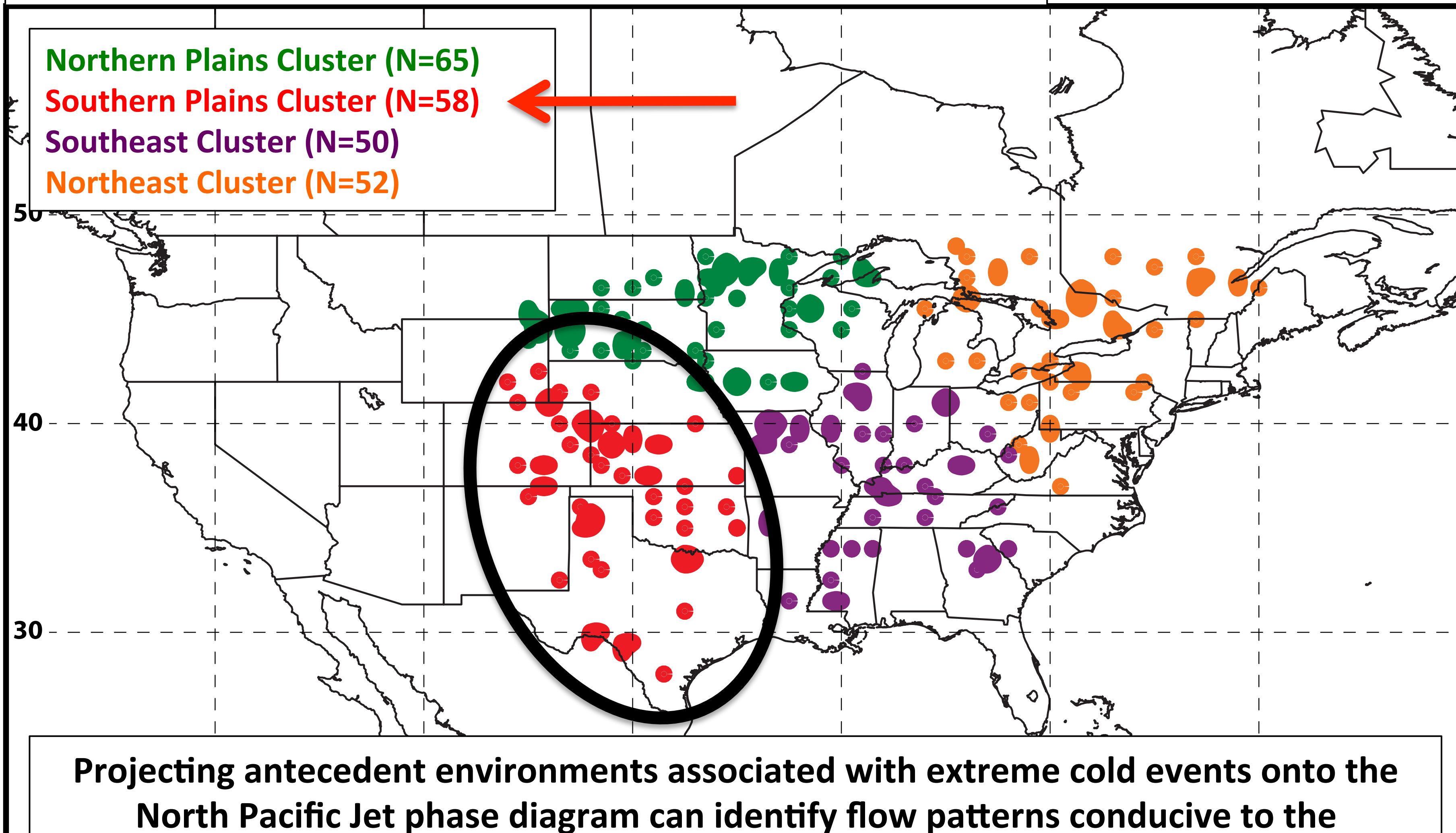
250-hPa North Pacific Zonal Wind Variability



Instantaneous 250-hPa zonal wind anomalies can be projected onto EOF 1 and EOF 2, resulting in a point on a North Pacific Jet phase diagram

250-hPa North Pacific Zonal Wind Variability

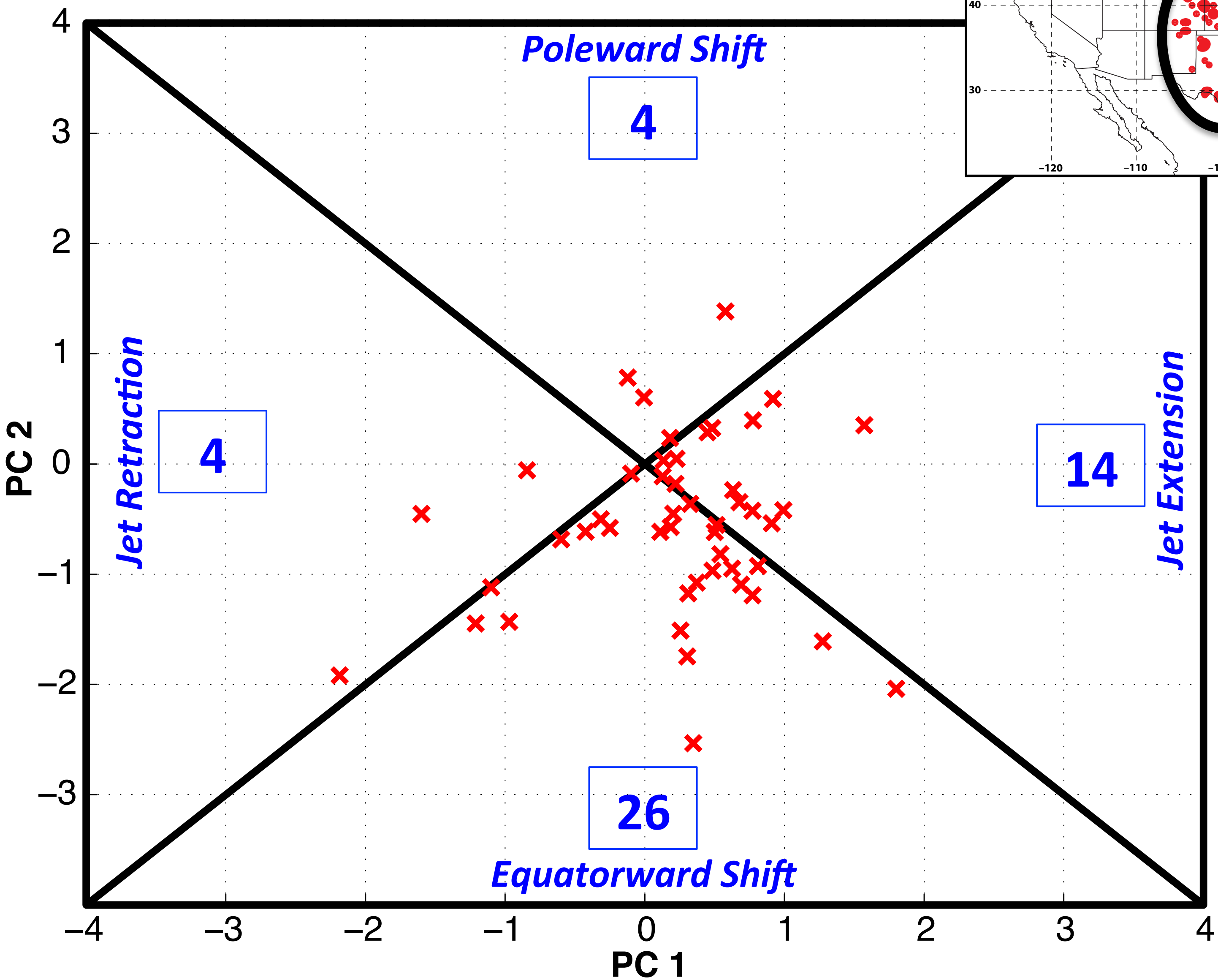
Extreme Cold Event Centroids: Eastern U.S. Domain (N = 225)

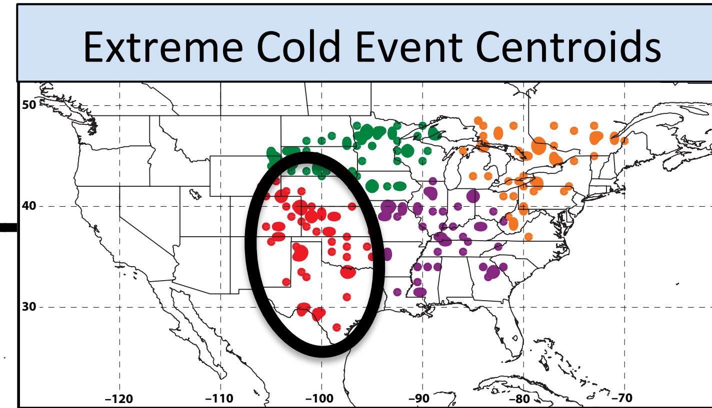


Projecting antecedent environments associated with extreme cold events onto the North Pacific Jet phase diagram can identify flow patterns conducive to the development of these events

Eastern U.S. – S. Plains Cluster

COLD EVENTS (N = 48)





Events during Sept. – May projected onto phase diagram

Each point is an average of the PCs 3–7 days prior to an event

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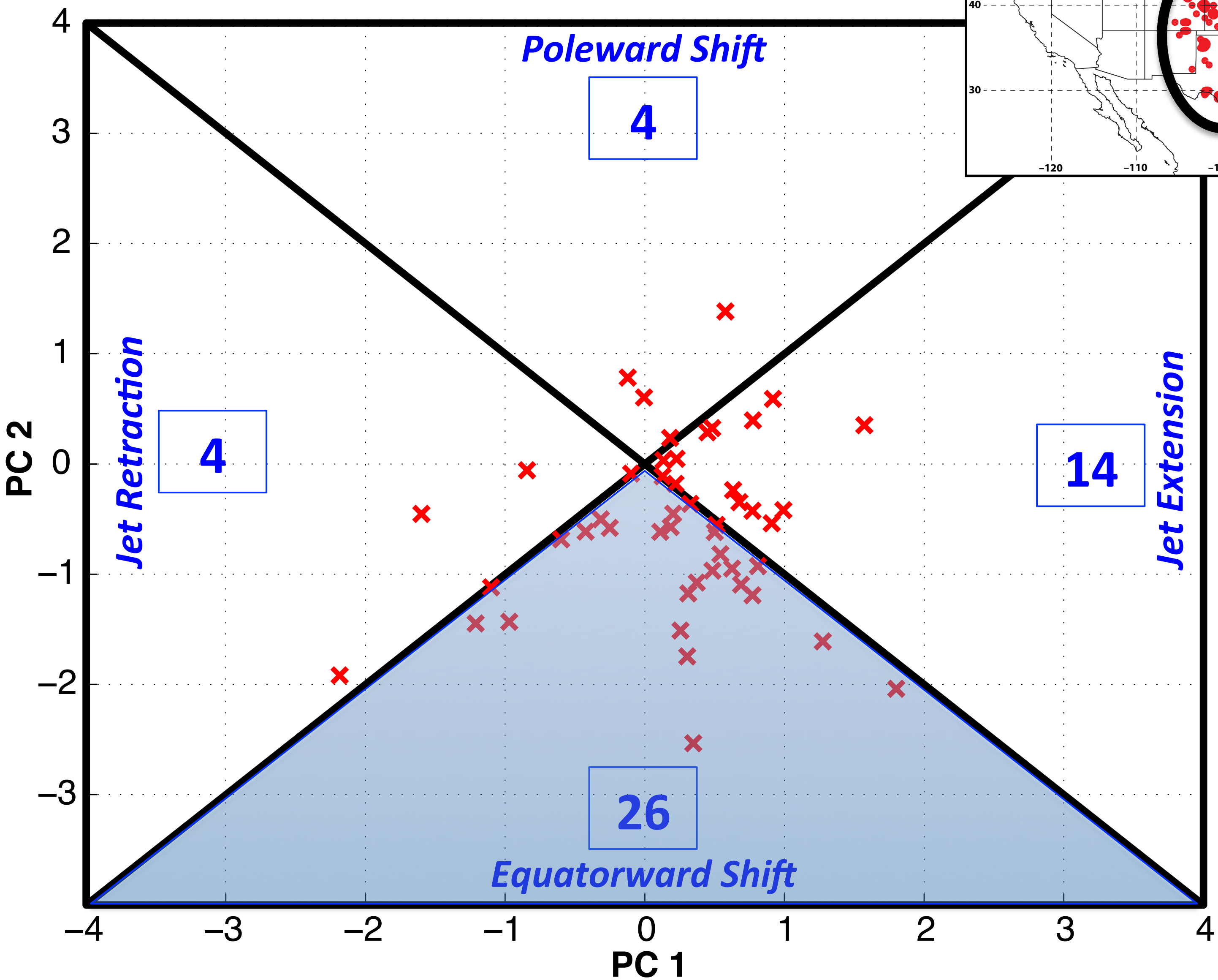

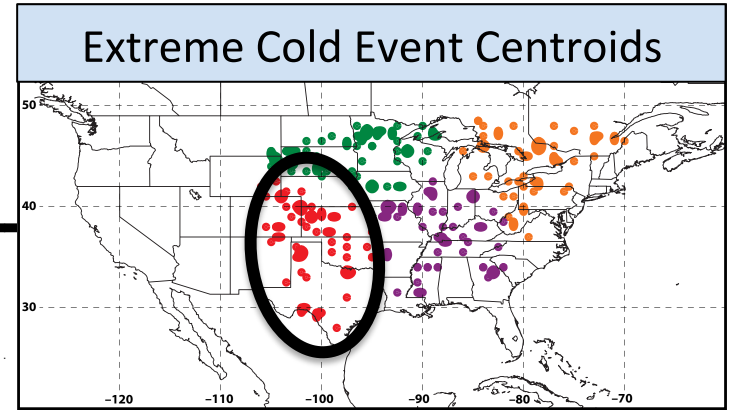

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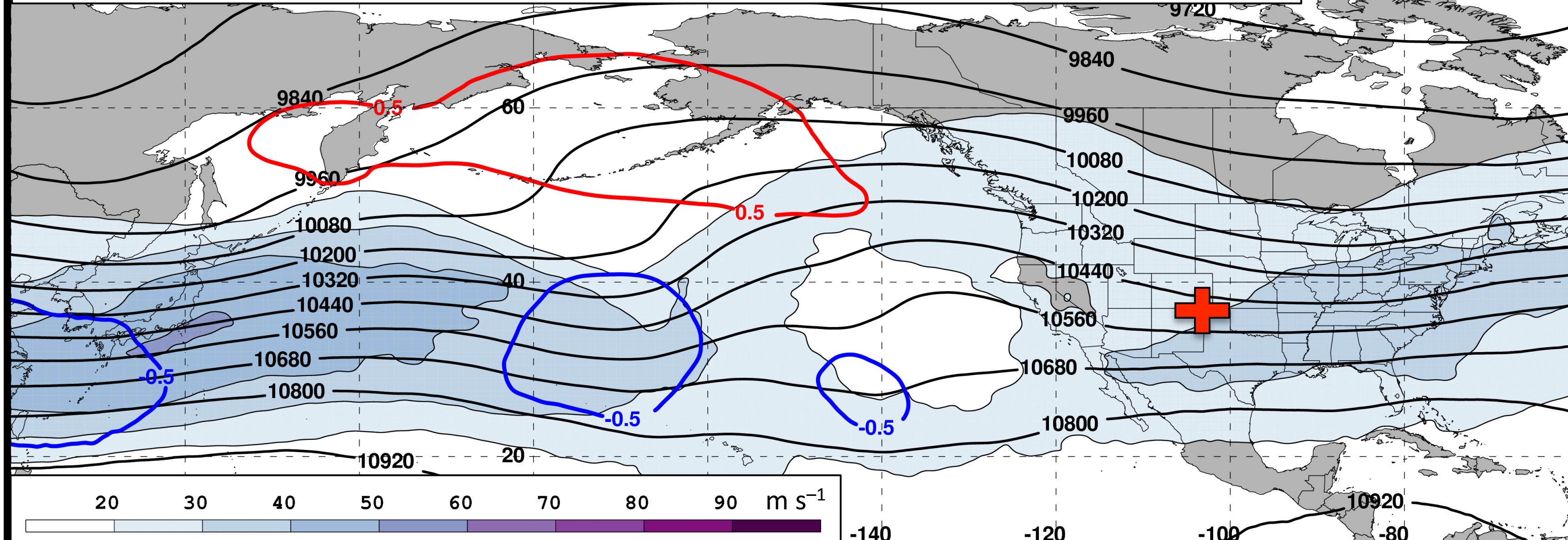
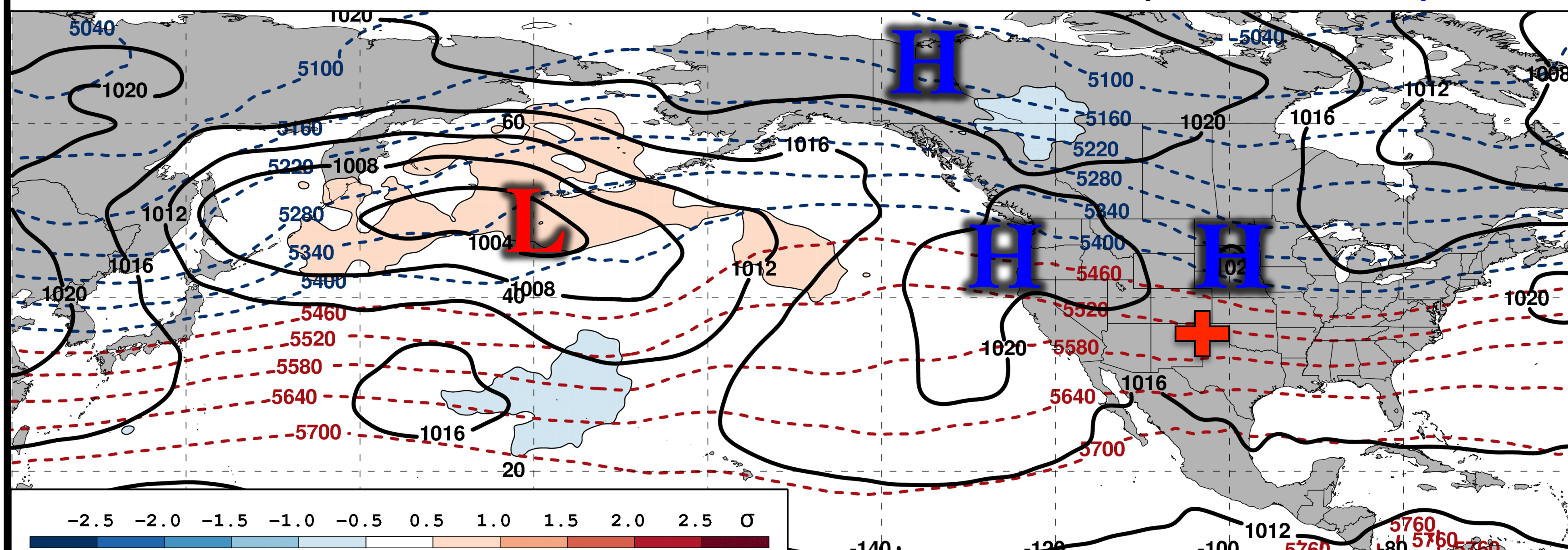
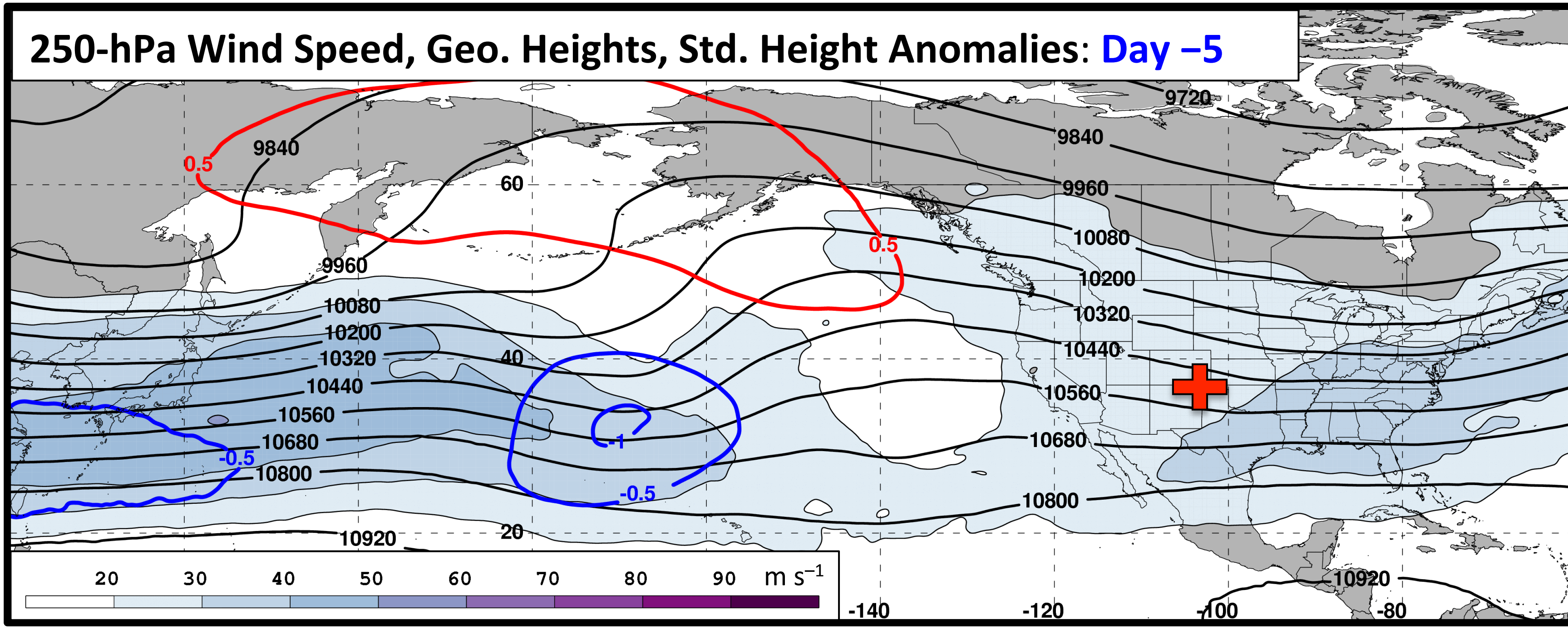
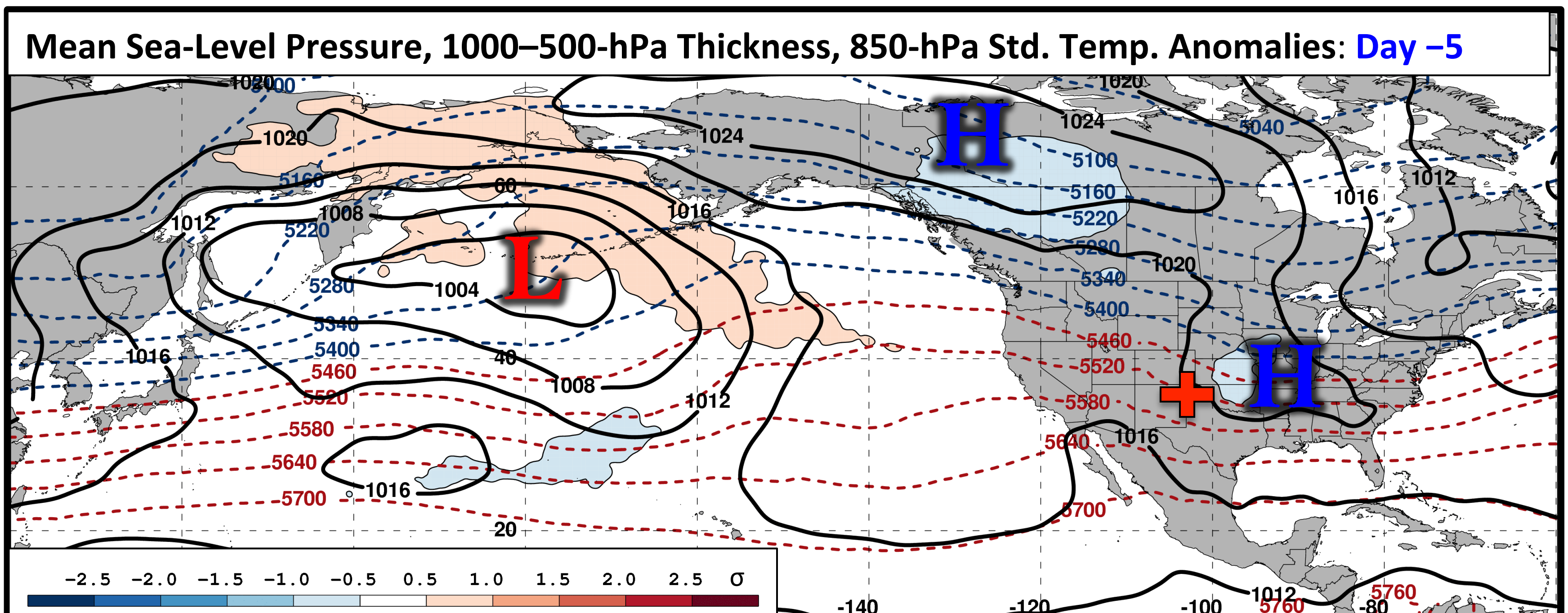
250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day −6

