Multiscale Interactions during the Winters of 2009−2010 and 2010−2011: A Link to the February 1979 Presidents' Day Storm

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Motivation

- Winter 1978-1979 featured distinct large-scale weather regimes
- Transitions between these 1978-1979 weather regimes were very abrupt
- The Presidents' Day storm marked a transition from cold and dry to warm and wet
- Gridded datasets available at that time were insufficient to study large-scale regime changes
- The 2009-2010 and 2010-2011 featured prominent large-scale regime transitions.

Outline of presentation

1. Large-scale regime transitions before and after the Presidents' Day Storm of February 1979

2. Large-scale blocking, extreme weather, and the "Coast-to-Coast" and "Screaming Eastern Pacific Jet" storms

3. "Flavors" of cyclone-jet interactions in late winter 2010

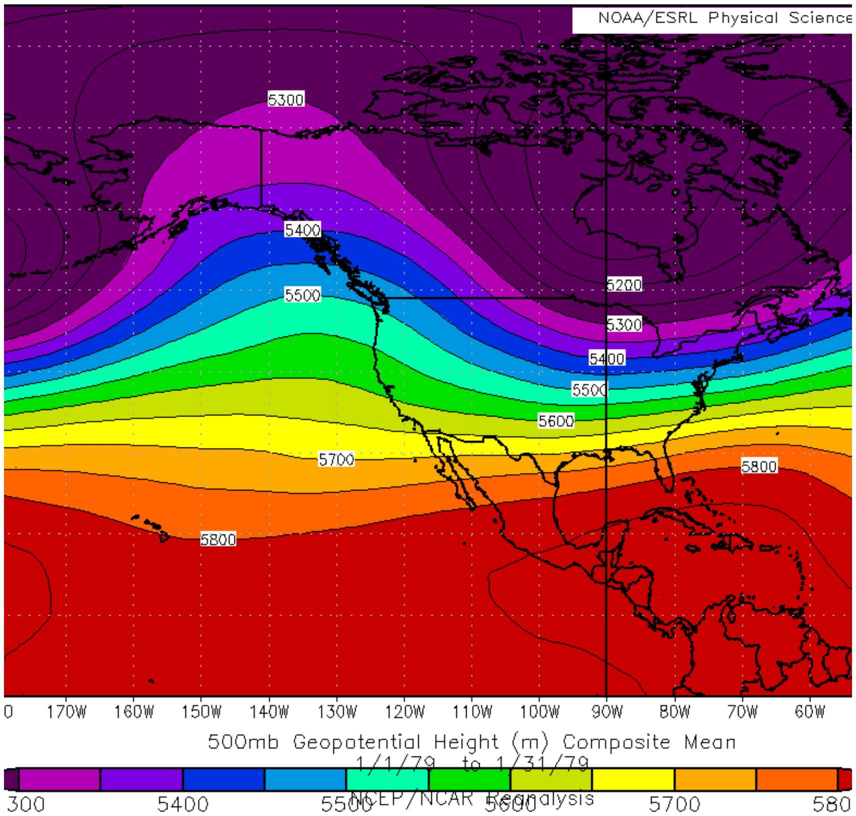
4. The "half and half" winter of 2010-2011: Cold early and mild late

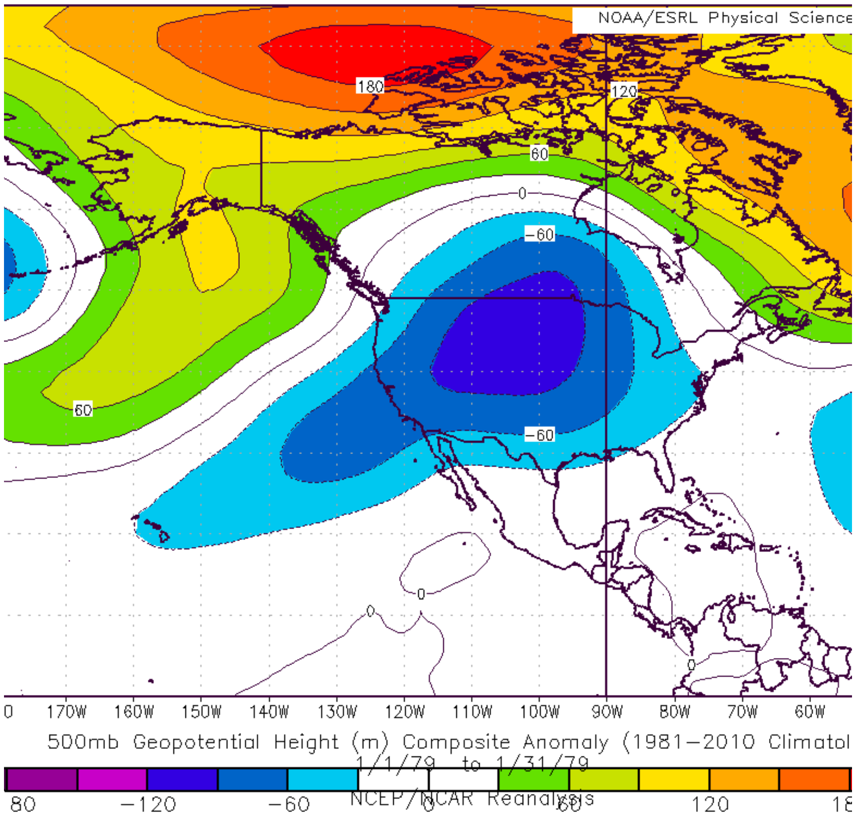
5. CONUS weather variability during the winter 2010-2011 transition from cold early to mild late

6. A comparison of the CONUS bomb of 25-26 Oct 2010 and the "Cleveland Superbomb" of 25-26 January 1978 (time permitting)

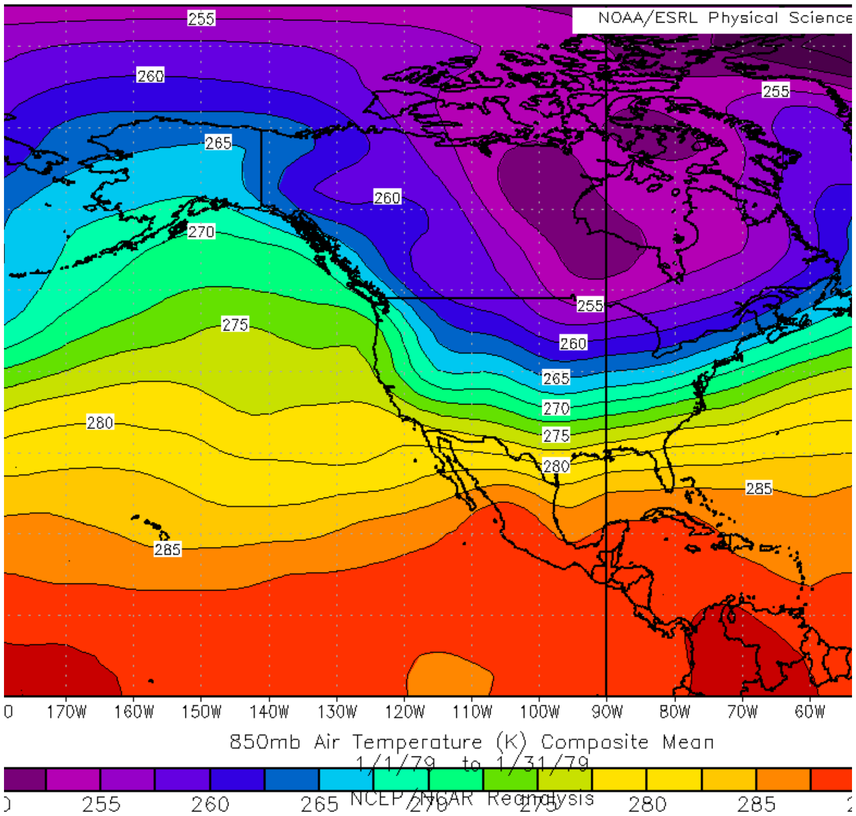
North American 500-hPa height and 850-hPa Temperature Patterns: 1 Jan to 15 Mar 1979

