The Development of the North Pacific Jet Phase Diagram as a Tool to Monitor the State of the Upper-Tropospheric Flow Pattern

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DAES/ASRC Colloquium Series

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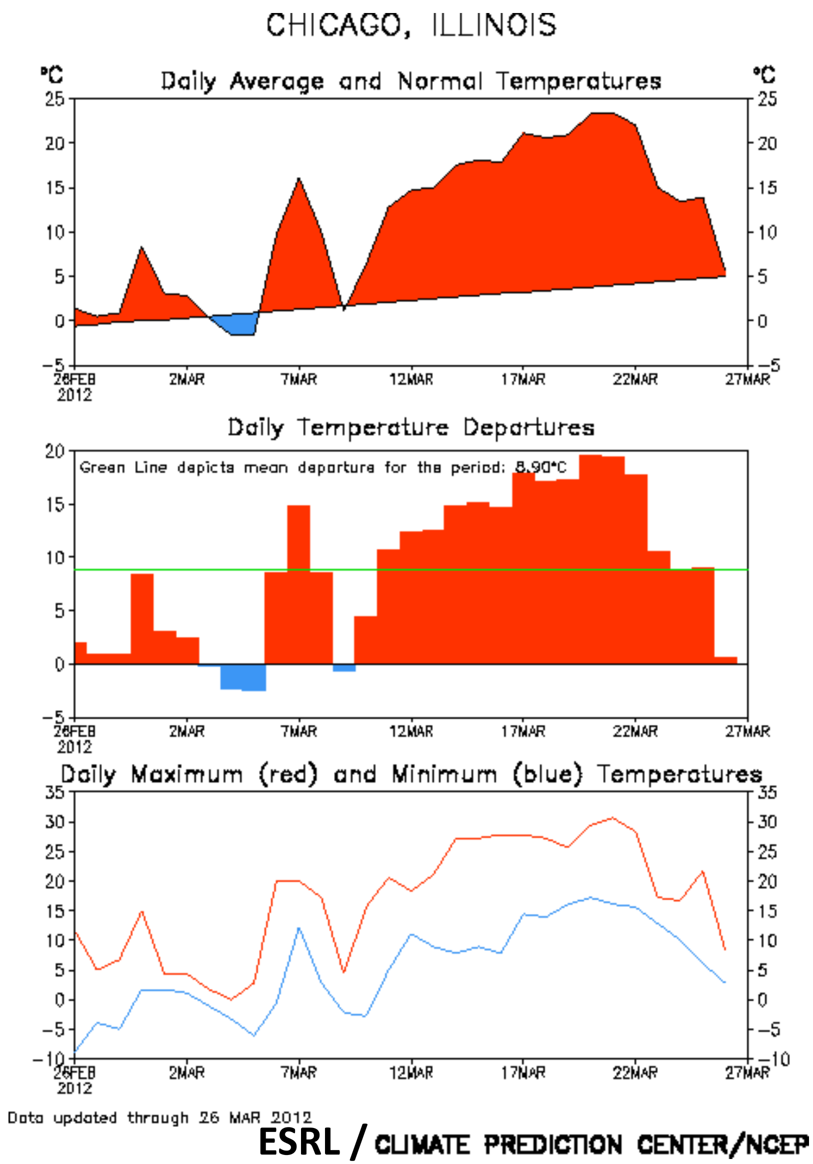
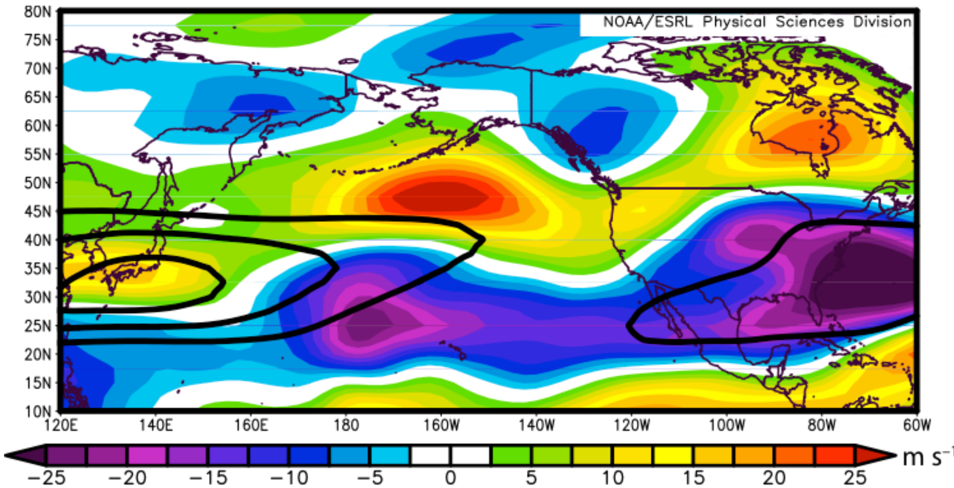
March 2012 Heat Wave

- Extreme and persistent warmth prevailed east of the Rocky Mountains during 13–24 March 2012
- Over 15,000 combined maximum and high minimum temperature records were broken during March 2012
- March 2012 ranked as the warmest March on record for 25 different states

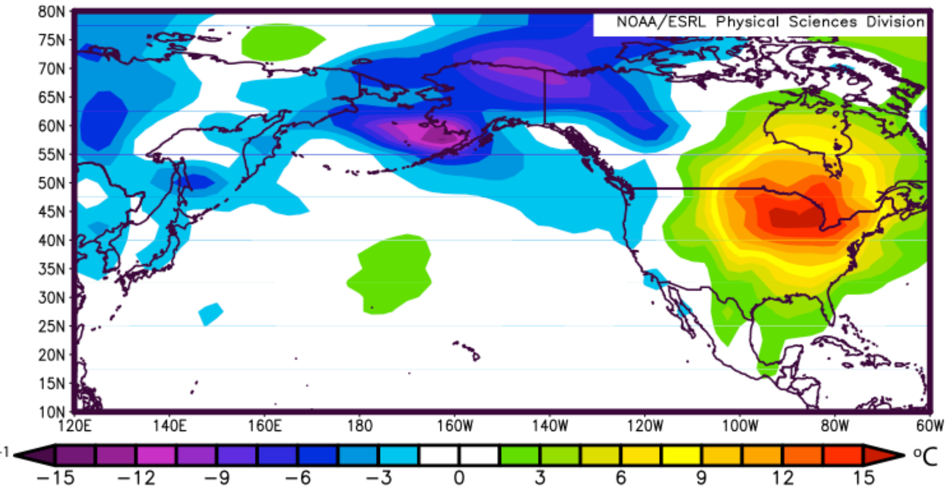


March 2012 Heat Wave

250-hPa U-Wind Anomalies (13–24 March 2012)



Surface Temp. Anomalies (13–24 March 2012)



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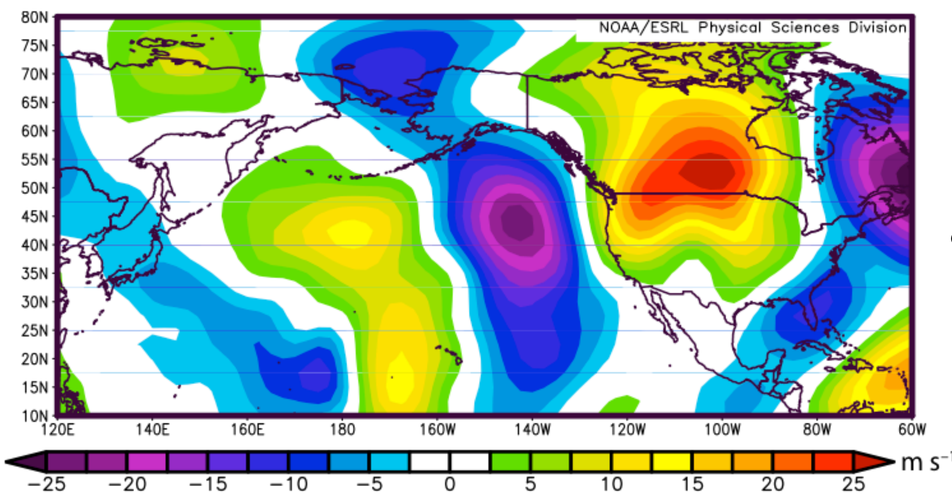

- Surface temperature anomalies exceeded 15°C in the Upper-Midwest
- The North Pacific Jet (NPJ) was shifted poleward and characterized by an amplified flow pattern

March 2012 Heat Wave

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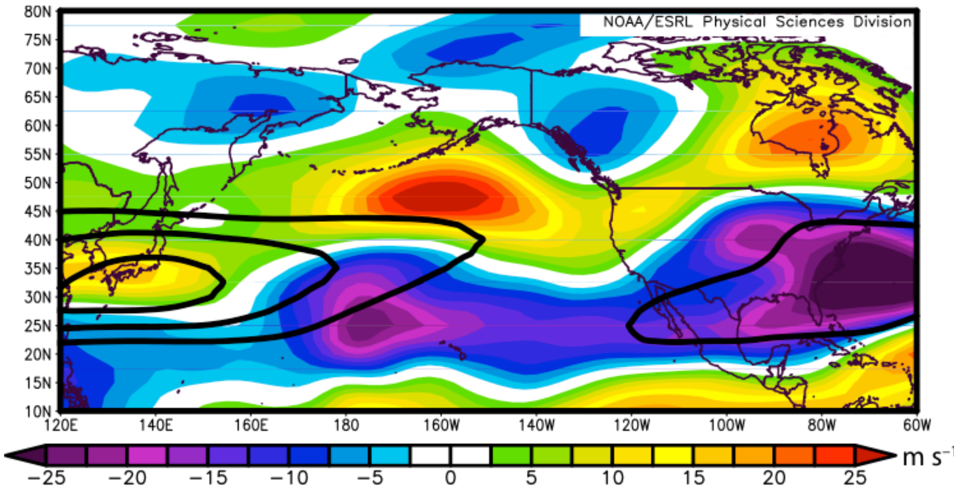

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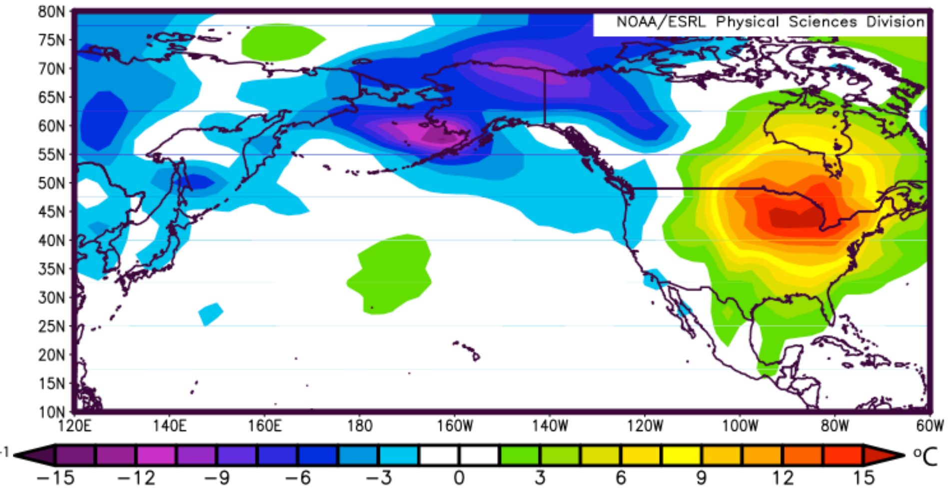

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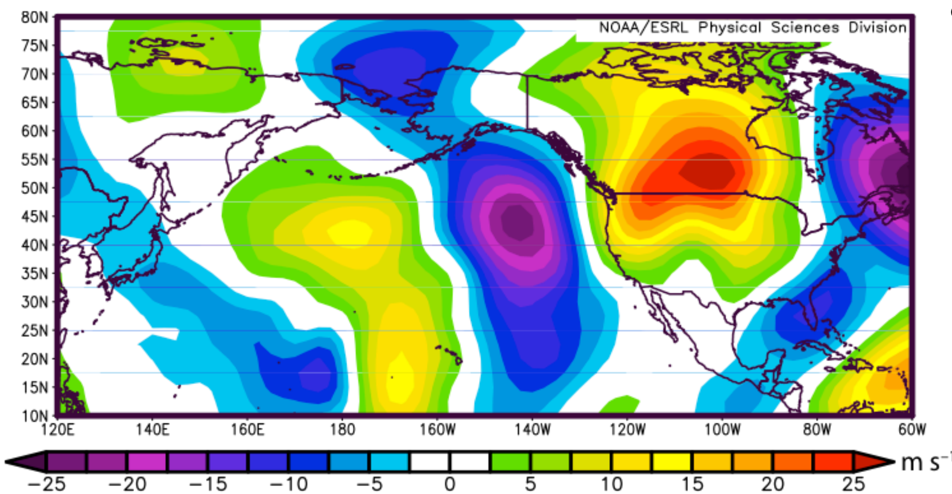
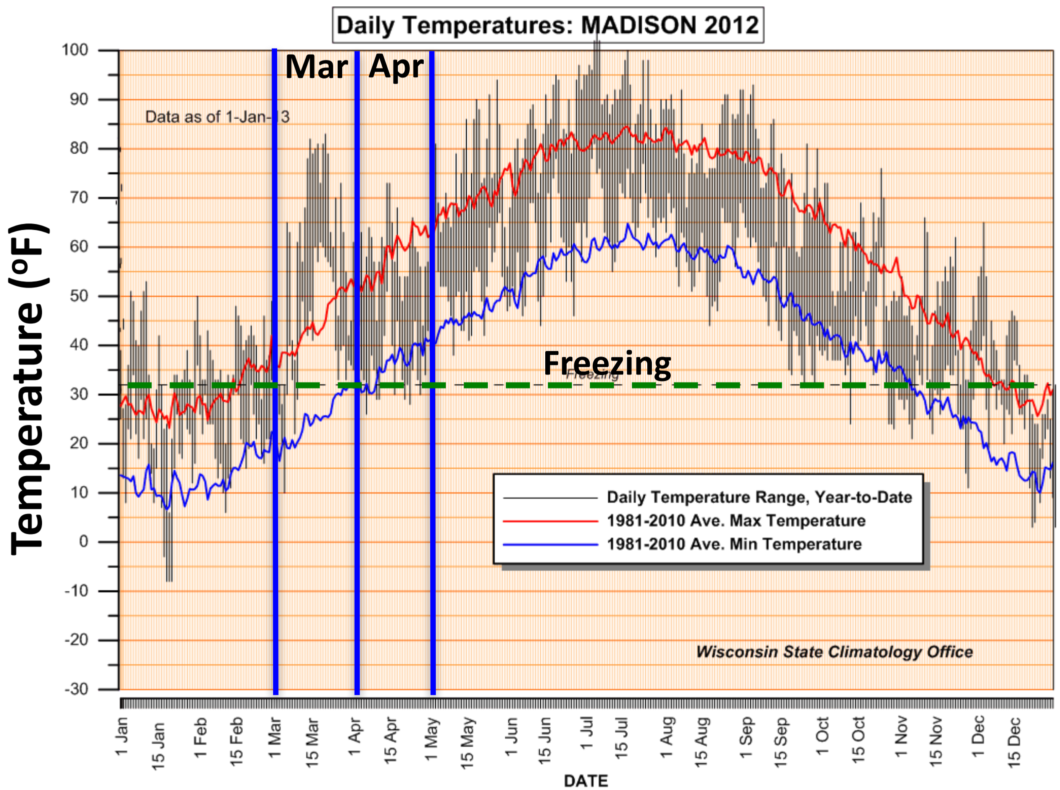


- Dole et al. (2014) demonstrated that this extreme warm event developed due to the favorable superposition of a number of inter- and intra-annual teleconnection patterns

March 2012 Heat Wave

- A return to near-normal temperatures during April 2012 posed problems for fruit crops in the Upper Midwest
- Apple orchards in Iowa, Minnesota, and Wisconsin lost 20–100% of their crop



Wisconsin State Climatology Office

- Pear, plum, cherry, and strawberry crops in southwestern Wisconsin were also severely damaged

Project Motivation

- One or several extreme temperature events (ETEs) during a single season can contribute disproportionately to temperature anomaly statistics for a particular season
- The disproportionate contribution of ETEs to seasonal temperature anomaly statistics suggests that ETEs need to be considered in understanding the dynamical and thermodynamic processes that operate at the weather–climate intersection

Project Motivation

- One or several extreme temperature events (ETEs) during a single season can contribute disproportionately to temperature anomaly statistics for a particular season
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- However, the antecedent environments associated with continental U.S. ETEs exhibit considerable NPJ variability

Project Motivation

- One or several extreme temperature events (ETEs) during a single season can contribute disproportionately to temperature anomaly statistics for a particular season
- The disproportionate contribution of ETEs to seasonal temperature anomaly statistics suggests that ETEs need to be considered in understanding the dynamical and thermodynamic processes that operate at the weather–climate intersection
- However, the antecedent environments associated with continental U.S. ETEs exhibit considerable NPJ variability
- **The development of an objective tool to characterize the state and evolution of the upper-tropospheric flow pattern over the North Pacific is desirable**

Outline

1) Develop the NPJ Phase Diagram

2) Examine the influence of the prevailing NPJ regime on the downstream flow pattern over North America and the development of continental U.S. ETEs

3) Examine the GEFS forecast skill in the context of the NPJ phase diagram

4) Apply the NPJ phase diagram to a period characterized by reduced GEFS forecast skill in late-February 2017

The Development of the NPJ Phase Diagram

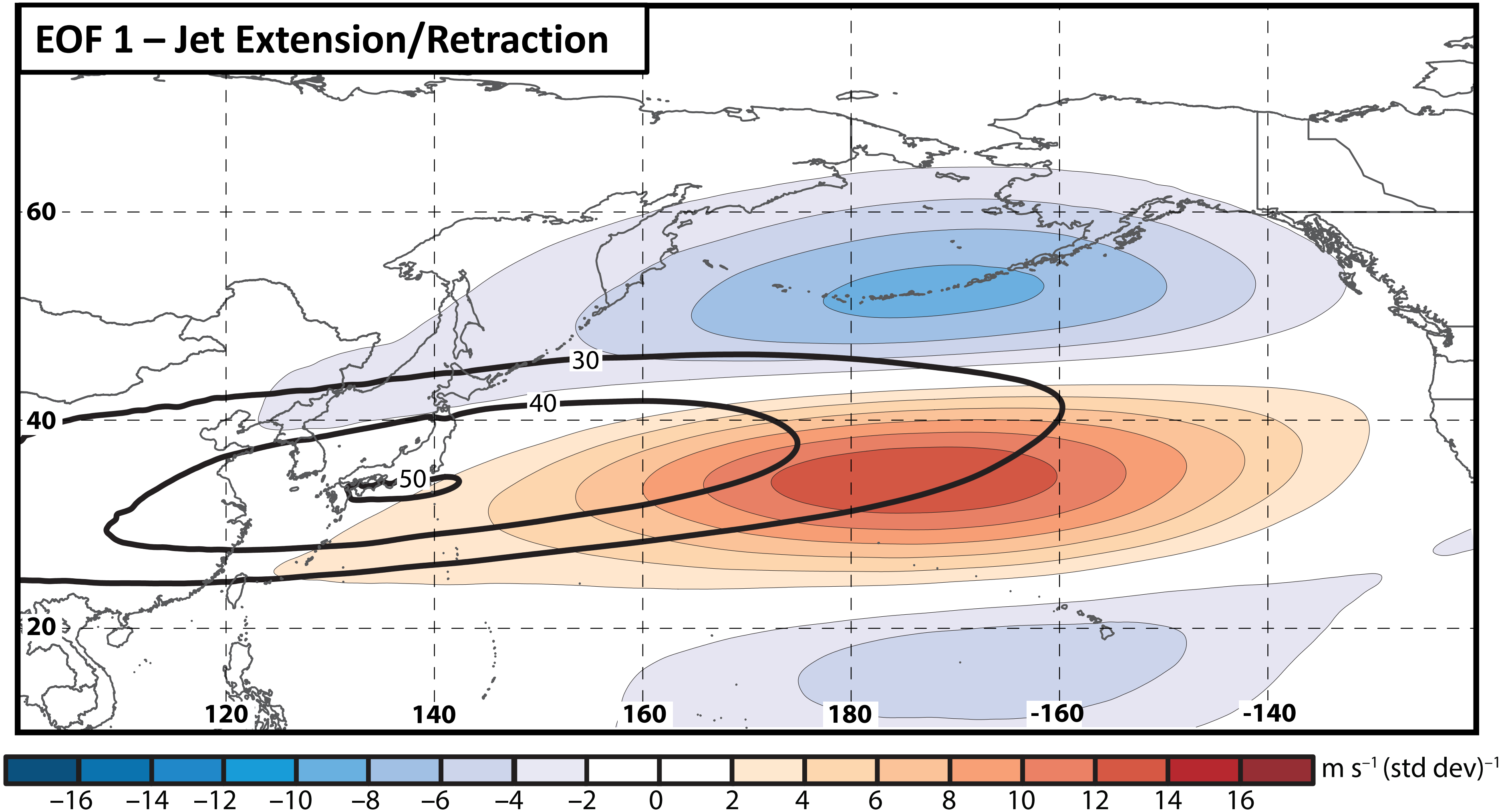
The NPJ Phase Diagram

- Removed the mean and the annual and diurnal cycles from 6-hourly, 250-hPa zonal wind data from the CFSR (1979–2014) (Saha et al. 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 NPJ:

- Athanasiadis et al. (2010)
- Jaffe et al. (2011)
- Griffin and Martin (2017)

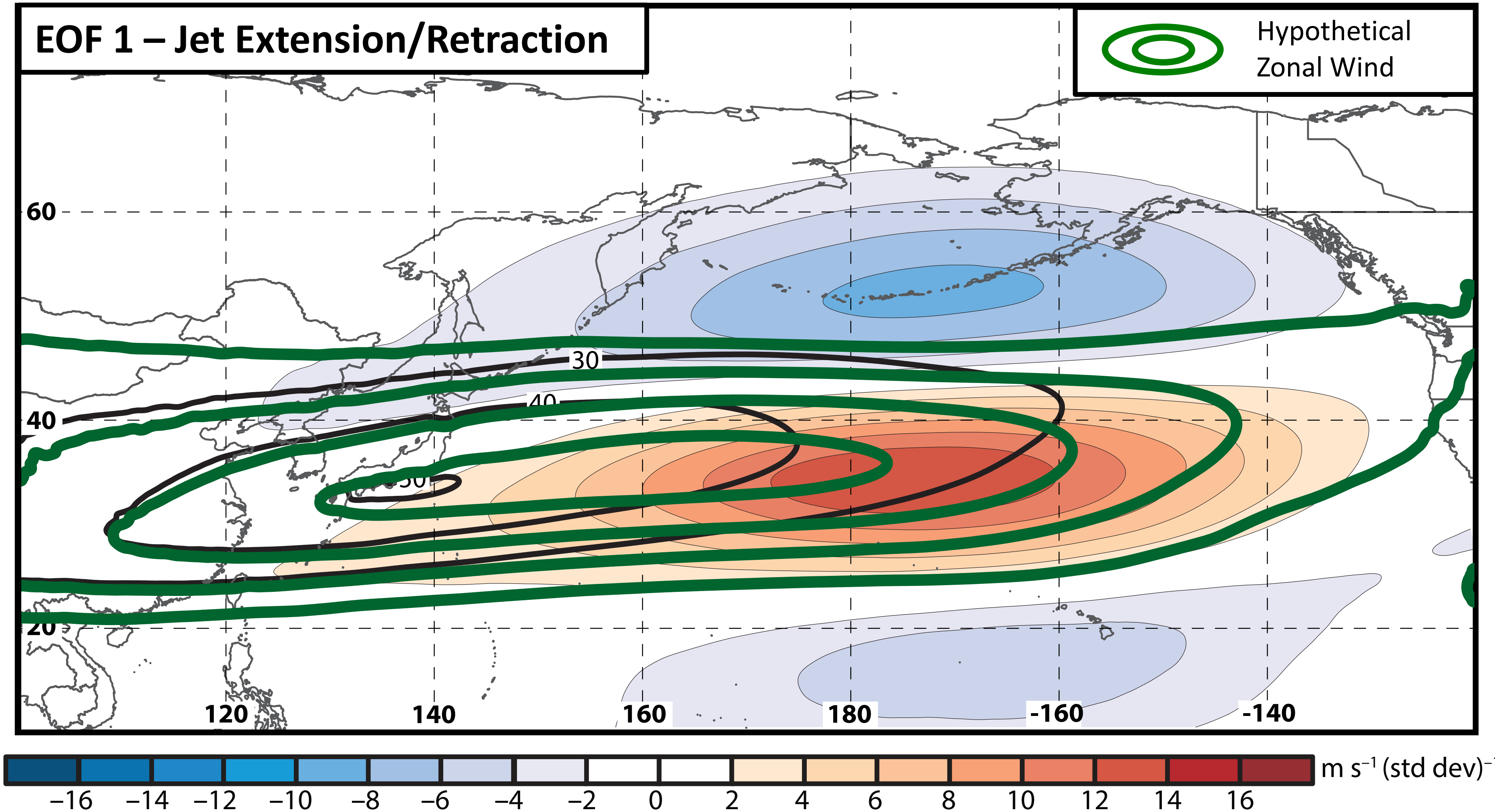
The NPJ Phase Diagram



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

The NPJ Phase Diagram



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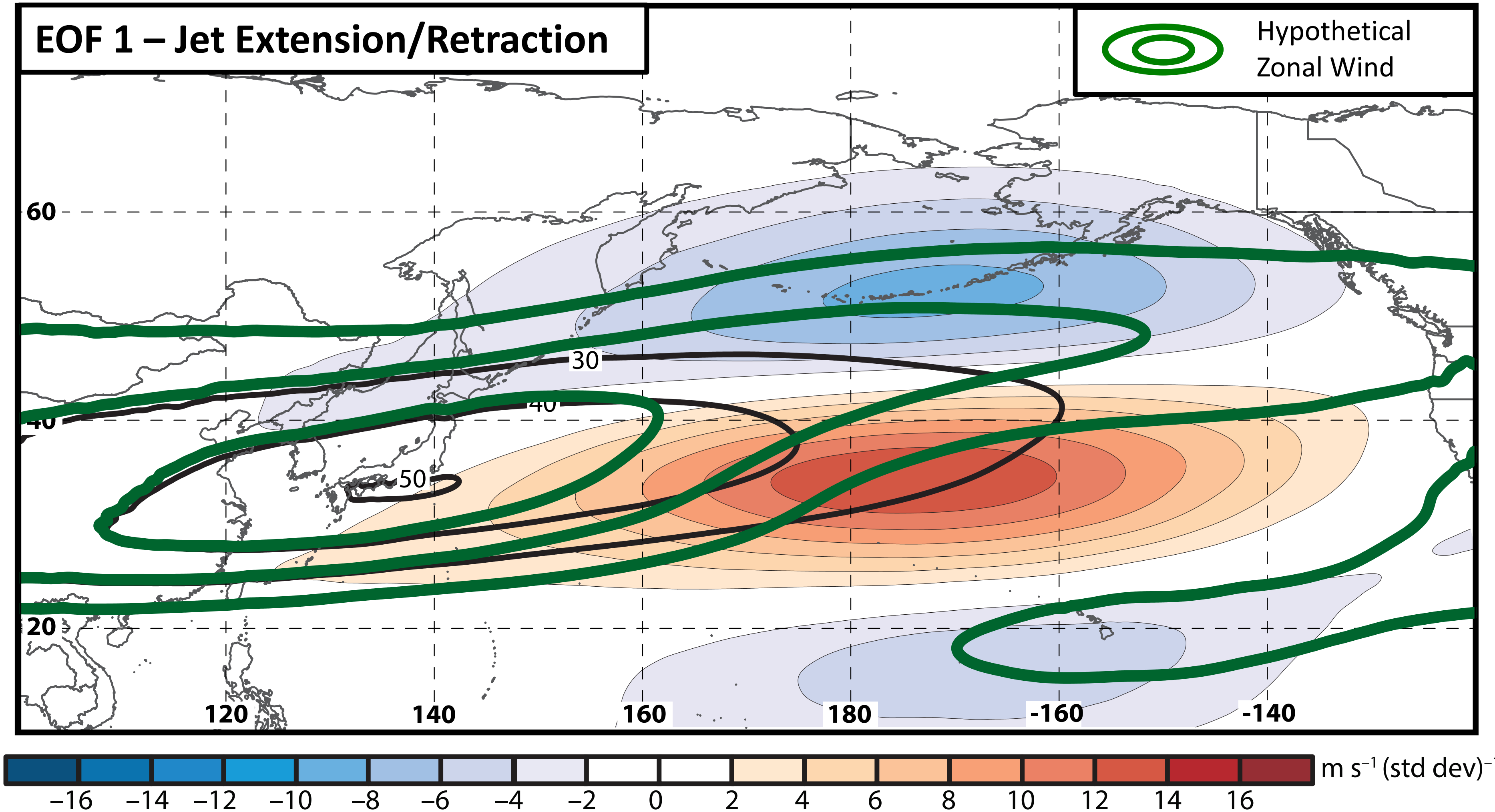

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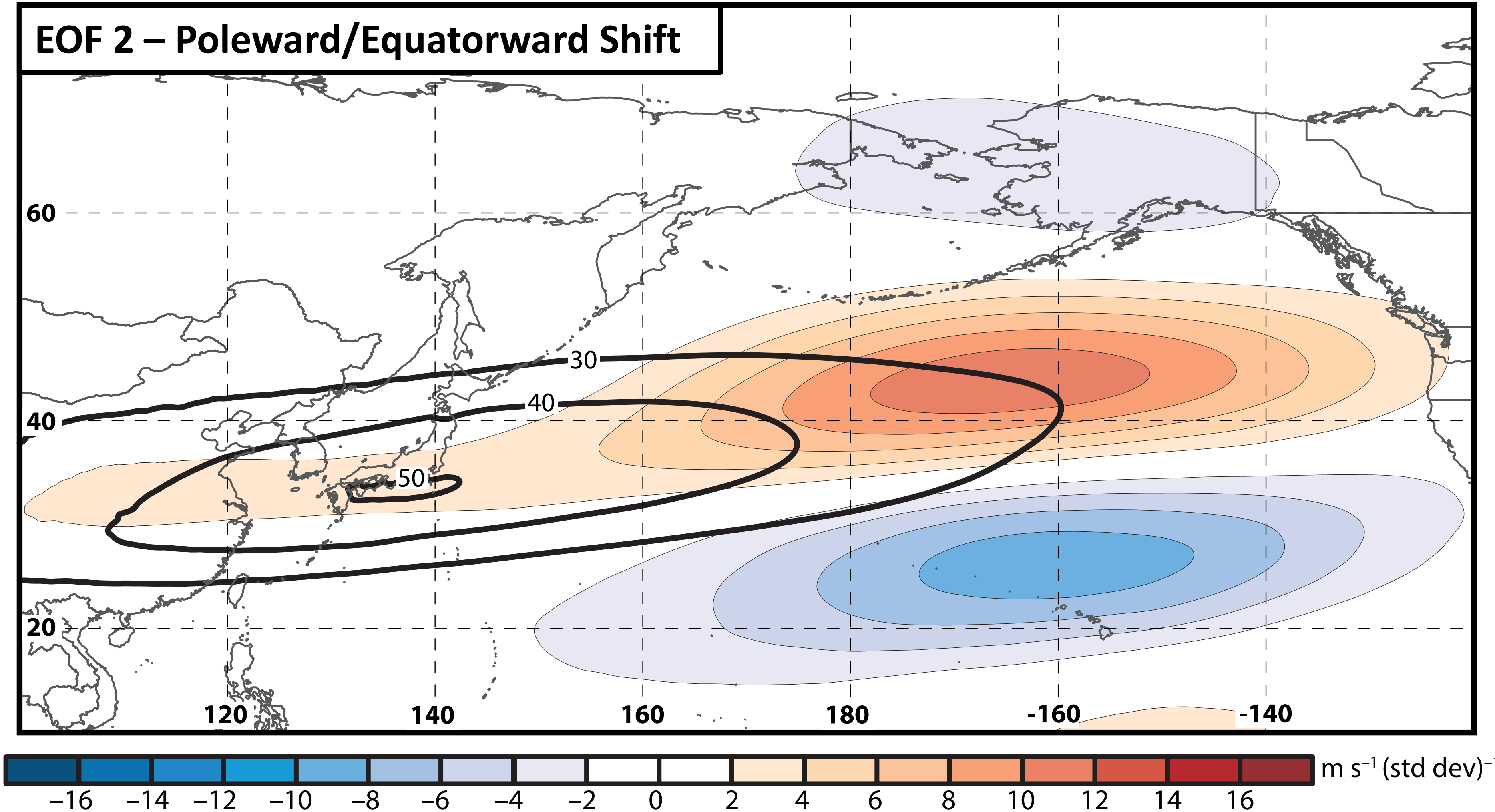

Sept.–May mean 250-hPa zonal wind: black contours
Sept.–May 250-hPa zonal wind EOF 2 pattern: shading

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

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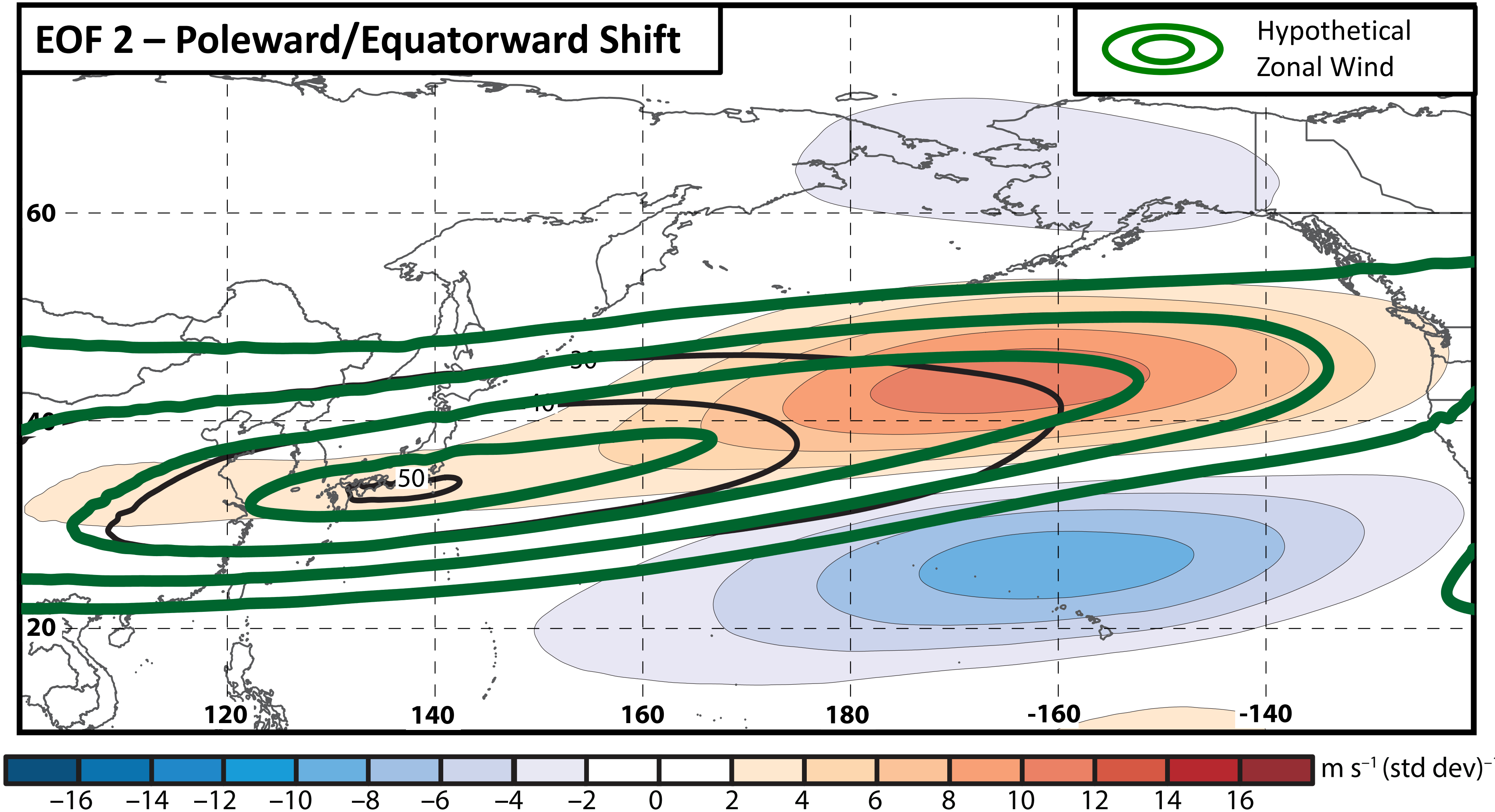

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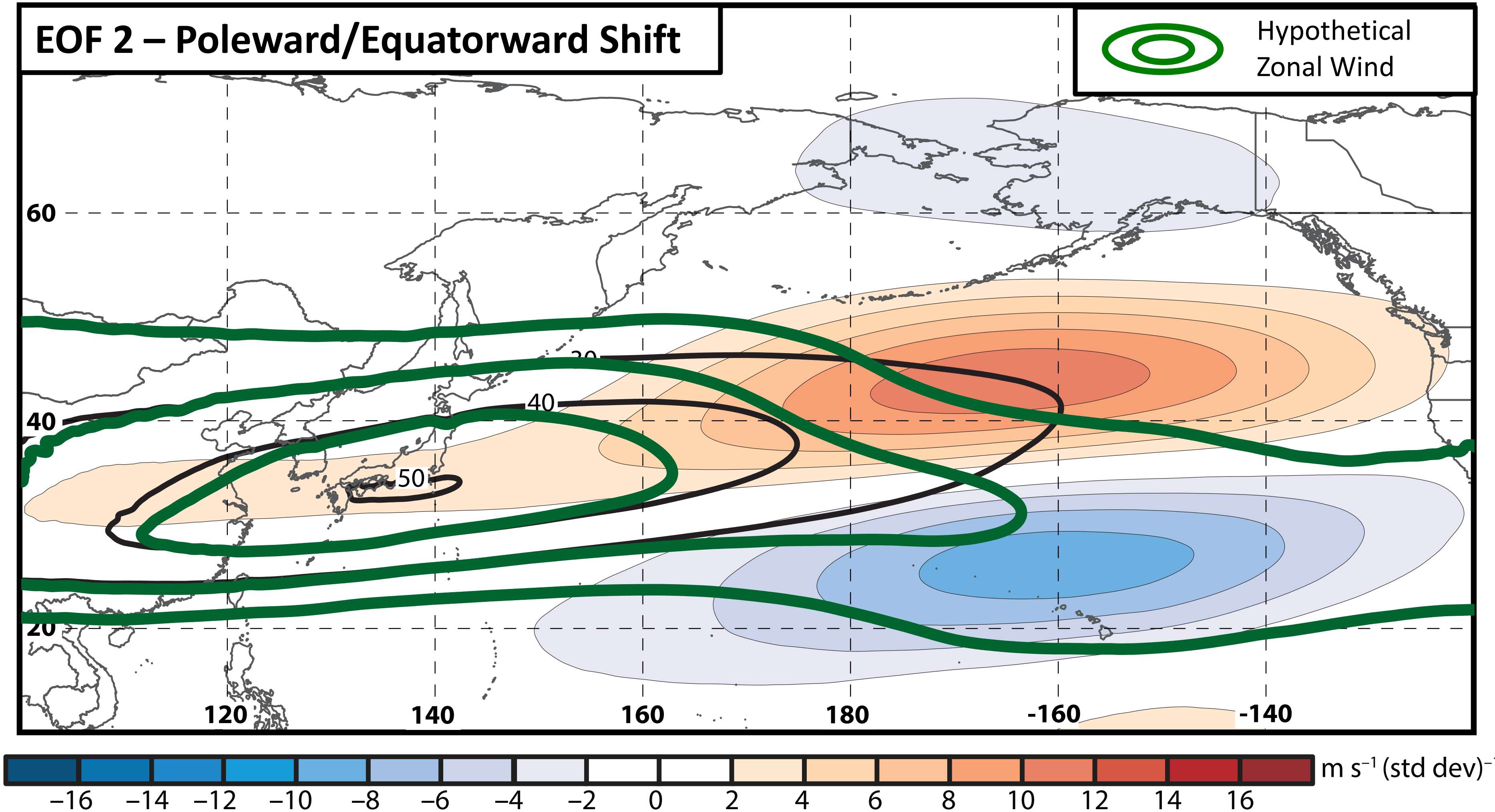

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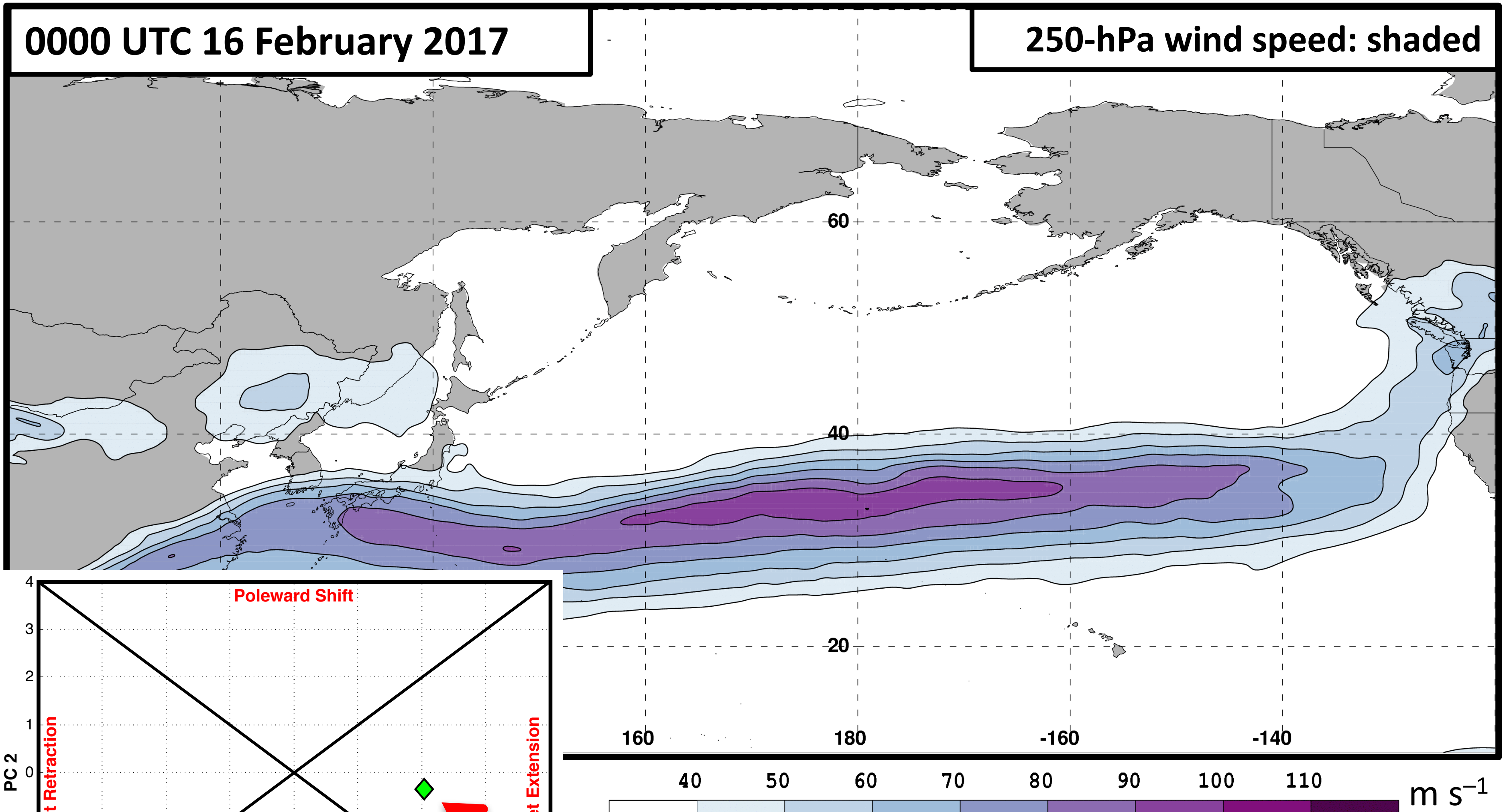
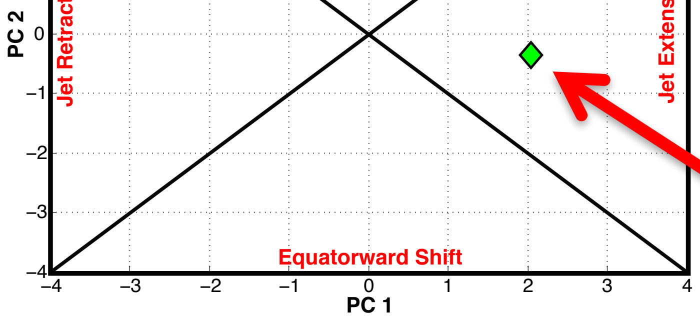
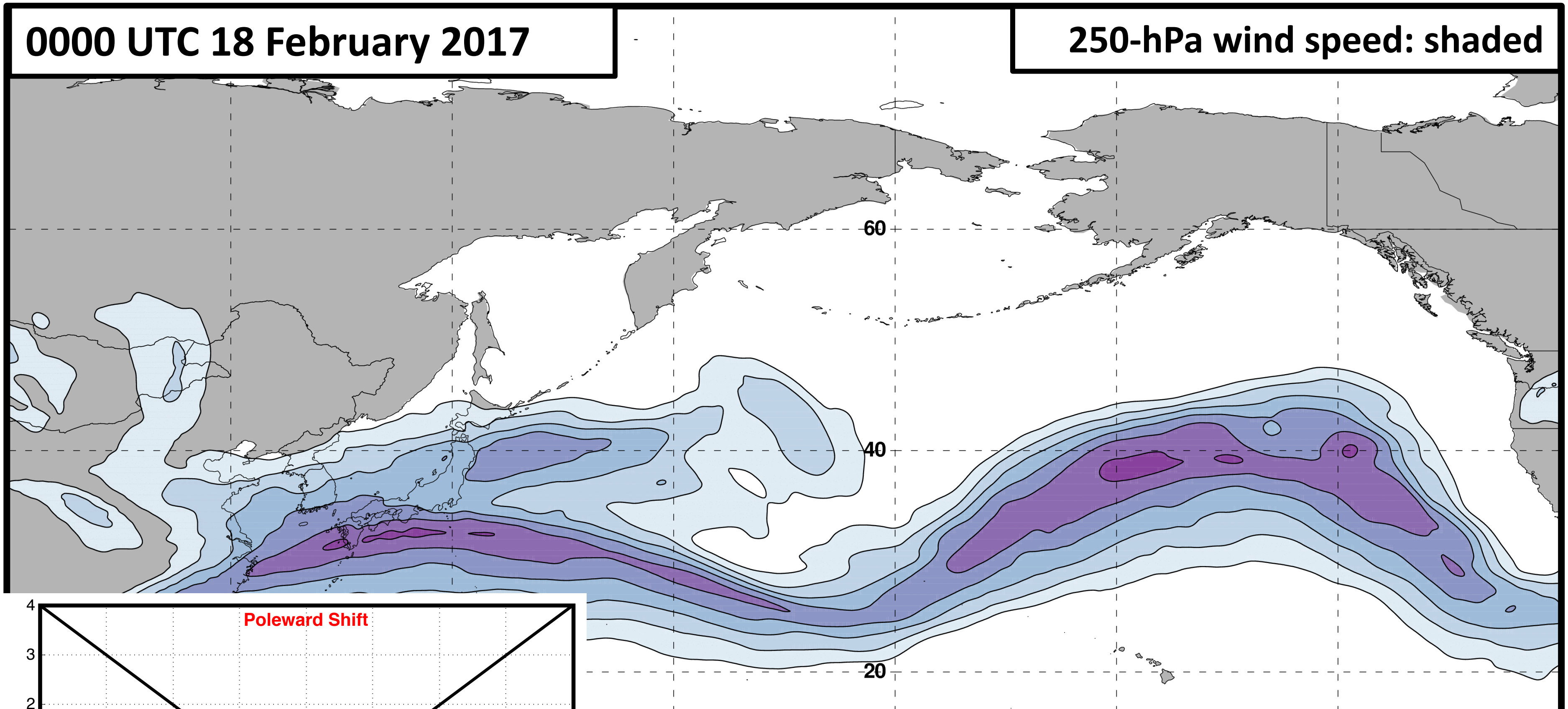
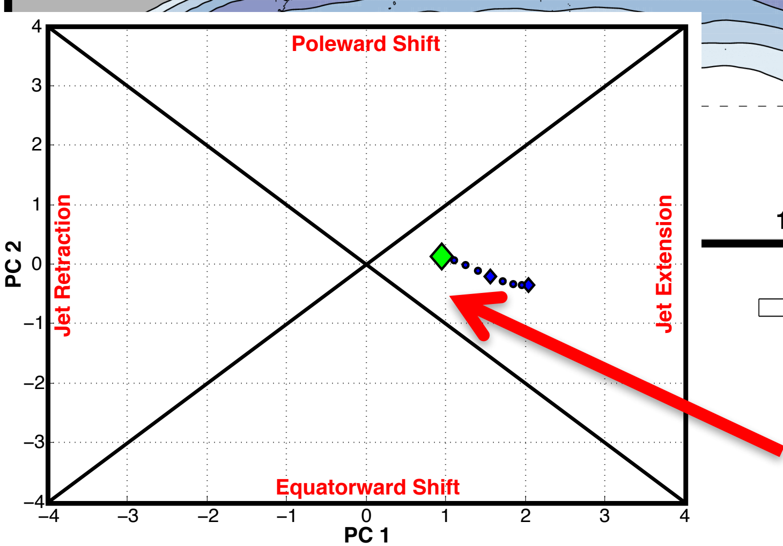




Instantaneous 250-hPa zonal wind anomalies can be projected onto EOF 1 and EOF 2, resulting in a point on an NPJ phase diagram

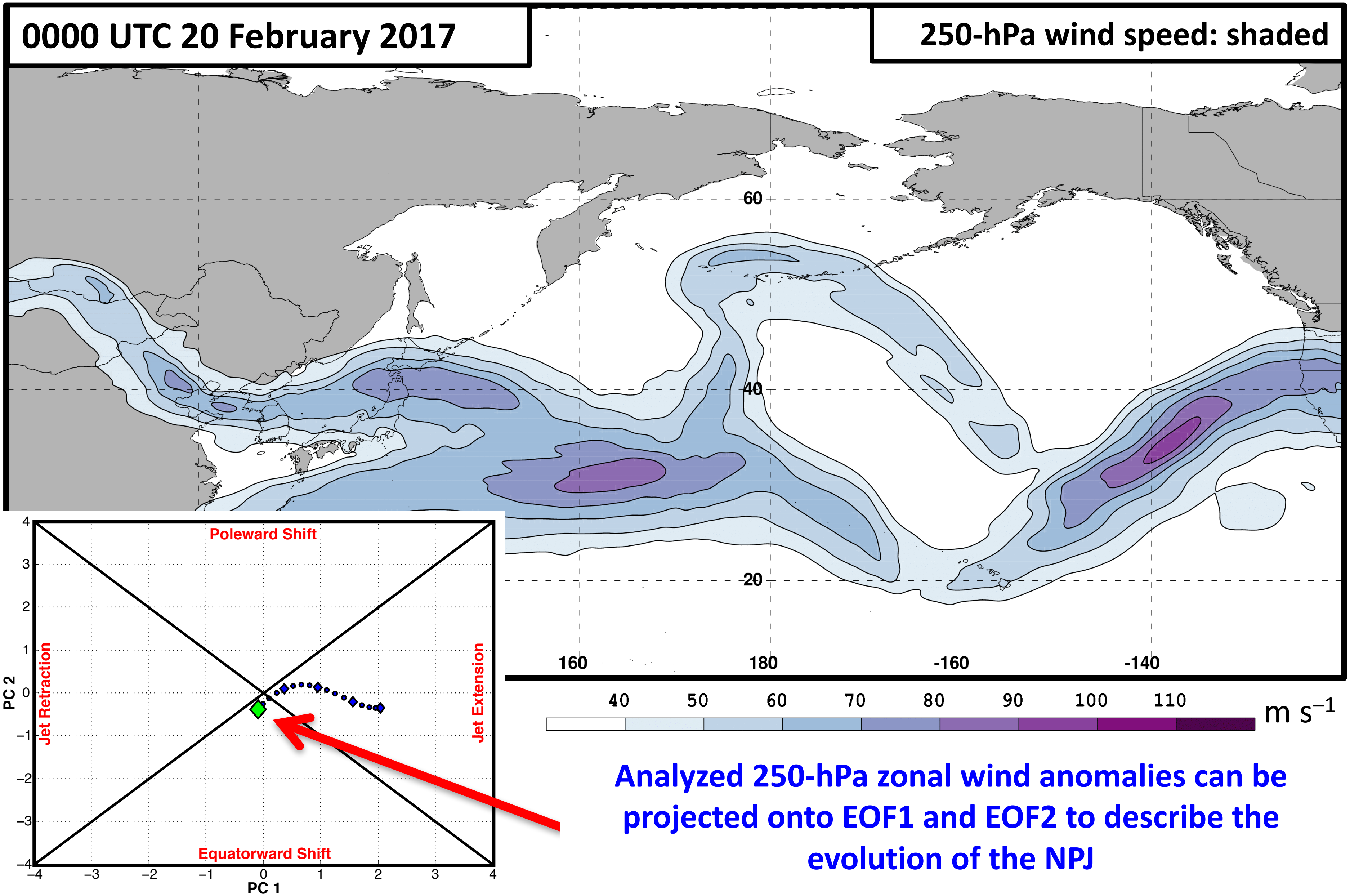
The NPJ Phase Diagram





Analyzed 250-hPa zonal wind anomalies can be projected onto EOF1 and EOF2 to describe the evolution of the NPJ

The NPJ Phase Diagram



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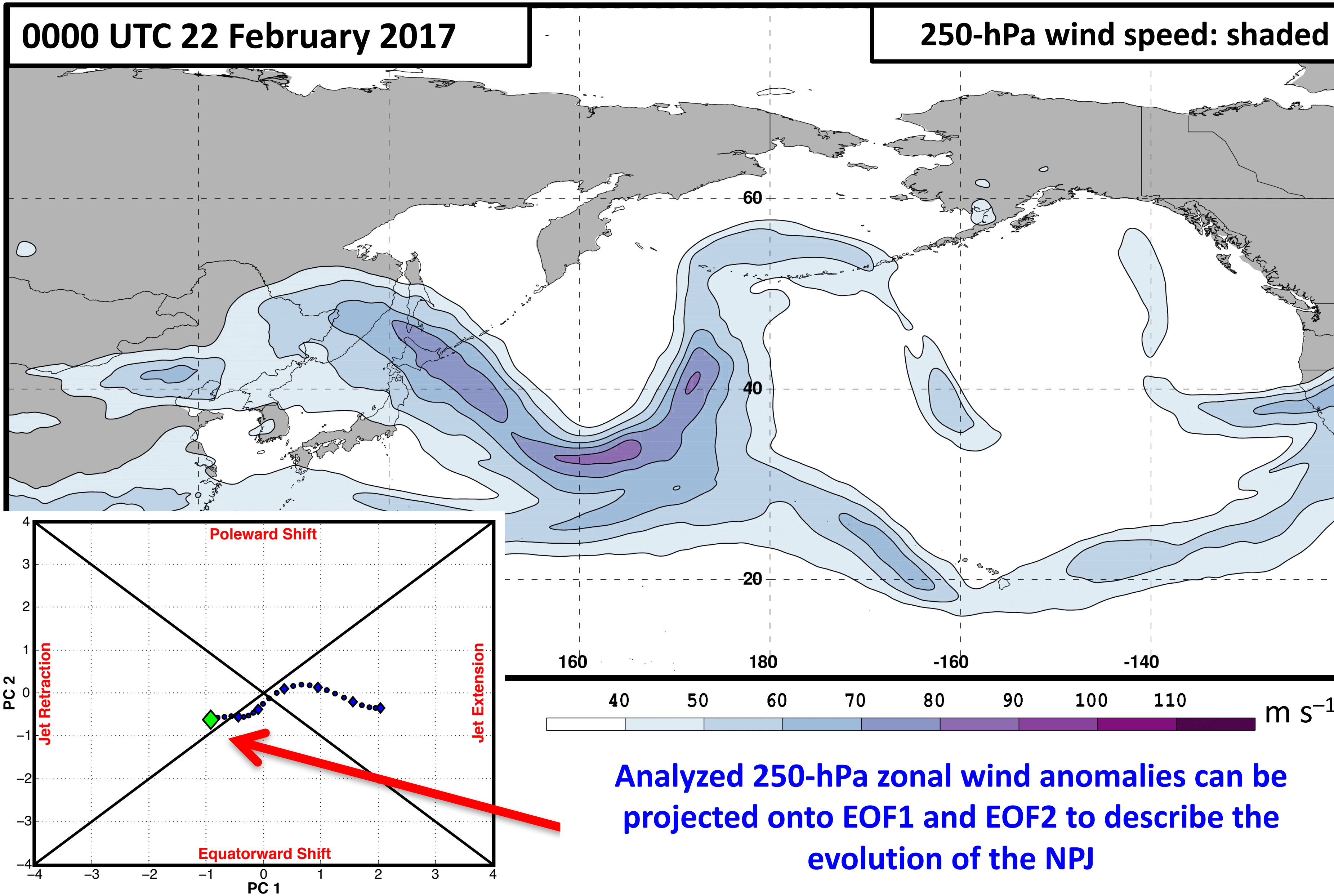

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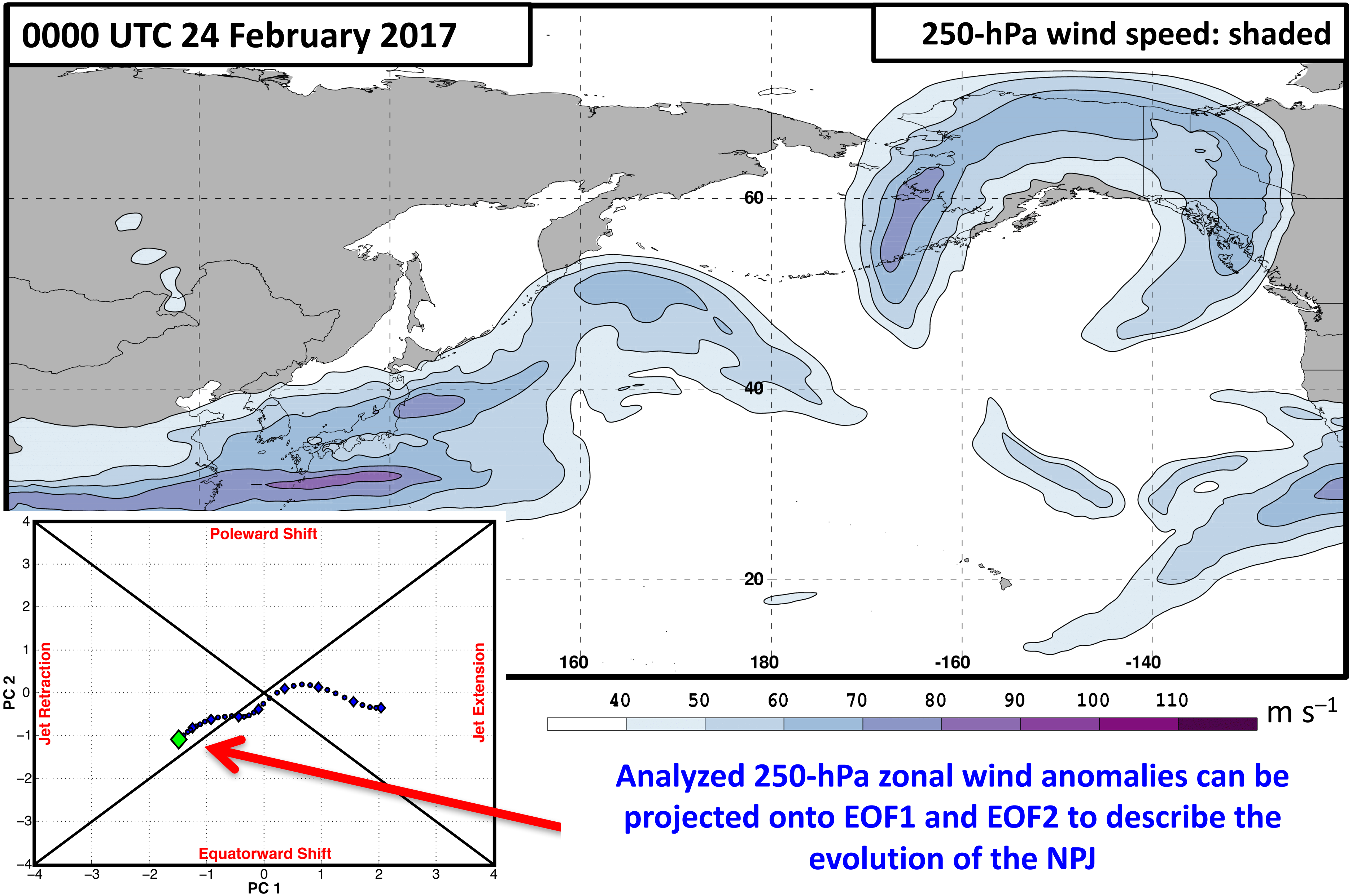