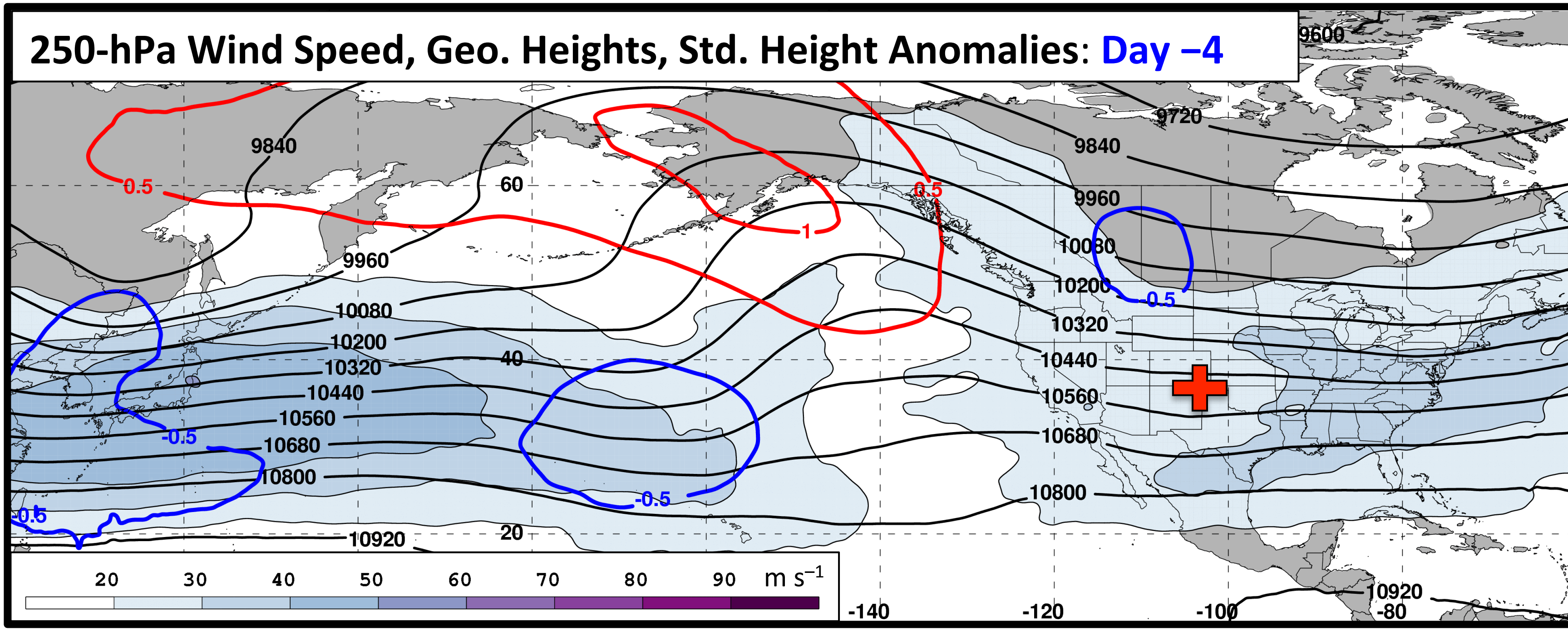


Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day −6

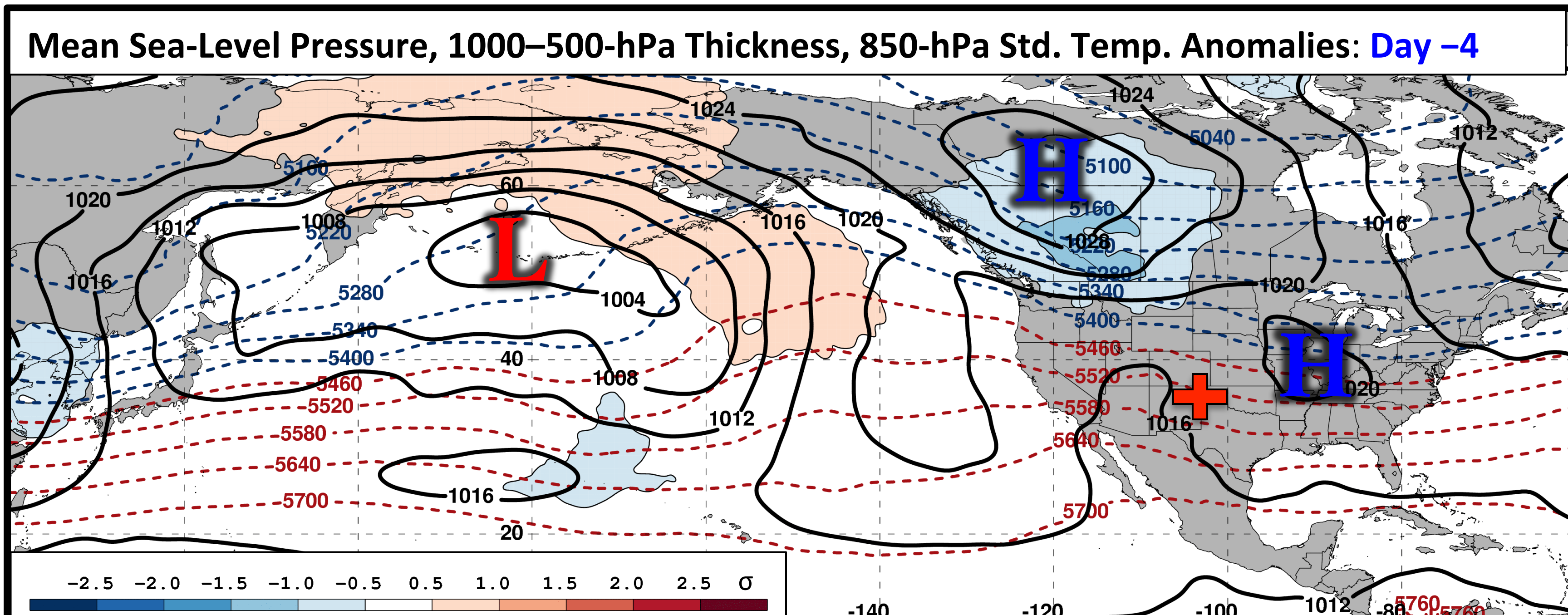



250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day −5
20 30 40 50 60 70 80 90 m s−1
9720
9840
9960
10080
10200
10320
10440
10560
10680
10800
10920
0.5
-0.5
-1
60
40
20
-140
-120
-100
-80


Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day −5
−2.5 −2.0 −1.5 −1.0 −0.5 0.5 1.0 1.5 2.0 2.5 σ
H
L
H
1004
1008
1012
1016
1020
1024
5040
5100
5160
5220
5280
5340
5400
5460
5520
5580
5640
5700
5760
60
40
20
-140
-120
-100
-80

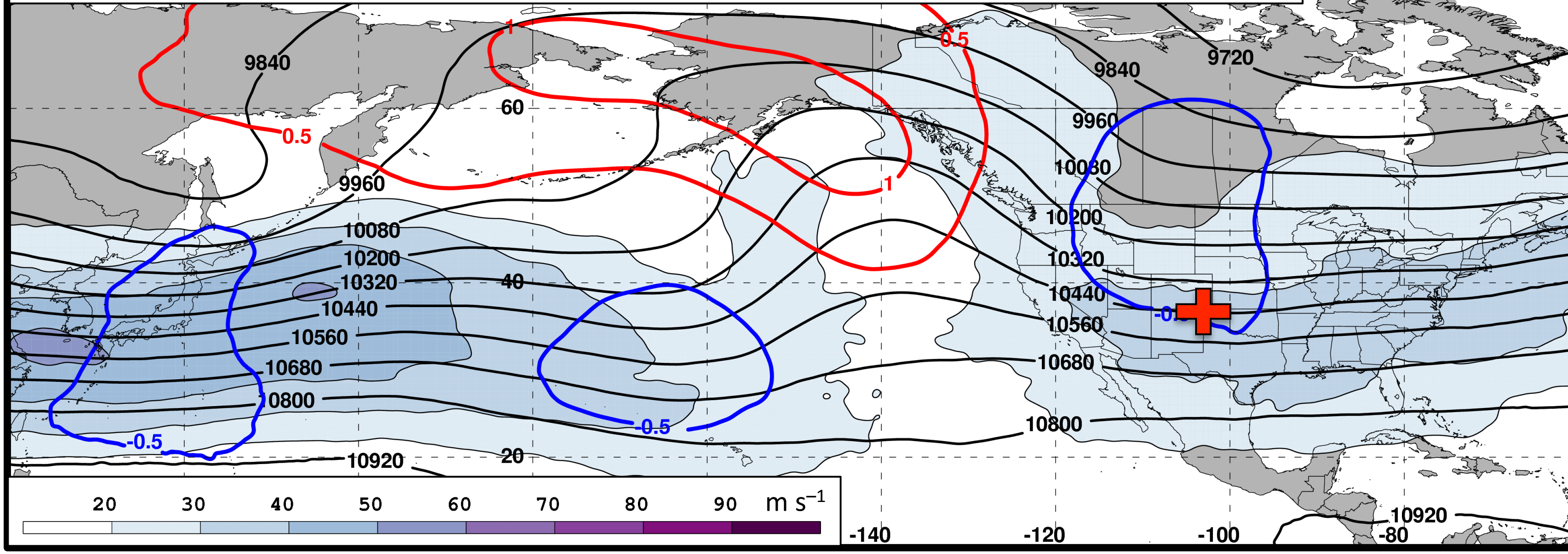


250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day –4

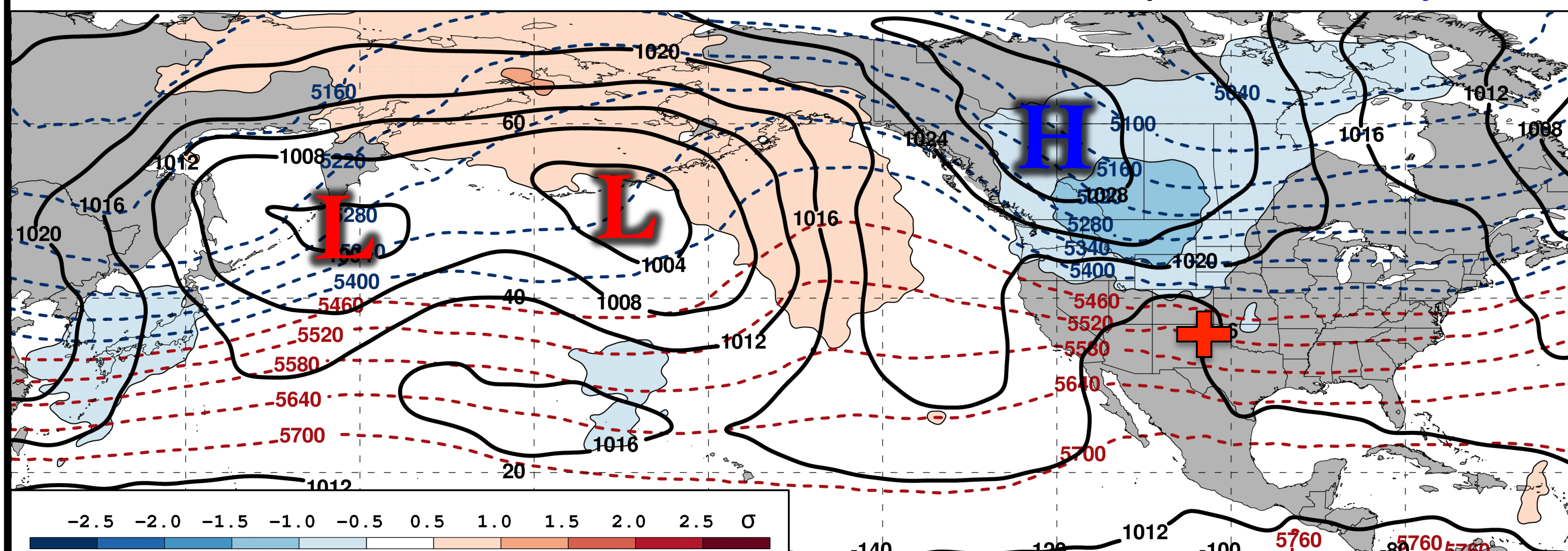


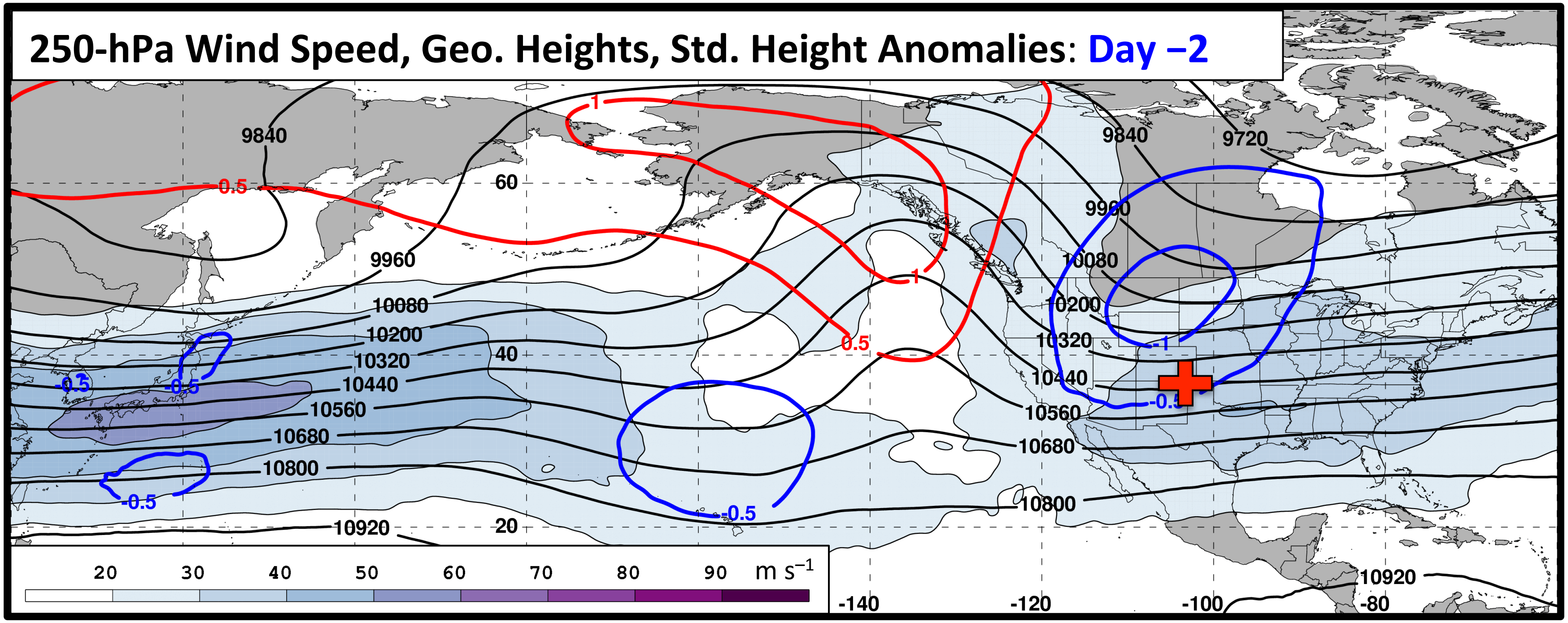
Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day –4

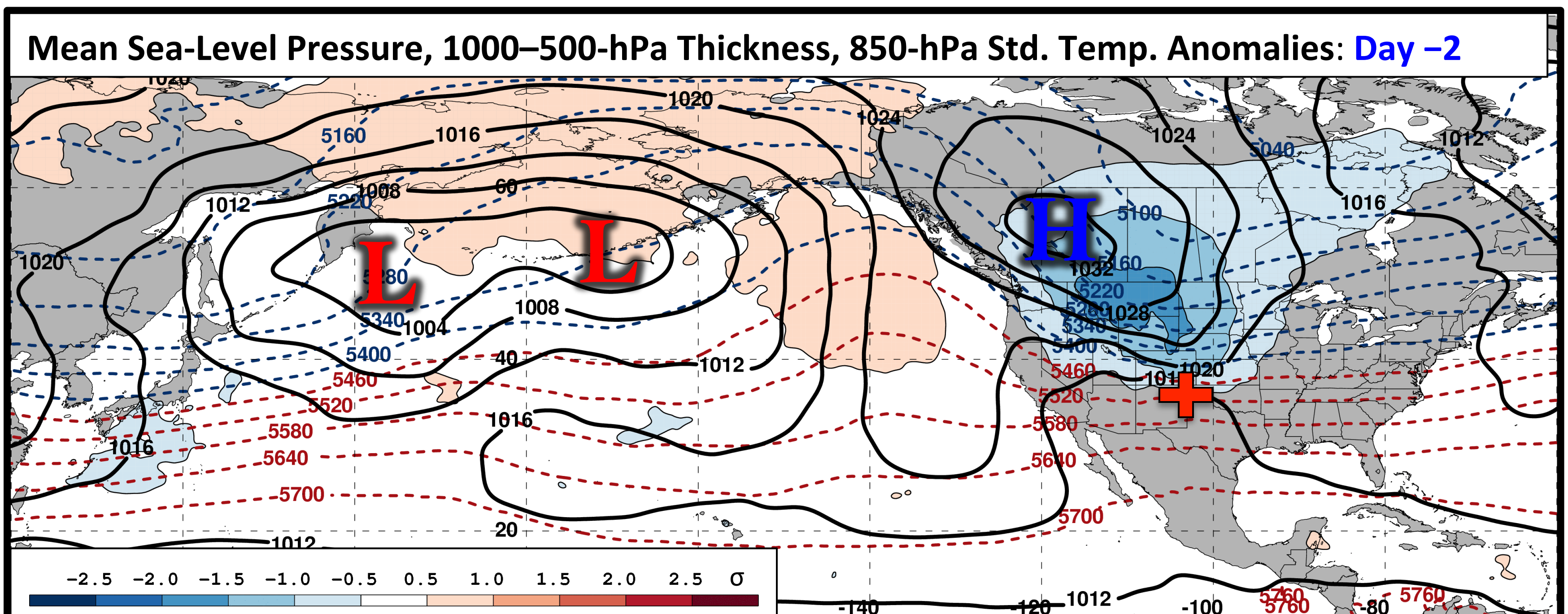
250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day −3

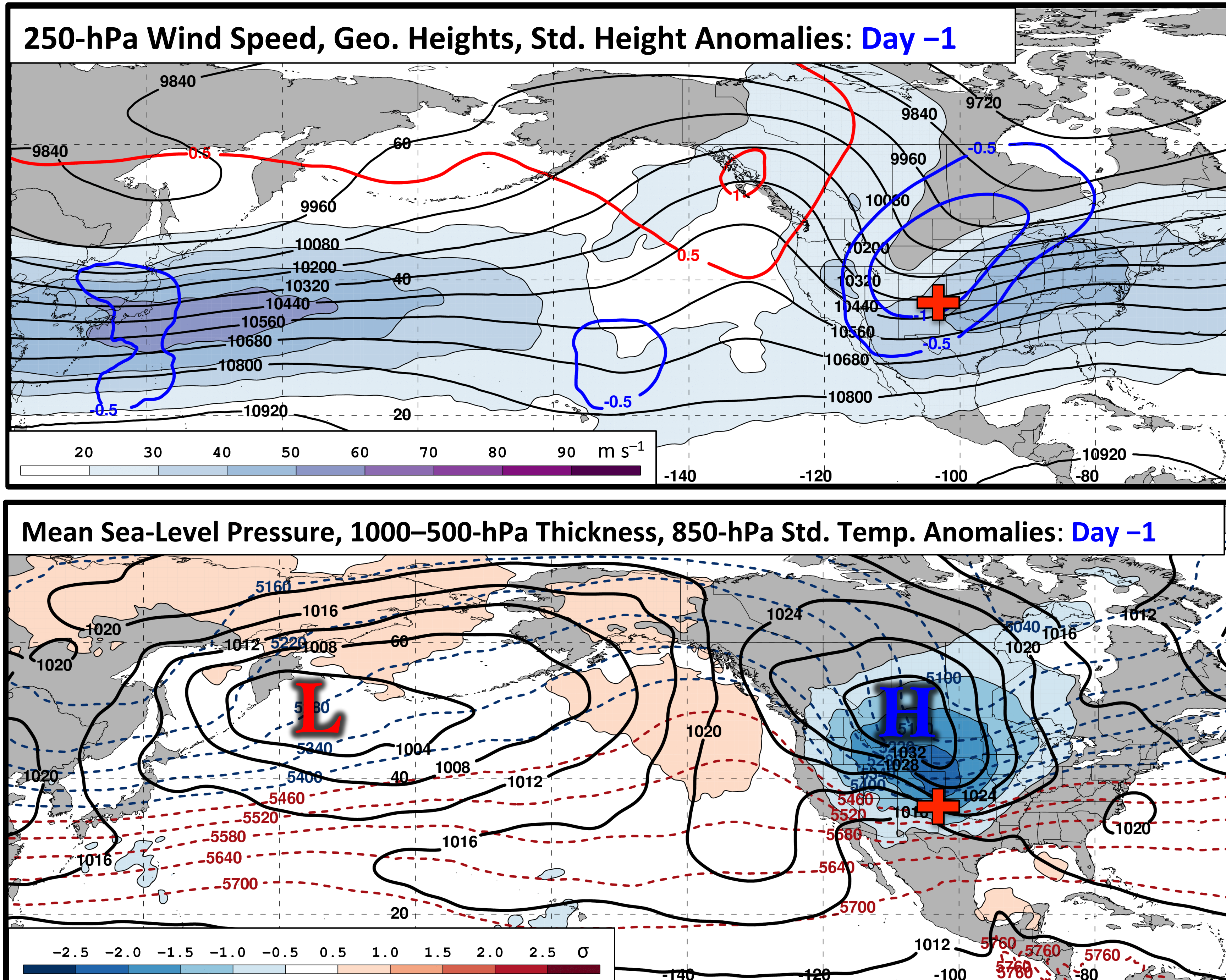


Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day −3




250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day −2
9840
9720
9960
10080
10200
10320
10440
10560
10680
10800
10920
60
40
20
1
0.5
-0.5
-1
20 30 40 50 60 70 80 90 m s−1
-140
-120
-100
-80


Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day −2
L
L
H
1004
1008
1012
1016
1020
1024
1028
1032
5040
5100
5160
5220
5280
5340
5400
5460
5520
5580
5640
5700
5760
60
40
20
−2.5 −2.0 −1.5 −1.0 −0.5 0.5 1.0 1.5 2.0 2.5 σ
-140
-120
-100
-80