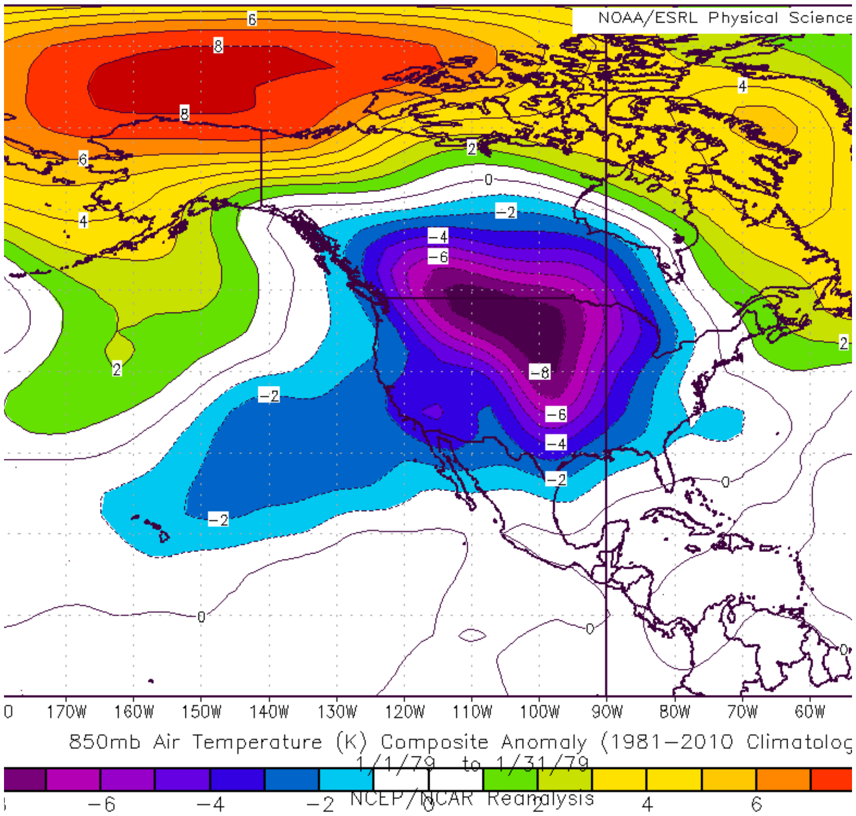
500-hPa Z(dam)/Z'(m): 1-31 Jan 1979



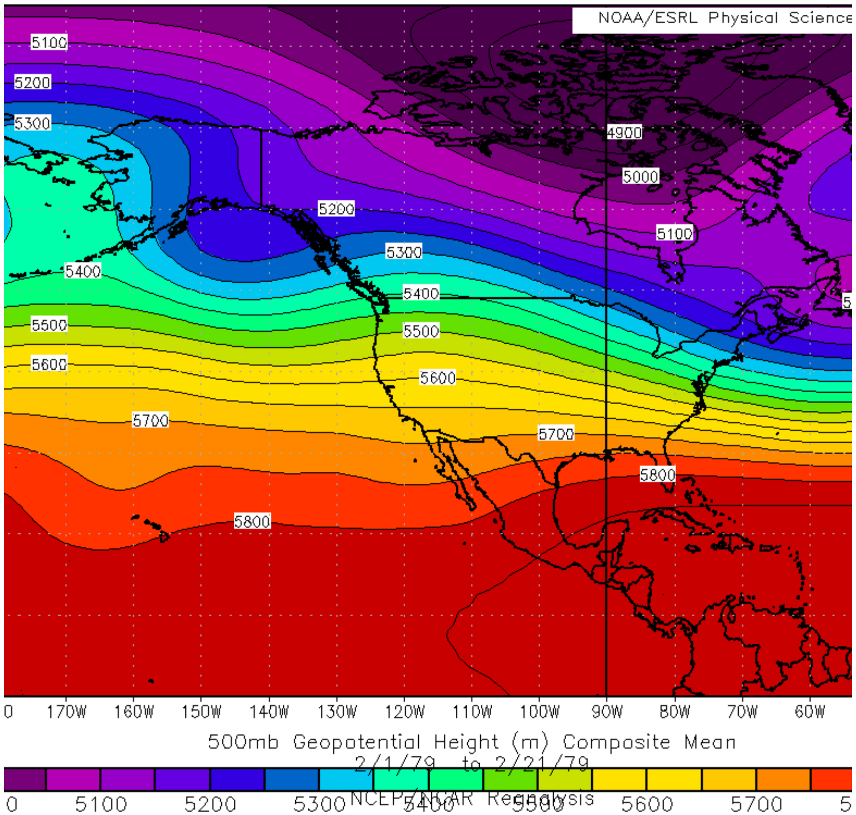


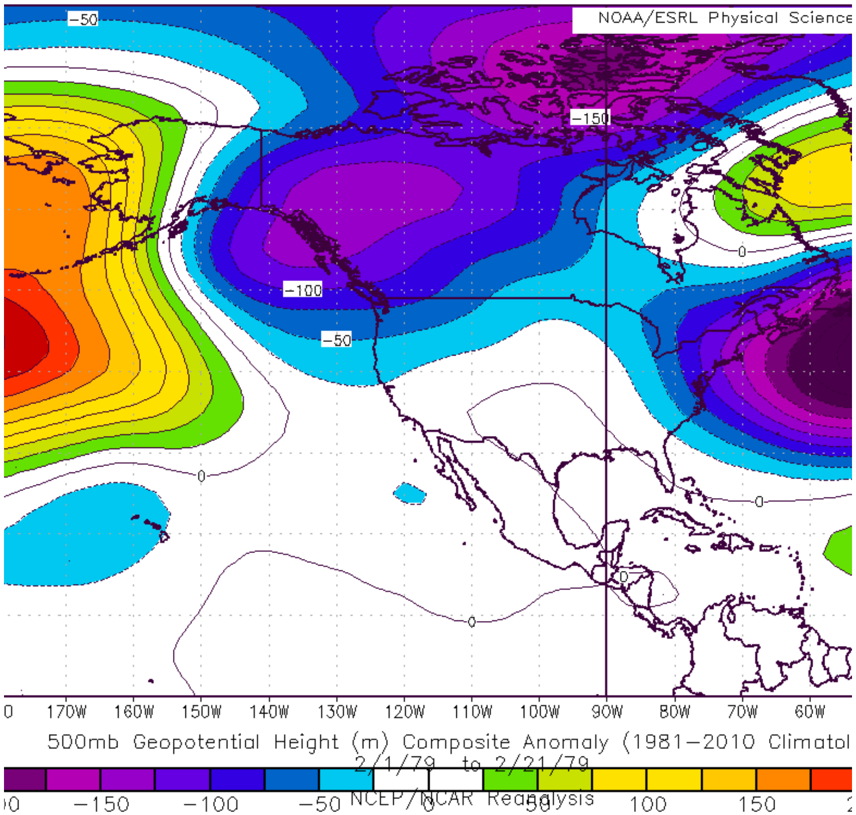
850-hPa T(C)/T'(C): 1-31 Jan 1979



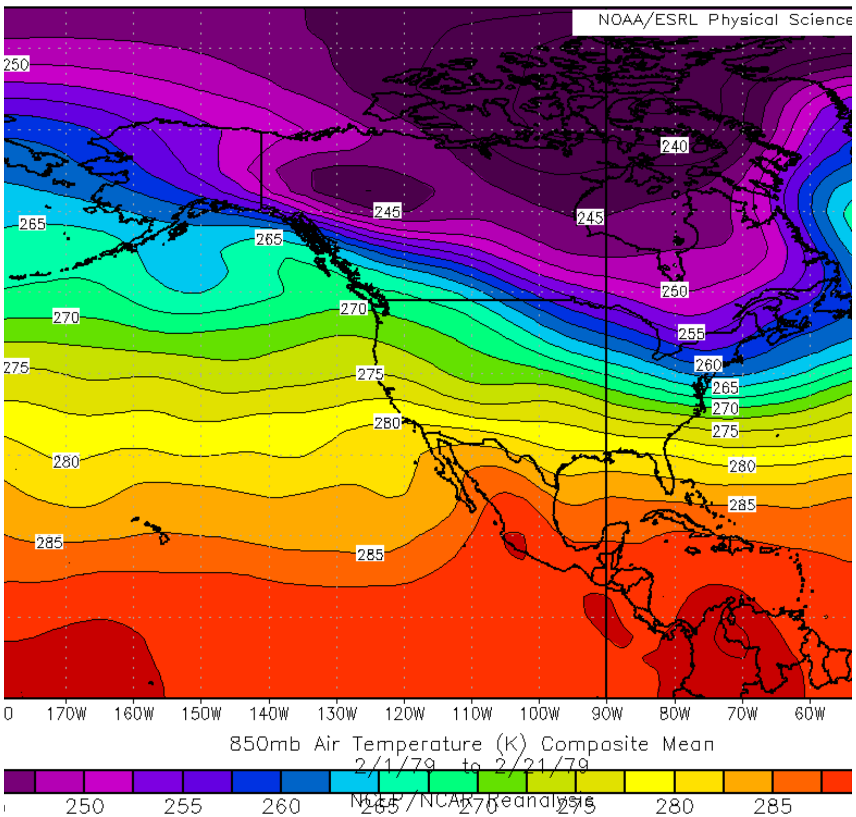


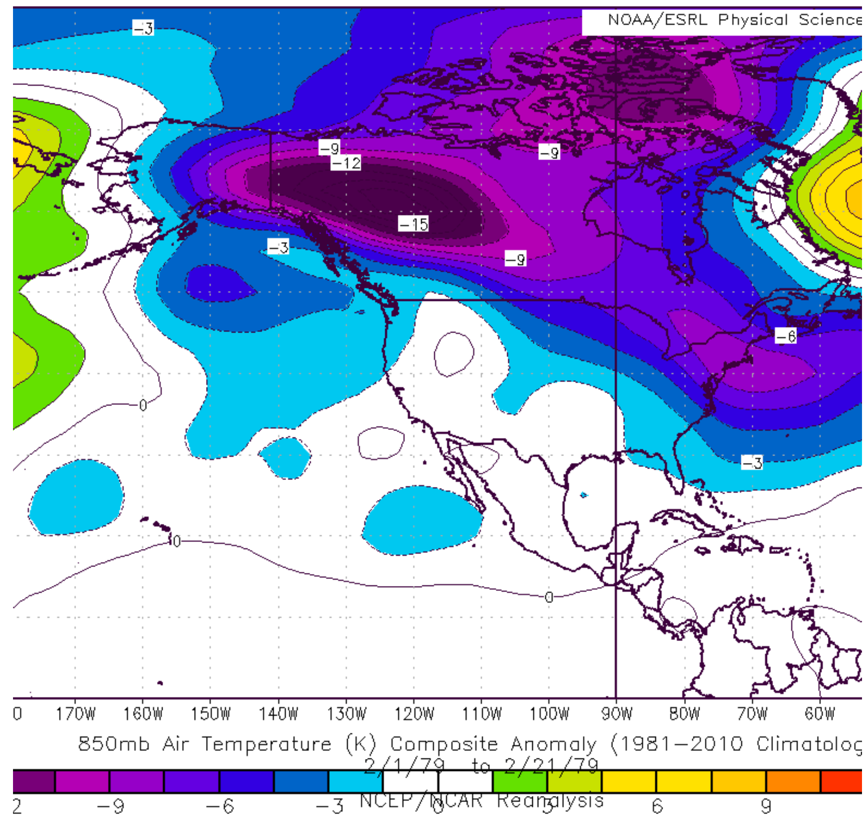
500-hPa Z(dam)/Z'(m): 1- 21 Feb 1979



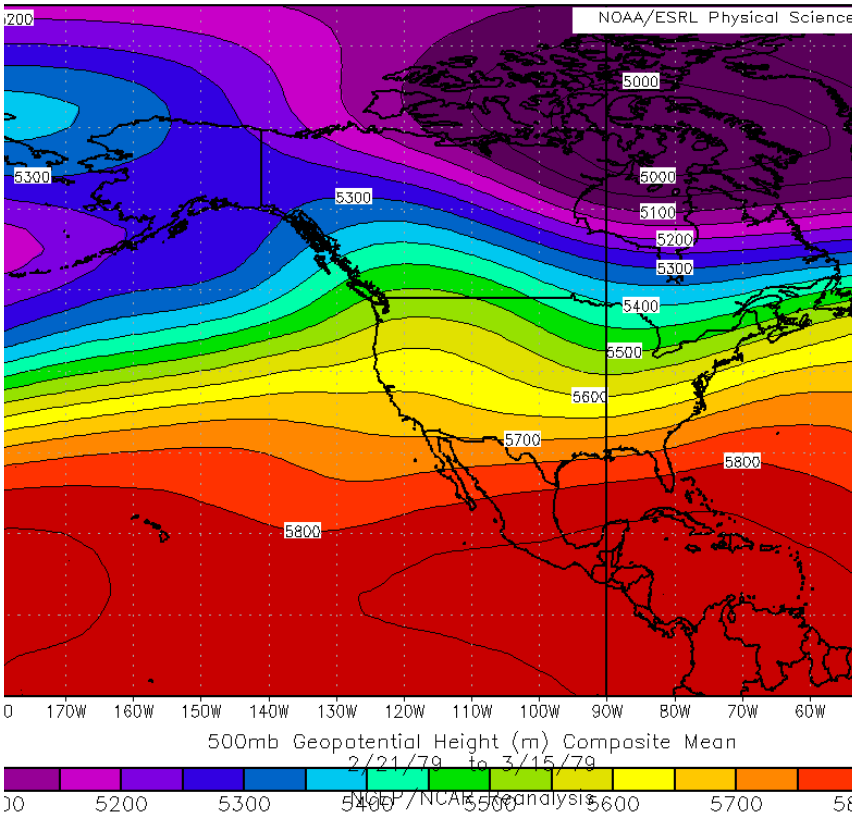


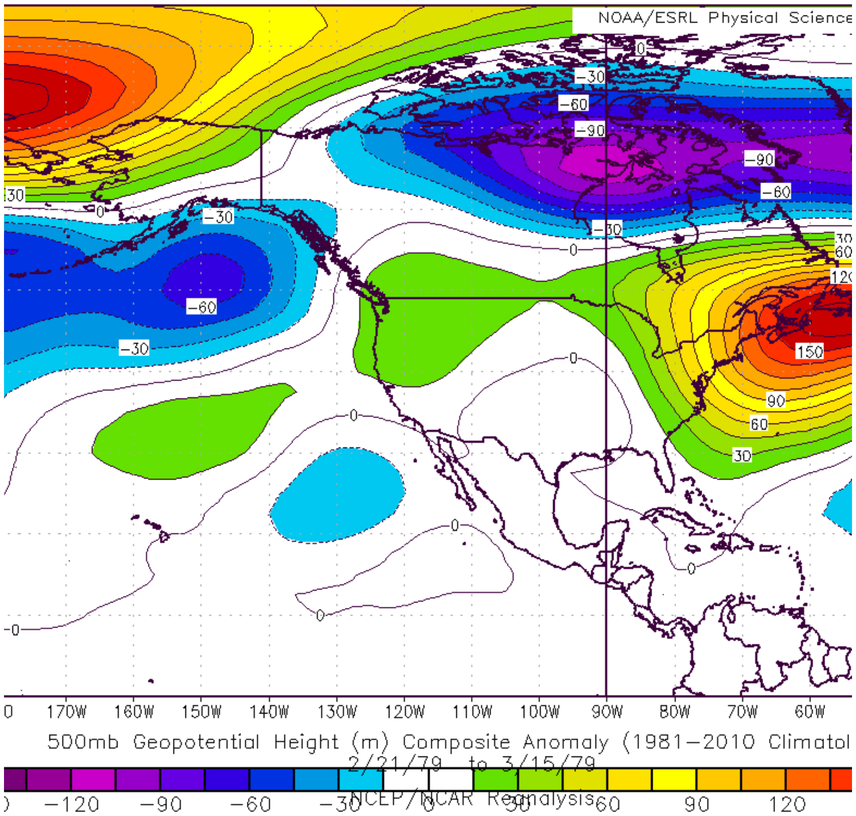
850-hPa T(C)/T'(C): 1-21 Feb 1979



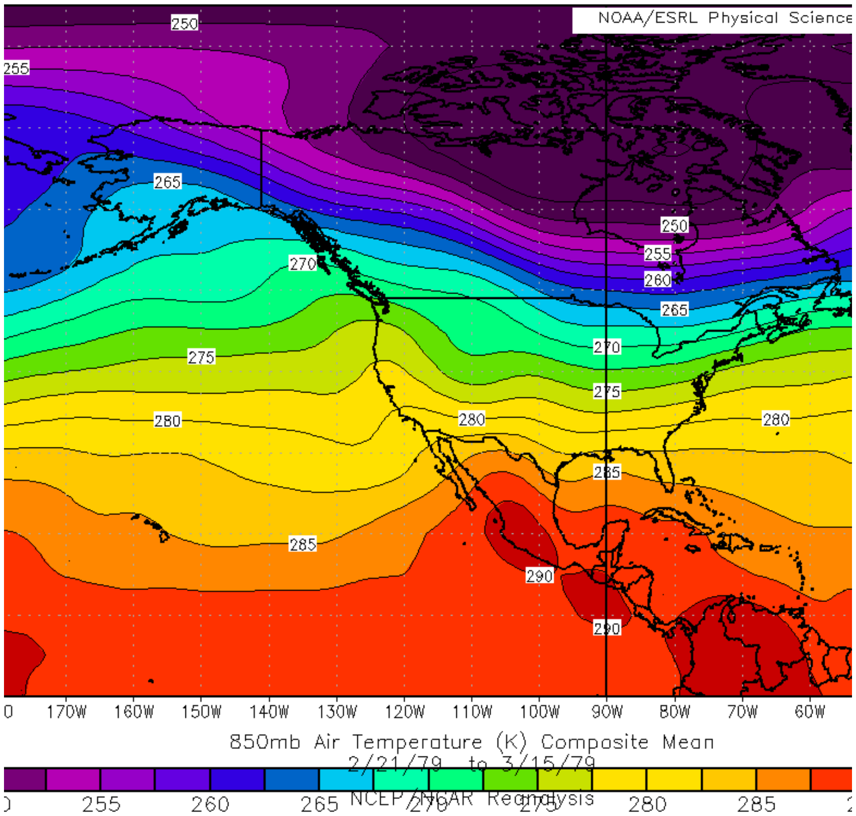


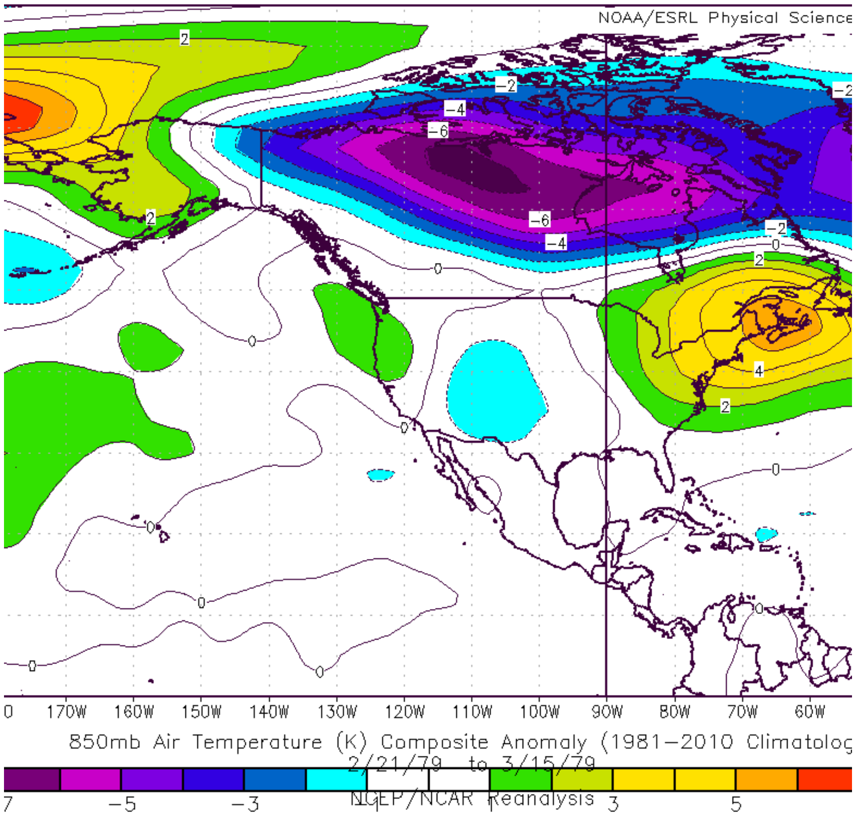
500-hPa Z(dam)/Z’(m): 21 Feb-15 Mar 1979





850 T(C)/T'(C): 21 Feb – 15 Mar 1979





Winters 2009–2010 and 2010–2011

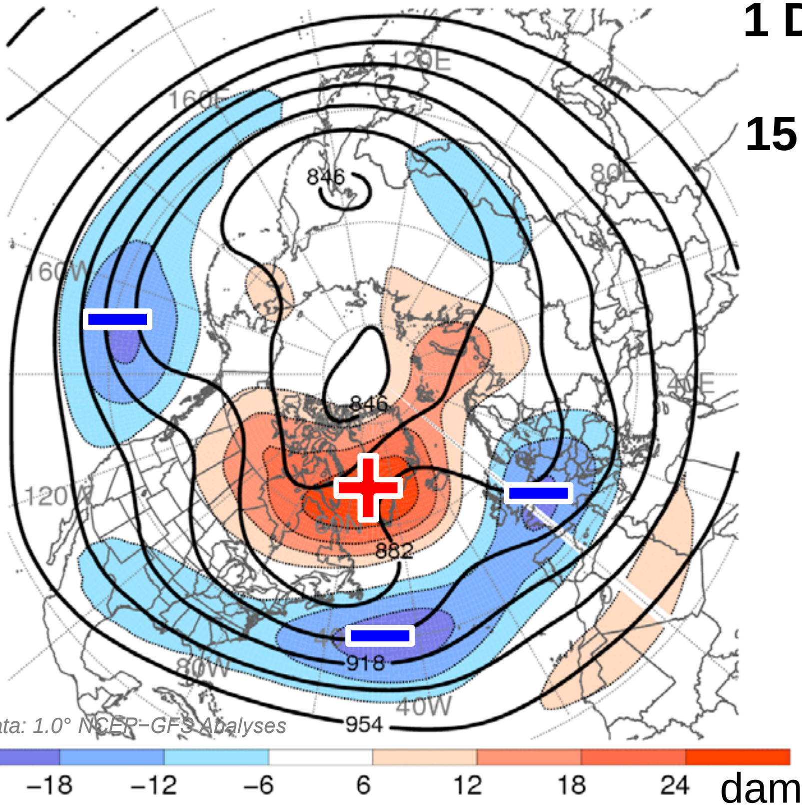
- Given that these winters were:
  - Dominated by disruption of the NH polar vortex, which enables arctic air masses to reach lower latitudes,
  - Characterized by extreme weather events along the margins of the arctic air masses,
  - Associated with El Niño (2009–2010) and La Niña (2010–2011),
- We ask: What are the ingredients behind this observed extreme weather variability?

Winter 2009–2010

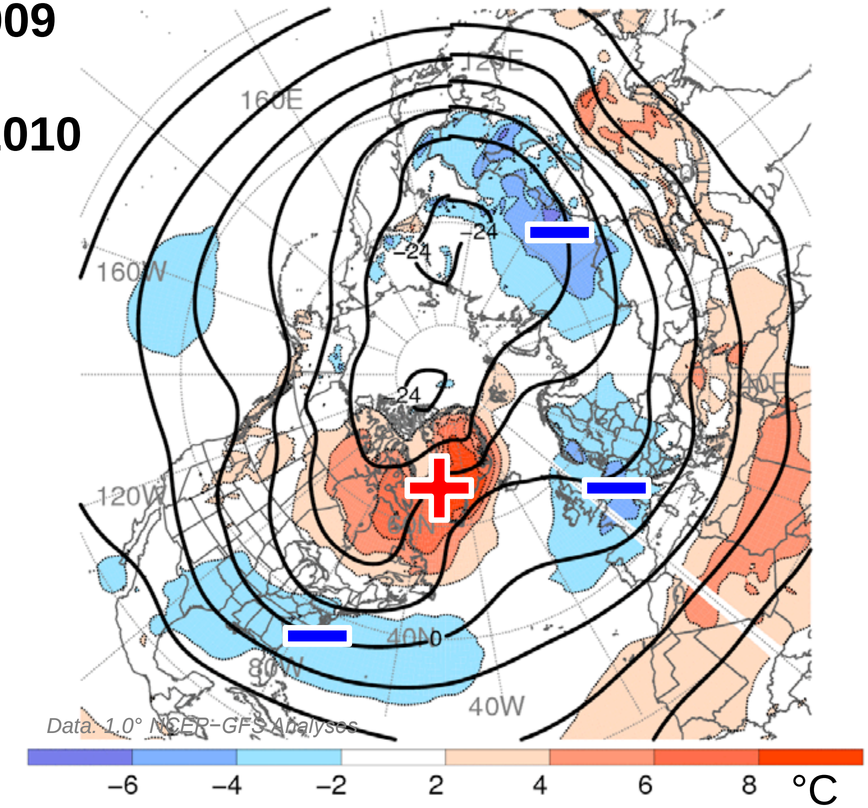
Winter 2009–2010: "Blocked" Flow Pattern

300-hPa Geo. Height (contoured, dam) and Geo. Height Anomaly (shaded, dam)

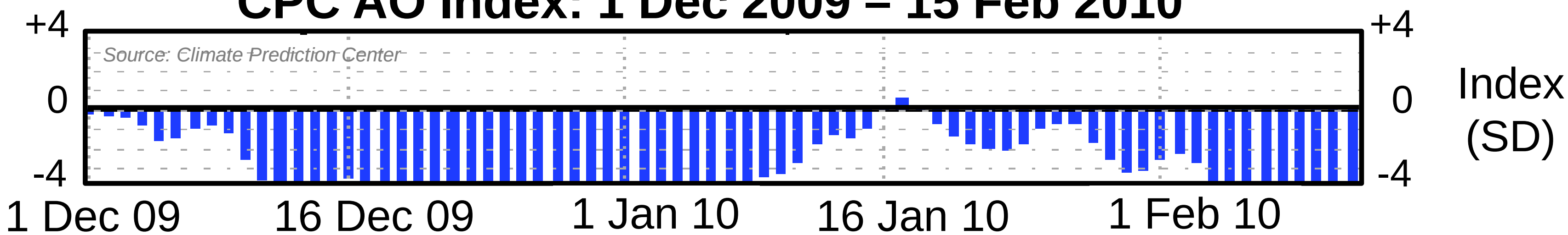
850-hPa Temperature (contoured, °C) and Temperature Anomaly (shaded, °C)



1 Dec 2009 to 15 Feb 2010



CPC AO Index: 1 Dec 2009 – 15 Feb 2010



Part III: Two Major North Atlantic Blocking Events

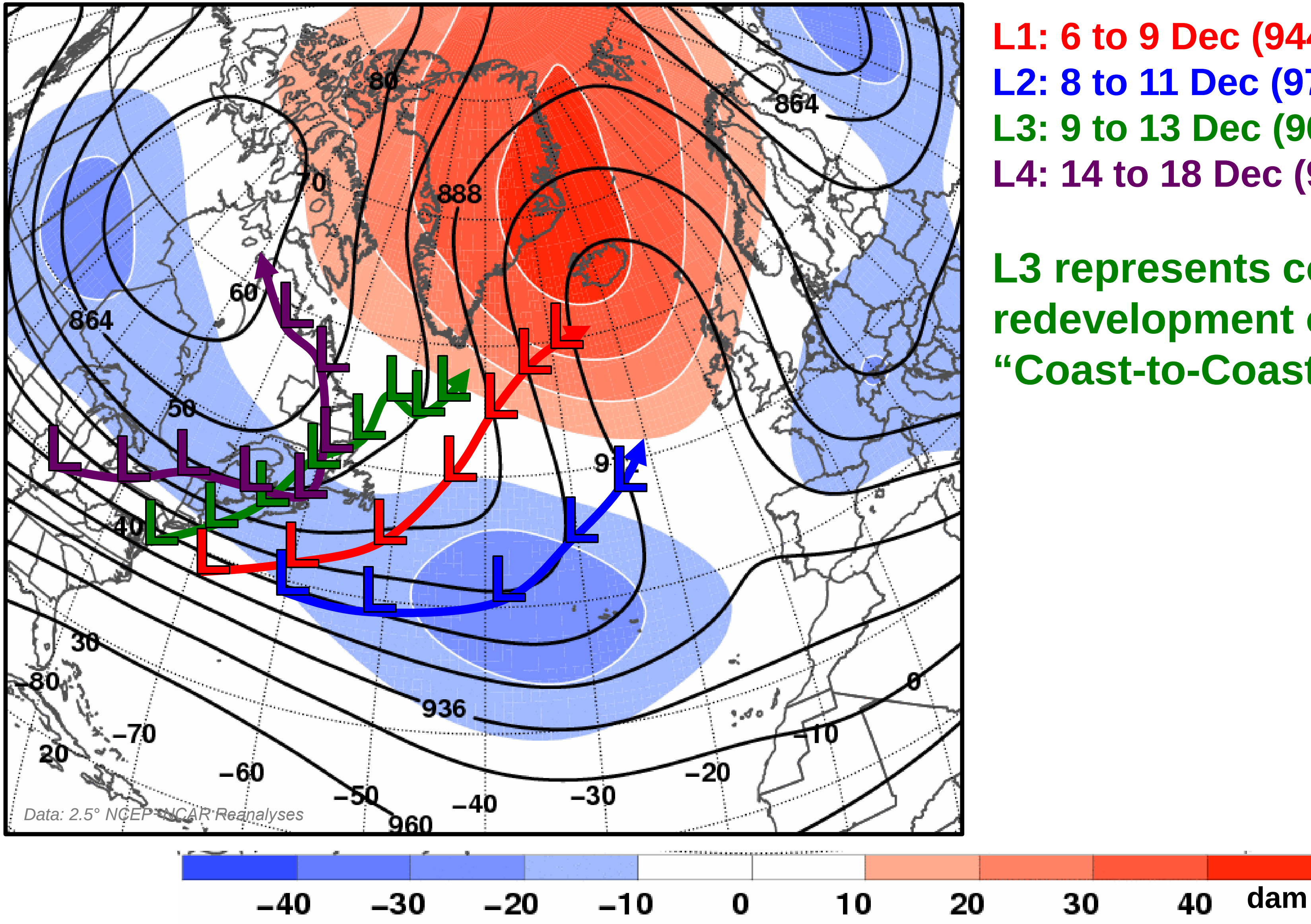
Episode I: 9 Dec 2009 – 18 Dec 2009
Episode II: 31 Dec 2009 – 8 Jan 2010

- Western Atlantic cyclones build/reinforce block
- Omega/Rex block transition
- European cold and storminess
- Southeast U.S. cold

3. North Atlantic Blocking Episodes I and II

300-hPa Geopotential Height (dam, solid) and geopotential height anomaly (dam, shaded):

I) 9 Dec 2009 to 18 Dec 2009



L1: 6 to 9 Dec (944 hPa)

L2: 8 to 11 Dec (976 hPa)

L3: 9 to 13 Dec (960 hPa)

L4: 14 to 18 Dec (988 hPa)

L3 represents coastal redevelopment of "Coast-to-Coast" Storm

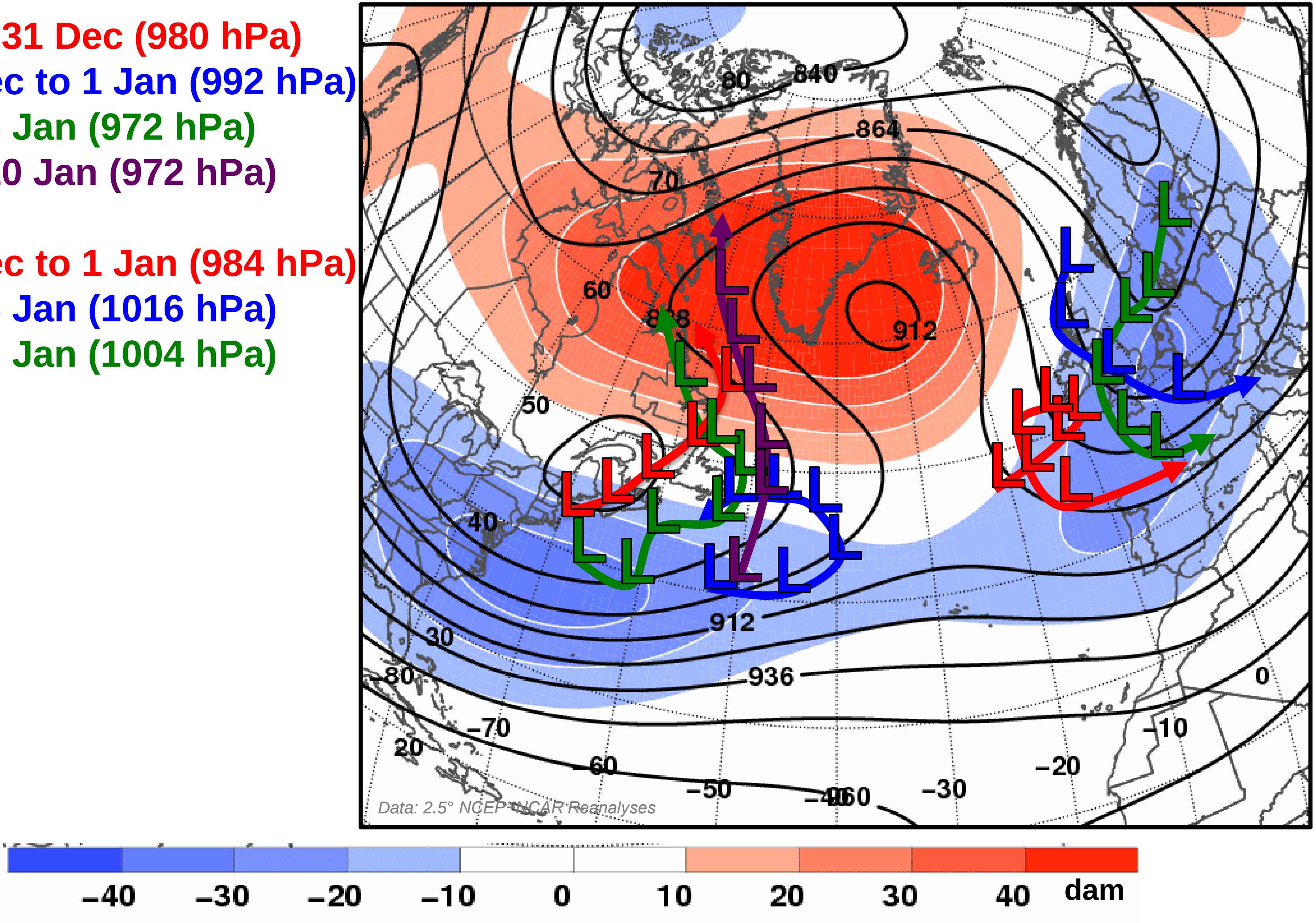
3. North Atlantic Blocking Episodes I and II

300-hPa Geopotential Height (dam, solid) and geopotential height anomaly (dam, shaded):

II) 31 Dec 2009 to 8 Jan 2010

L1: 29 to 31 Dec (980 hPa)
L2: 31 Dec to 1 Jan (992 hPa)
L3: 1 to 6 Jan (972 hPa)
L4: 7 to 10 Jan (972 hPa)

L5: 29 Dec to 1 Jan (984 hPa)
L6: 1 to 3 Jan (1016 hPa)
L7: 5 to 7 Jan (1004 hPa)



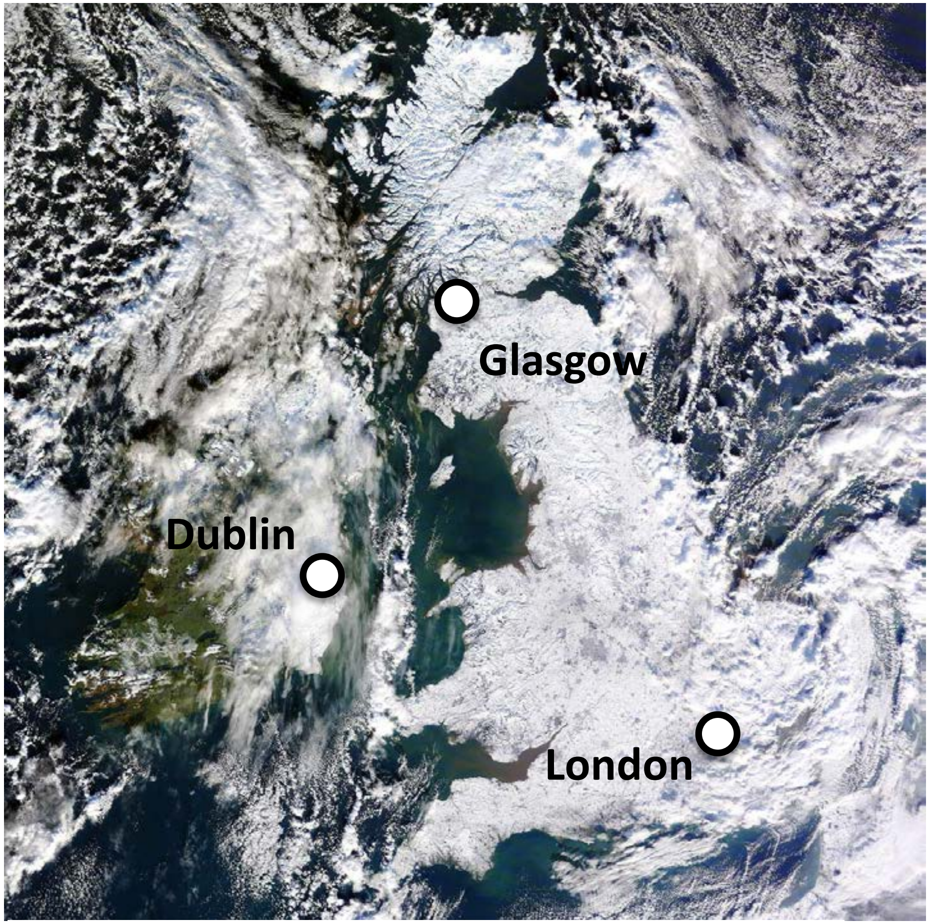
Winter 2009−2010: North Atlantic Blocking – Episodes I and II