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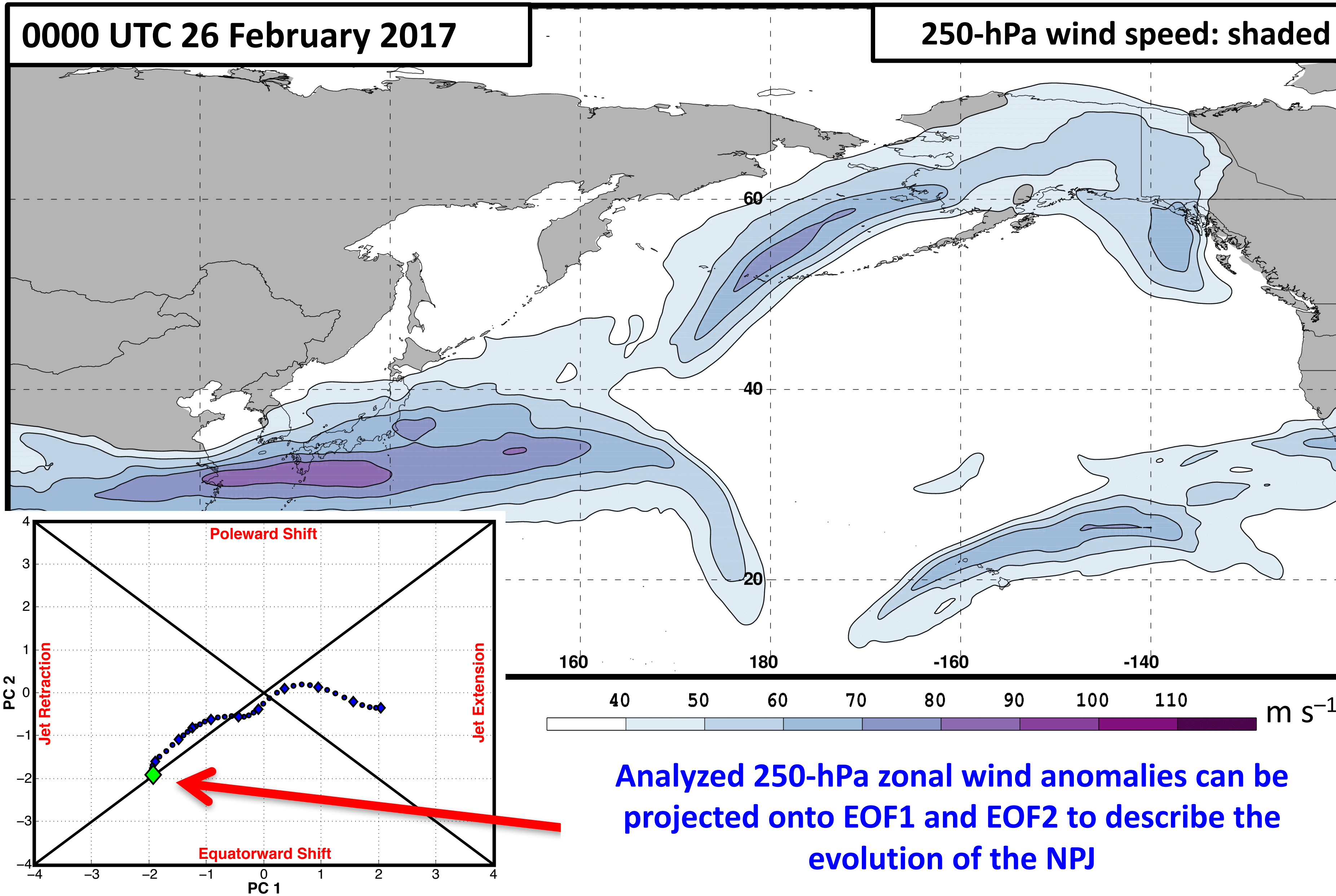
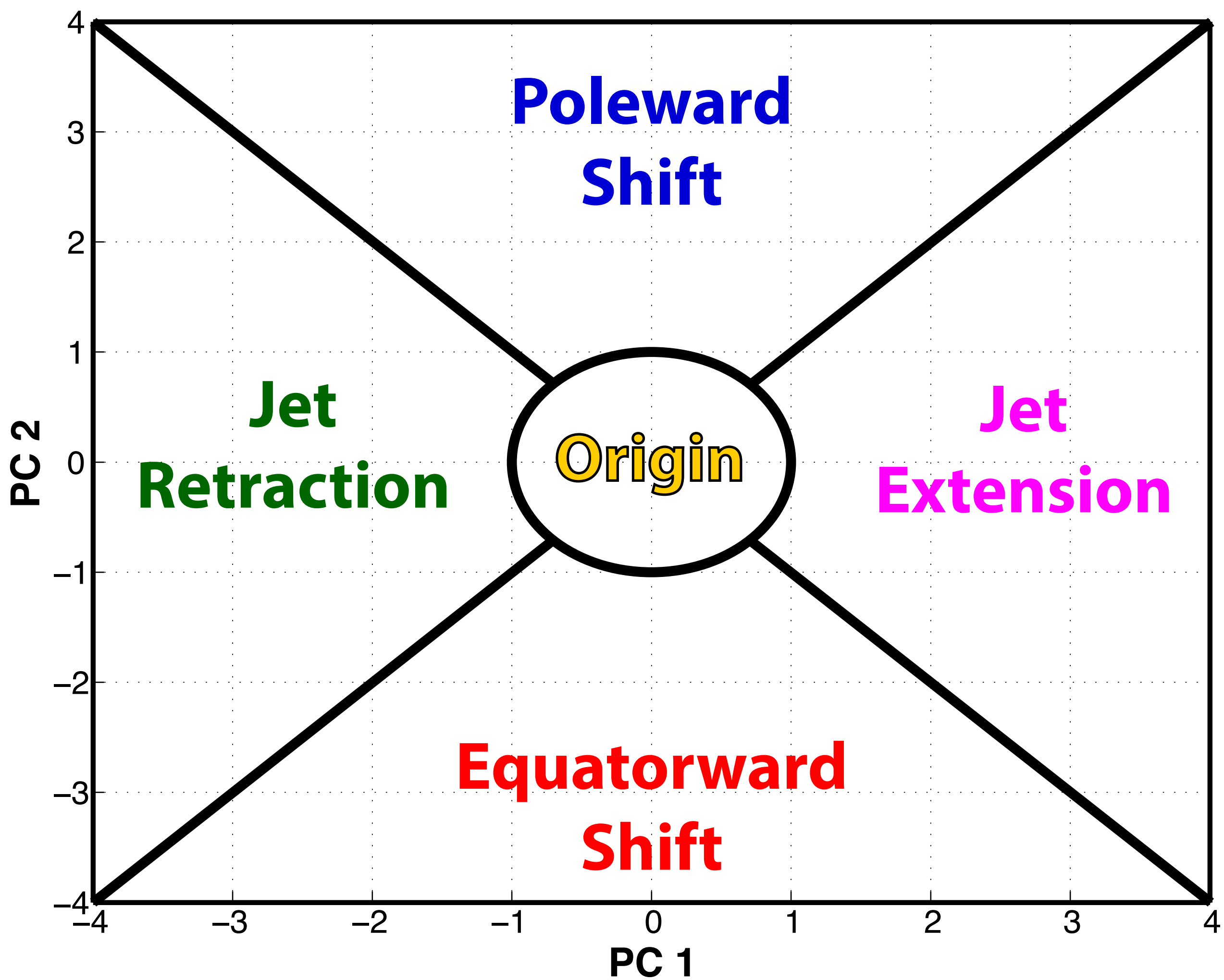


Analyzed 250-hPa zonal wind anomalies can be projected onto EOF1 and EOF2 to describe the evolution of the NPJ

Influence of the Prevailing NPJ Regime on North American Weather

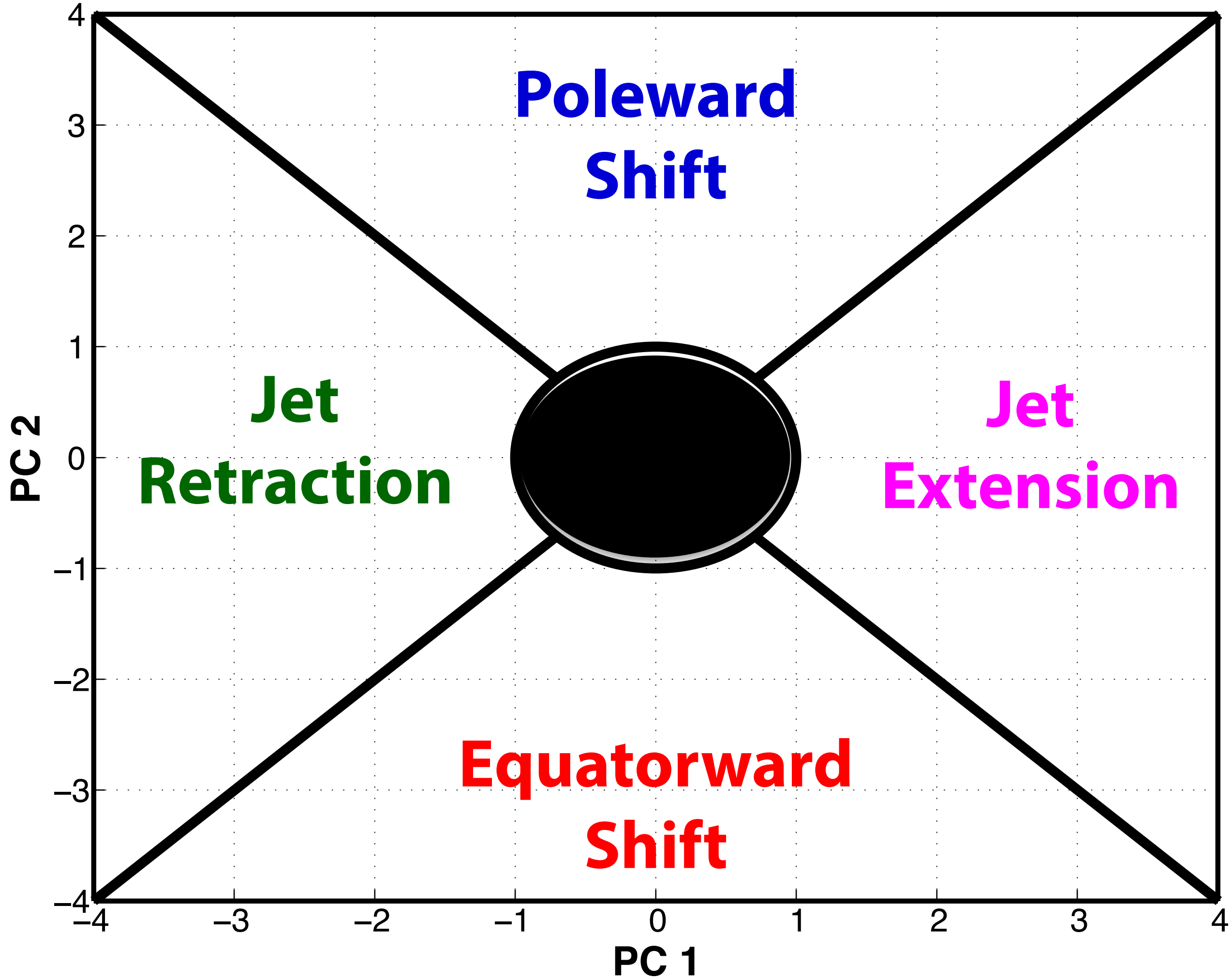
NPJ Regime Composites

Determined the position within the NPJ phase diagram at all analysis times in the CFSR between Sept.–May 1979–2014



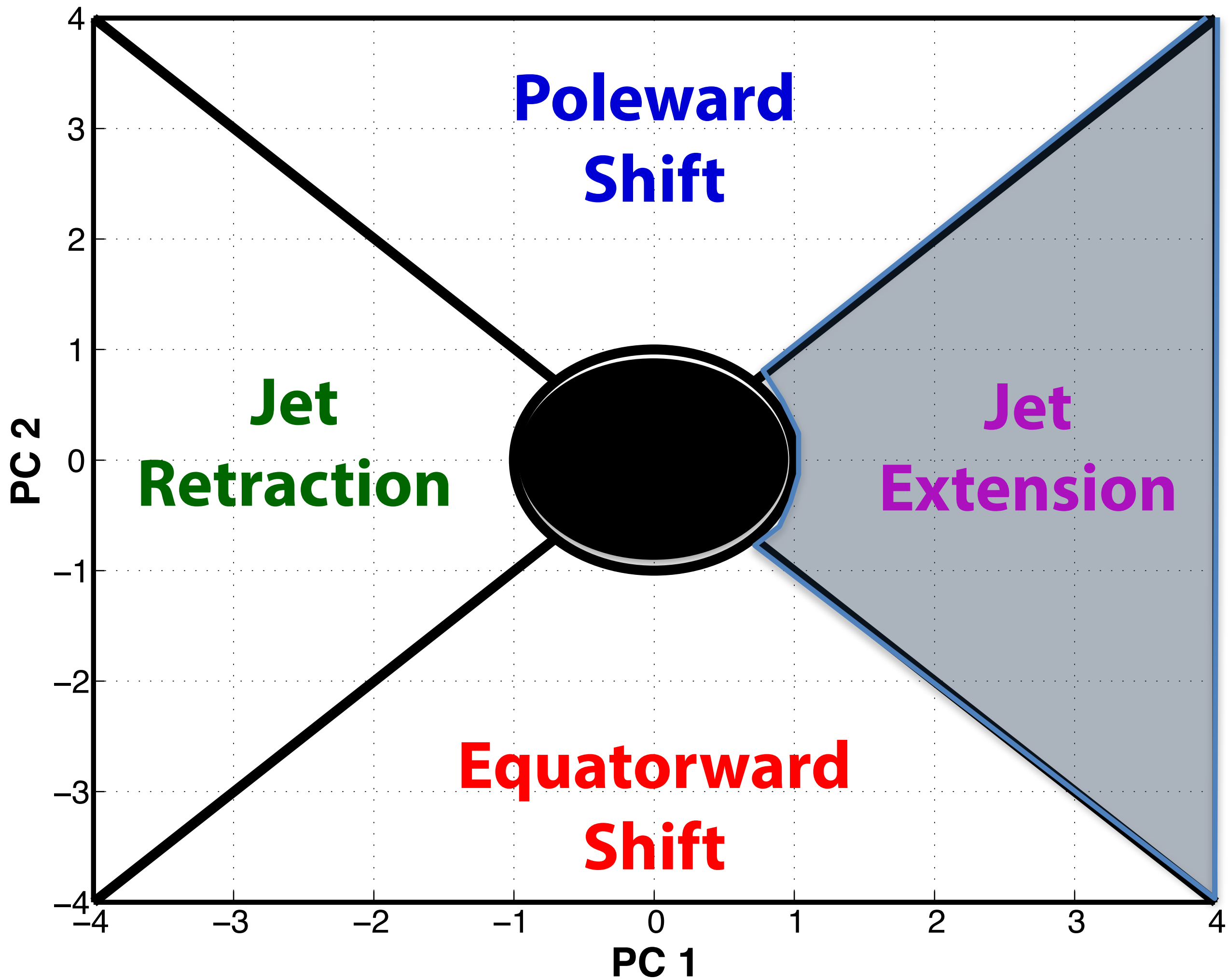
NPJ Regime Composites

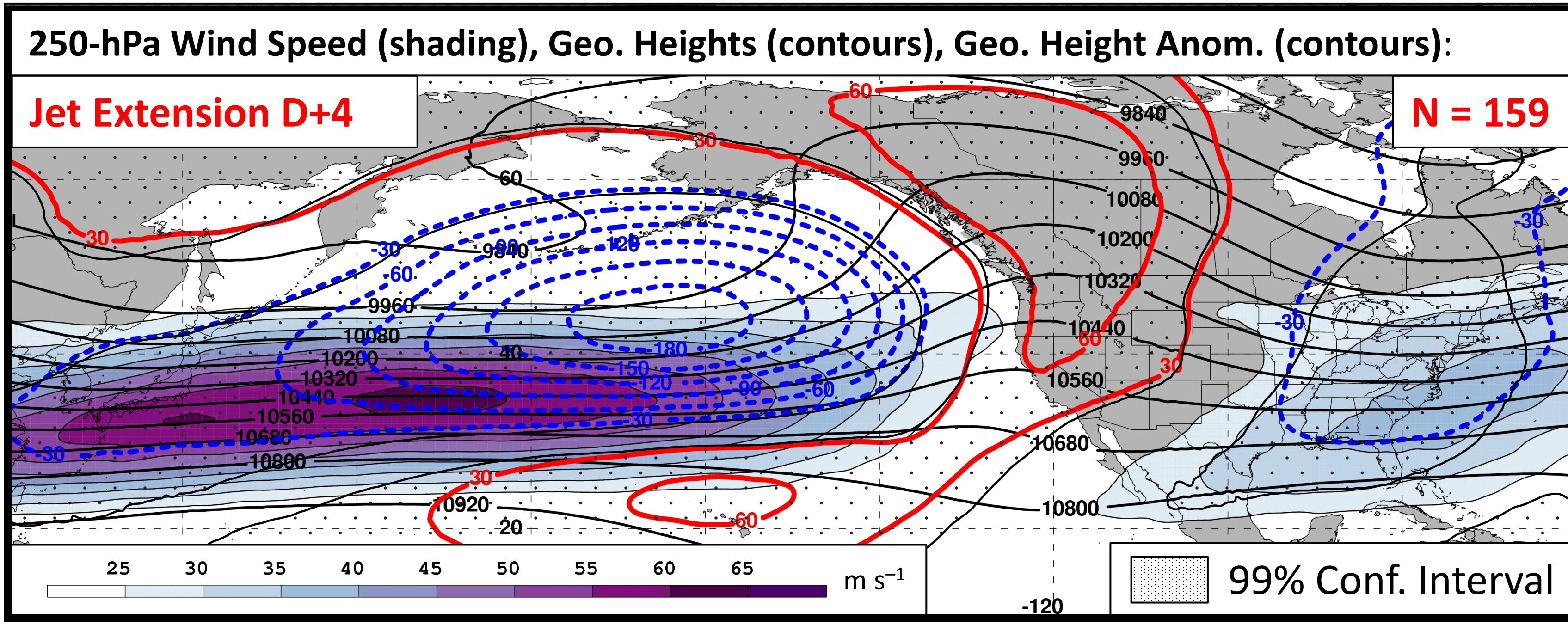
Isolated the analysis times during which there was a strong projection onto one of the four NPJ regimes (i.e., >1 PC unit from the origin)

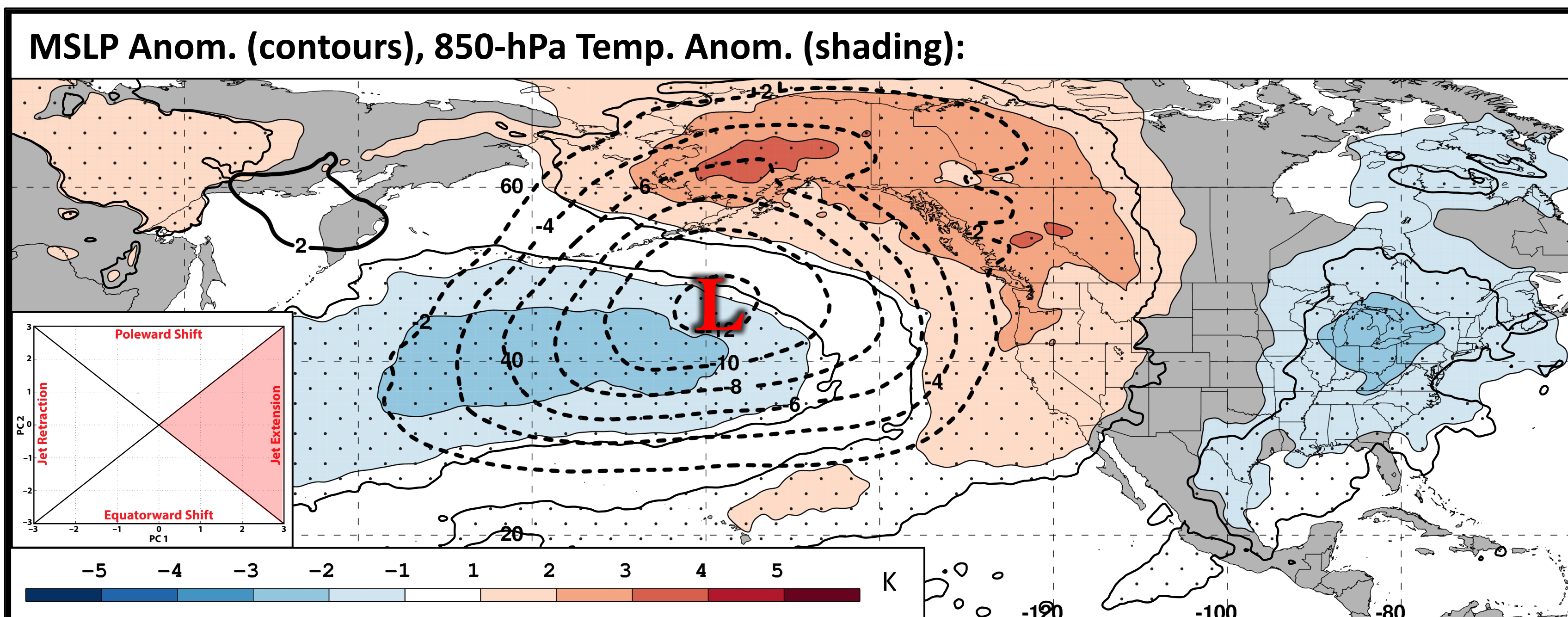


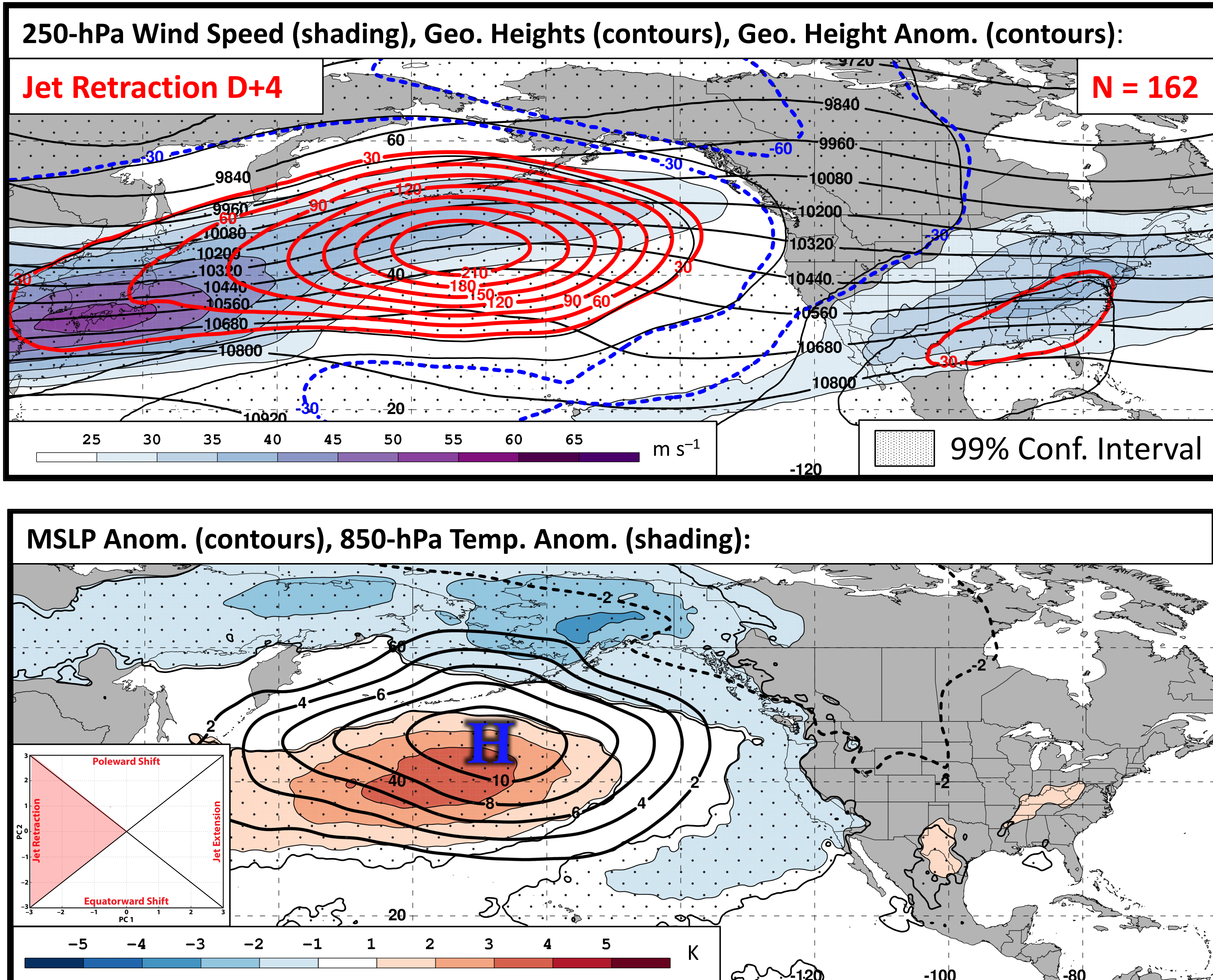
NPJ Regime Composites

Isolated periods during which the NPJ resided within the same quadrant of the NPJ phase diagram for 3 consecutive days




250-hPa Wind Speed (shading), Geo. Heights (contours), Geo. Height Anom. (contours):
Jet Extension D+4
N = 159
25 30 35 40 45 50 55 60 65
m s⁻¹
99% Conf. Interval
9840
9960
10080
10200
10320
10440
10560
10680
10800
10920
-30
-60
-90
-120
-150
-180
30
60
-120


MSLP Anom. (contours), 850-hPa Temp. Anom. (shading):
L
−5 −4 −3 −2 −1 1 2 3 4 5
K
Poleward Shift
Equatorward Shift
Jet Retraction
Jet Extension
PC 1
PC 2
-120
-100
-80



250-hPa Wind Speed (shading), Geo. Heights (contours), Geo. Height Anom. (contours):
Jet Retraction D+4
N = 162
9720
9840
9960
10080
10200
10320
10440
10560
10680
10800
10920
60
40
20
-120
30
60
90
120
150
180
210
-30
-60
25
30
35
40
45
50
55
60
65
m s^{-1}
99% Conf. Interval
MSLP Anom. (contours), 850-hPa Temp. Anom. (shading):
H
2
4
6
8
10
-2
60
40
20
Poleward Shift
Equatorward Shift
Jet Retraction
Jet Extension
PC 1
PC 2
−5
−4
−3
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−1
1
2
3
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K
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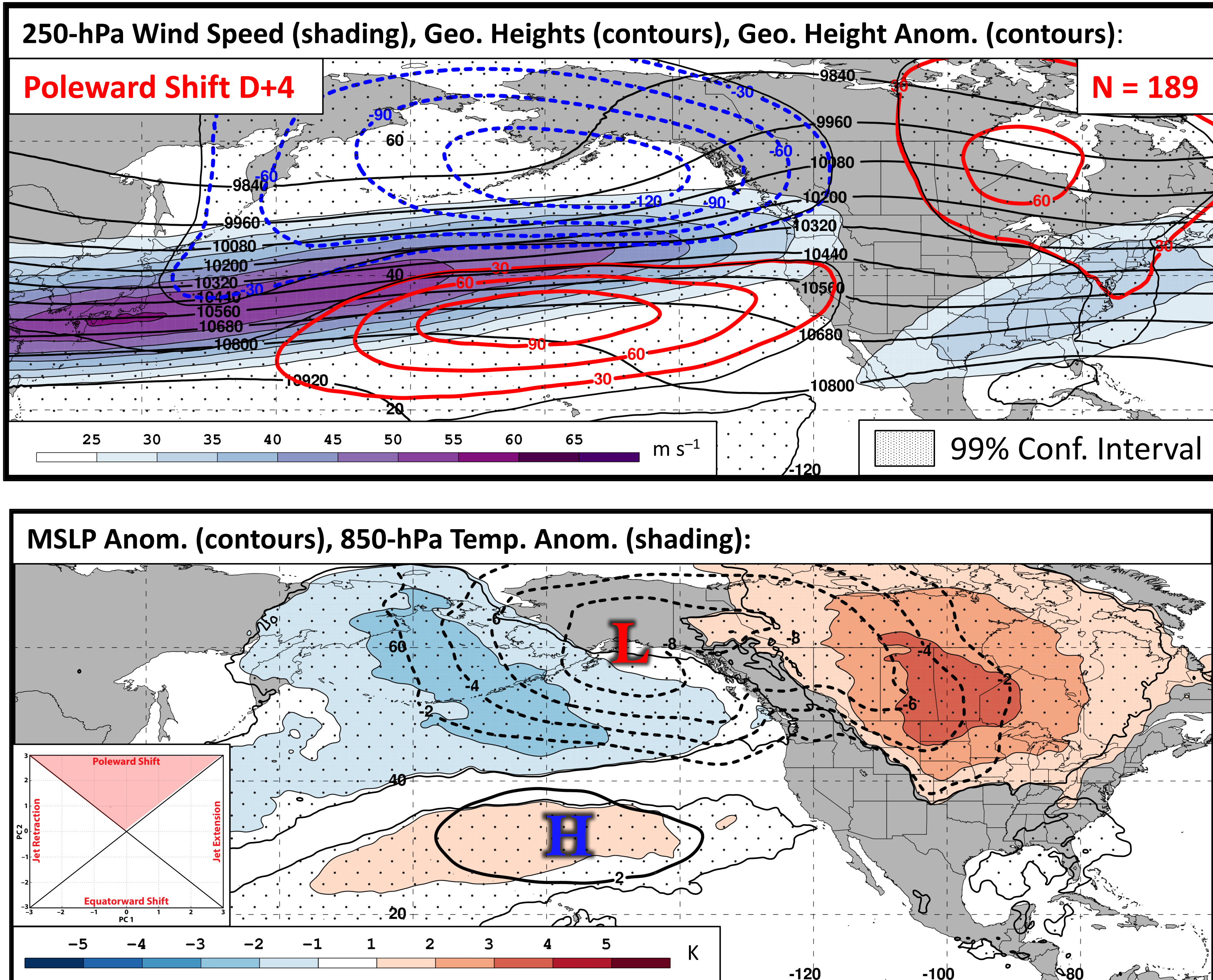

250-hPa Wind Speed (shading), Geo. Heights (contours), Geo. Height Anom. (contours):
Poleward Shift D+4
N = 189
m s⁻¹
99% Conf. Interval
MSLP Anom. (contours), 850-hPa Temp. Anom. (shading):
L
H
Poleward Shift
Jet Retraction
Jet Extension
Equatorward Shift
PC 1
PC 2
K
-120
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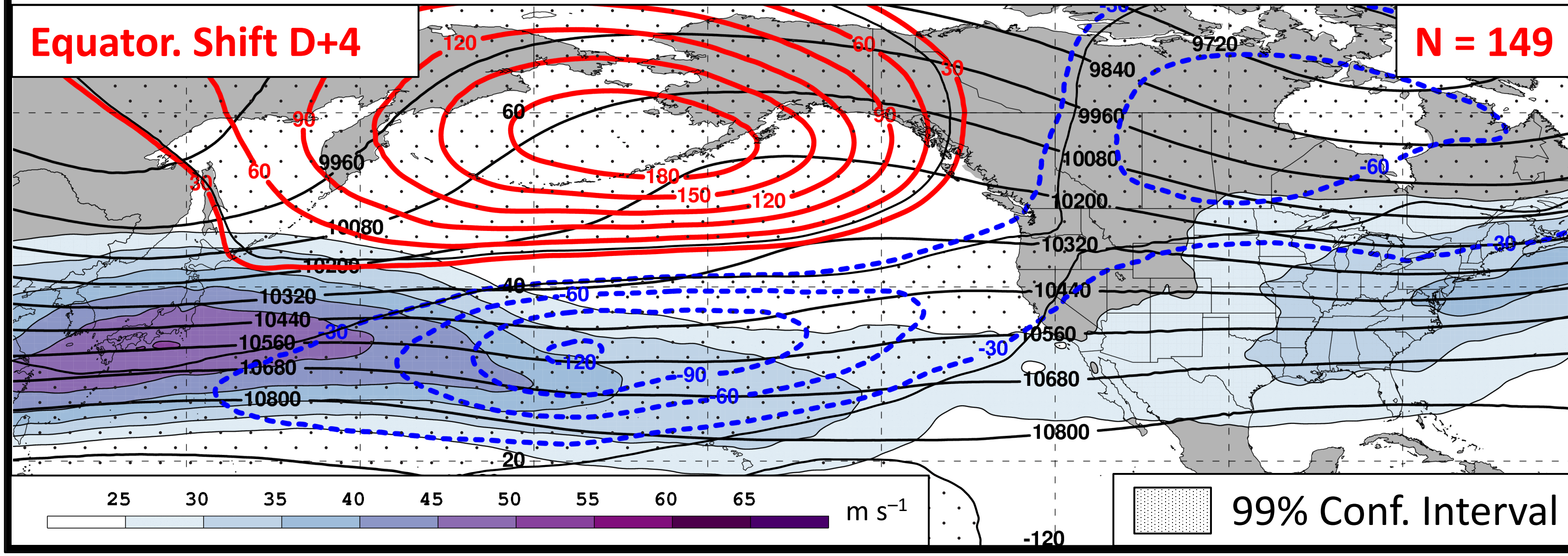
-80

250-hPa Wind Speed (shading), Geo. Heights (contours), Geo. Height Anom. (contours):



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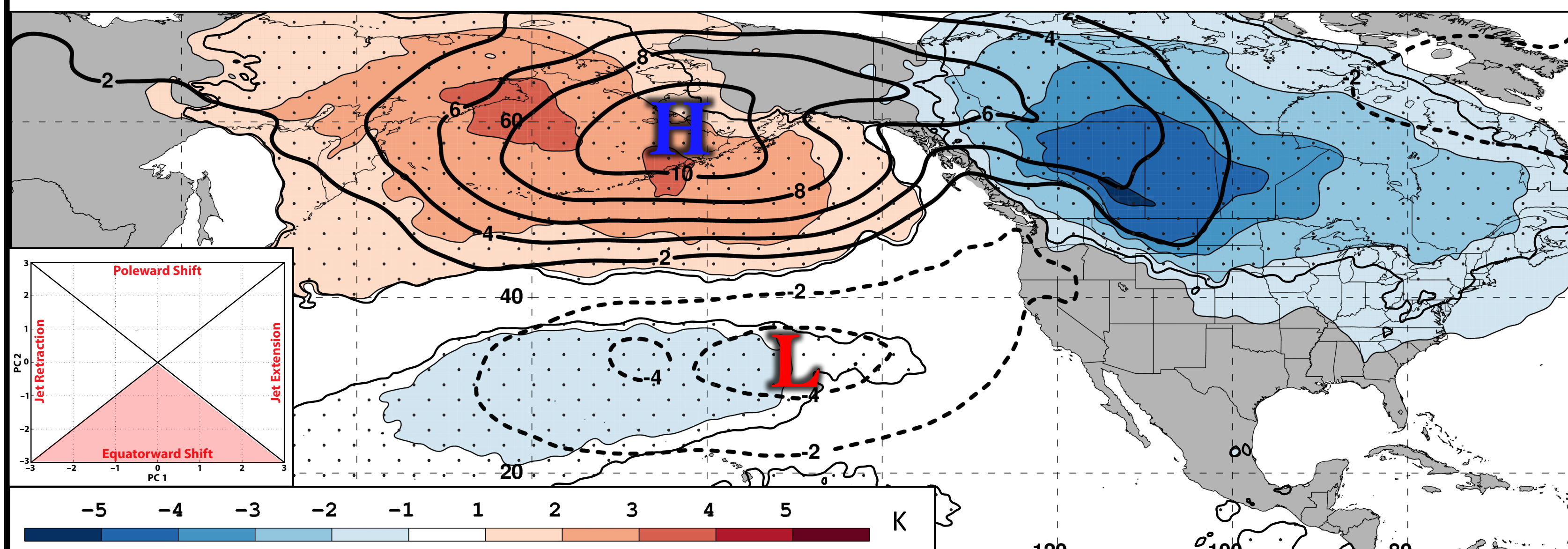
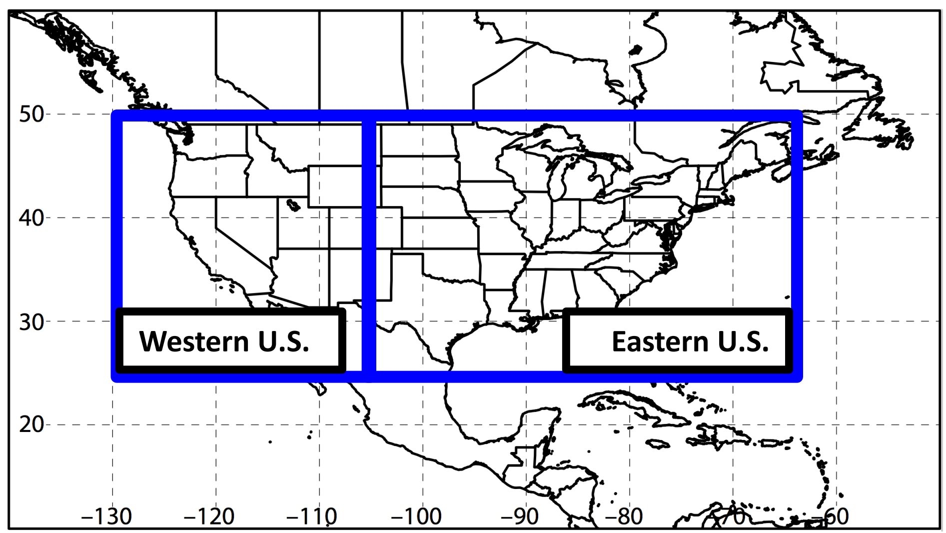


NPJ Regime Characteristics

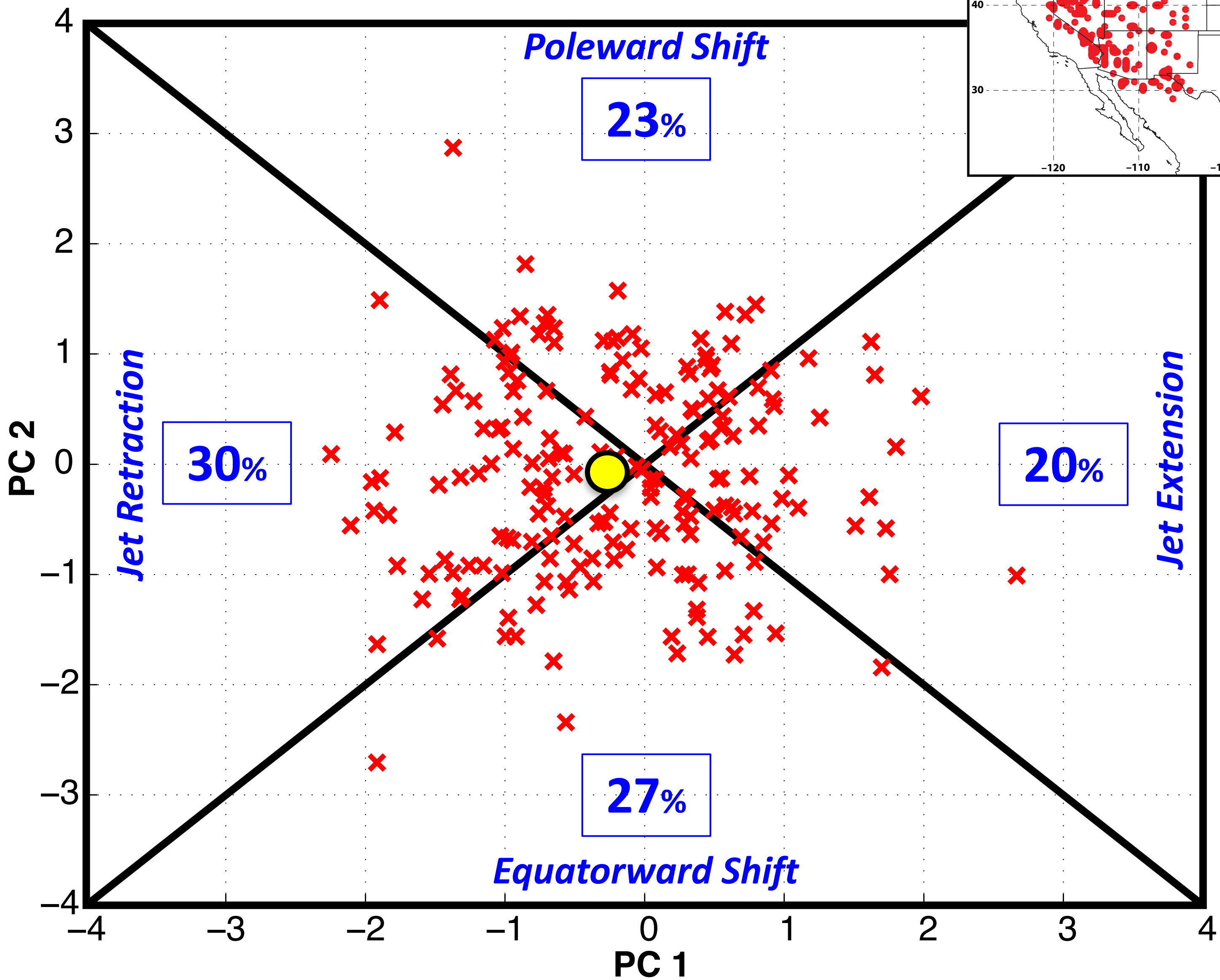
Extreme Temperature Events:

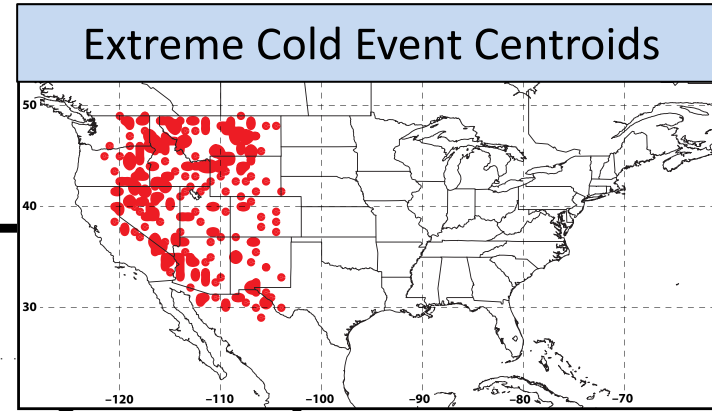
- Employed 1-h forecasts of 2-m temperature from the CFSR (0.5°× 0.5°) at 6-h intervals during 1979–2014 (Saha et al. 2014)
- Compiled times during which at least one grid point was characterized by a temperature **< 1st percentile** or **> 99th percentile** within separate domains over the western and eastern U.S.
- Identified times that ranked in the **top 5%** in terms of the number of grid points **< 1st percentile** or **> 99th percentile** as extreme temperature events



Western U.S. – All Events

EXTREME COLD EVENTS (N = 196)



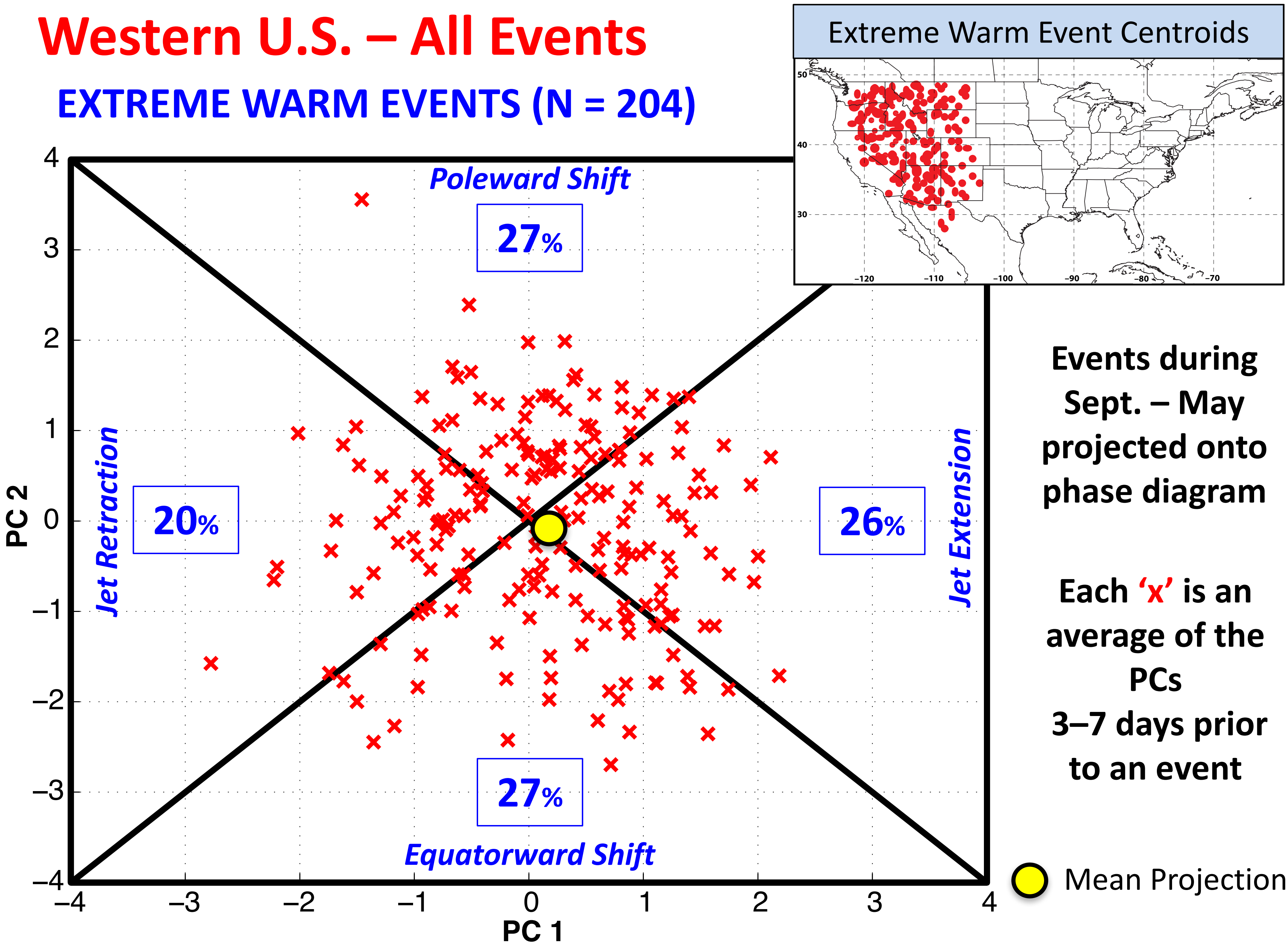


Events during Sept. – May projected onto phase diagram

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

Western U.S. – All Events

EXTREME WARM EVENTS (N = 204)



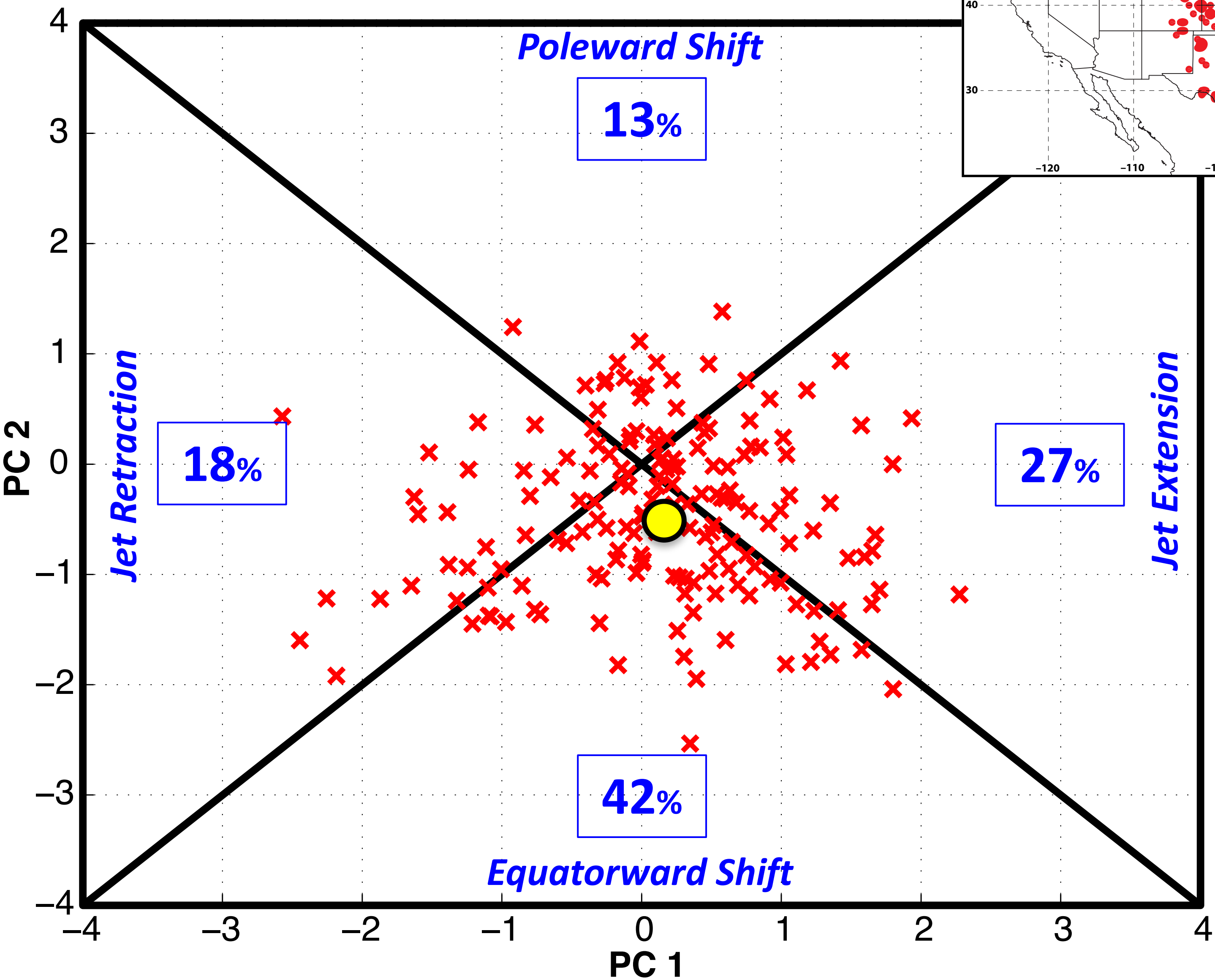
Events during Sept. – May projected onto phase diagram

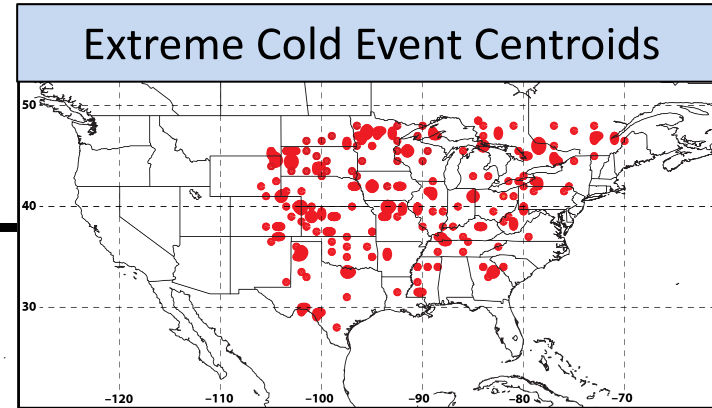
Each 'x' is an average of the PCs 3–7 days prior to an event

Mean Projection

Eastern U.S. – All Events

EXTREME COLD EVENTS (N = 173)





Events during Sept. – May projected onto phase diagram

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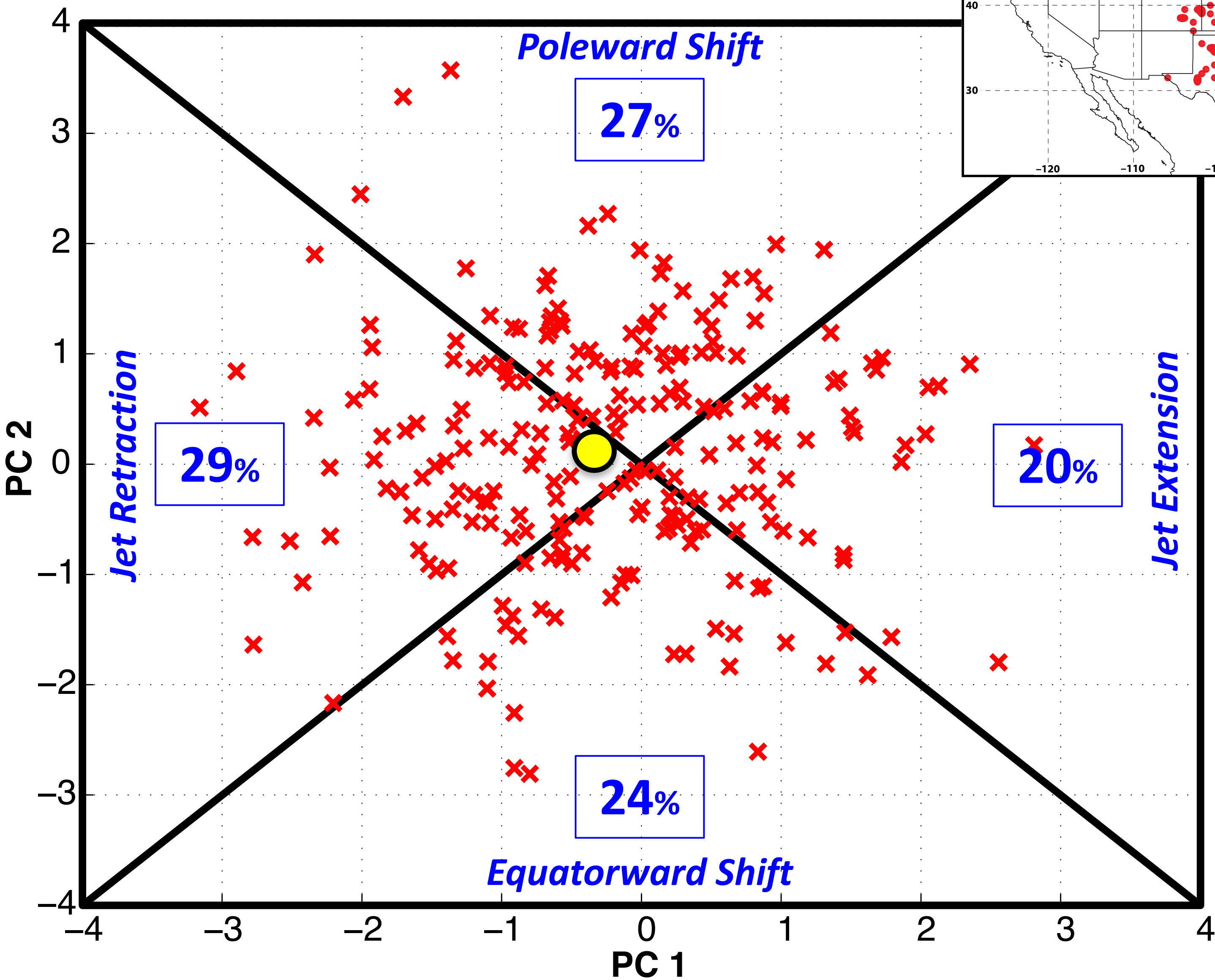
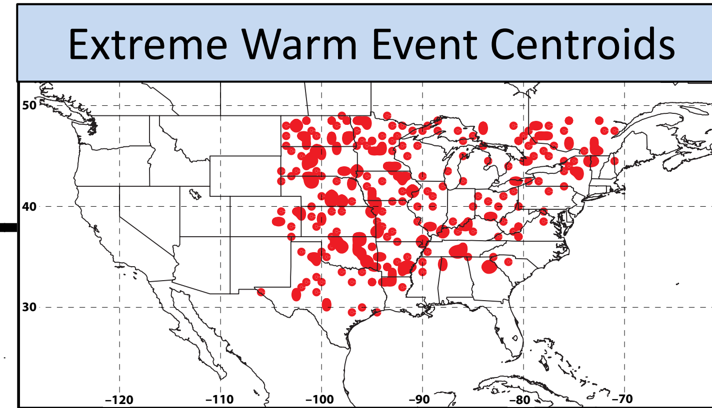
Mean Projection

Eastern U.S. – All Events

EXTREME WARM EVENTS (N = 239)





Events during Sept. – May projected onto phase diagram

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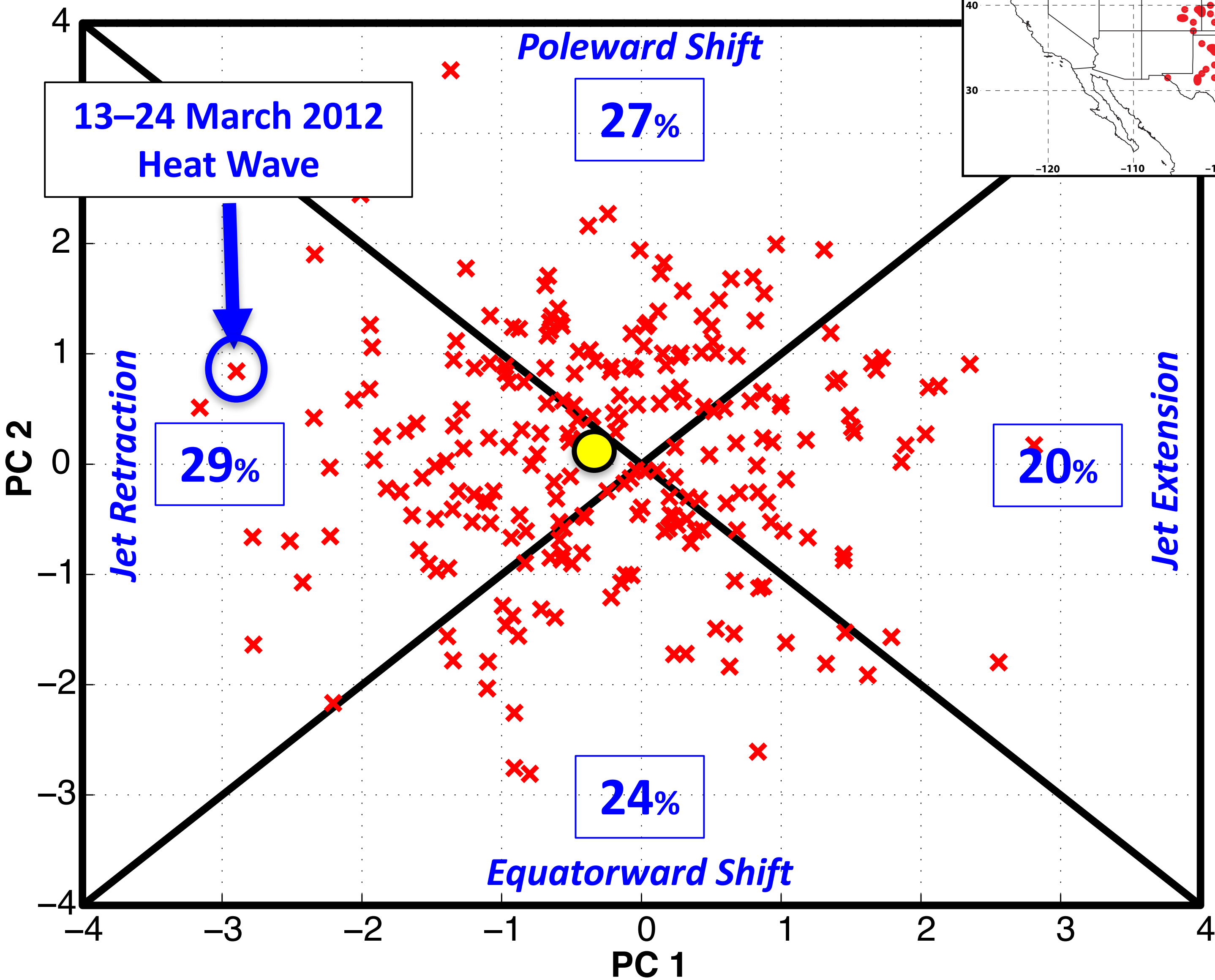
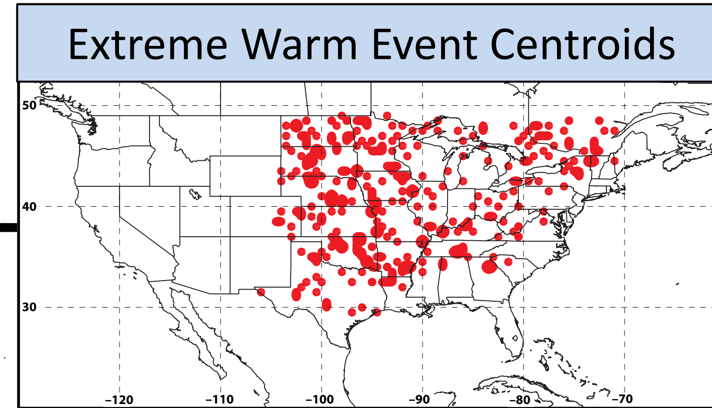
Eastern U.S. – All Events

EXTREME WARM EVENTS (N = 239)





Events during Sept. – May projected onto phase diagram

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Mean Projection

March 2012 Heat Wave

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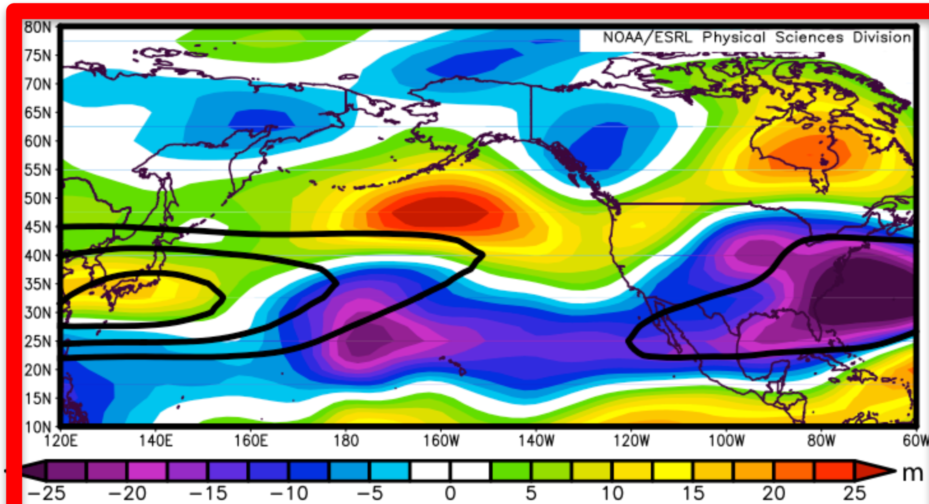