250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day −1
9840
9720
9960
10080
10200
10320
10440
10560
10680
10800
10920
0.5
-0.5
-1
1
20 30 40 50 60 70 80 90 m s⁻¹
-140 -120 -100 -80
Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day −1
L
H
1004
1008
1012
1016
1020
1024
1028
1032
5040
5100
5160
5220
5340
5400
5460
5520
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5640
5700
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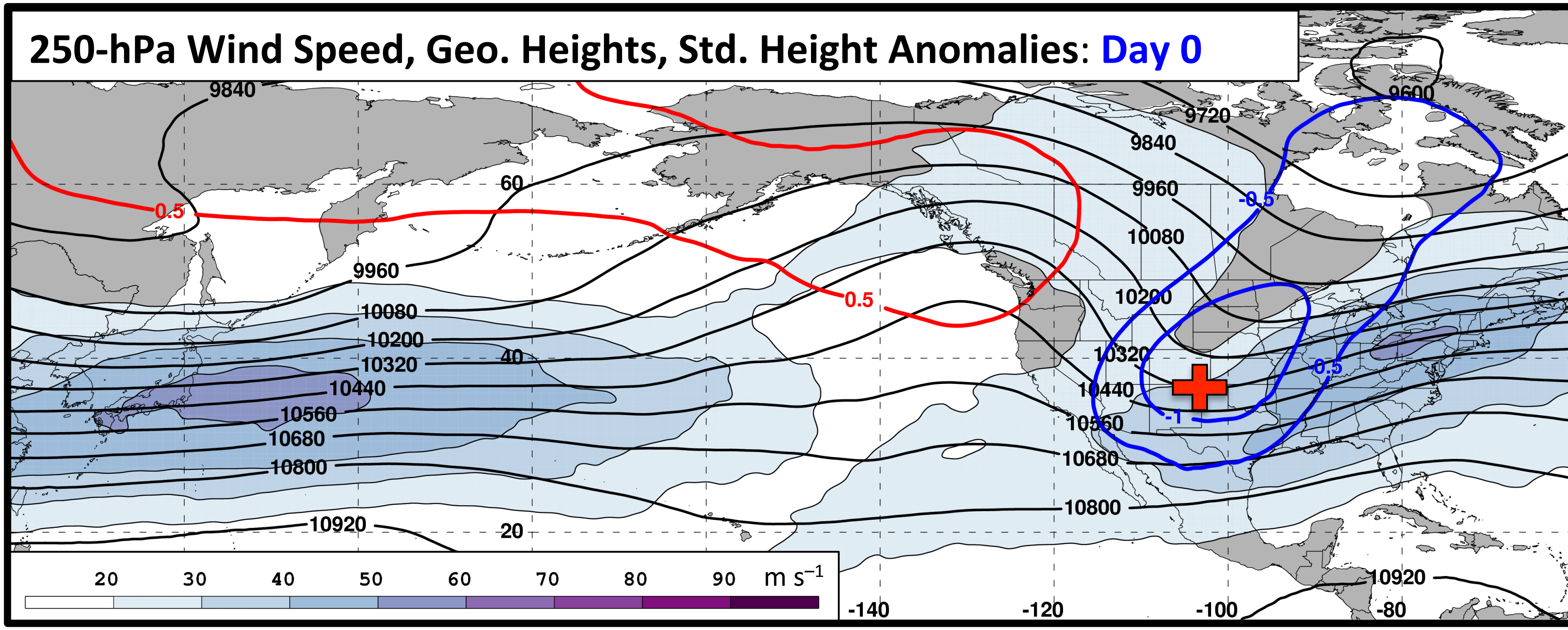
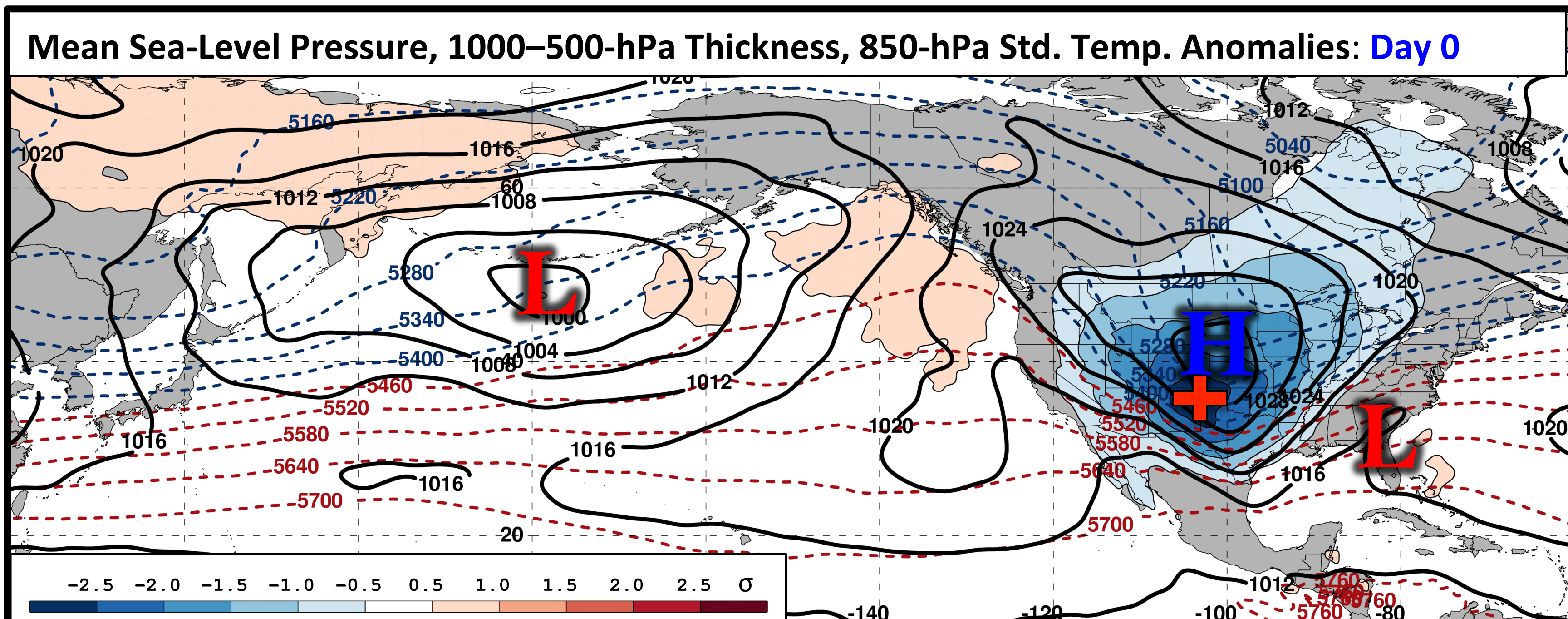
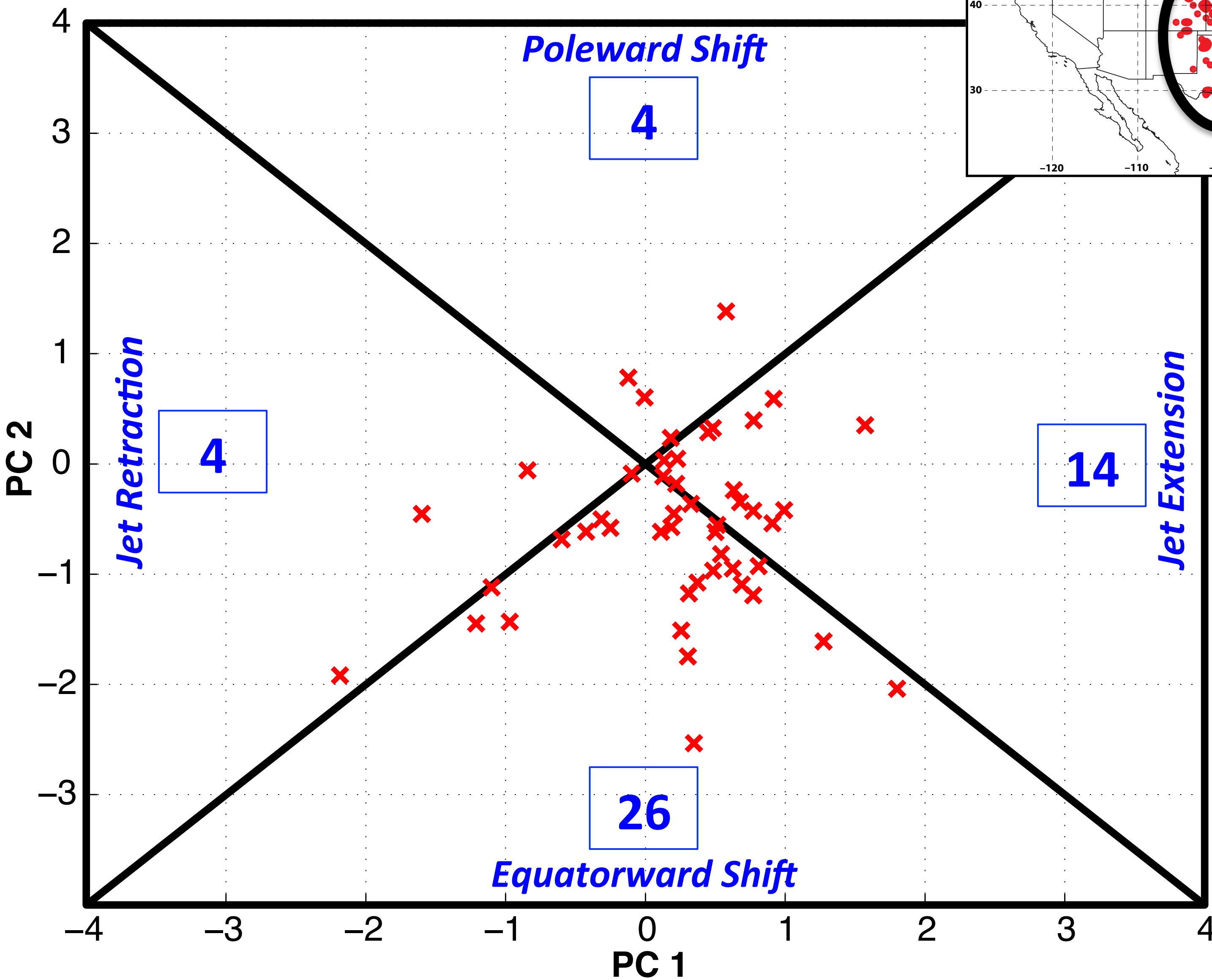
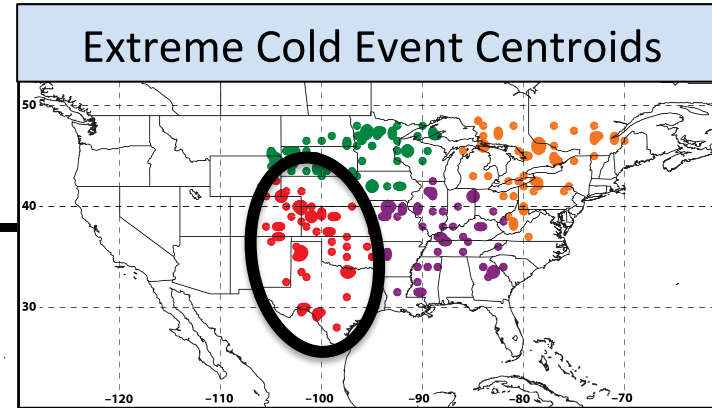

250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day 0
9840
9720
9600
9960
10080
10200
10320
10440
10560
10680
10800
10920
0.5
-0.5
-1
20 30 40 50 60 70 80 90 m s^{-1}
-140 -120 -100 -80
60
40
20


Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day 0
L
H
L
1000
1004
1008
1012
1016
1020
1024
1028
5040
5100
5160
5220
5280
5340
5400
5460
5520
5580
5640
5700
5760
−2.5 −2.0 −1.5 −1.0 −0.5 0.5 1.0 1.5 2.0 2.5 σ
-140 -120 -100 -80
60
40
20

Eastern U.S. – S. Plains Cluster

COLD EVENTS (N = 48)





Events during Sept. – May projected onto phase diagram

Each point is an average of the PCs 3–7 days prior to an event

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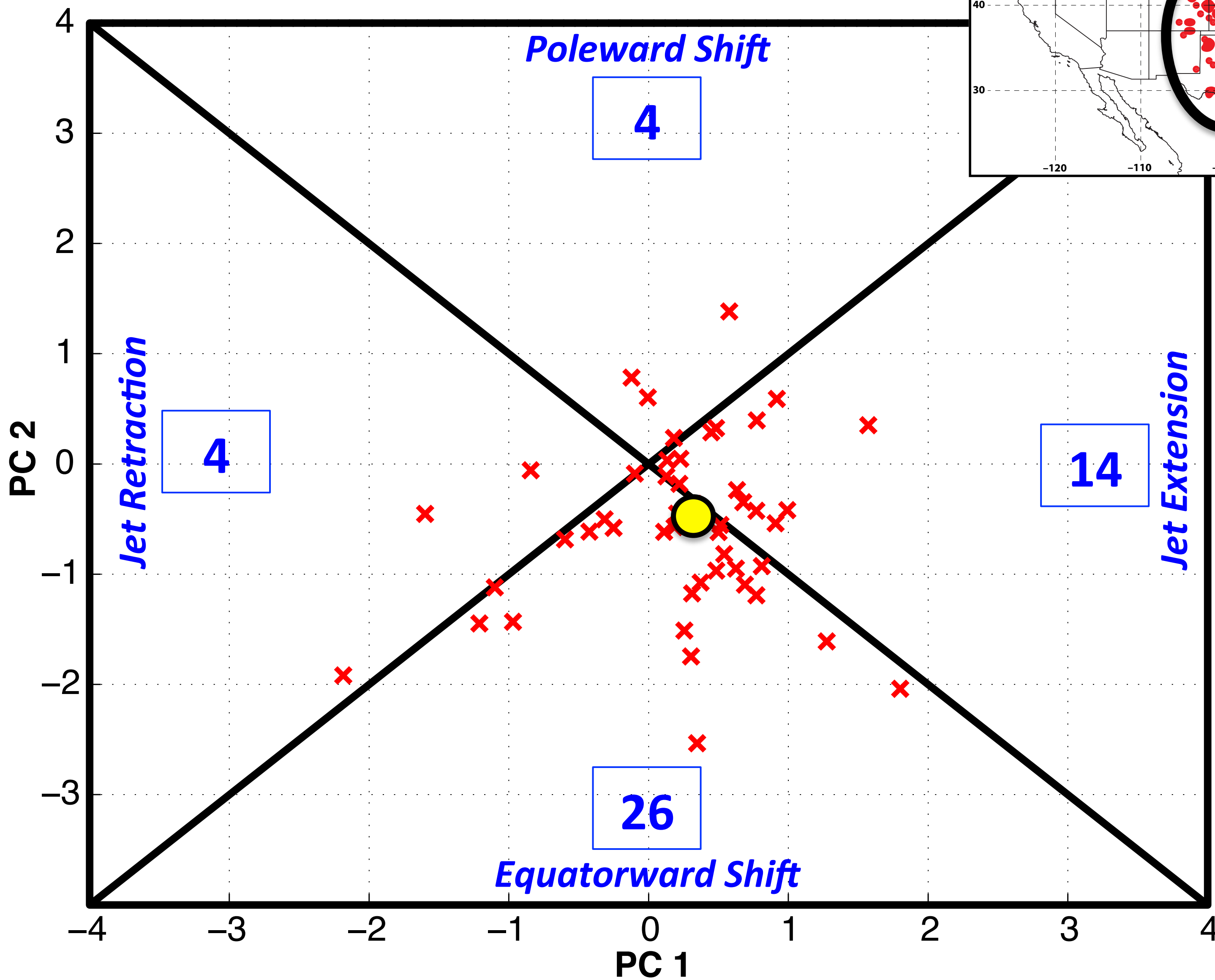

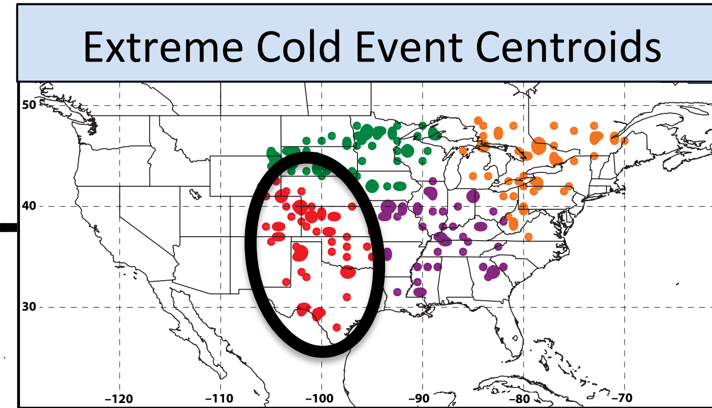

Events during Sept. – May projected onto phase diagram

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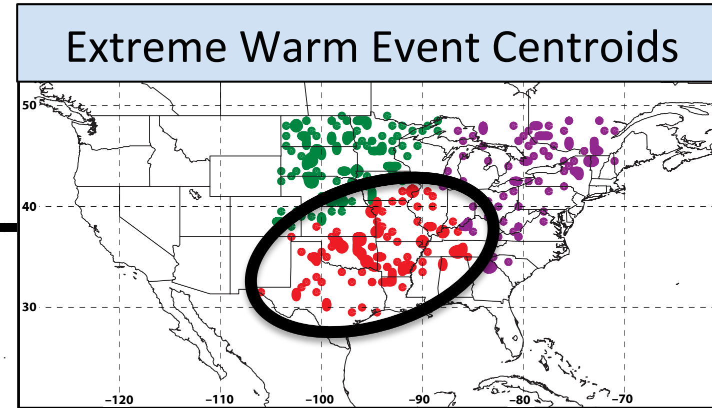
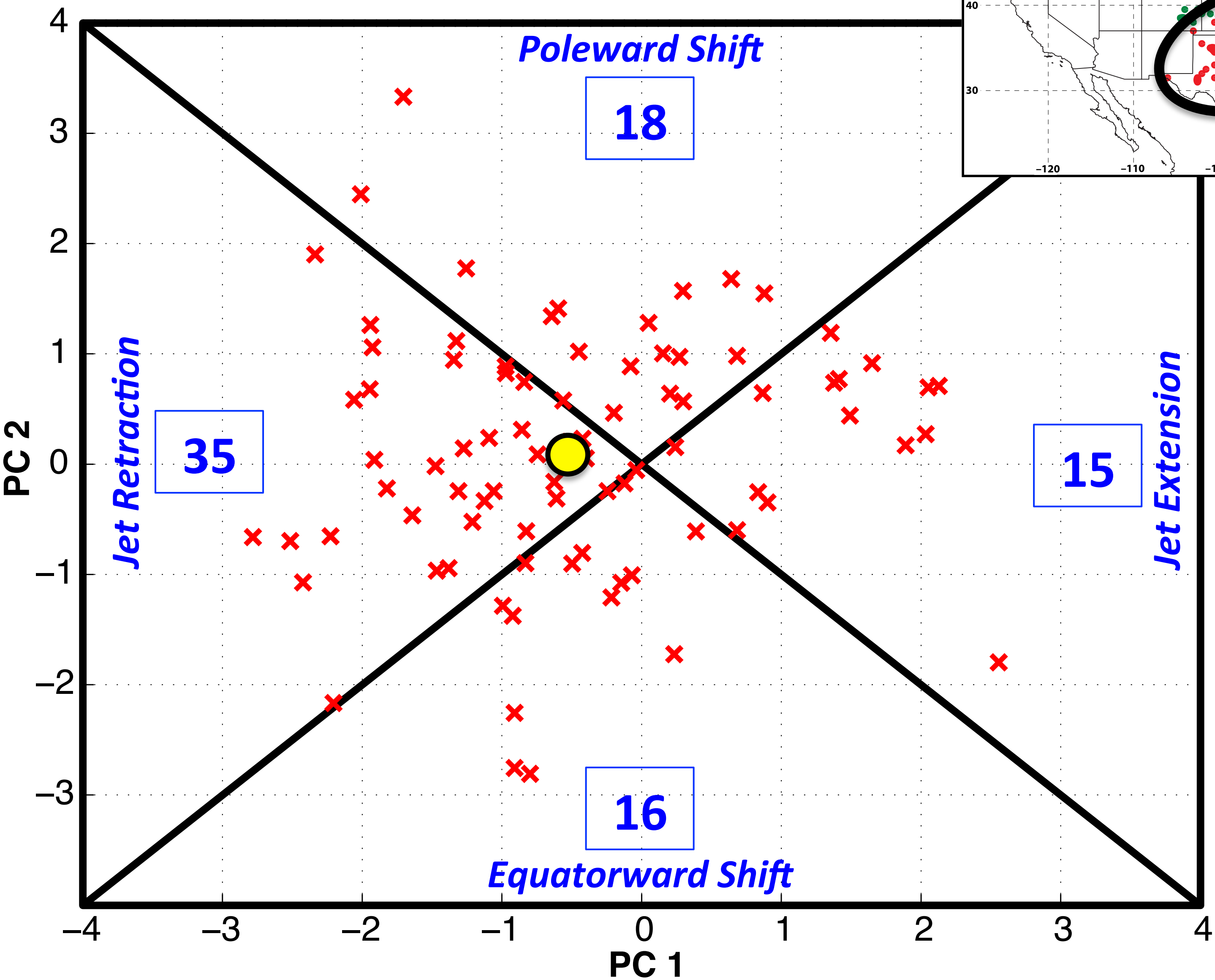
Mean Projection

Eastern U.S. – S. Plains Cluster

WARM EVENTS (N = 84)





Events during Sept. – May projected onto phase diagram

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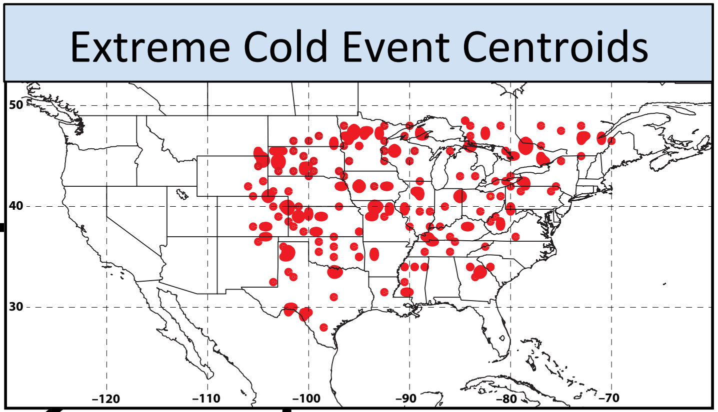
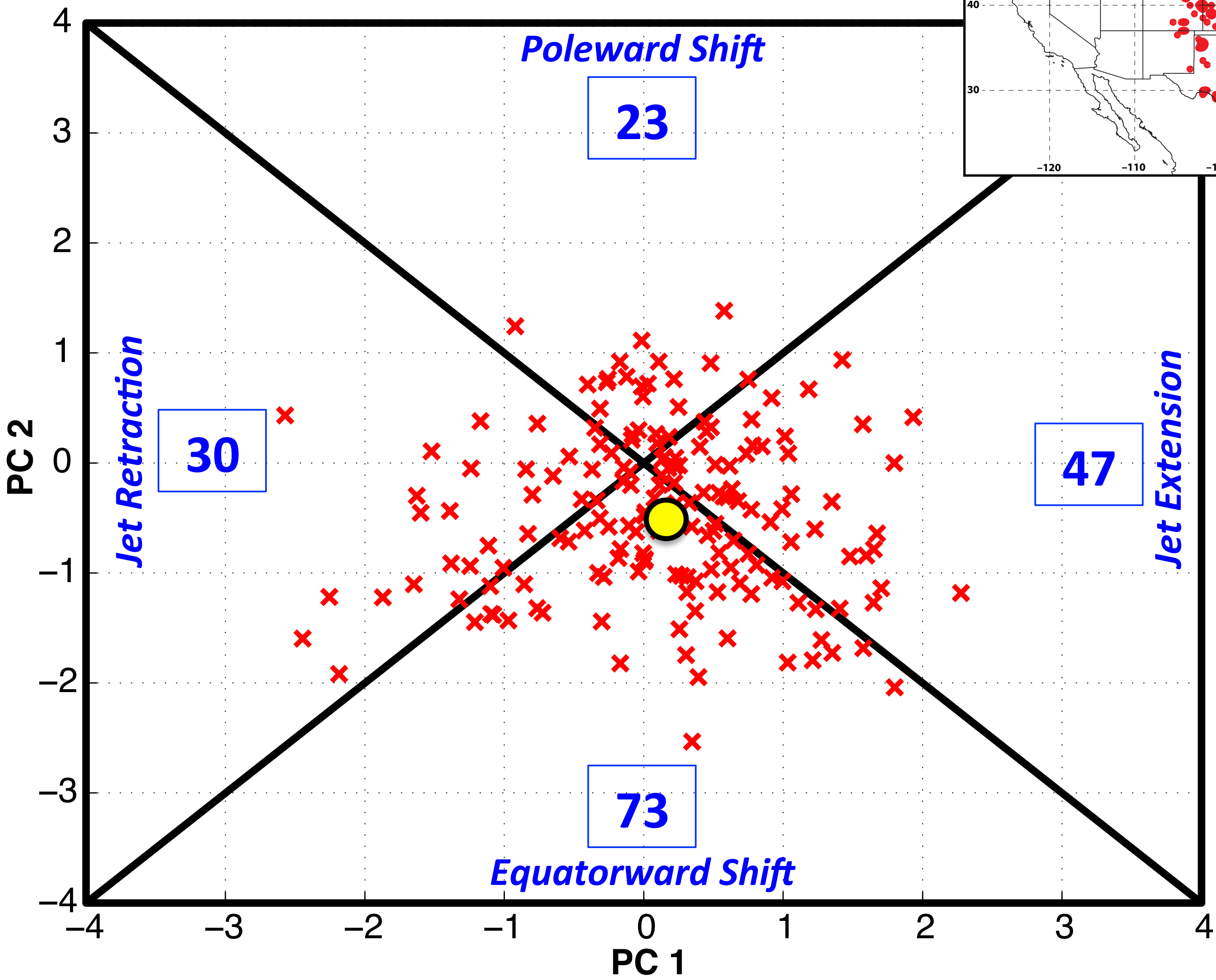
Eastern U.S. – All Events

COLD EVENTS (N = 173)



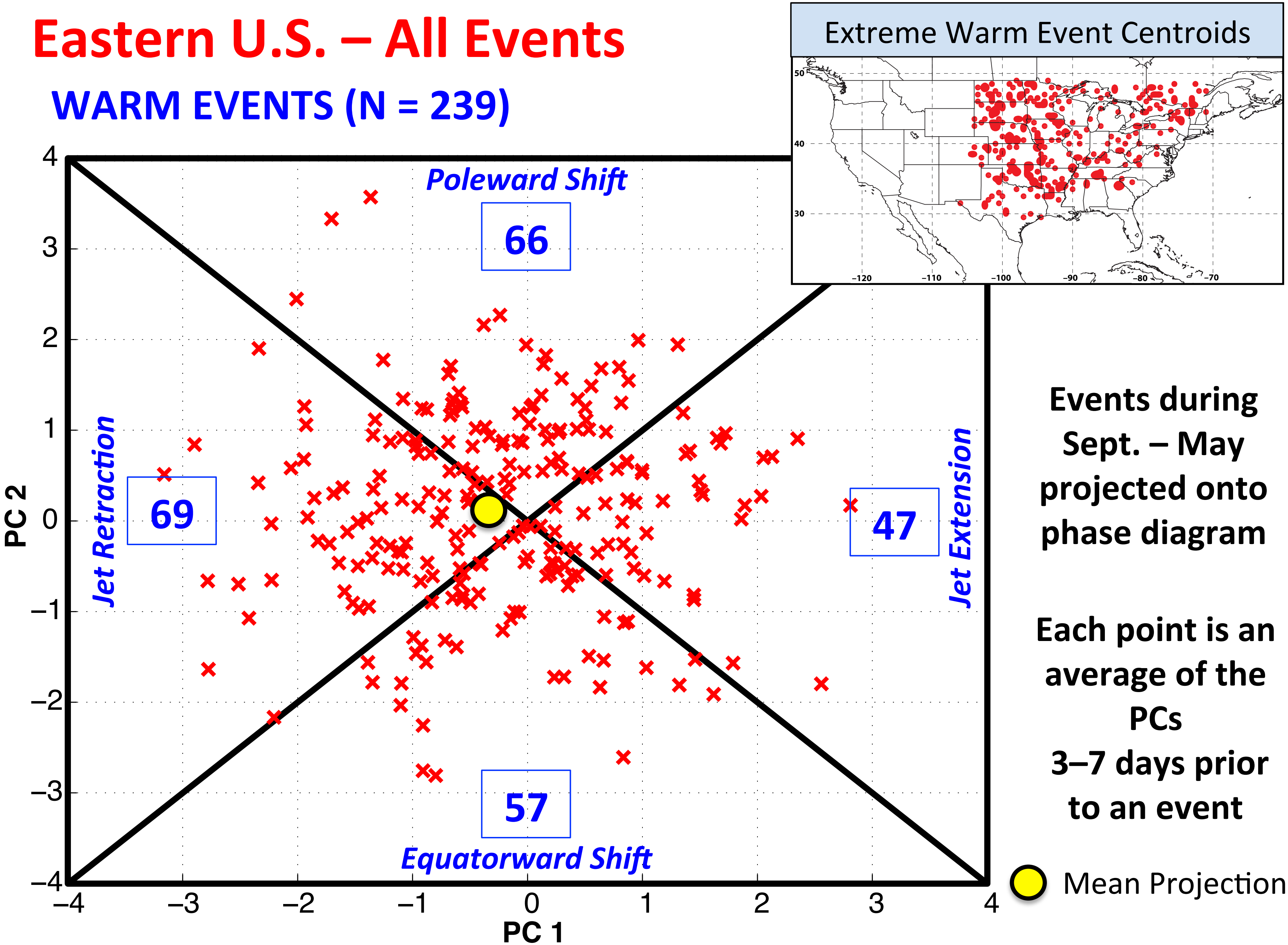


Events during Sept. – May projected onto phase diagram

Each point is an average of the PCs 3–7 days prior to an event

Eastern U.S. – All Events

WARM EVENTS (N = 239)



Events during Sept. – May projected onto phase diagram

Each point is an average of the PCs 3–7 days prior to an event

Forecast Skill of Extreme Temperature Events

Forecast Skill of Extreme Temperature Events

- GEFS Reforecasts (Hamill et al. 2013) of extreme cold and warm events at each forecast lead time were binned based on whether they exhibited a standardized root-mean-square error (RMSE) or standardized anomaly correlation coefficient (ACC) of 500-hPa geopotential height over the CONUS (25–55°N; 140–60°W) that was:
  - Above-normal ($>0.5\sigma$)
  - Below-normal ($<–0.5\sigma$)
  - Near-normal ($–0.5\sigma < x < 0.5\sigma$)