- **Impact**: Upstream warmth and ultimate influence on polar ice cover
- **Impact**: Downstream snow storms and unprecedented snow cover

16 Feb 2010 Sea Ice Extent

Source: National Snow and Ice Data Center

7 Jan 2010 Visible Image



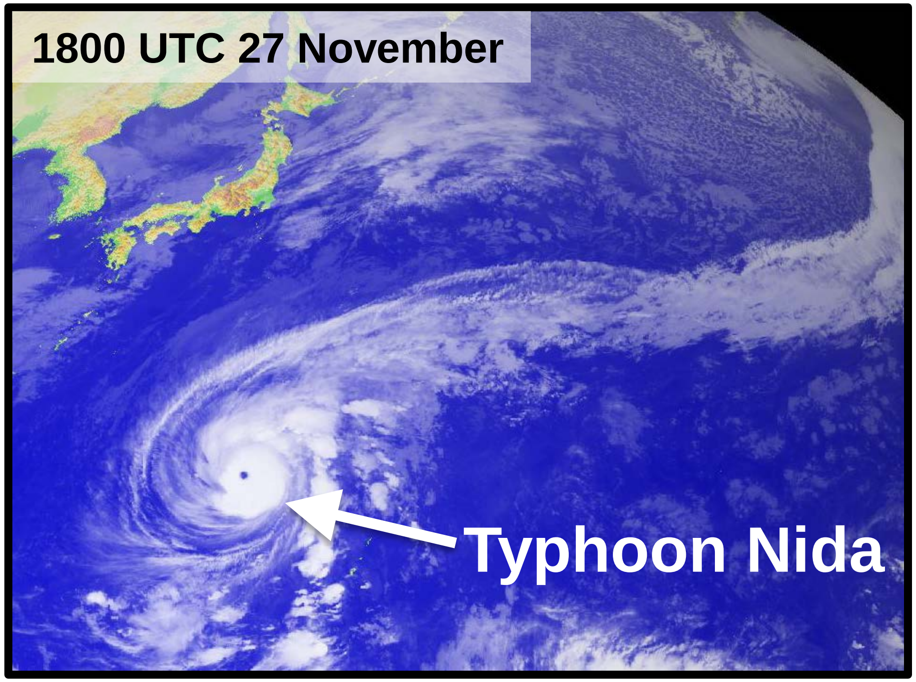
Source: MODIS Rapid Fire Online Server

Winter 2009−2010: Extreme Weather Events

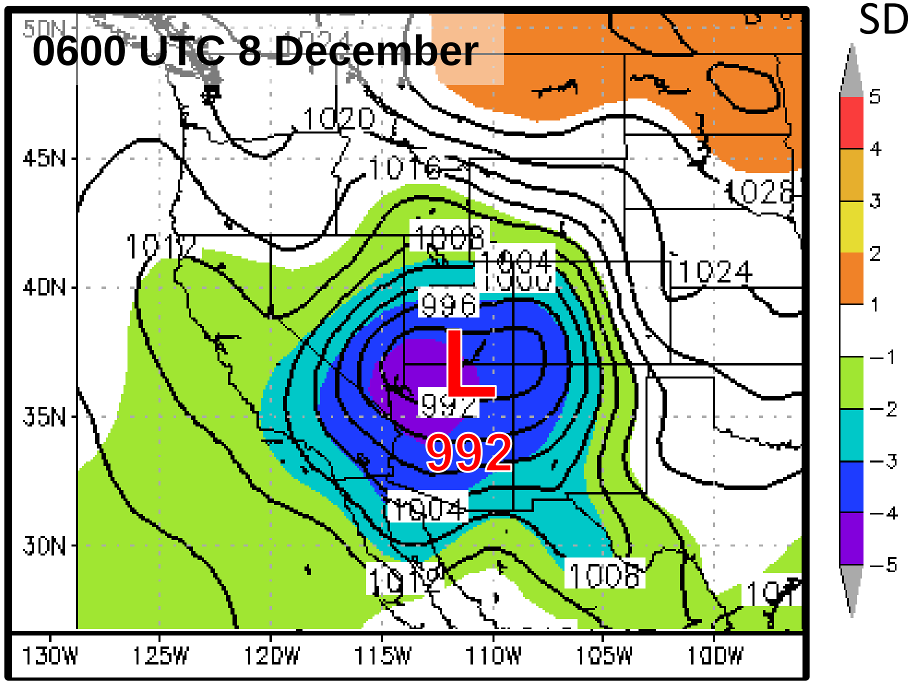
	Day	Month	Year	Event
Dec 2009	8−10	Dec	2009	“Coast-to-Coast” Storm (influenced by Typhoon Nida) ☆
	20	Dec	2009	Mid-Atlantic (I) and Southeast New England Snowstorm
Jan 2010	14	Jan	2010	Two-week cold air outbreak sets records in Florida
	22	Jan	2010	Record-breaking West Coast Wind/Rain Storm
	24−25	Jan	2010	Midwest Snowstorm
	29−30	Jan	2010	Southern Plains Ice Storm
Feb 2010	6	Feb	2010	Mid-Atlantic Snowstorm (II)
	10−11	Feb	2010	Mid-Atlantic Snowstorm (III)
	15	Feb	2010	Second cold air outbreak sets records in Florida

Pacific precursors and "Coast-to-Coast" Storm

27 November to 9 December 2009



Satellite imagery courtesy Digital Typhoon

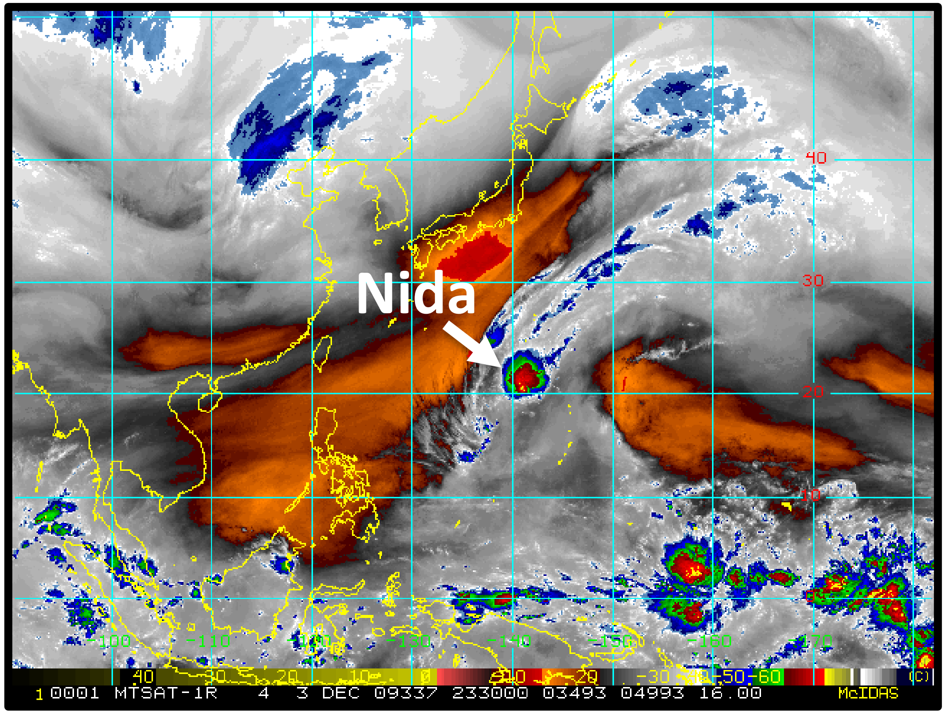


GFS SLP and Anomaly courtesy Rich Grumm

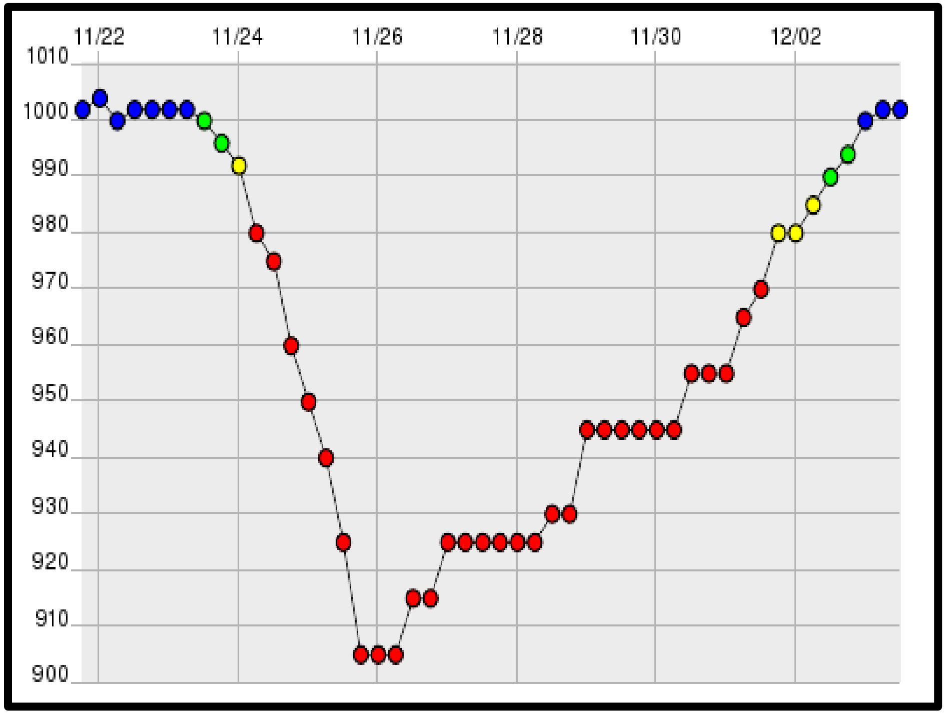
- TY Nida as a moisture source for mid-Pacific cyclones
- Mid-Pacific cyclones build Alaskan ridge/block
- Downstream development/coast-to-coast storm

Pacific Precursors and the "Coast-to-Coast Storm"

Water Vapor: 2330 UTC 3 Dec



SLP vs. Time (22 Nov – 3 Dec)

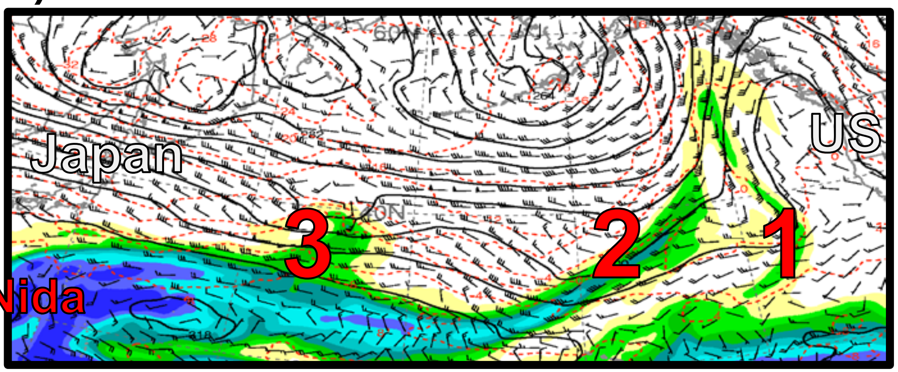


Pacific precursors and "Coast-to-Coast" Storm

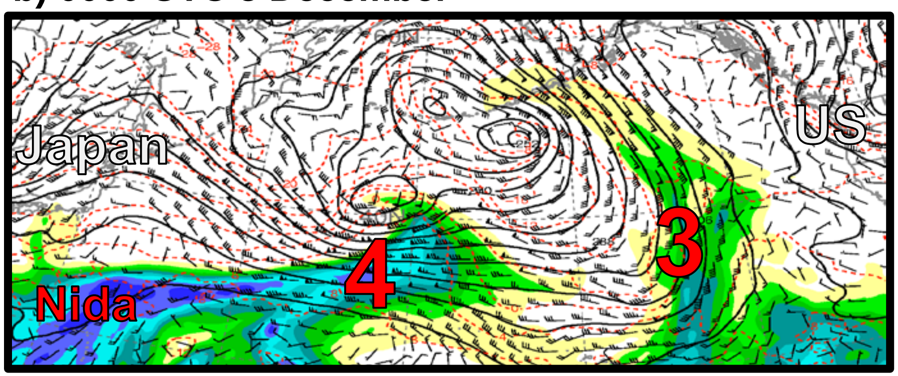
700-hPa Geo. Height (dam; solid black), Temperature (°C; dashed red), Wind (kt; barbs), and Precipitable Water (mm; shaded)

1000−500-hPa Thickness (dam; dashed), SLP (hPa; solid black), and 300-hPa Wind Speed (m s^{-1}; shaded)

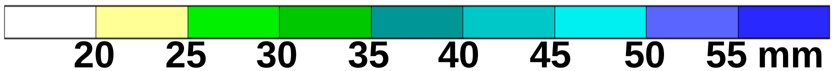
a) 0000 UTC 2 December



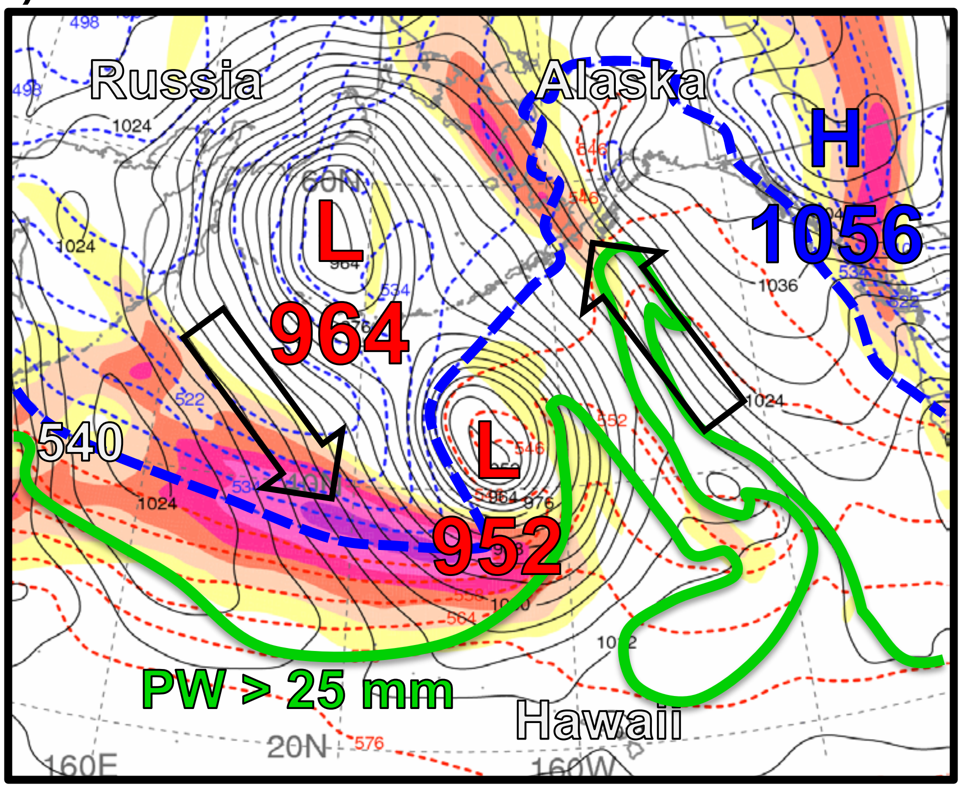
b) 0000 UTC 5 December



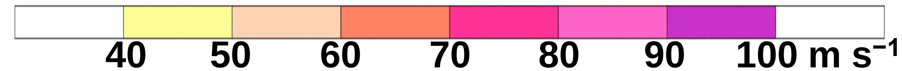
Data: 1.0° NCEP−GFS Analyses



c) 0000 UTC 6 December

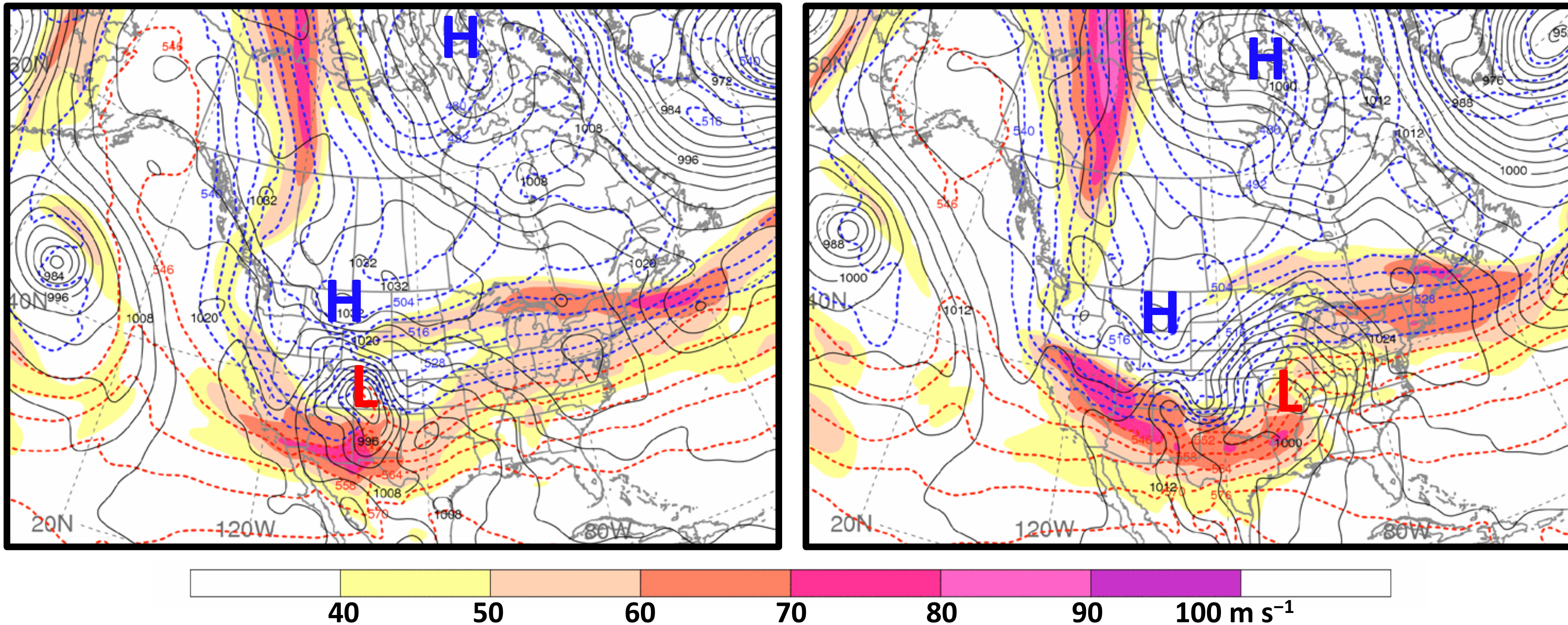


Data: 1.0° NCEP−GFS Analyses



Pacific Precursors and the "Coast-to-Coast Storm"

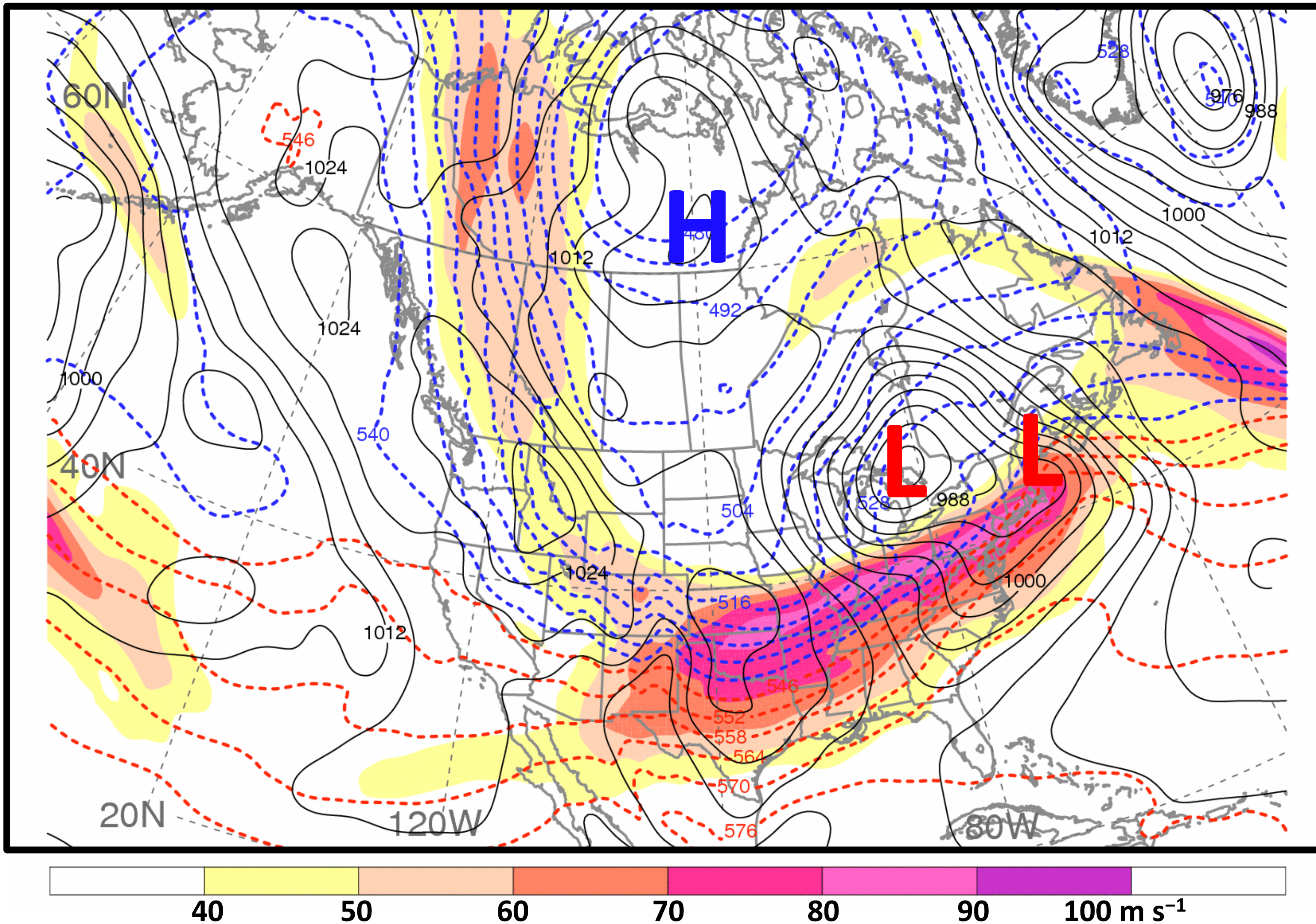
1200 UTC 8 December | 0000 UTC 9 December



1000–500-hPa Thickness (dam; dashed), SLP (hPa; solid black), and 300-hPa Wind Speed (m s^{-1}; shaded)

Pacific Precursors and the "Coast-to-Coast Storm"