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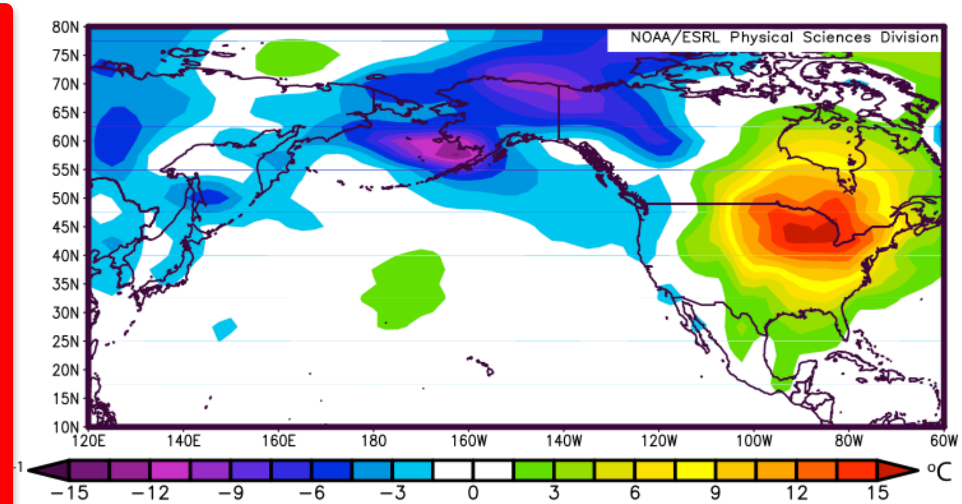
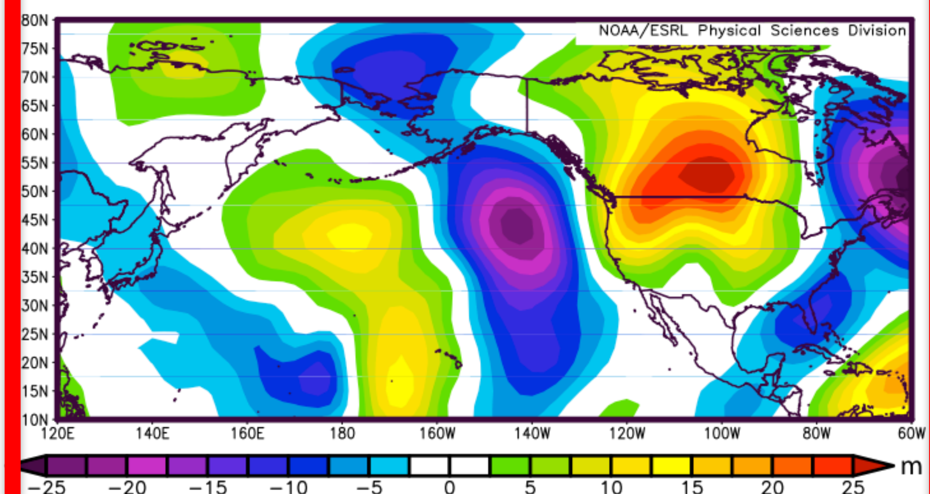


250-hPa V-Wind Anomalies (13–24 March 2012)



- Surface temperature anomalies exceeded 15°C in the Upper-Midwest
- **The North Pacific Jet (NPJ) was shifted poleward and characterized by an amplified flow pattern**

Summary: NPJ Regime Characteristics

- The NPJ phase diagram is a tool that objectively characterizes the state and evolution of the upper-tropospheric flow pattern over the North Pacific

- The NPJ phase diagram characterizes the relationship between each NPJ regime and the downstream flow pattern over North America

- The NPJ phase diagram illuminates the variability that characterizes the antecedent environments associated with continental U.S. extreme temperature events

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- The NPJ phase diagram characterizes the relationship between each NPJ regime and the downstream flow pattern over North America

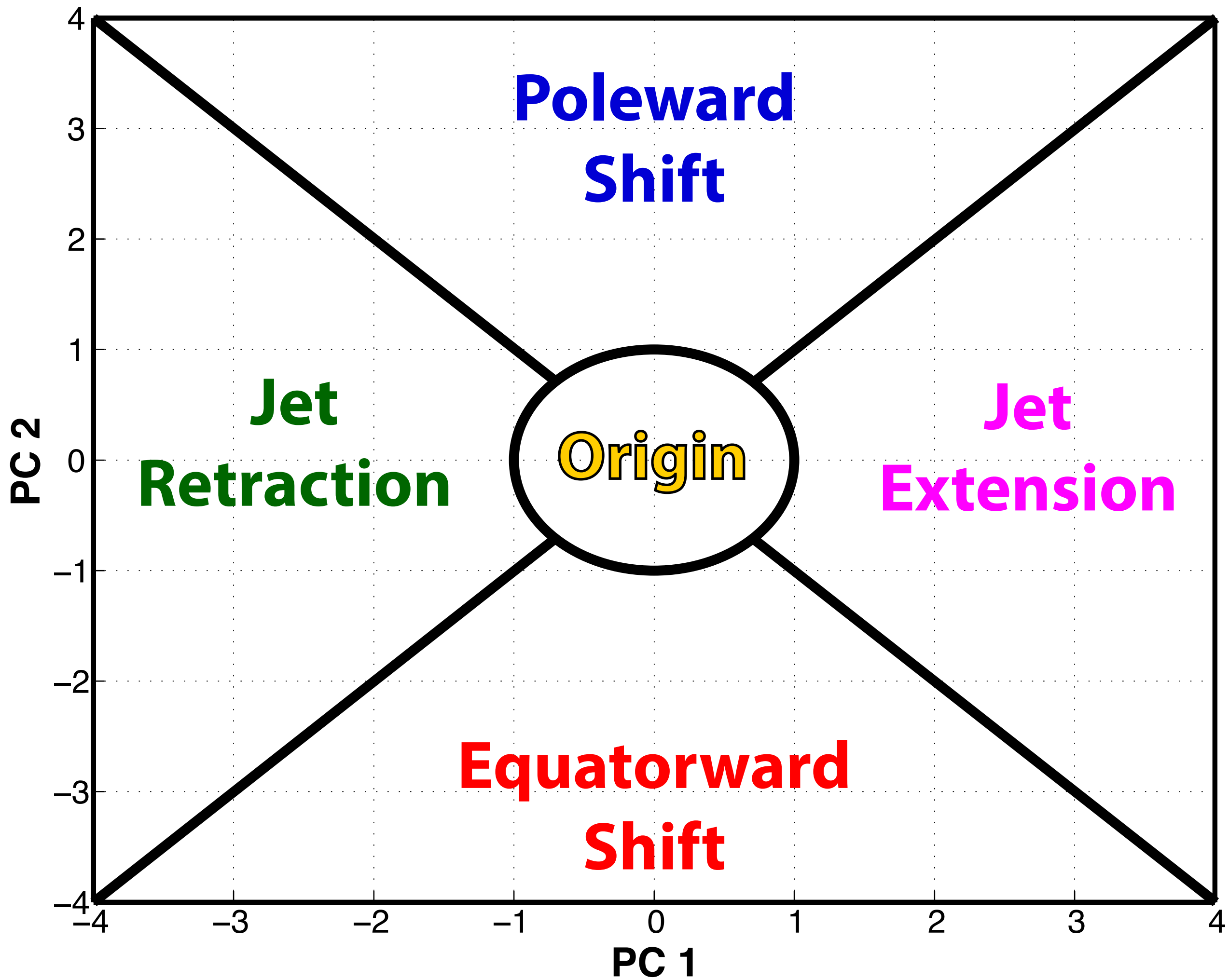
- The NPJ phase diagram illuminates the variability that characterizes the antecedent environments associated with continental U.S. extreme temperature events

- **Knowledge of both the downstream upper-tropospheric flow pattern and forecast skill associated with each NPJ regime offers the potential to increase confidence in operational temperature forecasts over the continental U.S.**

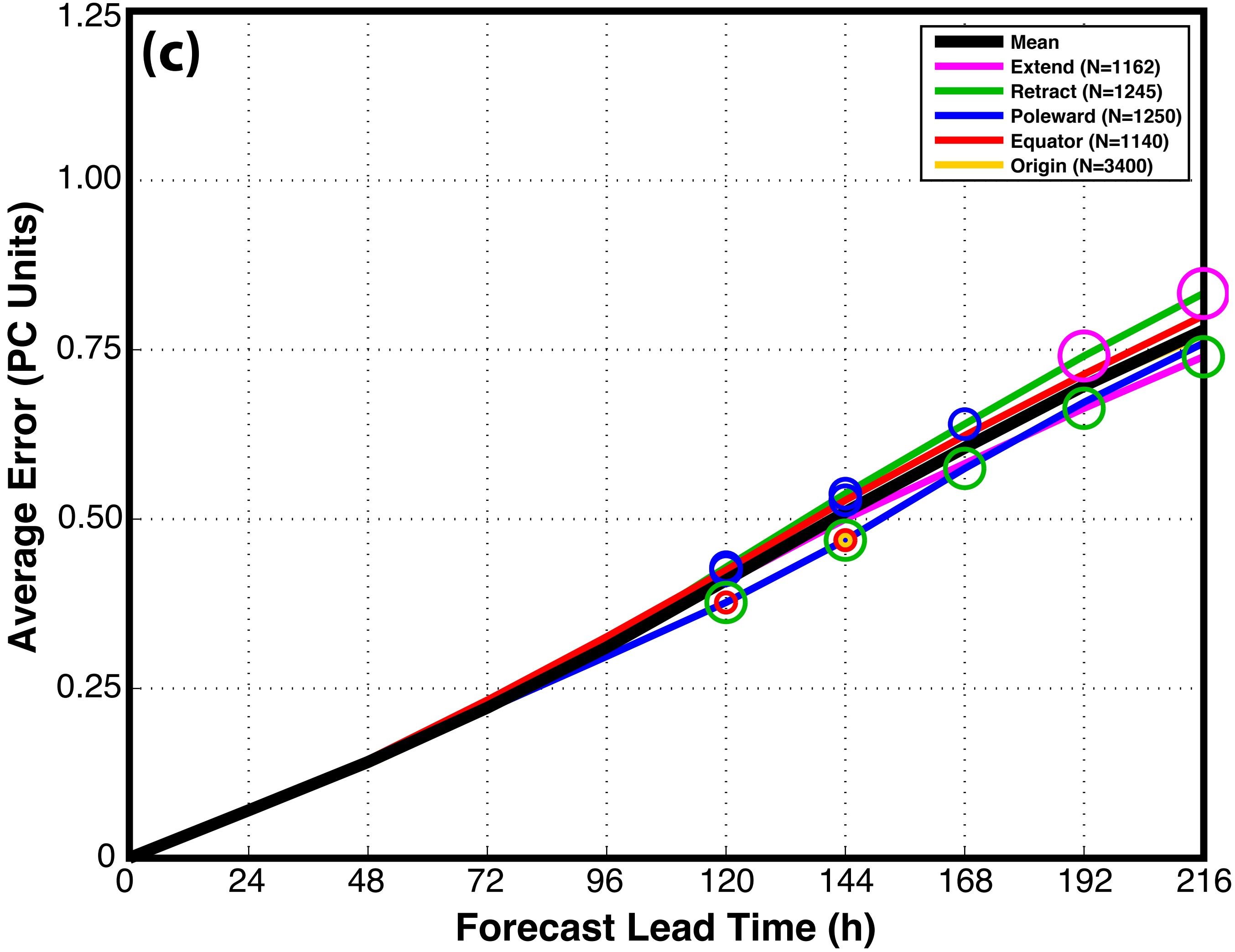
GEFS Forecast Skill in the Context of the NPJ Phase Diagram

NPJ Phase Diagram Forecast Skill

Determined the position within the NPJ phase diagram for all 0-h forecasts during Sept.–May 1985–2014 in the GEFS Reforecast v2 (Hamill et al. 2013)



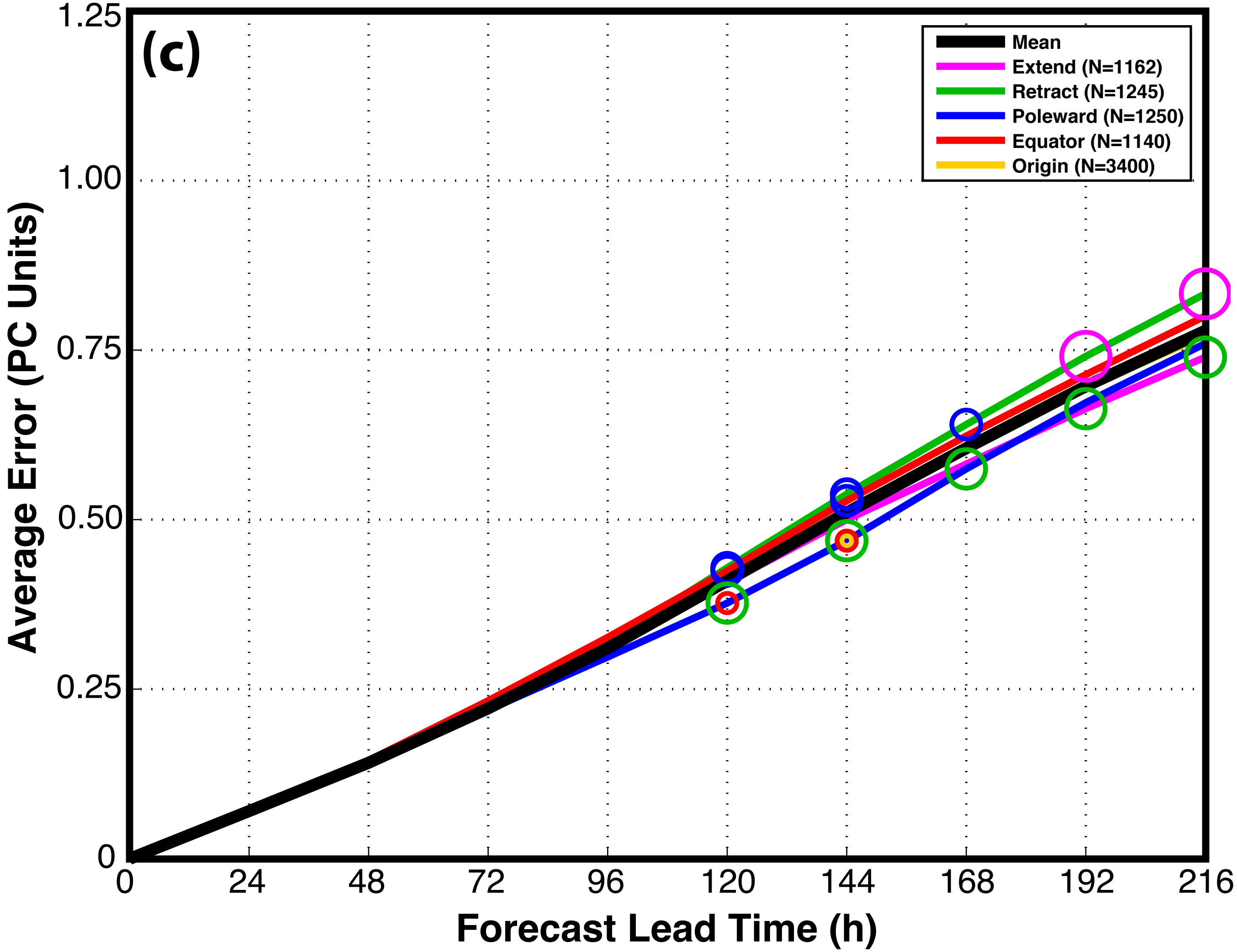
GEFS Ensemble Mean Error by NPJ Regime



GEFS Reforecasts *initialized* during a particular NPJ regime

Circles on a particular line indicate statistically significant differences at the 99% confidence level with respect to another NPJ regime

GEFS Ensemble Mean Error by NPJ Regime

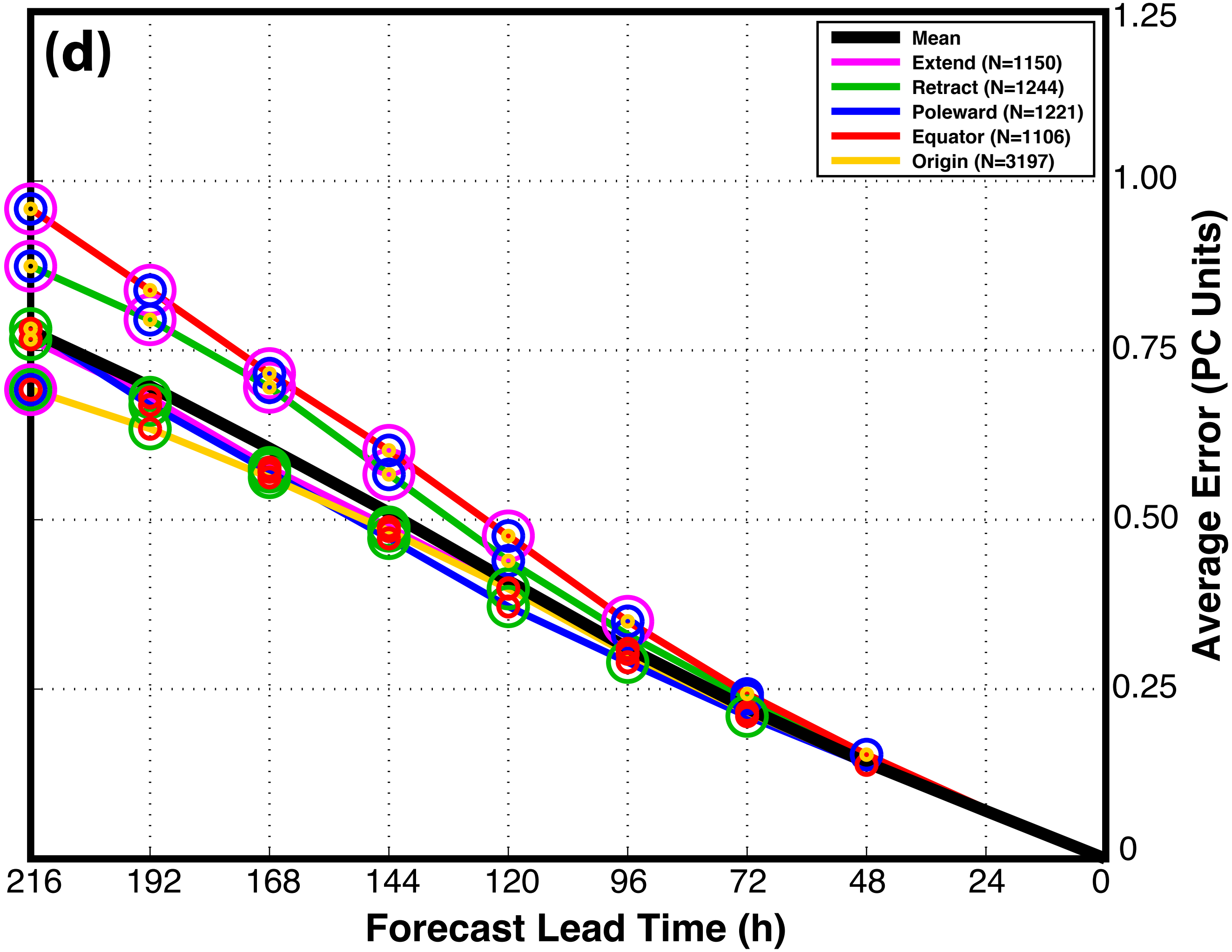


GEFS Reforecasts *initialized* during a particular NPJ regime

Circles on a particular line indicate statistically significant differences at the 99% confidence level with respect to another NPJ regime

Forecasts initialized during **jet retractions** exhibit significantly larger errors than **jet extensions** in the 192–216-h forecast period

GEFS Ensemble Mean Error by NPJ Regime



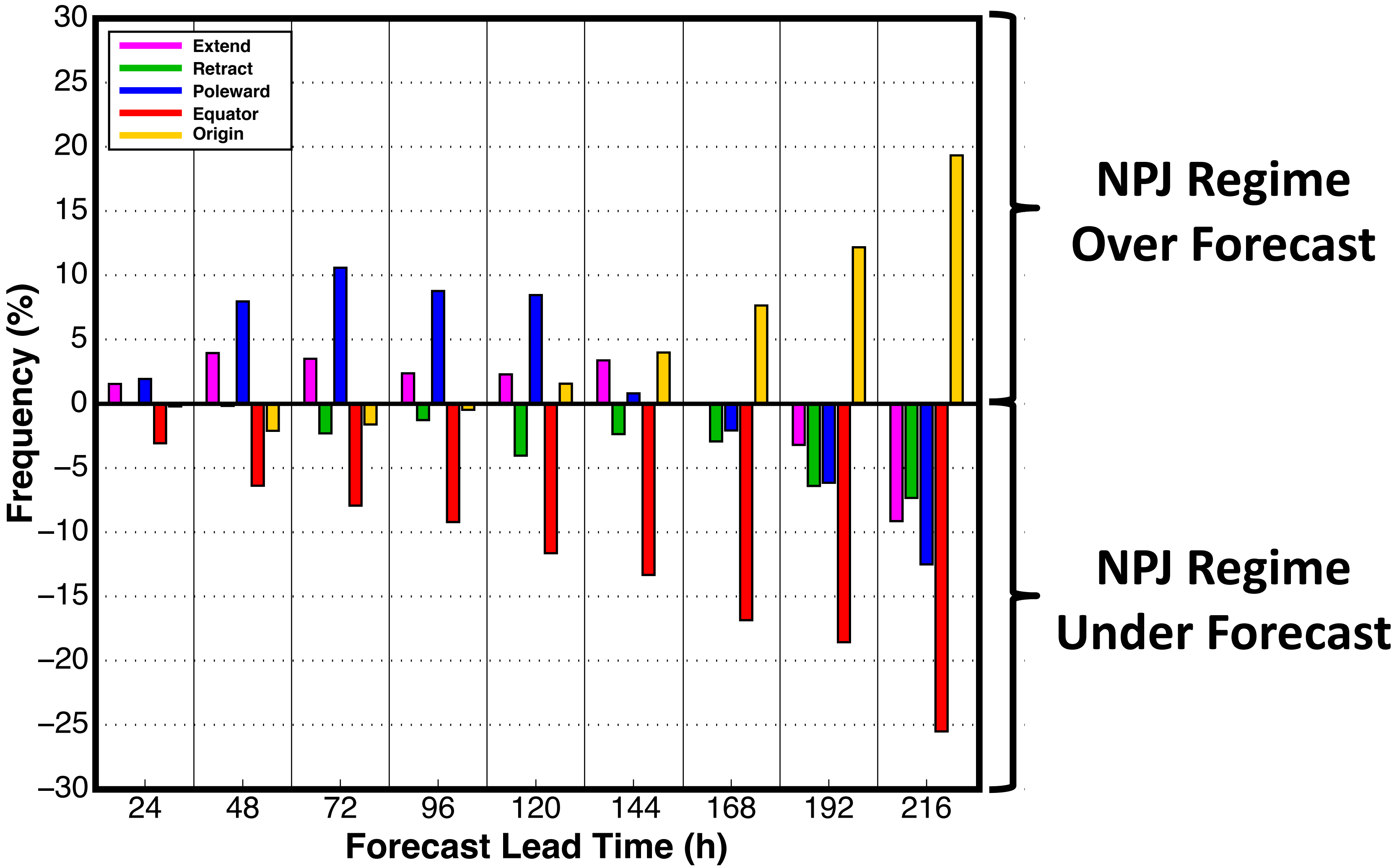
GEFS Reforecasts *verifying* during a particular NPJ regime

Circles on a particular line indicate statistically significant differences at the 99% confidence level with respect to another NPJ regime

Forecasts verifying during **equatorward shifts** and **jet retractions** exhibit significantly larger errors than **jet extensions** and **poleward shifts** in the 96–216-h forecast period

NPJ Regime Forecast Frequency

The percent frequency that an NPJ regime is over/under forecast relative to verification at various forecast lead times in the GEFS ensemble mean reforecasts



Best/Worst NPJ Phase Diagram Forecasts

Comparison between the periods characterized by the best/worst medium-range forecasts

Criteria: Forecasts must rank in the top/bottom 10% in terms of *both*:

(1) The average GEFS ensemble mean error in the Day 8 and 9 forecasts

(2) The average GEFS ensemble member error in the Day 8 and 9 forecasts

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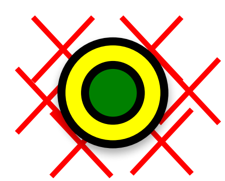
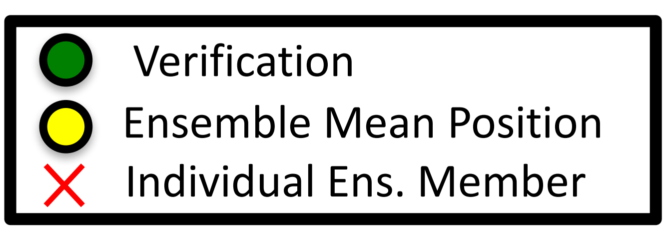
Hypothetical Best Forecast





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Represents a forecast with negligible ensemble mean error

(1) Ens. Mean error ≈ 0 ✓

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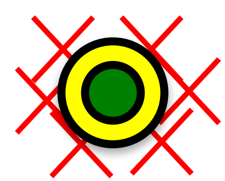

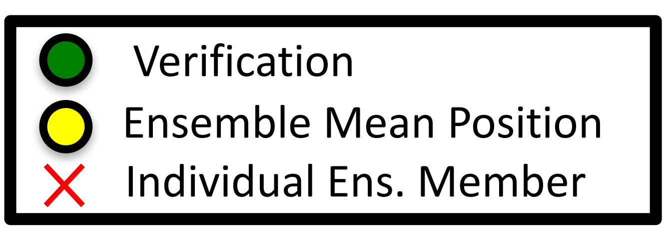

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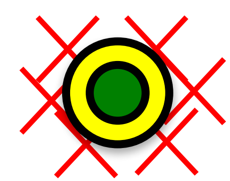
Hypothetical Best Forecast



Verification

Ensemble Mean Position

Individual Ens. Member

Best/Worst NPJ Phase Diagram Forecasts

Comparison between the periods characterized by the best/worst medium-range forecasts

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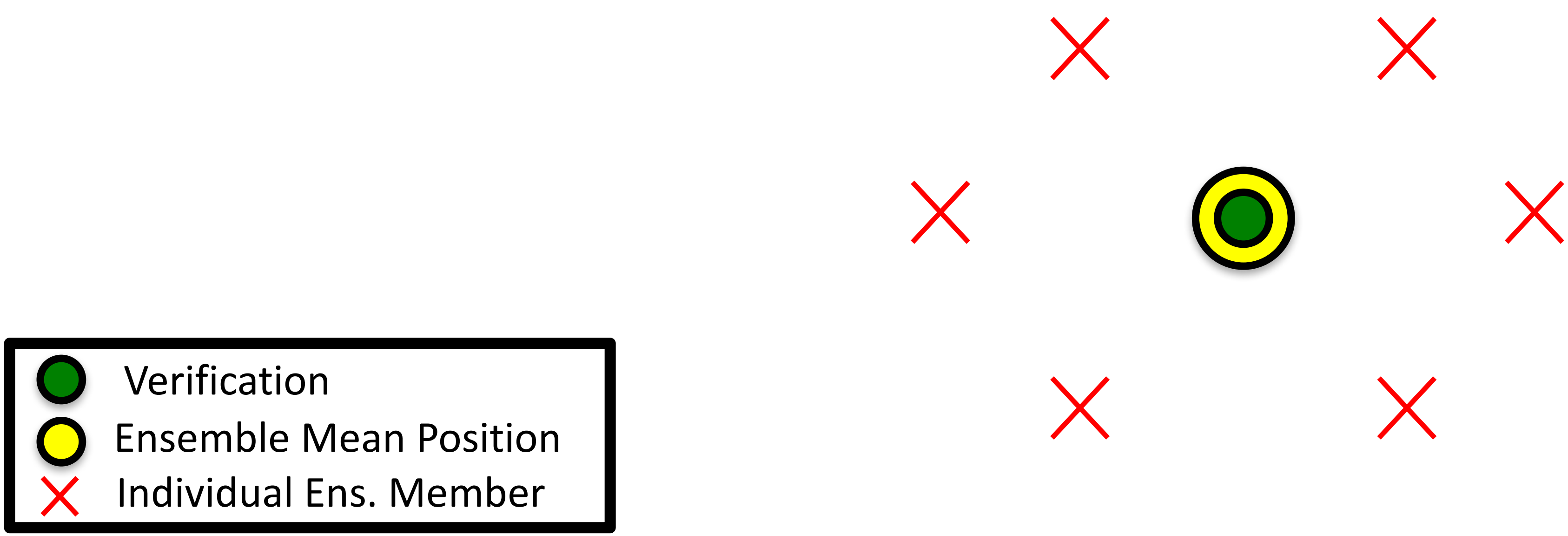
Hypothetical Intermediate Forecast



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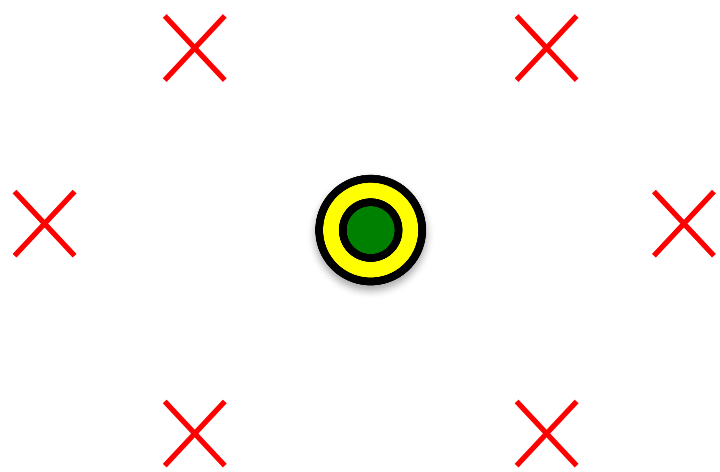

Verification

Ensemble Mean Position

Individual Ens. Member

Best/Worst NPJ Phase Diagram Forecasts

Comparison between the periods characterized by the best/worst medium-range forecasts

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(2) The average GEFS ensemble member error in the Day 8 and 9 forecasts

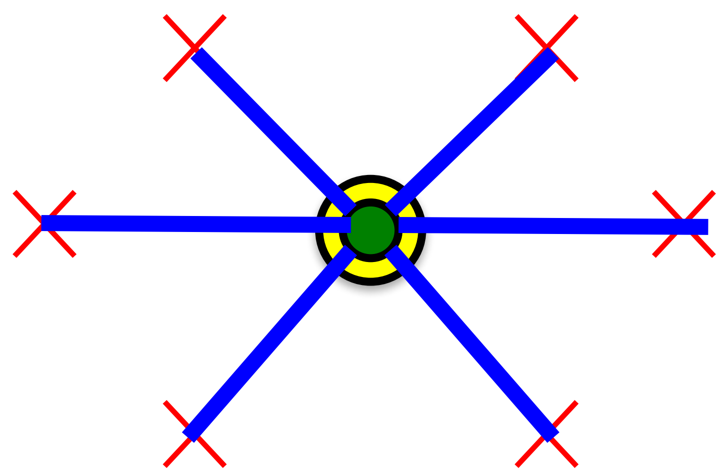
Represents a forecast with considerable ensemble member error

(1) Ens. Mean error ≈ 0 ✓

(2) Avg. Ens. Member error >> 0 ✗

- Verification
- Ensemble Mean Position
- Individual Ens. Member

Hypothetical Intermediate Forecast



Best/Worst NPJ Phase Diagram Forecasts

Comparison between the periods characterized by the best/worst medium-range forecasts

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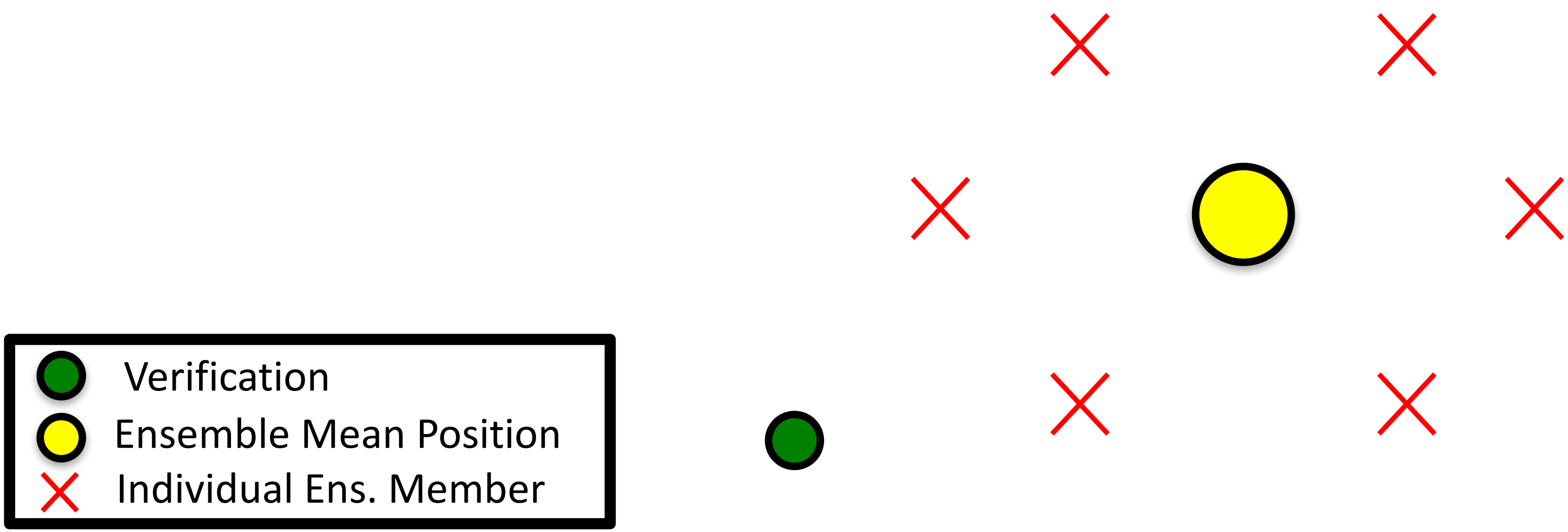
Hypothetical Worst Forecast



Best/Worst NPJ Phase Diagram Forecasts

Comparison between the periods characterized by the best/worst medium-range forecasts

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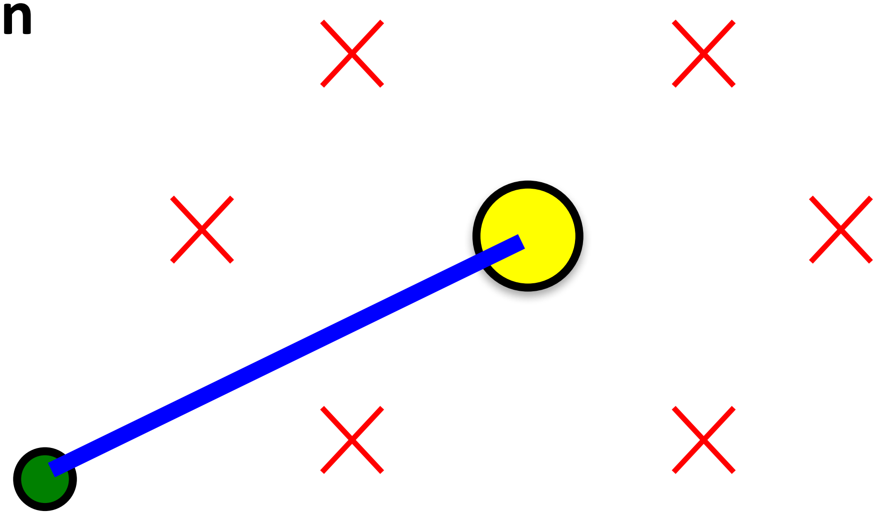
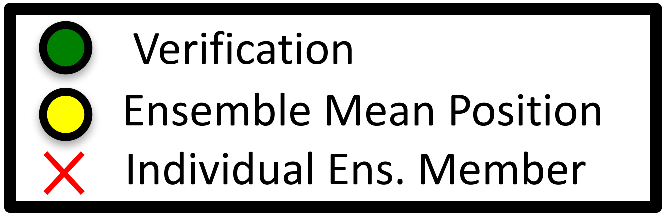
Hypothetical Worst Forecast





Best/Worst NPJ Phase Diagram Forecasts

Comparison between the periods characterized by the best/worst medium-range forecasts

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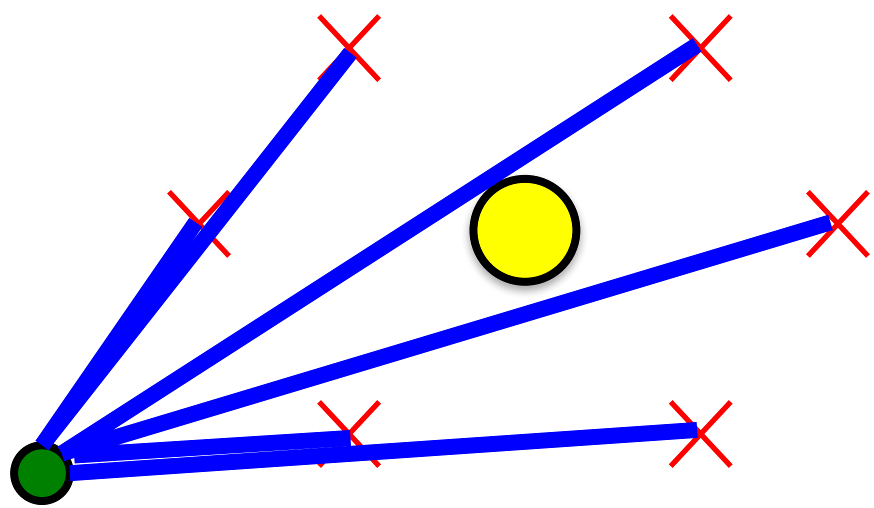
- Verification
- Ensemble Mean Position
- ✗ Individual Ens. Member

Hypothetical Worst Forecast



Best/Worst NPJ Phase Diagram Forecasts

Comparison between the periods characterized by the best/worst medium-range forecasts

	Extend	Retract	Poleward	Equator.	Origin
Best Forecasts (N=475)	77	63	63	61	211
Worst Forecasts (N=763)	90	145	90	112	326
Best/Worst Ratio (Ave = 0.62)	0.86	0.43	0.70	0.54	0.65

Best/Worst NPJ Phase Diagram Forecasts

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- The best forecasts occur disproportionately more during **jet extensions** and **poleward shifts**
- The worst forecasts occur disproportionately more during **jet retractions** and **equatorward shifts**

Best/Worst NPJ Phase Diagram Forecasts

Comparison between the periods characterized by the best/worst medium-range forecasts

	Avg. ΔPC1	Avg. ΔPC2	Avg. 10-d Traj. Length.
Best Forecasts (N=475)	0.09	0.16 Poleward Shift	3.50 PC units
Worst Forecasts (N=763)	0.01	–0.21 Equatorward Shift	4.33 PC units

Statistically significant at the 99.9% confidence interval

- The best forecast periods are typically characterized by **poleward shifts** over the next 10 days and anomalously short trajectories within the NPJ phase diagram
- The worst forecast periods are typically characterized by **equatorward shifts** over the next 10 days and anomalously long trajectories within the NPJ phase diagram

Best/Worst NPJ Phase Diagram Forecasts

Comparison between the periods characterized by the best/worst medium-range forecasts

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What are the synoptic flow patterns associated with the best and worst forecasts initialized during a particular NPJ regime?

Best/Worst NPJ Phase Diagram Forecasts

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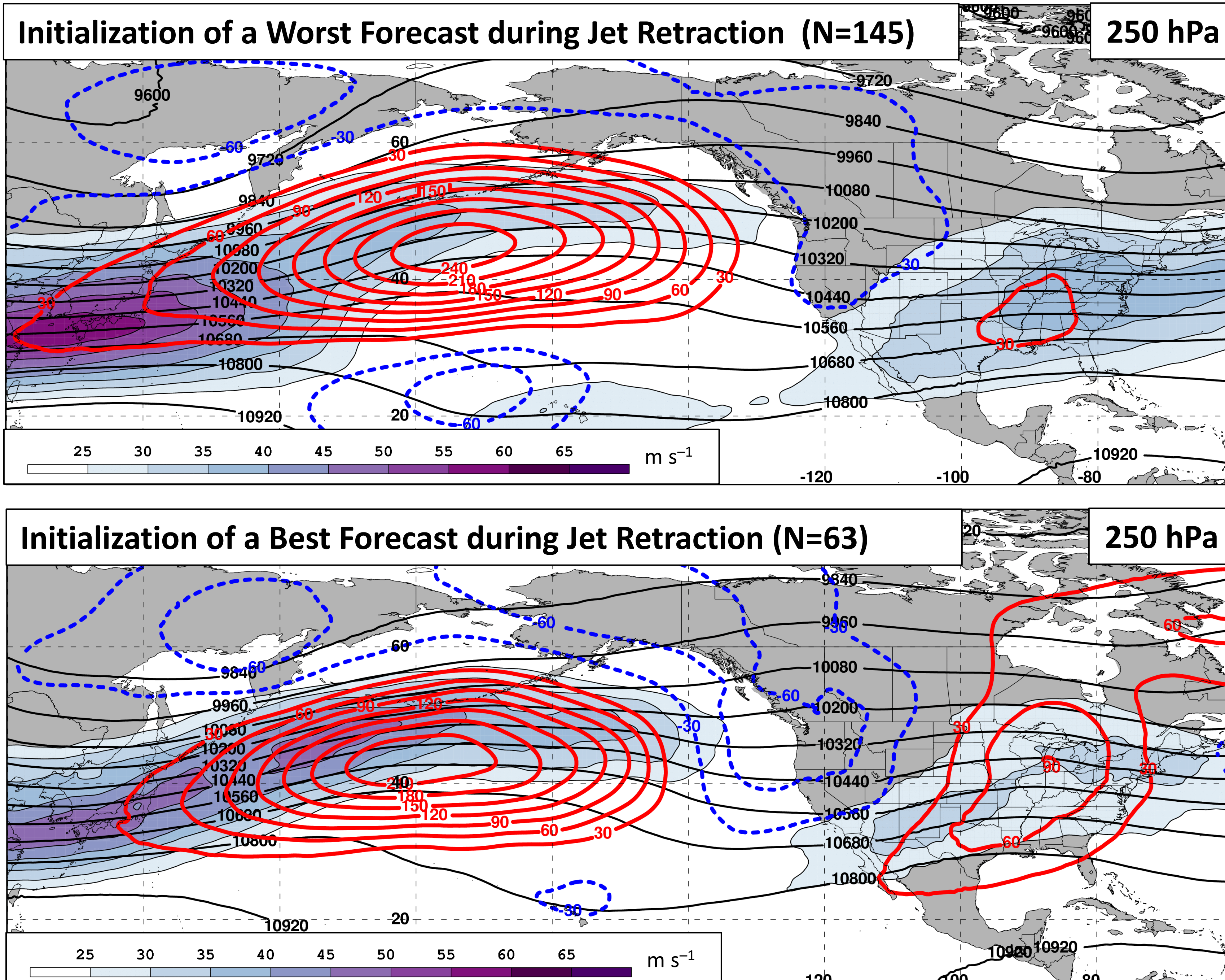
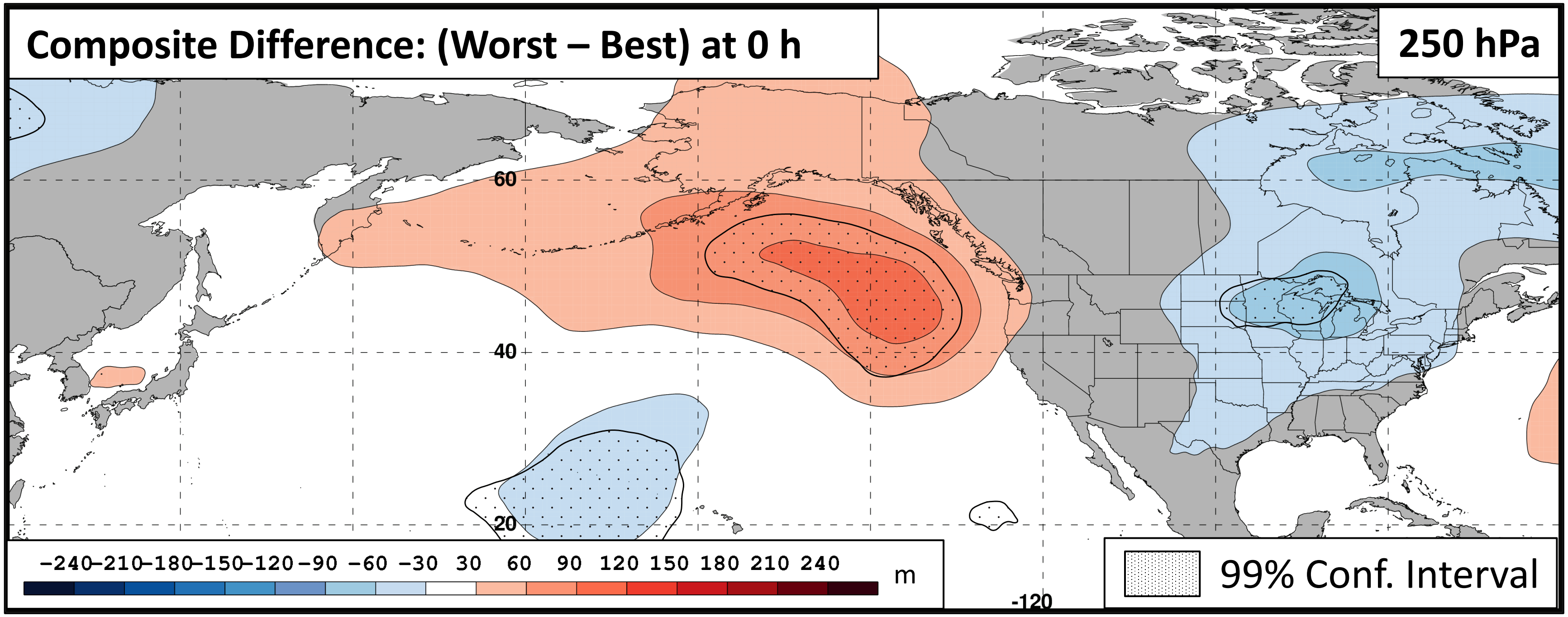
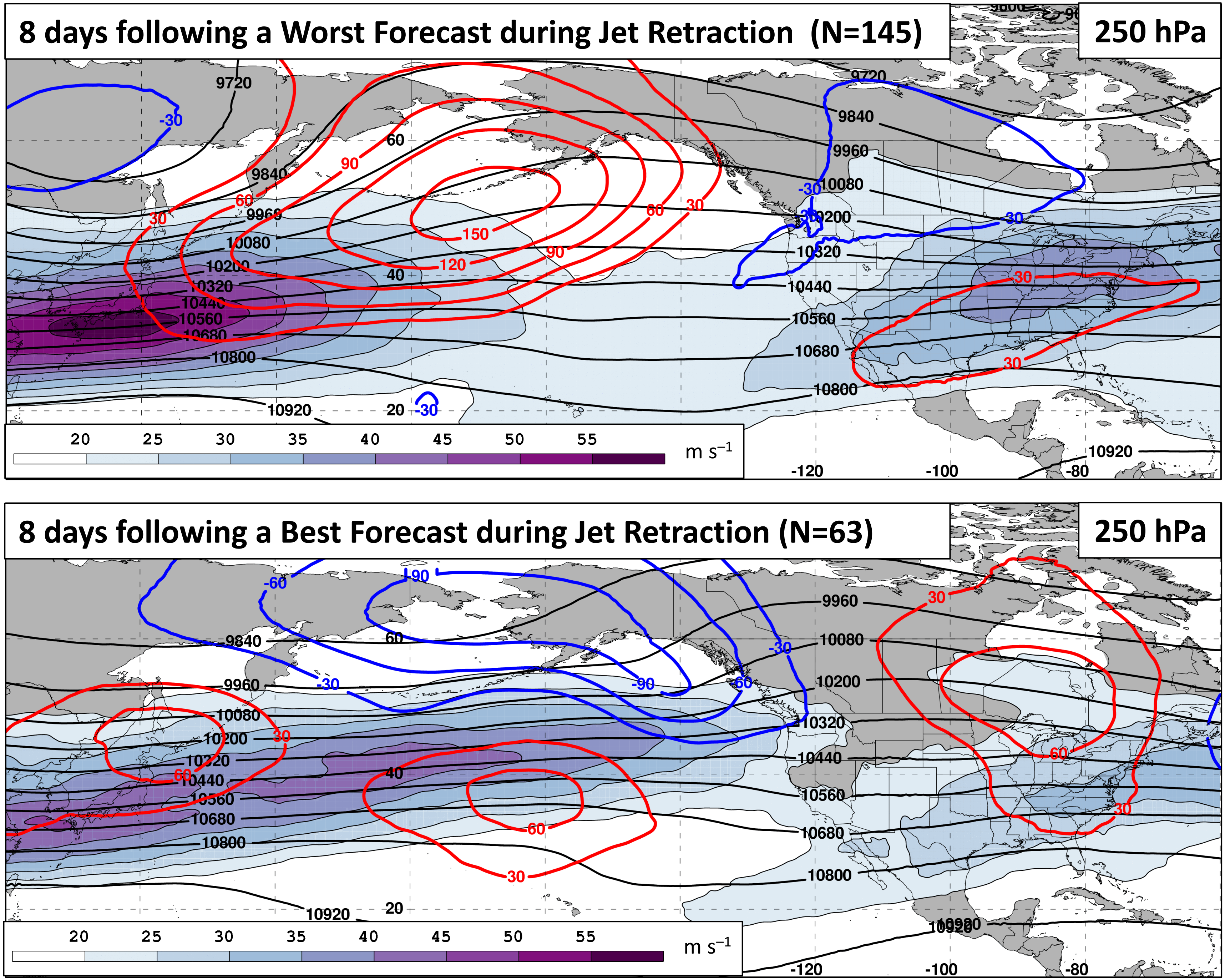
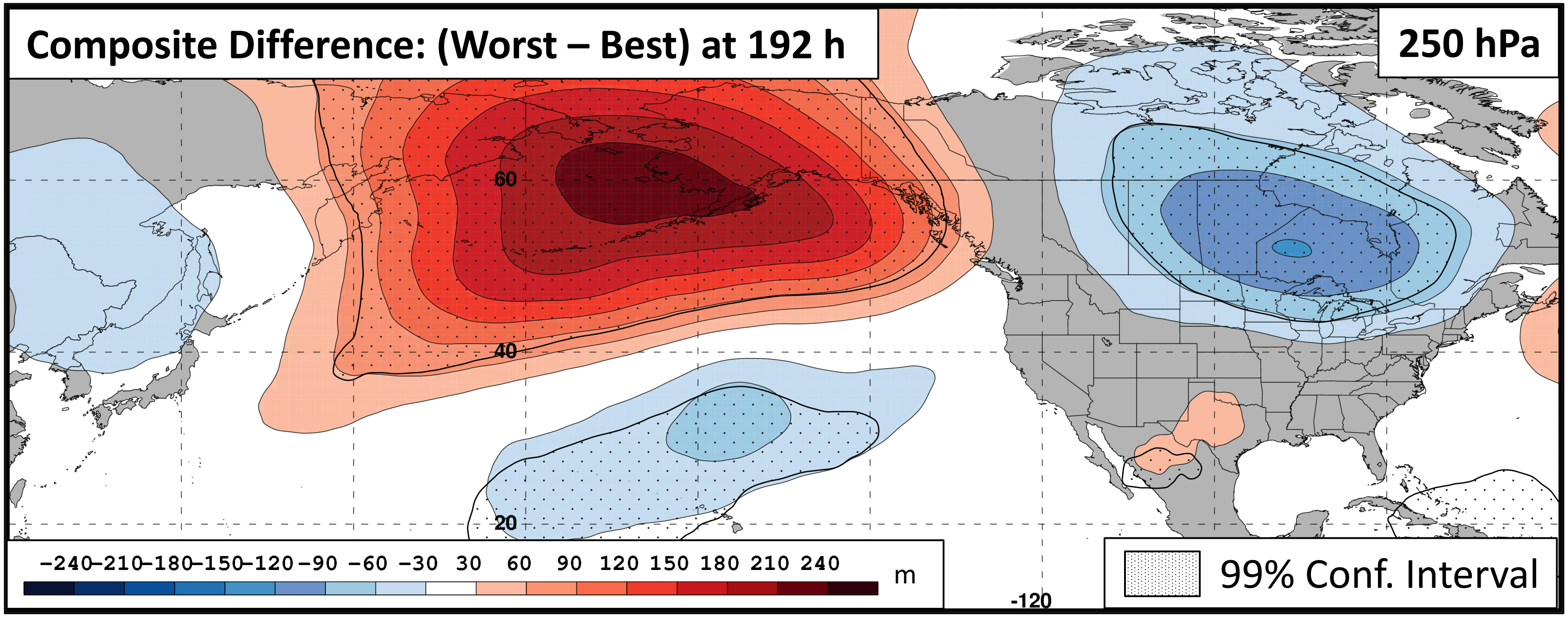
What are the synoptic flow patterns associated with the best and worst forecasts initialized during a particular NPJ regime?