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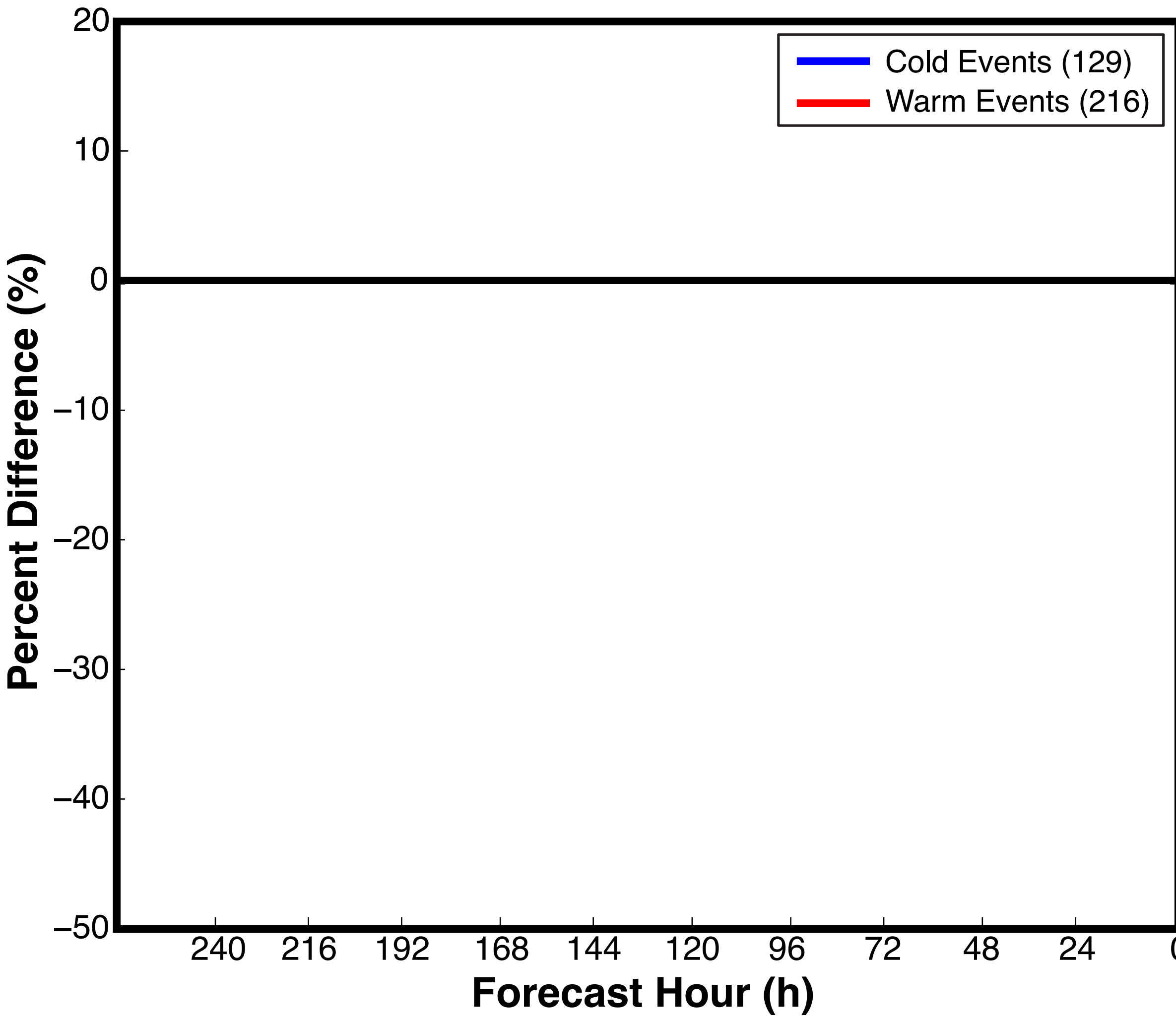
    - Above-normal (>0.5σ)
    - Below-normal (<–0.5σ)
    - Near-normal (–0.5σ < x < 0.5σ)
- The percent difference between the frequency of events with below-normal and above-normal RMSE or ACC offers information regarding the forecast skill of extreme events.

$$Freq_{below-normal} - Freq_{above-normal}$$

Forecast Skill of Extreme Temperature Events

Percent Difference Between the Frequency of Forecasts with Below-Normal and Above-Normal ACC



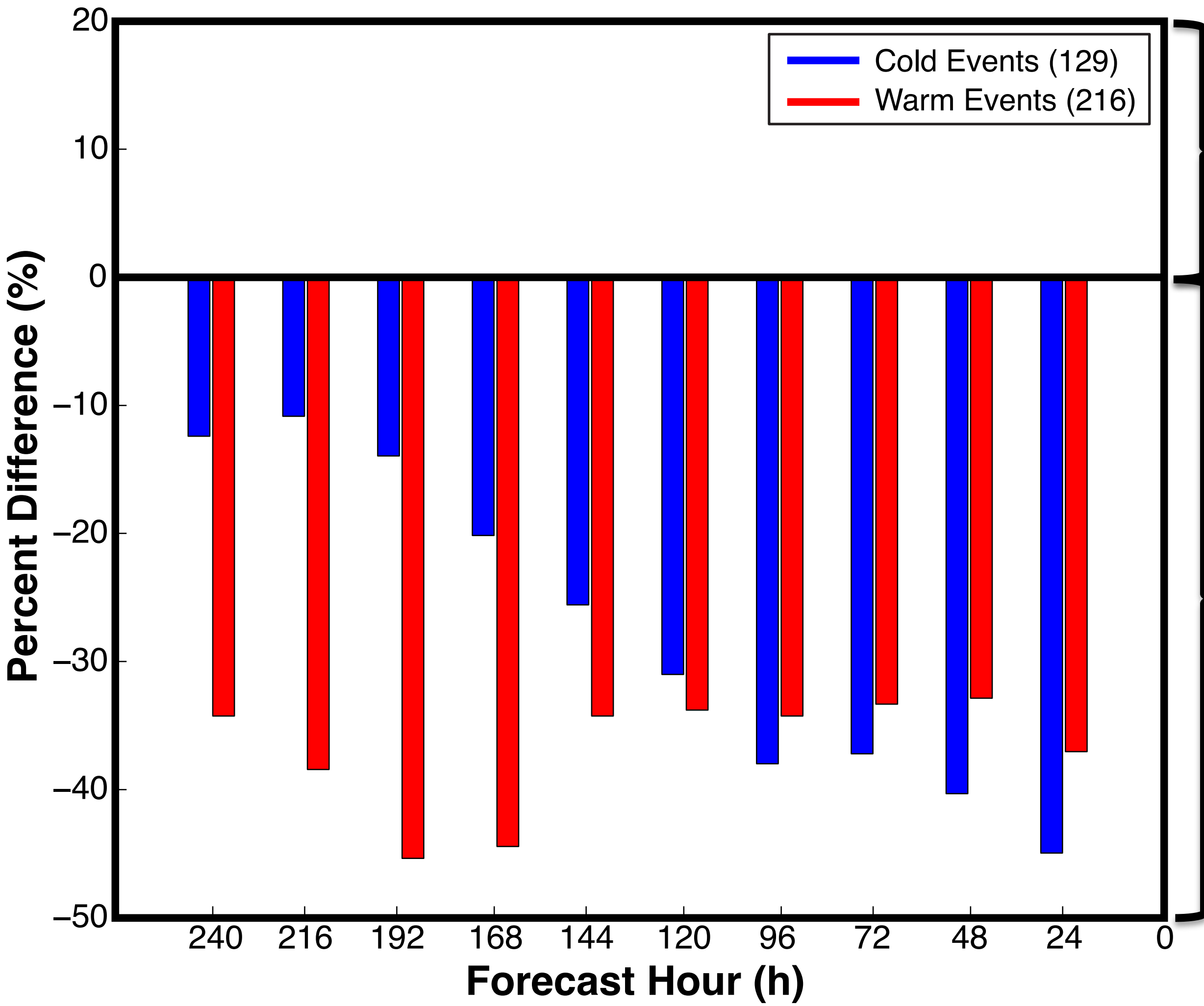
Higher frequency of forecasts with below-normal ACC (i.e., more bad forecasts)

Higher frequency of forecasts with above-normal ACC (i.e., more good forecasts)

$$Freq_{below-normal} - Freq_{above-normal}$$

Forecast Skill of Extreme Temperature Events

Percent Difference Between the Frequency of Forecasts with Below-Normal and Above-Normal ACC



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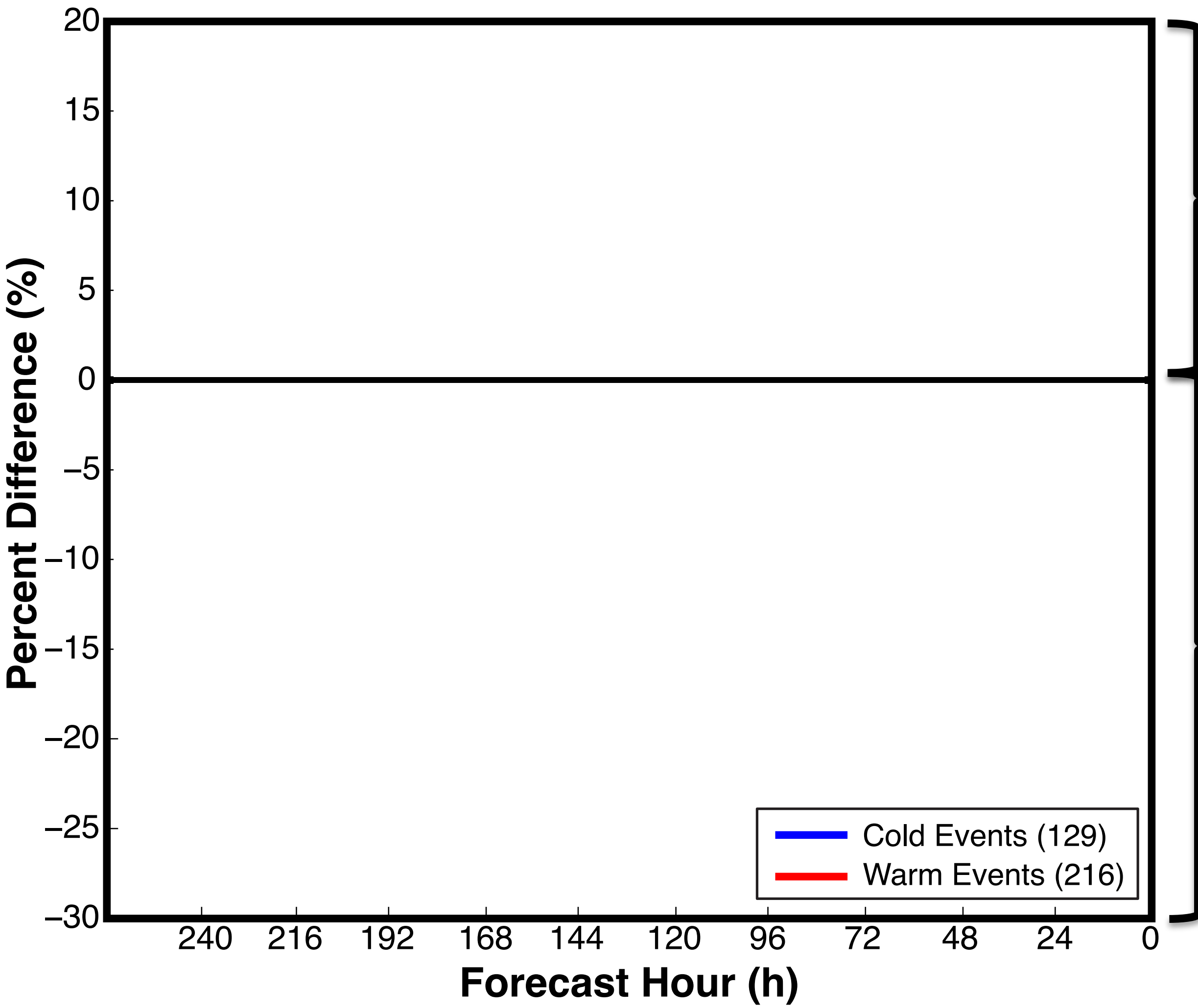
$$Freq_{below-normal} - Freq_{above-normal}$$

Forecast Skill of Extreme Temperature Events

Percent Difference Between the Frequency of Forecasts with Below-Normal and Above-Normal RMSE



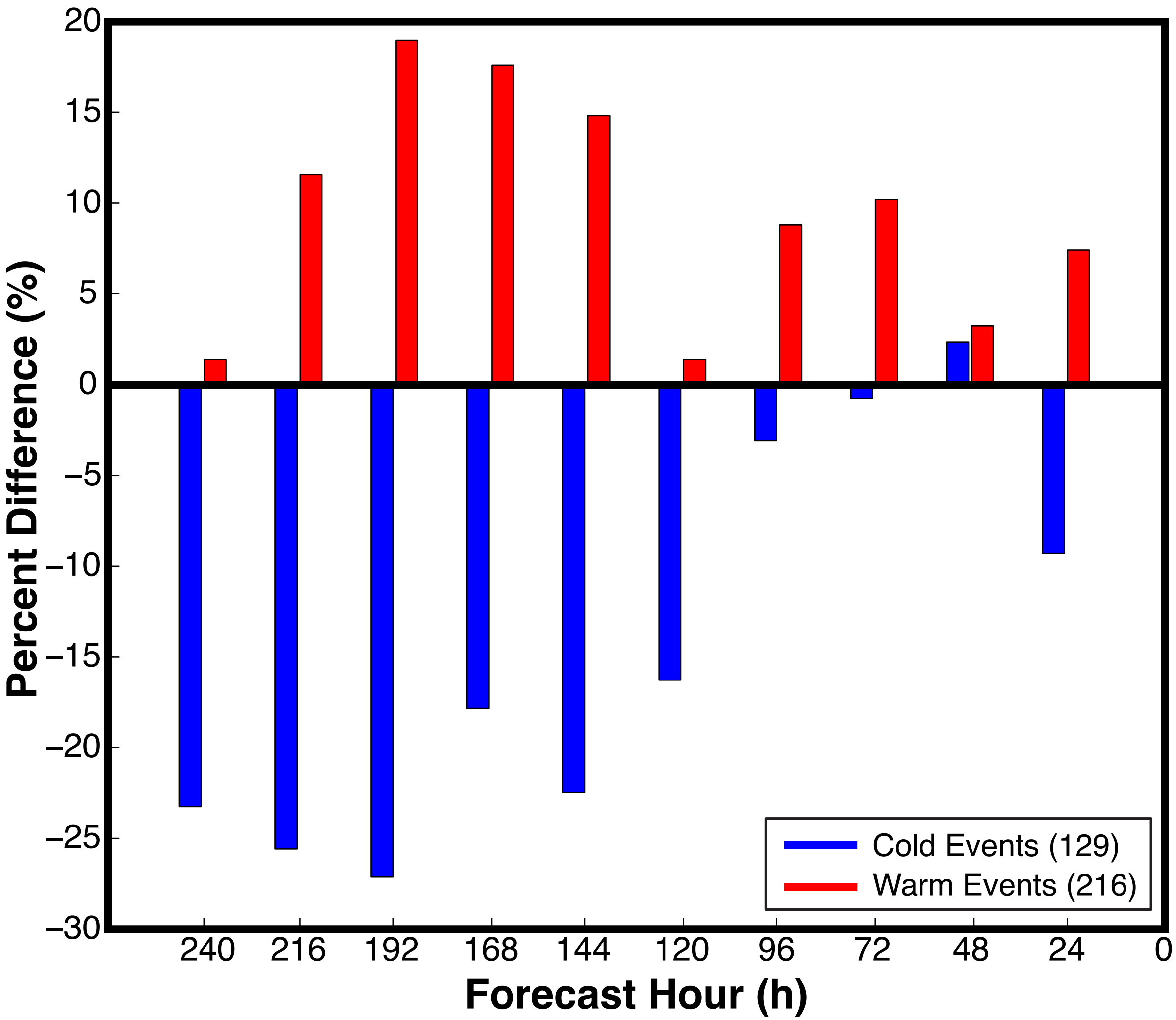
Higher frequency of forecasts with <u>below-normal</u> RMSE (i.e., more good forecasts)

Higher frequency of forecasts with <u>above-normal</u> RMSE (i.e., more bad forecasts)

$$Freq_{below-normal} - Freq_{above-normal}$$

Forecast Skill of Extreme Temperature Events

Percent Difference Between the Frequency of Forecasts with Below-Normal and Above-Normal RMSE



Higher frequency of forecasts with below-normal RMSE (i.e., more good forecasts)

Higher frequency of forecasts with above-normal RMSE (i.e., more bad forecasts)

$$Freq_{below-normal} - Freq_{above-normal}$$

Summary

- The North Pacific Jet phase diagram is a tool that objectively characterizes the upper-tropospheric flow pattern over the North Pacific.
- The North Pacific Jet phase diagram can be used to identify antecedent environments that are favorable for the production of extreme temperature events over the U.S.
- Extreme warm and extreme cold events are both characterized by a higher frequency of forecasts with above-normal ACC scores than below-normal ACC scores.
- Extreme warm events are characterized by a higher frequency of forecasts with below-normal RMSE, whereas extreme cold events are characterized by a higher frequency of forecasts with above-normal RMSE.

Phase Diagram Web Interface

This work is supported by NOAA Grant NA15NWS4680006

Real time | Archive | Verification | Composites | About

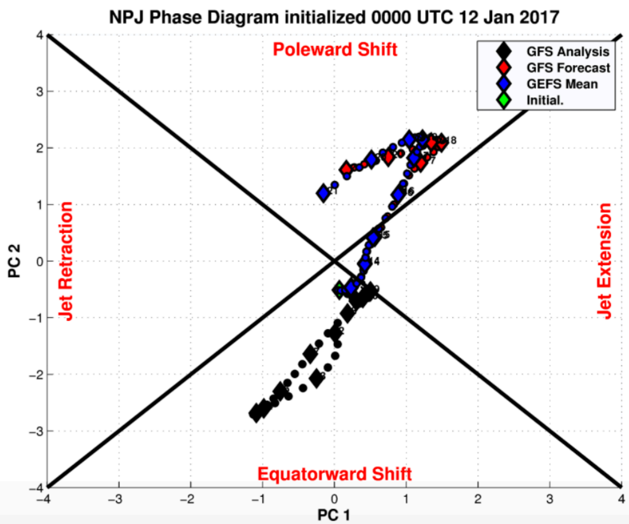
Phase Diagram (left): Shows the GFS analysis trajectory over the previous 10 days in black with diamonds corresponding to a position in the phase diagram at 00Z on the day labeled to the upper-right of its respective diamond. The red and blue symbols show the forecasted GFS and GEFS ensemble mean trajectories, respectively, within the phase diagram over the next 9 days with diamonds corresponding to a position in the phase diagram at 00Z on the day listed to the upper-right of its respective diamond. The green diamond shows the position within the phase diagram at 00Z on the day listed in the title.

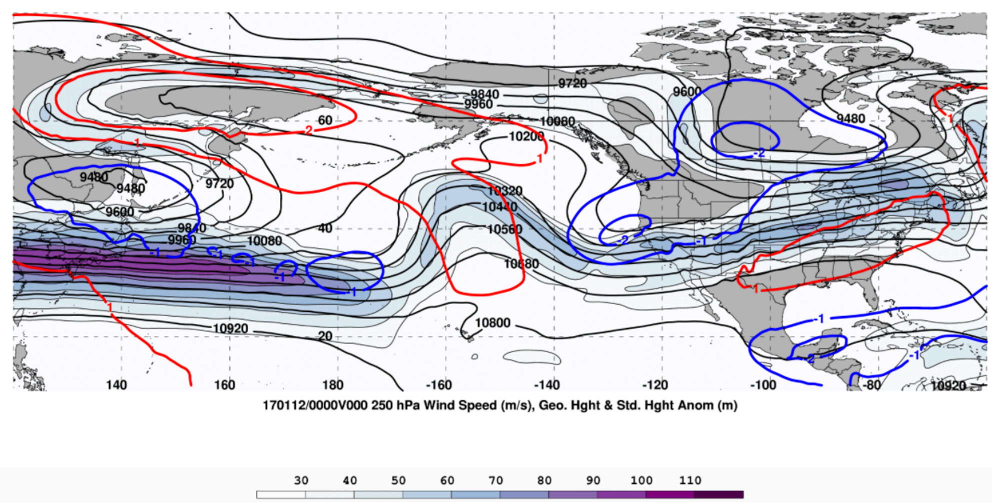
Synoptic Maps (right): Depicts GFS deterministic forecasts of (1) 250-hPa wind speed, geo. heights, and standardized geo. height anomalies, (2) 500-hPa relative vorticity, geo. heights, and standardized geo. height anomalies (3) mean sea level pressure, 1000-500-hPa thickness, and 850-hPa standardized temperature anomalies, and (4) 24-h accumulated precipitation. The 24-h forecasted accumulated precipitation is also used as 'verification' in Days -10 to 0.

Deterministic Forecast | Probabilistic Forecast | Ens. Spread Forecast | D(prog)/Dt

Arrow keys for navigation | Space = play/pause | Swipe for navigation on touchscreen

250-hPa Jet/Hght/Hght'	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8	+9
500-hPa Vort/Hght/Hght'	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8	+9
MSLP/Thick/Temp'	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8	+9
24-h Accum. Precip	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8	+9





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250-hPa Jet/Hght/Hght'	10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8	+9
500-hPa Vort/Hght/Hght'	10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8	+9
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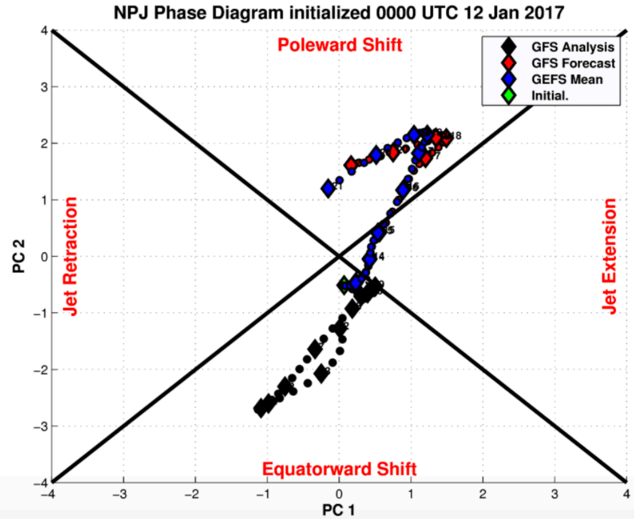

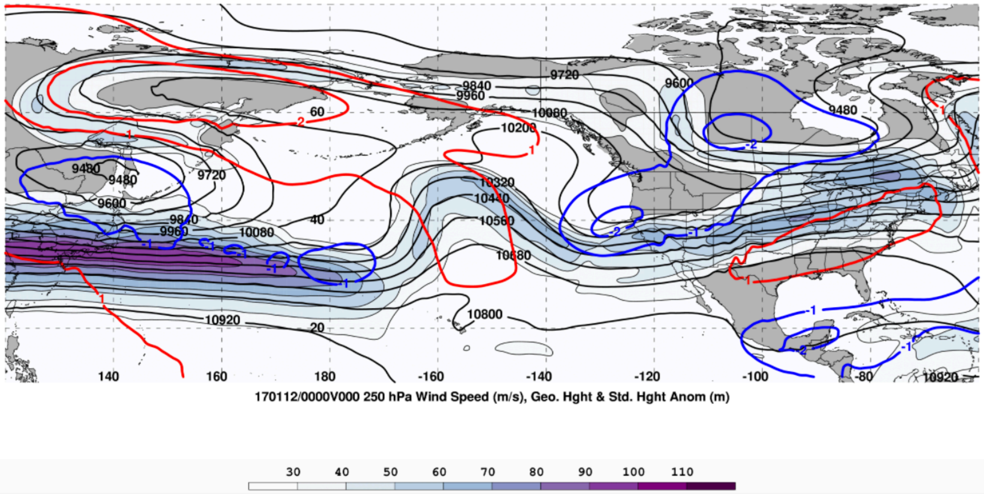

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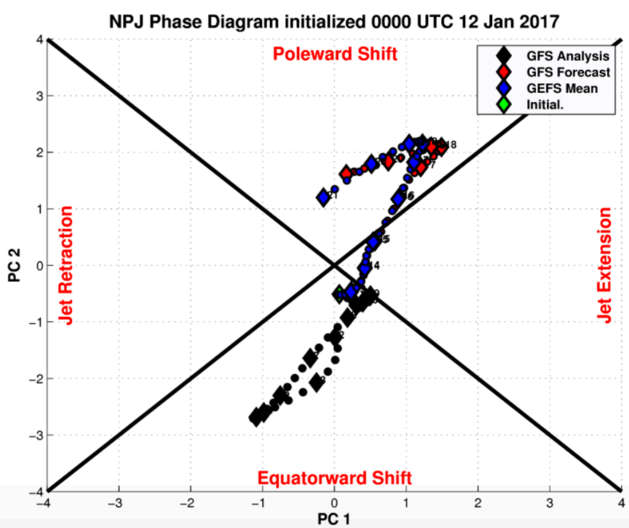

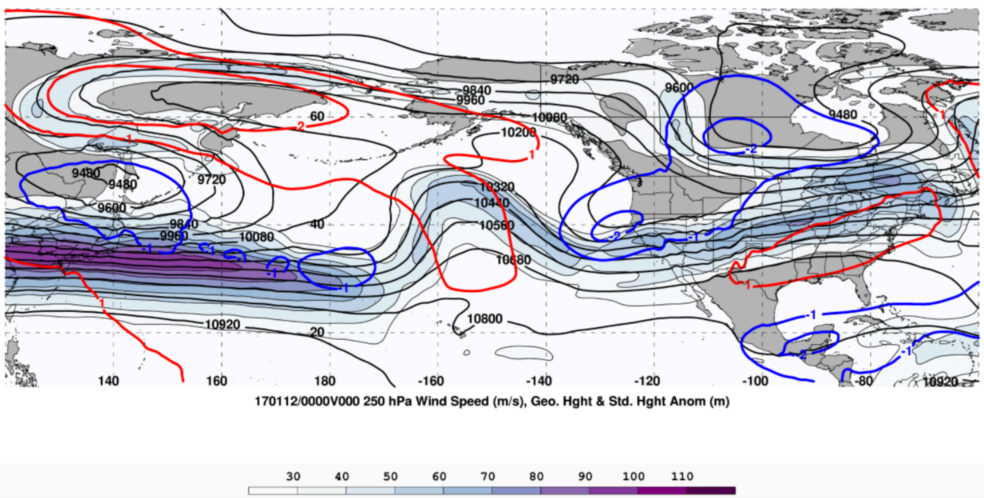

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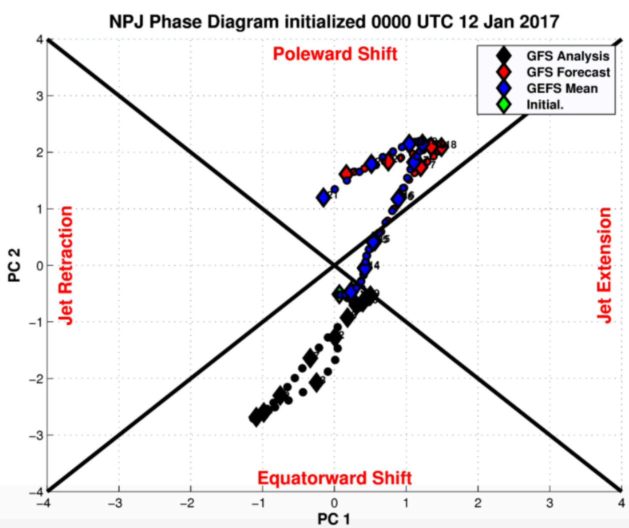
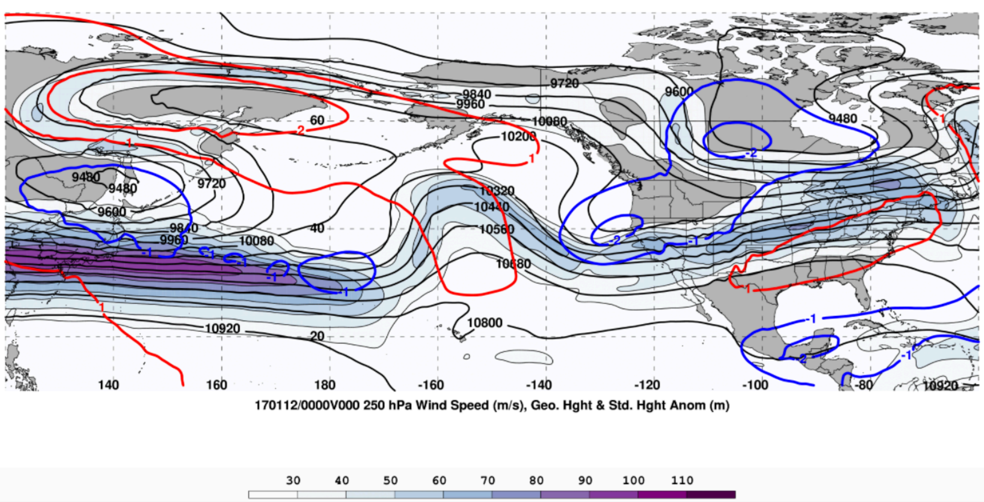




Summary

- A web interface has been developed that offers real time North Pacific Jet phase diagram forecasts and extreme event composites.

http://www.atmos.albany.edu/facstaff/awinters/realtime/About_EOFs.php

Contact: acwinters@albany.edu

Observational Need: The prediction of extreme events over the CONUS is likely to benefit from a greater understanding of the flow evolution over the North Pacific.