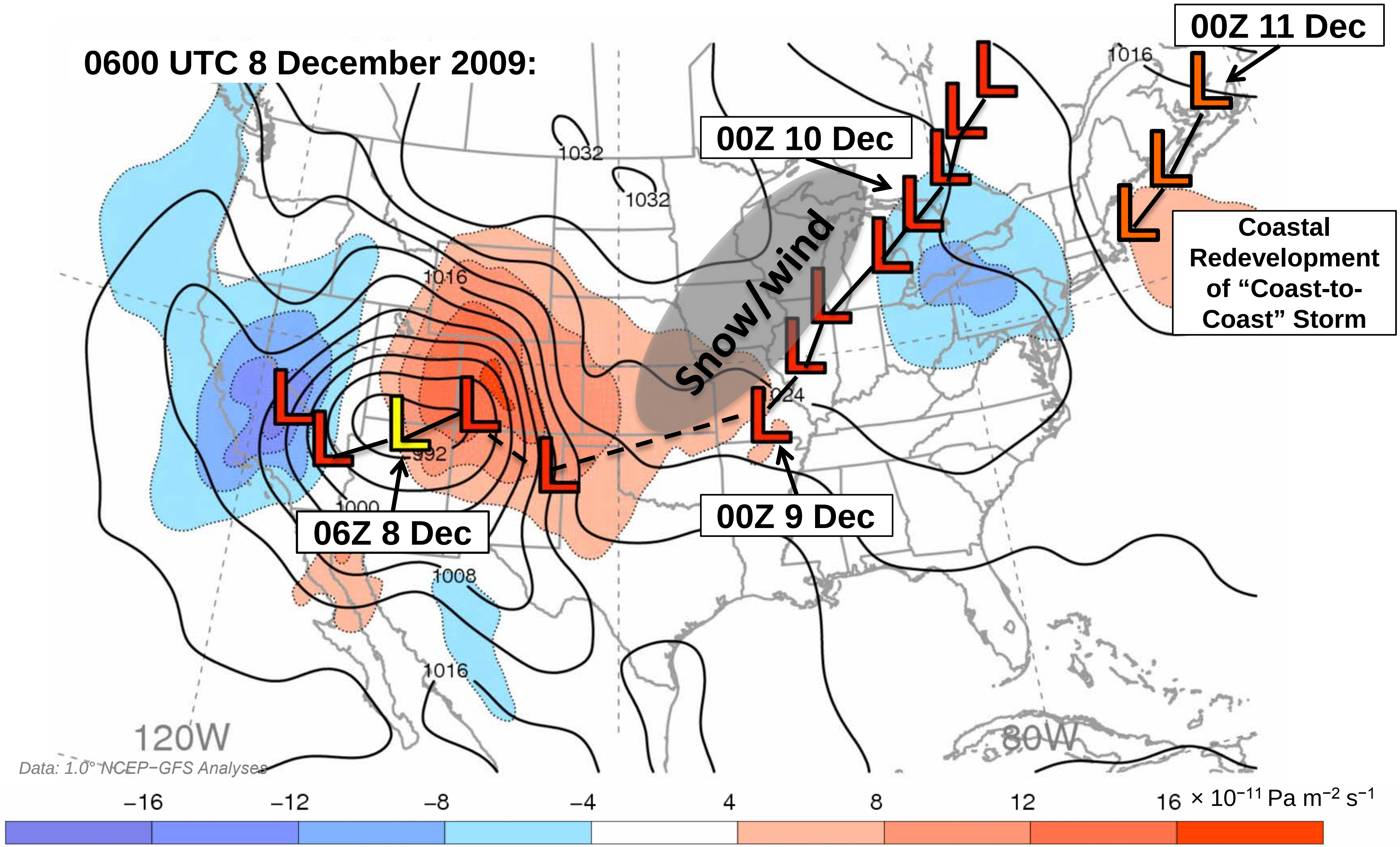
0000 UTC 10 December



1000–500-hPa Thickness (dam; dashed), SLP (hPa; solid black), and 300-hPa Wind Speed (m s^{-1}; shaded)

"Coast-to-Coast" Storm

700-hPa QG Forcing (RHS of Q-vector Eqn; shaded, 10^{-11} Pa m^{-2} s^{-1}) and SLP (black, every 4 hPa) at 0600 UTC 8 Dec 2009; L's denote 6-hourly surface low positions for 1800 UTC 7 Dec – 0000 UTC 11 Dec 2009



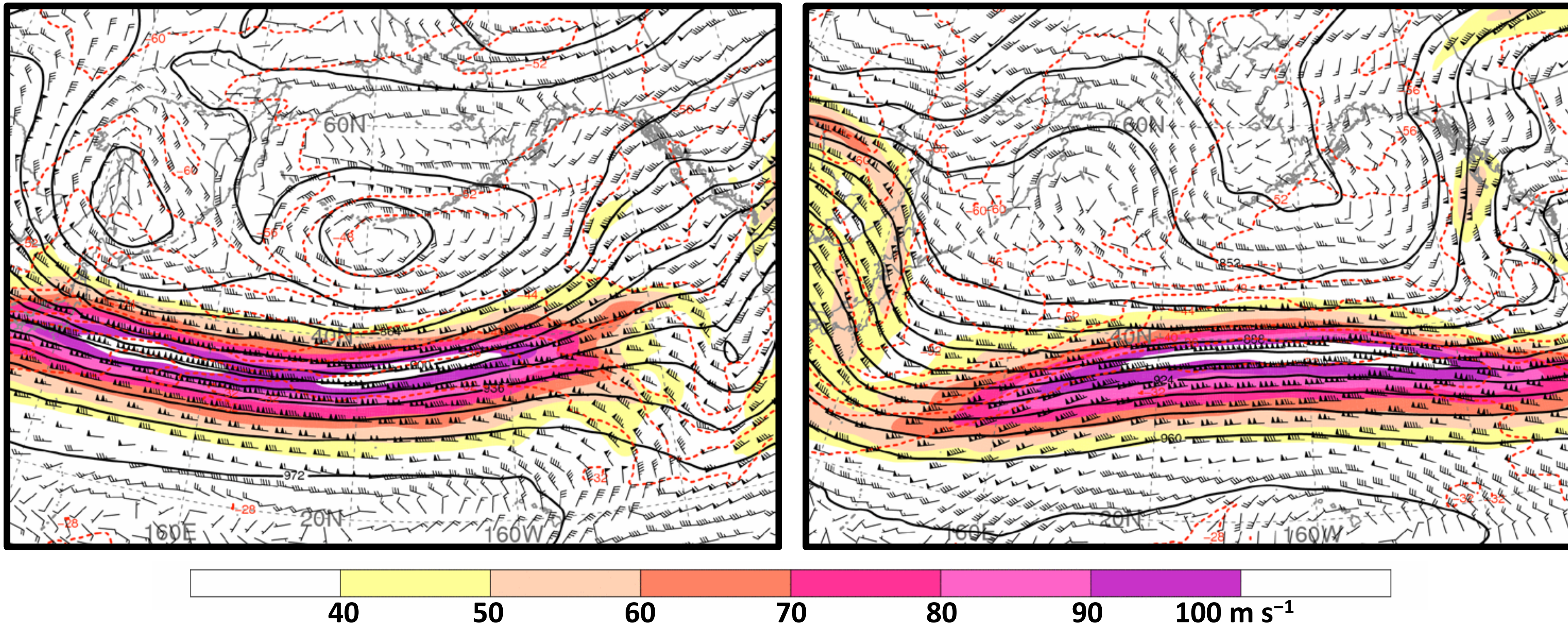
Part IV: Screaming Eastern Pacific Jet and the Downstream Impact

16 Jan 2010 – 25 Jan 2010

- STJ strengthens/expands eastward across Pacific
- AO phase is briefly positive
- Downstream flow amplifies; major western U.S. storm
- Brief El Nino signature over western U.S.
- Significant full-latitude trough over eastern U.S.

Screaming Eastern Pacific Jet and Downstream Impact

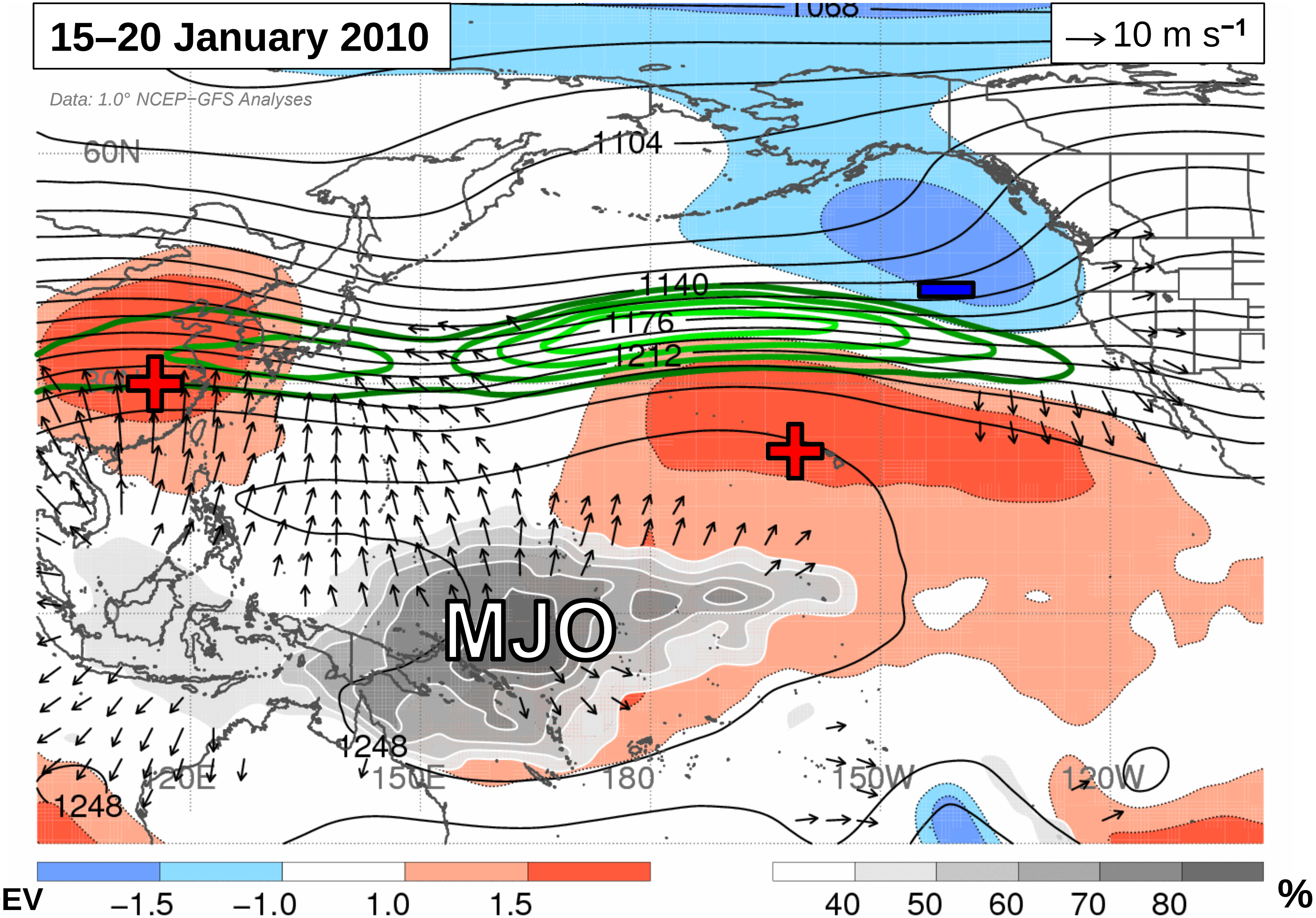
0000 UTC 16 January **0000 UTC 19 January**



300-hPa Geo. Height (dam; solid), Temperature (°C; dashed), Wind (kt; barbs), and Wind Speed (m s^{-1}; shaded)

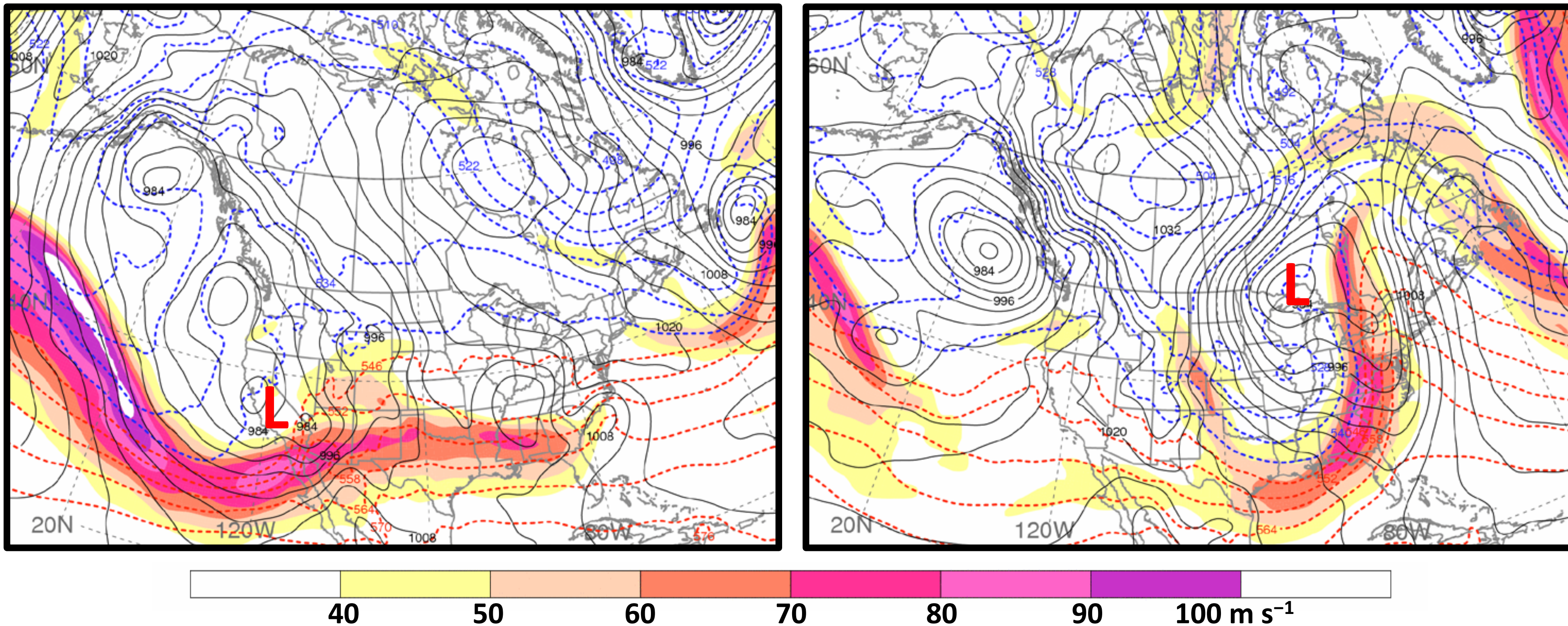
4. Screaming East Pacific Jet and Downstream Impact

400–100-hPa Rel. Humidity (%; gray shading, south of 20°N); 200-hPa Wind Speed (green every 10 m s^{-1}, starting at 60 m s^{-1}), Irrot. Wind (vectors, above 5 m s^{-1} only), Geo. Height (black every 12 dam) and Anomaly (std dev, color shading)



Screaming Eastern Pacific Jet and Downstream Impact

0000 UTC 22 January **1200 UTC 25 January**



1000–500-hPa Thickness (dam; dashed), SLP (hPa; solid black), and 300-hPa Wind Speed (m s^{-1}; shaded)

4. Screaming East Pacific Jet and Downstream Impact

All-Time Minimum SLP Records 21−22 Jan 2010	
978-hPa: Medford, OR	983-hPa: Las Vegas, NV
979-hPa: Eureka, CA	984-hPa: L.A., CA
979-hPa: Reno, NV	987-hPa: San Diego, CA
980-hPa: SLC, UT	989-hPa: Phoenix, AZ

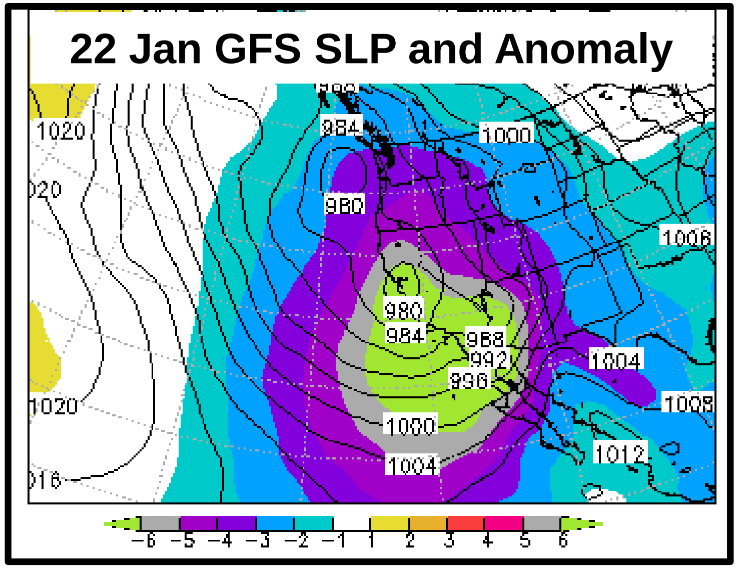
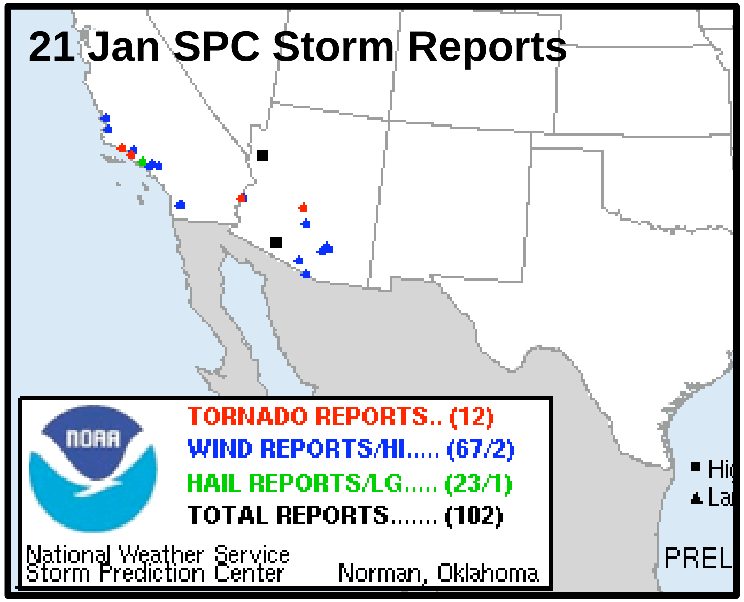


Image courtesy Rich Grumm

All-Time Wind Records 21−22 January 2010
88 knots: Kingman, AZ
82 knots: Ajo, AZ
81 knots: Newport Beach, CA
80 knots: Huntington Beach, CA



Conclusions

- Anomalous high-impact extreme weather events occurred on intraseasonal time scales during an unusual NH flow pattern characterized by negative AO and El Niño conditions

- TC Nida acted as a catalyst for tropical moisture surges that contributed to Alaskan blocking, downstream development, and the “Coast-to-Coast” Storm

- “Coast-to-coast” Storm contributed to first North Atlantic blocking episode; continued western Atlantic storminess helped initiate second blocking episode

- Screaming jet, downstream development, a second western U.S. storm, and short-lived positive AO marked onset of a brief El Niño signature over western U.S.

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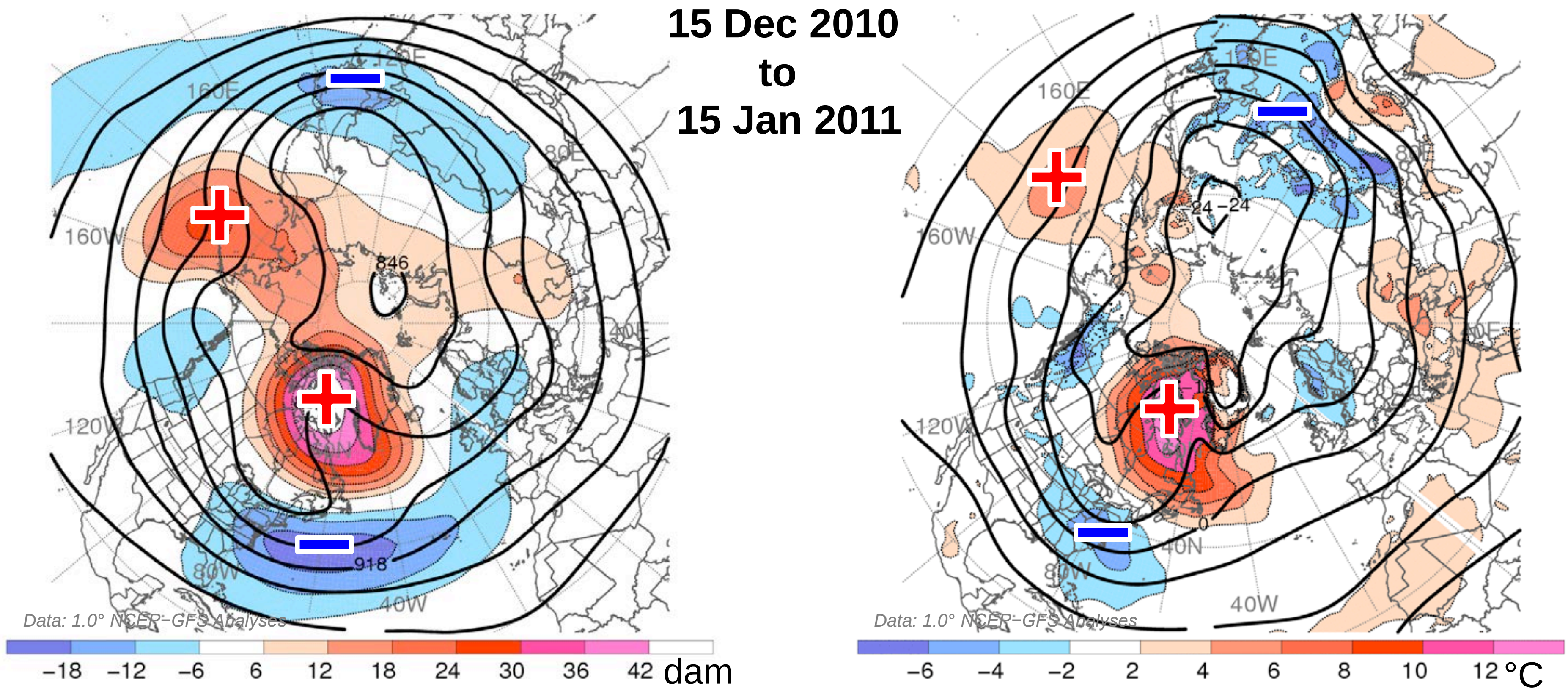
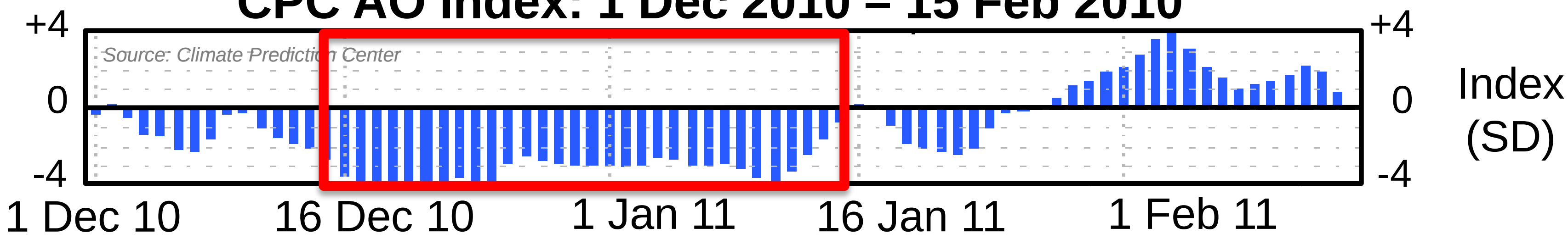
Winter 2010–2011