Initialization of a Worst Forecast during Jet Retraction (N=145)
250 hPa
25 30 35 40 45 50 55 60 65
m s−1
-120
-100
-80
Initialization of a Best Forecast during Jet Retraction (N=63)
250 hPa
25 30 35 40 45 50 55 60 65
m s−1
-120
-100
-80



- Relative to the best forecast periods, the worst forecast periods are frequently characterized by significantly higher heights over the eastern North Pacific at the time of forecast initialization

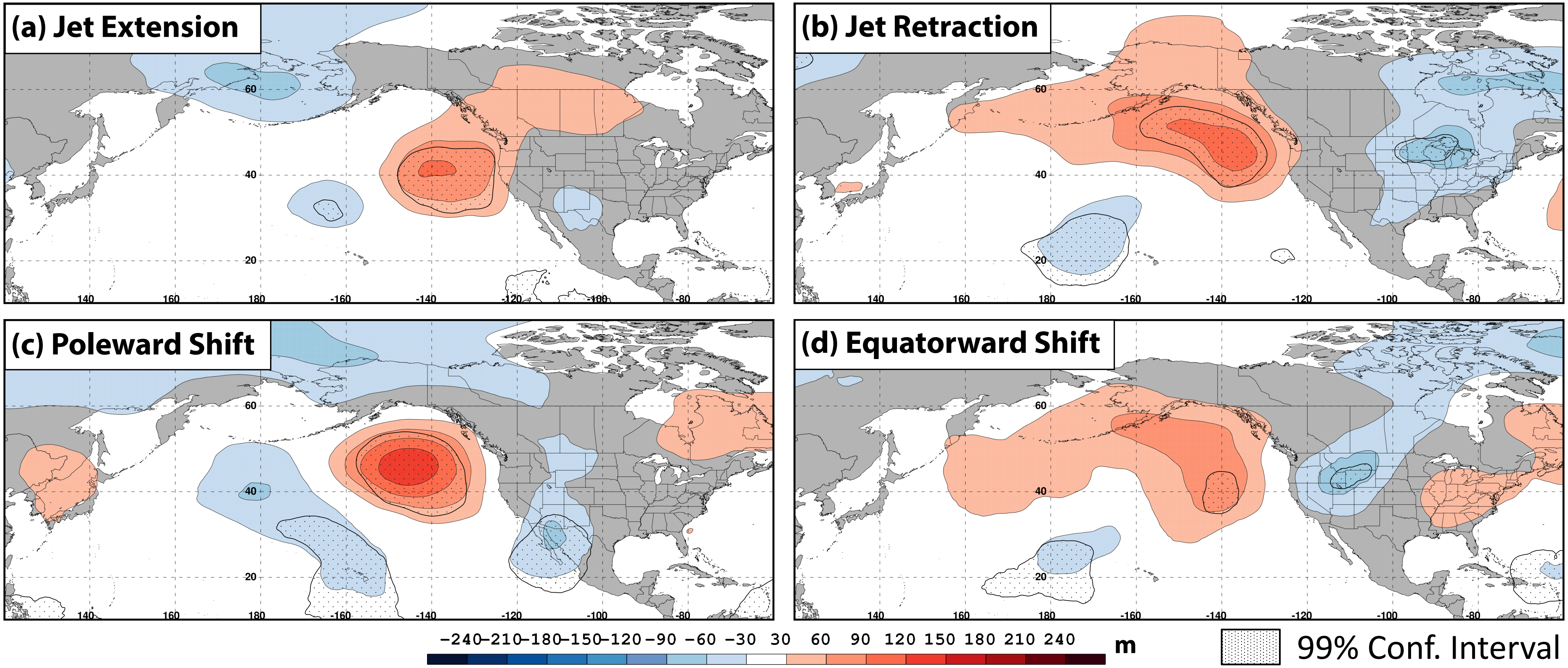

8 days following a Worst Forecast during Jet Retraction (N=145)
250 hPa
20 25 30 35 40 45 50 55
m s⁻¹
-120
-100
-80
8 days following a Best Forecast during Jet Retraction (N=63)
250 hPa
20 25 30 35 40 45 50 55
m s⁻¹
-120
-100
-80



- Relative to the best forecast periods, the worst forecast periods are frequently characterized by significantly higher heights at high latitudes and significantly lower heights at low latitudes over the North Pacific

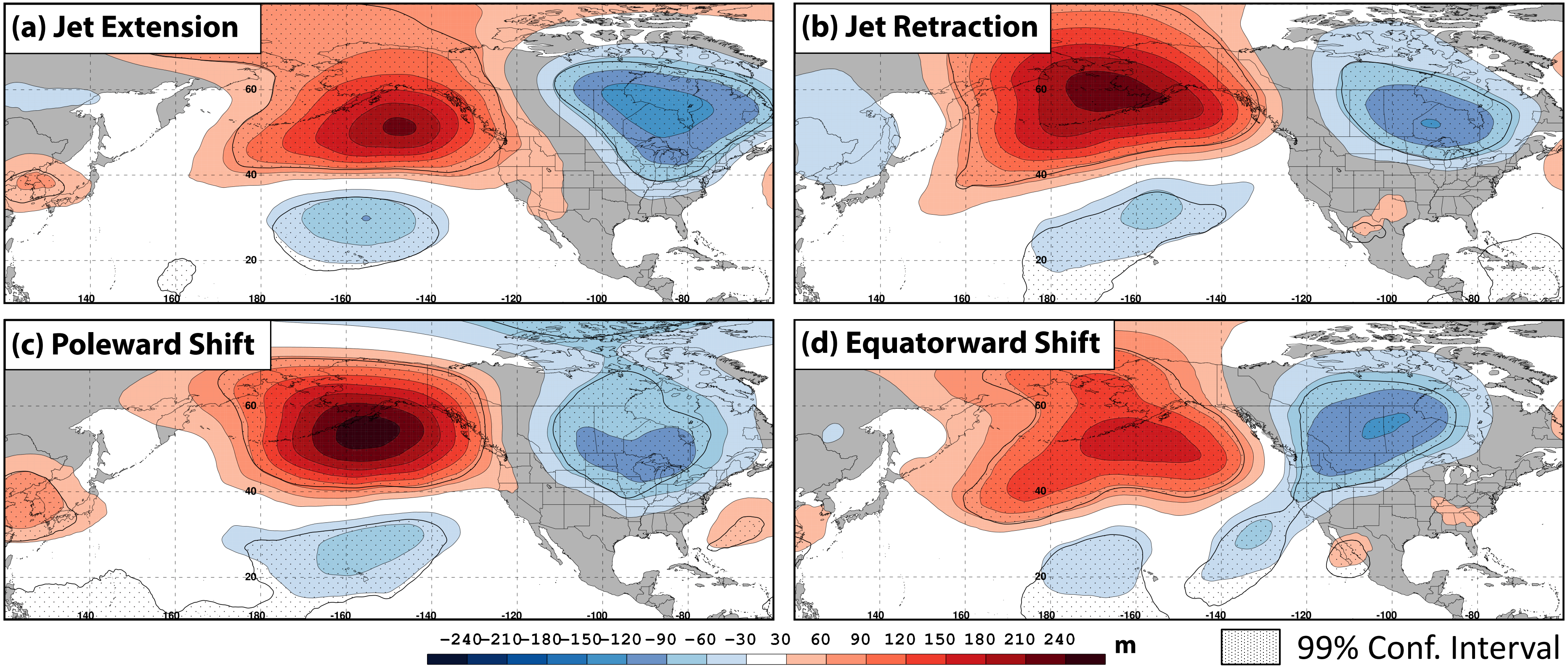
- The above composite difference pattern suggests that the worst forecast periods are often associated with upper-tropospheric blocking events over the North Pacific

Composite Difference: (Worst – Best) at 0 h



- Relative to the best forecasts, the worst forecast periods exhibit significantly higher heights over the eastern North Pacific irrespective of the NPJ regime at the time of forecast initialization

Composite Difference: (Worst – Best) at 192 h



- The composite differences suggest that the worst forecast periods are often associated with upper-tropospheric blocking events over the North Pacific 8 days following forecast initialization irrespective of the NPJ regime at the time of forecast initialization

Summary: GEFS Forecast Skill

- Forecasts initialized during **jet retractions** are characterized by larger errors than those initialized during **jet extensions**
- Forecasts verifying during **jet retractions** and **equatorward shifts** are characterized by substantially larger errors than those verifying during **jet extensions** and **poleward shifts**

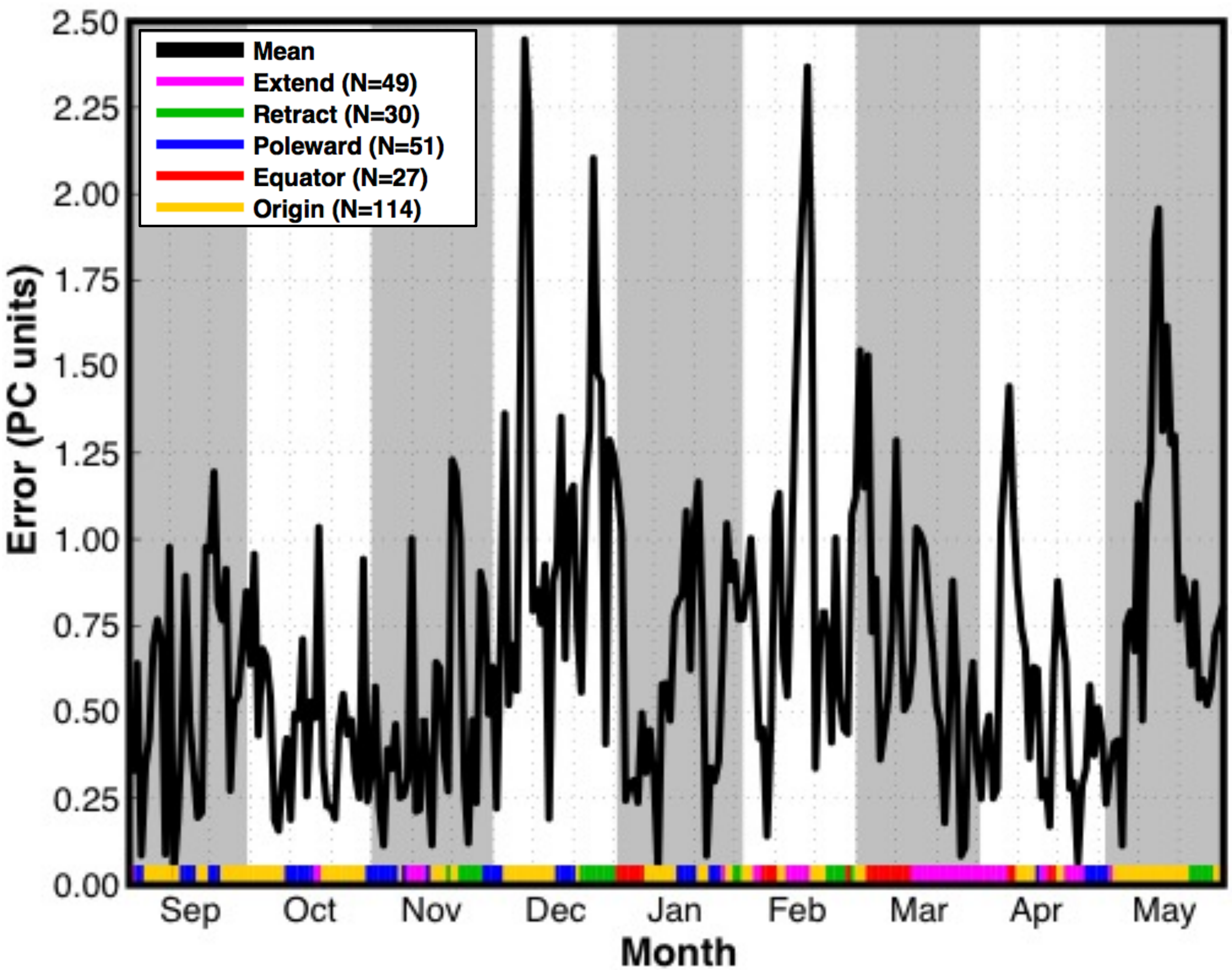
Summary: GEFS Forecast Skill

- Forecasts initialized during **jet retractions** are characterized by larger errors than those initialized during **jet extensions**
- Forecasts verifying during **jet retractions** and **equatorward shifts** are characterized by substantially larger errors than those verifying during **jet extensions** and **poleward shifts**
- The worst forecasts are more frequently initialized during **jet retractions** and **equatorward shifts**
- The worst forecast periods are associated with **equatorward shifts** and longer trajectories within the NPJ phase diagram during the 10-day period following forecast initialization
- The worst forecast periods are often associated with upper-tropospheric blocking events over the North Pacific

Application of the NPJ Phase Diagram

Real Time NPJ Phase Diagram Forecasts

Time series of 2016–2017 GEFS ensemble mean 9-day forecast error classified by initialization date



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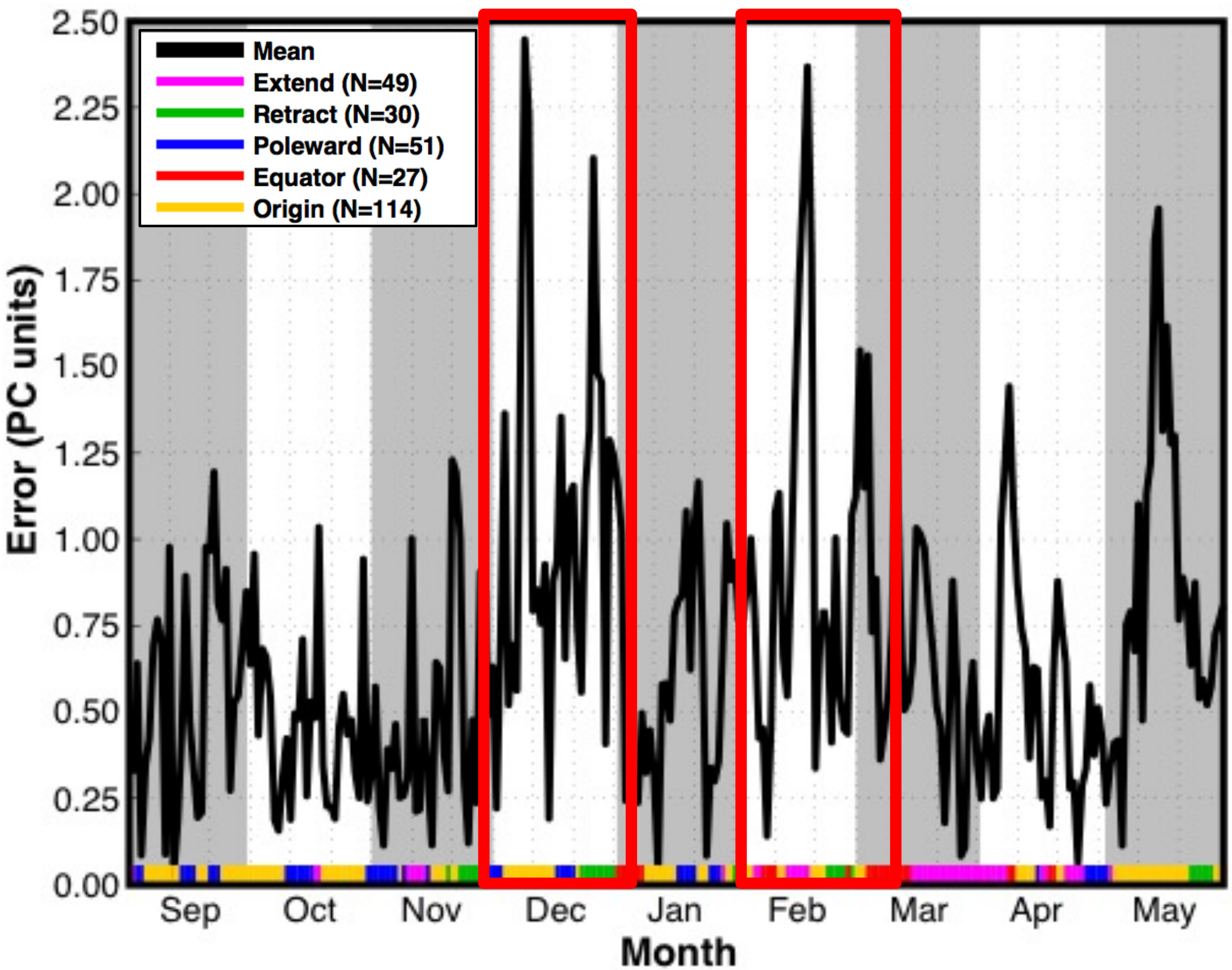
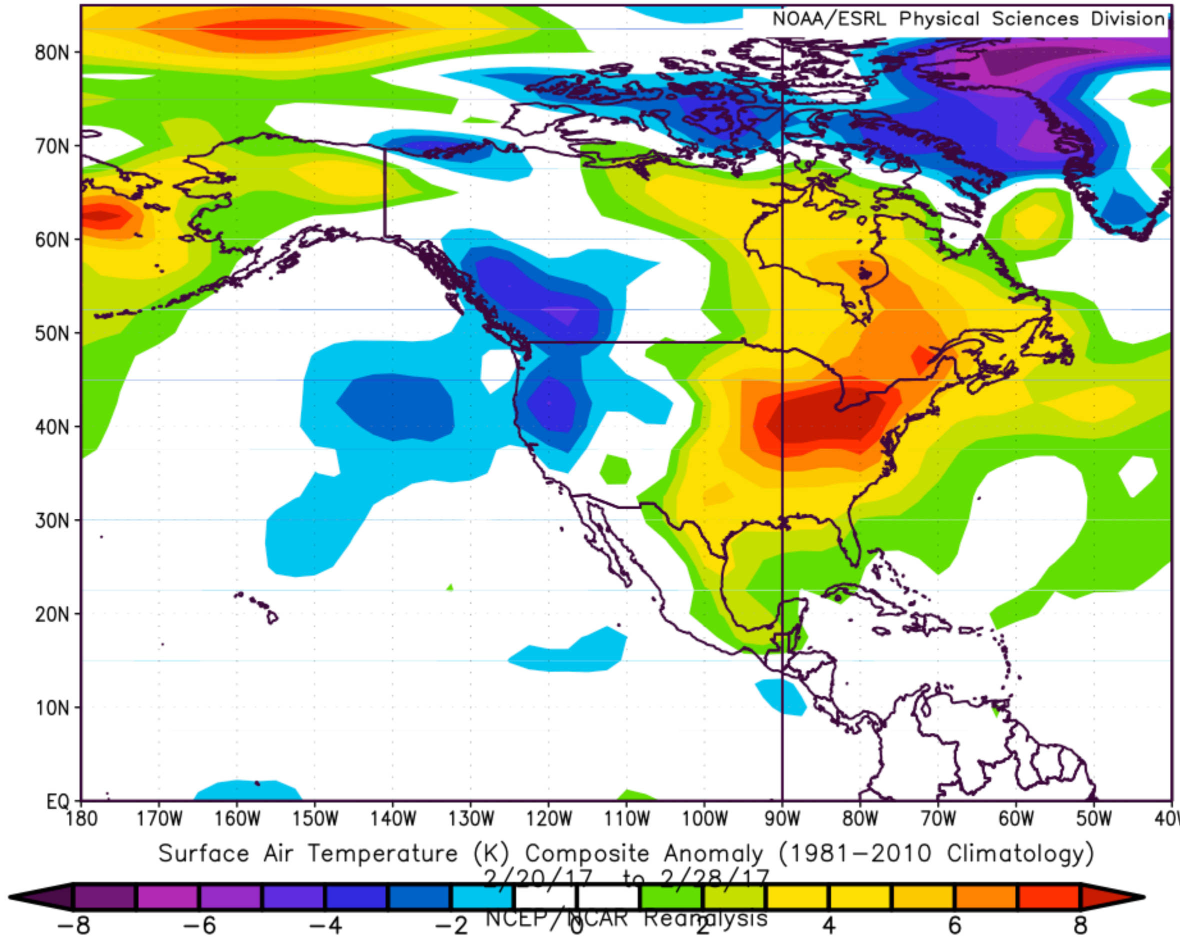


9-day NPJ phase diagram forecasts initialized during December, February, and early-March were characterized by substantial errors

February 2017 NPJ Regime Change

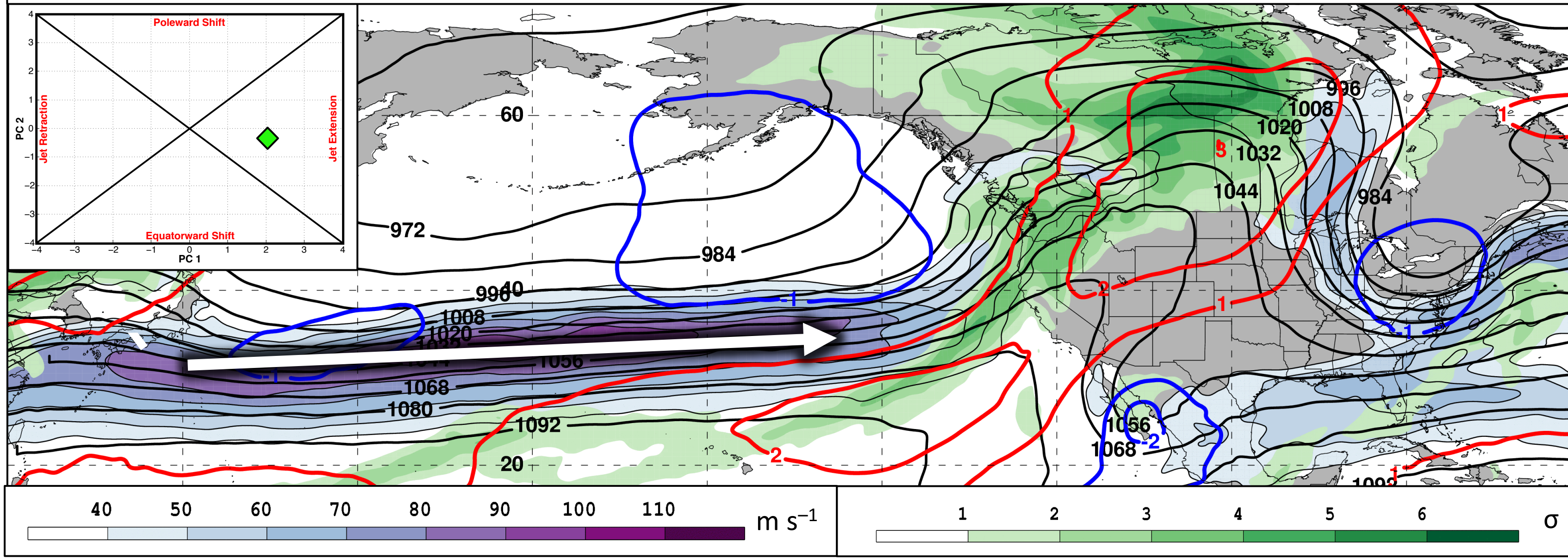
An NPJ regime change in late-February 2017 ushered anomalously warm/cold temperatures into the eastern/western U.S.

Composite Temperature Anomalies 20–28 Feb

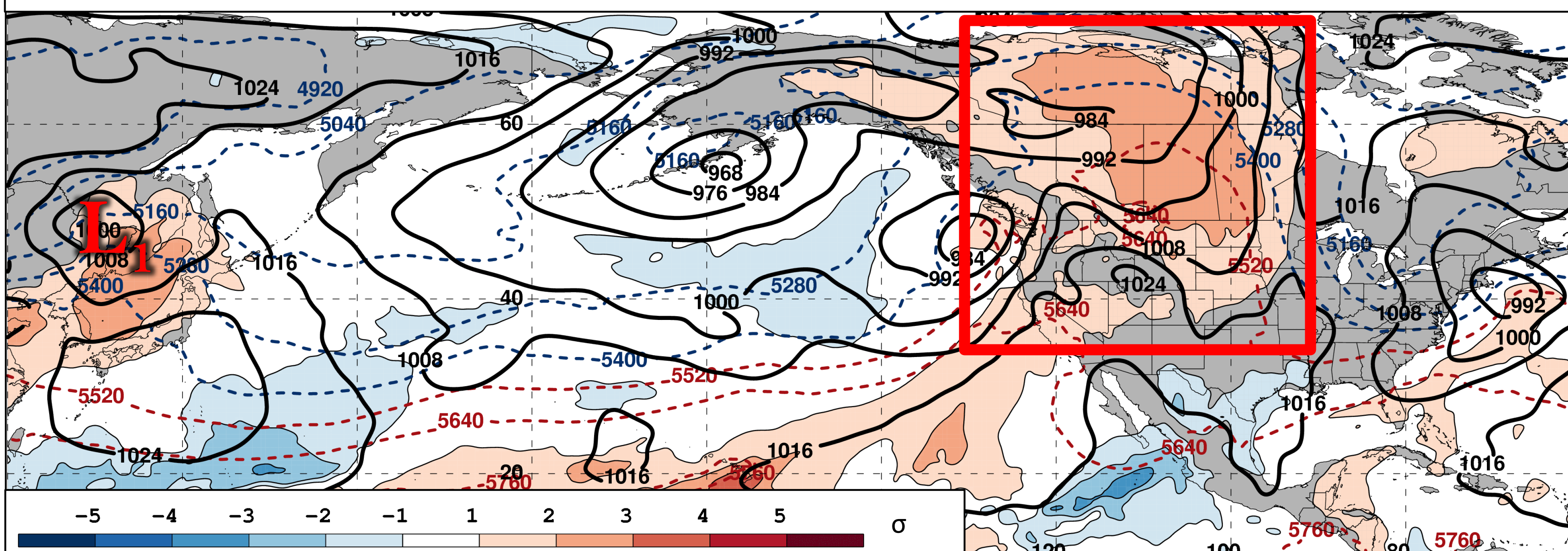


ESRL

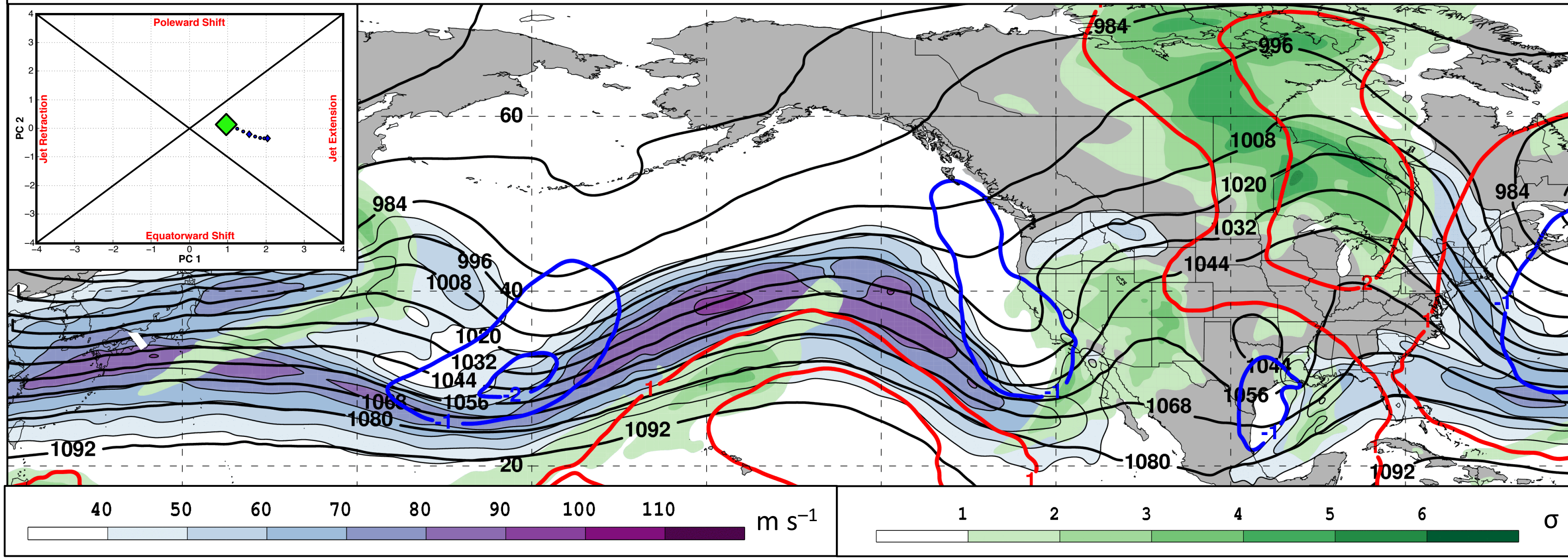
0000 UTC 16 February: 250-hPa Jet (shading) and Precipitable Water Anom. (shading)



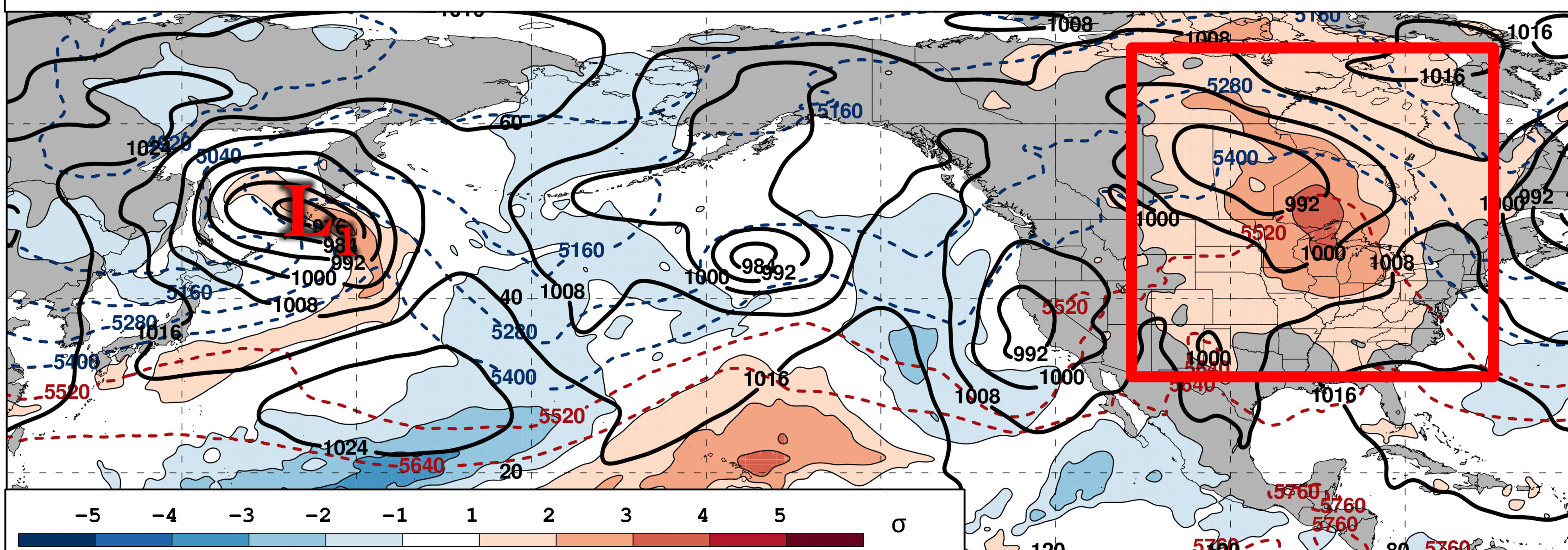
0000 UTC 16 February: MSLP (contours), Thick. (contours), 850-hPa Temp. Anom. (shading)



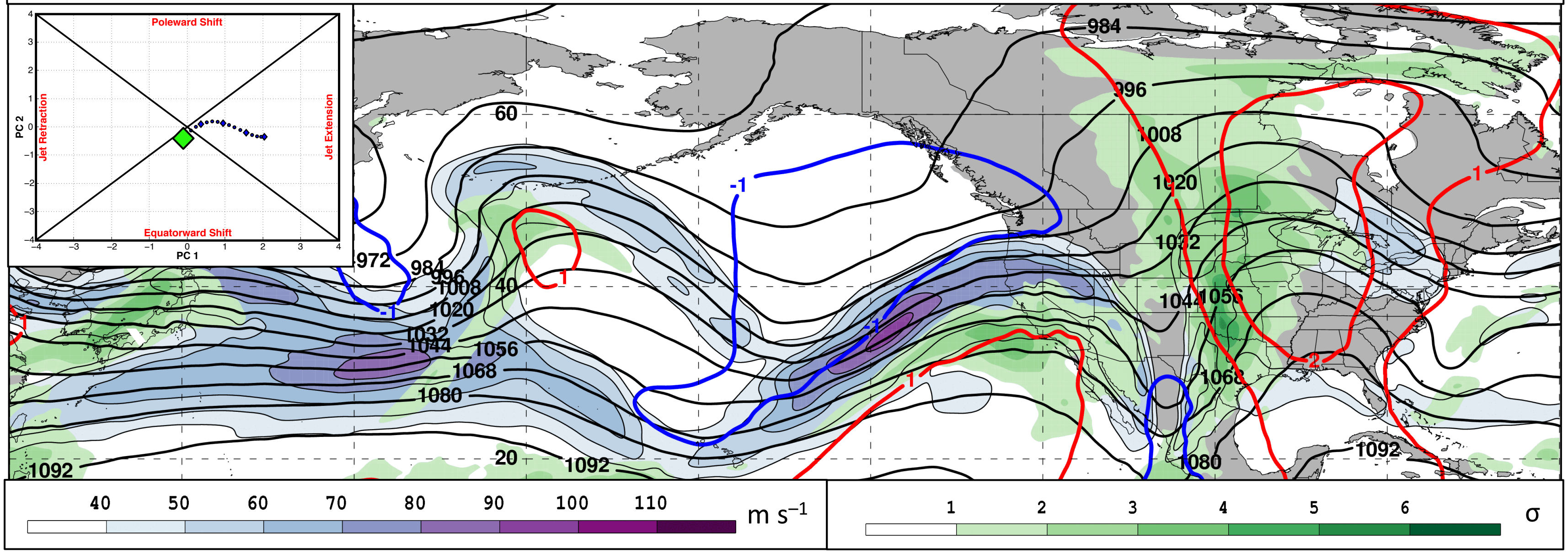
0000 UTC 18 February: 250-hPa Jet (shading) and Precipitable Water Anom. (shading)



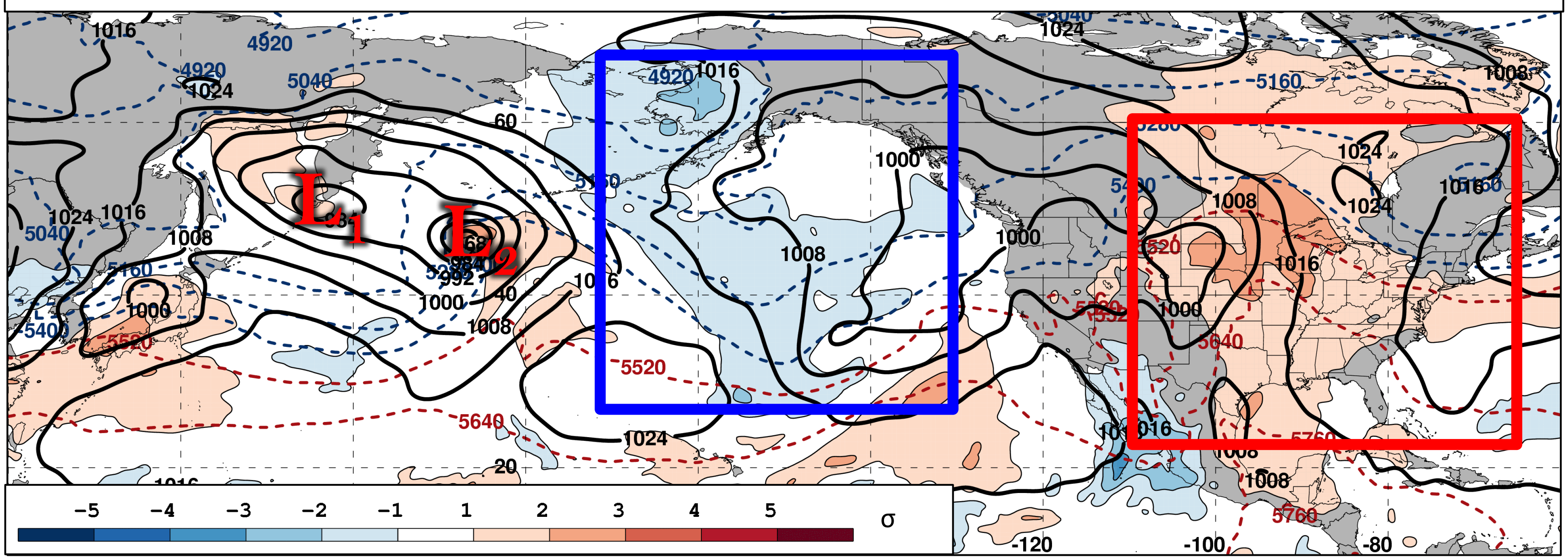
0000 UTC 18 February: MSLP (contours), Thick. (contours), 850-hPa Temp. Anom. (shading)



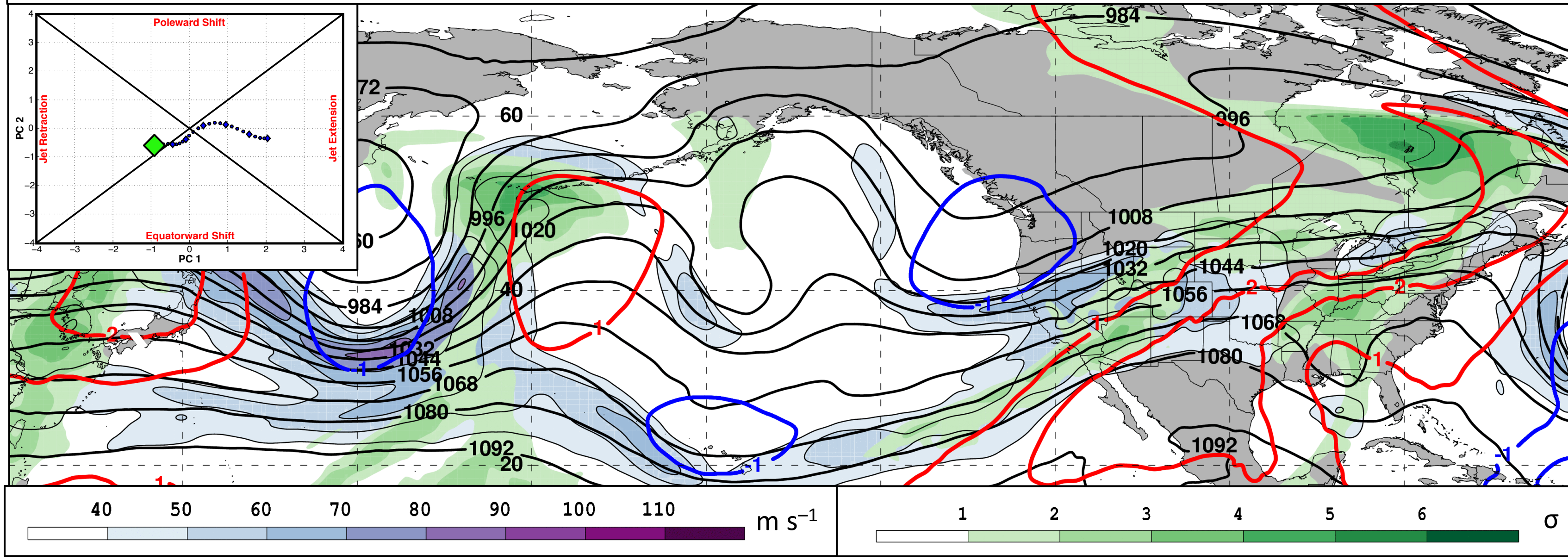
0000 UTC 20 February: 250-hPa Jet (shading) and Precipitable Water Anom. (shading)



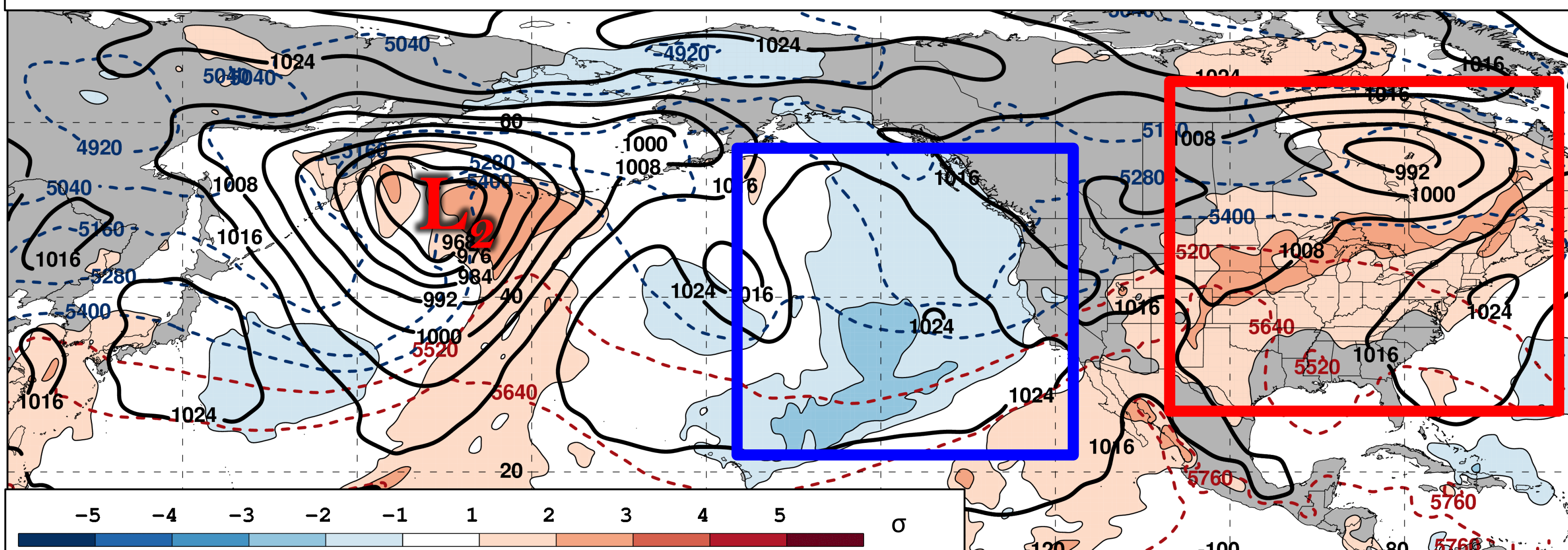
0000 UTC 20 February: MSLP (contours), Thick. (contours), 850-hPa Temp. Anom. (shading)



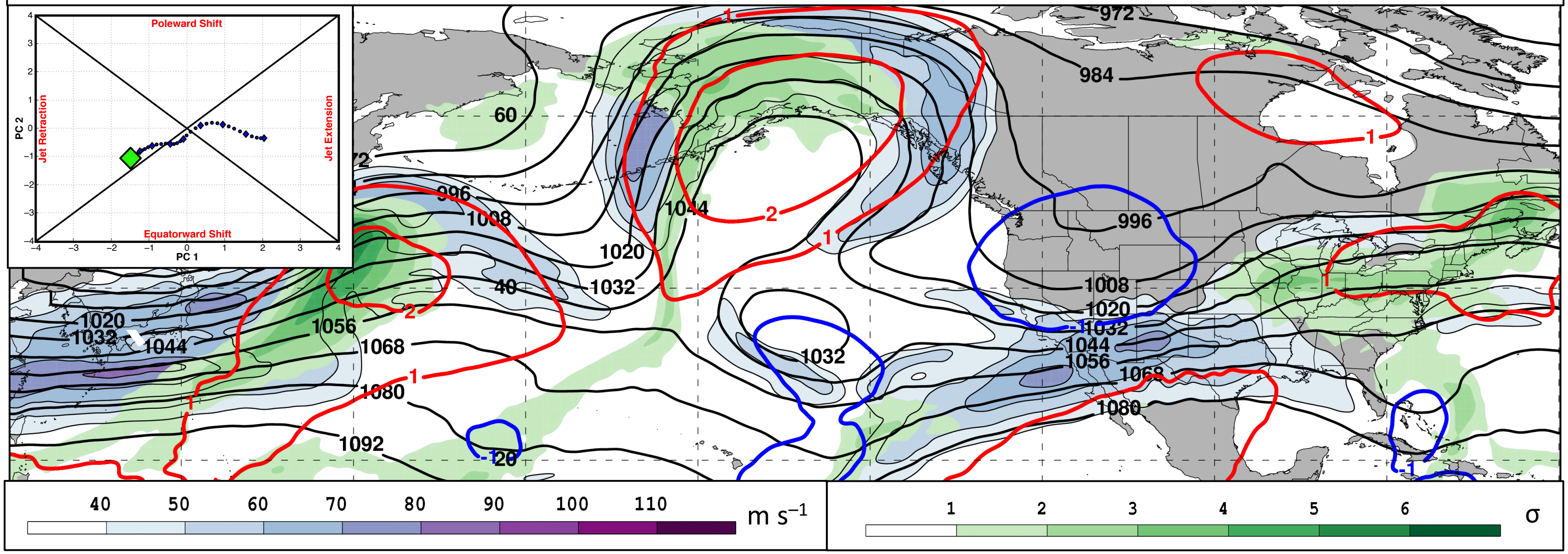
0000 UTC 22 February: 250-hPa Jet (shading) and Precipitable Water Anom. (shading)



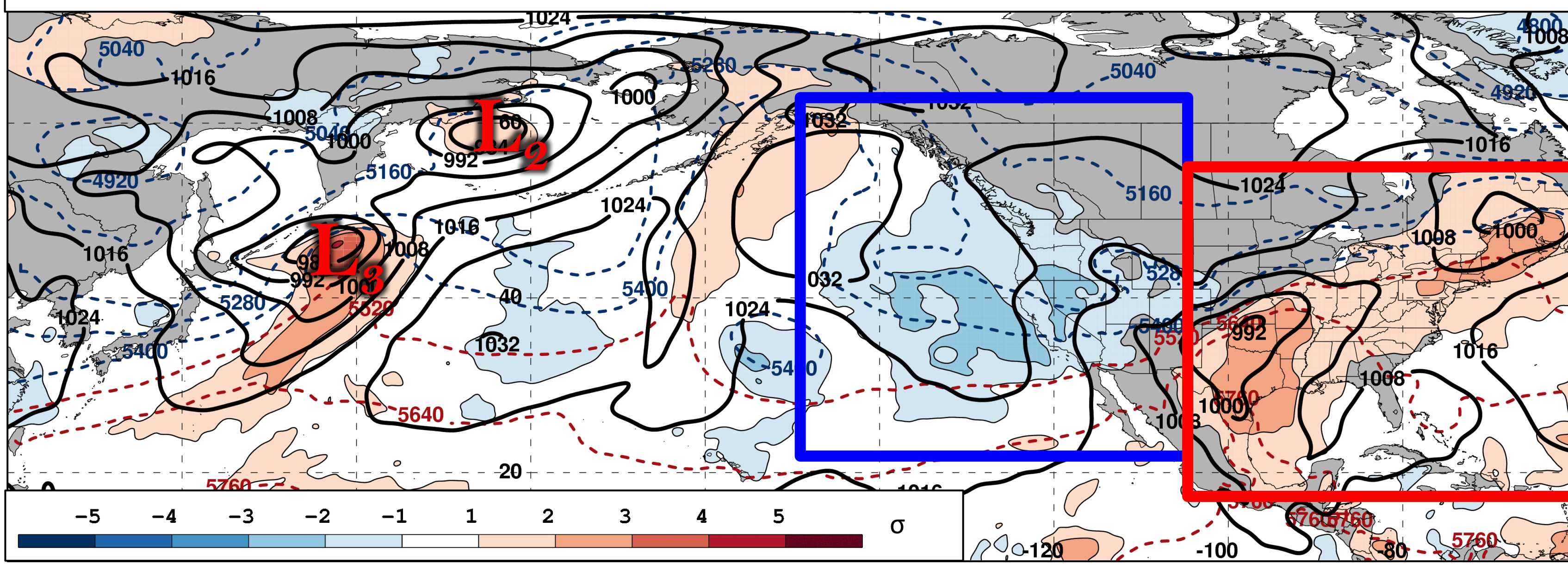
0000 UTC 22 February: MSLP (contours), Thick. (contours), 850-hPa Temp. Anom. (shading)



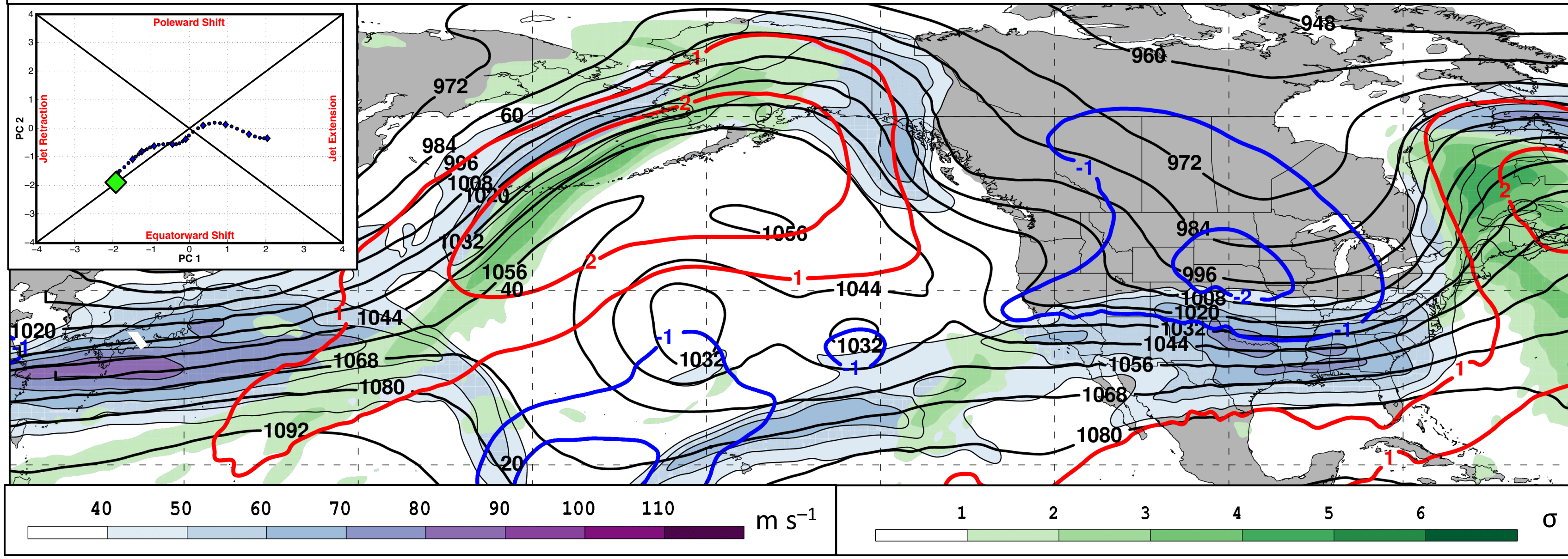
0000 UTC 24 February: 250-hPa Jet (shading) and Precipitable Water Anom. (shading)



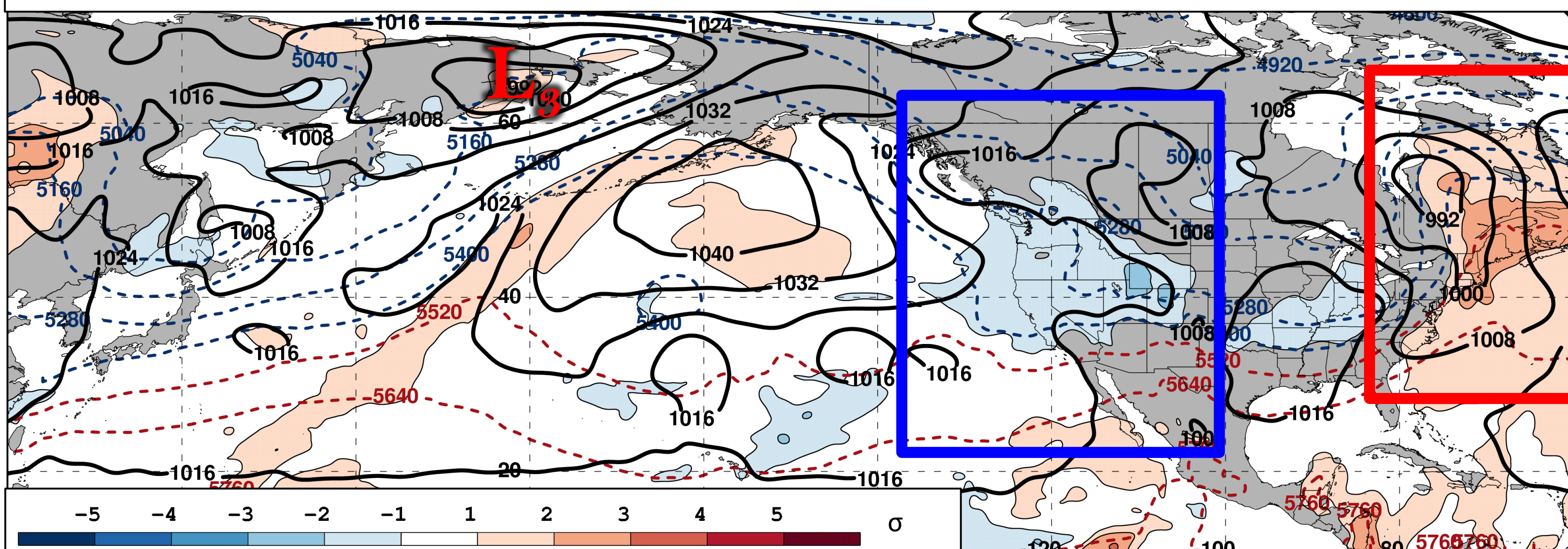
0000 UTC 24 February: MSLP (contours), Thick. (contours), 850-hPa Temp. Anom. (shading)



0000 UTC 26 February: 250-hPa Jet (shading) and Precipitable Water Anom. (shading)



0000 UTC 26 February: MSLP (contours), Thick. (contours), 850-hPa Temp. Anom. (shading)



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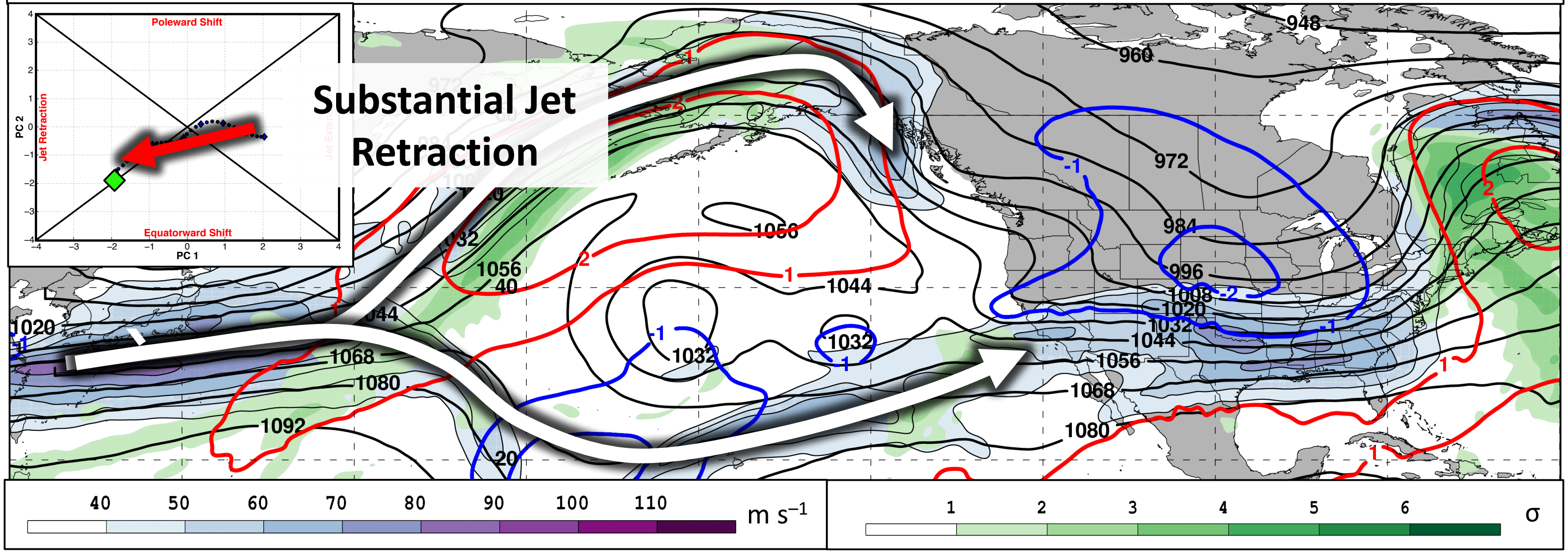
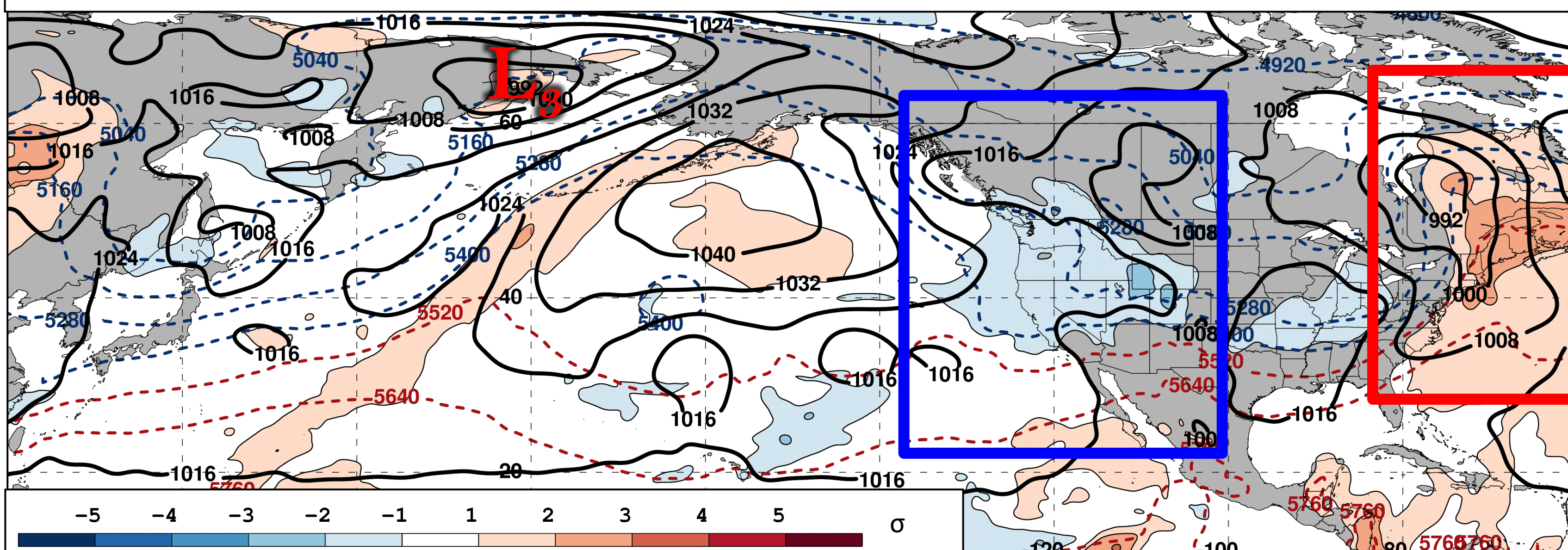
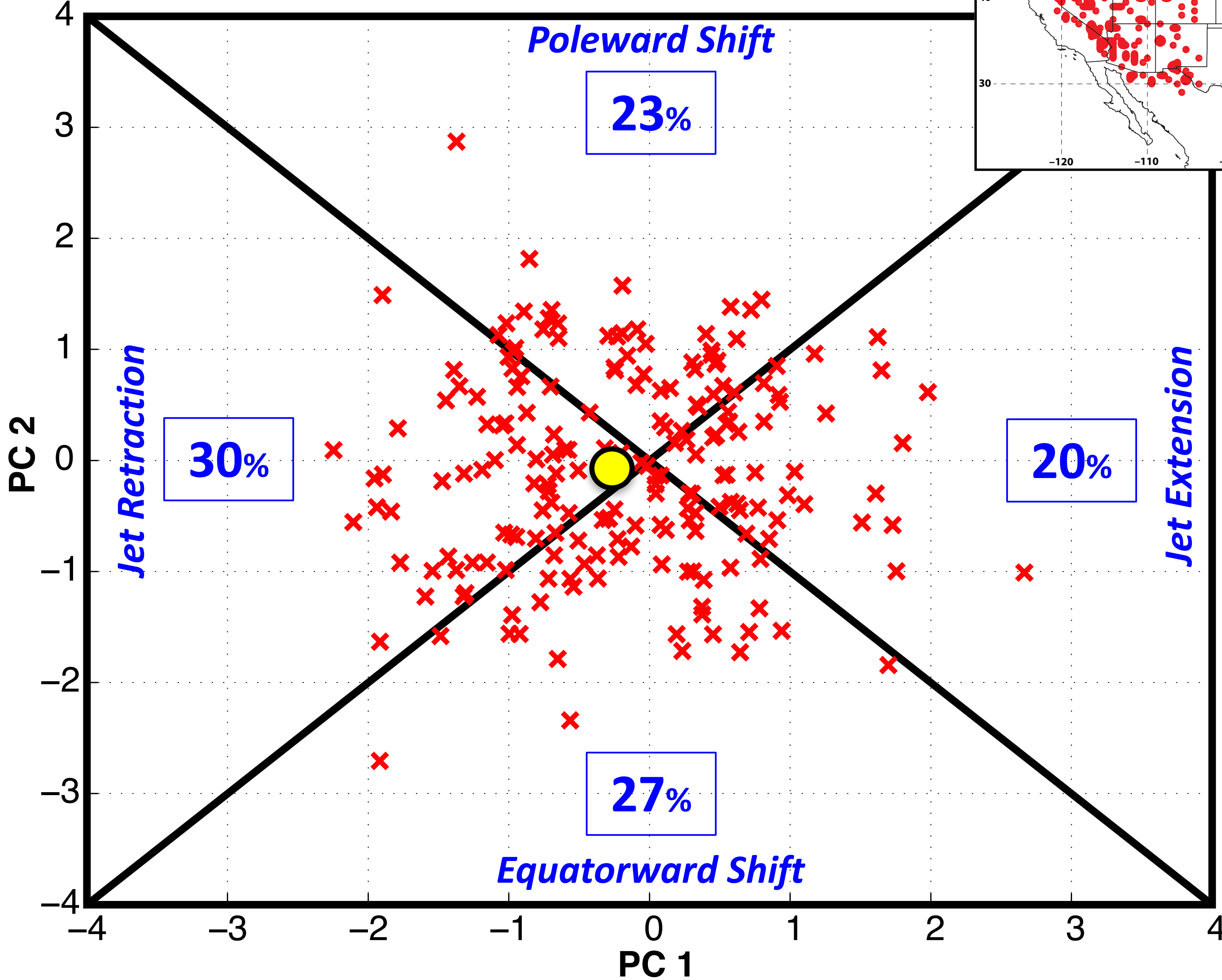


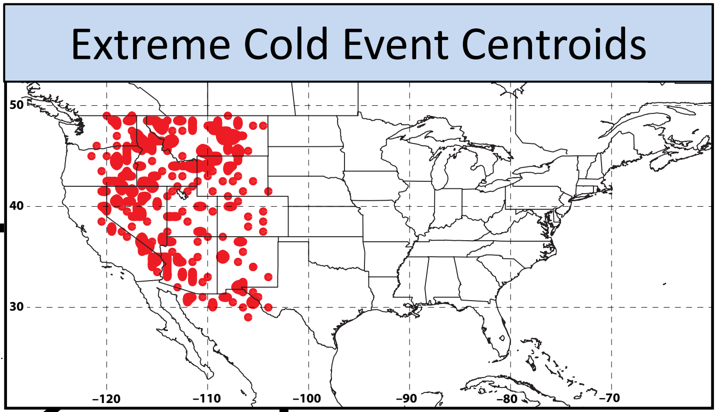
0000 UTC 26 February: MSLP (contours), Thick. (contours), 850-hPa Temp. Anom. (shading)



Western U.S. – All Events

EXTREME COLD EVENTS (N = 196)



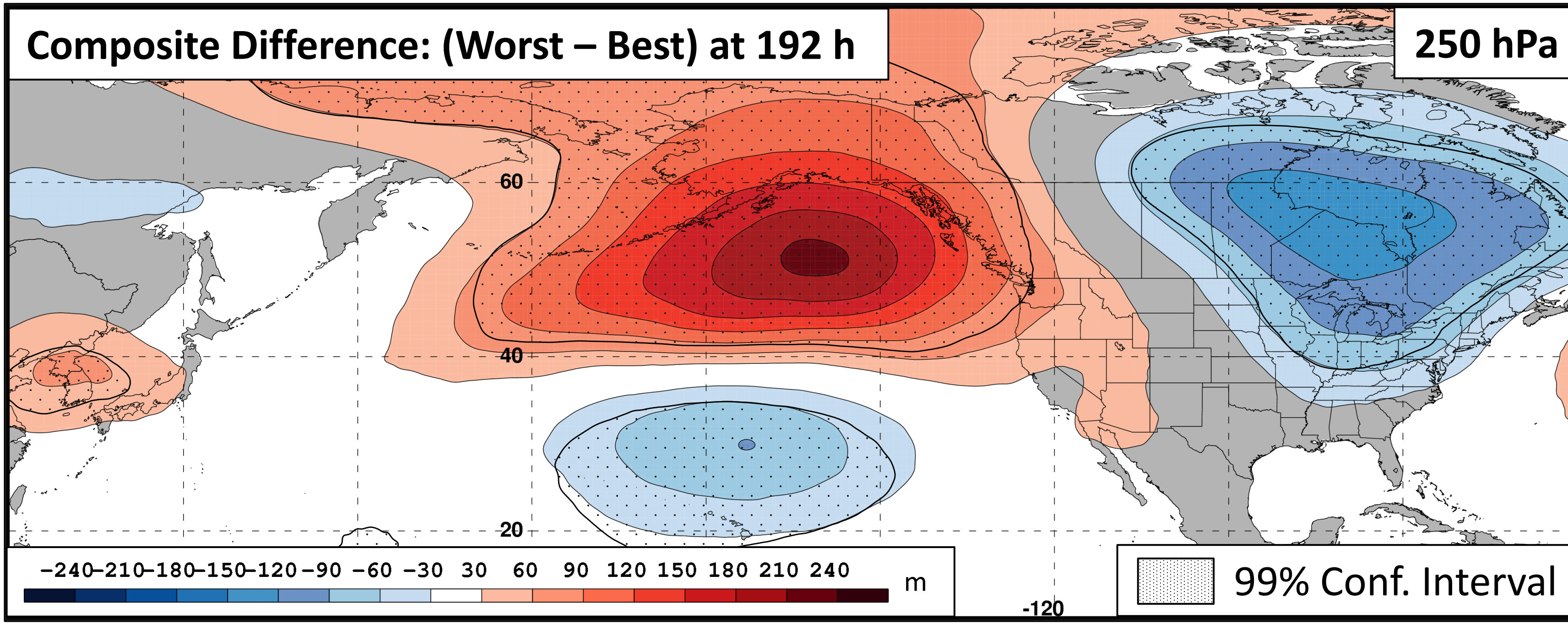


Events during Sept. – May projected onto phase diagram

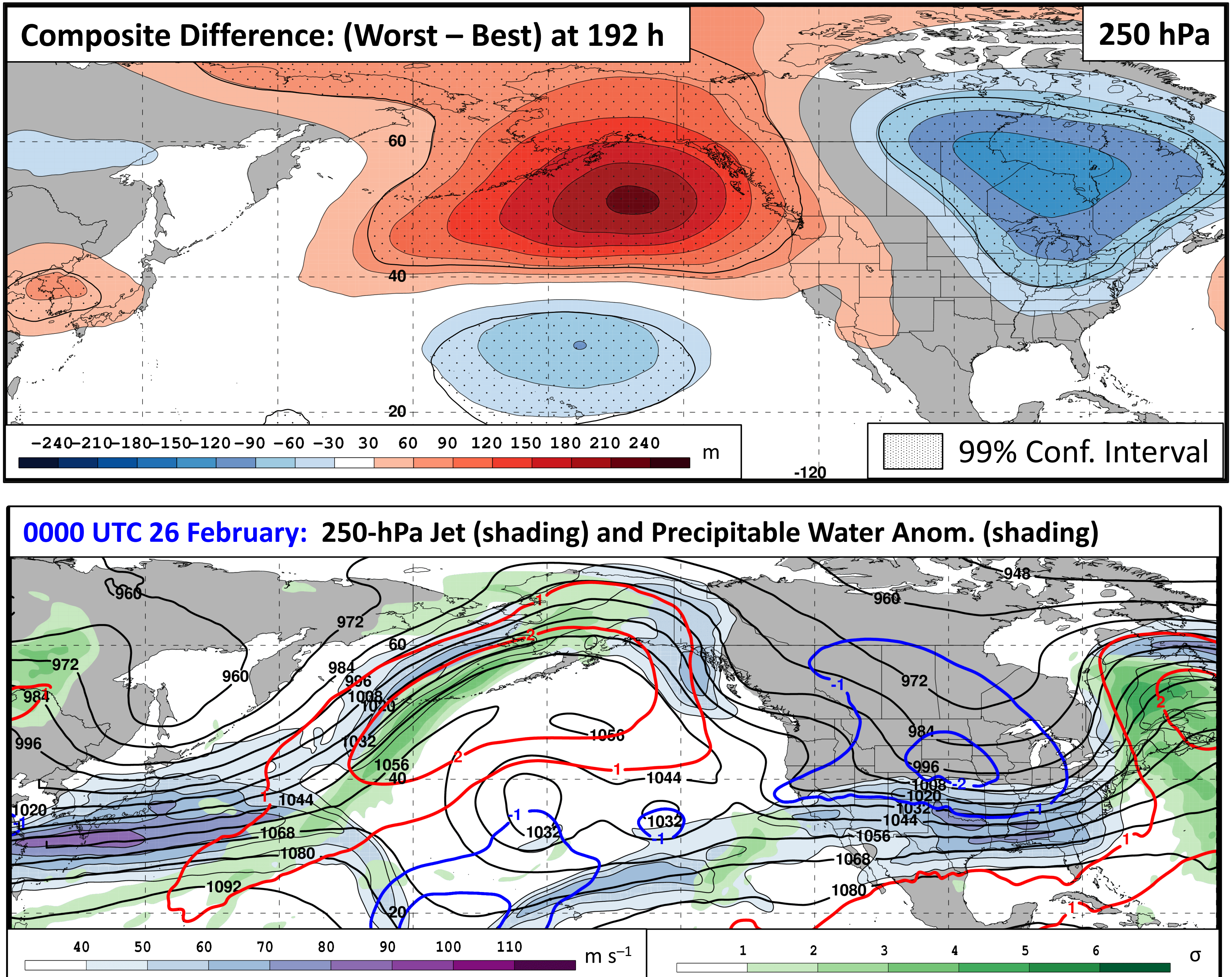
Each 'x' is an average of the PCs 3–7 days prior to an event