Supplementary Slides

References

Athanasiadis, P. J., J. M. Wallace, and J. J. Wettstein, 2010: Patterns of wintertime jet stream variability and their relation to the storm tracks. *J. Atmos. Sci.*, **67,** 1361–1381.

Griffin, K. S., and J. E. Martin, 2016: Synoptic features associated with temporally coherent modes of variability of the North Pacific jet stream. *J. Climate, **29**,* in press.

Hamill, T. M., G. T. Bates, J. S. Whitaker, D. R. Murray, M. Fiorino, T. J. Galarneau, Y. Zhu, and W. Lapenta, 2013: NOAA's Second-Generation Global Medium-Range Ensemble Forecast Dataset. *Bull. Amer. Meteor. Soc.*, **94,** 1553–1565.

Jaffe, S. C., J. E. Martin, D. J. Vimont, and D. L. Lorenz, 2011: A synoptic climatology of episodic, subseasonal retractions of the Pacific jet. *J. Climate*, **24,** 2846–2860.

Saha, S., and Coauthors, 2014: The NCEP Climate Forecast System Version 2. *J. Climate*, **27,** 2185–2208.

Project Outcomes

- Provide forecasters with a **"first alert"** to the possibility of the occurrence of extreme temperature and precipitation events during week two on the basis of current conditions and model forecasts.

- Provide forecasters with an indication of the **character and flavor** of possible extreme events as inferred from where the events lie in the frequency distributions of the anticipated event types.

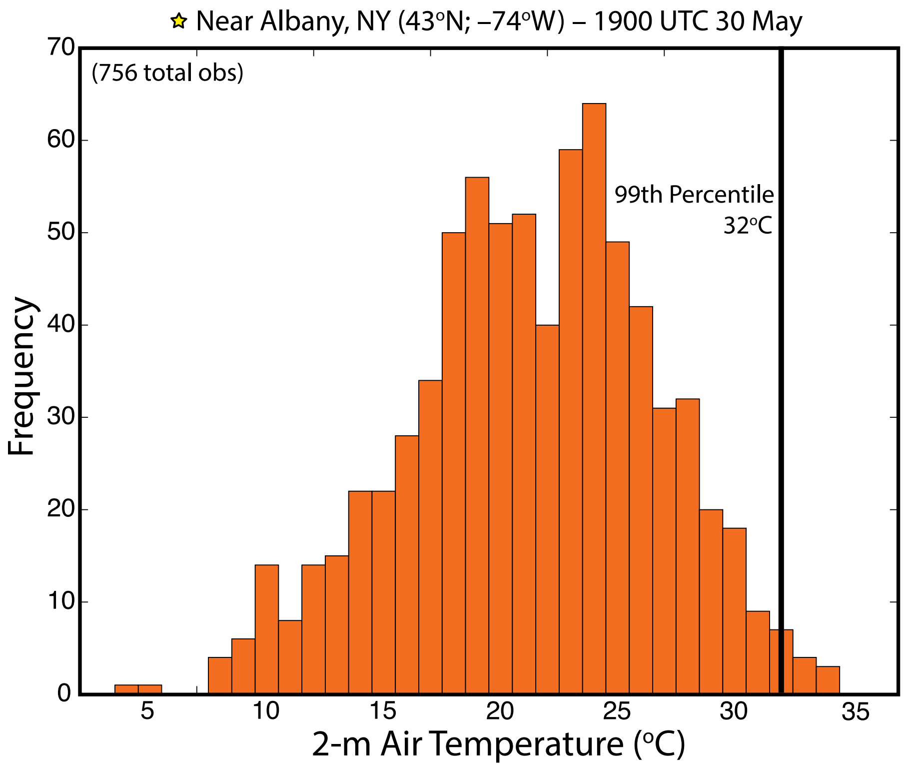
- Provide forecasters with knowledge that allows them to make **science-based adjustments** to model guidance and add value to week two forecasts of temperature and precipitation.

Extreme Event Identification

Extreme Event Identification

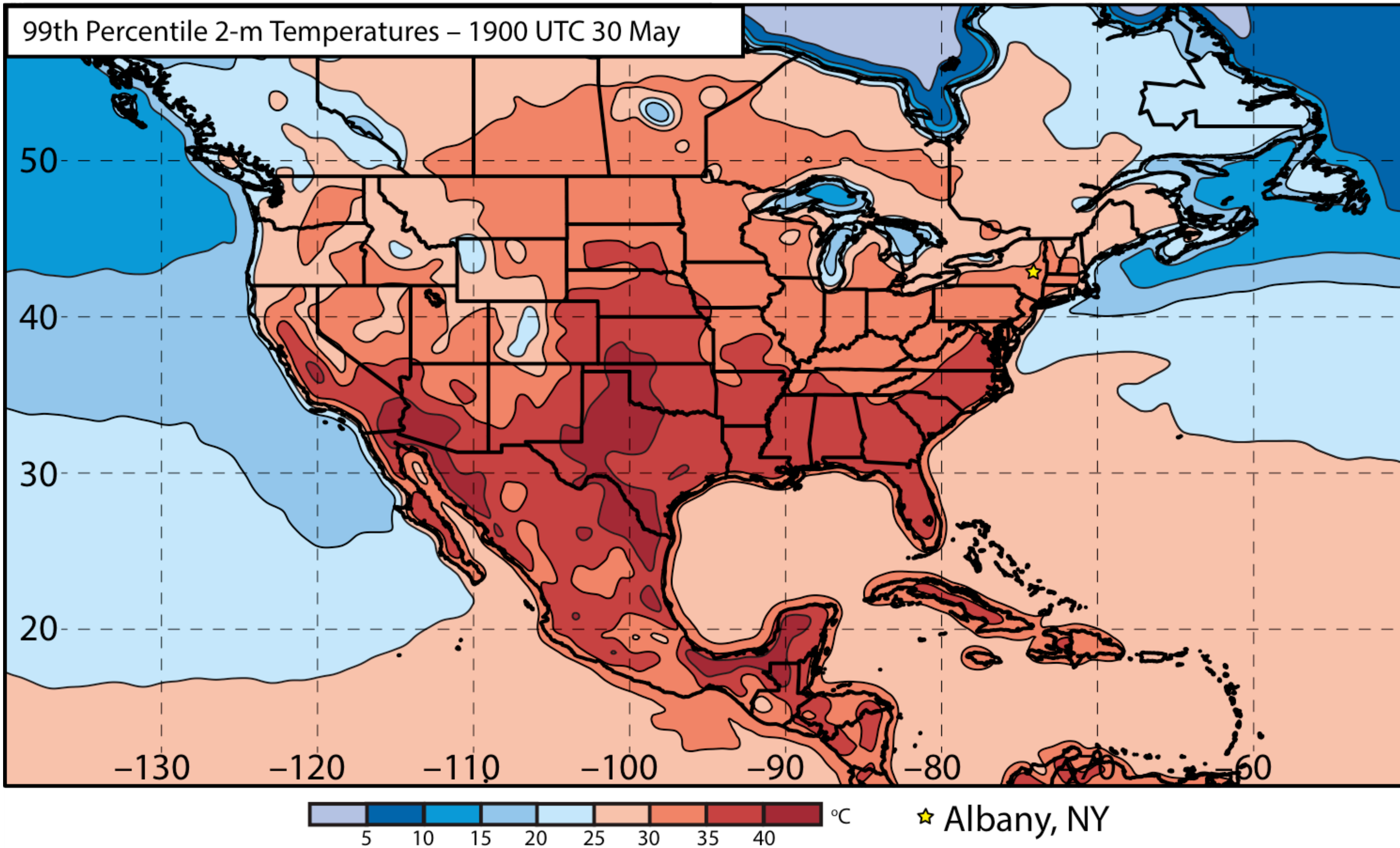
Extreme Warm Events:

- Employed 1-h forecasts of 2-m temperature from the CFSR (0.5°× 0.5°) at 6-h intervals
- Compiled data for each grid point within 21-day windows centered on each analysis time for 36 years, 1979–2014
  - Each grid point has 756 (21×36) data points for each analysis time
- Determined the temperature that corresponds to the **99th percentile** for each grid point at a given analysis time

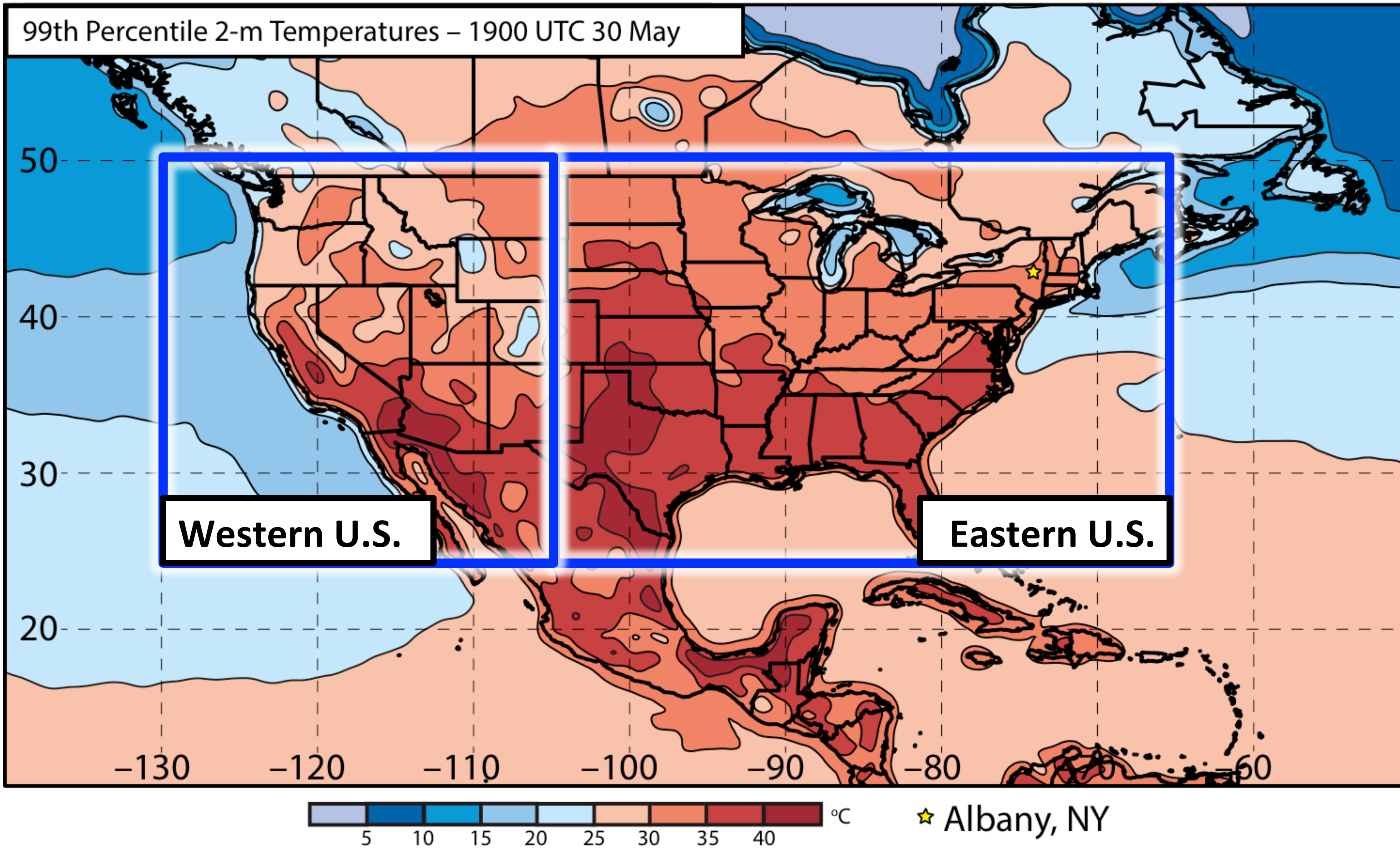


Frequency distribution of 2-m temperature at 1900 UTC 30 May for a grid point near Albany, NY

Extreme Event Identification



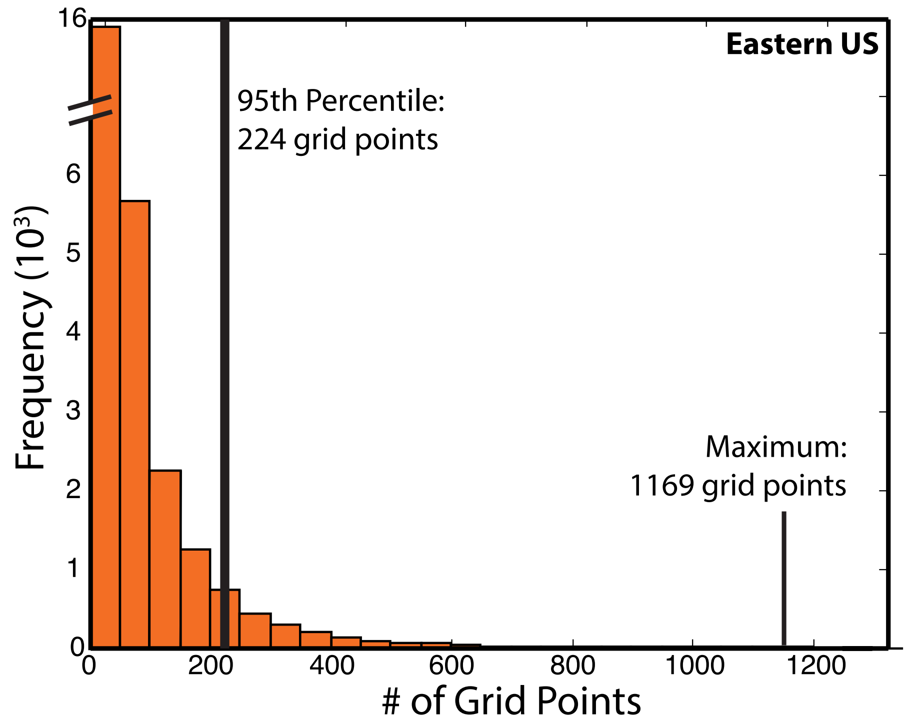
Extreme Event Identification



Extreme Event Identification

Extreme Warm Events:

- Cataloged times during which at least one grid point was characterized by a temperature > **99th percentile**
- Ranked times within each domain by the number of grid points > **99th percentile**
- Identified times that rank in the **top 5%** in terms of the number of grid points > **99th percentile** within each domain as **extreme warm events**



Frequency distribution of times exhibiting at least one grid point > 99th percentile

Extreme Event Identification

Extreme Precip. Events:

- Employed CPC Unified Gauge-Based Analysis of Daily Precipitation over CONUS during 1979–2014 (0.25°× 0.25°)
- Compiled data within 21-day windows centered on each time for all 36 years
  - Each grid point has (21 × 36) 756 data points for a given time
- Determined the precipitation values that correspond to the 99th percentile for each grid point at a given time (only for days precipitation was observed)
- Identified times that rank in the **top 5%** in terms of the number of grid points > 99th percentile within each domain as **extreme precipitation events**

Extreme Event Identification

Temperature

Eastern U.S. (**1st % Cold**):
- Threshold: 221 grid points ~7.0°×7.0° box
- After QC: 225 events

Eastern U.S. (**99th % Warm**):
- Threshold: 224 grid points ~7.0°×7.0° box
- After QC: 304 events

Western U.S. (**1st % Cold**):
- Threshold: 125 grid points ~5.0°×5.0° box
- After QC: 271 events

Western U.S. (**99th % Warm**):
- Threshold: 144 grid points ~5.5°×5.5° box
- After QC: 264 events

Precipitation

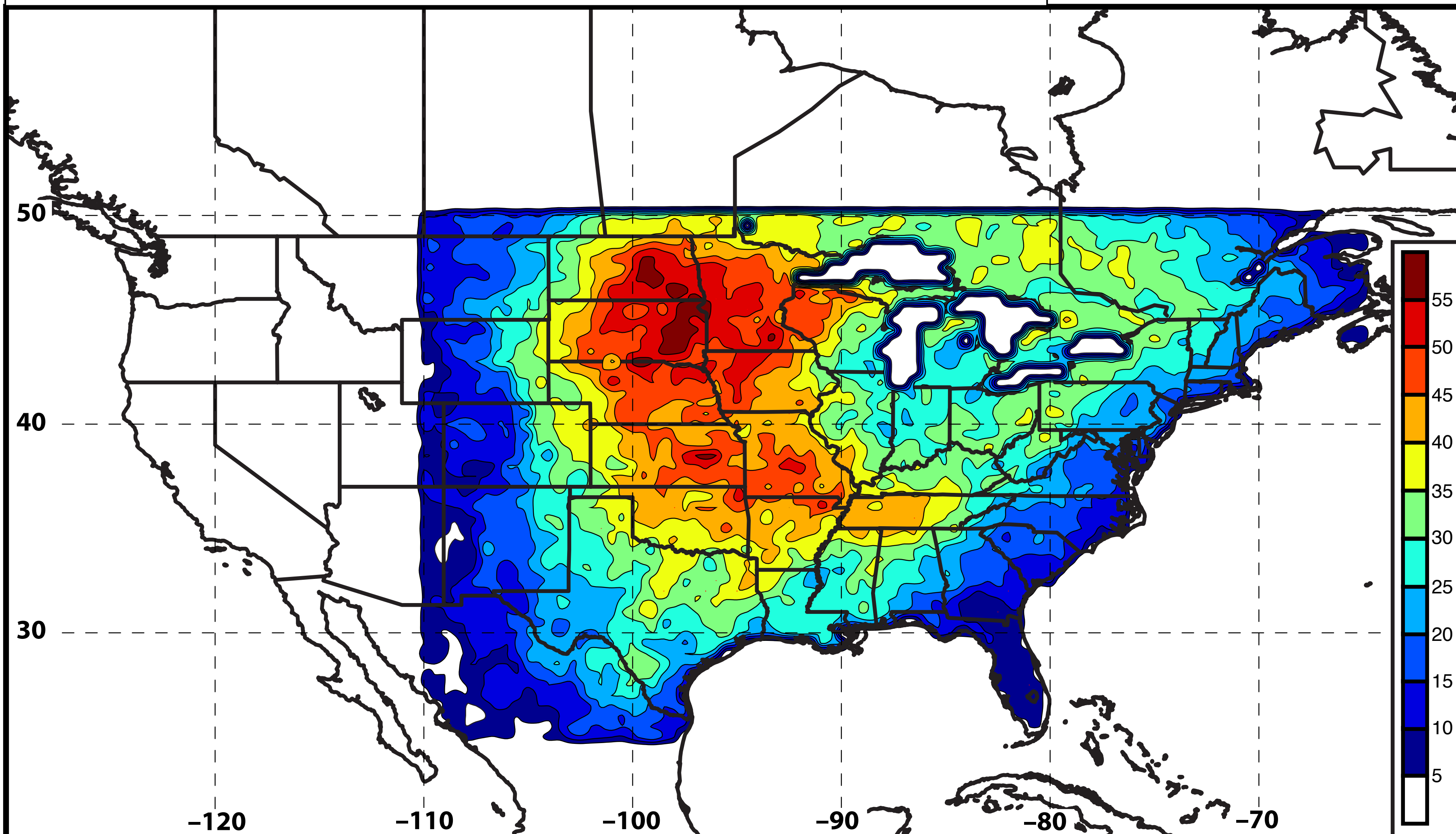
Eastern U.S. (**99th %**):
- Threshold: 211 grid points ~3.5°×3.5° box
- After QC: 351 events

Western U.S. (**99th %**):
- Threshold: 141 grid points ~2.75°×2.75° box
- After QC: 333 events

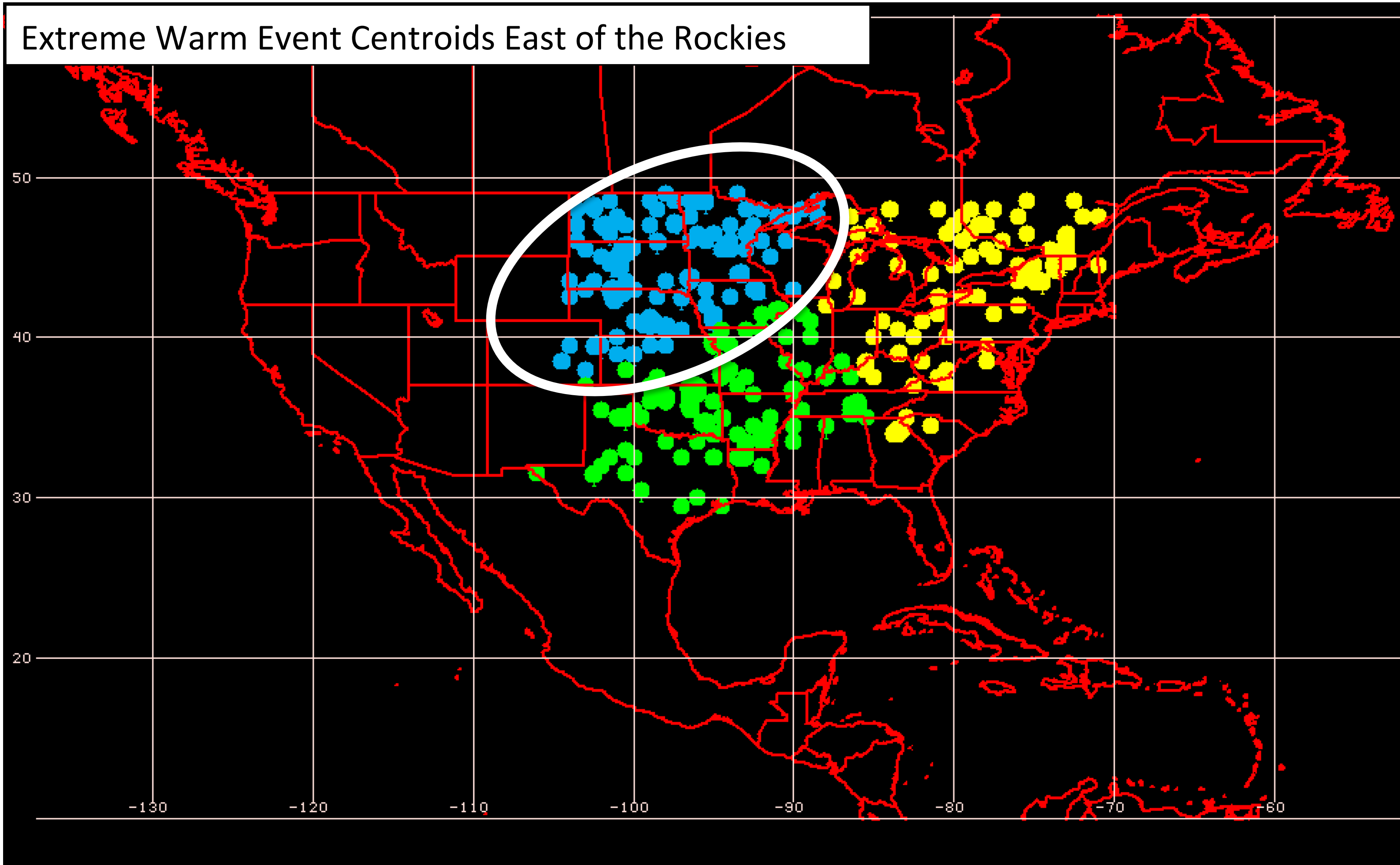
Quality control: Events within 24-h of another event were considered to be the same event.