Winter 2010–2011: Blocked Flow Pattern

300-hPa Geo. Height (contoured, dam) and Geo. Height Anomaly (shaded, dam)	850-hPa Temperature (contoured, °C) and Temperature Anomaly (shaded, °C)

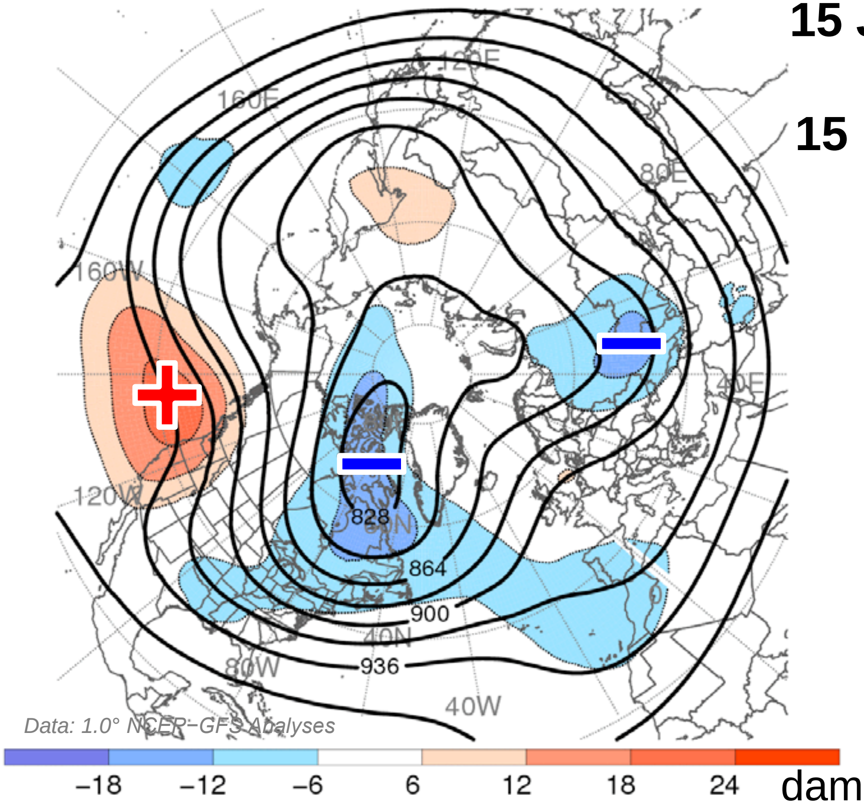


CPC AO Index: 1 Dec 2010 – 15 Feb 2010

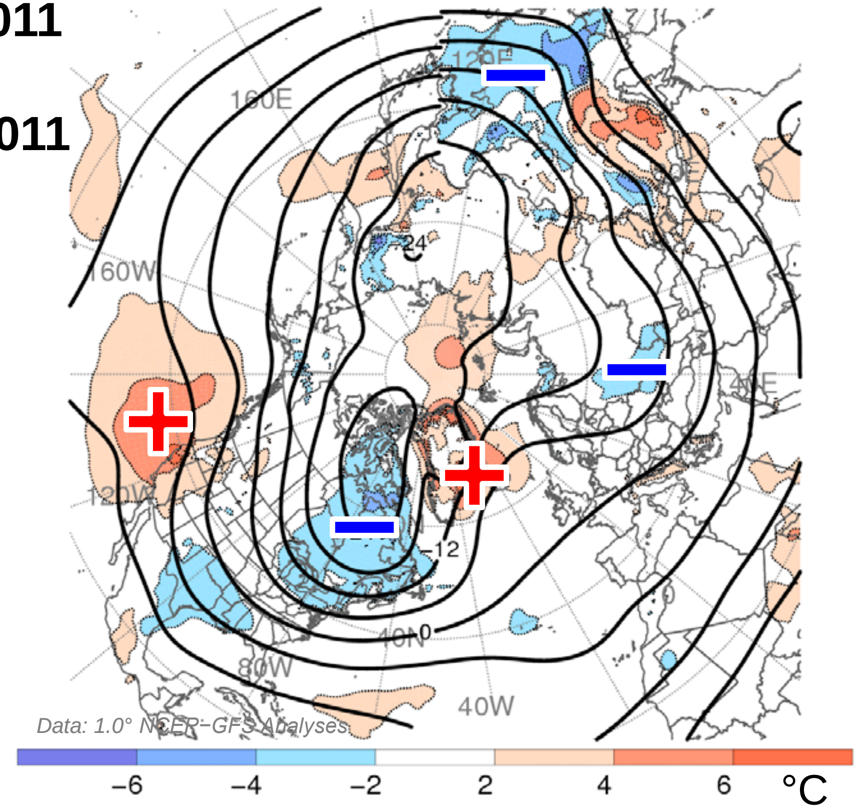


Winter 2010–2011: Transitioning Flow Pattern

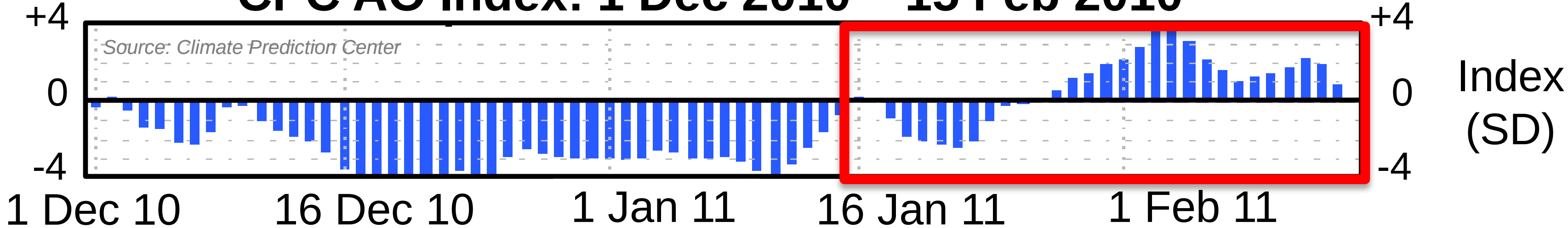
300-hPa Geo. Height (contoured, dam) and Geo. Height Anomaly (shaded, dam)	850-hPa Temperature (contoured, °C) and Temperature Anomaly (shaded, °C)



15 Jan 2011
to
15 Feb 2011



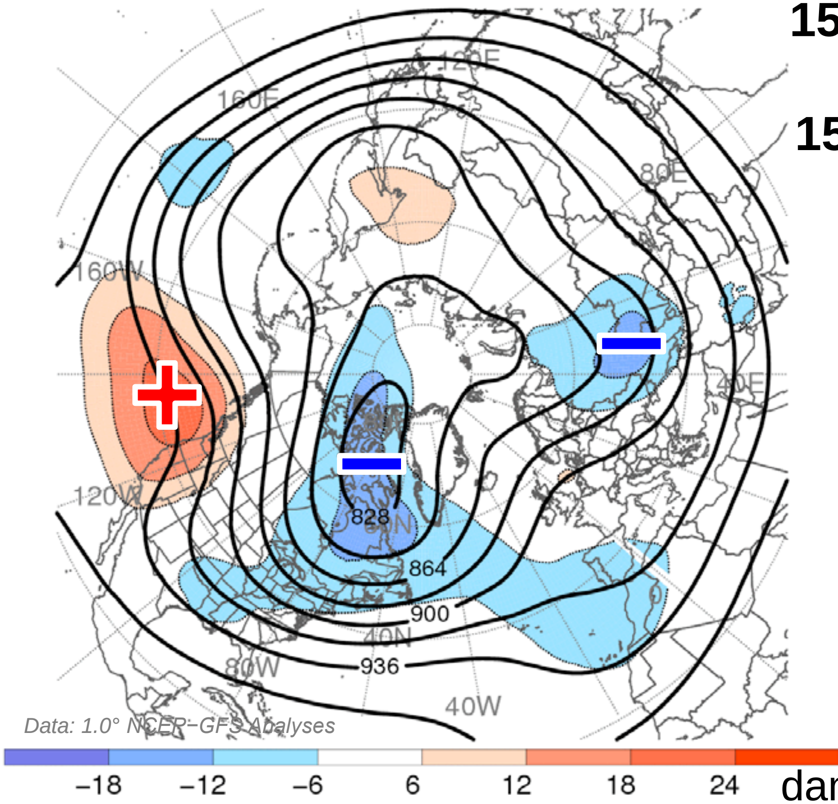
CPC AO Index: 1 Dec 2010 – 15 Feb 2010

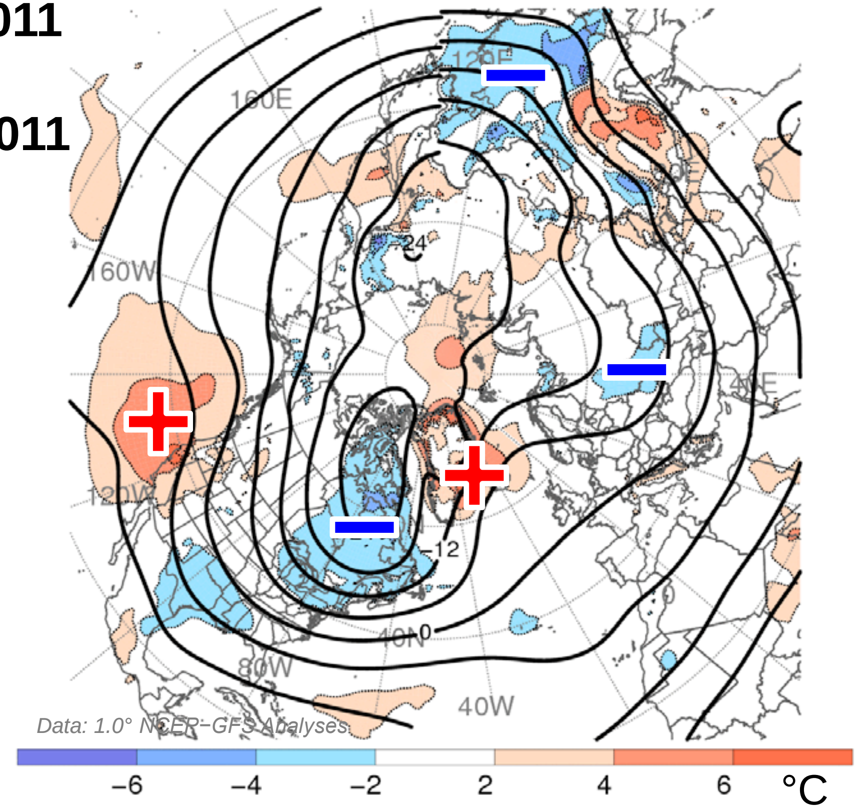


Winter 2010–2011: Transitioning Flow Pattern

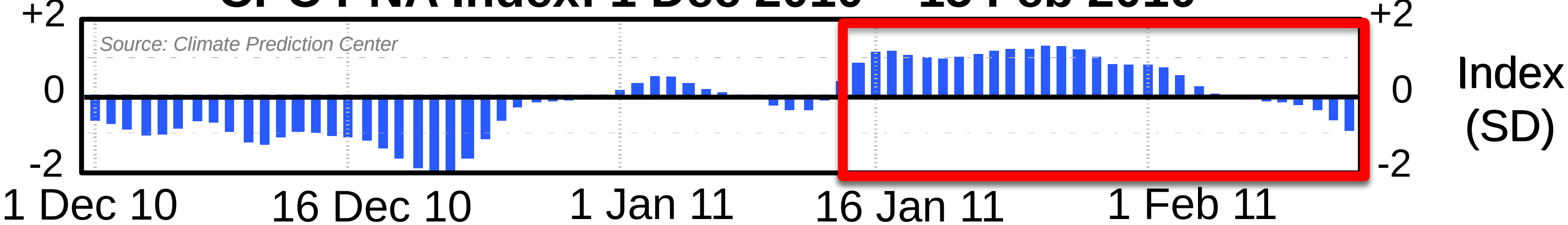
300-hPa Geo. Height (contoured, dam) and Geo. Height Anomaly (shaded, dam)	850-hPa Temperature (contoured, °C) and Temperature Anomaly (shaded, °C)

15 Jan 2011 to 15 Feb 2011





CPC PNA Index: 1 Dec 2010 – 15 Feb 2010

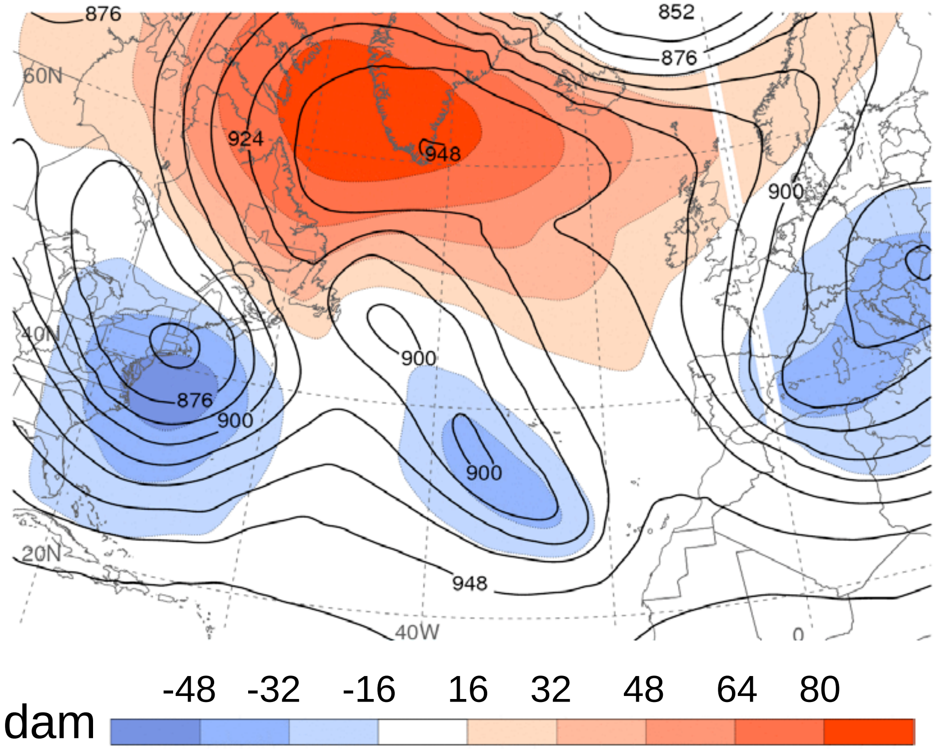


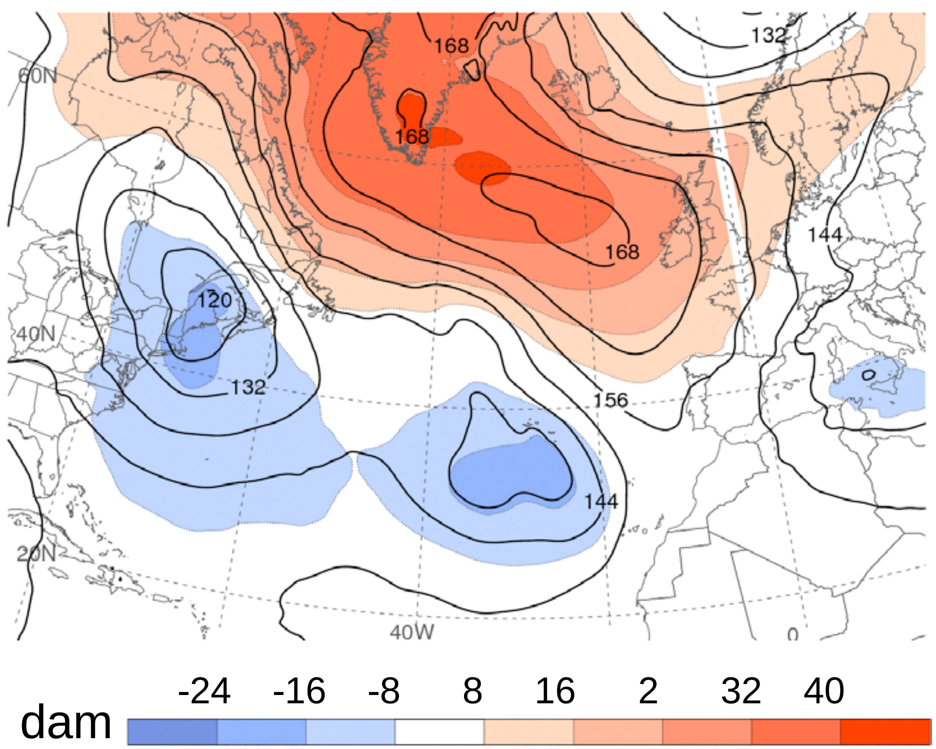
Weather Variability within These Large-Scale Flow Patterns

Winter 2010–2011: Blocked Flow Pattern

300-hPa HGHT (solid, dam) and HGHT ANOM (departure from long-term climatology, shaded, dam)

850-hPa HGHT (solid, dam) and HGHT ANOM (departure from long-term climatology, shaded, dam)



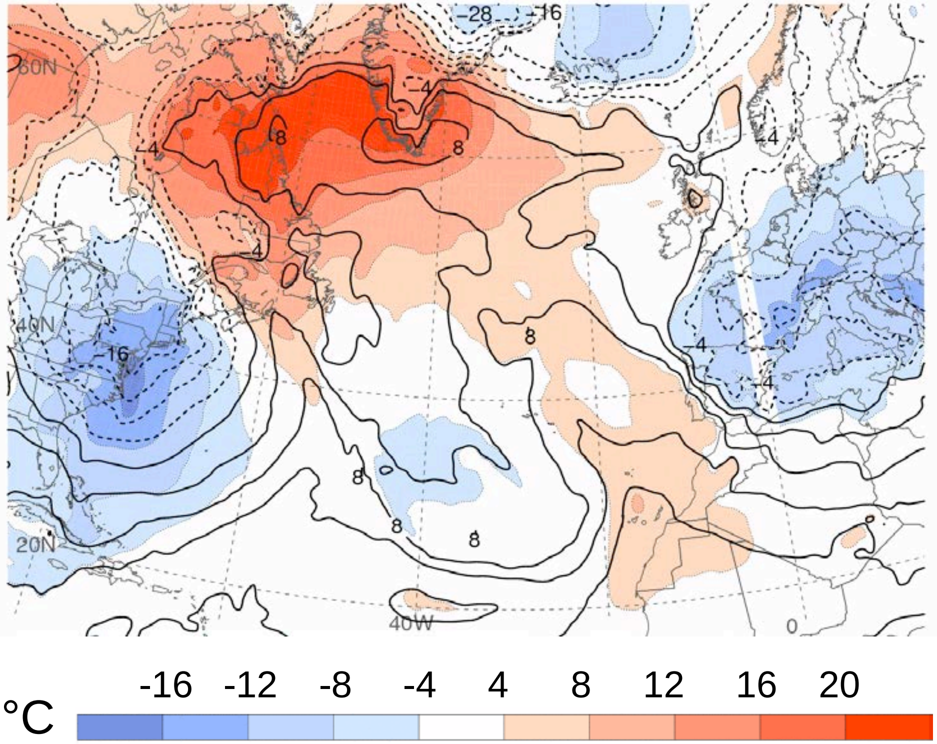


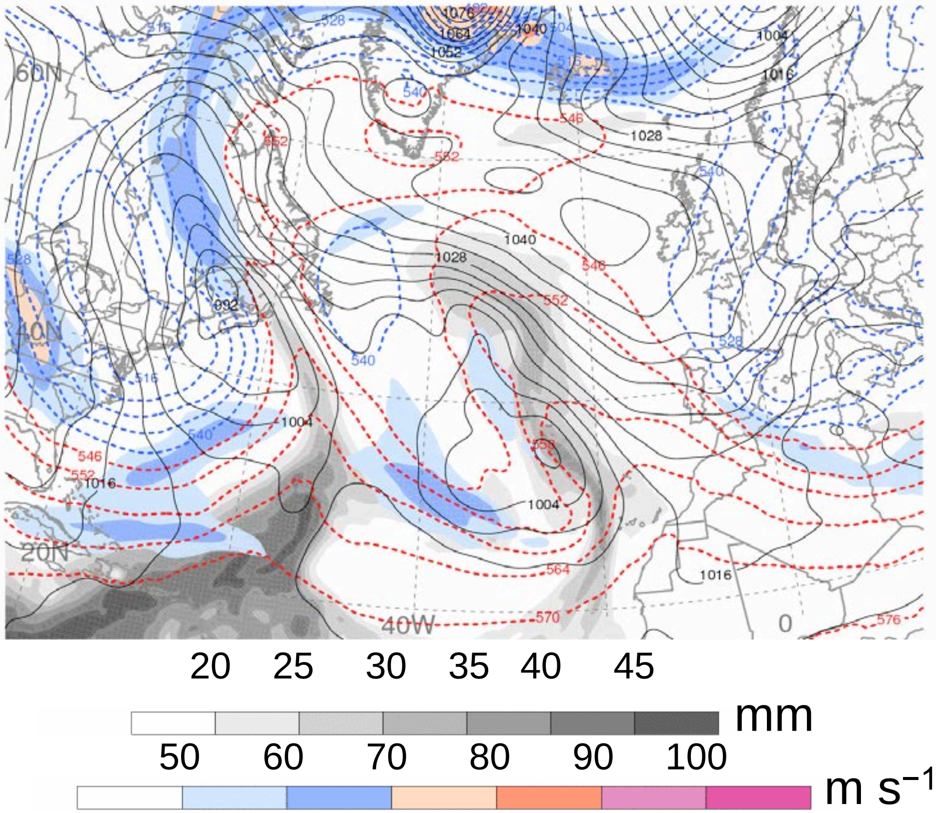
1200 UTC 15 Dec 2010

Winter 2010−2011: Blocked Flow Pattern

850-hPa TEMP (solid, °C) and TEMP ANOM (departure from long-term climatology, shaded, °C)

1000–500-hPa THICK (dashed, dam), PRECIP WATER (mm, gray shading), SLP (solid contours, hPa), and 250-hPa WND SPEED (m s^{-1}, color shading)