19–23 Feb. 2017

February 2017 NPJ Regime Change



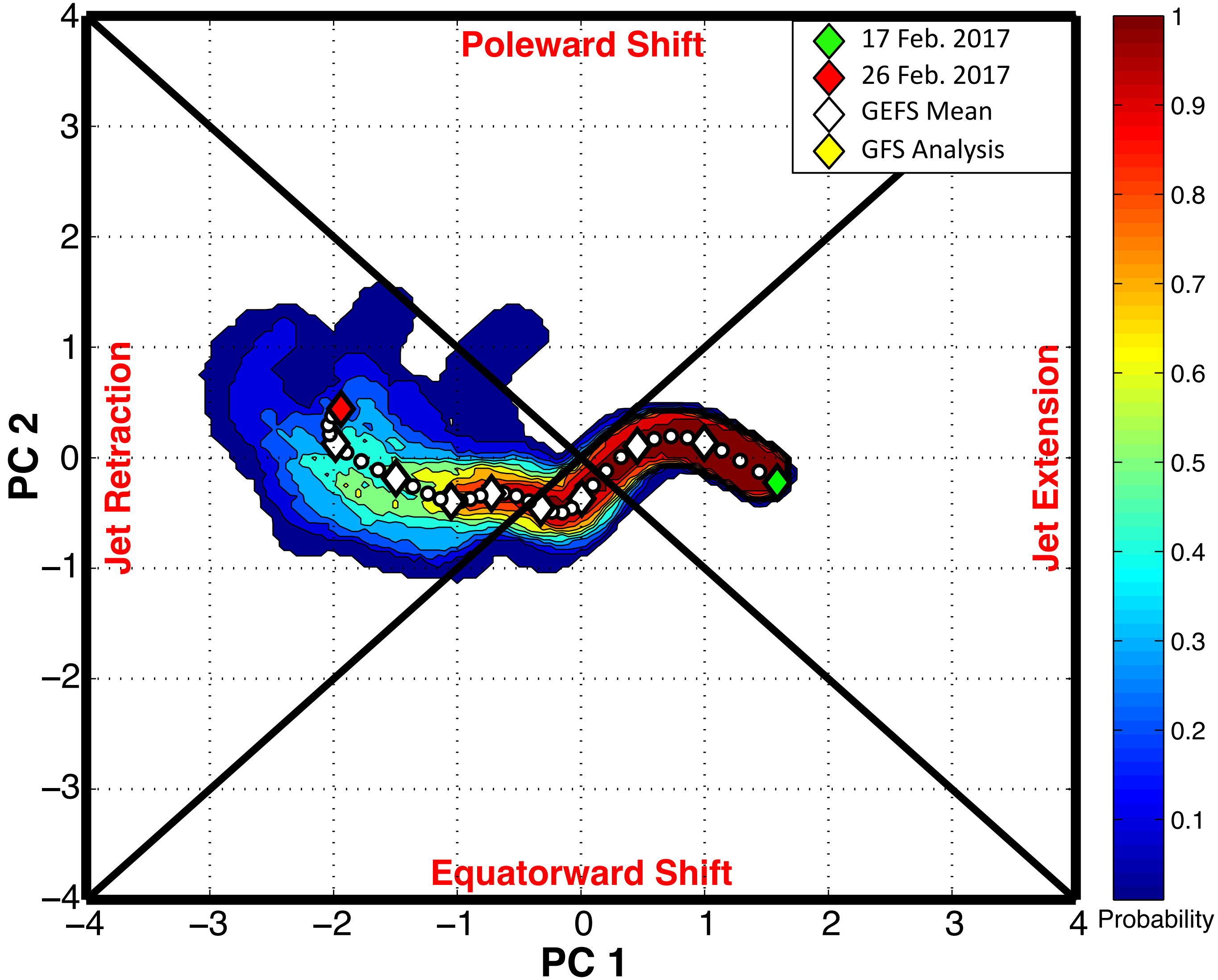
- Recall, the worst NPJ phase diagram forecasts initialized during a **jet extension** are frequently associated with significantly higher heights over the North Pacific and significantly lower heights over North America 8 days after forecast initialization



Composite Difference: (Worst – Best) at 192 h
250 hPa
60
40
20
-120
−240 −210 −180 −150 −120 −90 −60 −30 30 60 90 120 150 180 210 240
m
99% Conf. Interval
0000 UTC 26 February: 250-hPa Jet (shading) and Precipitable Water Anom. (shading)
40 50 60 70 80 90 100 110
m s−1
1 2 3 4 5 6
σ

February 2017 NPJ Regime Change

9-day Probabilistic Forecast Trajectory Initialized at 0000 UTC 17 February 2017



- The GEFS ensemble forecast indicated the NPJ regime transition was likely

February 2017 NPJ Regime Change

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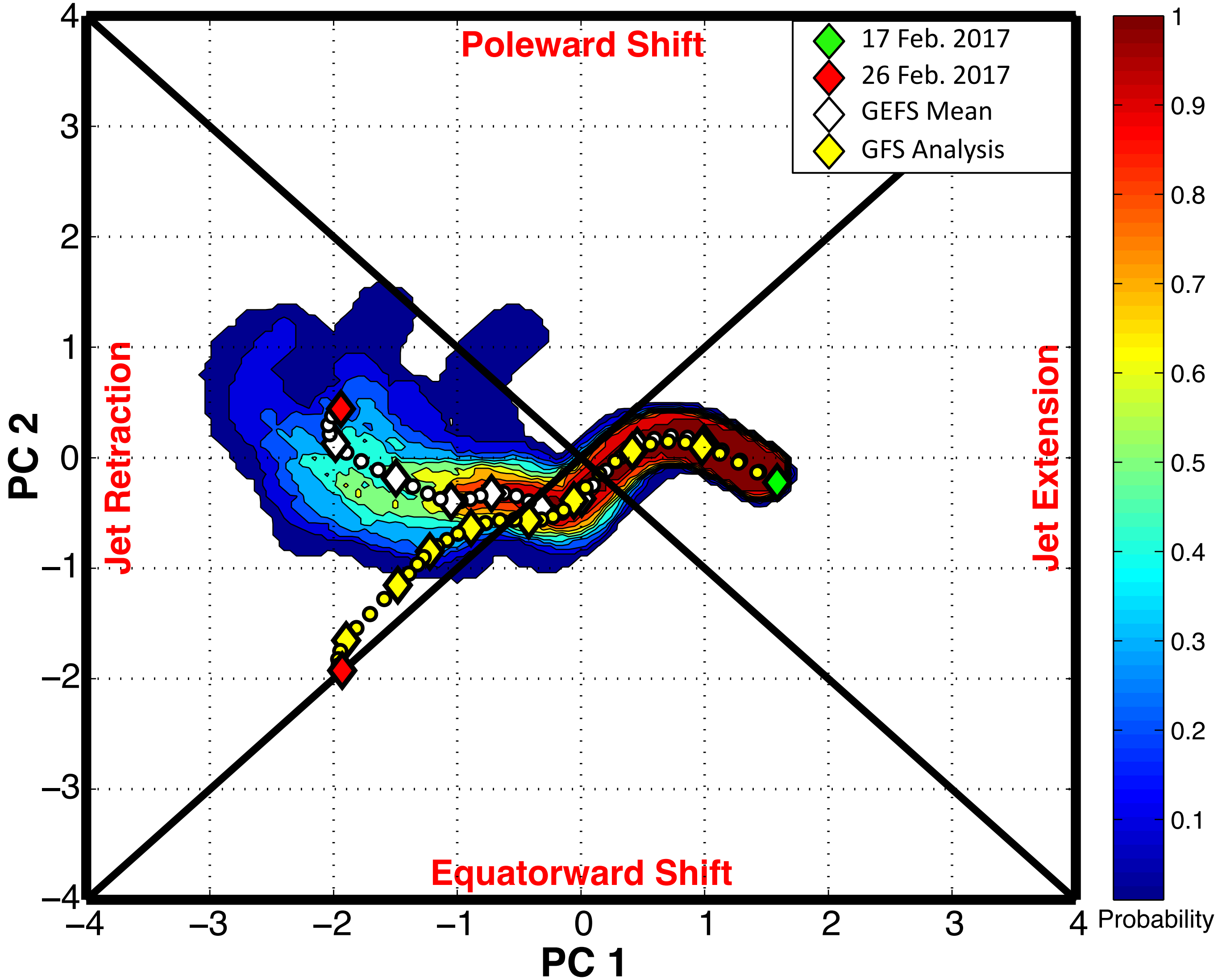
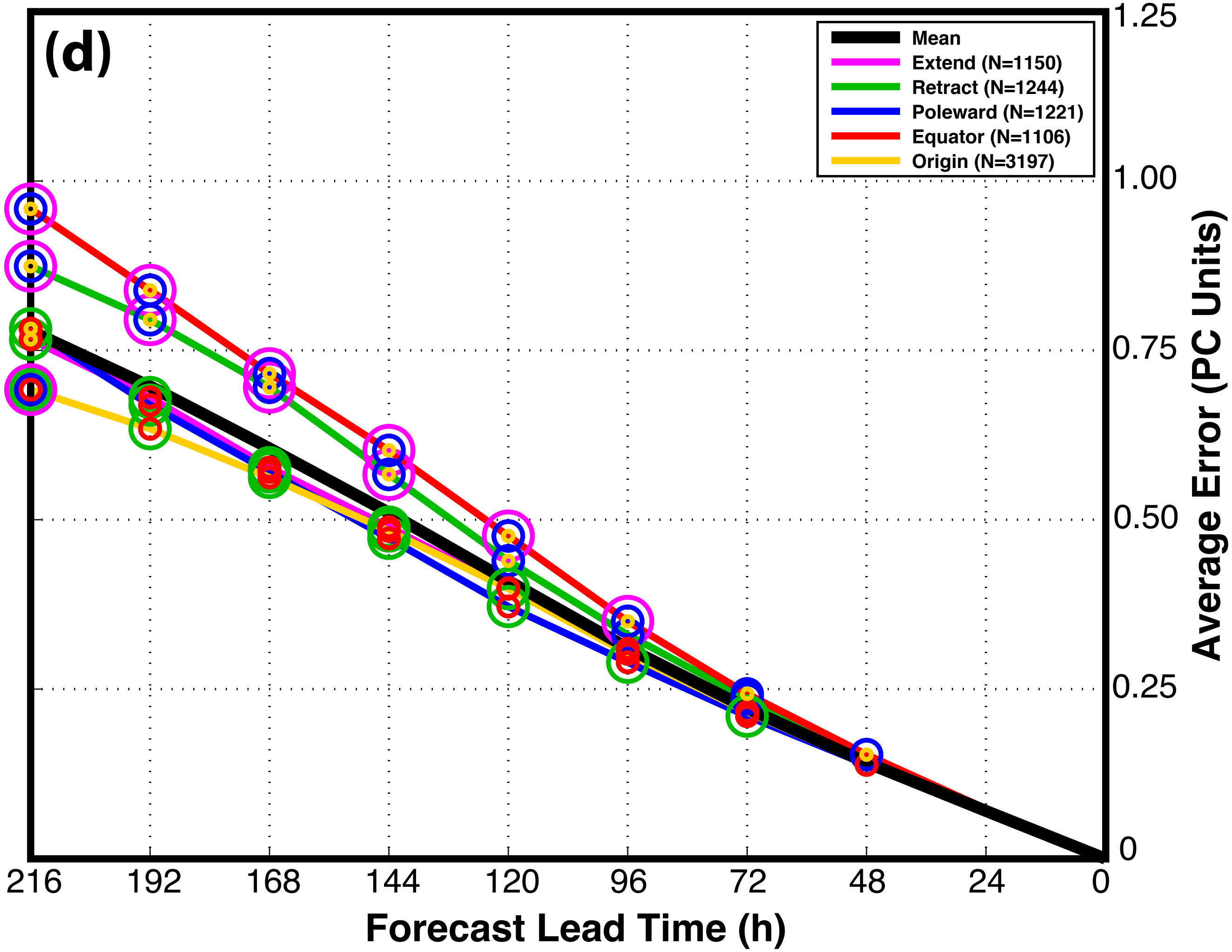


- The GEFS ensemble forecast indicated the NPJ regime transition was likely
- The GEFS ensemble did not capture an **equatorward shift** of the NPJ axis
- This 9-day forecast ranked 2nd worst during the 2016–2017 cool season

GEFS Ensemble Mean Error by NPJ Regime



GEFS Reforecasts *verifying* during a particular NPJ regime

Circles on a particular line indicate statistically significant differences at the 99% confidence level with respect to another NPJ regime

Forecasts verifying during **equatorward shifts** and **jet retractions** exhibit significantly larger errors than **jet extensions** and **poleward shifts** in the 96–216-h forecast period

Summary: February 2017 NPJ Regime Change

- Knowledge of both the forecast skill and the downstream upper-tropospheric flow pattern associated with each NPJ regime offers the potential to increase confidence in operational temperature forecasts over the continental U.S.

- The **retraction** and **equatorward shift** of the NPJ in late-February 2017 was associated with the development of an upper-tropospheric block over the North Pacific, as well as above-normal/below-normal temperatures in the eastern/western U.S.

- The NPJ regime transition towards a **jet retraction** and **equatorward shift** was characterized by large medium-range NPJ phase diagram forecast errors

NPJ Phase Diagram Web Interface

- A web interface has been developed that offers real time NPJ phase diagram forecasts and extreme event composites:

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

NPJ 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.

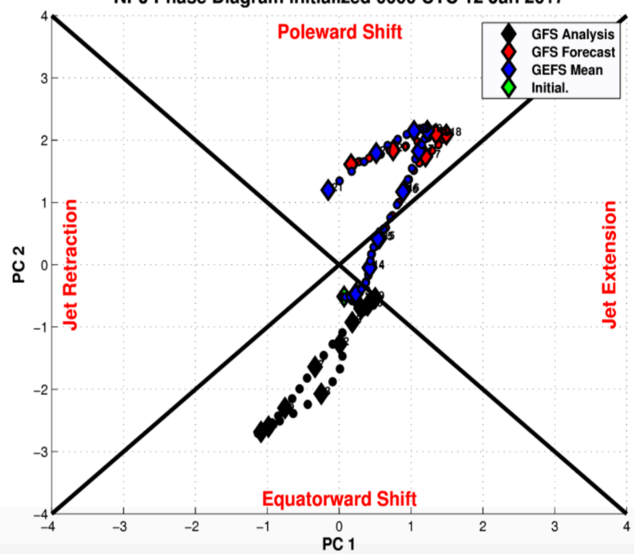
Synoptic Maps (right): Depicts GFS deterministic forecasts of (1) 250-hPa wind speed, geo. heights, and standardized geo. height anomalies, (2) 500-hPa relative vorticity, geo. heights, and standardized geo. height anomalies (3) mean sea level pressure, 1000-500-hPa thickness, and 850-hPa standardized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

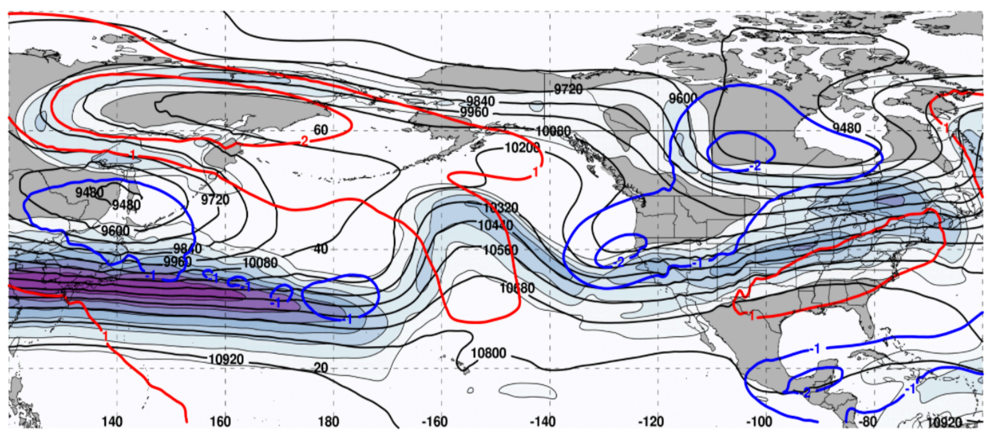
Deterministic Forecast | Probabilistic Forecast | Ens. Spread Forecast | D(prog)/Dt

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

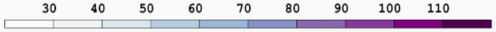
250-hPa Jet/Hght/Hght'	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8	+9
500-hPa Vort/Hght/Hght'	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8	+9
MSLP/Thick/Temp'	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8	+9
24-h Accum. Precip	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2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

NPJ Phase Diagram initialized 0000 UTC 12 Jan 2017





170112/0000V000 250 hPa Wind Speed (m/s), Geo. Hght & Std. Hght Anom (m)



NPJ Phase Diagram Web Interface

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

Contact: acwinters@albany.edu

Collaborators: Mike Bodner (WPC), Arlene Laing (NOAA), Dan Halperin (WPC), Bill Lamberson (WPC), Josh Kastman (WPC), and Sara Ganetis (WPC)

Supplementary Slides

References

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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.

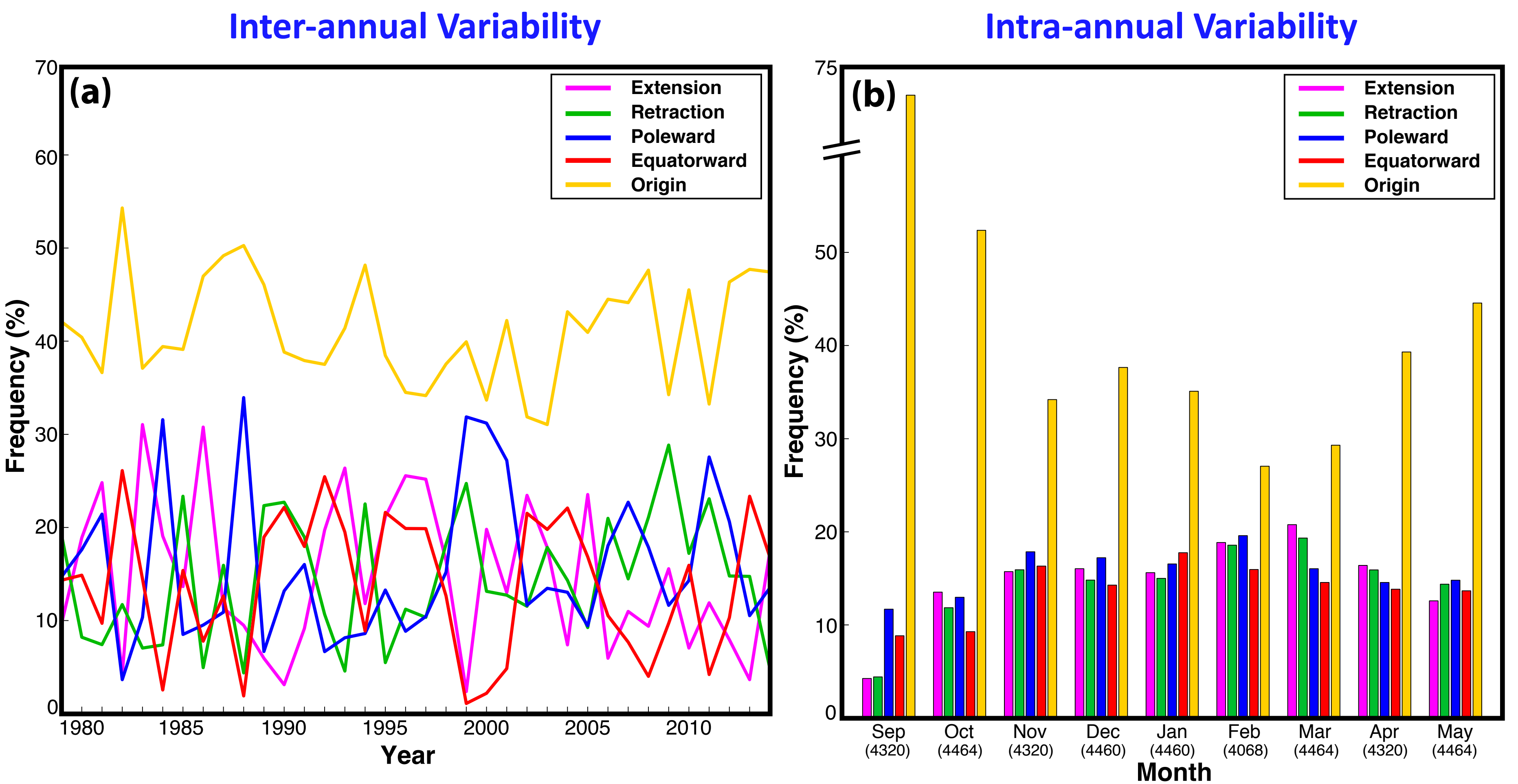
Hamill, T. M., G. T. Bates, J. S. Whitaker, D. R. Murray, M. Fiorino, T. J. Galarneau, Y. Zhu, and W. Lapenta, 2013: NOAA's Second-Generation Global Medium-Range Ensemble Forecast Dataset. *Bull. Amer. Meteor. Soc.*, **94,** 1553–1565.

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.

NPJ Characteristics

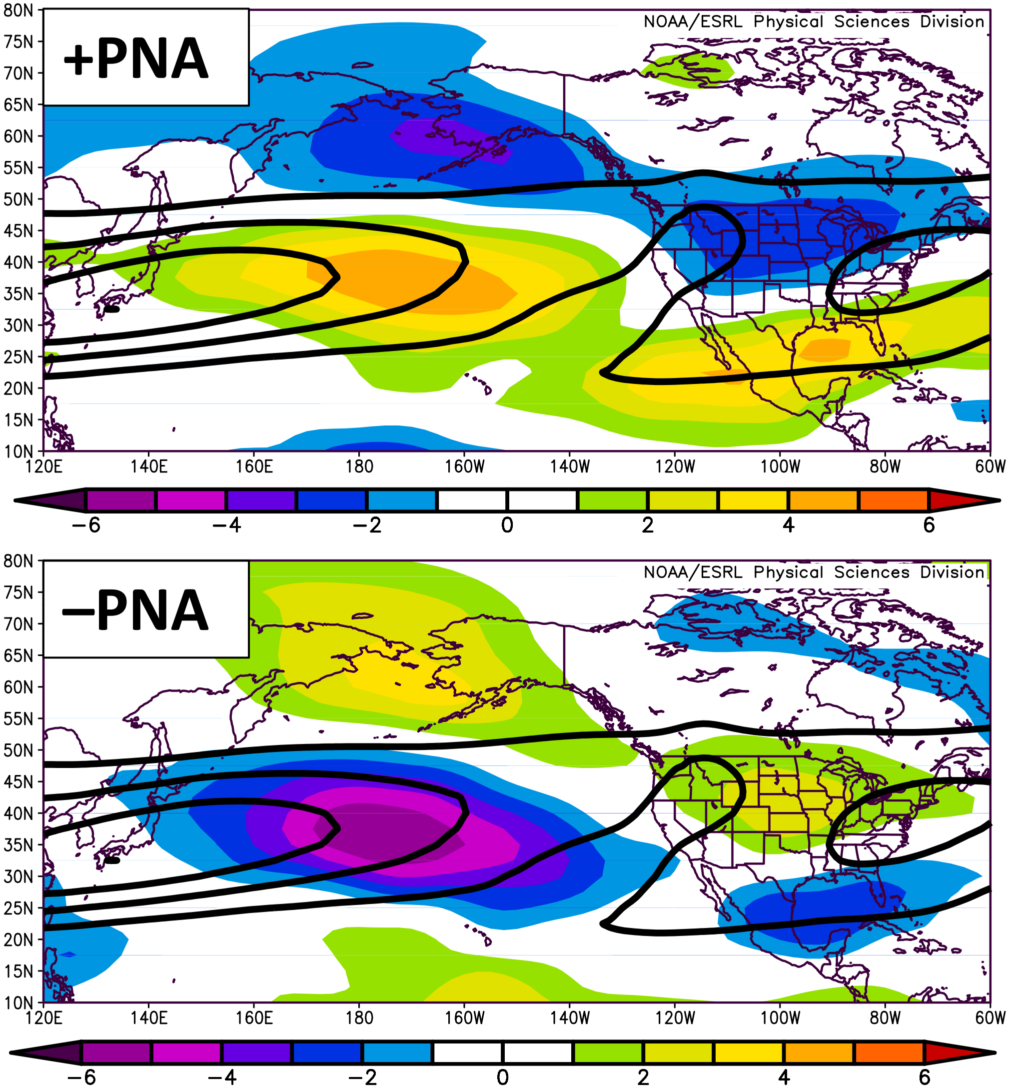
NPJ Regime Characteristics



- The frequency of each NPJ regime exhibits considerable inter-annual and intra-annual variability

NPJ Regime Characteristics

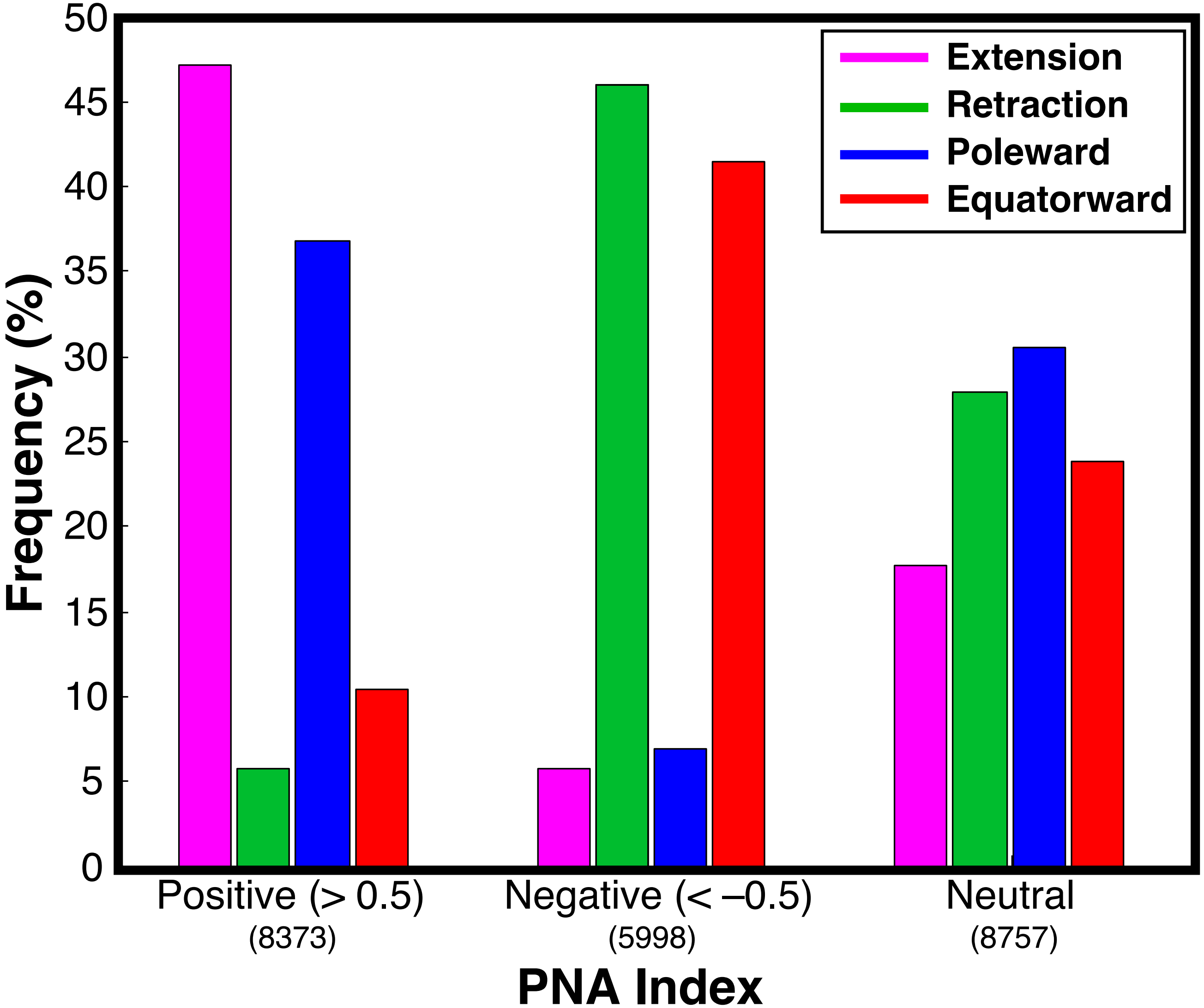
Composite 250-hPa Zonal Wind Anomalies (m s^{-1})



- A positive PNA pattern is characterized by above-normal 250-hPa zonal wind speed in the exit region of the climatological NPJ
- A negative PNA pattern is characterized by below-normal 250-hPa zonal wind speed in the exit region of the climatological NPJ

NOAA/ESRL

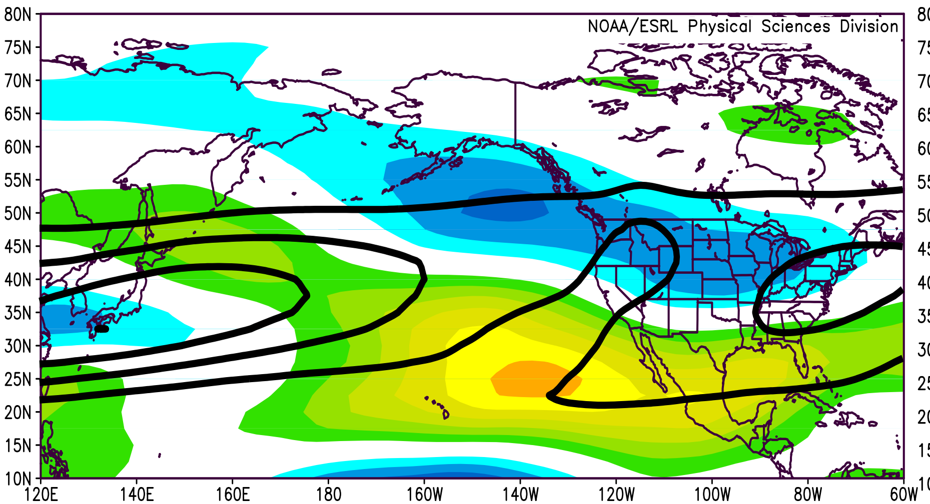
NPJ Regime Characteristics



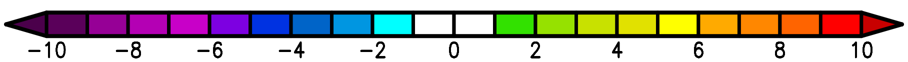
- Jet extensions and poleward shifts are favored during a positive PNA
- Jet retractions and equatorward shifts are favored during a negative PNA

NPJ Regime Characteristics

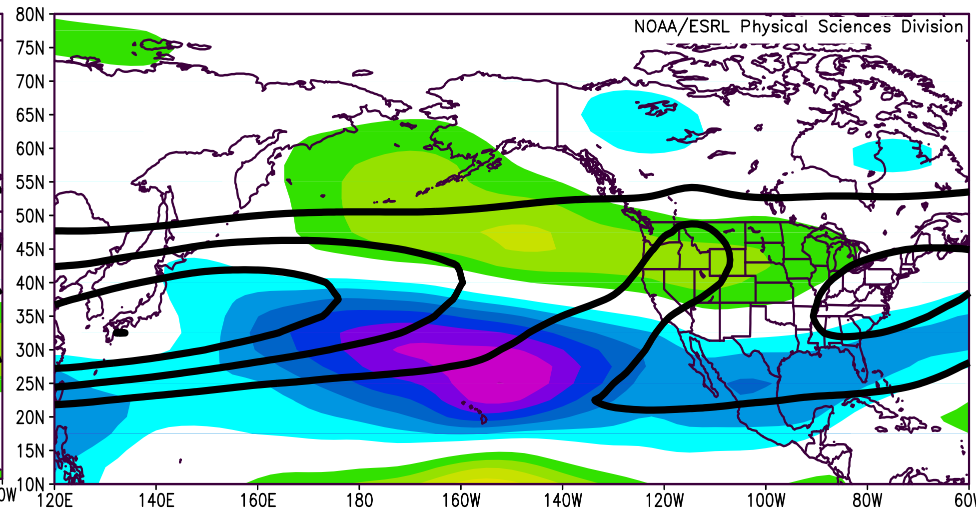
El Niño



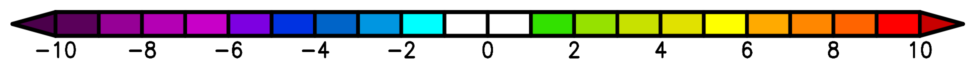
Composite 250-hPa Zonal Wind Anomalies (m s^{-1})



La Niña



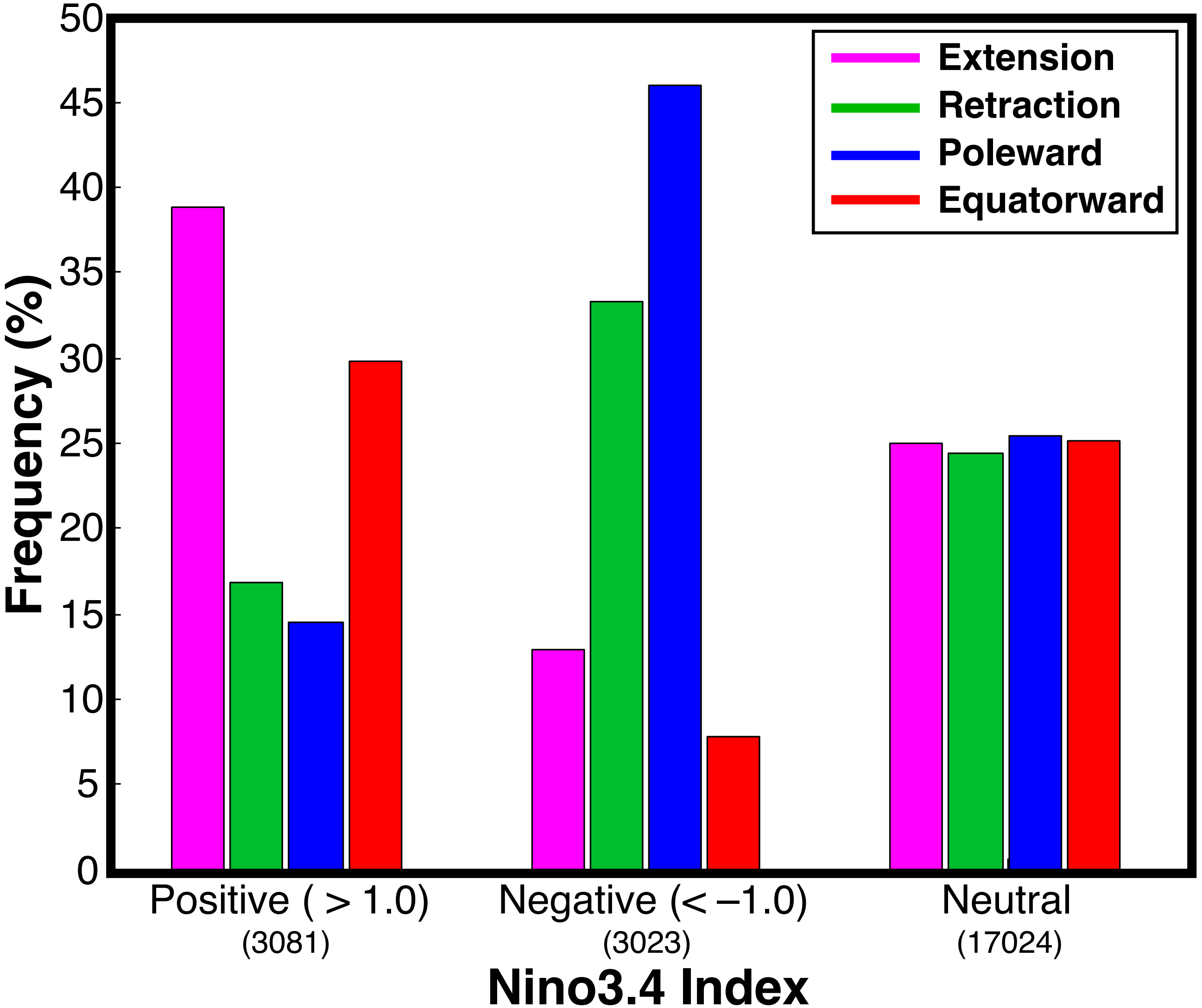
Composite 250-hPa Zonal Wind Anomalies (m s^{-1})



- El Niño favors anomalously strong zonal wind speed east of the dateline over the North Pacific
- La Niña favors anomalously weak zonal wind speed east of the dateline over the North Pacific

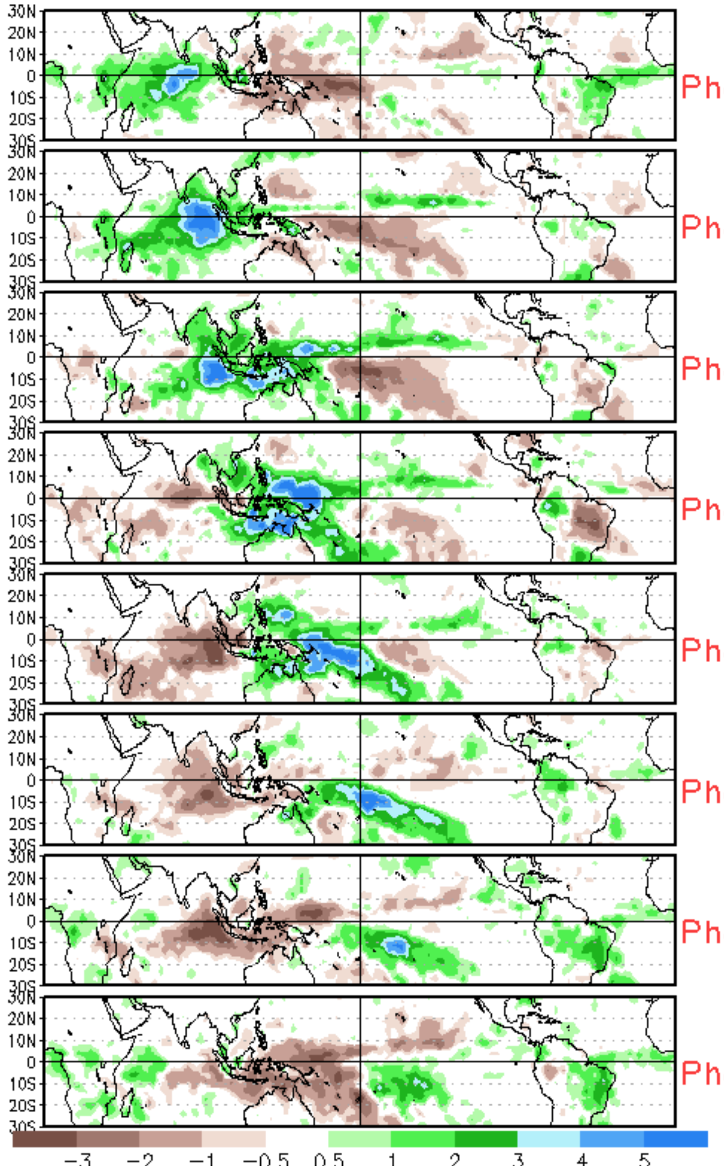
NOAA/ESRL

NPJ Regime Characteristics



- **Jet extensions** and **equatorward shifts** are favored during an El Niño
- **Jet retractions** and **poleward shifts** are favored during a La Niña

NPJ Regime Characteristics

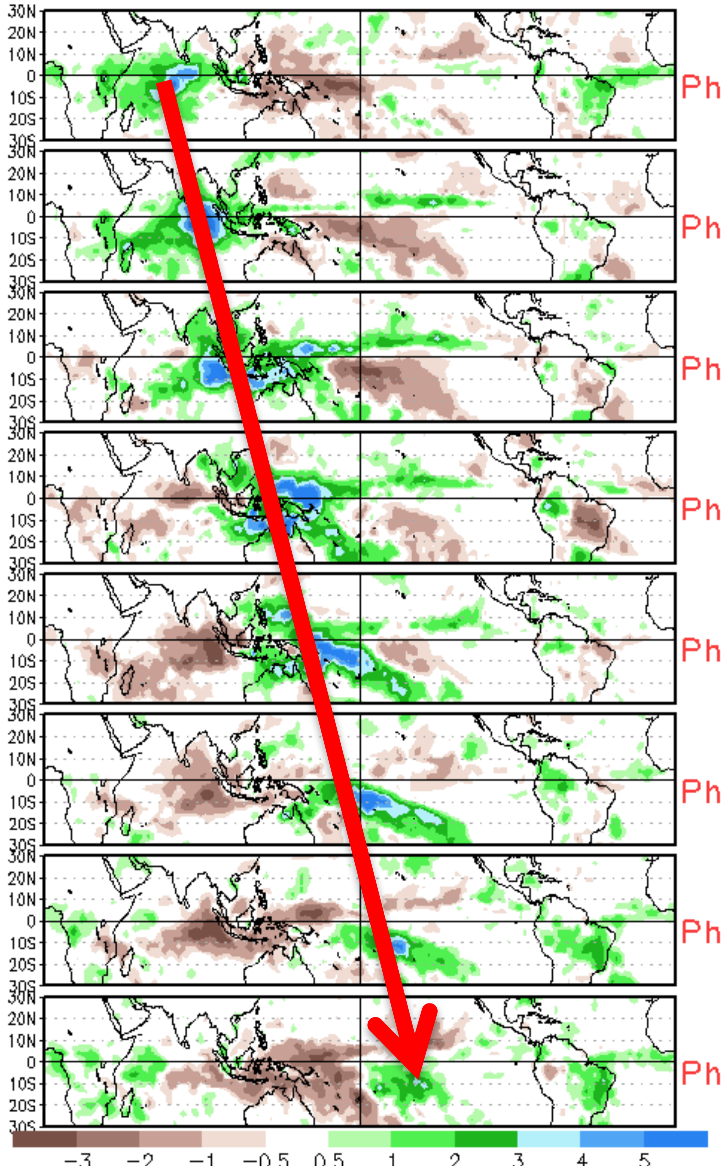


Nov–Mar Composite Daily Precipitation (mm)

- The Madden–Julian Oscillation (MJO) is a leading mode of intra-annual variability in the tropics with a period of 30–60 days

Climate Prediction Center

NPJ Regime Characteristics

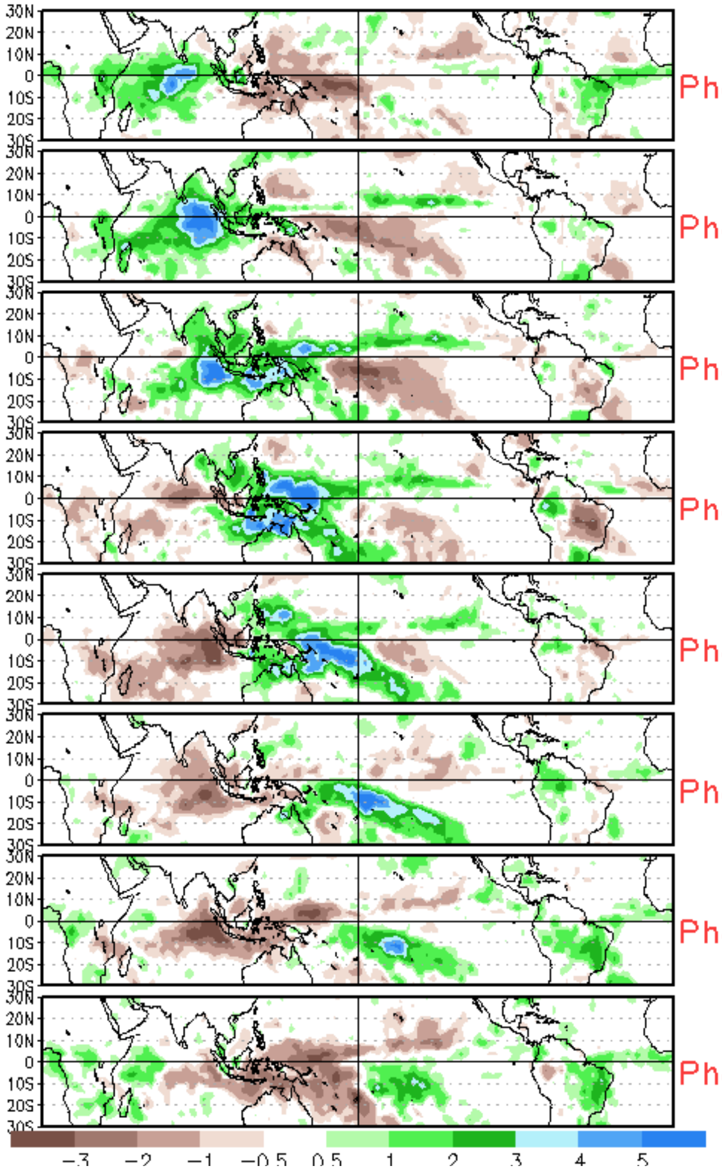


Nov–Mar Composite Daily Precipitation (mm)

- The Madden–Julian Oscillation (MJO) is a leading mode of intra-annual variability in the tropics with a period of 30–60 days
- The MJO is characterized by an eastward propagating region of enhanced convection in the equatorial Indian and Pacific Oceans

Climate Prediction Center

NPJ Regime Characteristics

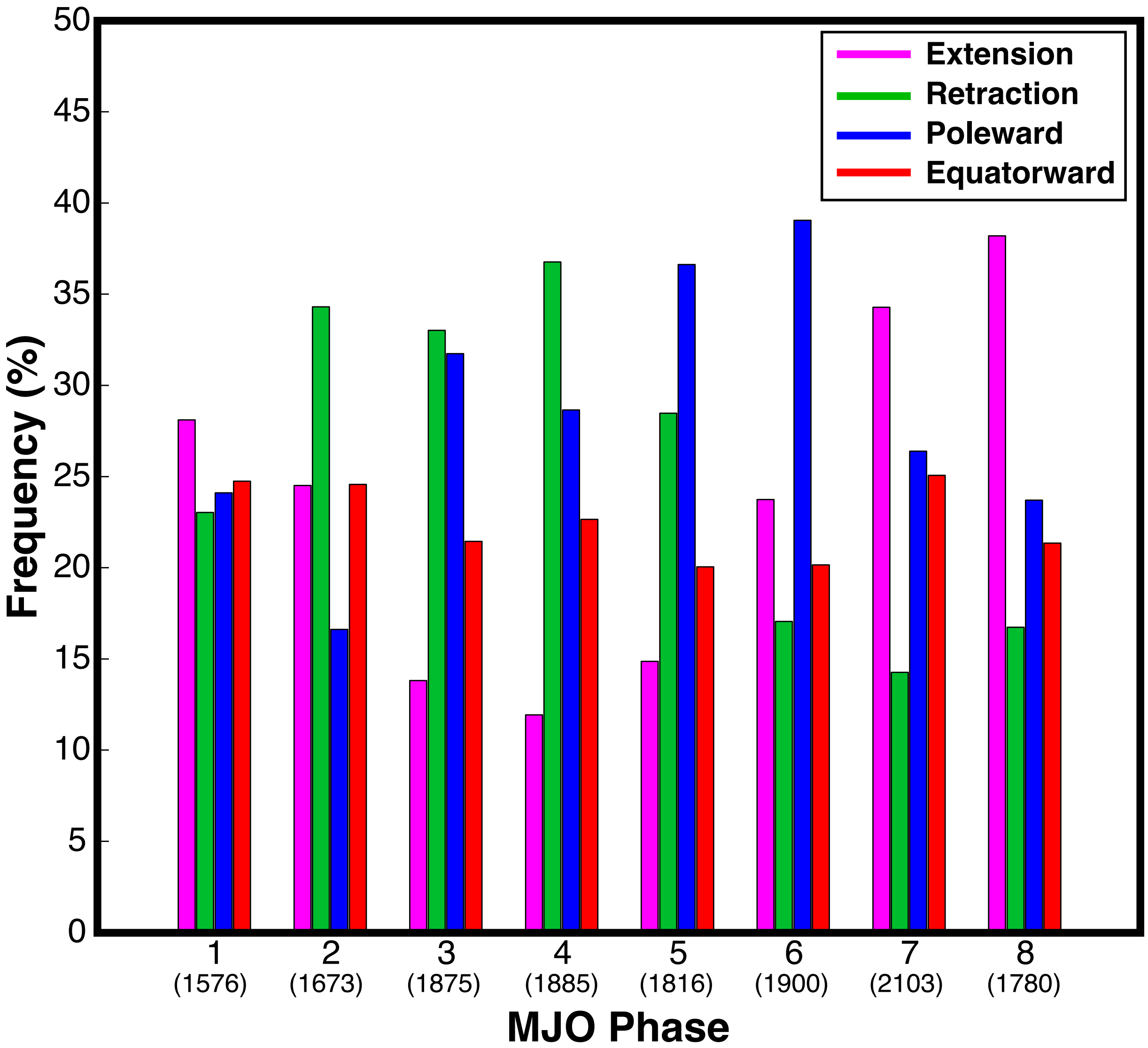


Nov–Mar Composite Daily Precipitation (mm)

- The Madden–Julian Oscillation (MJO) is a leading mode of intra-annual variability in the tropics with a period of 30–60 days
- The MJO is characterized by an eastward propagating region of enhanced convection in the equatorial Indian and Pacific Oceans
- The location of convection can strongly modulate the midlatitude circulation

Climate Prediction Center

NPJ Regime Characteristics



- **Jet retractions** are favored during Phases 2, 3, and 4
- **Poleward shifts** are favored during Phases 5 and 6
- **Jet extensions** are favored during Phases 7, 8, and 1

Extreme Temp. Events

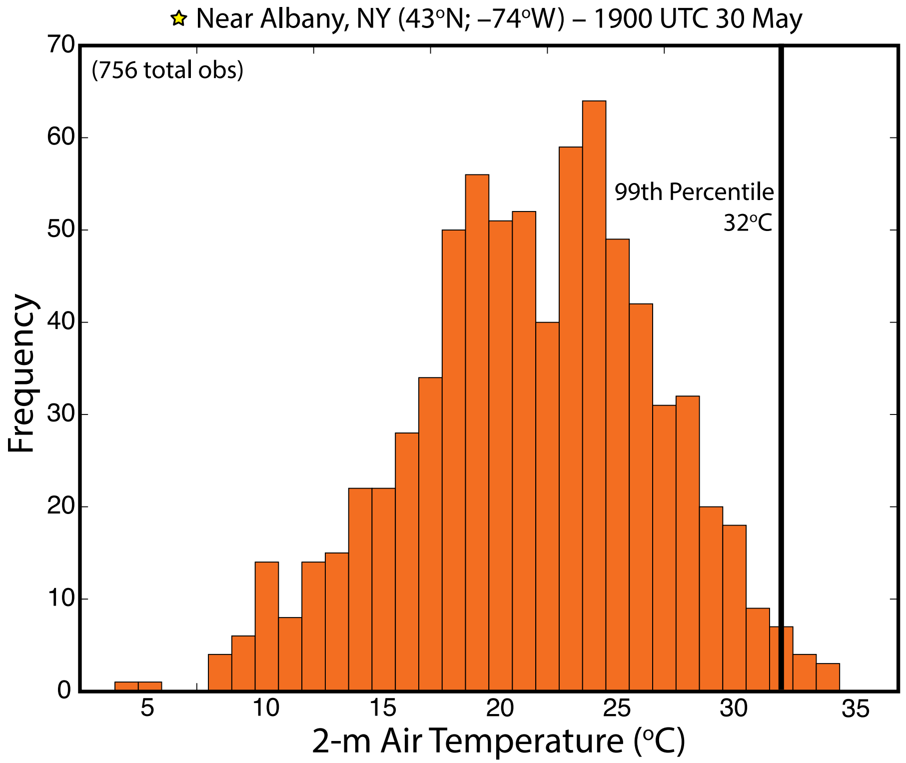
Extreme Event Identification

Extreme Warm Events:

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

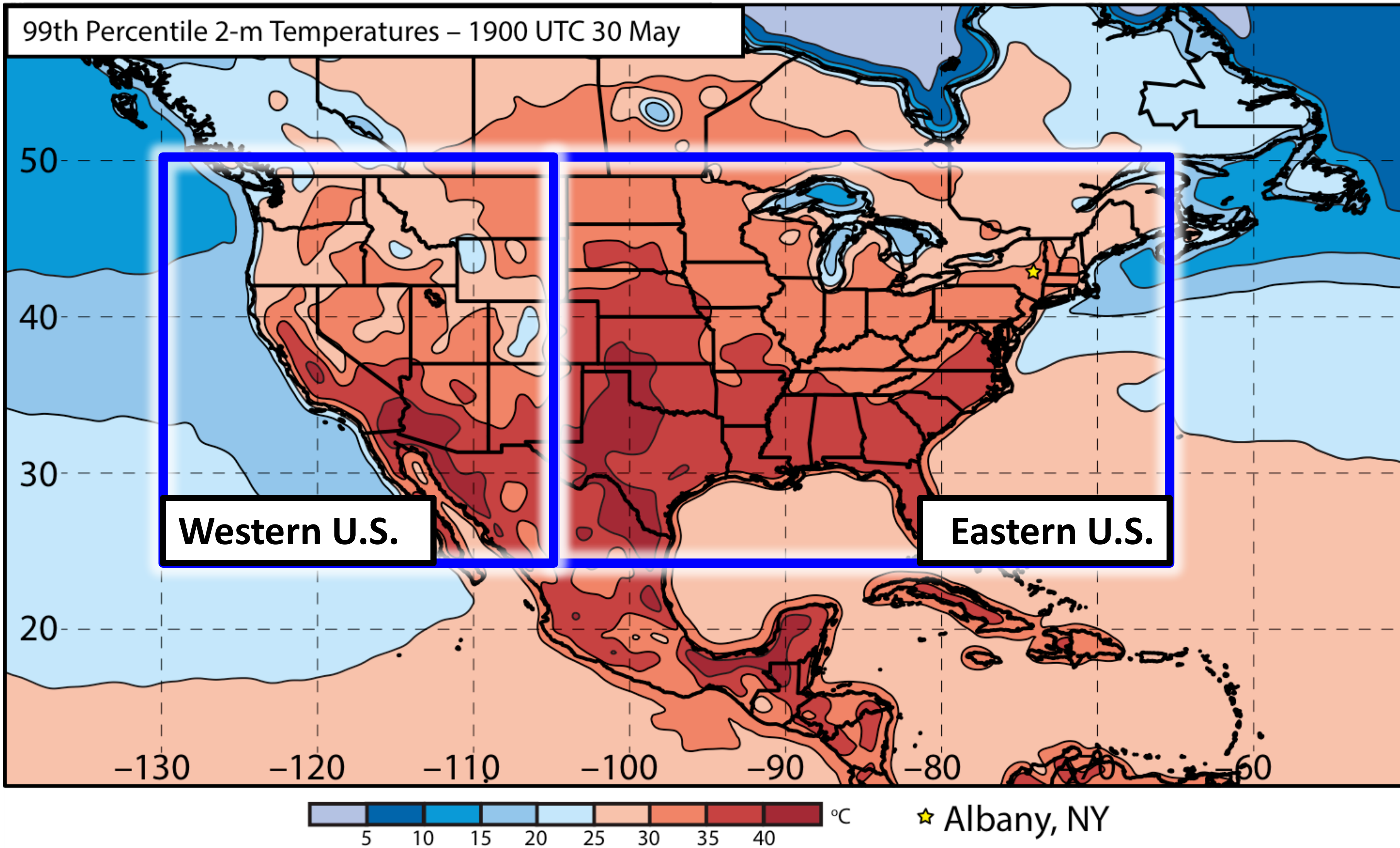
- Compiled data for each grid point within 21-day windows centered on each analysis time for 36 years, 1979–2014
  - Each grid point has 756 (21 × 36) data points for each analysis time

- 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

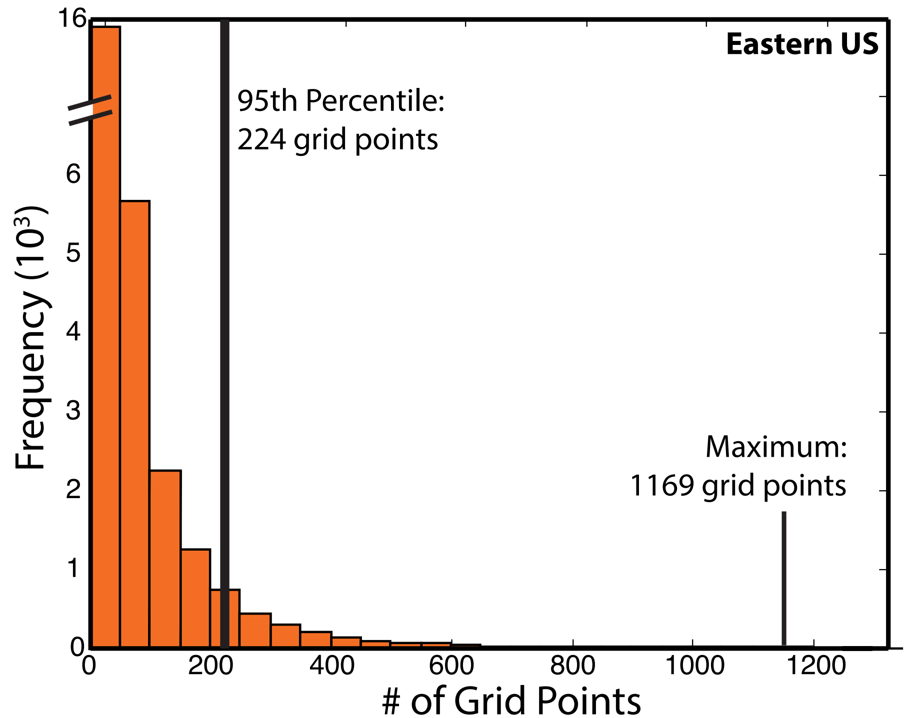
Extreme Event Identification



Extreme Event Identification

Extreme 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

Eastern U.S. Domain

Extreme Warm Events:

304 Events

Areal Coverage Threshold:

224 grid points

(~7.0°×7.0° box)

Extreme Cold Events:

225 Events

Areal Coverage Threshold:

221 grid points

(~7.0°×7.0° box)

Western U.S. Domain

Extreme Warm Events:

264 Events

Areal Coverage Threshold:

144 grid points

(~5.5°×5.5° box)

Extreme Cold Events:

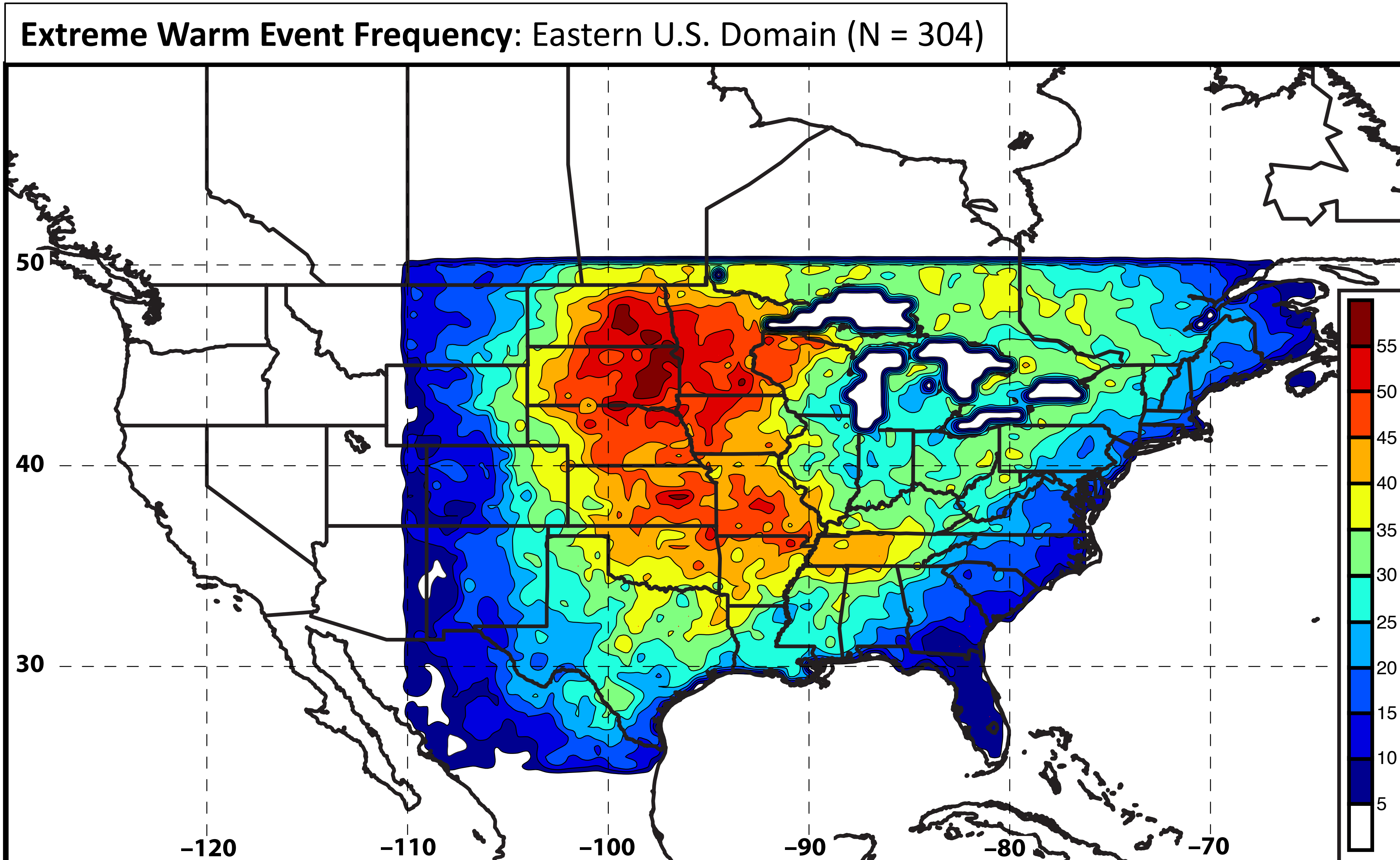
269 Events

Areal Coverage Threshold:

125 grid points

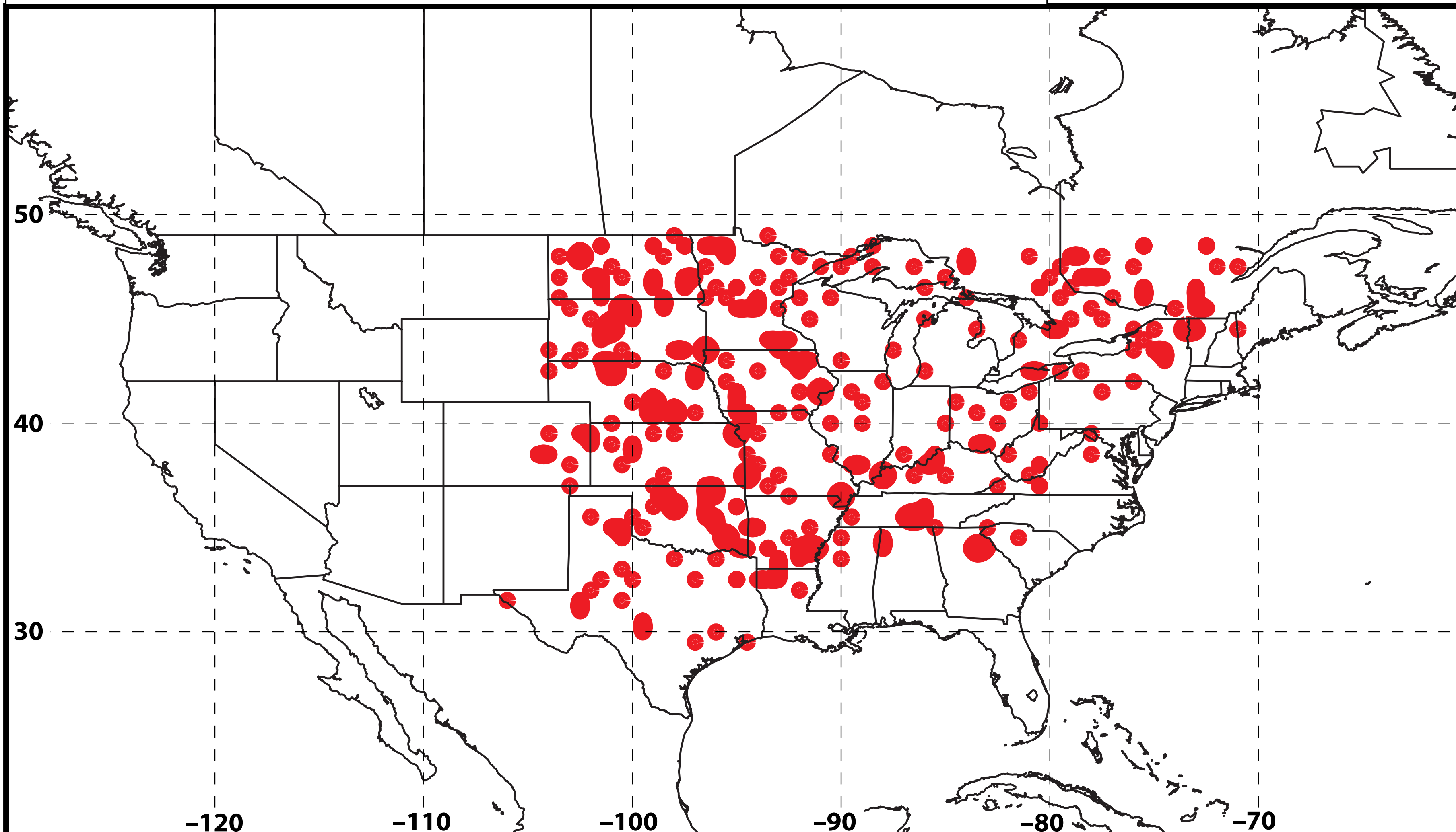
(~5.0°×5.0° box)

Extreme Event Identification

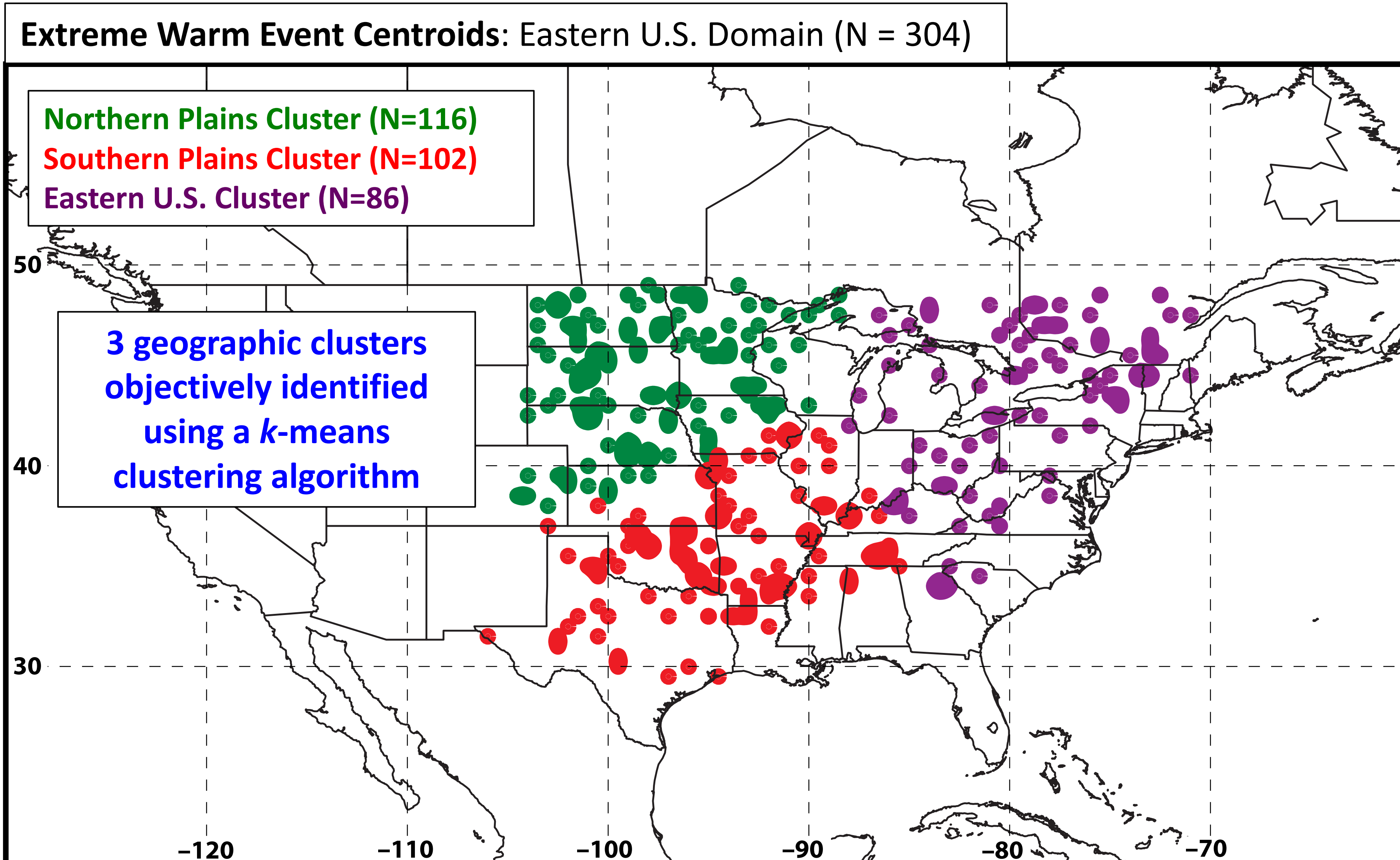


Extreme Event Identification

Extreme Warm Event Centroids: Eastern U.S. Domain (N = 304)



Extreme Event Identification



Extreme Event Identification

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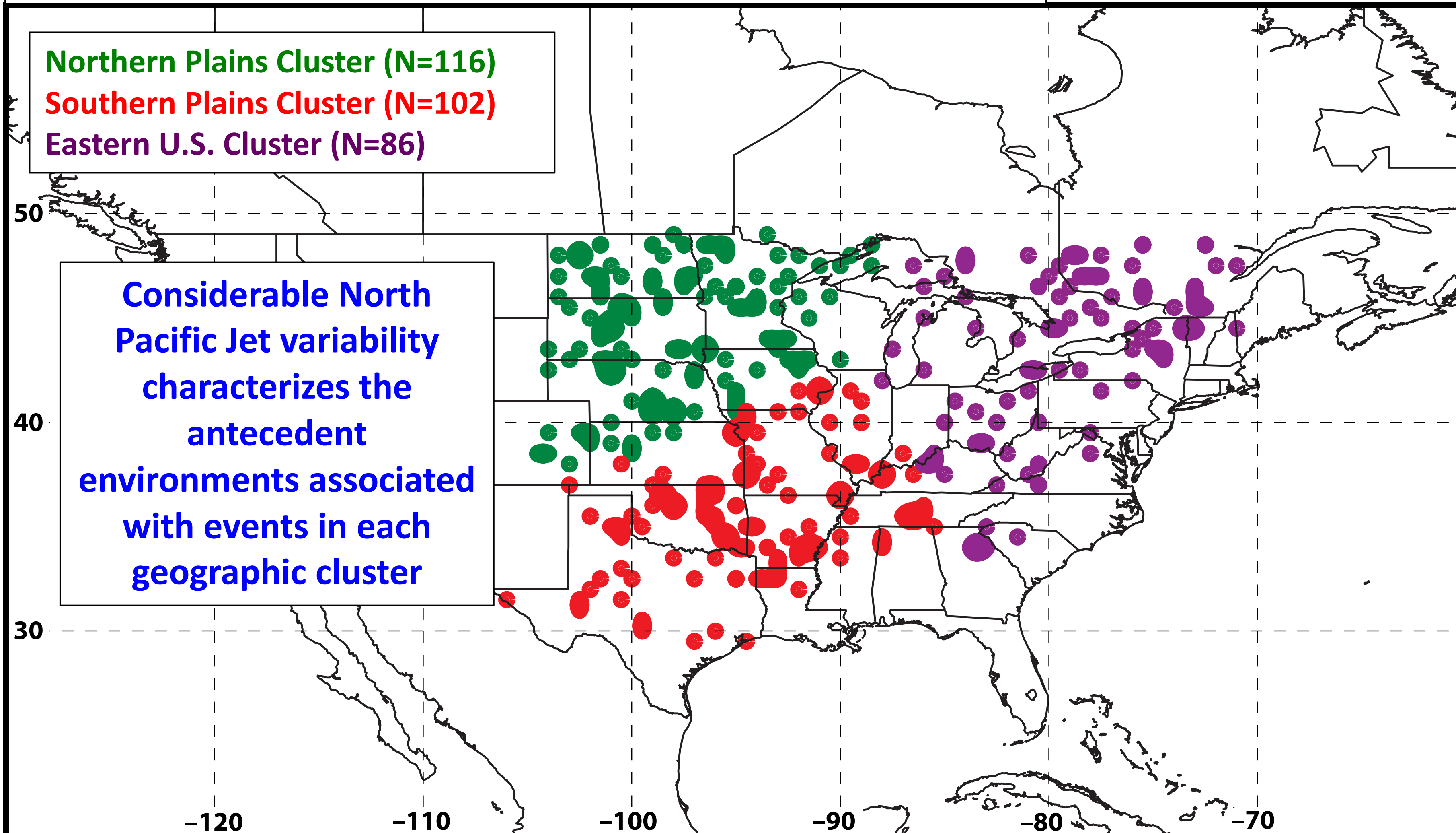
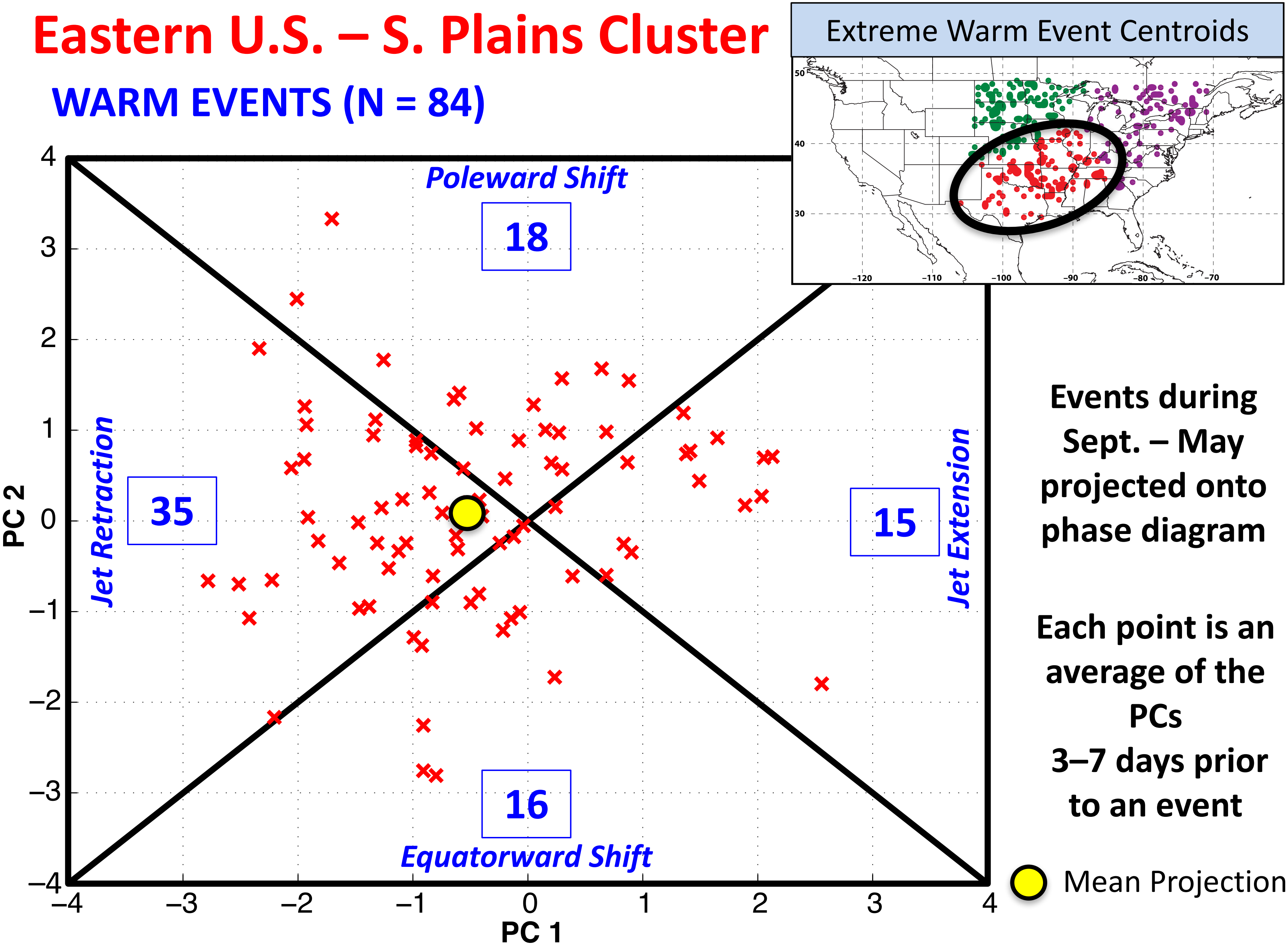


Eastern U.S. – S. Plains Cluster

WARM EVENTS (N = 84)

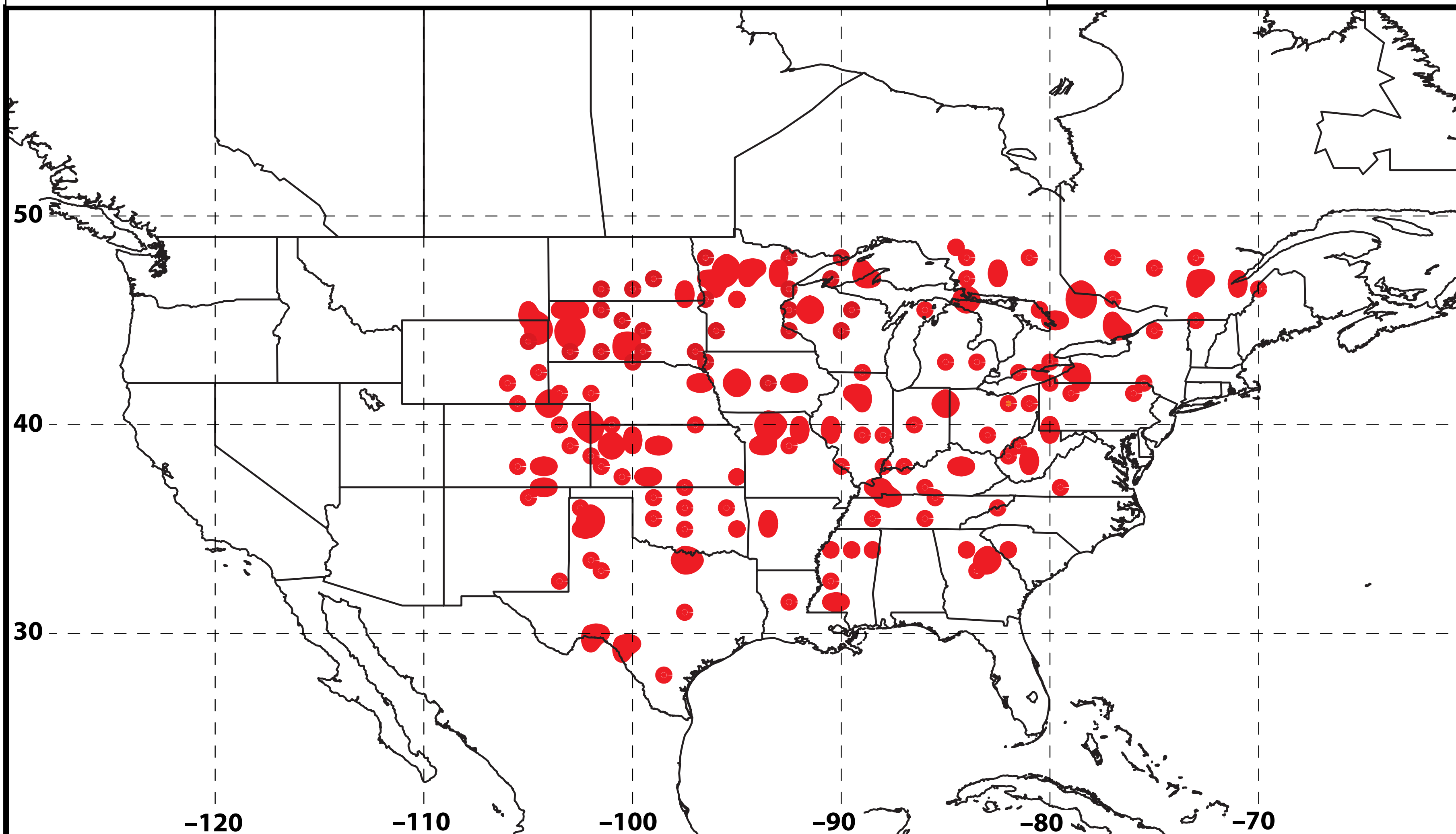


Events during Sept. – May projected onto phase diagram

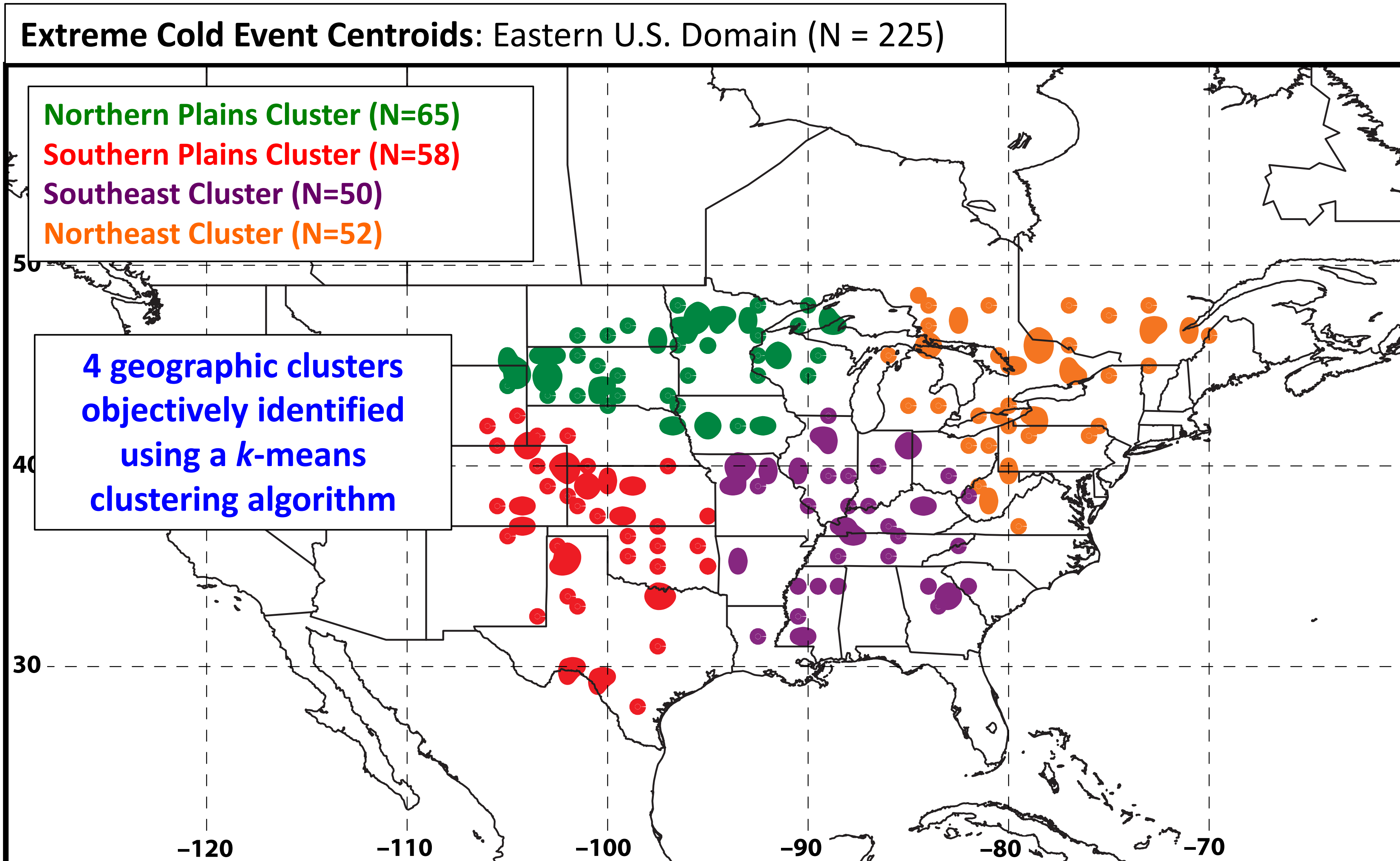
Each point is an average of the PCs 3–7 days prior to an event

250-hPa North Pacific Zonal Wind Variability

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

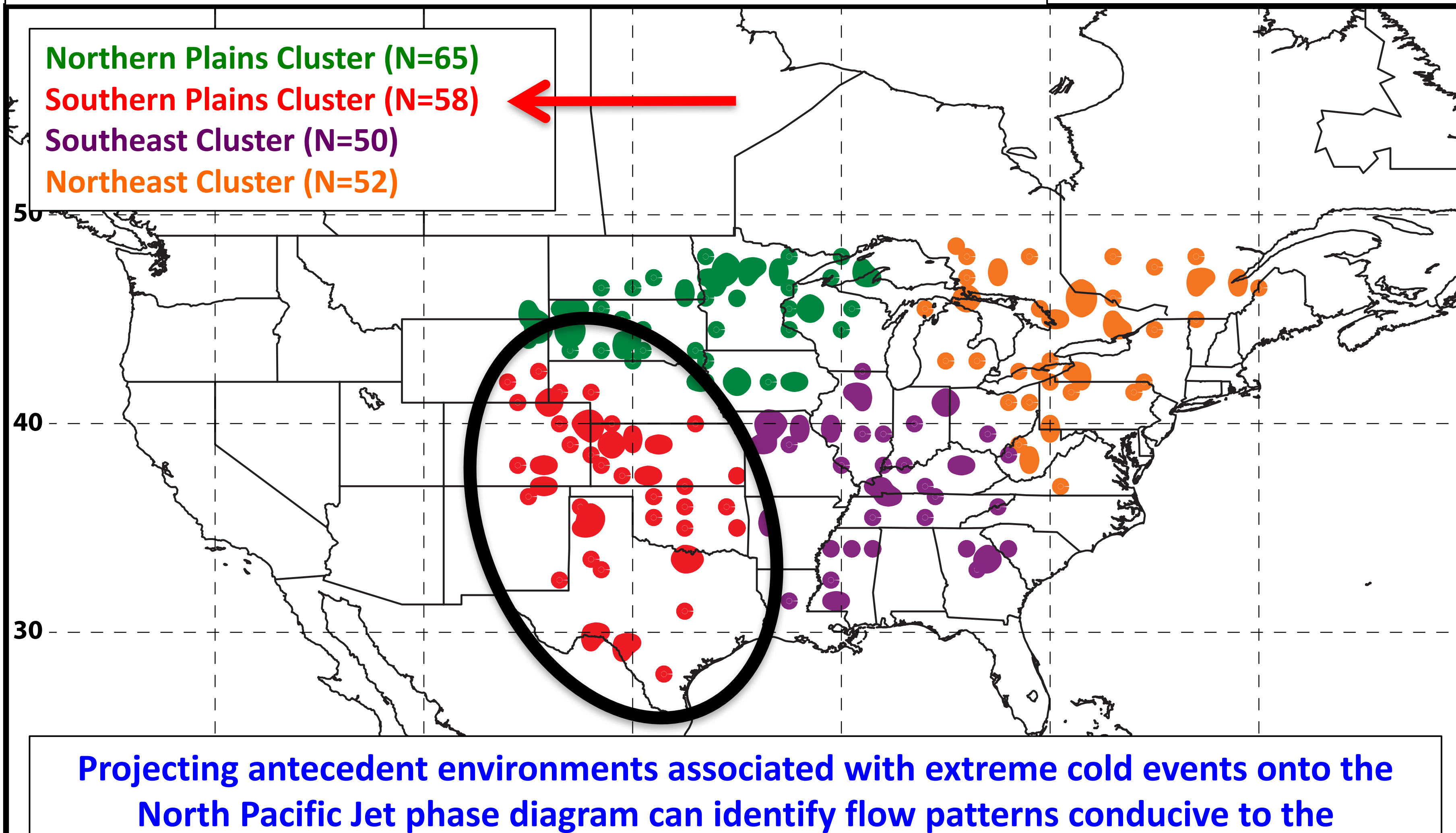


250-hPa North Pacific Zonal Wind Variability



250-hPa North Pacific Zonal Wind Variability

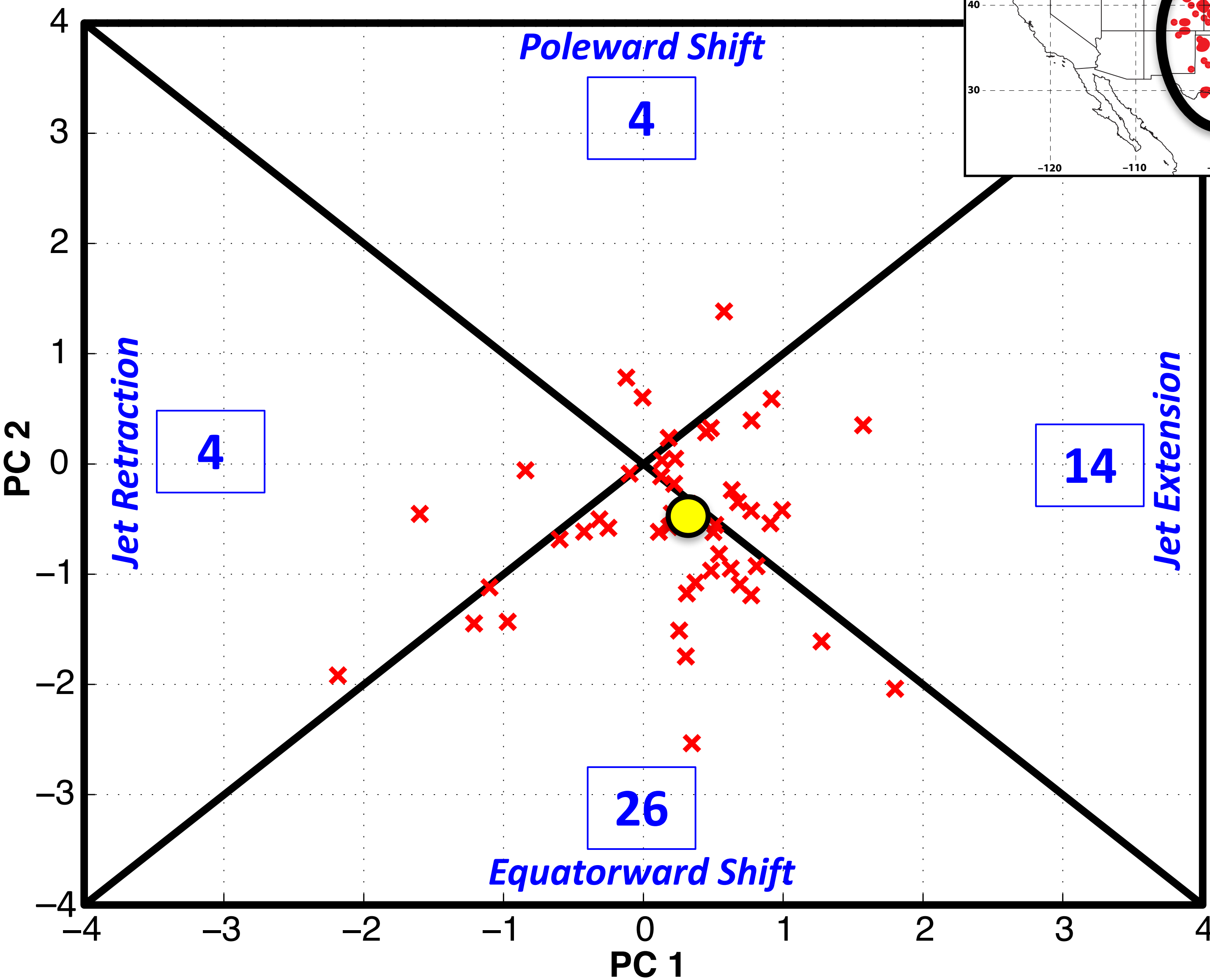
Extreme Cold Event Centroids: Eastern U.S. Domain (N = 225)

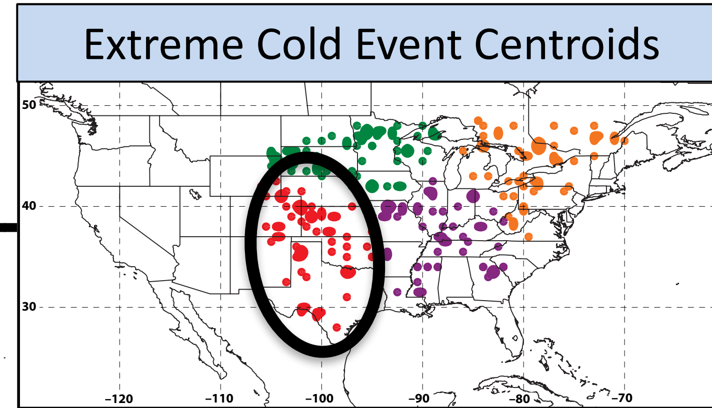


Projecting antecedent environments associated with extreme cold events onto the North Pacific Jet phase diagram can identify flow patterns conducive to the development of these events

Eastern U.S. – S. Plains Cluster

COLD EVENTS (N = 48)





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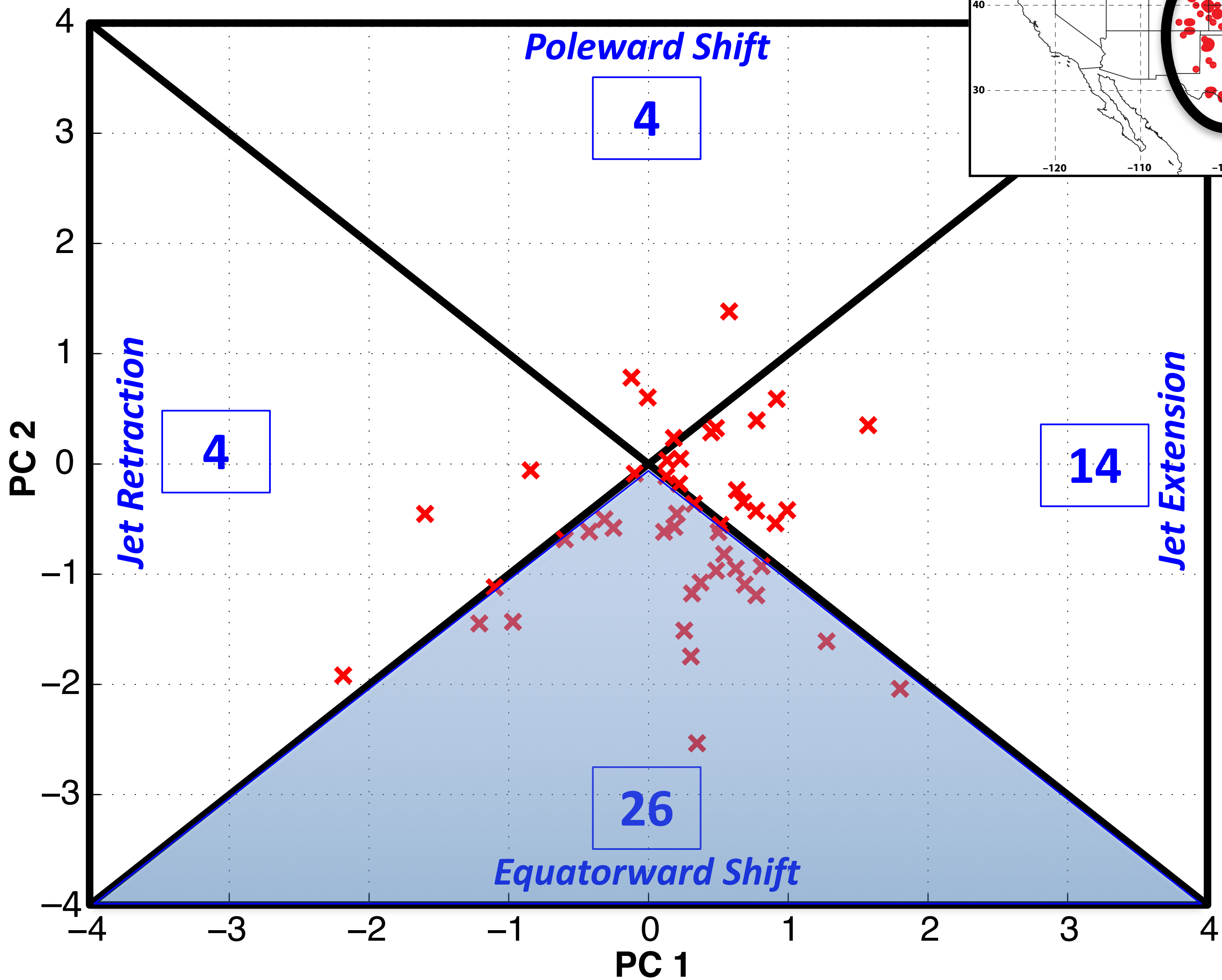
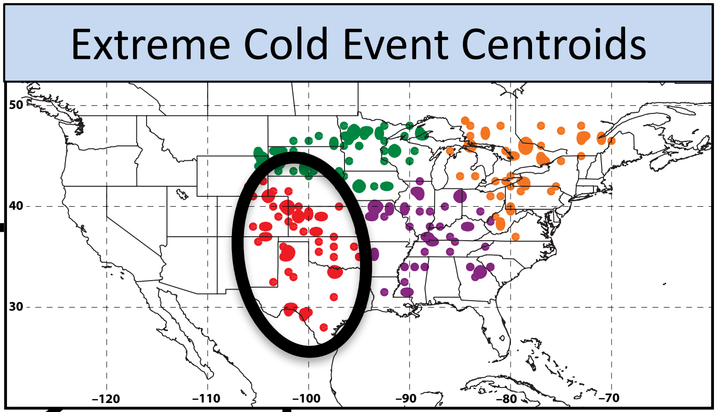
Mean Projection

Eastern U.S. – S. Plains Cluster

COLD EVENTS (N = 48)

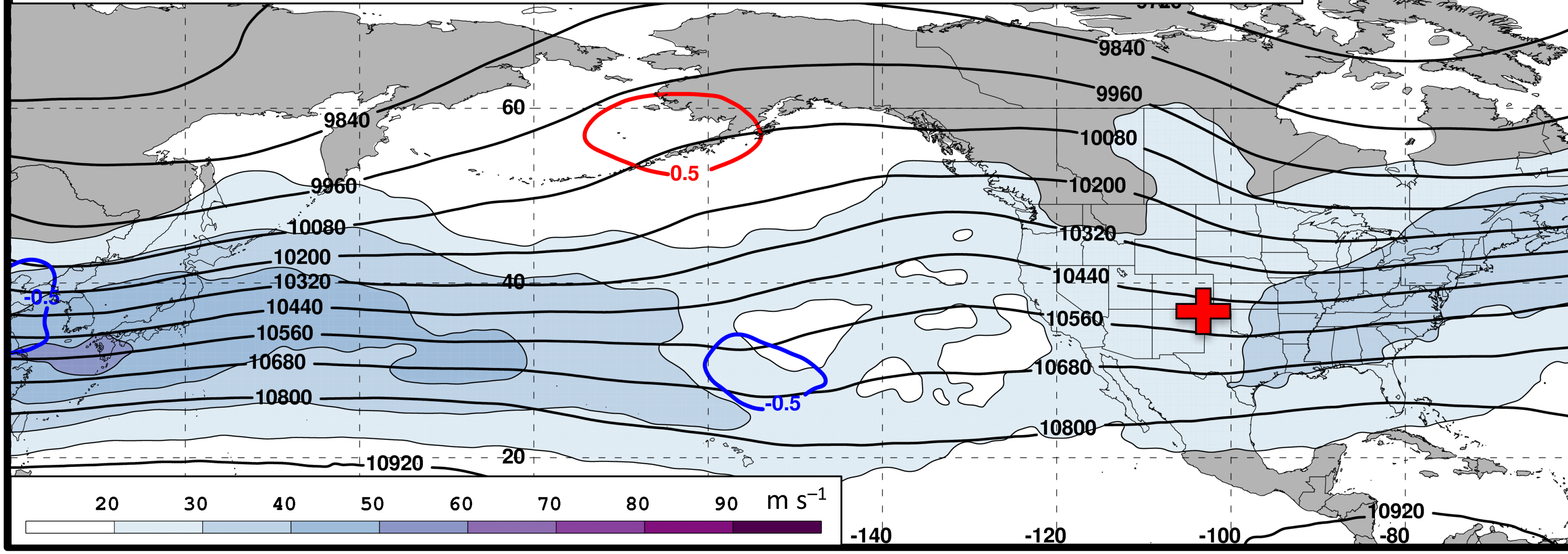




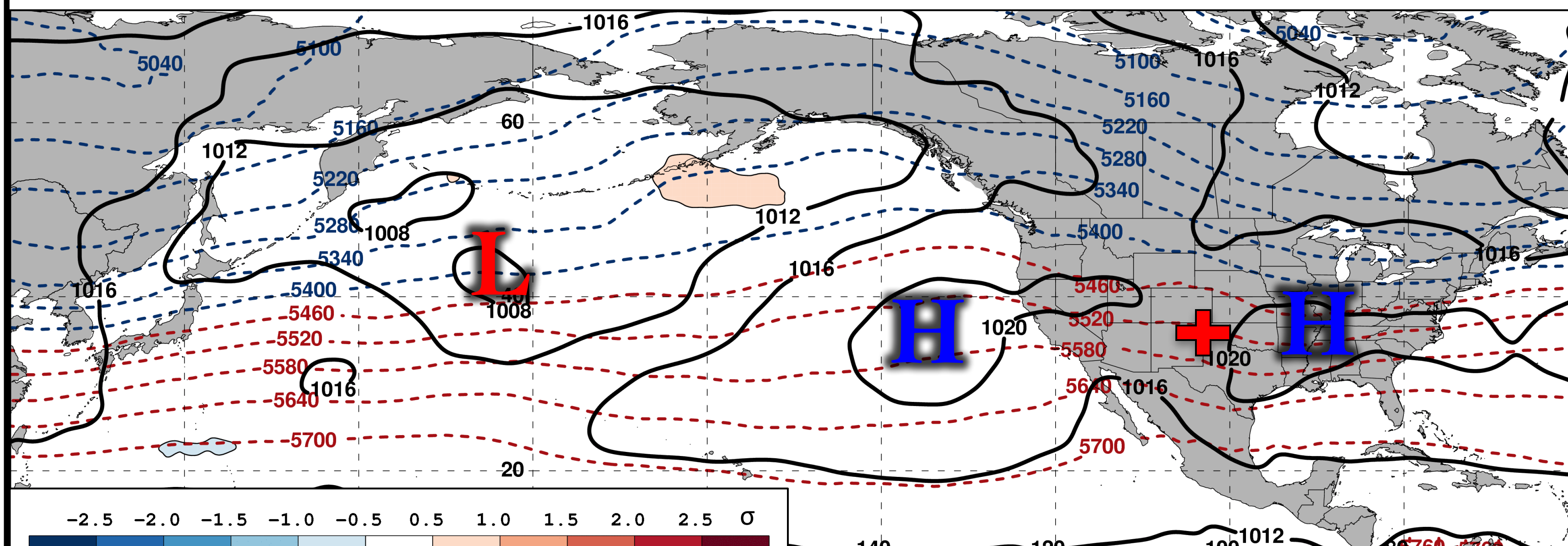
Events during Sept. – May projected onto phase diagram

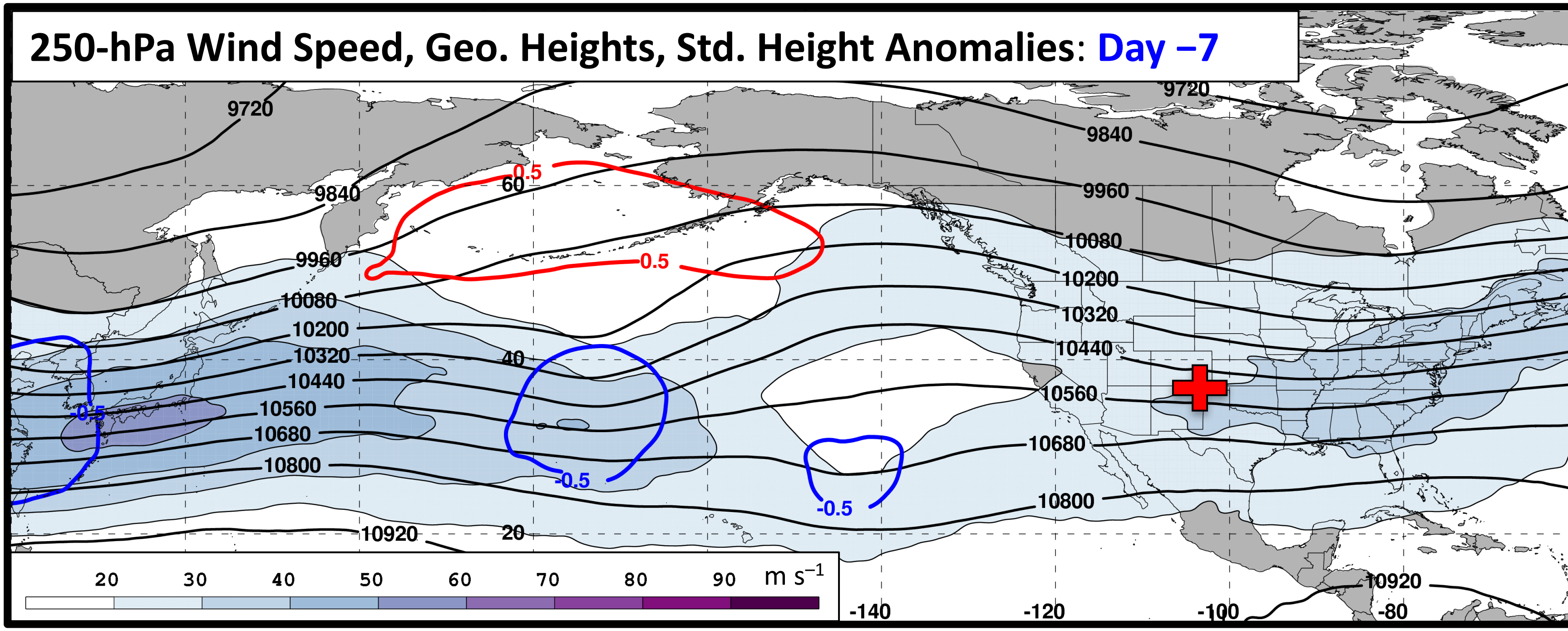
Each point is an average of the PCs 3–7 days prior to an event

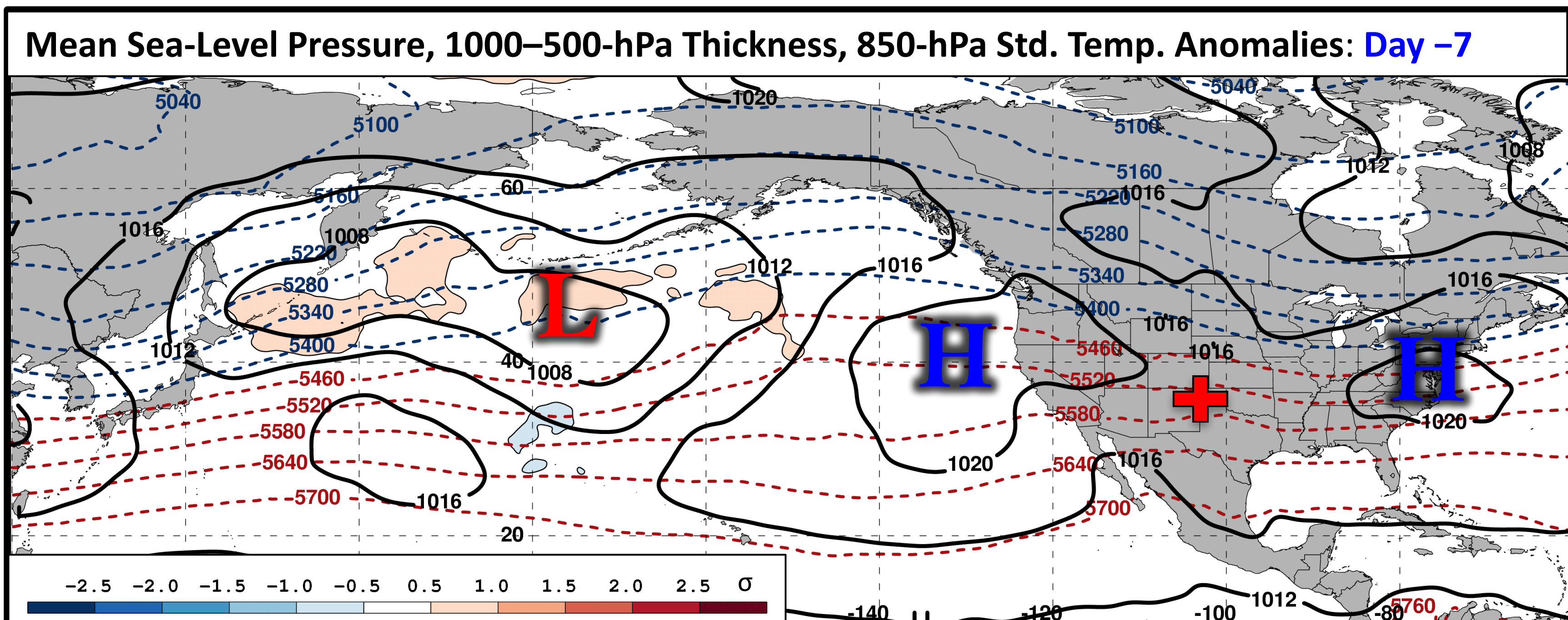
250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day −8

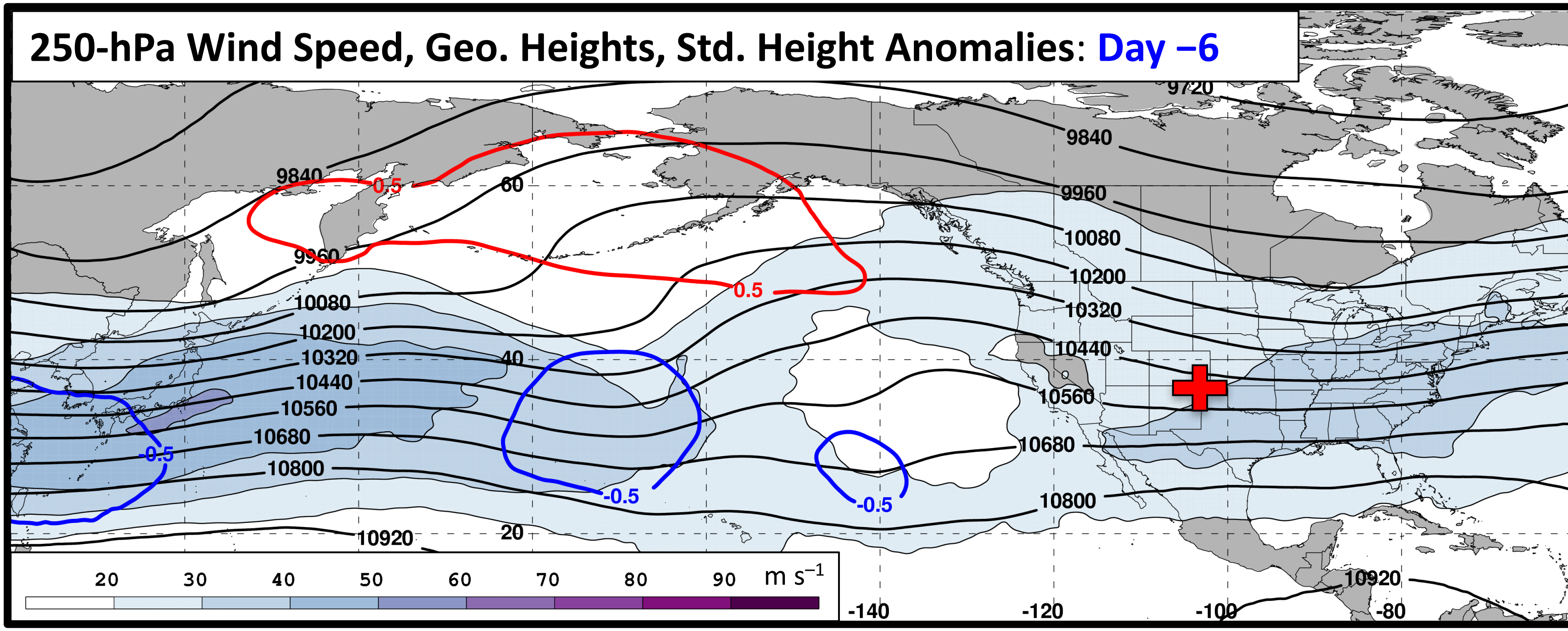


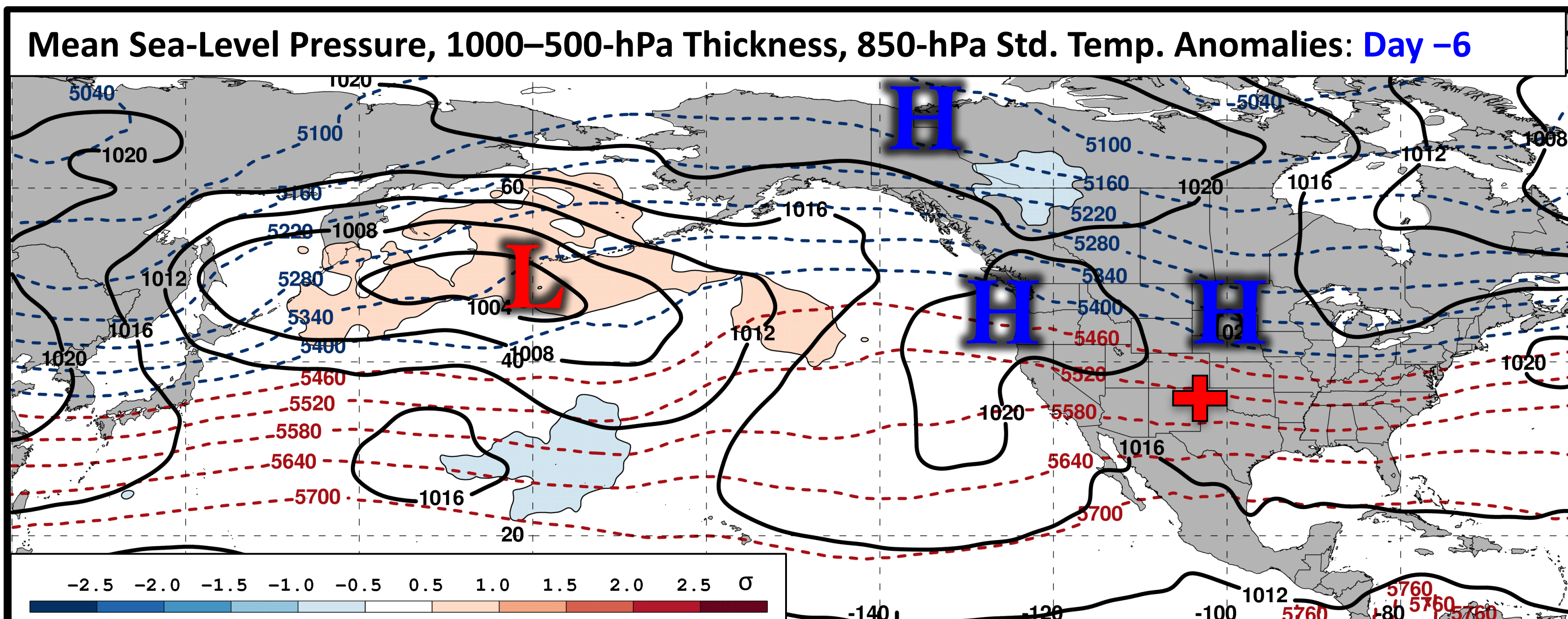
Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day −8

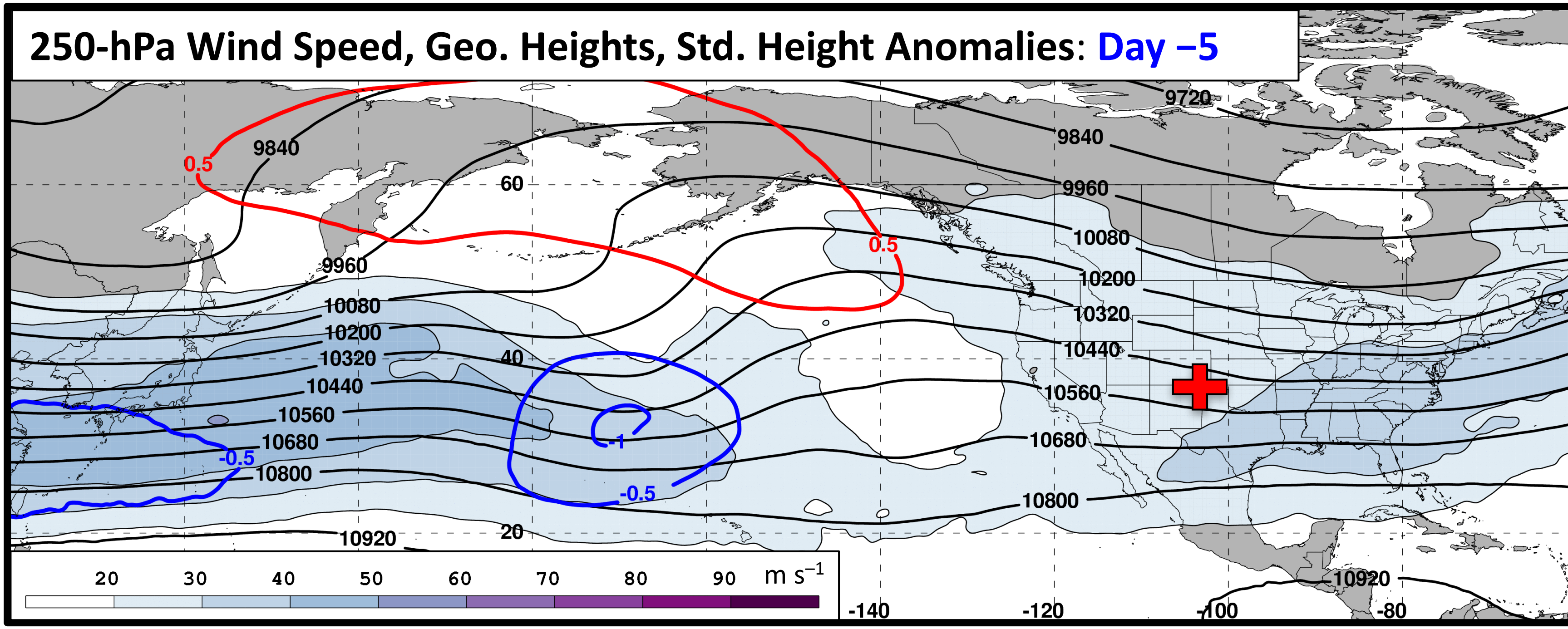


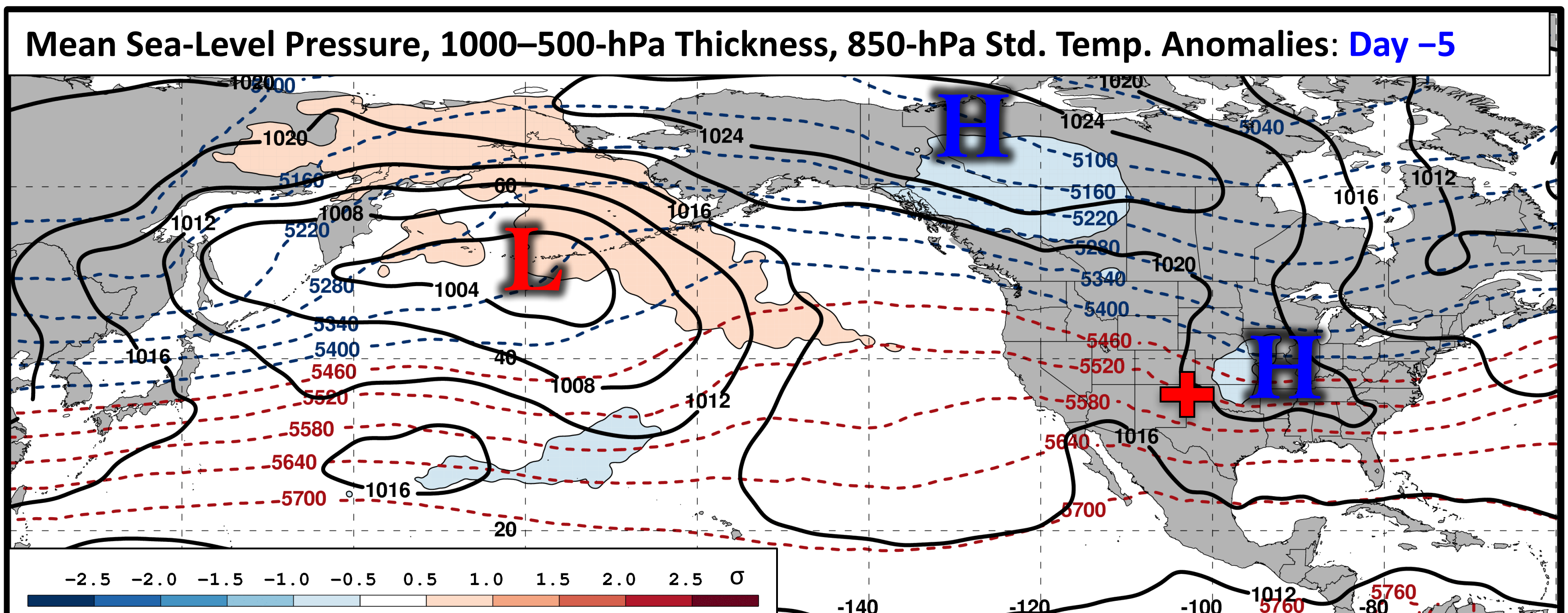

250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day –7
9720
9840
9960
10080
10200
10320
10440
10560
10680
10800
10920
0.5
-0.5
60
40
20
20 30 40 50 60 70 80 90 m s⁻¹
-140
-120
-100
-80