Extreme Event Identification

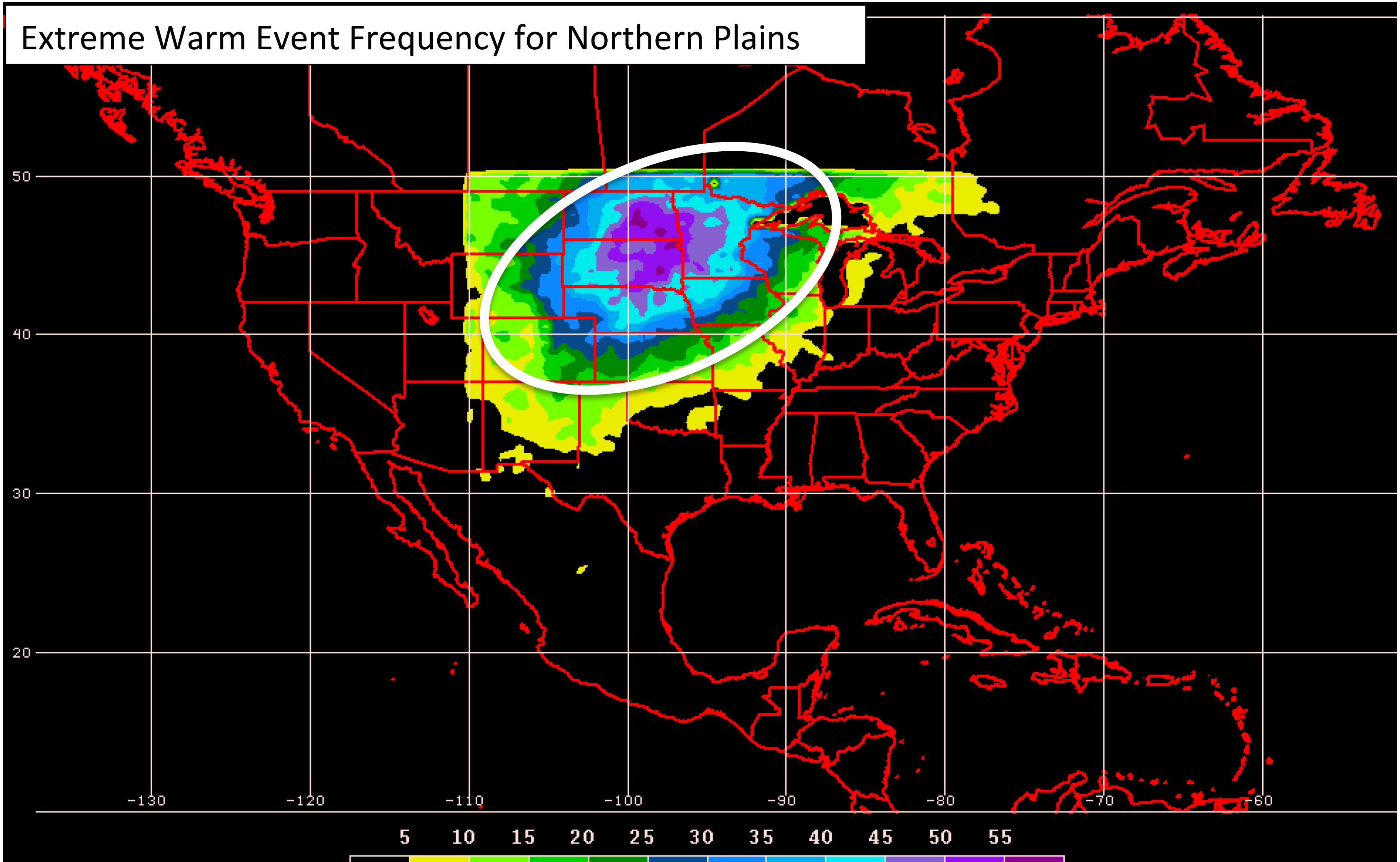
Extreme Warm Event Frequency: Eastern U.S. Domain (n = 304)



Geographic Event Clusters

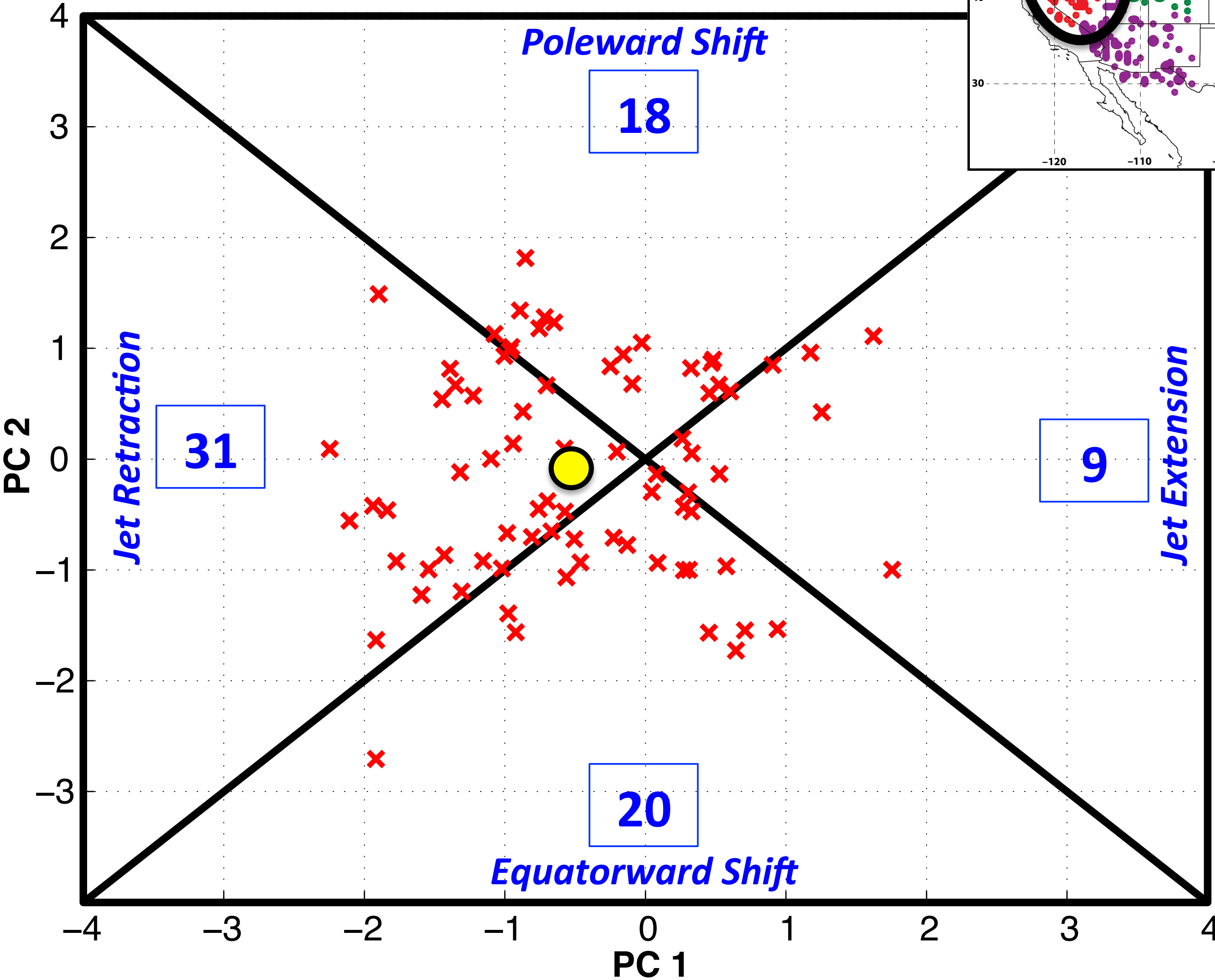


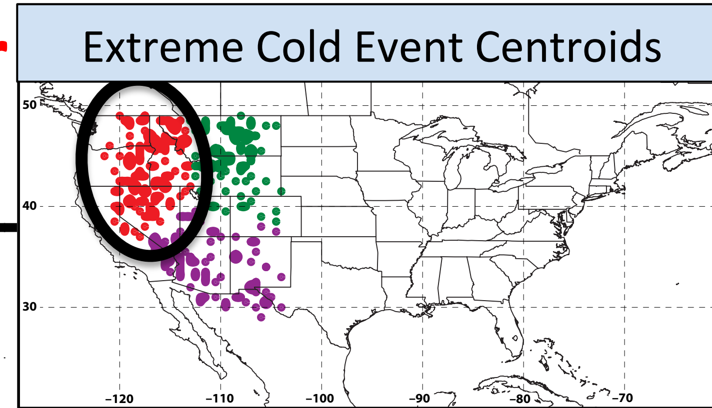
Geographic Event Clusters



Western U.S. – Pac. NW Cluster

COLD EVENTS (N = 78)





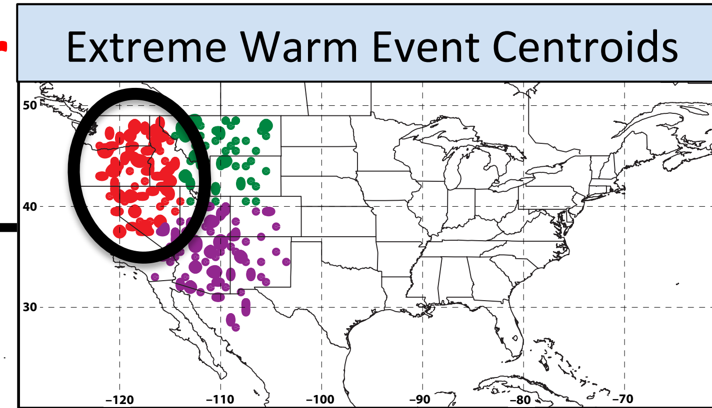
Events during Sept. – May projected onto phase diagram

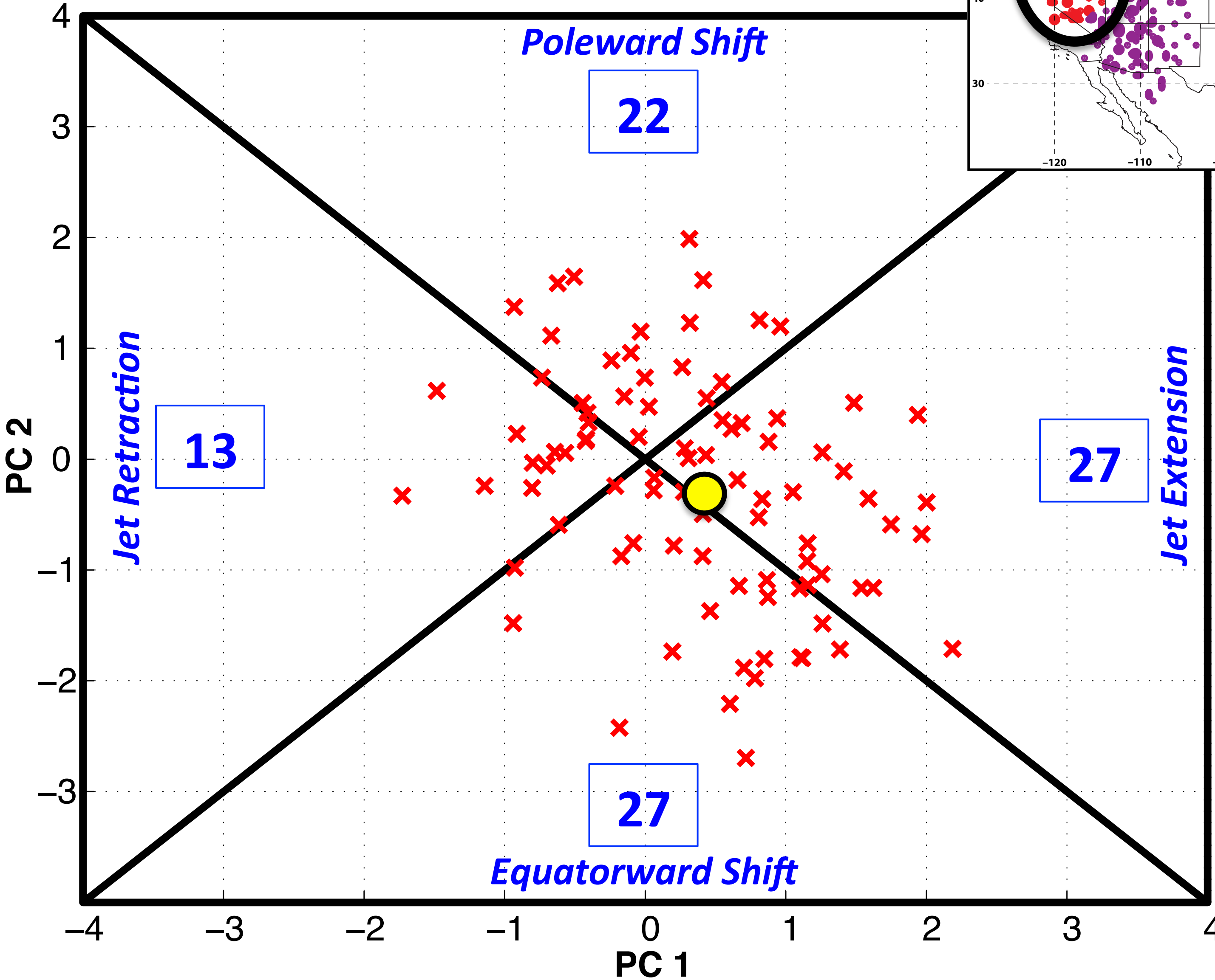
Each point is an average of the PCs 3–7 days prior to an event

Mean Projection

Western U.S. – Pac. NW Cluster

WARM EVENTS (N = 89)





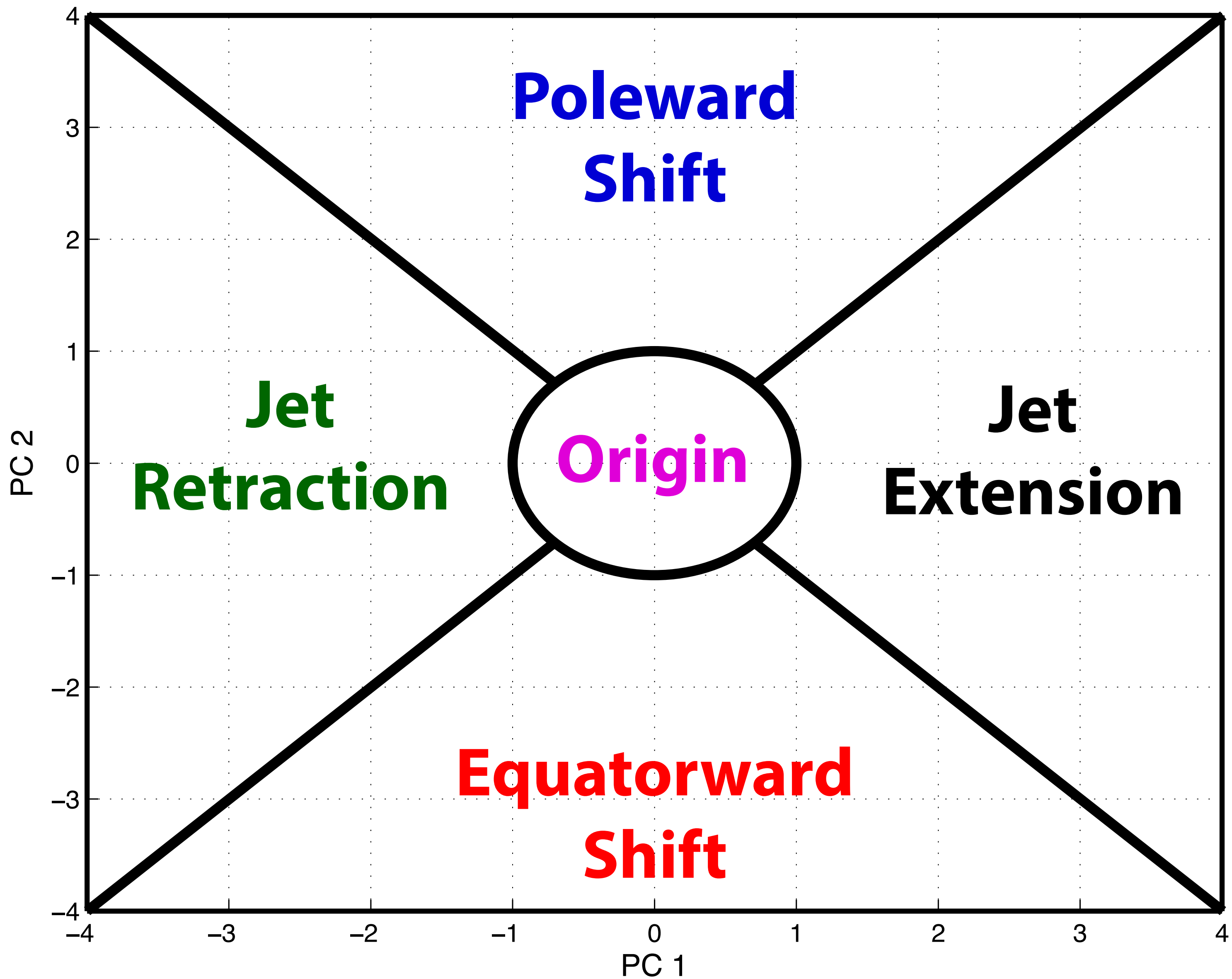
Events during Sept. – May projected onto phase diagram

Each point is an average of the PCs 3–7 days prior to an event

Mean Projection

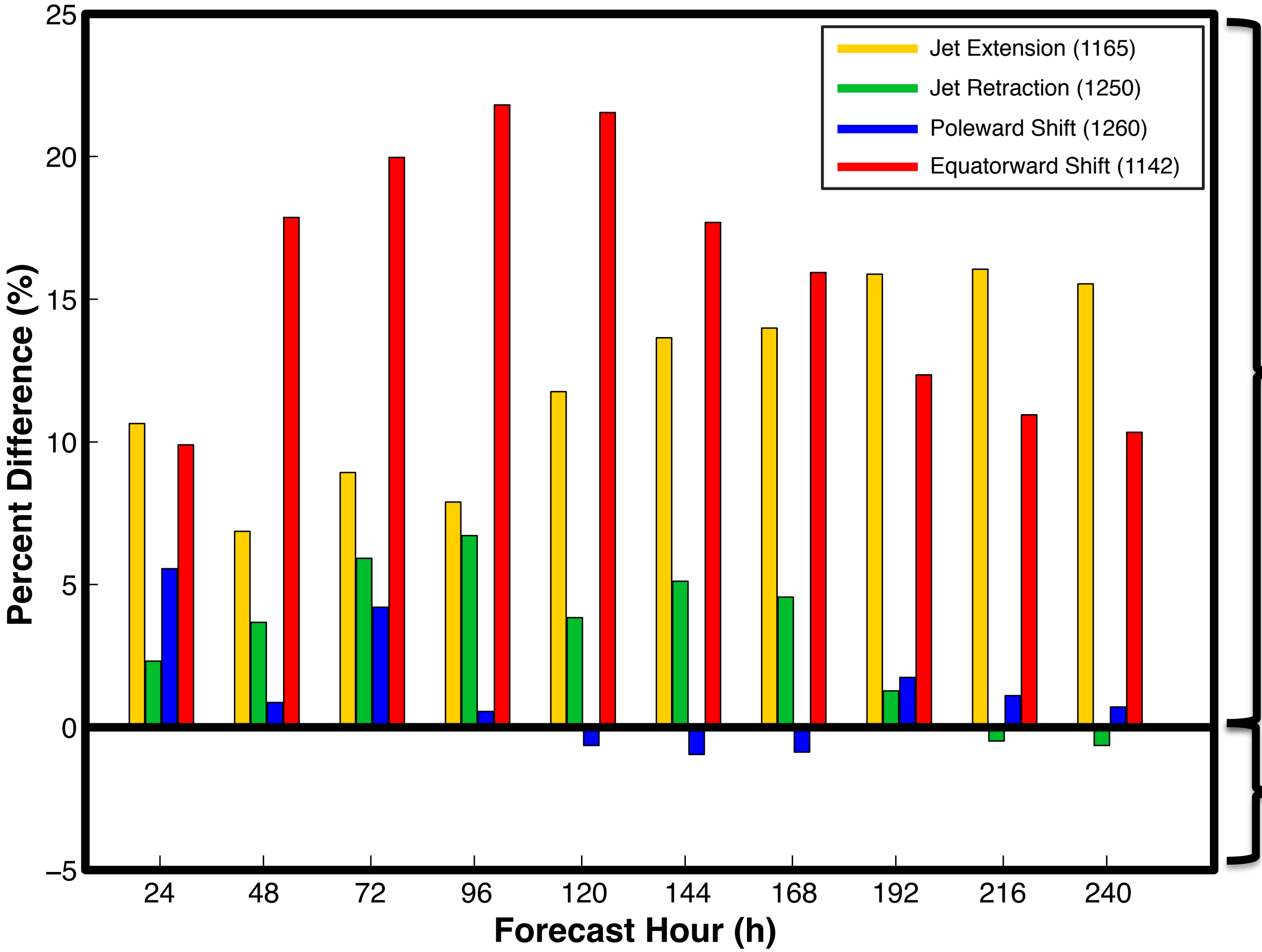
Predictability by Jet Regime

Forecasts binned based on where the North Pacific Jet is in the phase diagram when the forecasts were initialized.



Predictability of Extreme Temperature Events

Percent Difference in the Frequency of Forecasts with Below- and Above-Normal RMSE Initialized during the same NPJ Regime

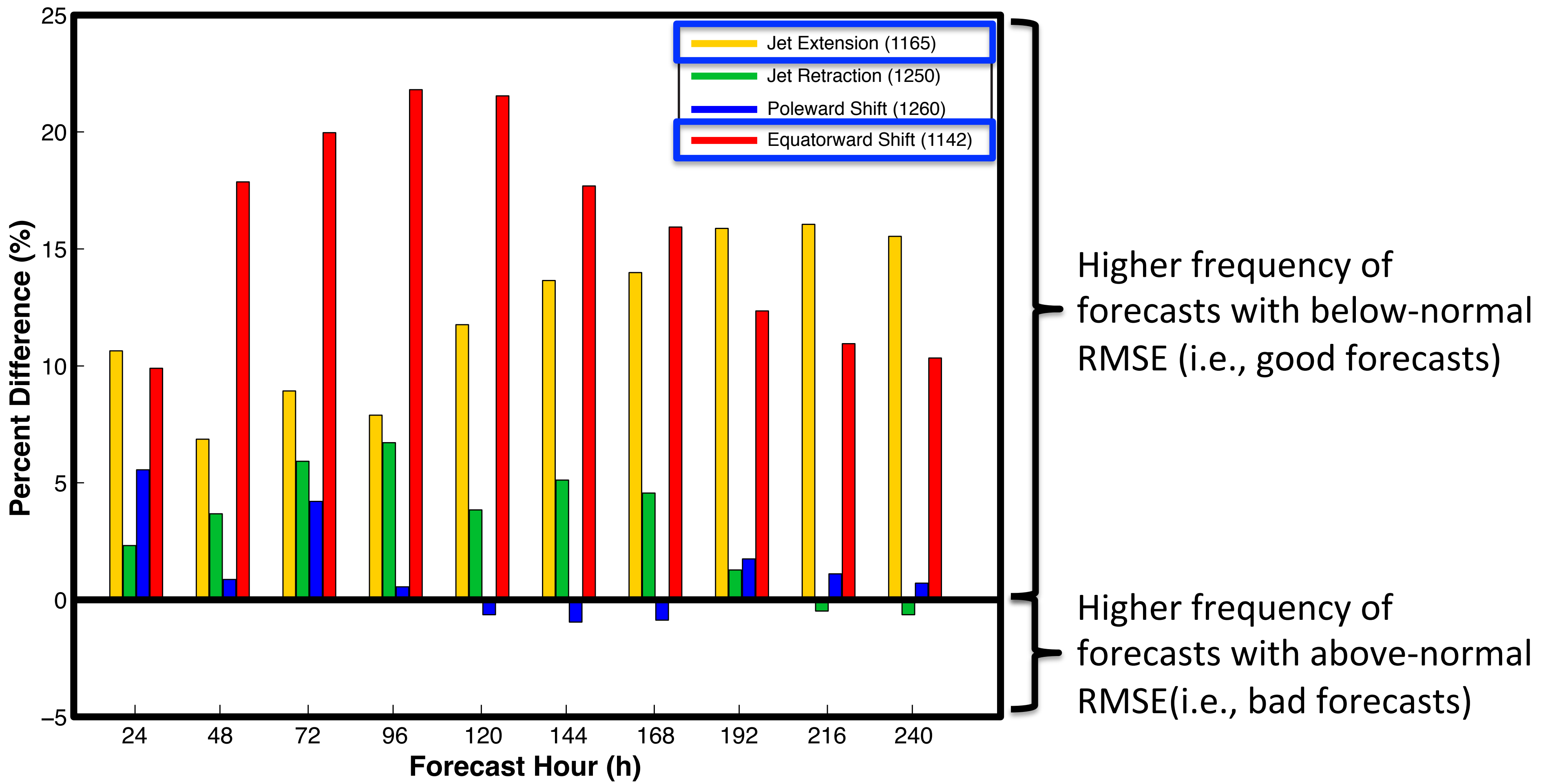


Higher frequency of forecasts with below-normal RMSE (i.e., good forecasts)

Higher frequency of forecasts with above-normal RMSE(i.e., bad forecasts)

Predictability of Extreme Temperature Events

Percent Difference in the Frequency of Forecasts with Below- and Above-Normal RMSE Initialized during the same NPJ Regime



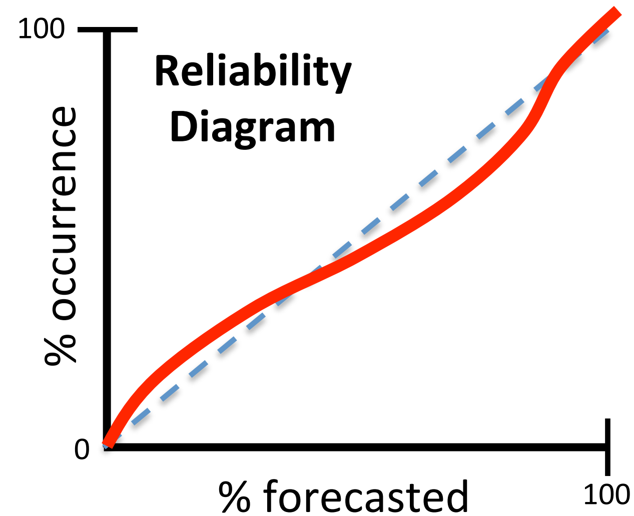
NPJ Phase Diagram

Candidate Verification Metrics

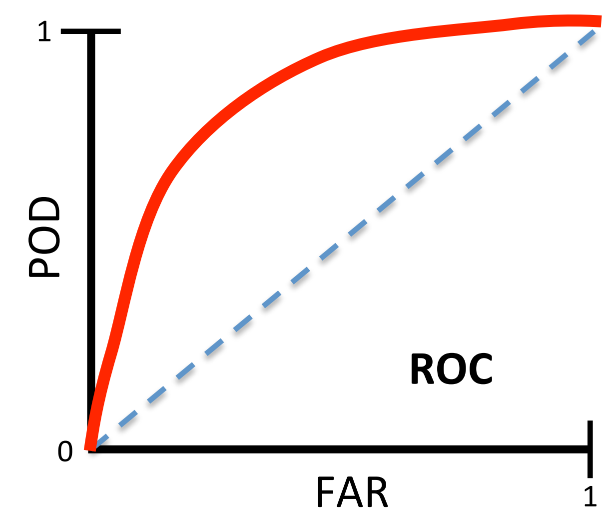
- **Forecast Error**
  - Distance between GFS deterministic forecast and the analysis at each forecast hour
  - Distance between the GEFS ensemble mean forecast and the analysis at each forecast hour
  - Average distance between ensemble members and the analysis at each forecast hour
- **Probability of Detection**
  - Did the analysis fall within the ensemble envelope at each forecast hour?