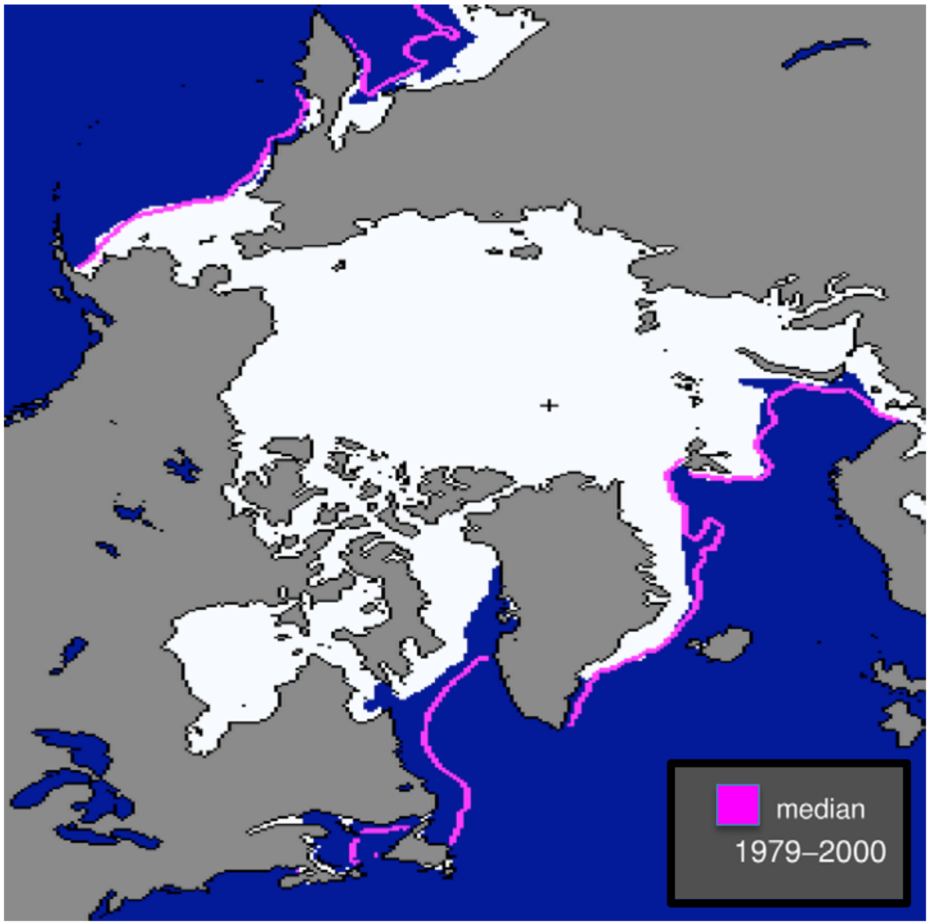


1200 UTC 15 Dec 2010

2010−2011 Regimes: Blocked Flow Pattern

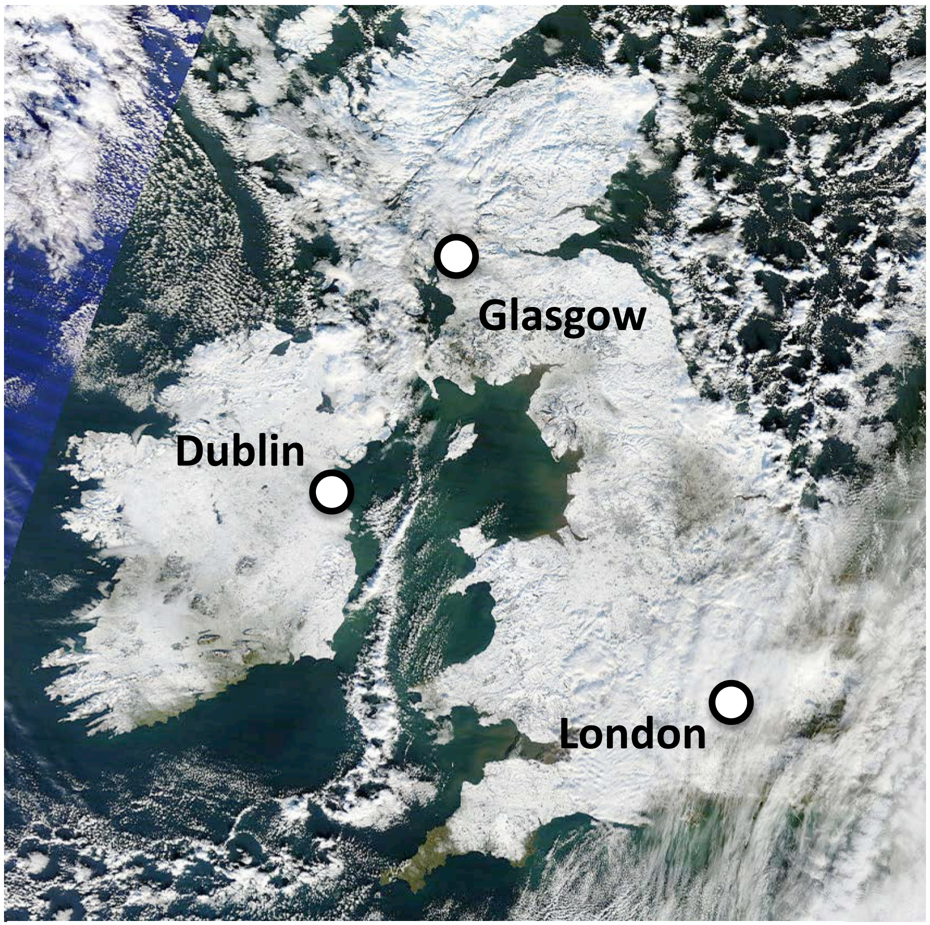
- Mild, onshore flow over eastern Canada limits extent of sea ice
- Anomalous cold air over northern Europe promotes extensive U.K. snow cover

2 Jan 2011 Sea Ice Extent



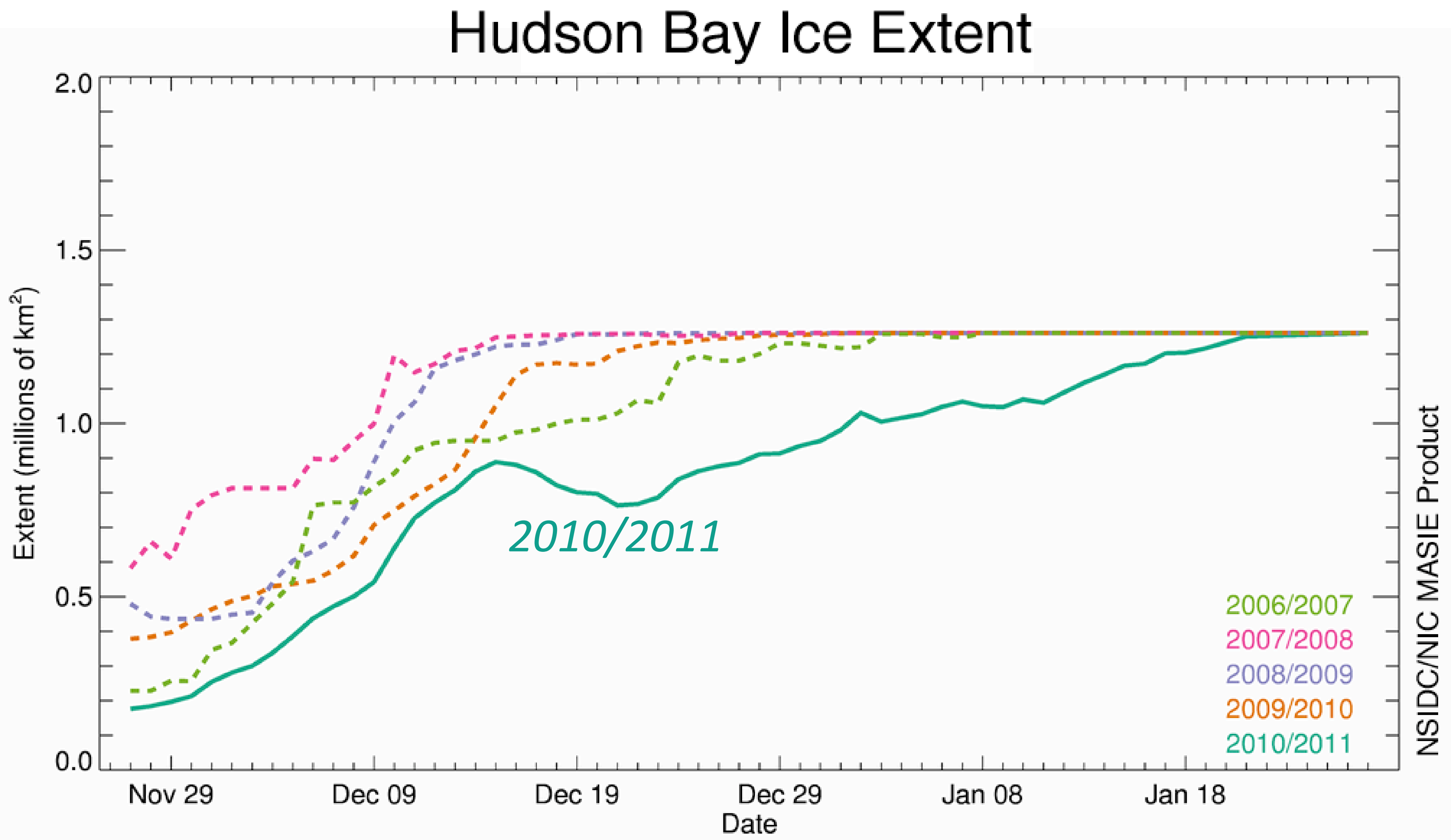
Source: National Snow and Ice Data Center

24 Dec 2010 Visible Image



Source: MODIS Rapid Fire Online Server

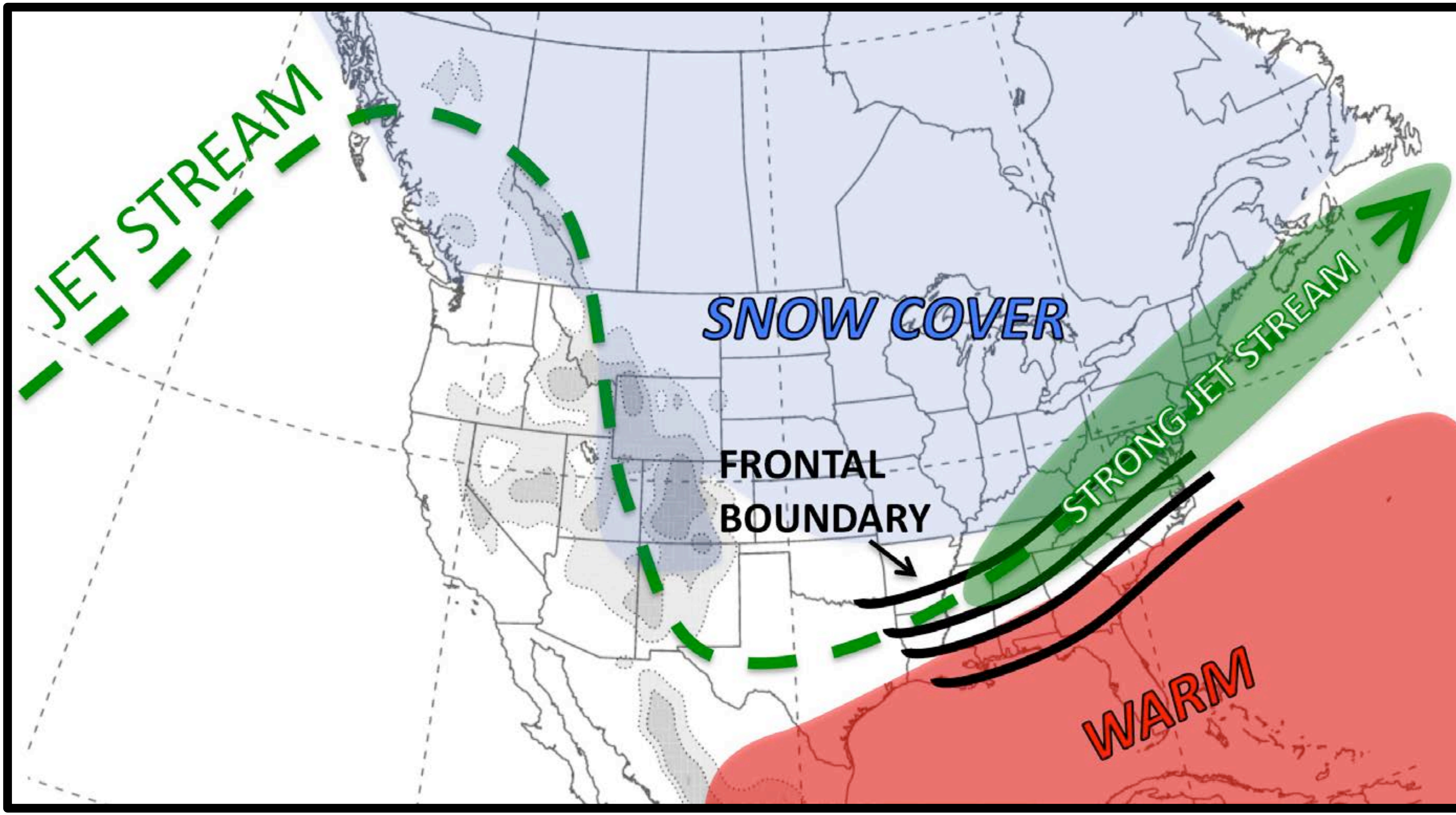
Hudson Bay Ice Extent: 26 Nov–28 Jan (2006/07–2010/11)



Weather Highlights: December 2010 through February 2011

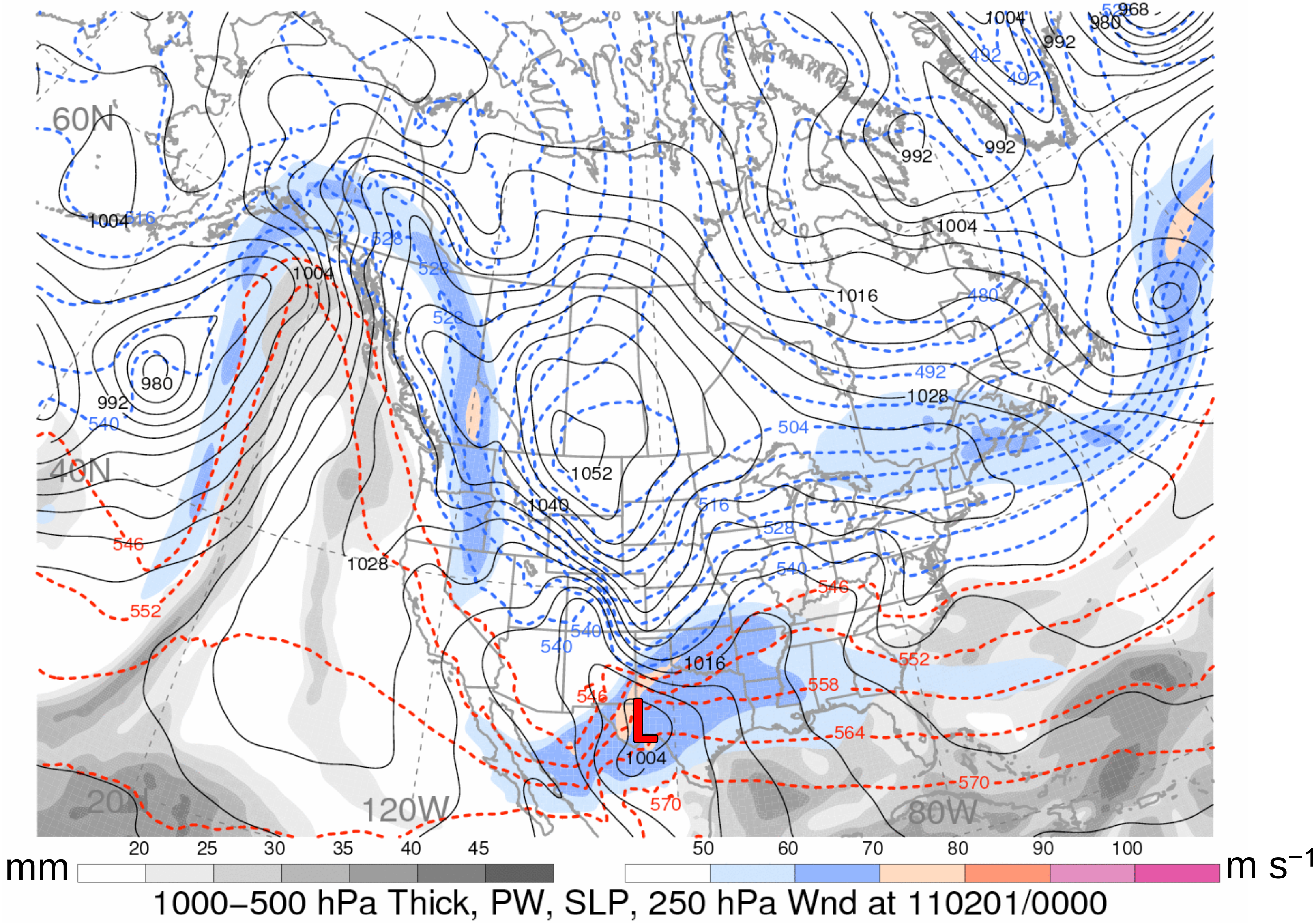
	Day	Month	Year	Event
Dec 2010	10−12	Dec	2010	Heavy rain in Pacific Northwest
	18−22	Dec	2010	Heavy rain/snow in southern California
	26−27	Dec	2010	Coastal Northeast snowstorm
Jan 2011	9−10	Jan	2011	Southeast snow and ice storm
	18−19	Jan	2011	NY/NJ and southern New England snowstorm
	20−21	Jan	2011	Northeast snowstorm
	26−27	Jan	2011	Northeast snowstorm ☆
Feb 2011	1−3	Feb	2011	Southern plains to lower Great Lakes snowstorm
	8−10	Feb	2011	OK/AR snowstorm
	10	Feb	2011	OK breaks all-time minimum temperature (−30.5°F)

Late Jan–Early Feb 2011: AO−/AO+ and PNA+/PNA− transition



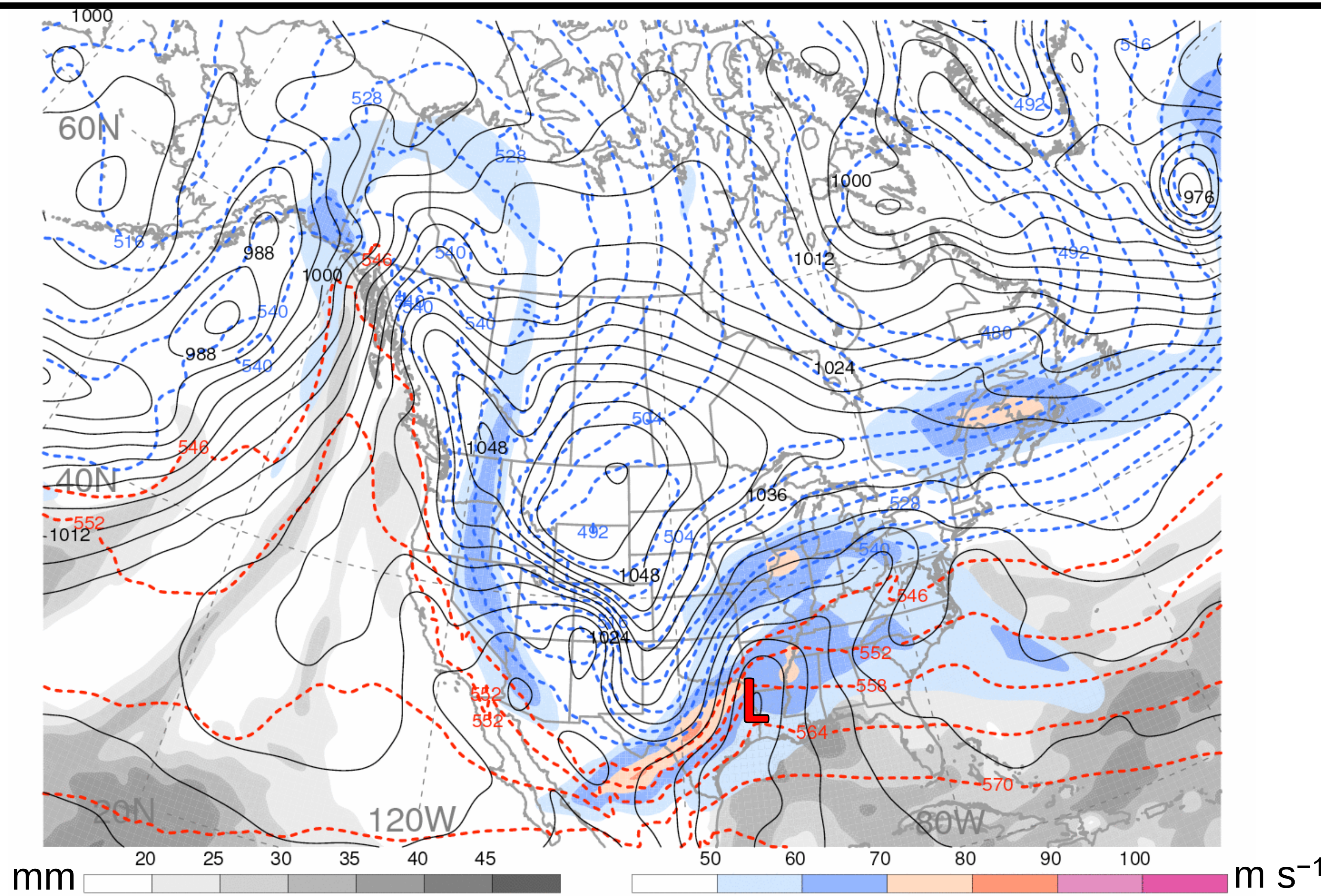
1–3 February 2011 Snowstorm: 0000 UTC 1 Feb

1000–500-hPa THICK (dashed, dam), PRECIP WATER (mm, gray shading), SLP (solid contours, hPa), and 250-hPa WND SPEED (m s^{-1}, color shading)