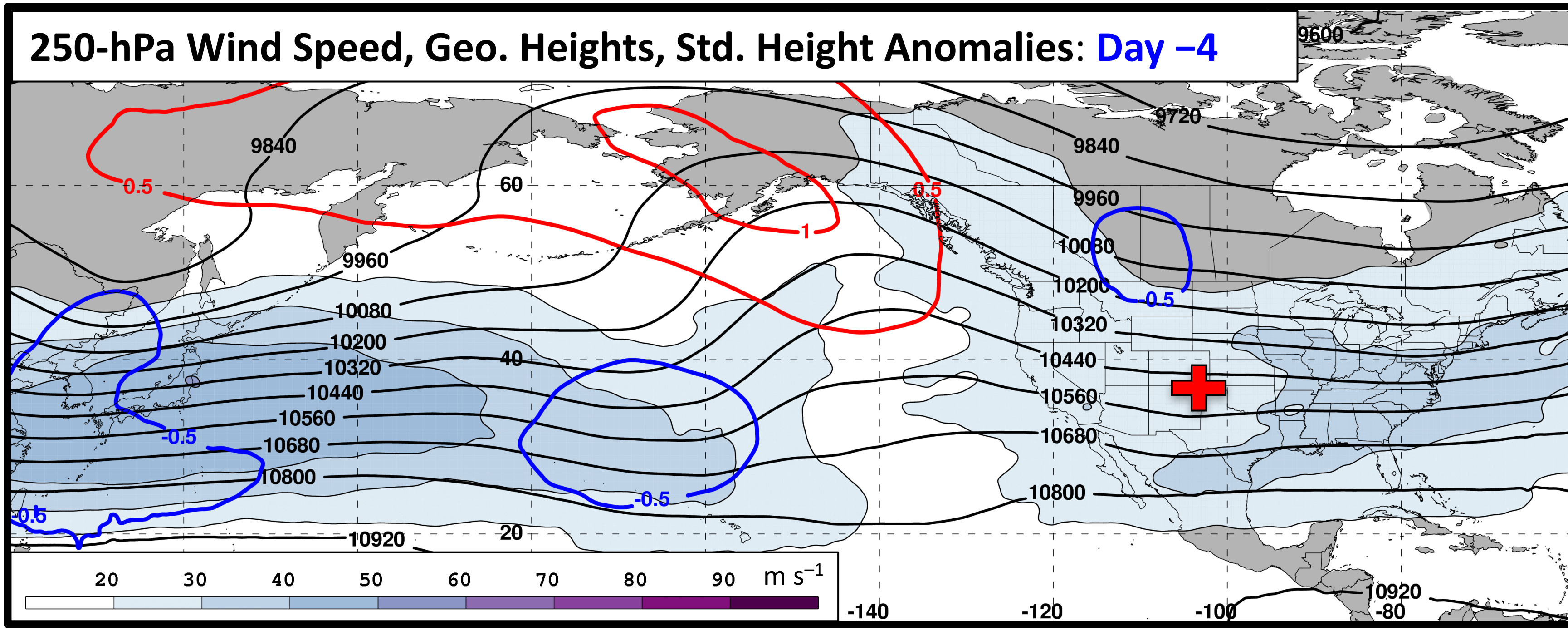

Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day –7
5040
5100
5160
5220
5280
5340
5400
5460
5520
5580
5640
5700
5760
1008
1012
1016
1020
L
H
H
60
40
20
−2.5 −2.0 −1.5 −1.0 −0.5 0.5 1.0 1.5 2.0 2.5 σ
-140
-120
-100
-80

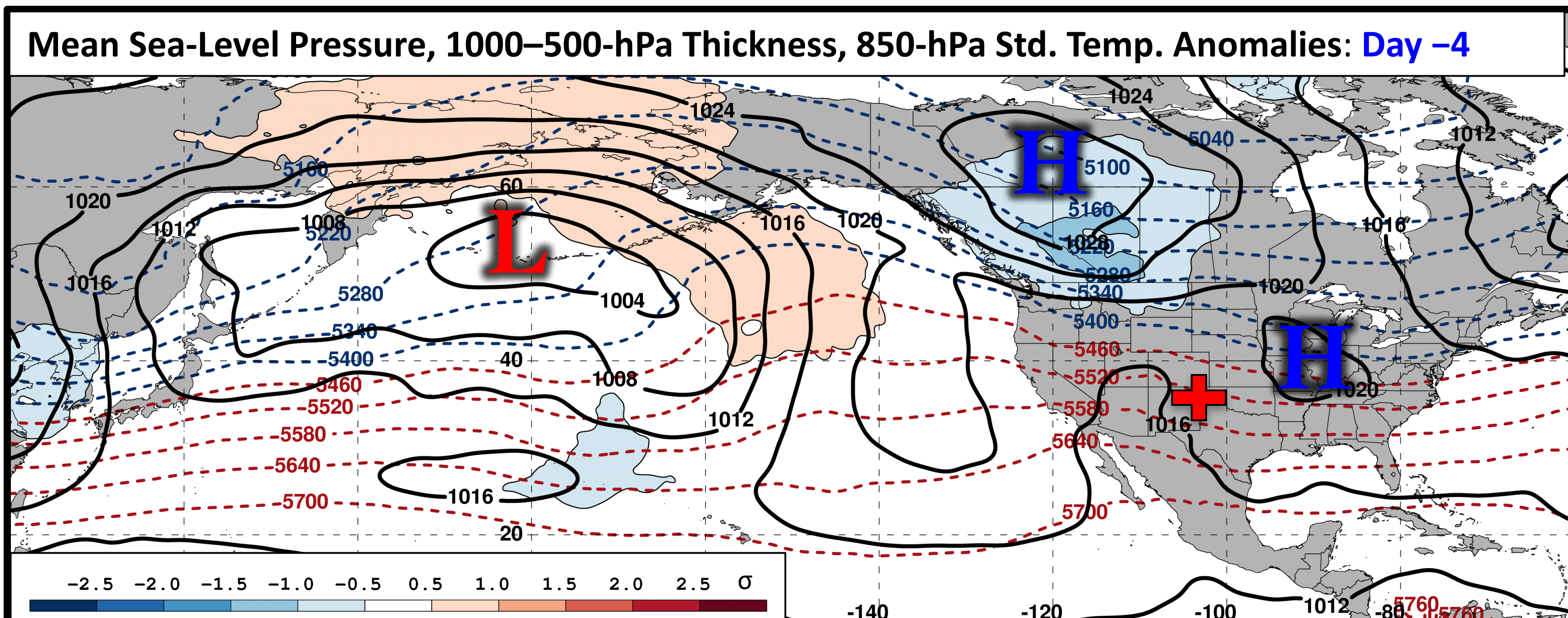

250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day –6
m s⁻¹
20 30 40 50 60 70 80 90

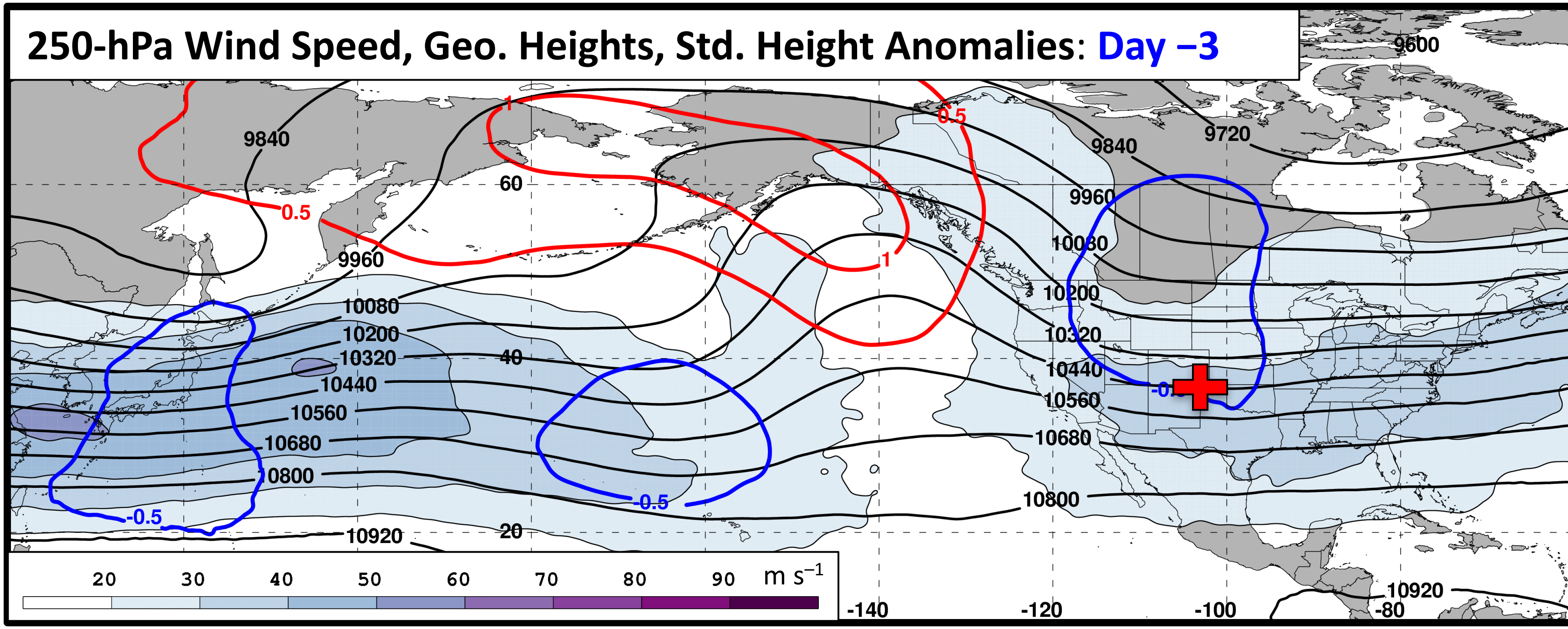

Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day –6
H
L
−2.5 −2.0 −1.5 −1.0 −0.5 0.5 1.0 1.5 2.0 2.5 σ

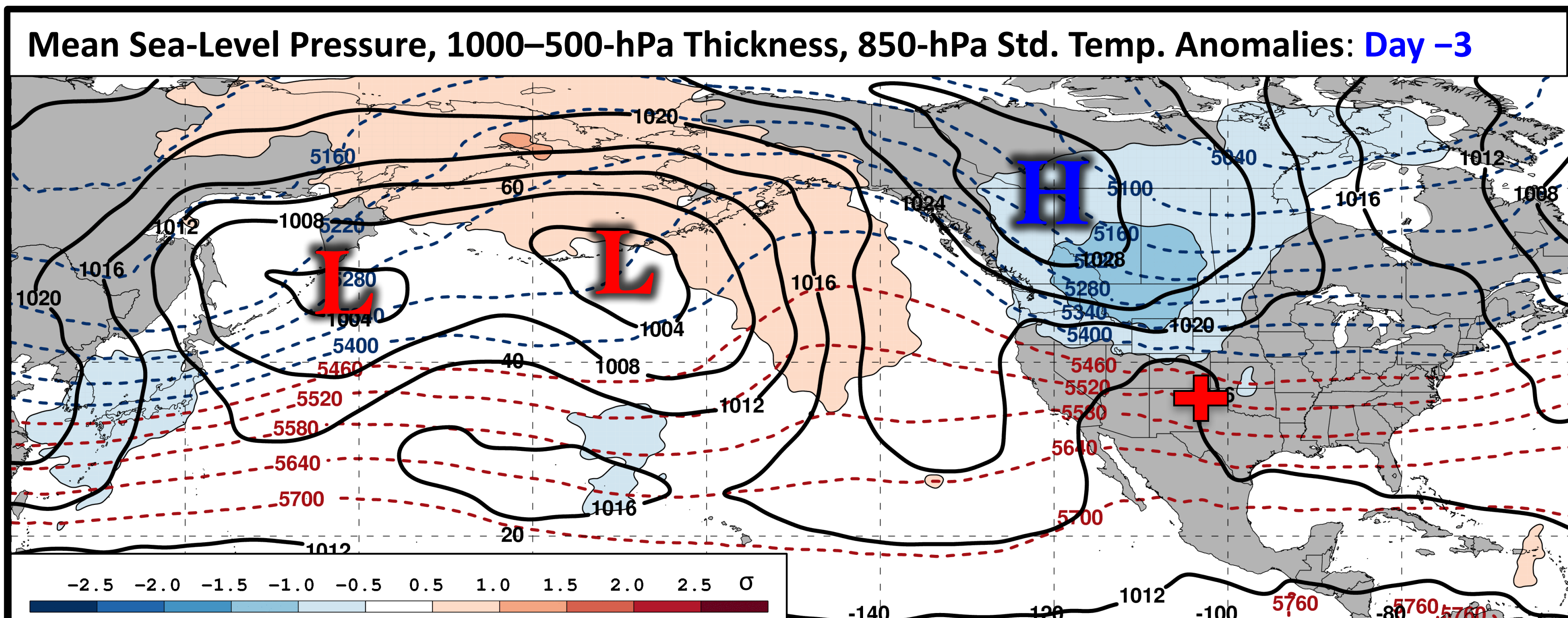

250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day –5
9720
9840
9960
10080
10200
10320
10440
10560
10680
10800
10920
0.5
-0.5
-1
60
40
20
20 30 40 50 60 70 80 90 m s⁻¹
-140
-120
-100
-80

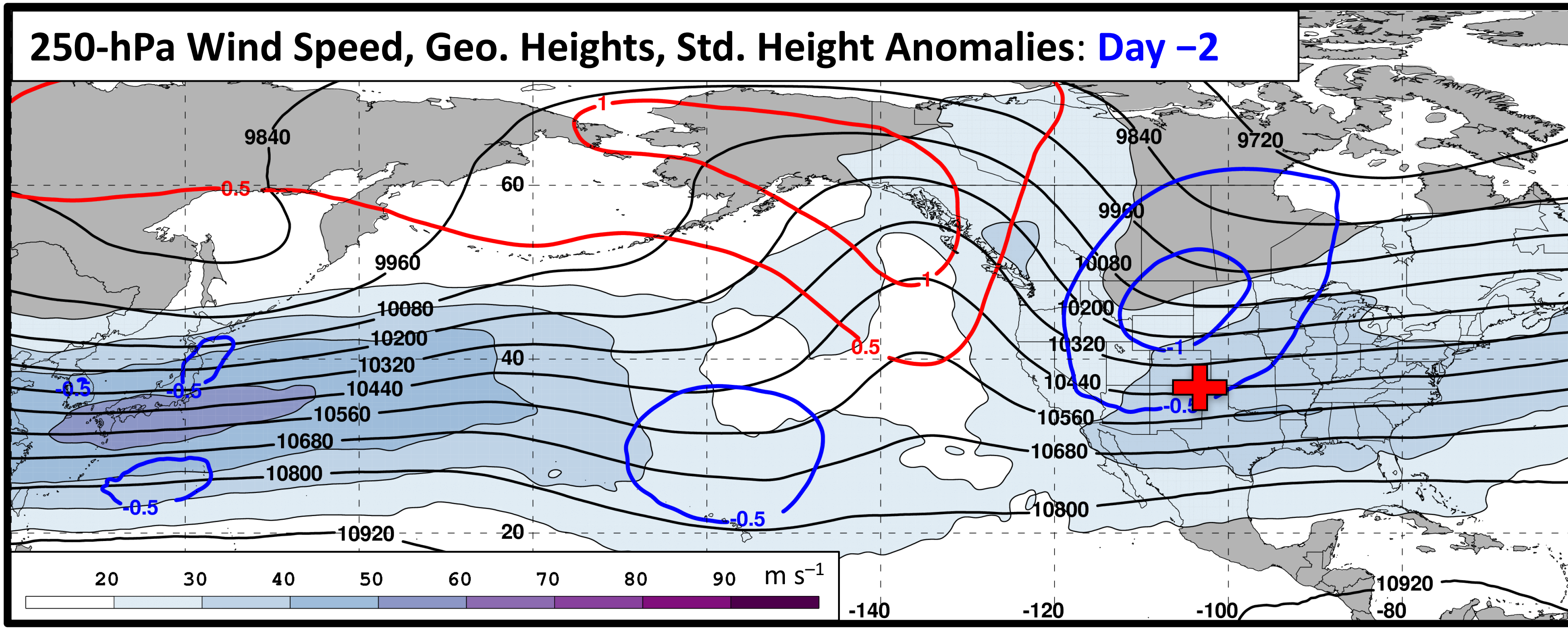

Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day –5
H
L
H
1004
1008
1012
1016
1020
1024
5040
5100
5160
5220
5280
5340
5400
5460
5520
5580
5640
5700
5760
60
40
20
−2.5 −2.0 −1.5 −1.0 −0.5 0.5 1.0 1.5 2.0 2.5 σ
-140
-120
-100
-80

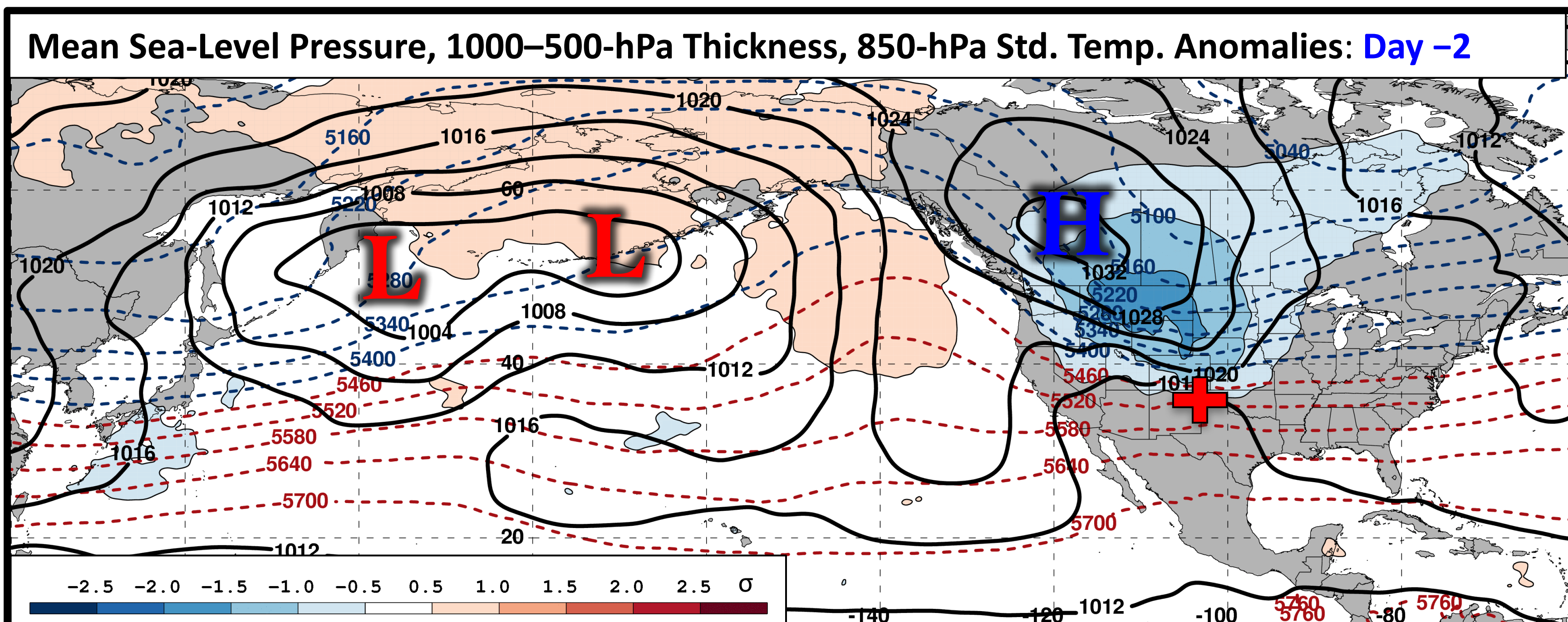

250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day –4
9600
9720
9840
9960
10080
10200
10320
10440
10560
10680
10800
10920
0.5
1
-0.5
60
40
20
-140
-120
-100
-80
20 30 40 50 60 70 80 90 m s⁻¹

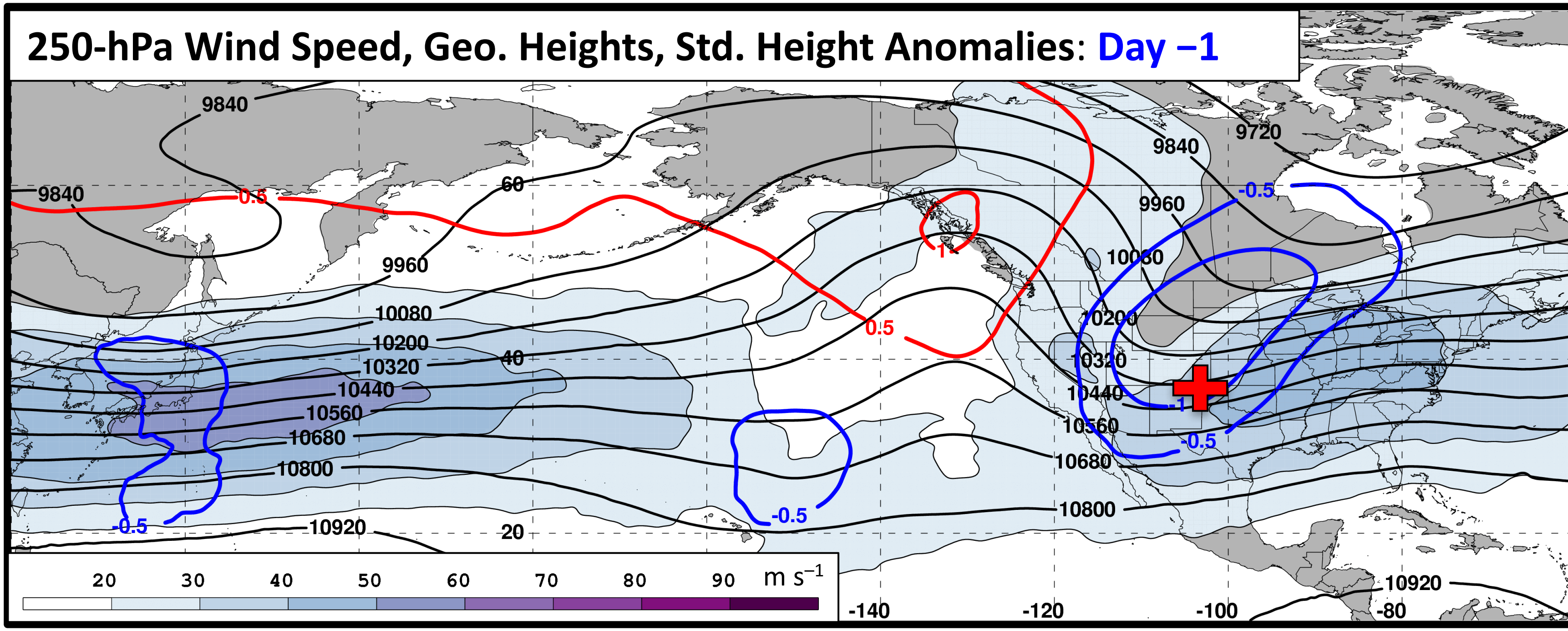

Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day –4
H
L
H
1004
1008
1012
1016
1020
1024
5040
5100
5160
5220
5280
5340
5400
5460
5520
5580
5640
5700
5760
60
40
20
-140
-120
-100
-80
−2.5 −2.0 −1.5 −1.0 −0.5 0.5 1.0 1.5 2.0 2.5 σ

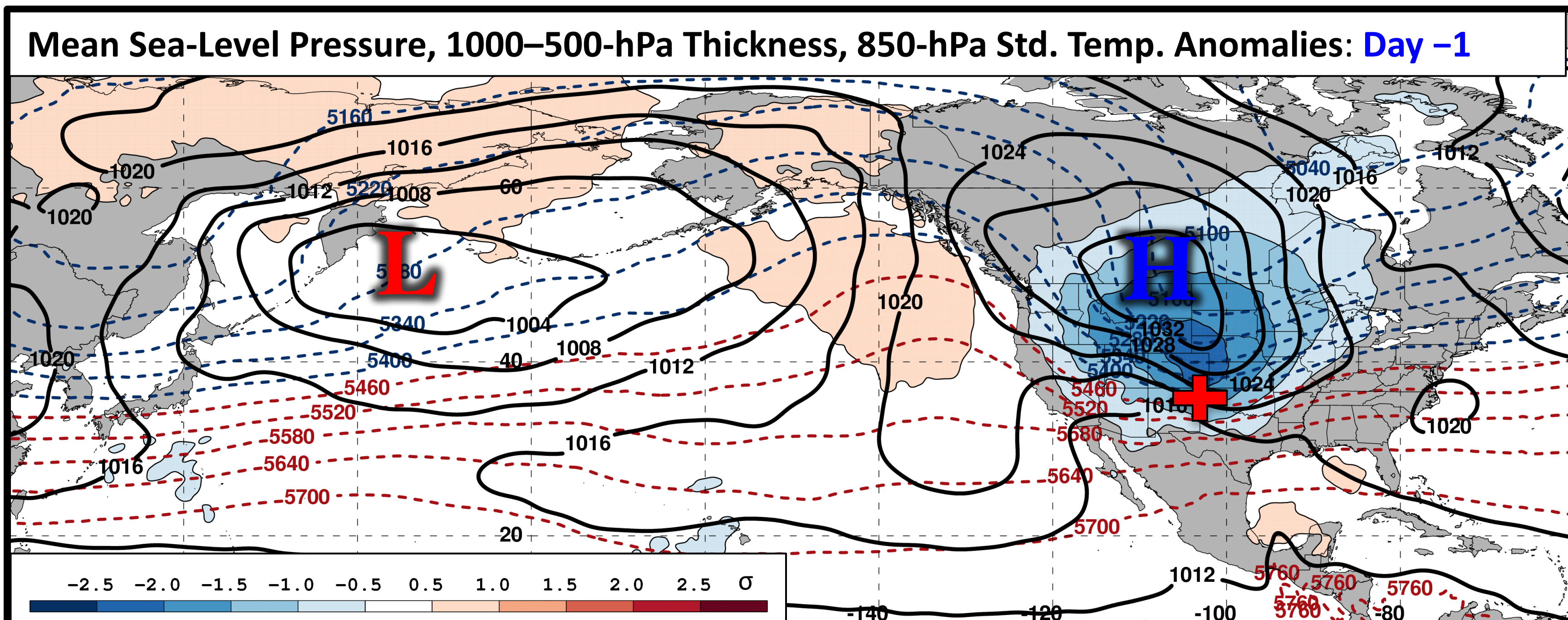

250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day −3
20 30 40 50 60 70 80 90 m s−1

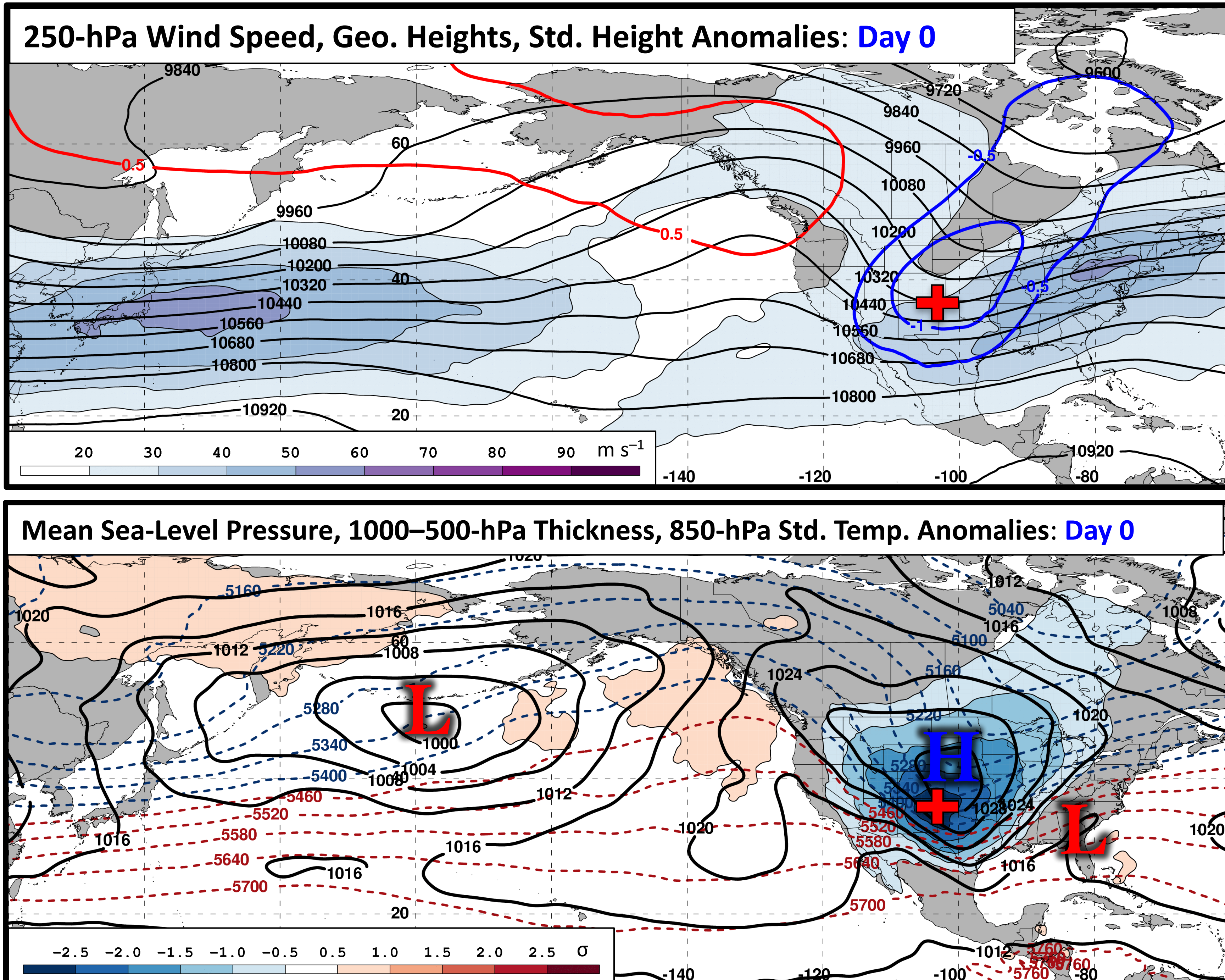

Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day −3
H
L
L
−2.5 −2.0 −1.5 −1.0 −0.5 0.5 1.0 1.5 2.0 2.5 σ


250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day −2
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
−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
20 30 40 50 60 70 80 90 m s−1
-140 -120 -100 -80

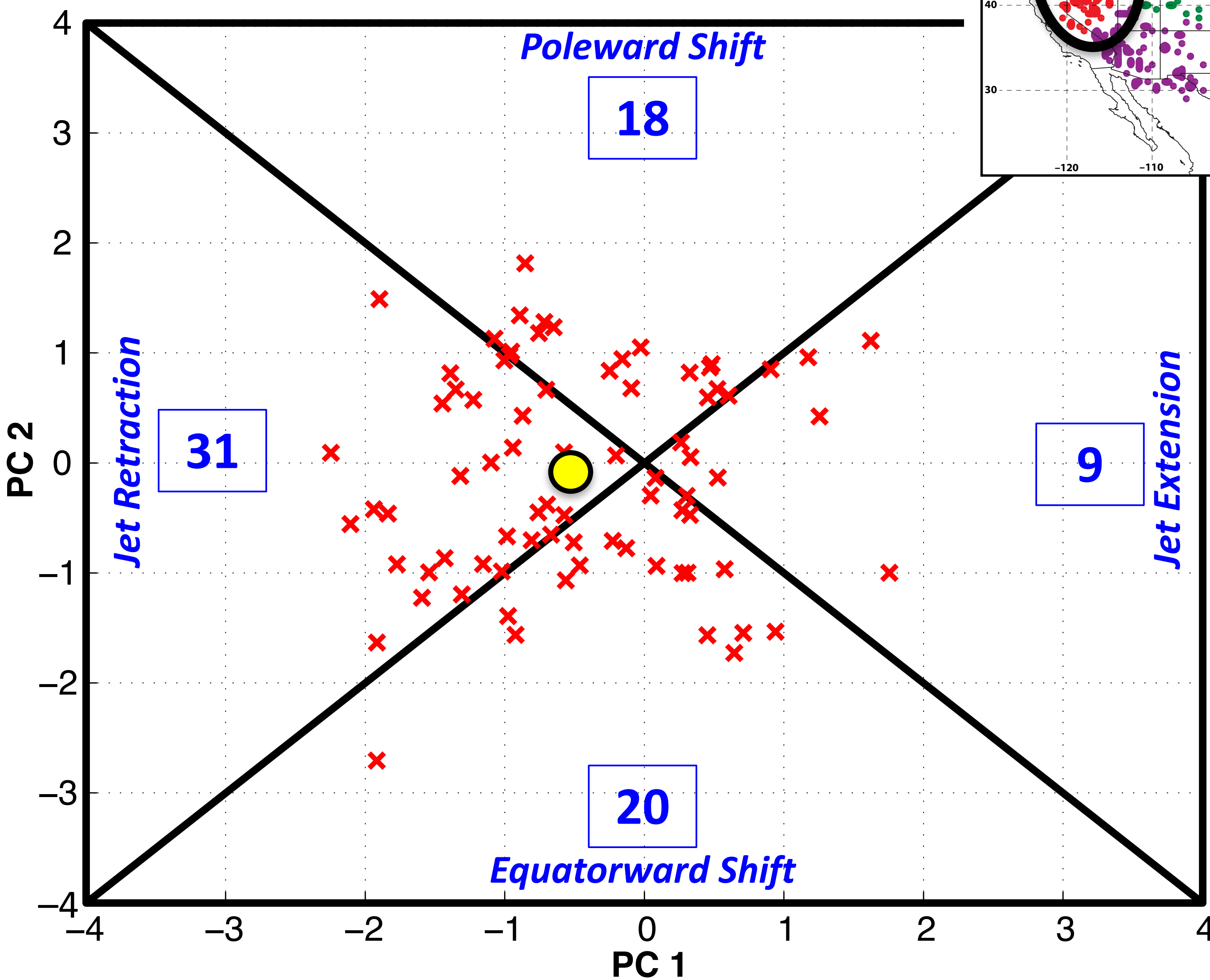

Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day −1
L
H
−2.5 −2.0 −1.5 −1.0 −0.5 0.5 1.0 1.5 2.0 2.5 σ
-140 -120 -100 -80

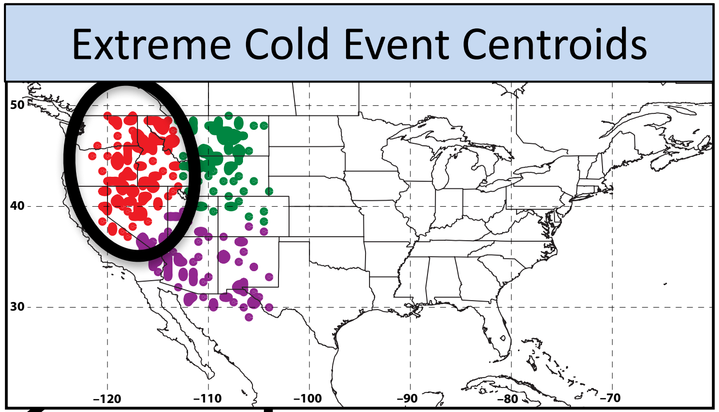


250-hPa Wind Speed, Geo. Heights, Std. Height Anomalies: Day 0
20 30 40 50 60 70 80 90 m s⁻¹
-140 -120 -100 -80
Mean Sea-Level Pressure, 1000–500-hPa Thickness, 850-hPa Std. Temp. Anomalies: Day 0
−2.5 −2.0 −1.5 −1.0 −0.5 0.5 1.0 1.5 2.0 2.5 σ
L
H
L

Western U.S. – Pac. NW Cluster

COLD EVENTS (N = 78)





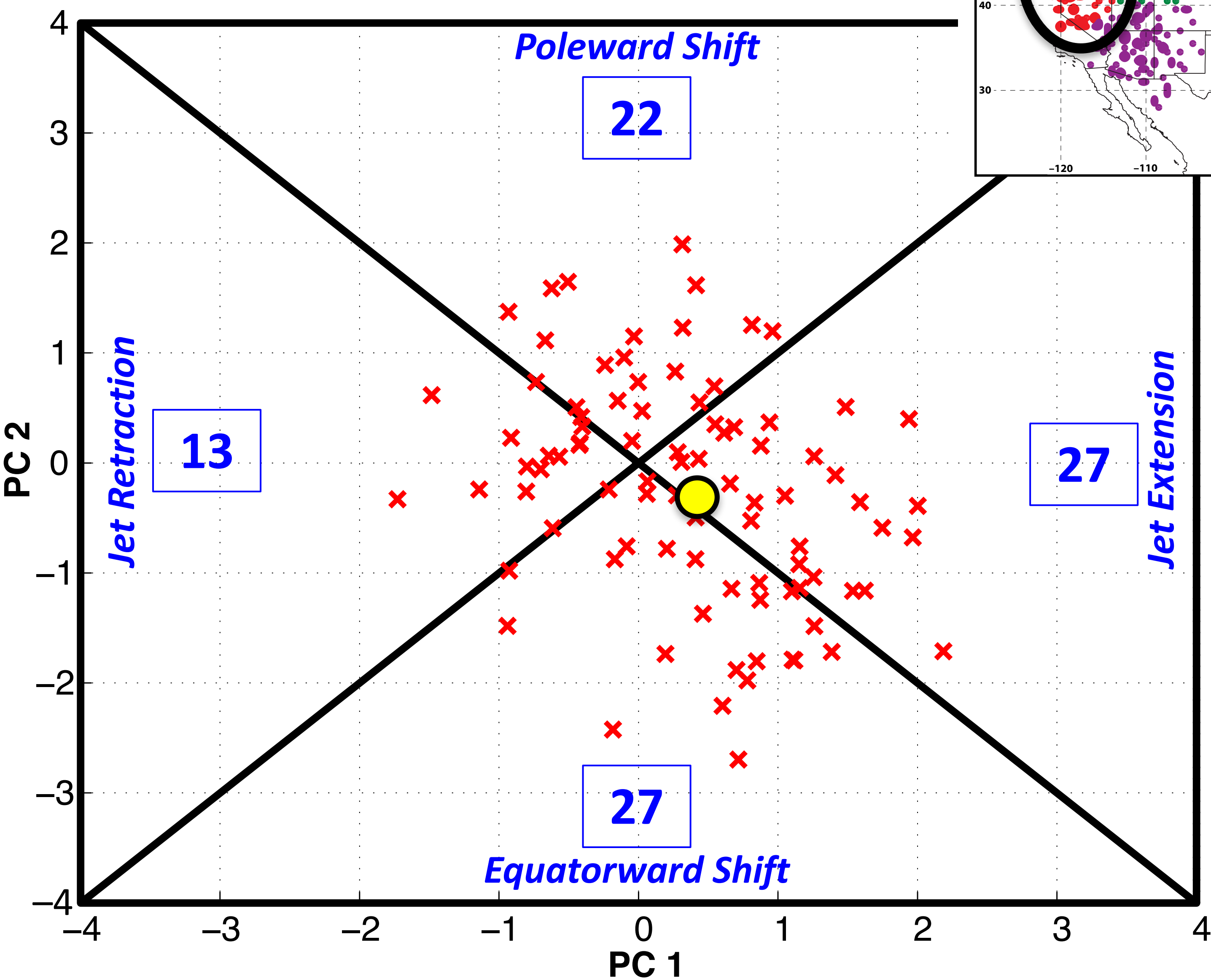
Events during Sept. – May projected onto phase diagram

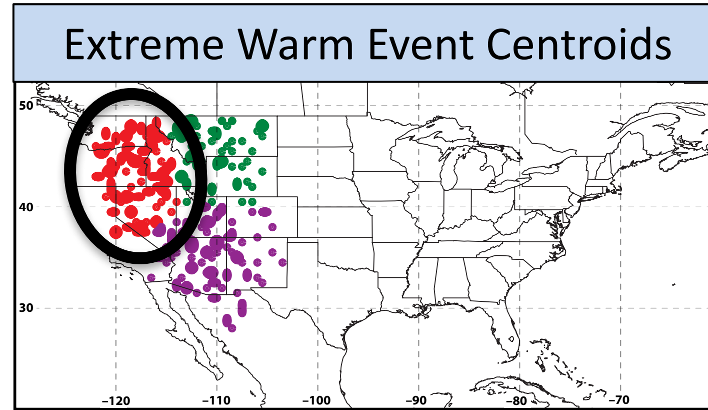
Each point is an average of the PCs 3–7 days prior to an event

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

GEFS Forecast Skill

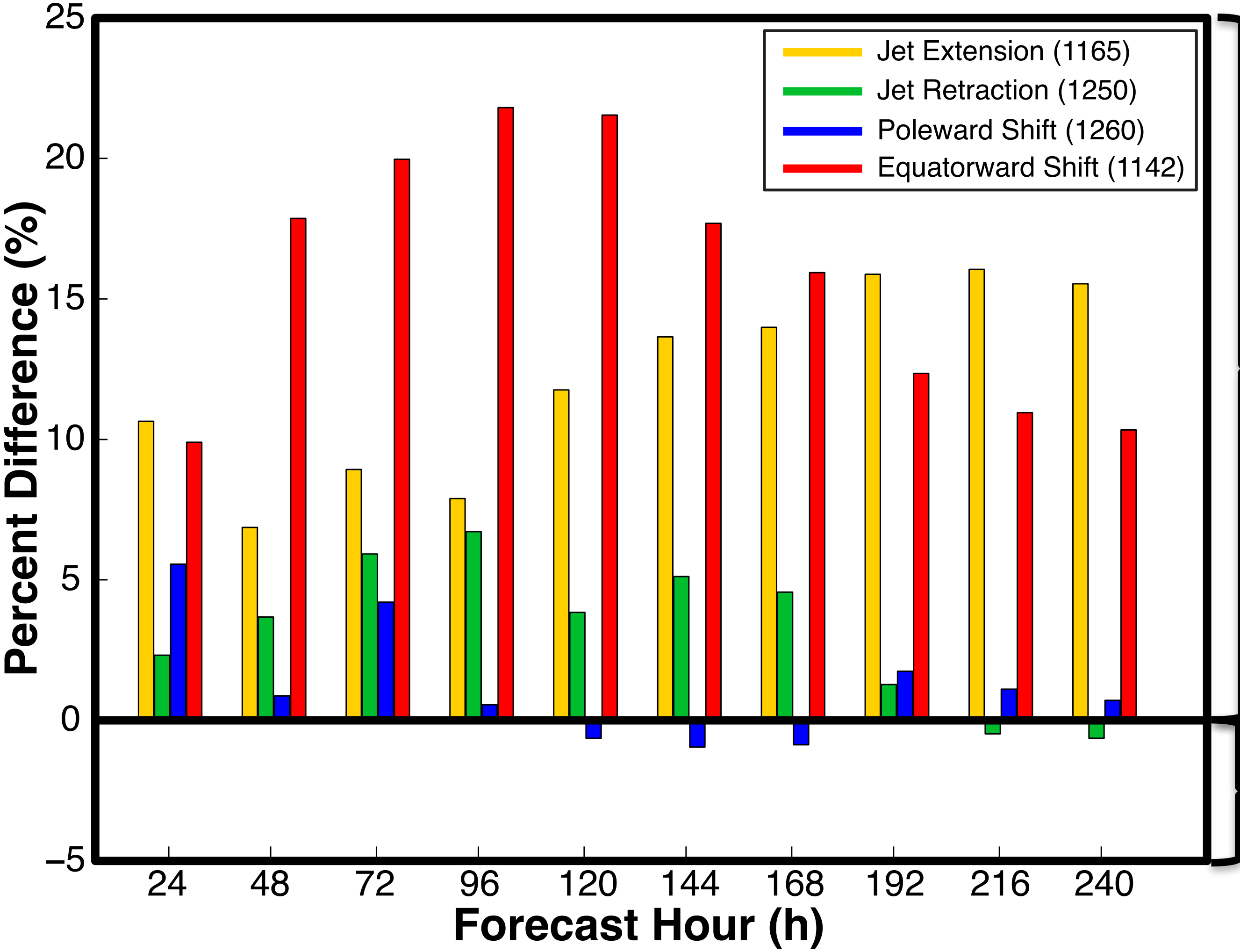
Best/Worst Forecast Statistics

10-d trajectory comparison between periods characterized by the best/worst medium-range forecasts

All Events	$PC1_{start}$	$PC2_{start}$	ΔPC1	ΔPC2	Mean Traj. Dist
Good Forecasts (475)	0.09	0.04	0.09	0.16	3.50
Bad Forecasts (763)	−0.18	−0.08	−0.01	−0.21	4.33
Jet Extensions	**$PC1_{start}$**	**$PC2_{start}$**	**ΔPC1**	**ΔPC2**	**Mean Traj. Dist**
Good Forecasts (77)	1.54	−0.09	−0.98	0.40	3.69
Bad Forecasts (90)	1.35	−0.01	−1.41	−0.14	4.57
Jet Retractions	**$PC1_{start}$**	**$PC2_{start}$**	**ΔPC1**	**ΔPC2**	**Mean Traj. Dist**
Good Forecasts (63)	−1.36	0.14	1.09	0.04	3.77
Bad Forecasts (145)	−1.58	−0.11	1.18	−0.25	4.56
Poleward Shifts	**$PC1_{start}$**	**$PC2_{start}$**	**ΔPC1**	**ΔPC2**	**Mean Traj. Dist**
Good Forecasts (63)	0.12	1.45	0.00	−0.81	3.59
Bad Forecasts (90)	−0.02	1.40	−0.31	−1.44	4.62
Equatorward Shifts	**$PC1_{start}$**	**$PC2_{start}$**	**ΔPC1**	**ΔPC2**	**Mean Traj. Dist**
Good Forecasts (61)	0.20	−1.42	0.36	1.08	3.52
Bad Forecasts (112)	−0.17	−1.52	0.05	1.09	4.36
Origin	**$PC1_{start}$**	**$PC2_{start}$**	**ΔPC1**	**ΔPC2**	**Mean Traj. Dist**
Good Forecasts (211)	−0.03	0.07	0.13	0.12	3.31
Bad Forecasts (326)	−0.04	0.01	−0.06	−0.31	4.08

Jet Regime-Dependent Forecast Skill

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

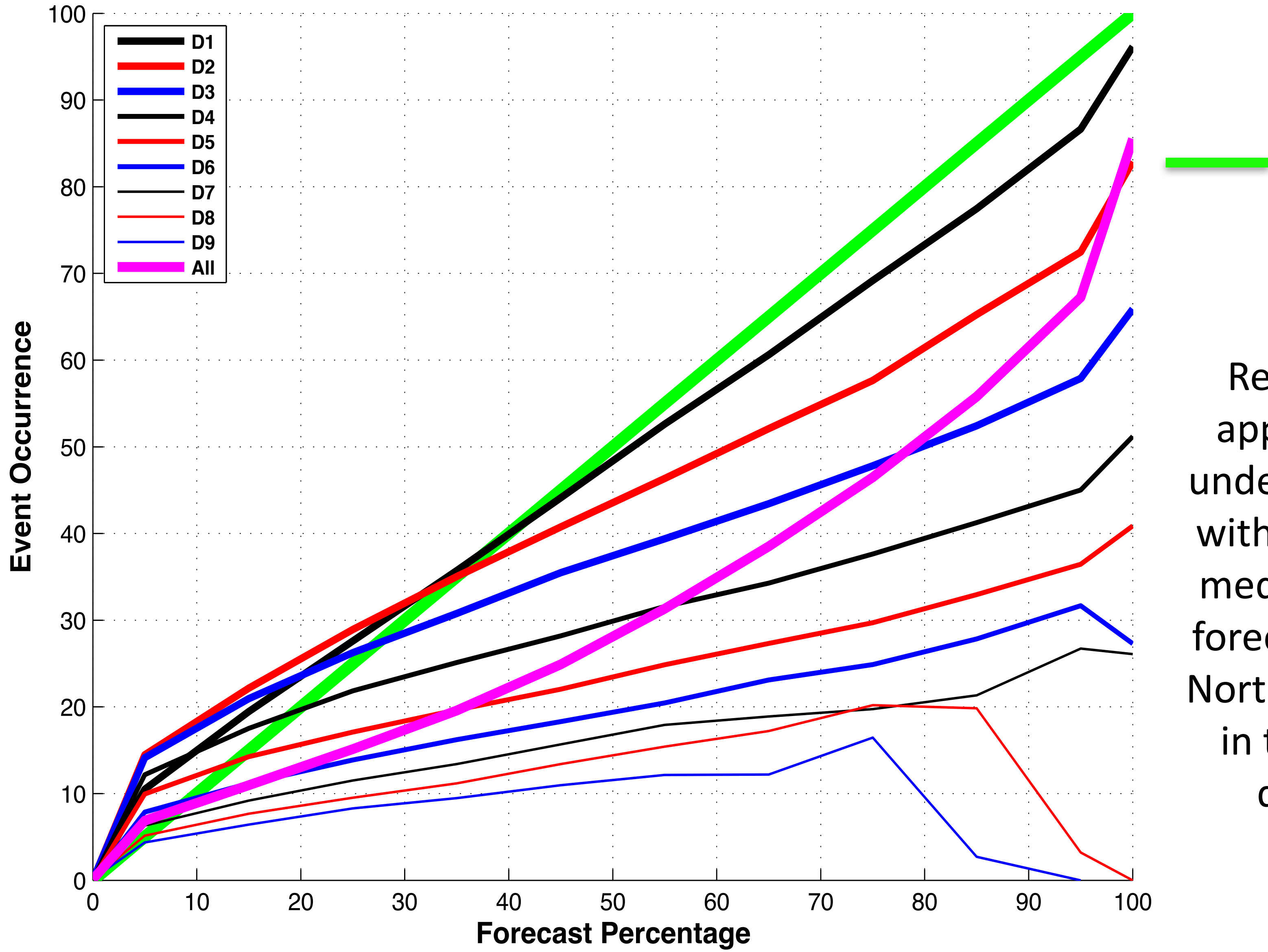


$$Freq_{below-normal} - Freq_{above-normal}$$

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)

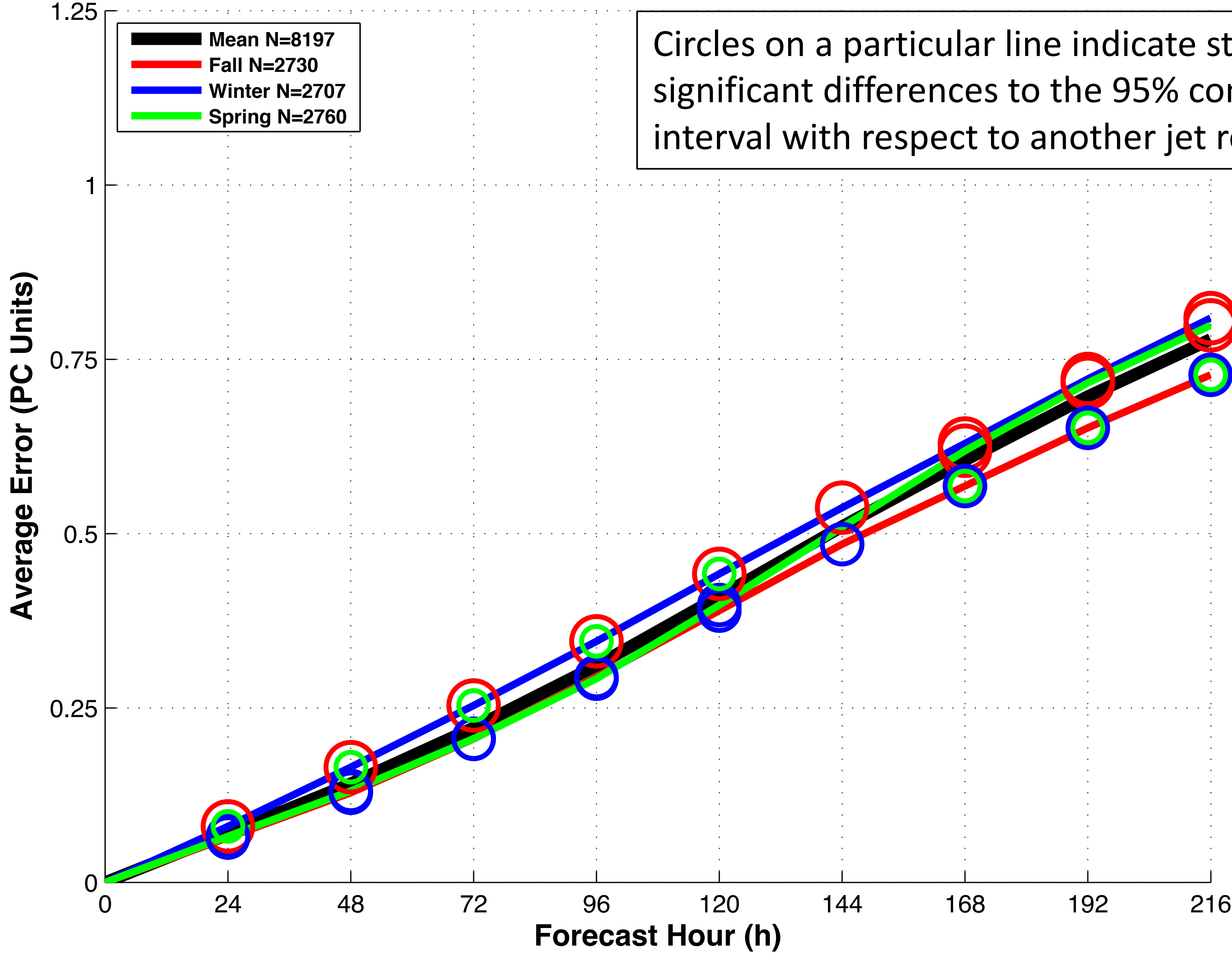
Reliability Diagram



Perfect Reliability

GEFS Reforecasts appear to be underdispersive with respect to medium-range forecasts of the North Pacific Jet in the phase diagram

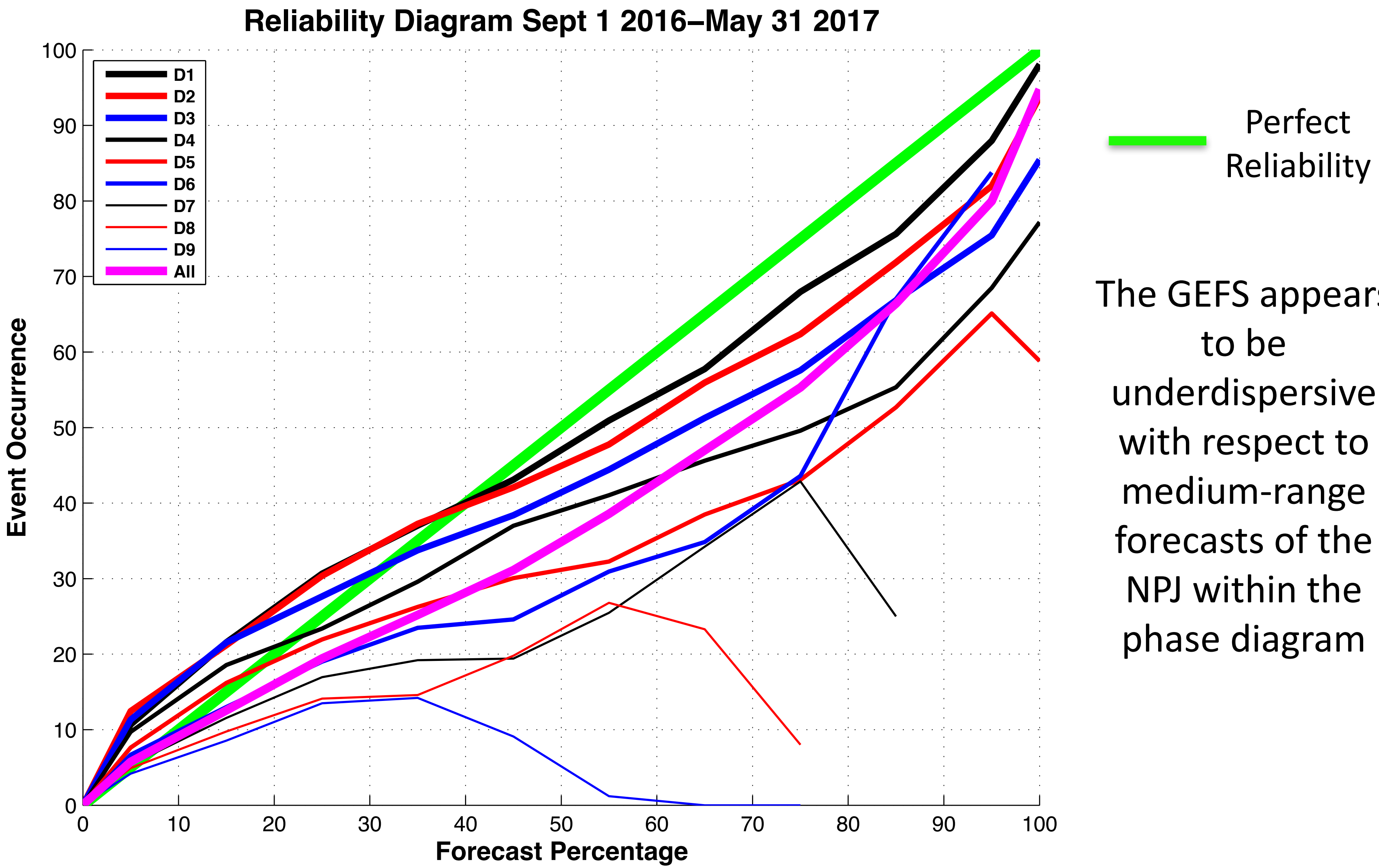
GEFS Ensemble Mean Error – Season



Circles on a particular line indicate statistically significant differences to the 95% confidence interval with respect to another jet regime.