Candidate Verification Metrics

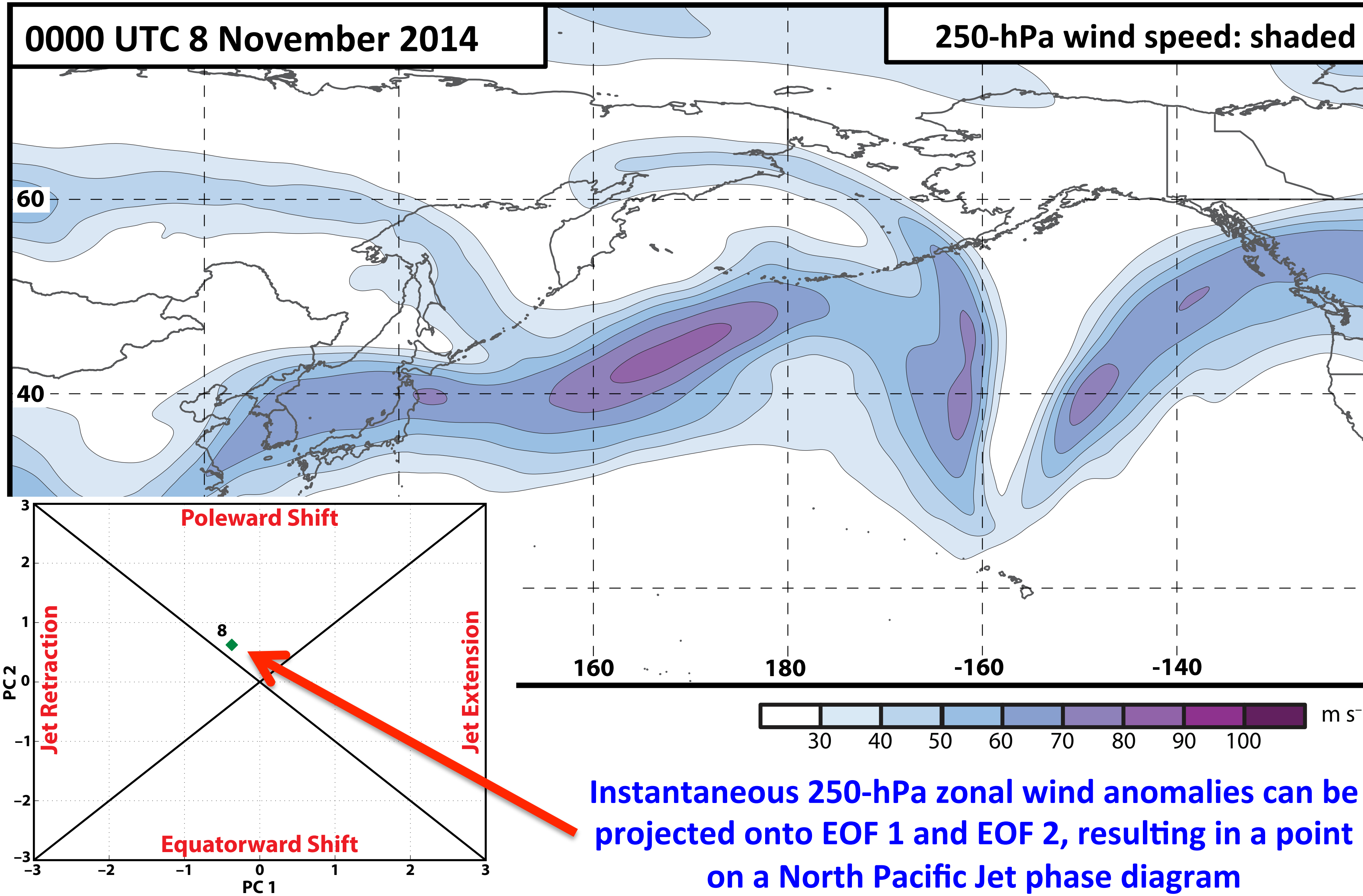
- **Reliability Diagram**
  - A reliability diagram is used to evaluate the performance of GEFS ensemble forecasts with respect to the NPJ Phase Diagram.



- **ROC**
  - Could a ROC be an alternative metric to evaluate the performance of GEFS ensemble forecasts with respect to the NPJ Phase Diagram?



Real Time North Pacific Jet Phase Diagram

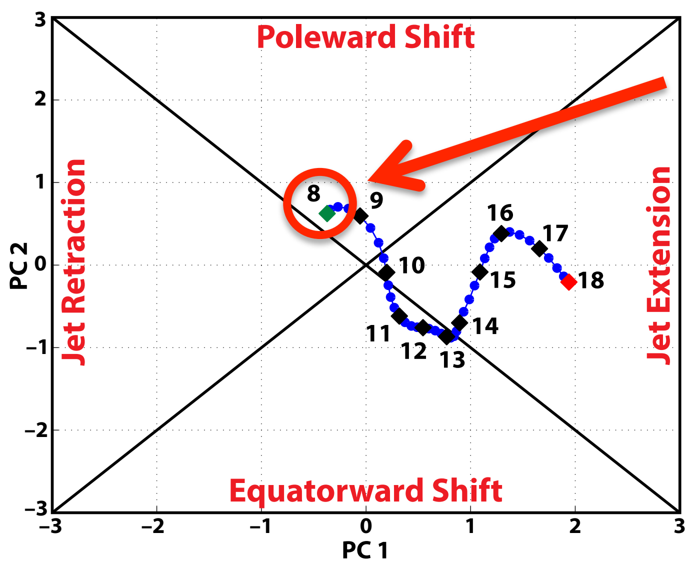


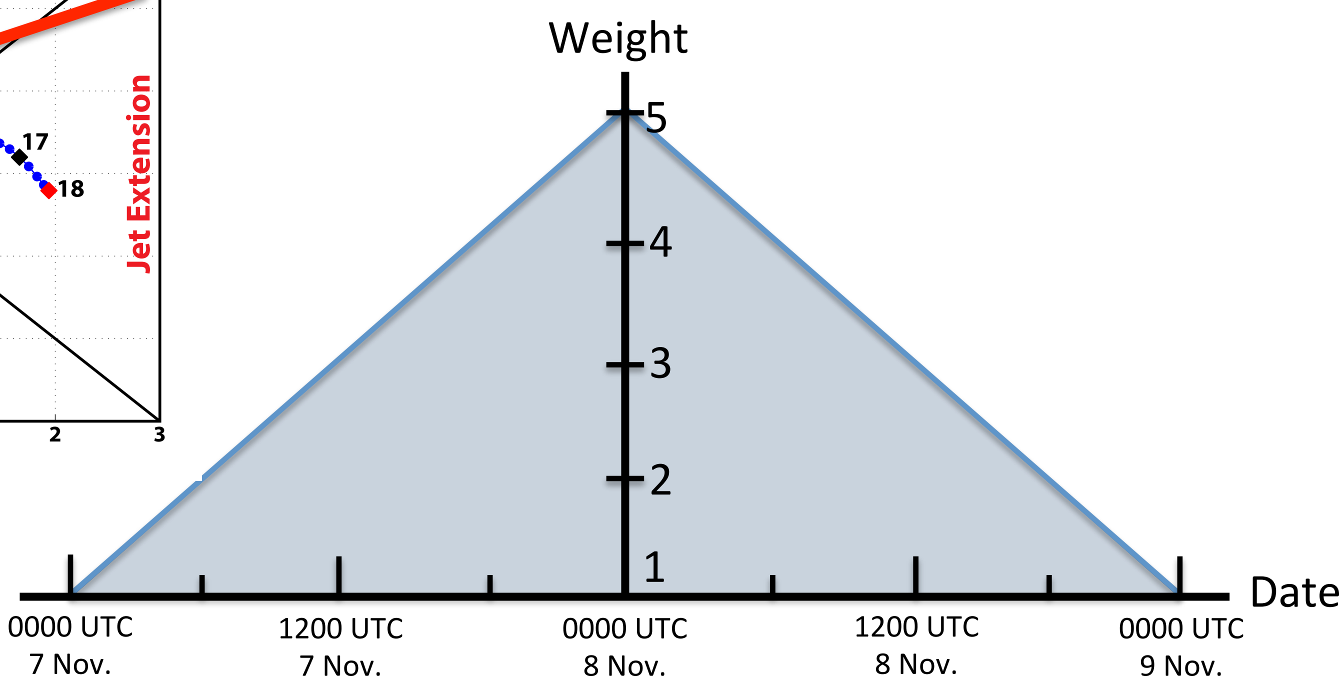
Instantaneous 250-hPa zonal wind anomalies can be projected onto EOF 1 and EOF 2, resulting in a point on a North Pacific Jet phase diagram

Real Time North Pacific Jet Phase Diagram

- Each point on the phase diagram is a weighted average of the principal components within +/− 1 day of the time under consideration

Example: 0000 UTC 8 November 2014





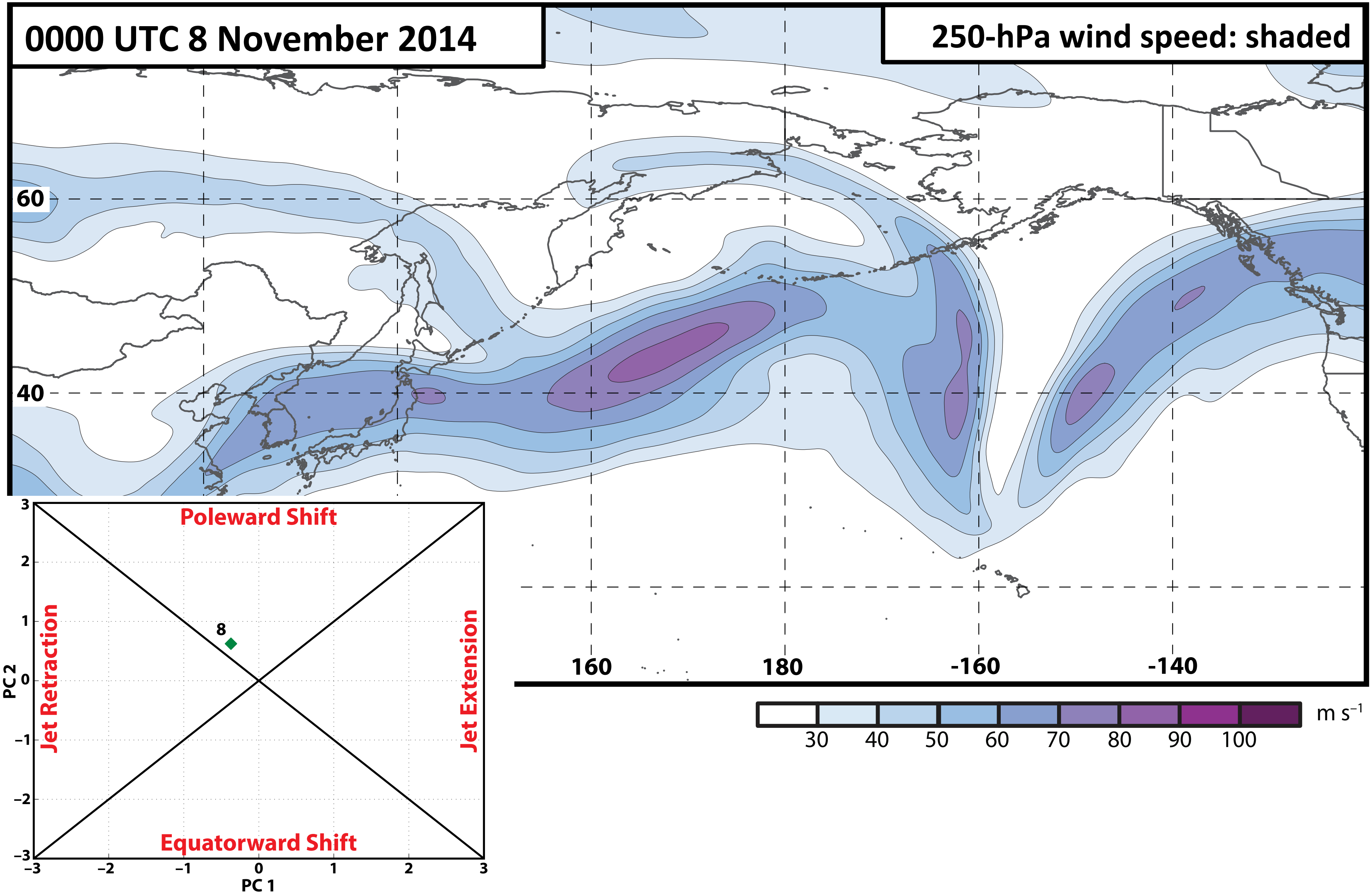
Real Time North Pacific Jet Phase Diagram

1. Characterizes the past evolution and present state of the upper-tropospheric flow pattern over the North Pacific.

   - Captures regime transitions
   - Identifies flow patterns conducive to the development of EWEs

2. Characterizes the forecasted evolution of the upper-tropospheric flow pattern over the North Pacific.

Real Time North Pacific Jet Phase Diagram



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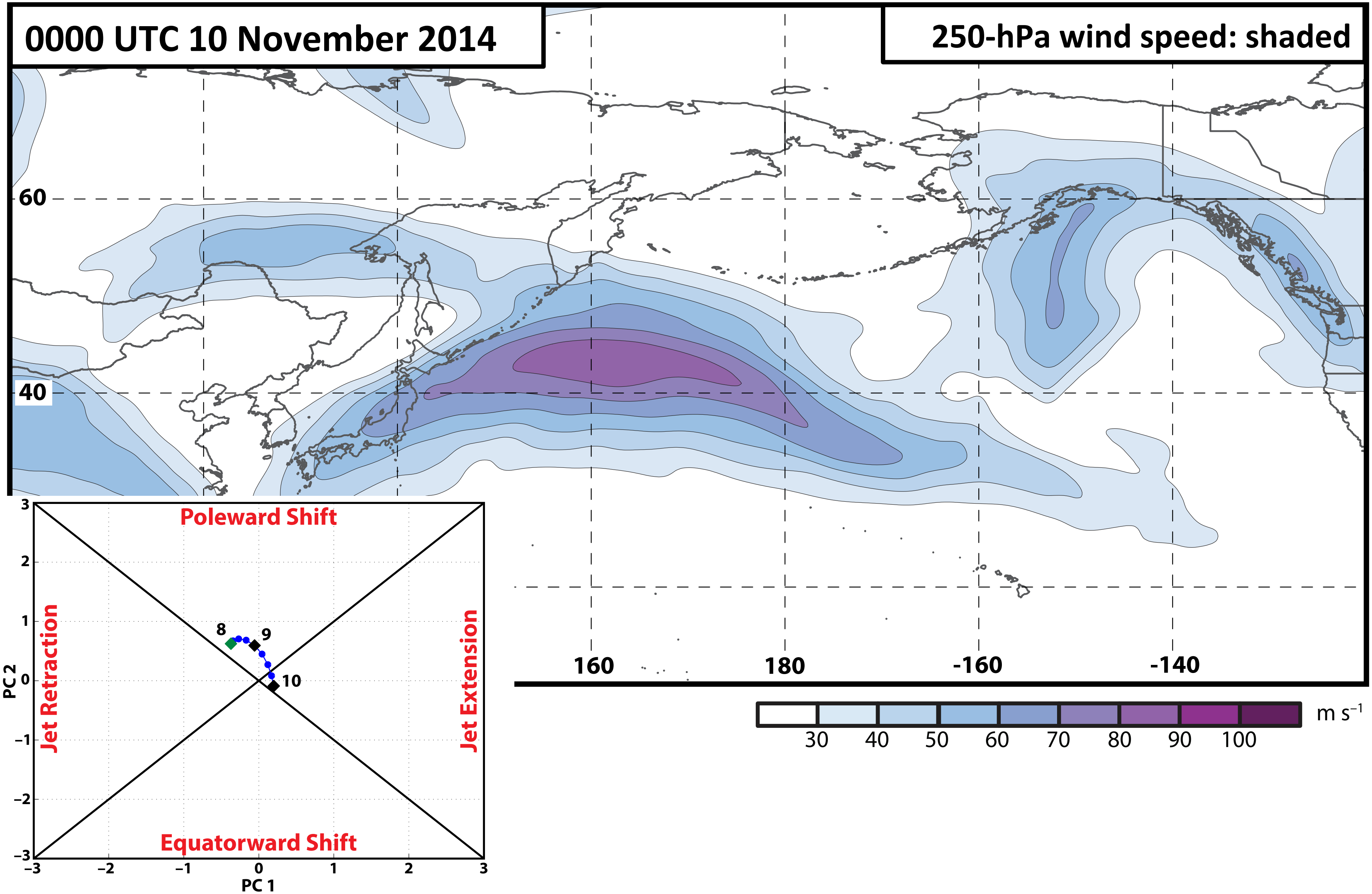

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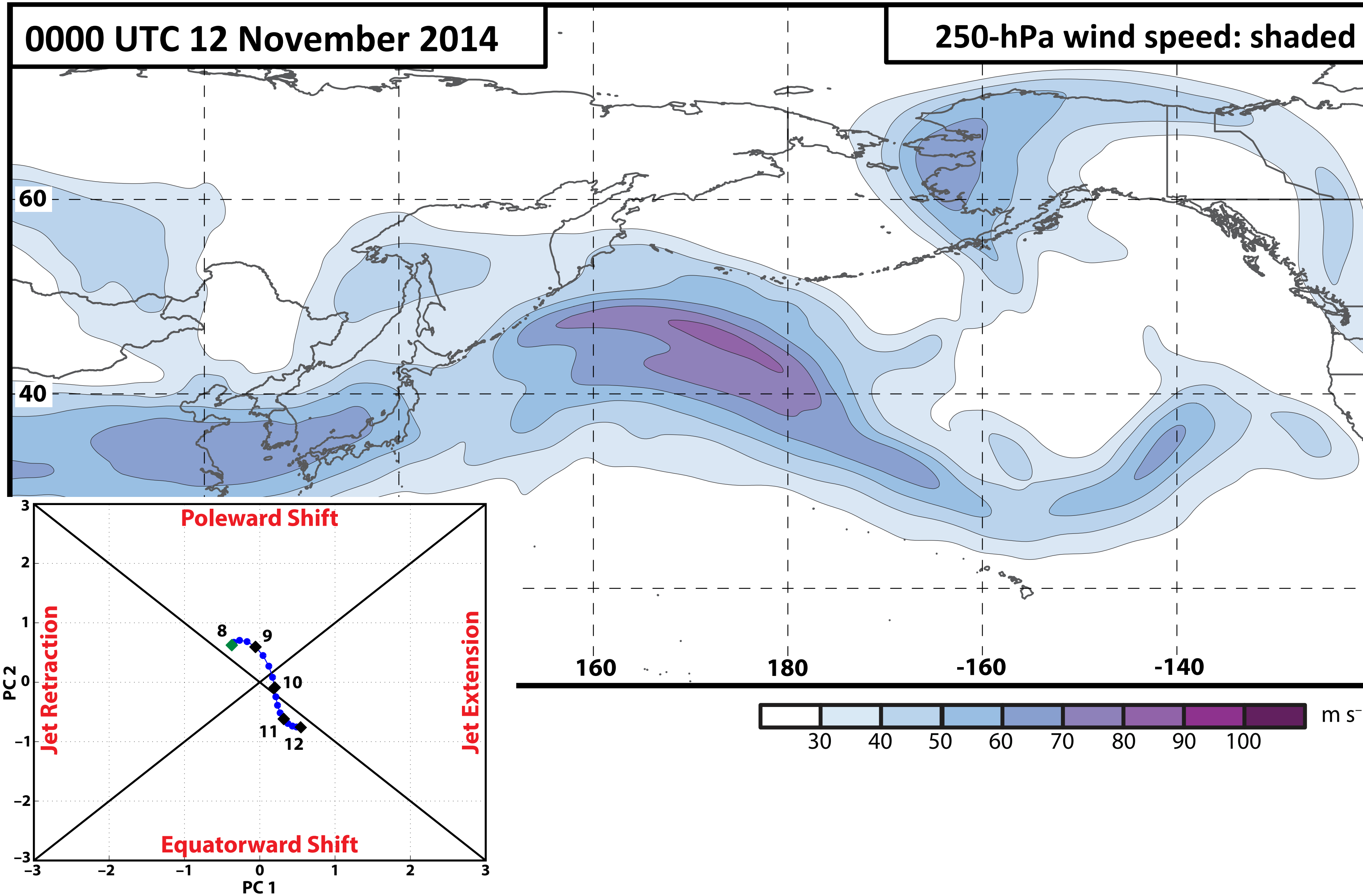

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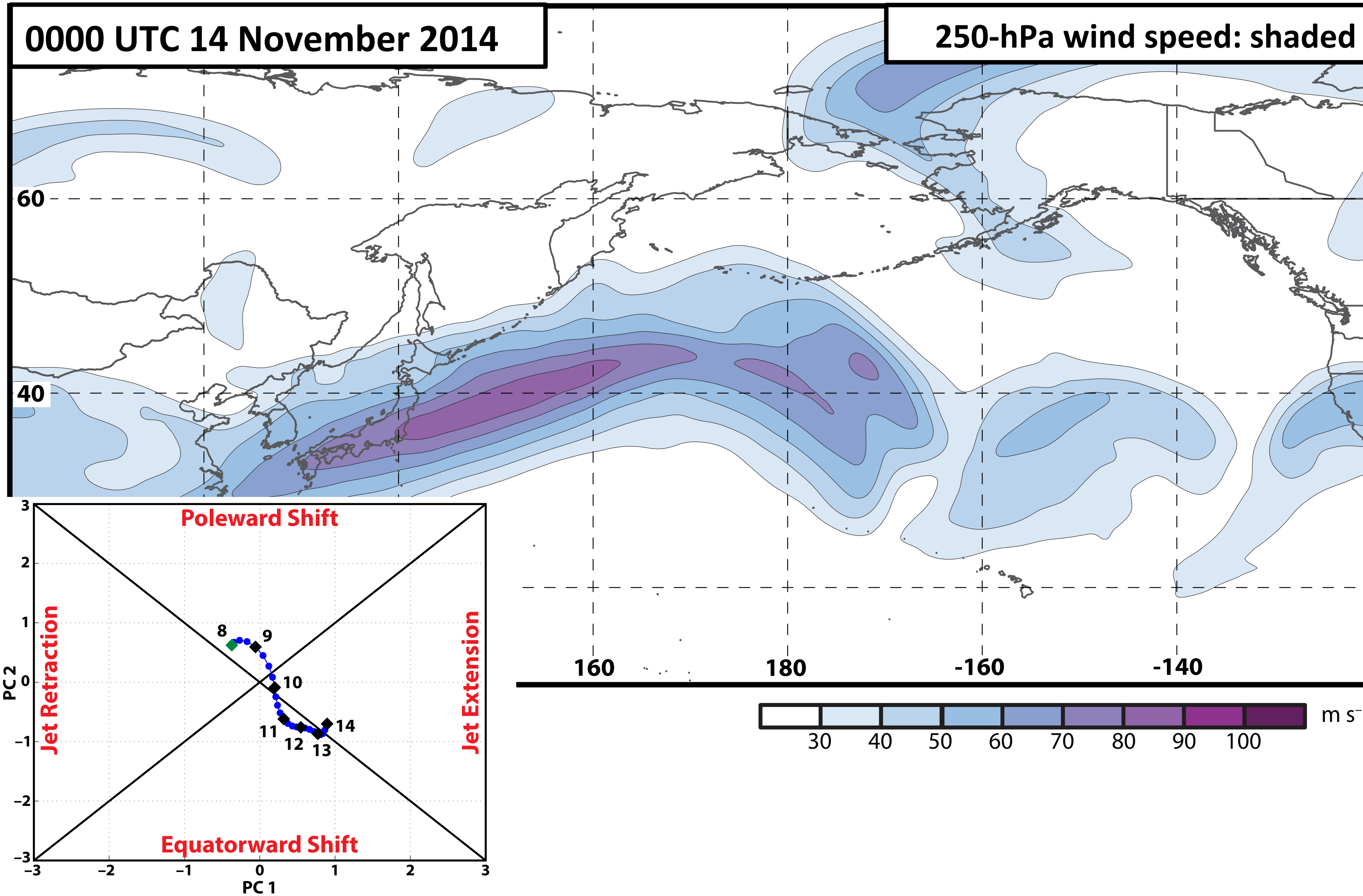