1–3 February 2011 Snowstorm: 1200 UTC 1 Feb

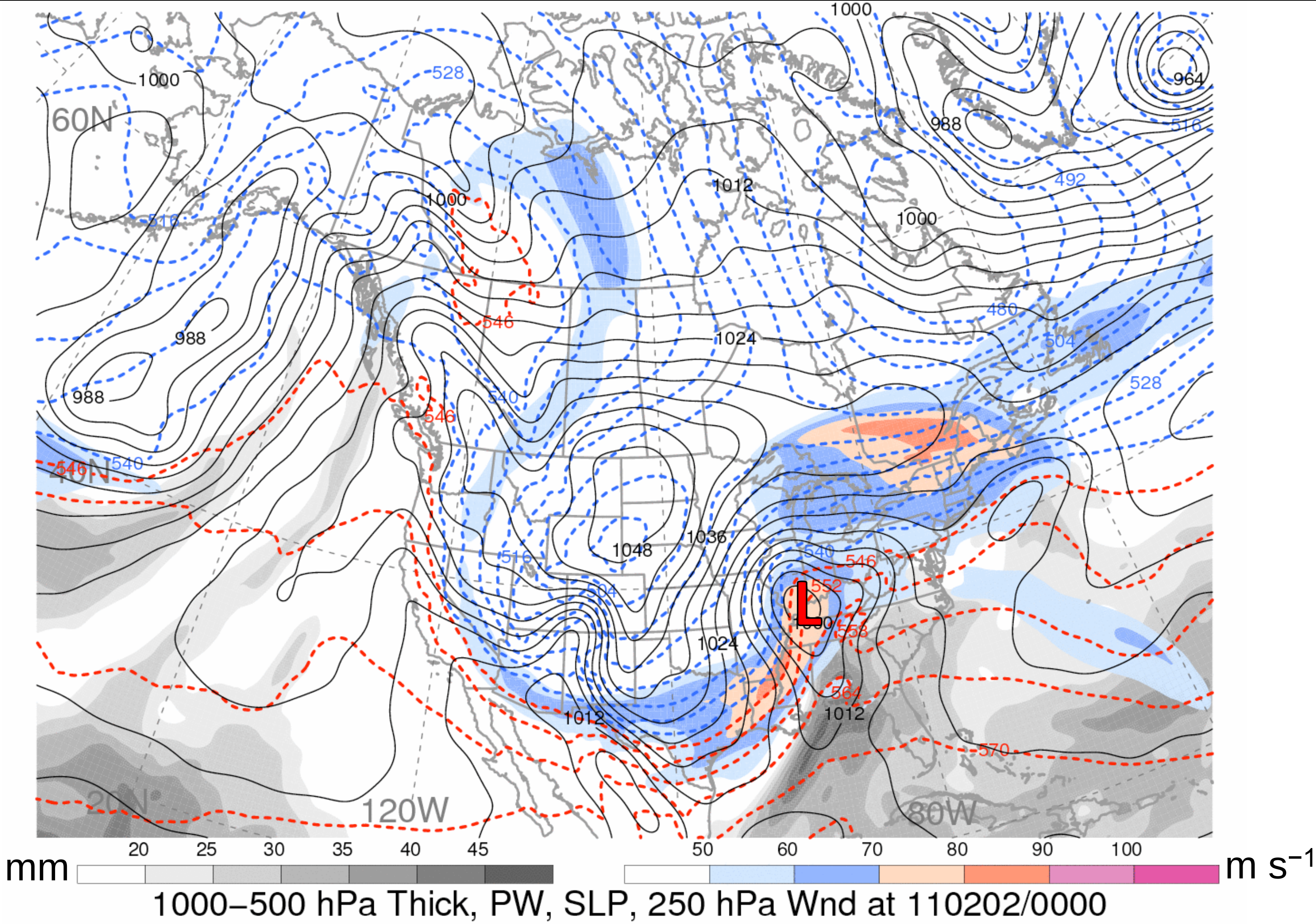
1000–500-hPa THICK (dashed, dam), PRECIP WATER (mm, gray shading), SLP (solid contours, hPa), and 250-hPa WND SPEED (m s^{-1}, color shading)



1000–500 hPa Thick, PW, SLP, 250 hPa Wnd at 110201/1200

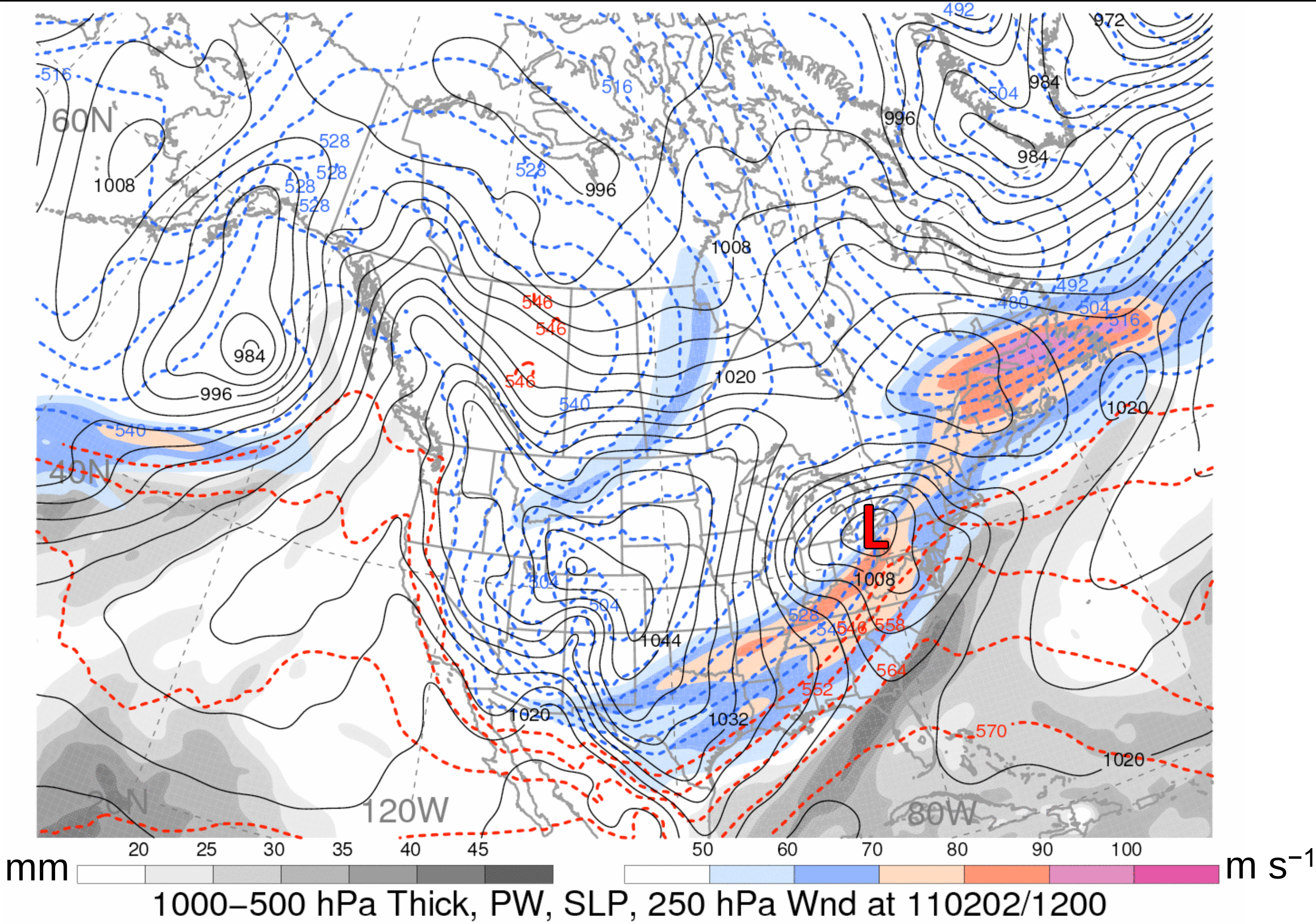
1–3 February 2011 Snowstorm: 0000 UTC 2 Feb

1000–500-hPa THICK (dashed, dam), PRECIP WATER (mm, gray shading), SLP (solid contours, hPa), and 250-hPa WND SPEED (m s^{-1}, color shading)



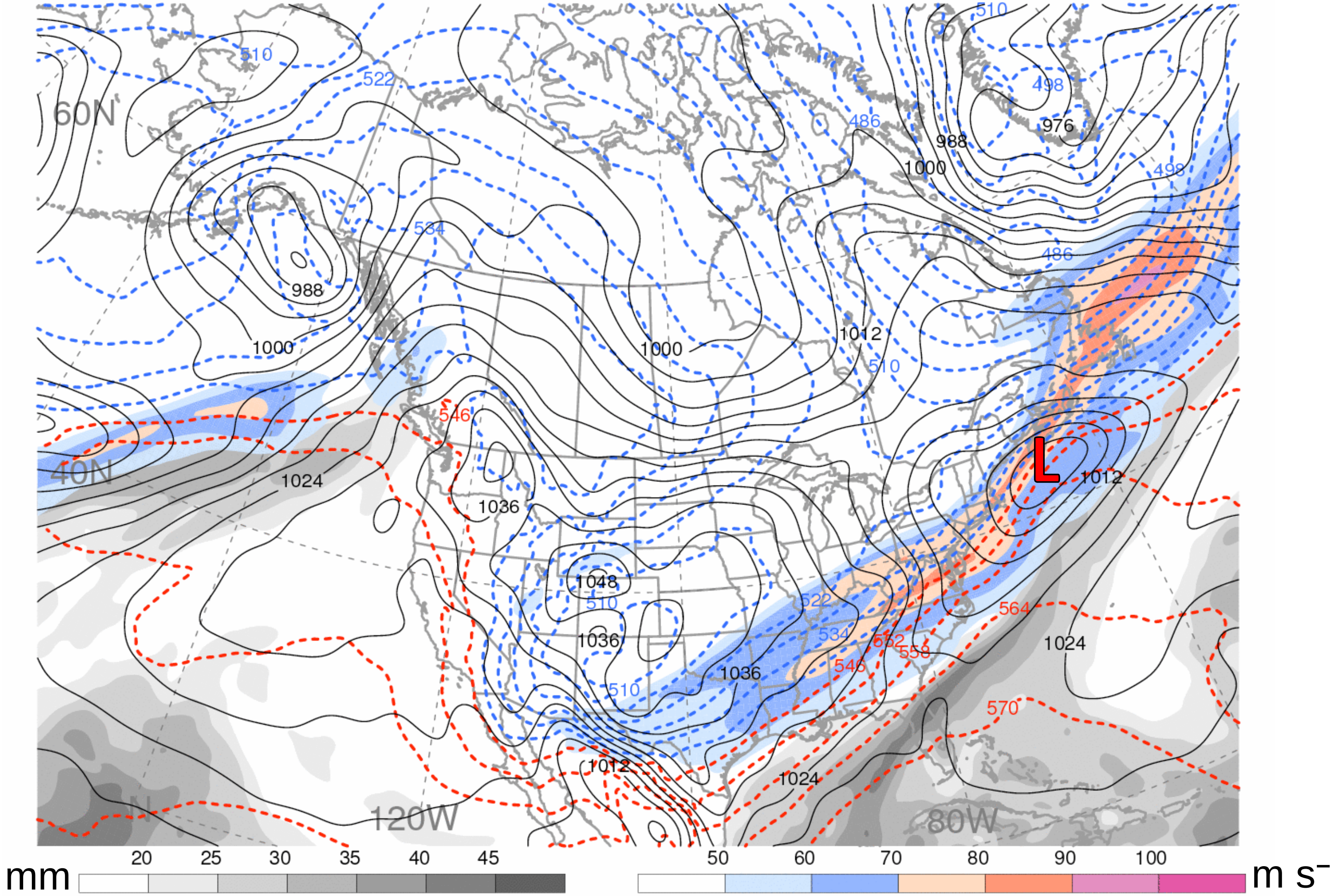
1–3 February 2011 Snowstorm: 1200 UTC 2 Feb

1000–500-hPa THICK (dashed, dam), PRECIP WATER (mm, gray shading), SLP (solid contours, hPa), and 250-hPa WND SPEED (m s^{-1}, color shading)



1–3 February 2011 Snowstorm: 0000 UTC 3 Feb

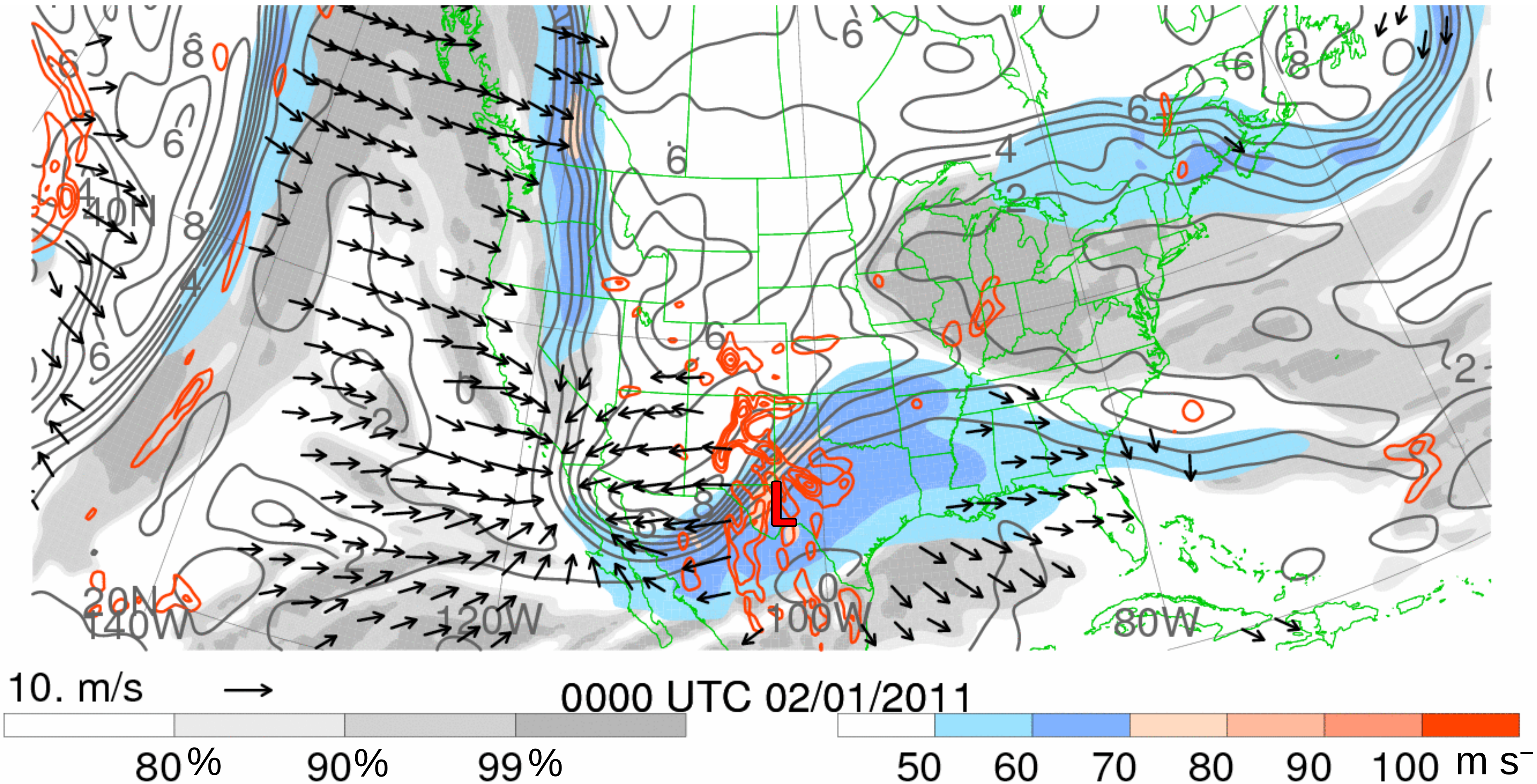
1000–500-hPa THICK (dashed, dam), PRECIP WATER (mm, gray shading), SLP (solid contours, hPa), and 250-hPa WND SPEED (m s^{-1}, color shading)



1000–500 hPa Thick, PW, SLP, 250 hPa Wnd at 110203/0000

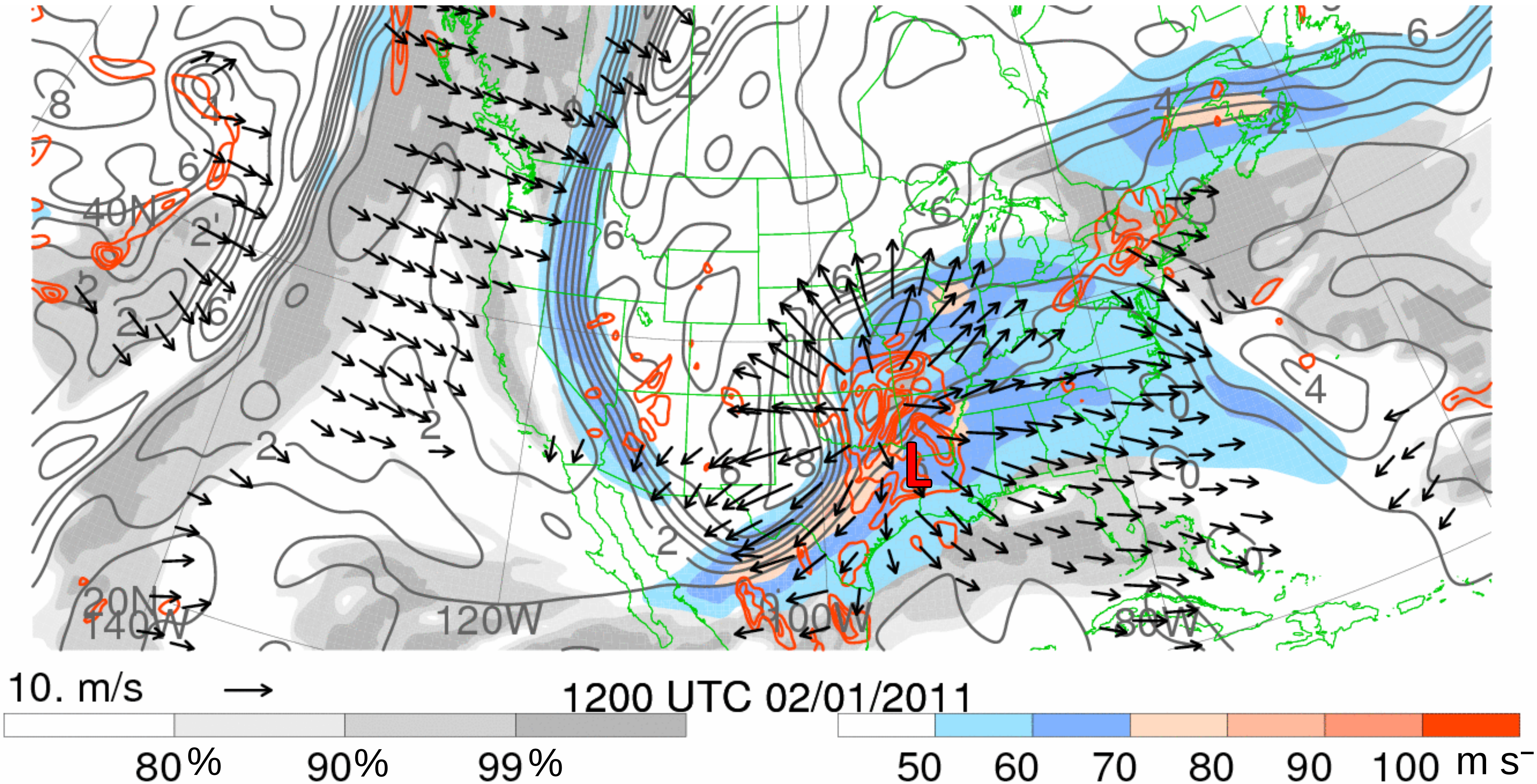
1–3 February 2011 Snowstorm: 0000 UTC 1 Feb

250-hPa WND (m s^{-1}, color shading), POT VORT (PVU, solid gray), REL HUM (%, gray shading); 300–200-hPa IRROT WND (vectors, m s^{-1}) and 600–400-hPa OMEG (red, every 5 x 10^{-3} hPa s^{-1}, neg. values only)



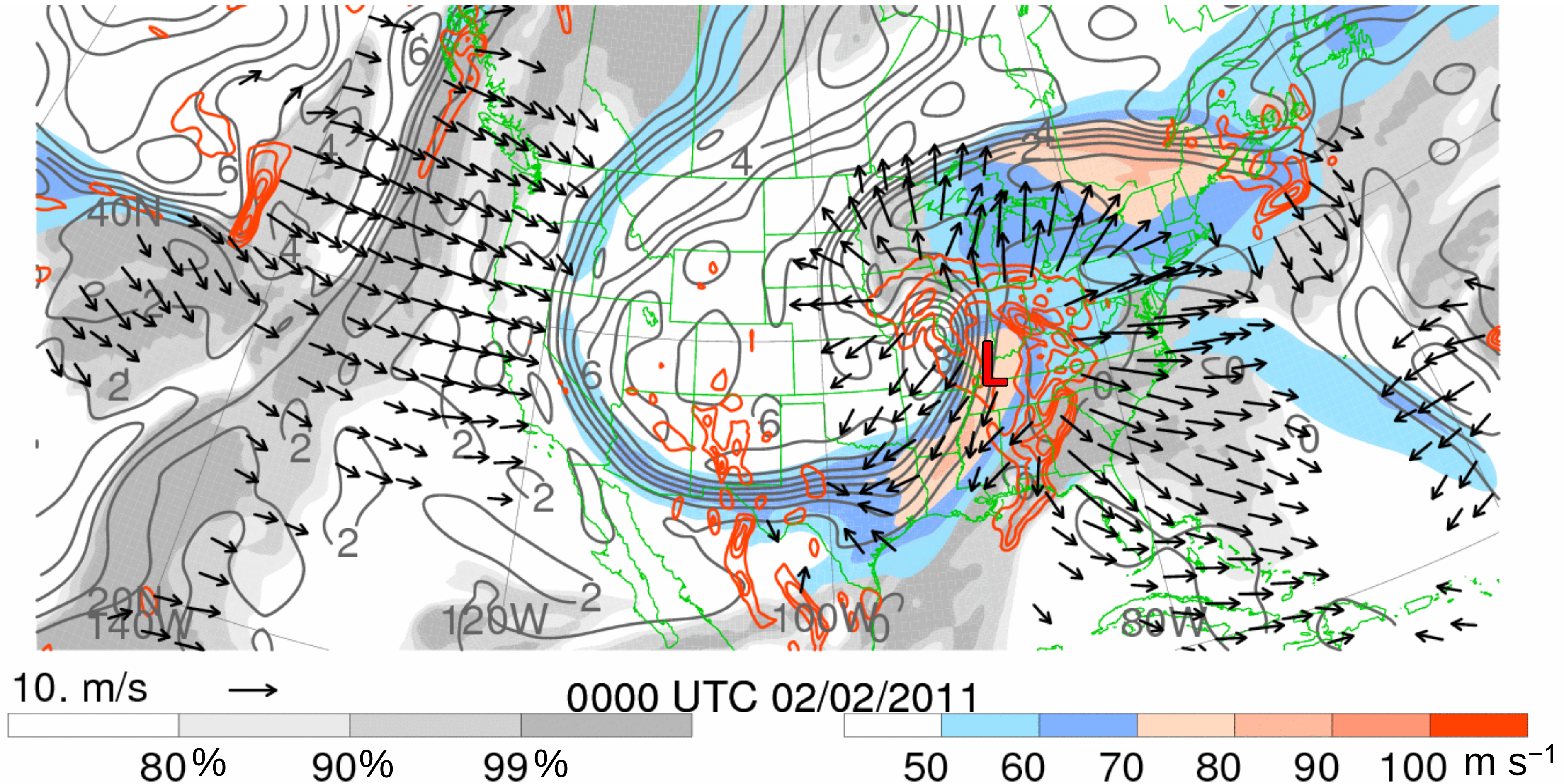
1–3 February 2011 Snowstorm: 1200 UTC 1 Feb

250-hPa WND (m s^{-1}, color shading), POT VORT (PVU, solid gray), REL HUM (%, gray shading); 300–200-hPa IRROT WND (vectors, m s^{-1}) and 600–400-hPa OMEG (red, every 5 x 10^{-3} hPa s^{-1}, neg. values only)