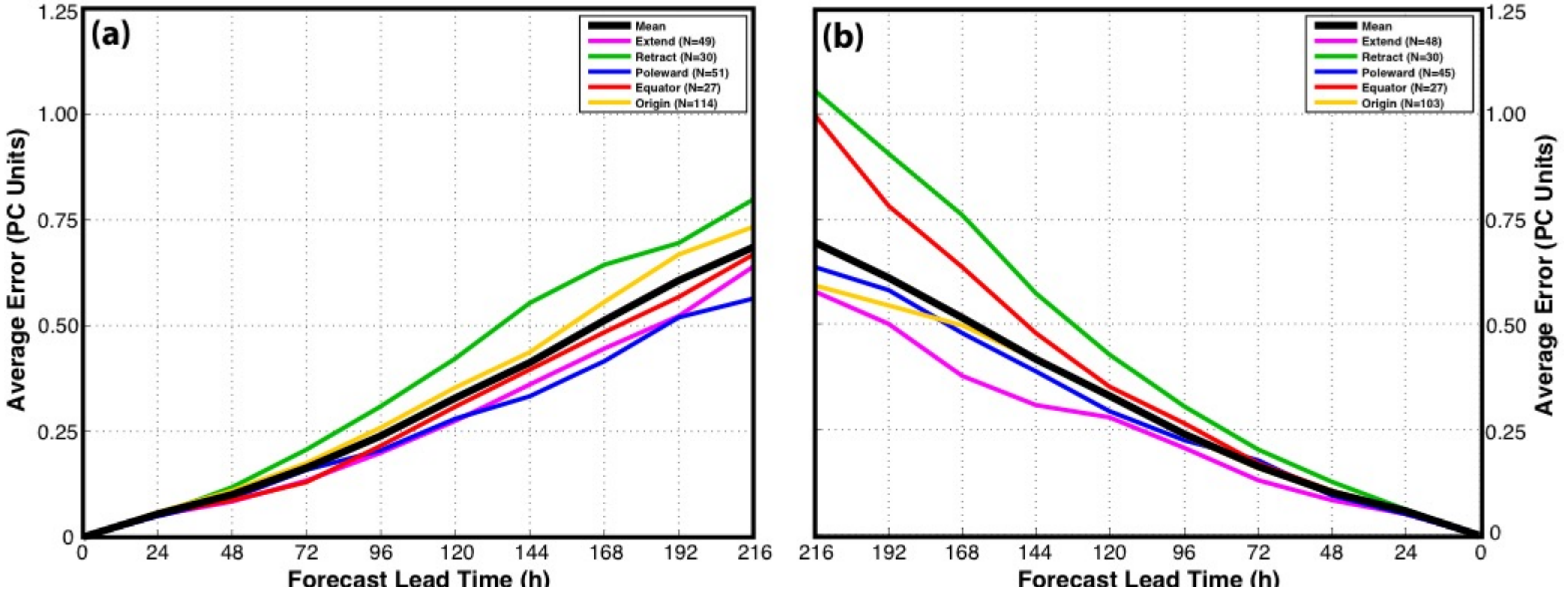
Real time NPJ Phase Diagram Verification Statistics 2016–2017

Reliability Diagram (Sept 1 – May 31)

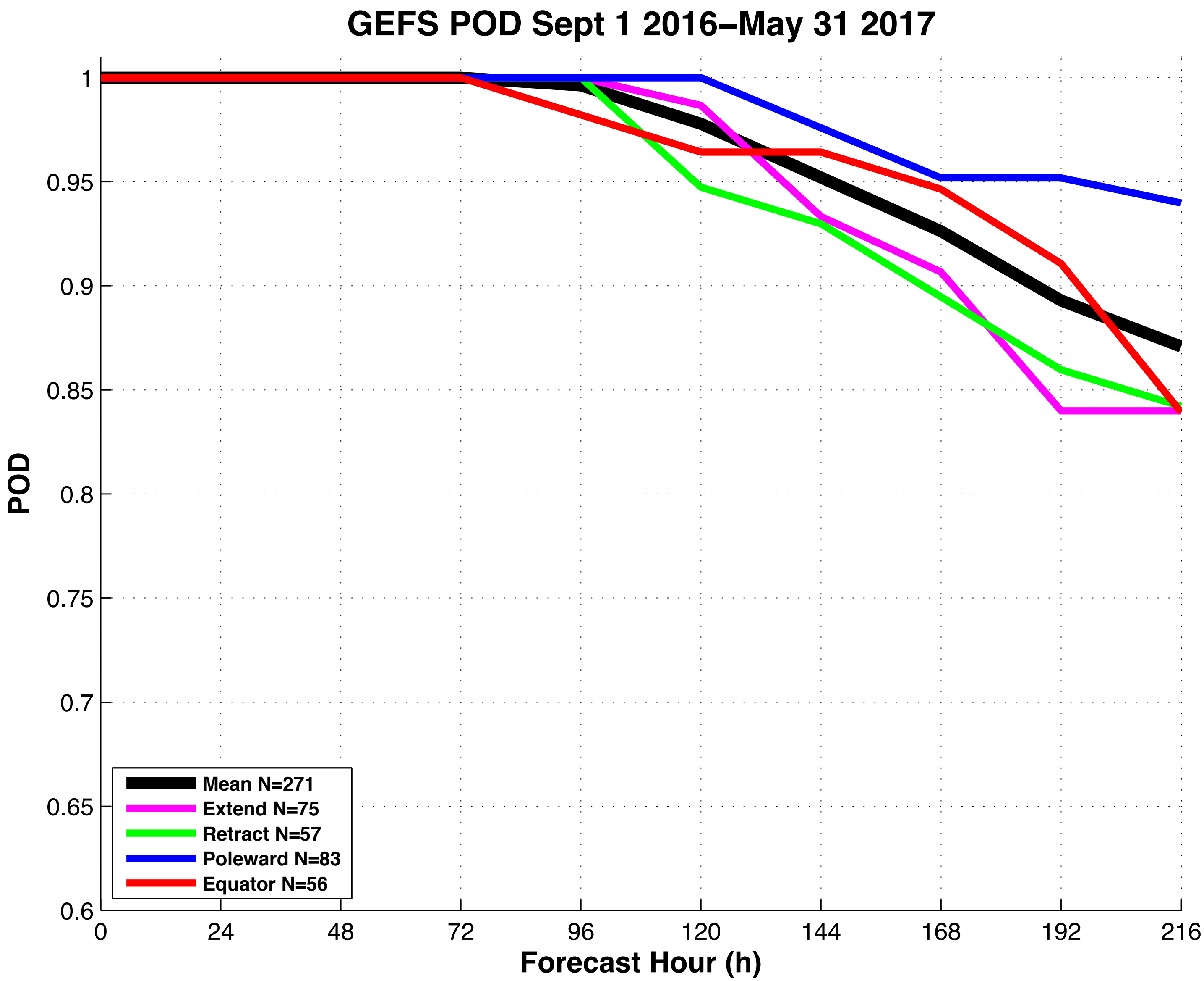


The GEFS appears to be underdispersive with respect to medium-range forecasts of the NPJ within the phase diagram

GEFS Ensemble Mean Error – Regime



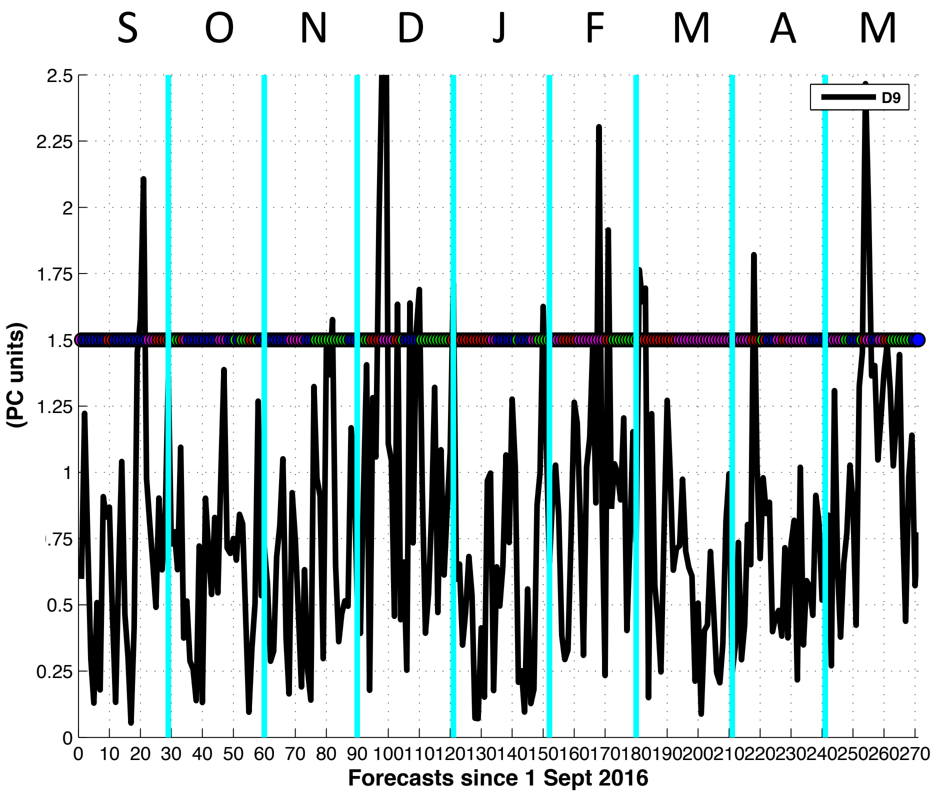
GEFS Probability of Detection – Regime



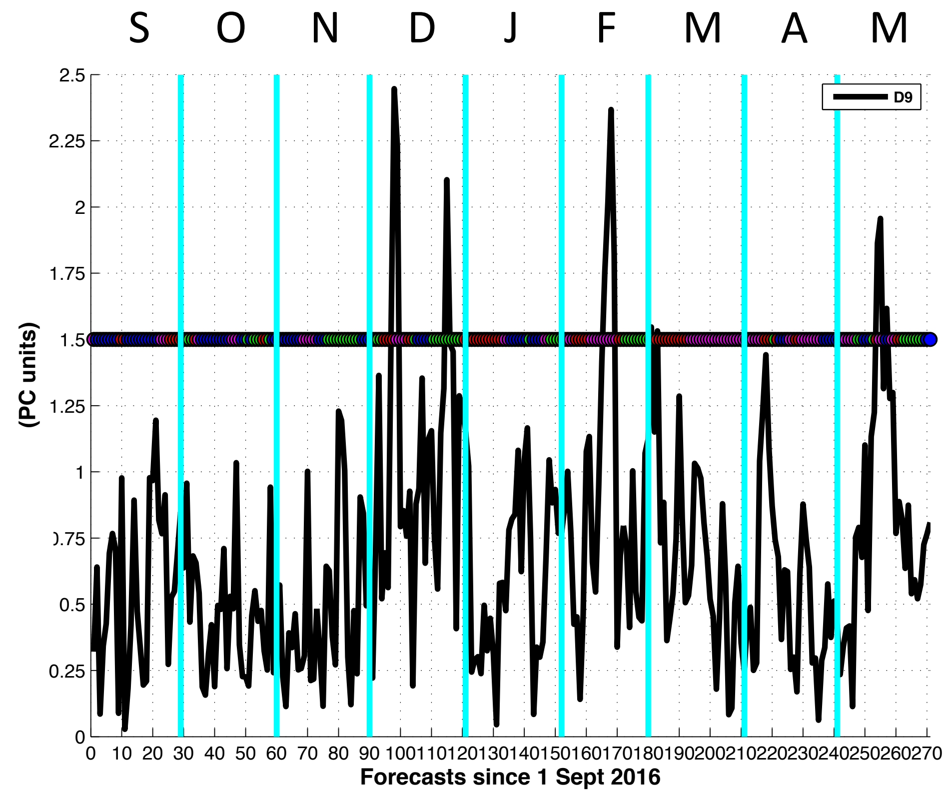
Time Series of GFS and GEFS Mean Error

9-Day Forecast

GFS



GEFS Mean

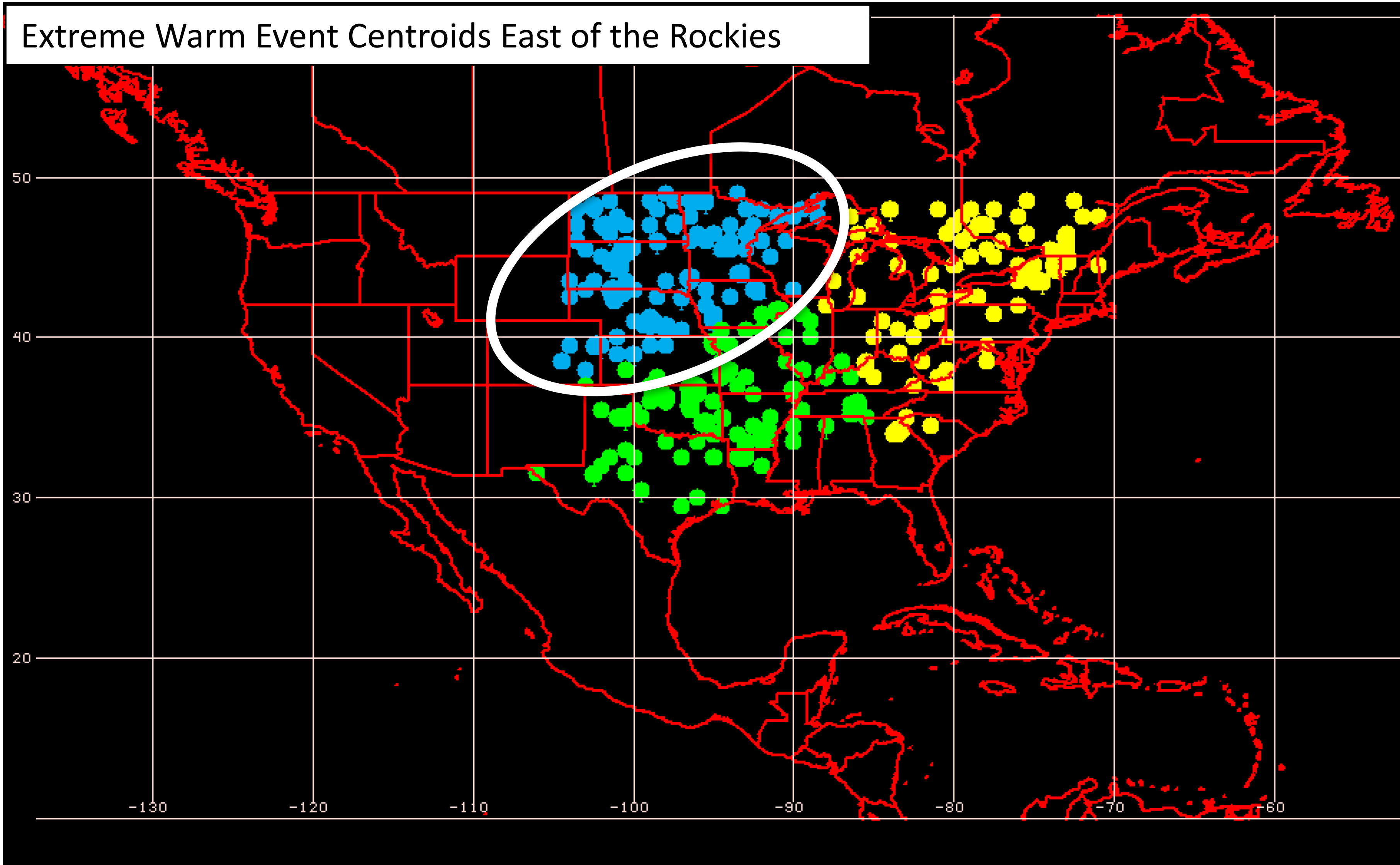


- **Extend N=75**
- **Retract N=57**
- **Poleward N=83**
- **Equator N=56**

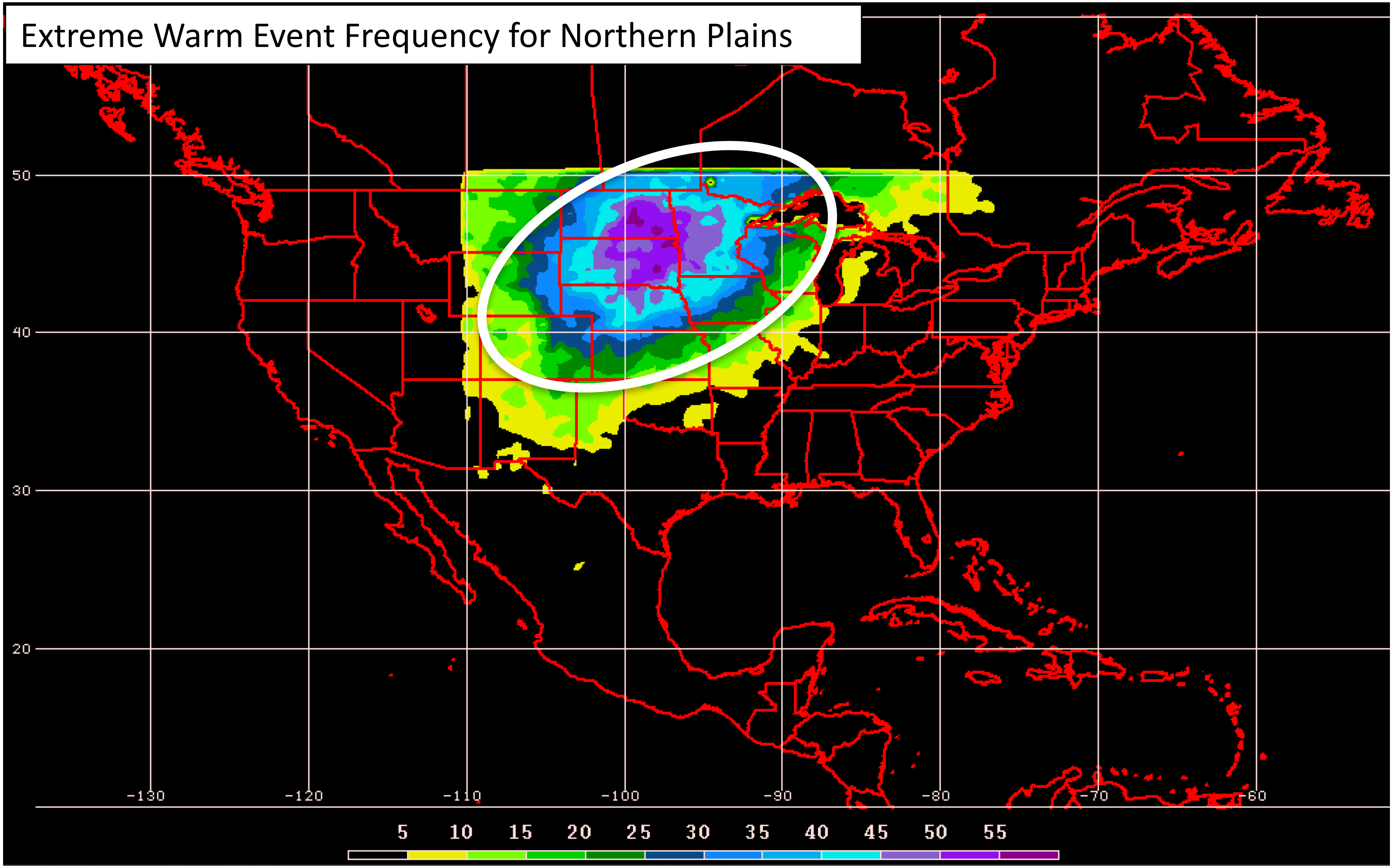
Colored dots identify the NPJ regime on a particular day

NPJ Phase Diagram Technical Slides

Geographic Event Clusters



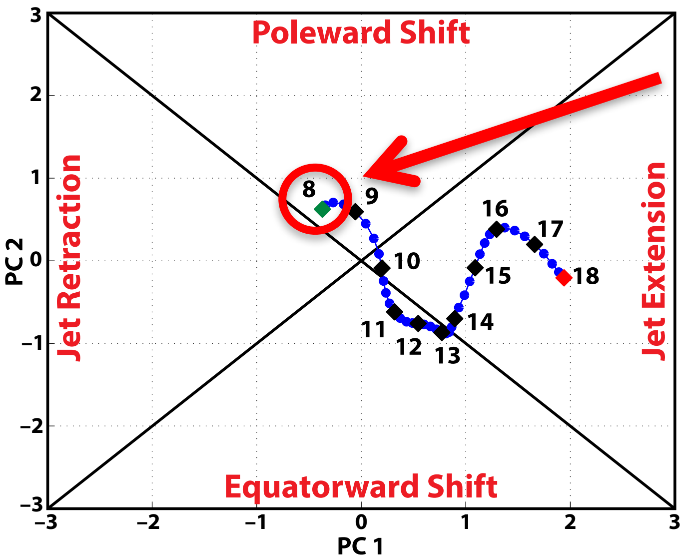
Geographic Event Clusters

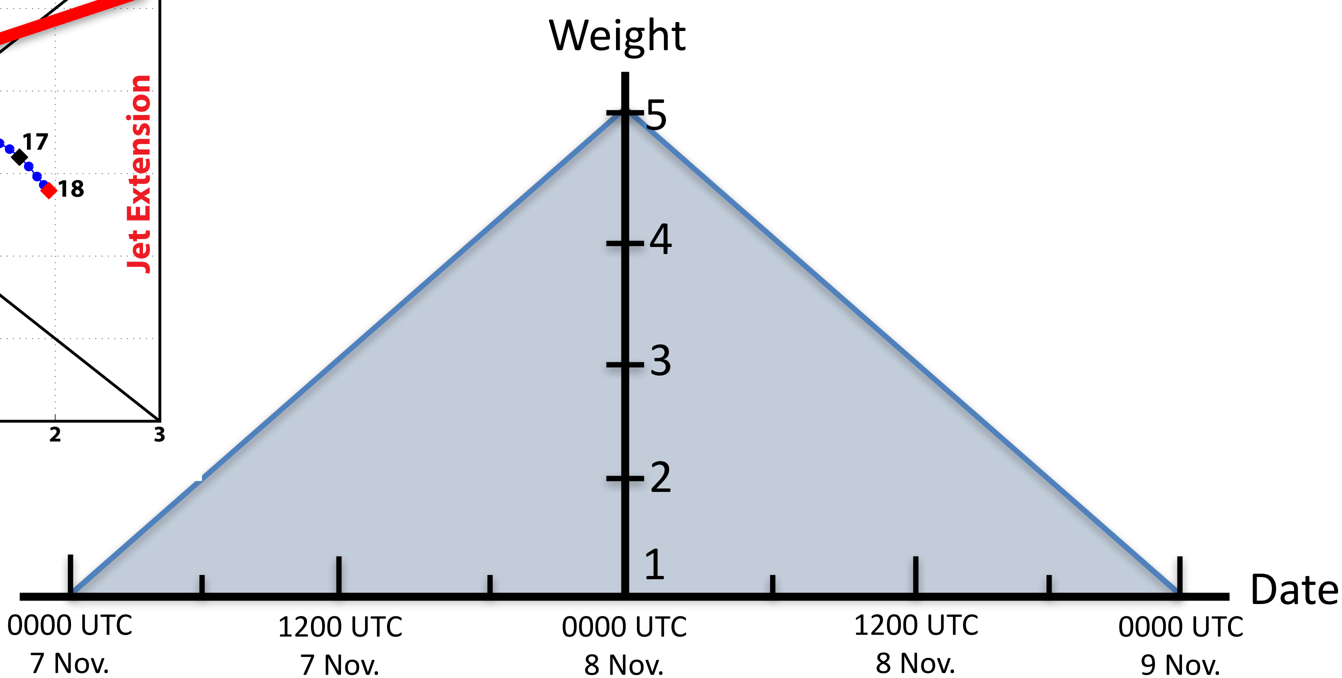


Real Time North Pacific Jet Phase Diagram

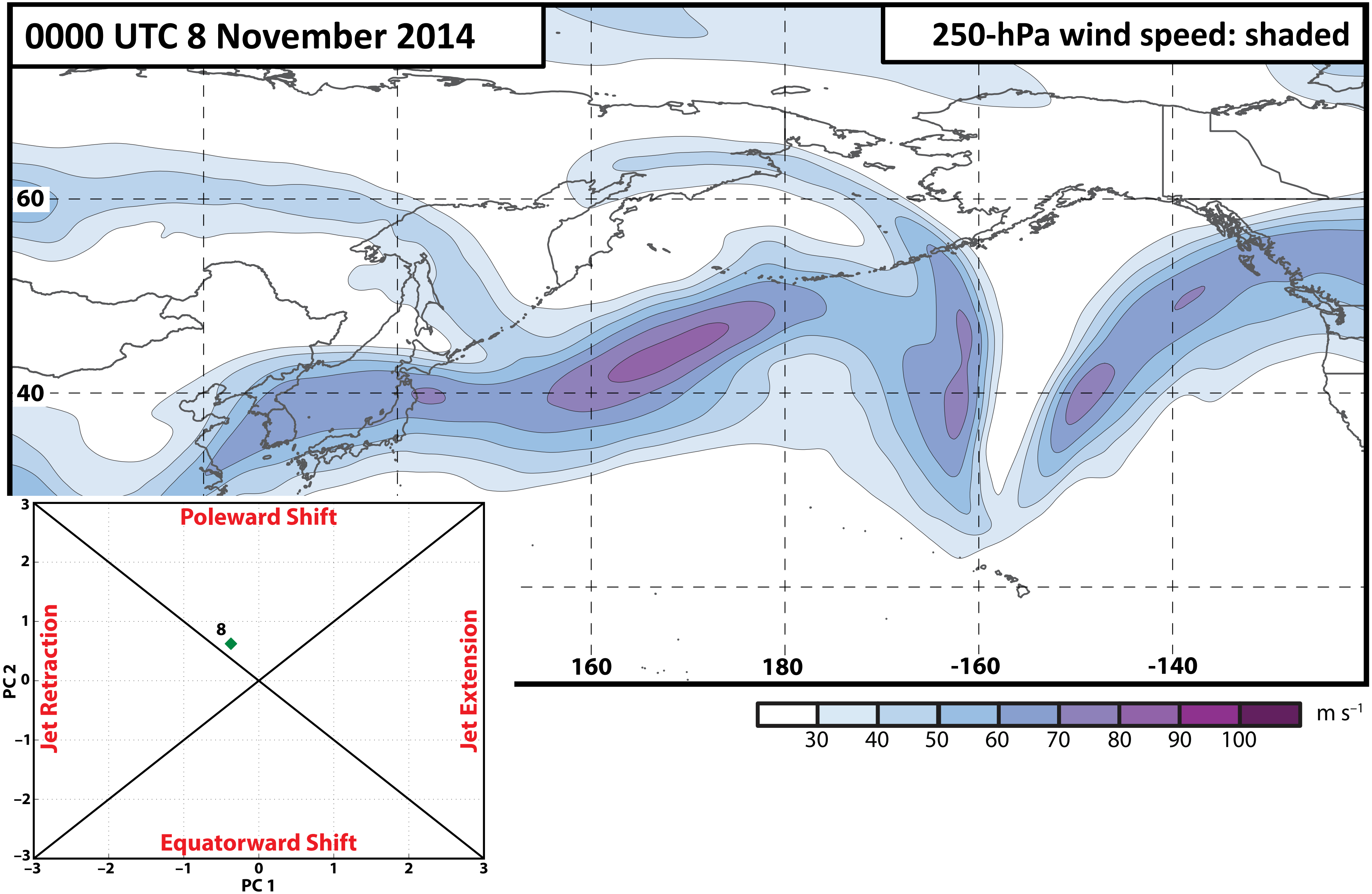
- Each point on the phase diagram is a weighted average of the principal components within +/− 1 day of the time under consideration

<u>Example</u>: 0000 UTC 8 November 2014

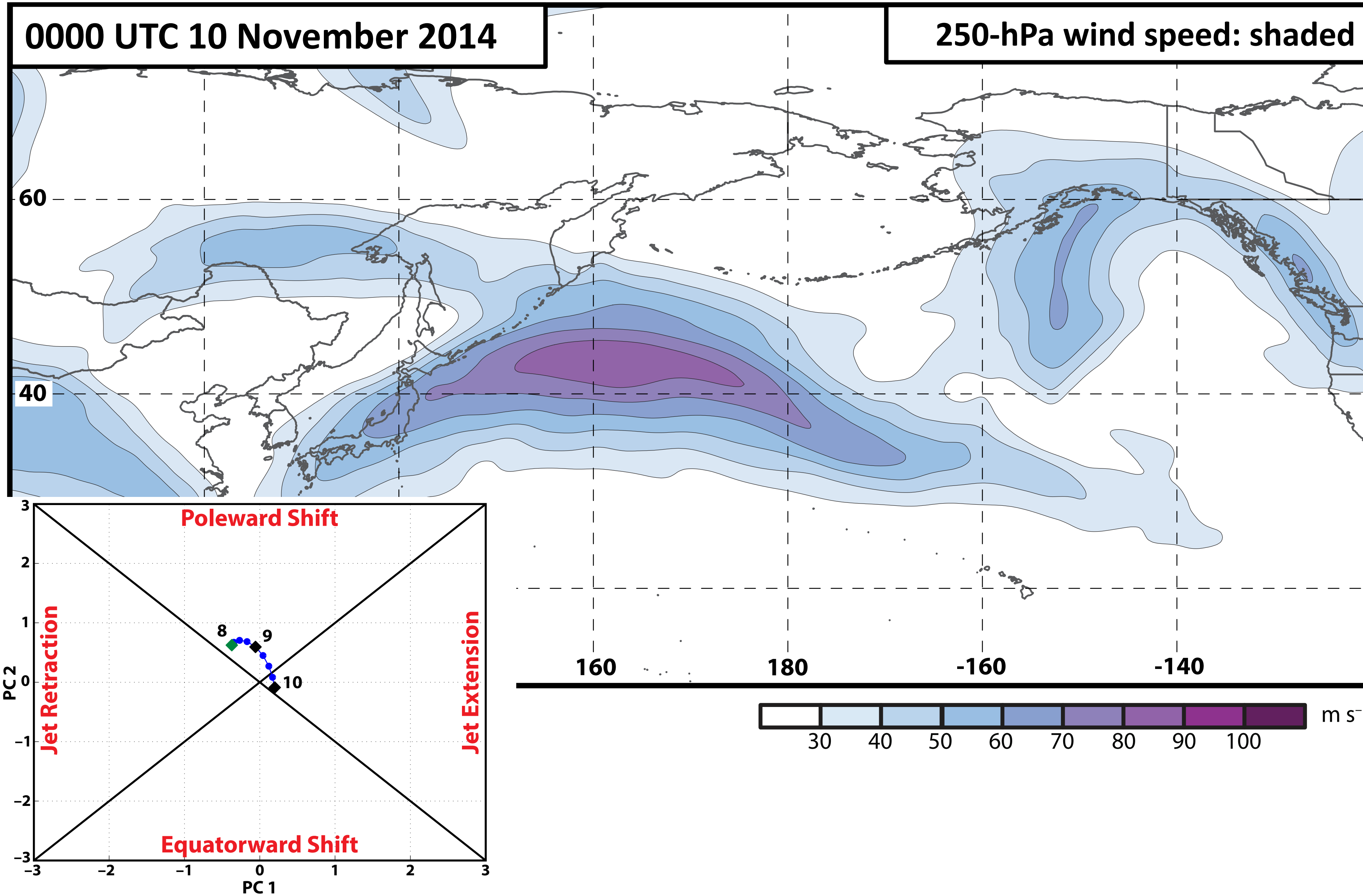




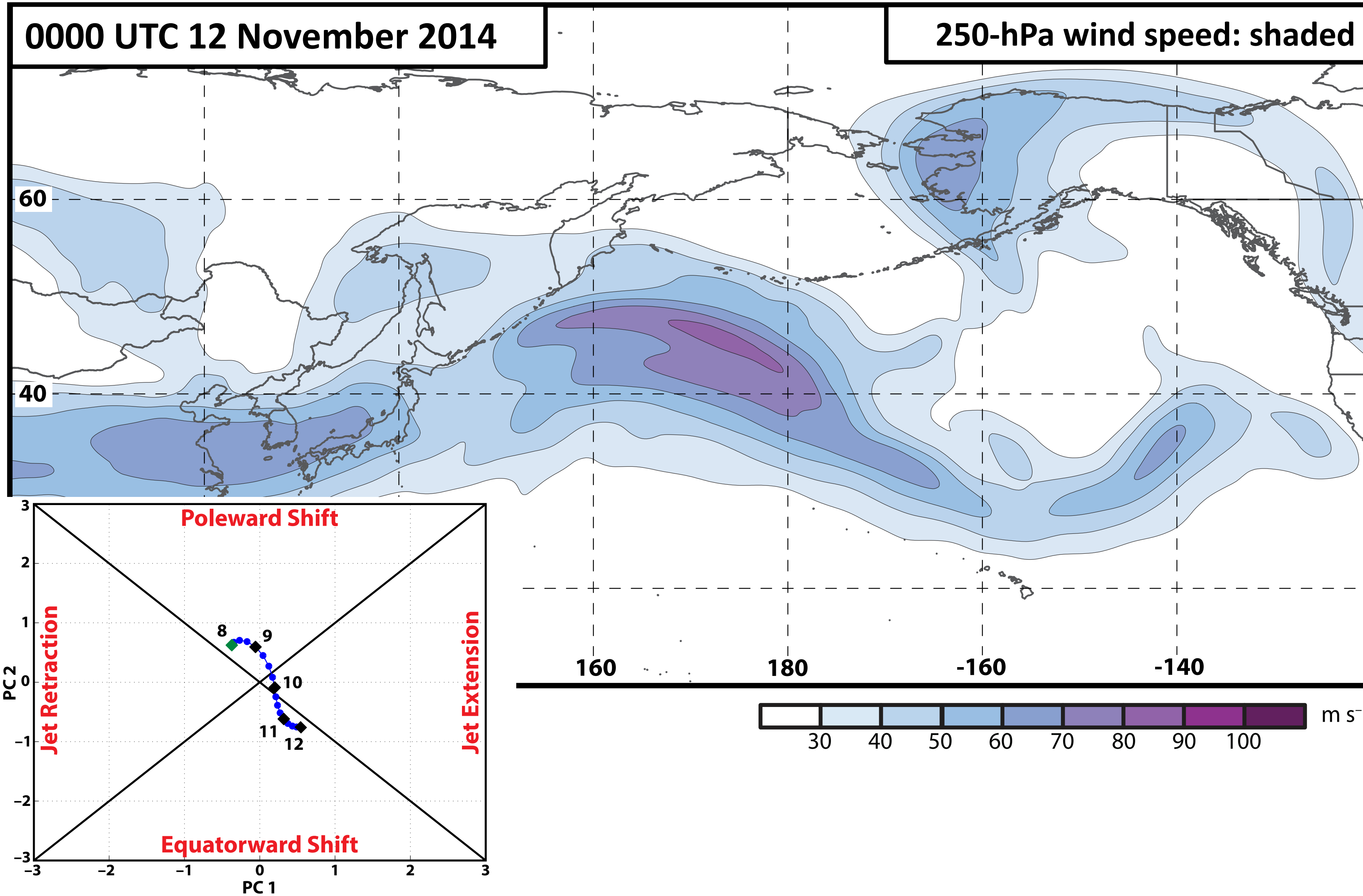
Real Time North Pacific Jet Phase Diagram



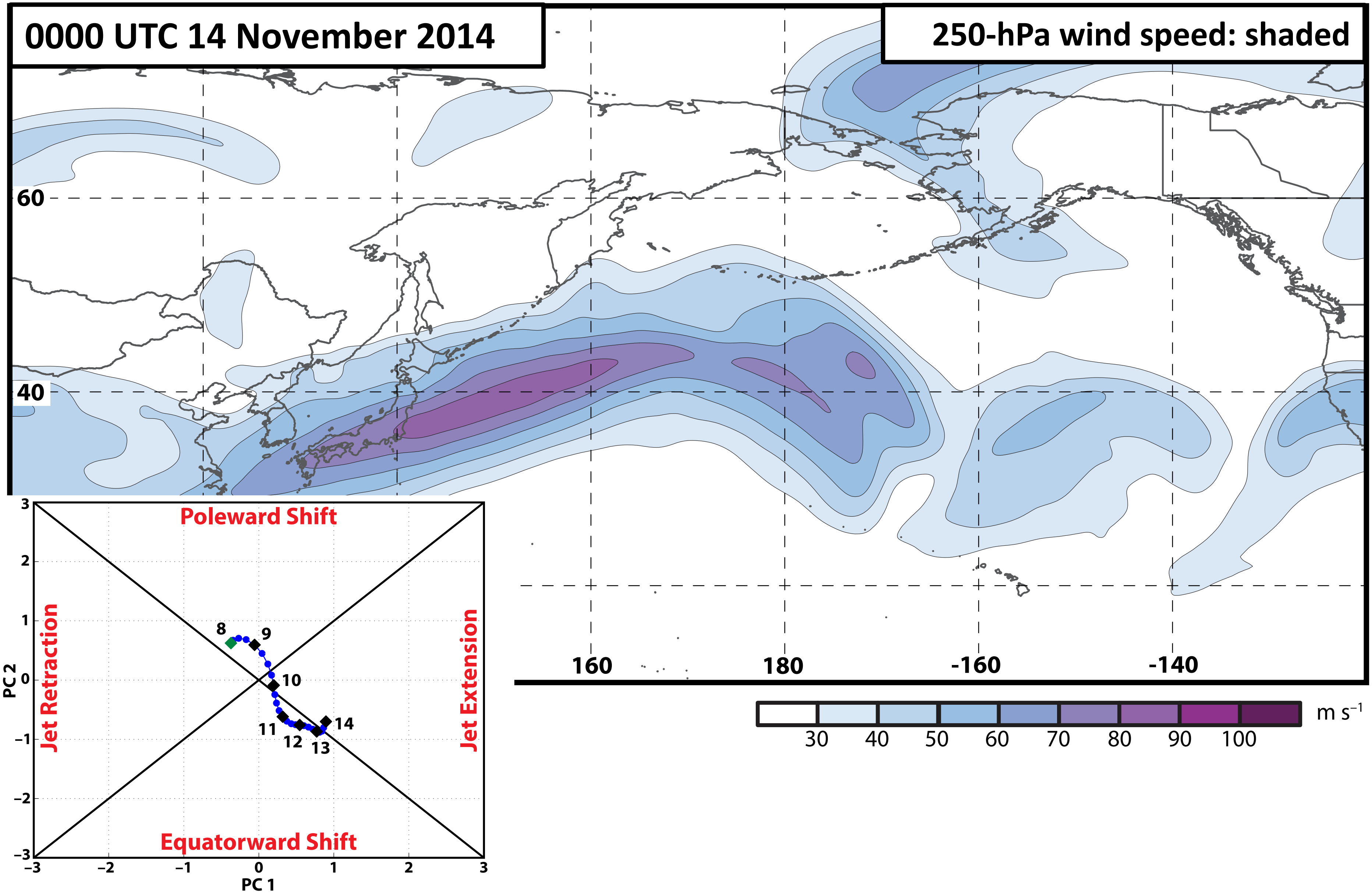
Real Time North Pacific Jet Phase Diagram



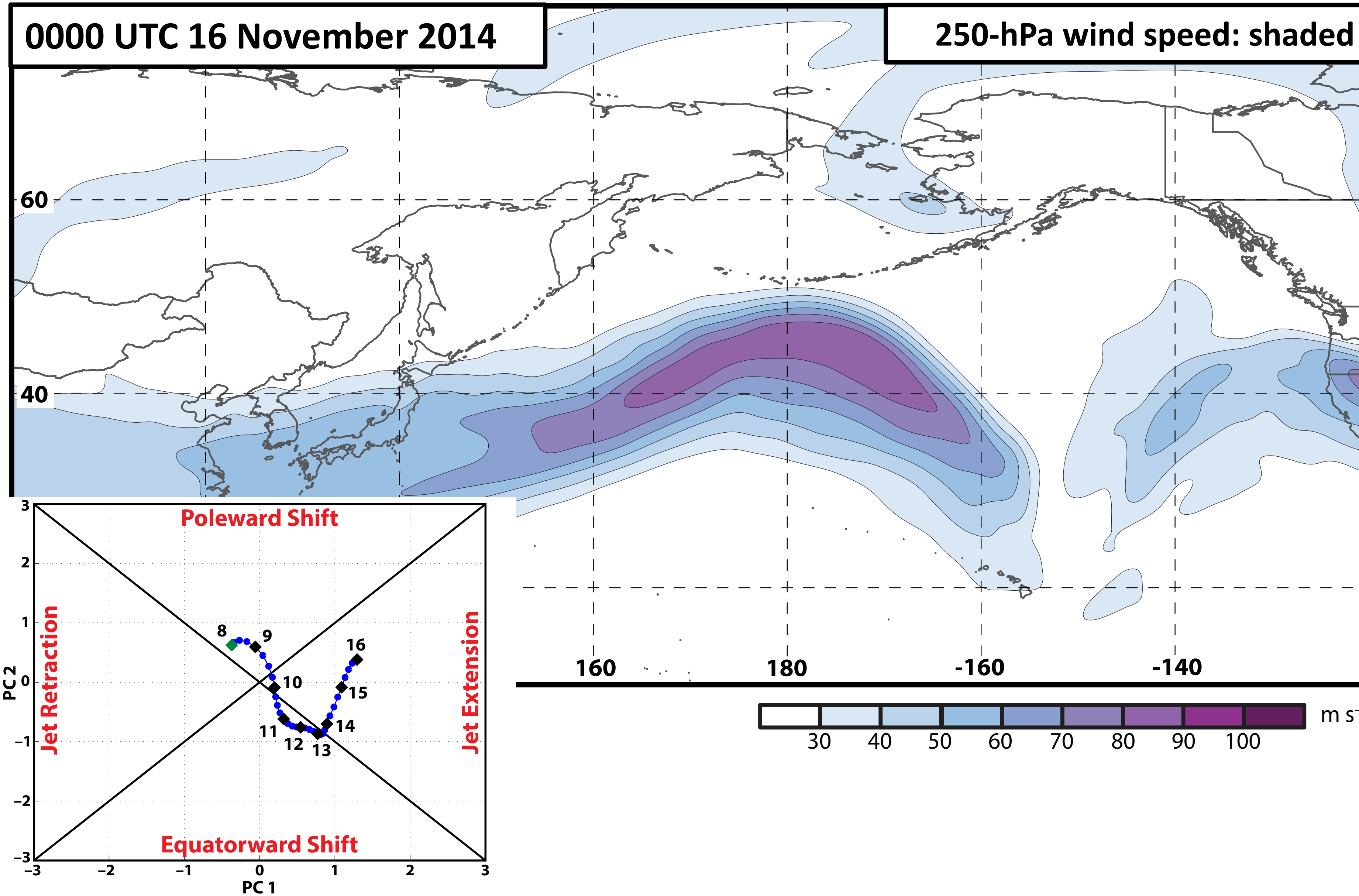
Real Time North Pacific Jet Phase Diagram



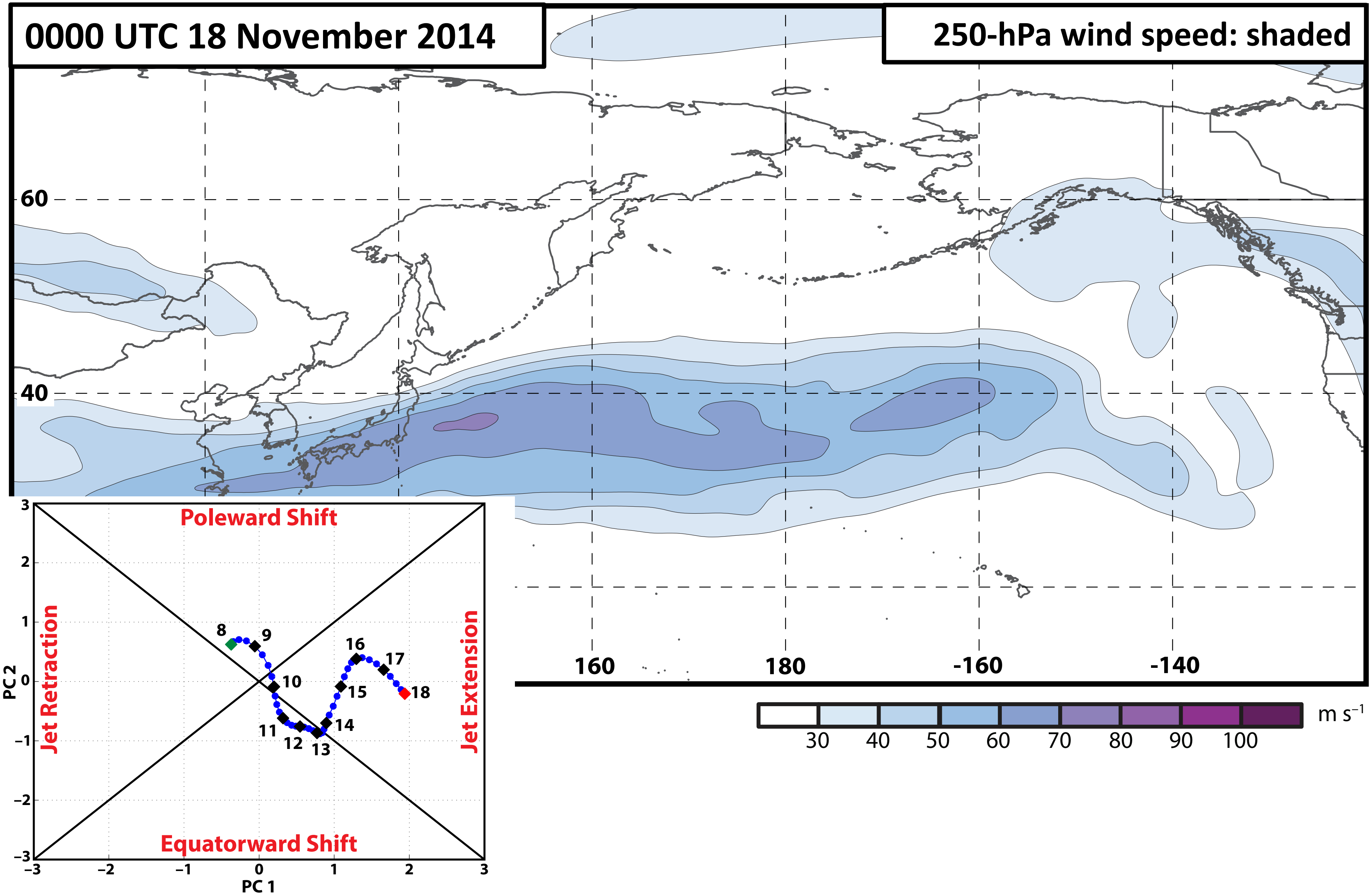
Real Time North Pacific Jet Phase Diagram



Real Time North Pacific Jet Phase Diagram



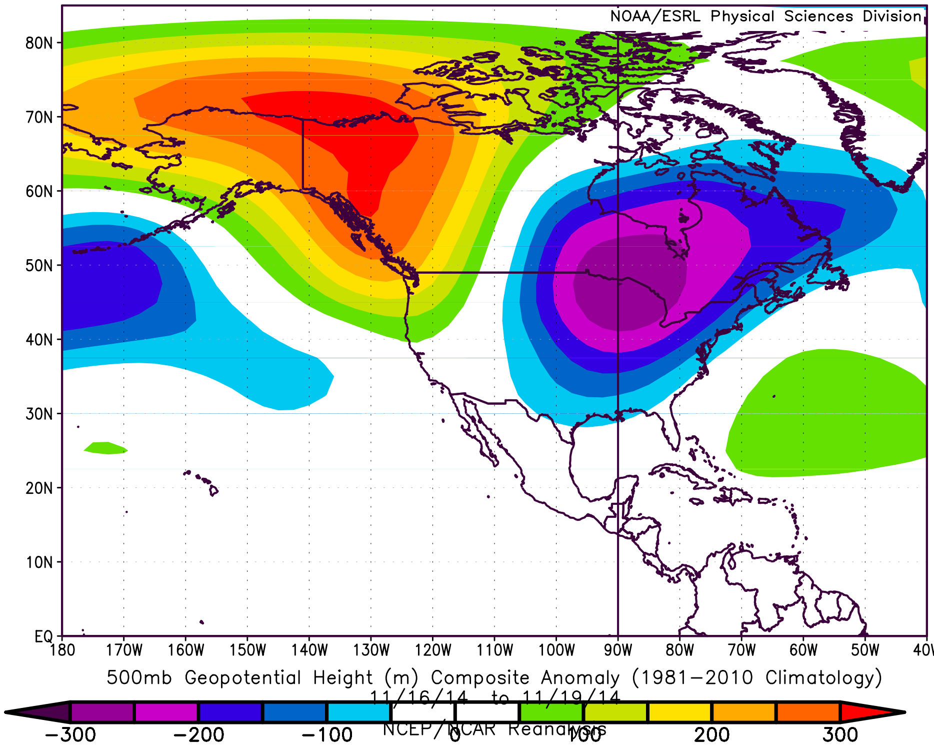
Real Time North Pacific Jet Phase Diagram



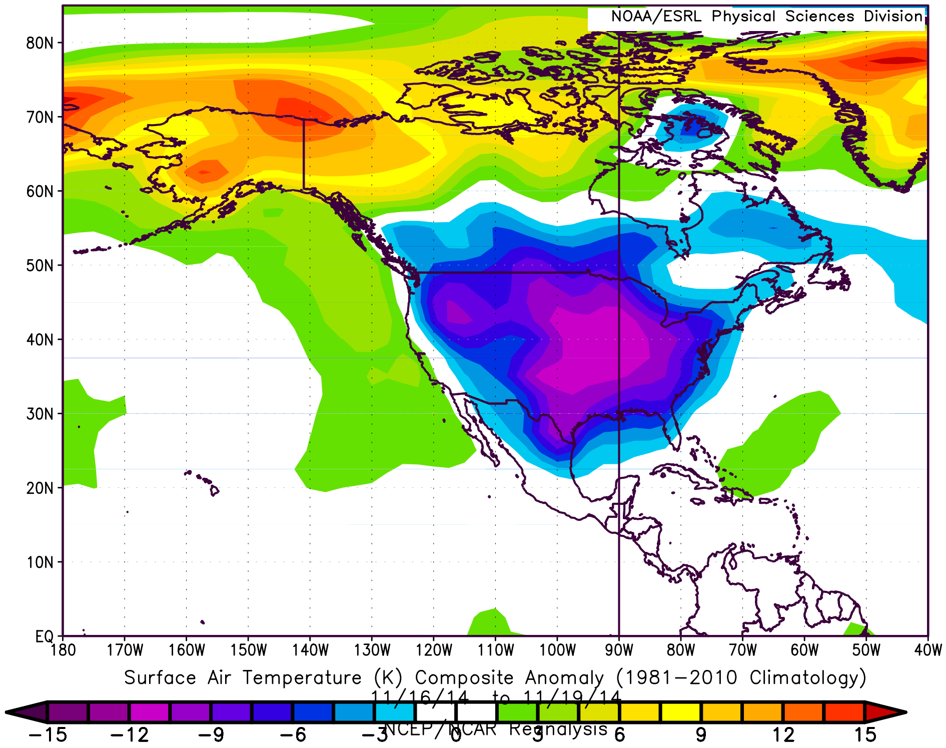
Real Time North Pacific Jet Phase Diagram

16–19 November 2014 Composite Anomalies

500-hPa Geo. Height (m)

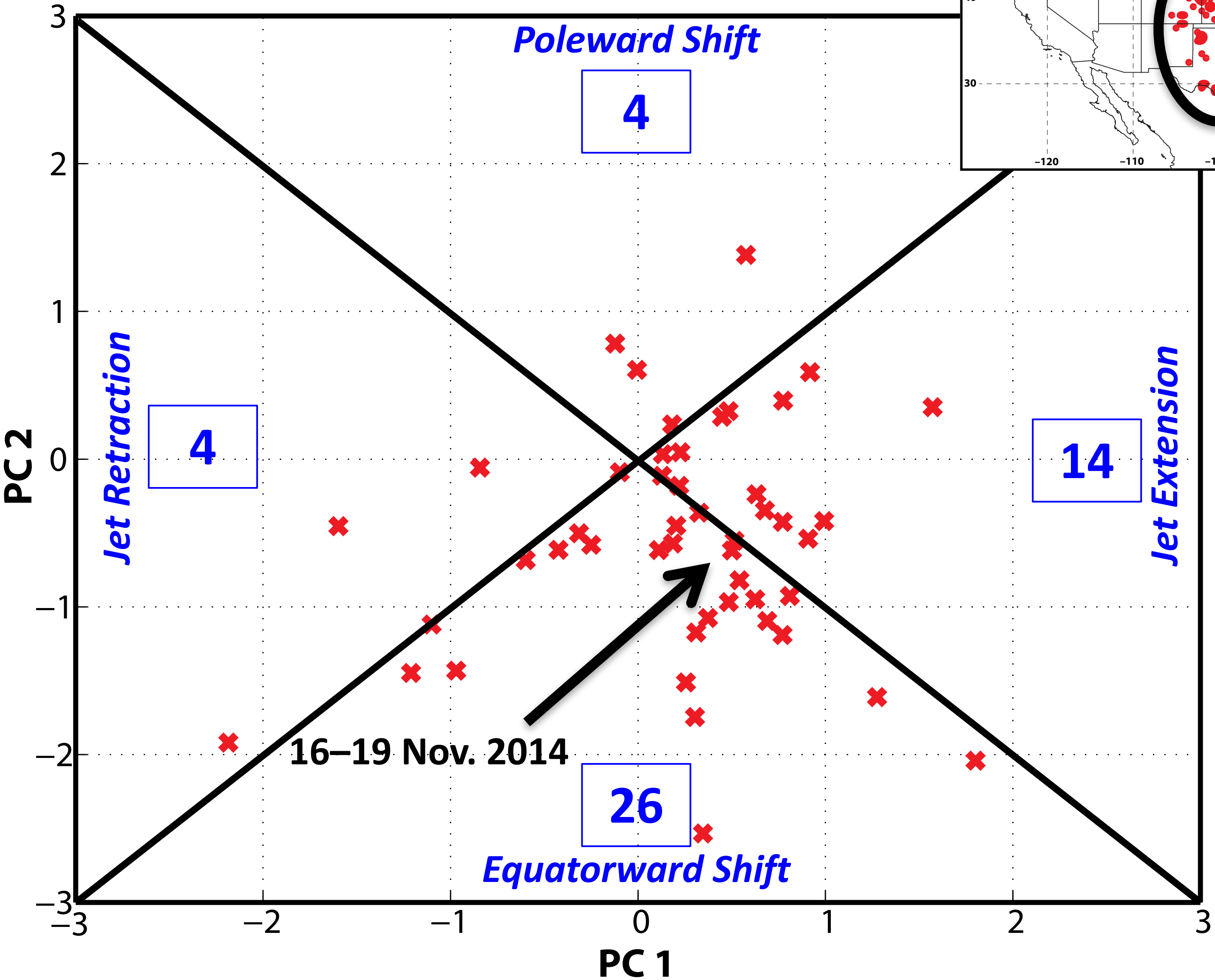


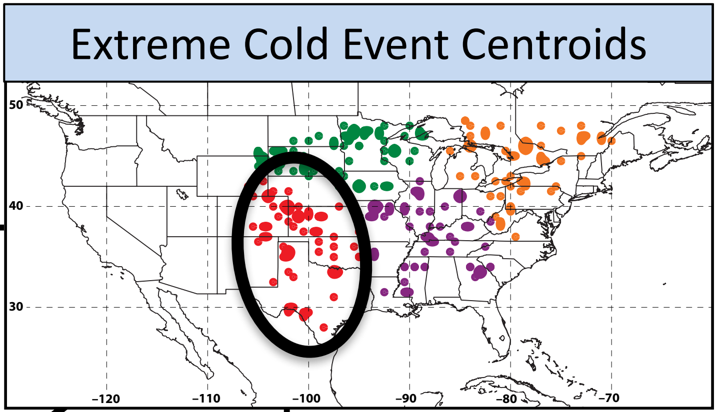
Surface Temperature (°C)



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

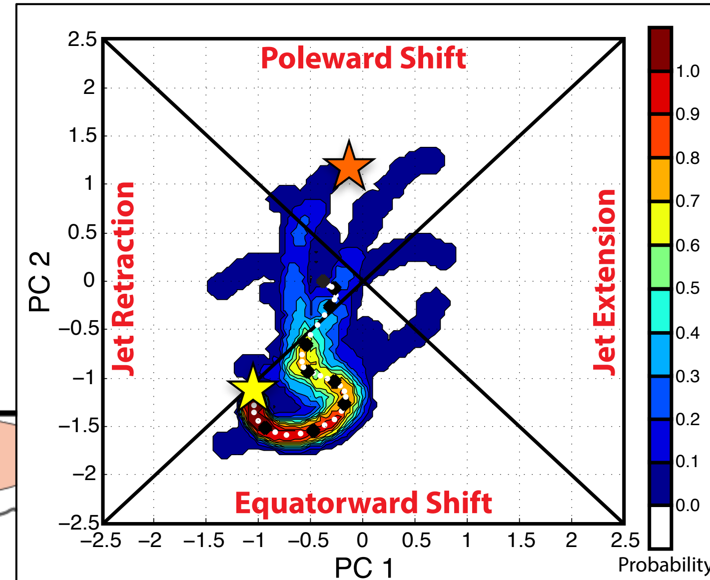
Real Time North Pacific Jet Phase Diagram

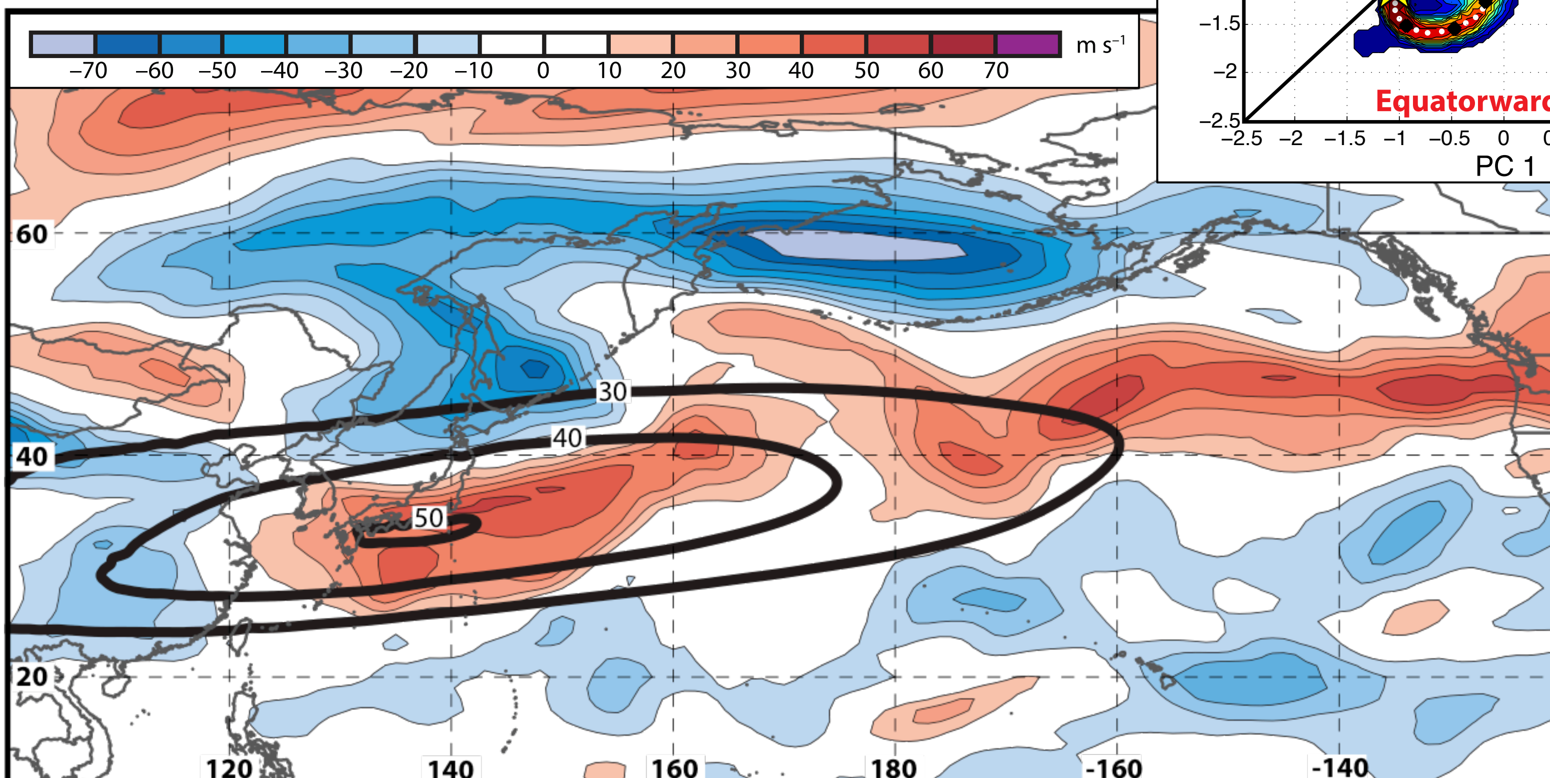
250-hPa zonal wind at 0000 UTC 2 Jun minus 250-hPa zonal wind at 0000 UTC 24 May (shading) in the GFS analyses shows the transition to a poleward-shifted jet regime

★ 0000 UTC 24 May (0-h forecast)

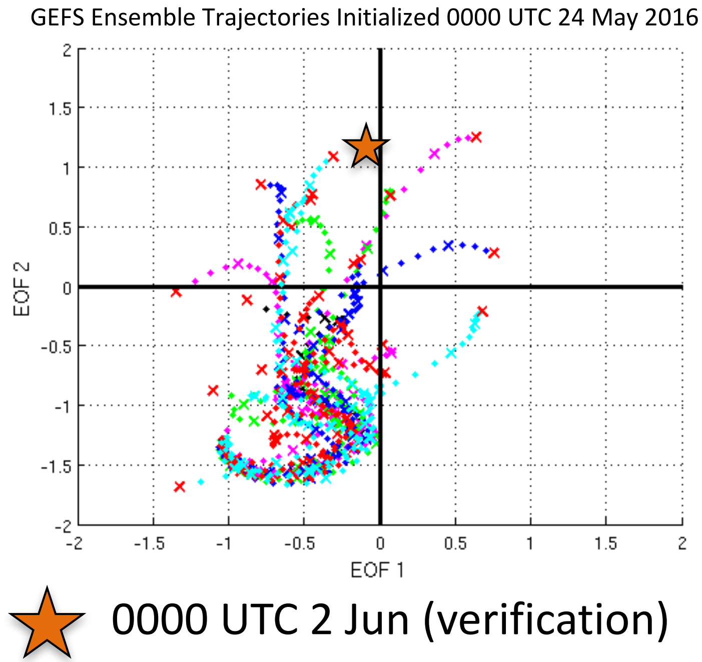
★ 0000 UTC 2 Jun (verification)

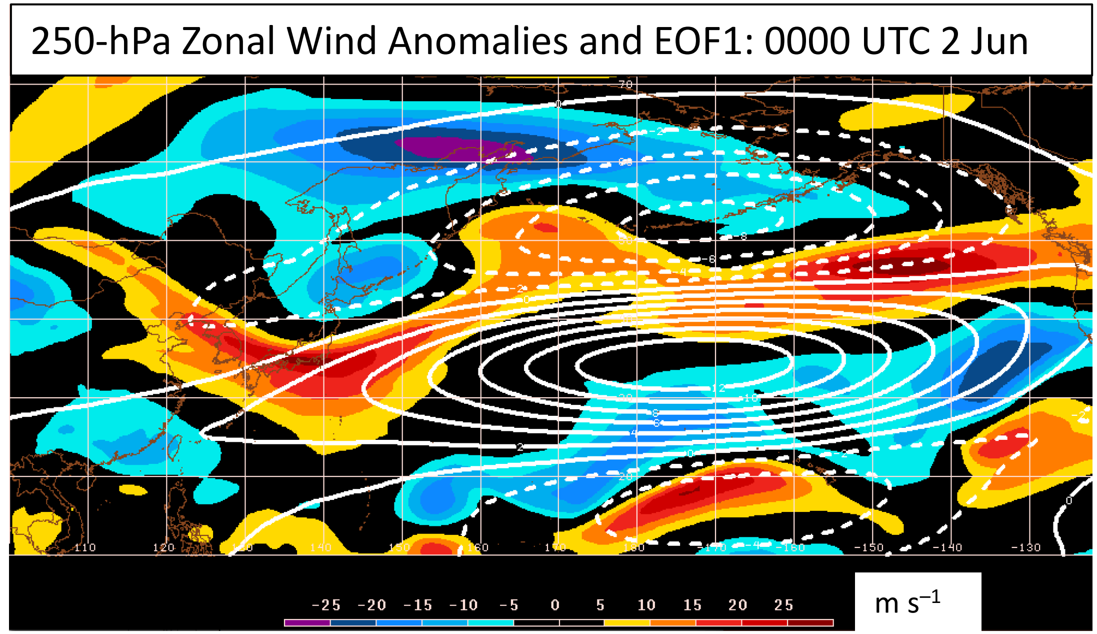
Ensemble mean

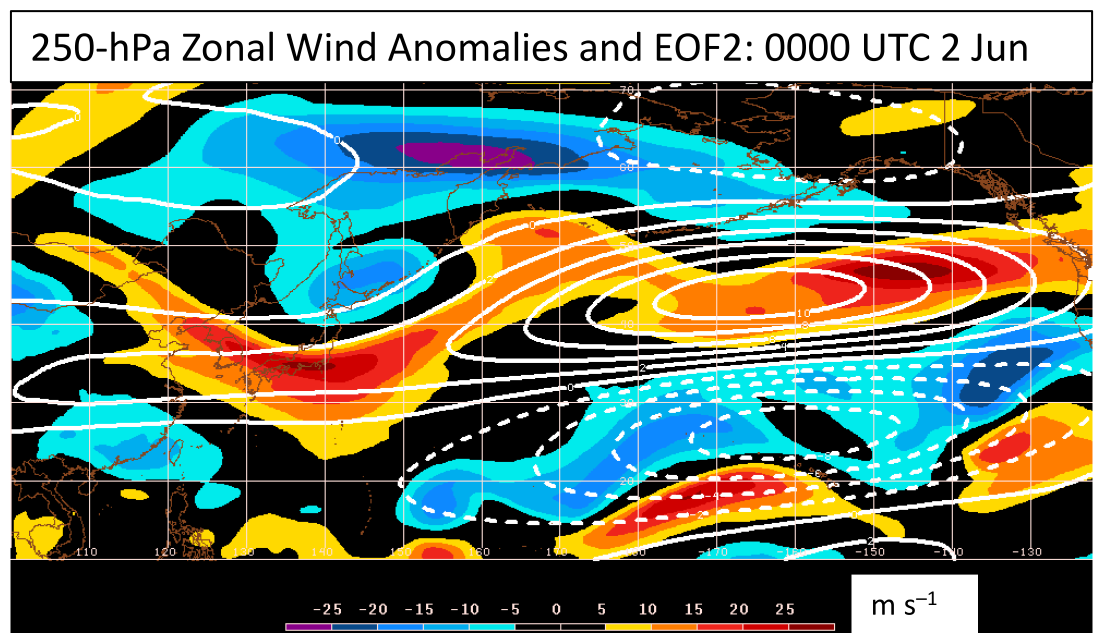




Sept.–May mean 250-hPa zonal wind: black contours







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