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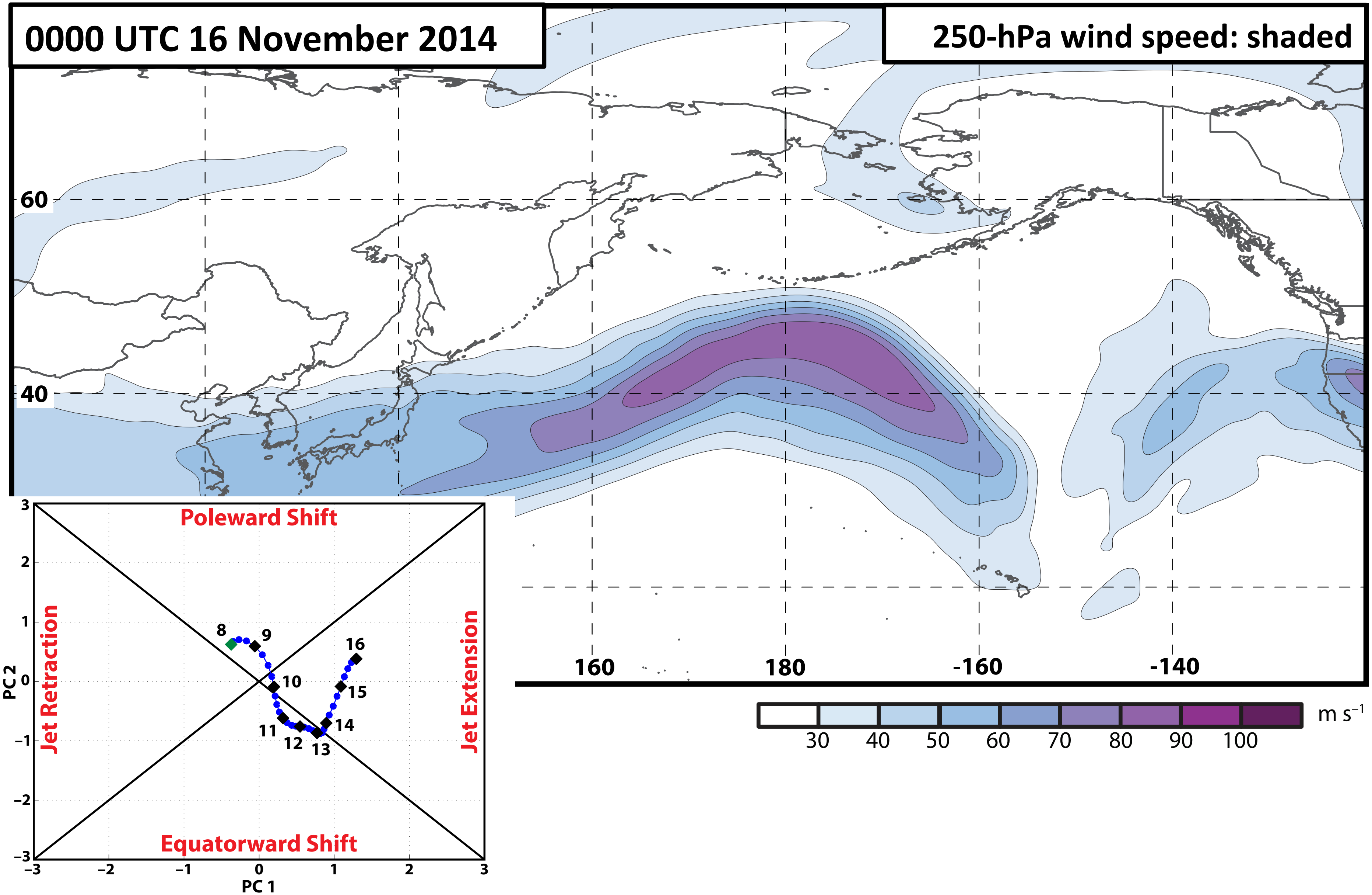
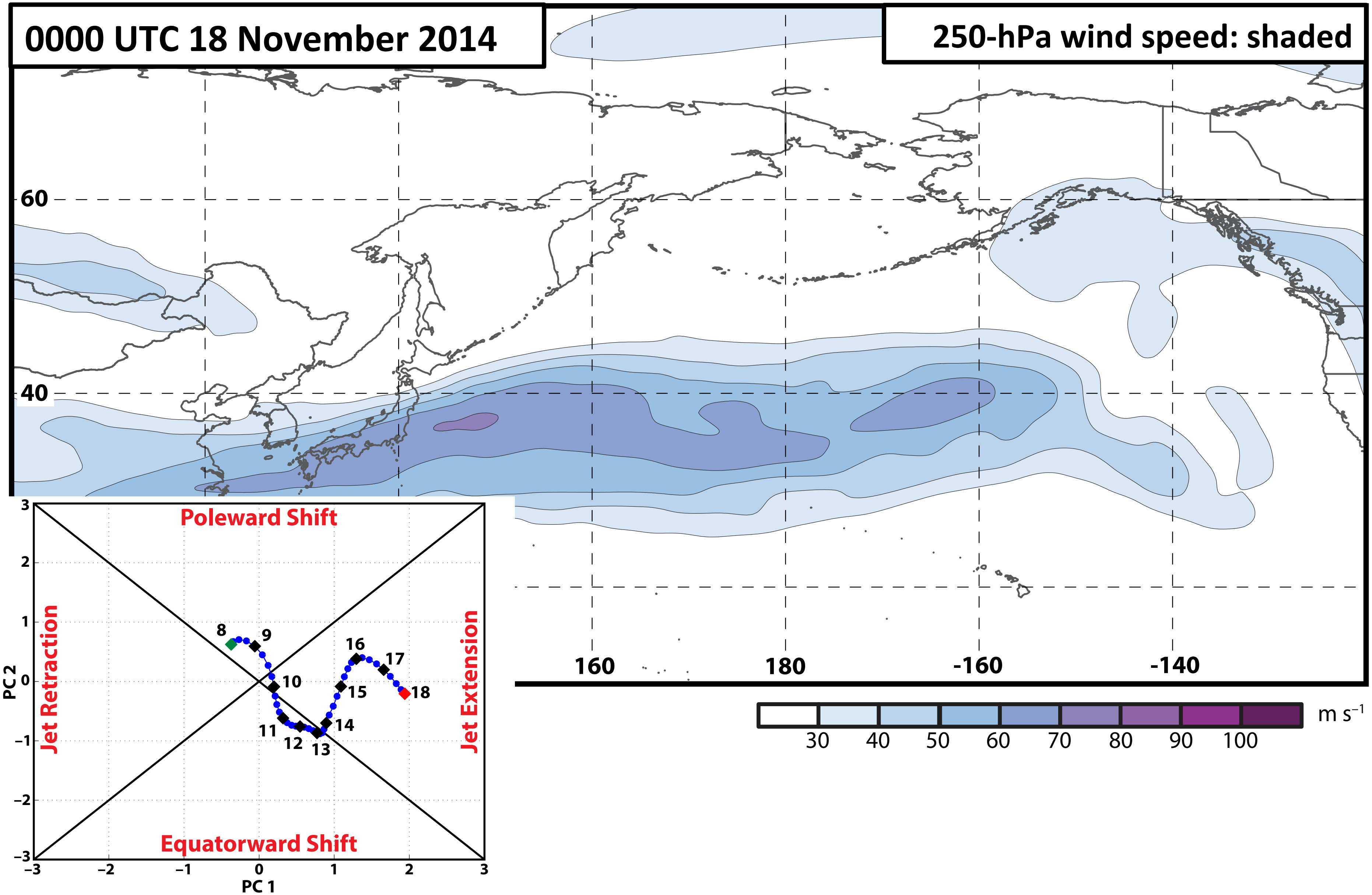


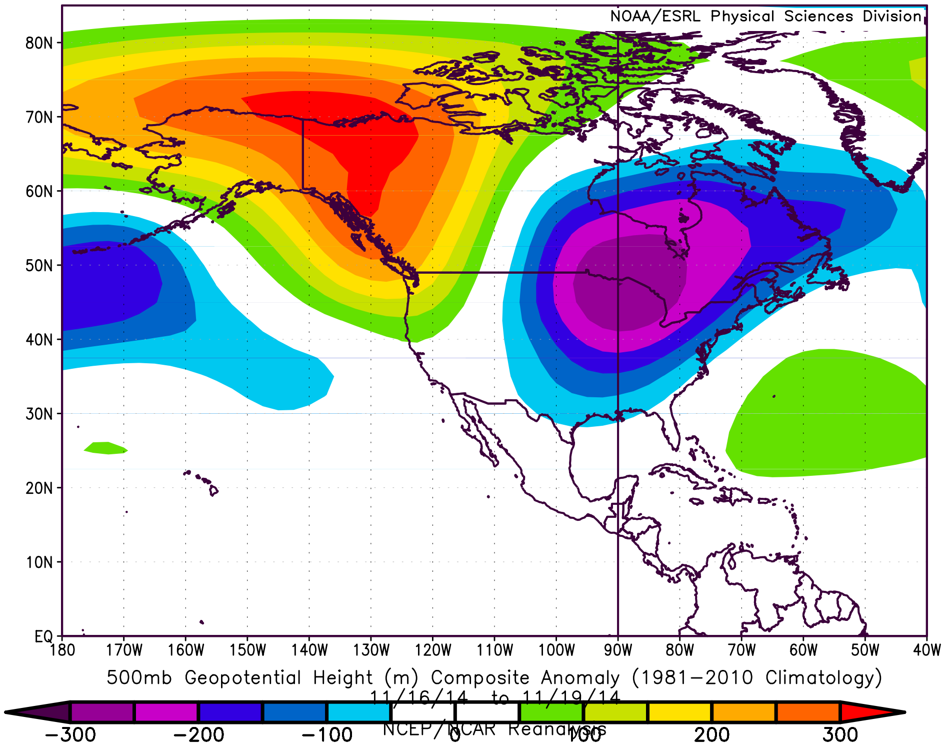
Real Time North Pacific Jet Phase Diagram



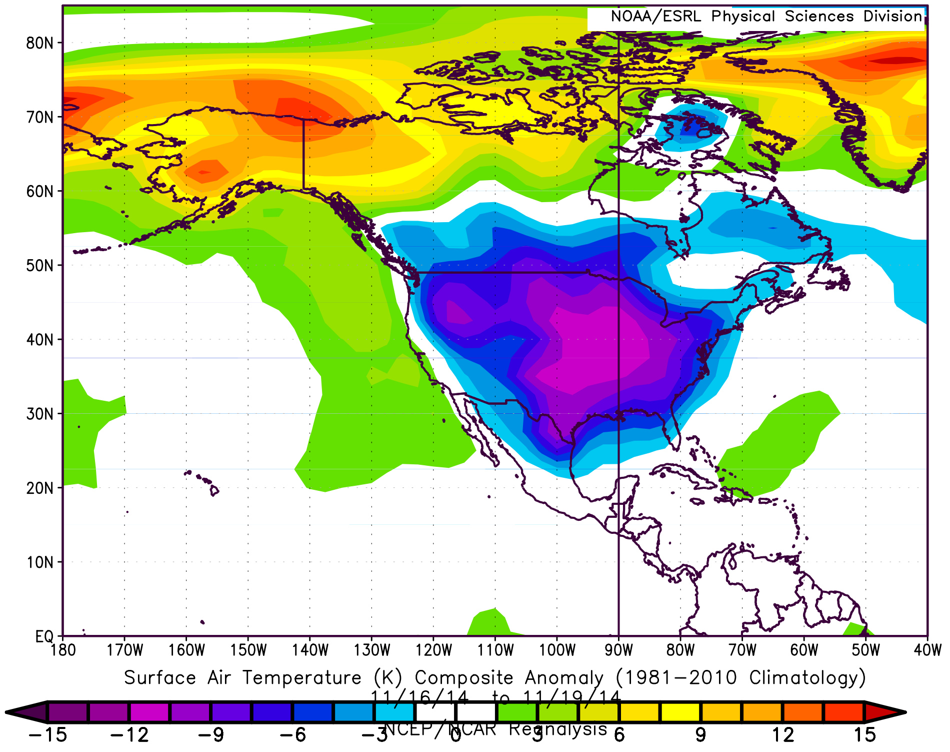
Real Time North Pacific Jet Phase Diagram

16–19 November 2014 Composite Anomalies

500-hPa Geo. Height (m)

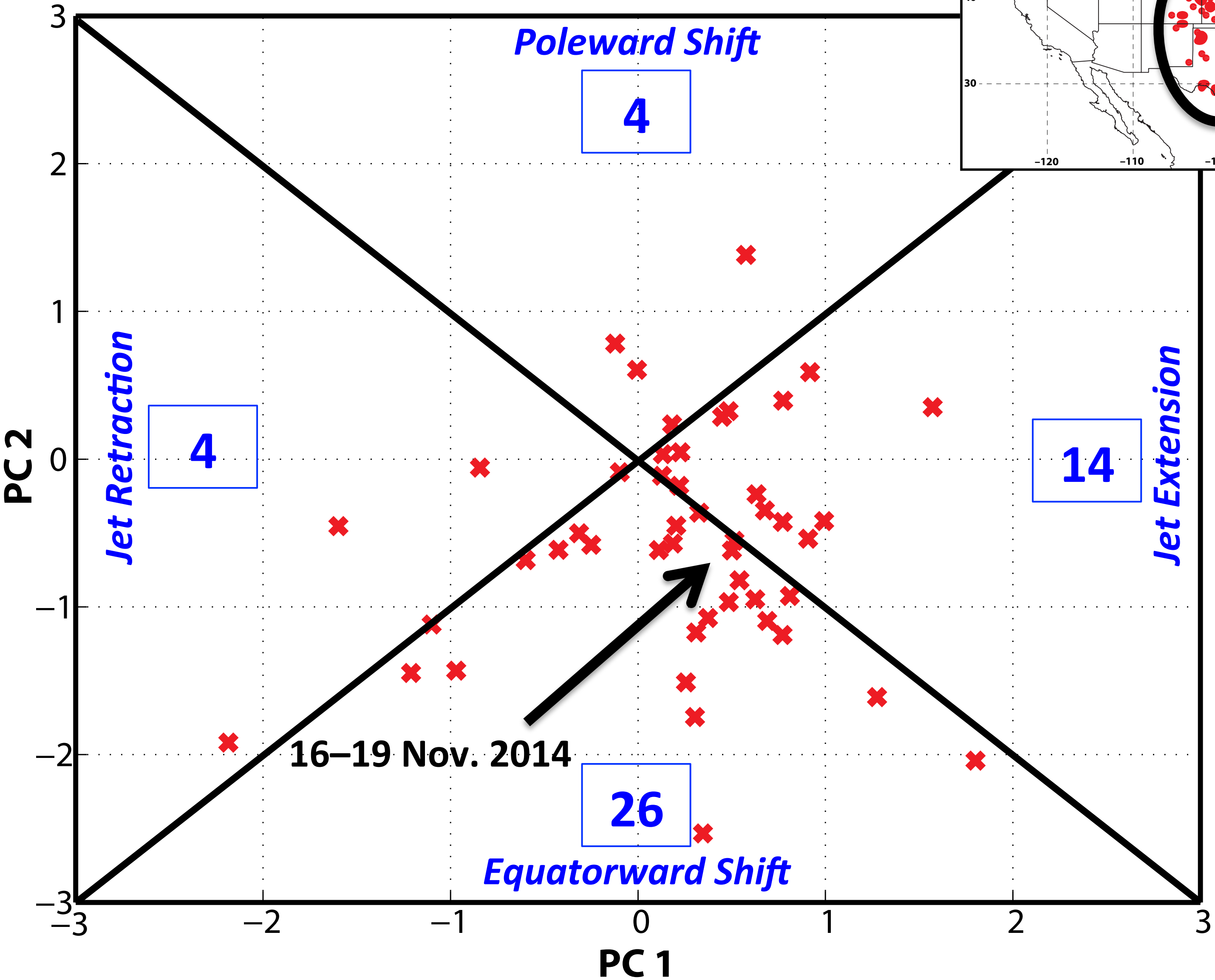


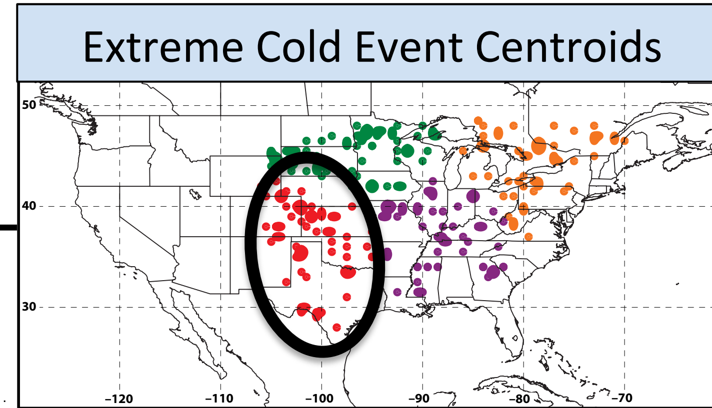
Surface Temperature (°C)



E. Rockies – S. Plains Cluster

COLD EVENTS (n = 48)





Events during Sept. – May projected onto phase diagram

Each point is an average of the PCs 3–7 days prior to the event

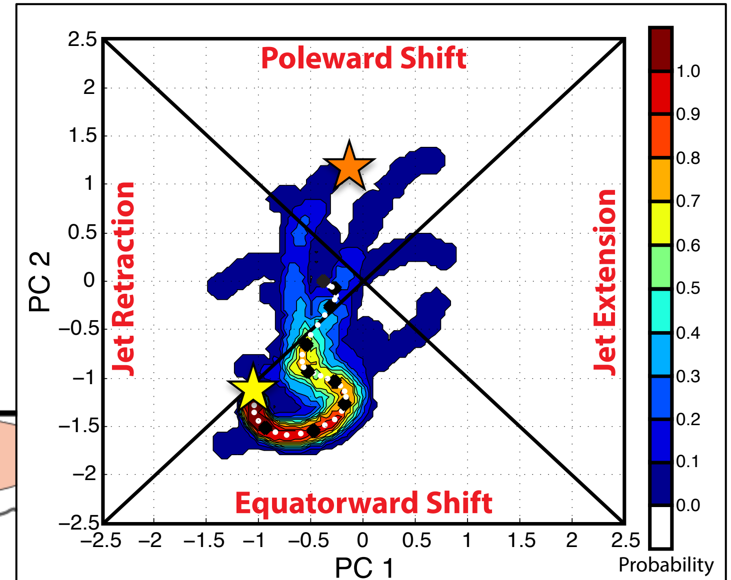
Real Time North Pacific Jet Phase Diagram

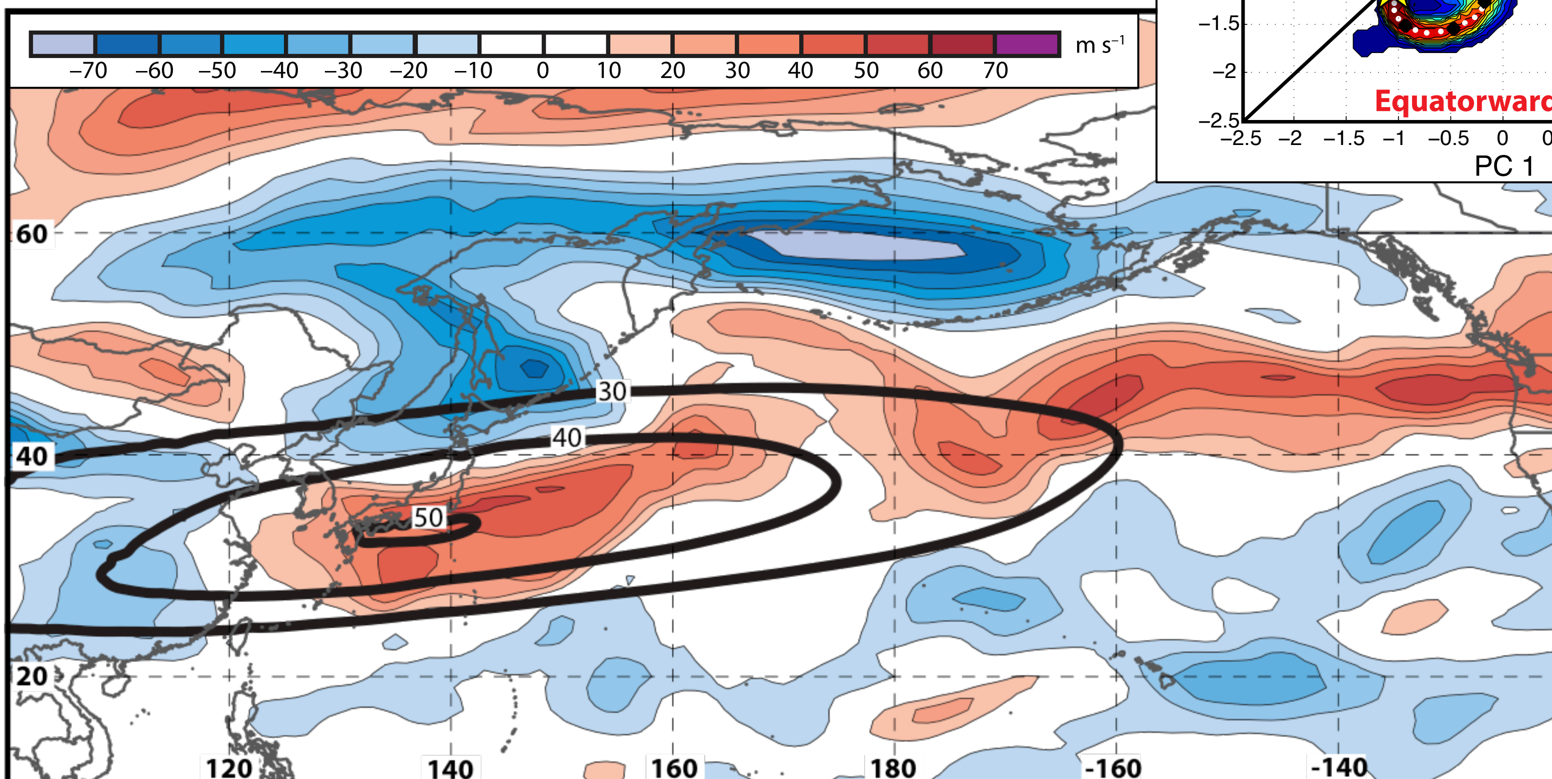
250-hPa zonal wind at 0000 UTC 2 Jun minus 250-hPa zonal wind at 0000 UTC 24 May (shading) in the GFS analyses shows the transition to a poleward-shifted jet regime

★ 0000 UTC 24 May (0-h forecast)

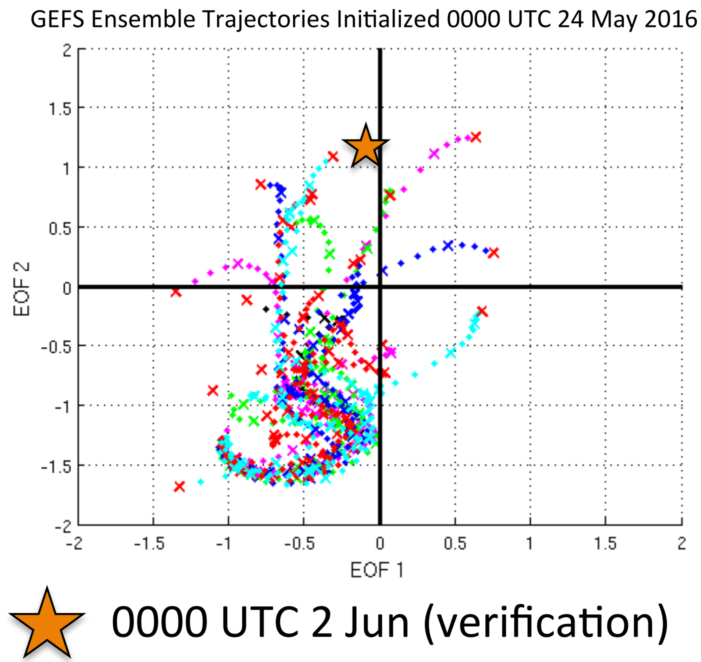
★ 0000 UTC 2 Jun (verification)

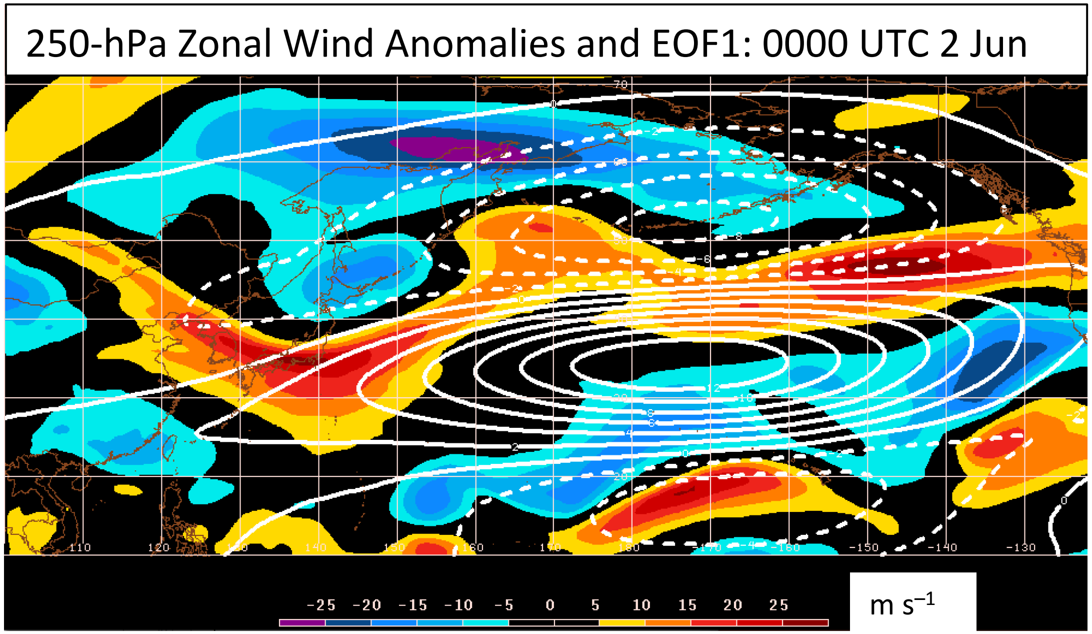
●— **Ensemble mean**





Sept.–May mean 250-hPa zonal wind: black contours





250-hPa zonal wind anomalies at 0000 UTC 2 Jun project strongly onto EOF2 > 0