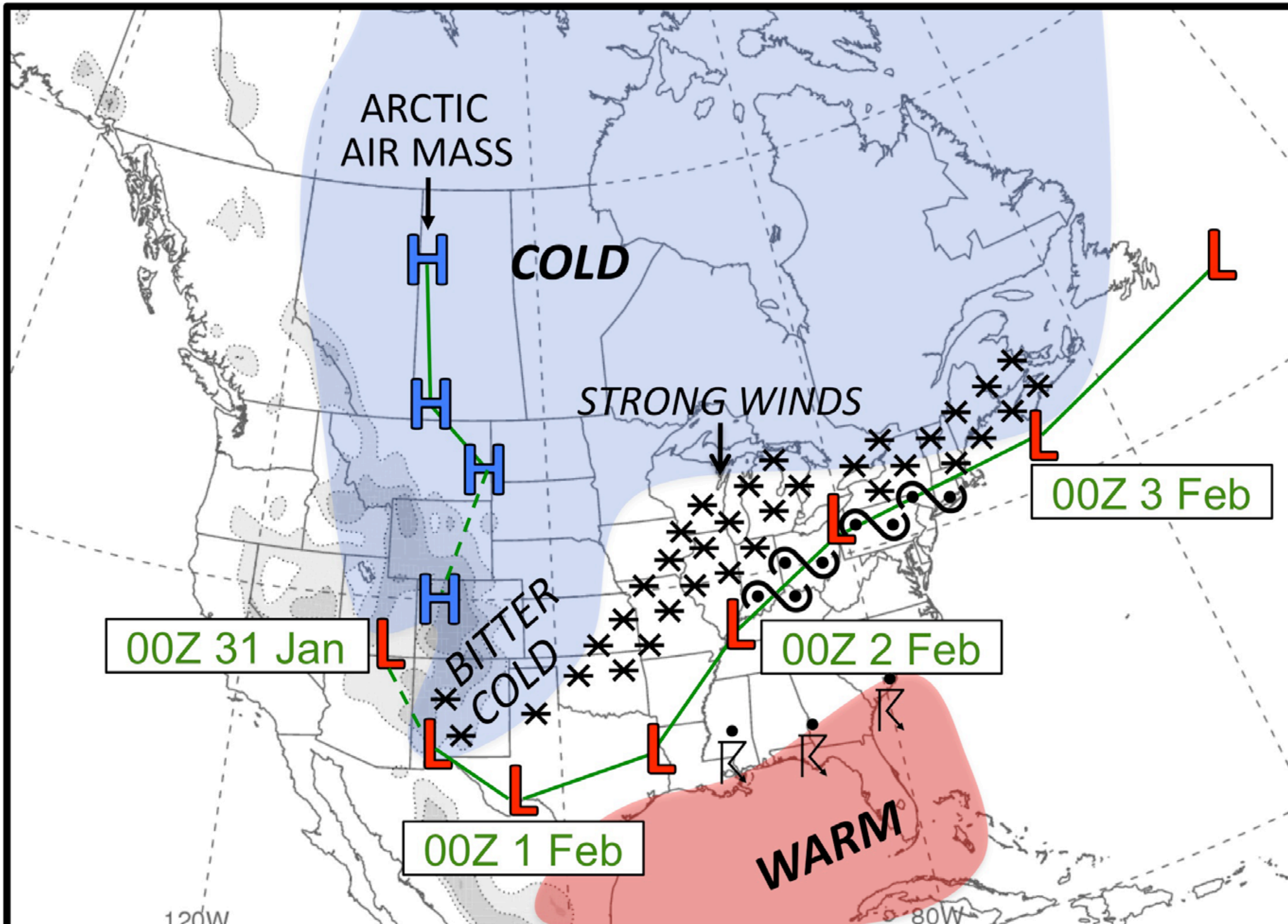


1–3 February 2011 Snowstorm: 0000 UTC 2 Feb

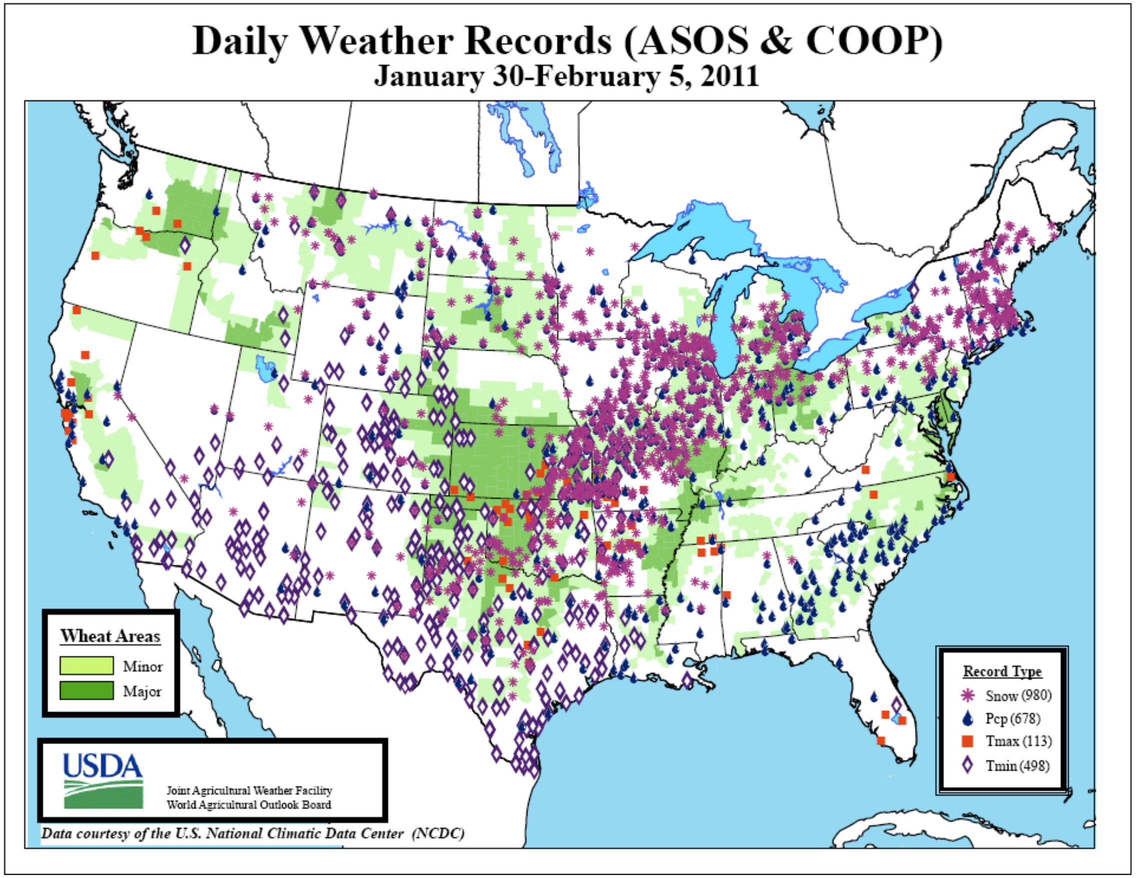
250-hPa WND (m s^{-1}, color shading), POT VORT (PVU, solid gray), REL HUM (%, gray shading); 300–200-hPa IRROT WND (vectors, m s^{-1}) and 600–400-hPa OMEG (red, every 5 x 10^{-3} hPa s^{-1}, neg. values only)



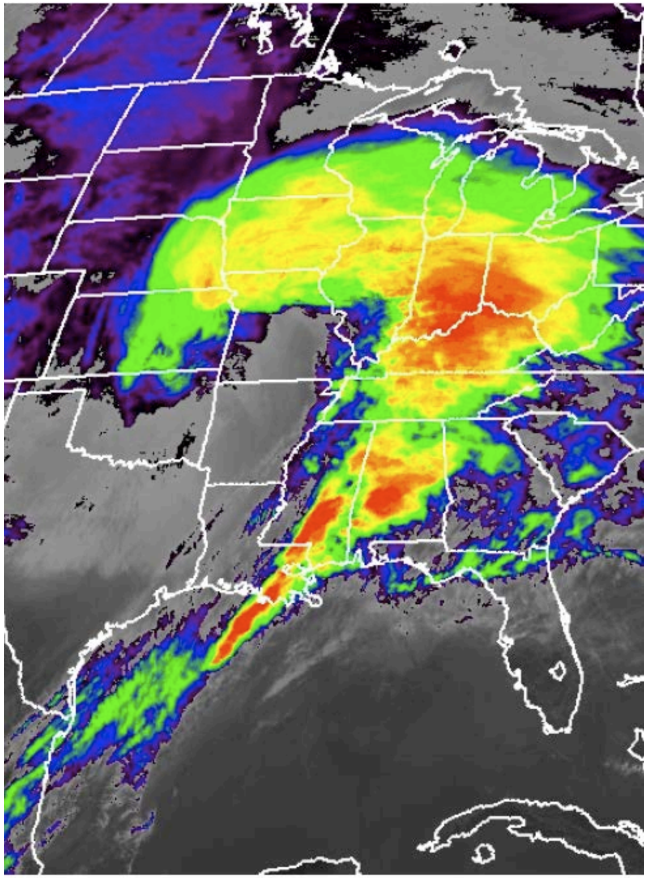
1–3 February 2011 Snowstorm



1–3 February 2011 Snowstorm



Daily Snow, Precipitation, and Temperature Records for 30 Jan–5 Feb 2011

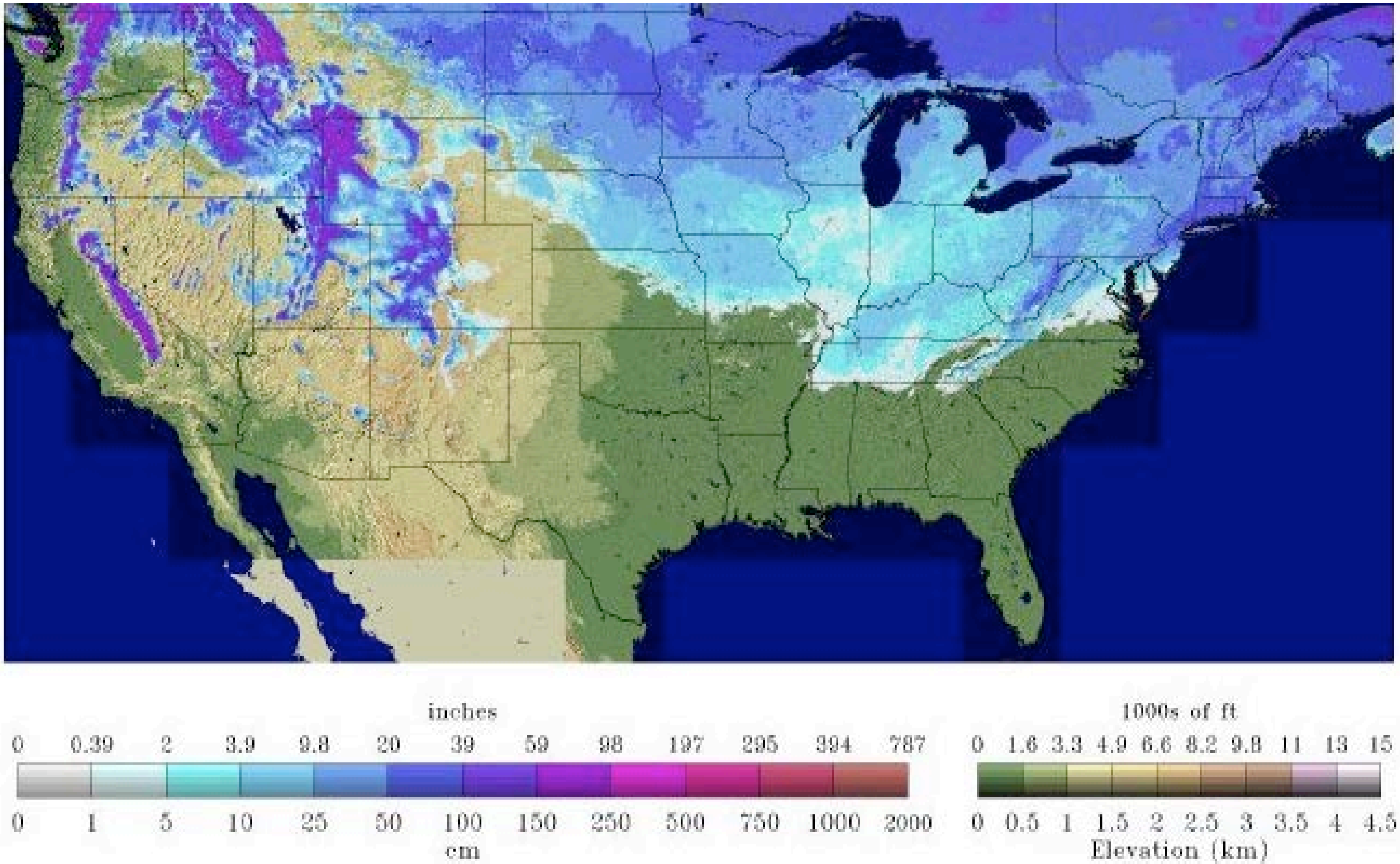


GOES East IR Satellite Image: 3:01 pm EST on 1 Feb 2011

Images taken from Weekly Weather and Crop Bulletin

Extensive Snow Cover: January–February 2011

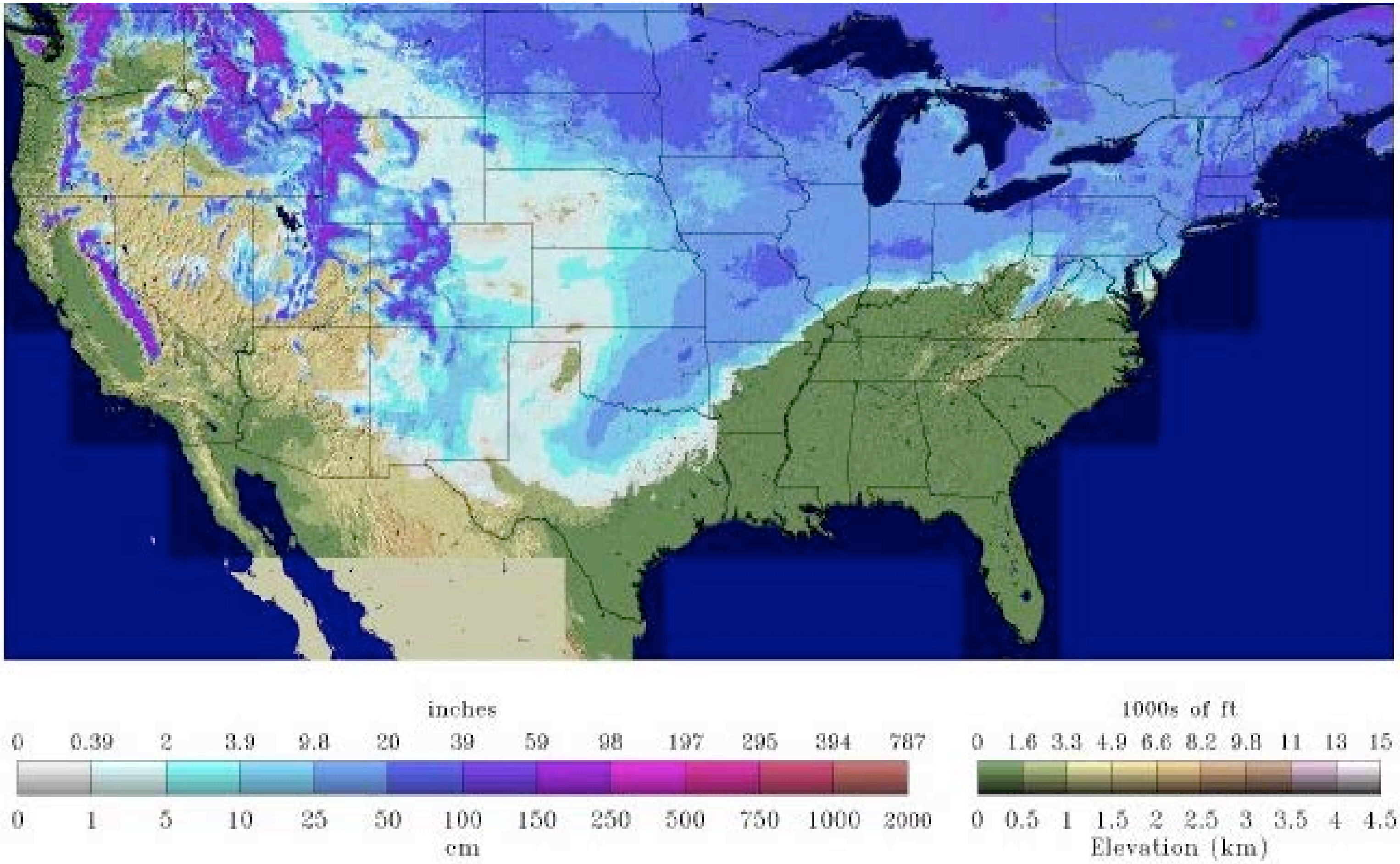
Snow Depth: 27 January 2011



NOAA National Operational Hydrologic Remote Sensing Center

Extensive Snow Cover: January–February 2011

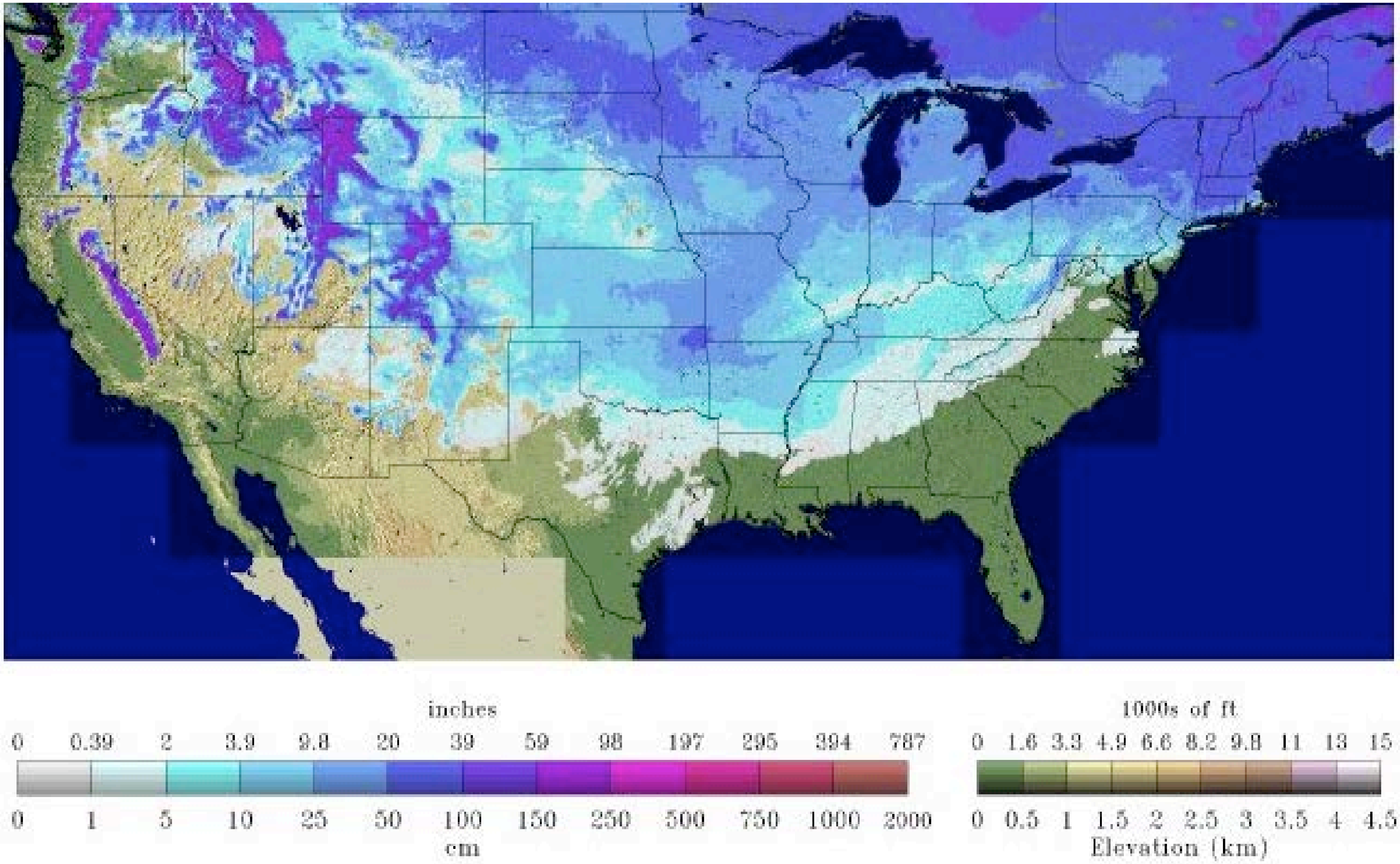
Snow Depth: 3 February 2011



NOAA National Operational Hydrologic Remote Sensing Center

Extensive Snow Cover: January–February 2011

Snow Depth: 10 February 2011



NOAA National Operational Hydrologic Remote Sensing Center

Summary

Extreme winter weather can be related to:

- Amplified flow pattern allowing mild Atlantic air to reach eastern Canada and cold air to reach western Europe and the southern U.S.
- Cold high pressure systems that deliver cold air to the southern U.S.
- Extensive snow cover at lower latitudes east of the Rockies that reinforces frontal boundaries
- Frequent storminess along these reinforced frontal boundaries

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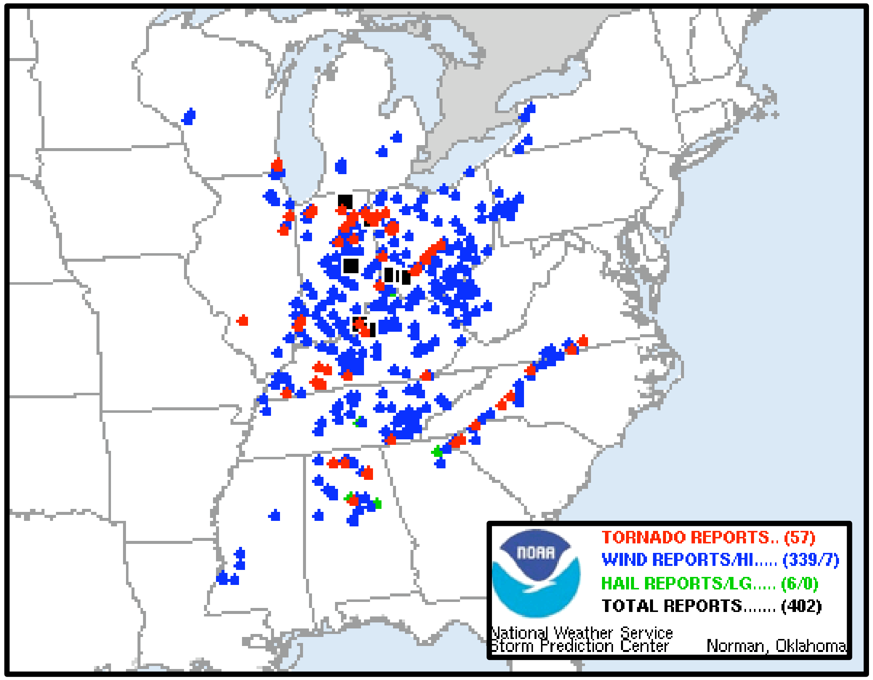
The CONUS Continental “Bomb” of 25-26 October 2010

Cyclone statistics: High-impact weather

- SLP of 955.2 hPa at Bigfork, MN (ASOS) at 2213 UTC 26 Oct
  - Set MN state record for lowest observed SLP
  - Record lowest observed SLP between Rockies and Appalachians, breaking record set by Jan 1978 Cleveland Superbomb

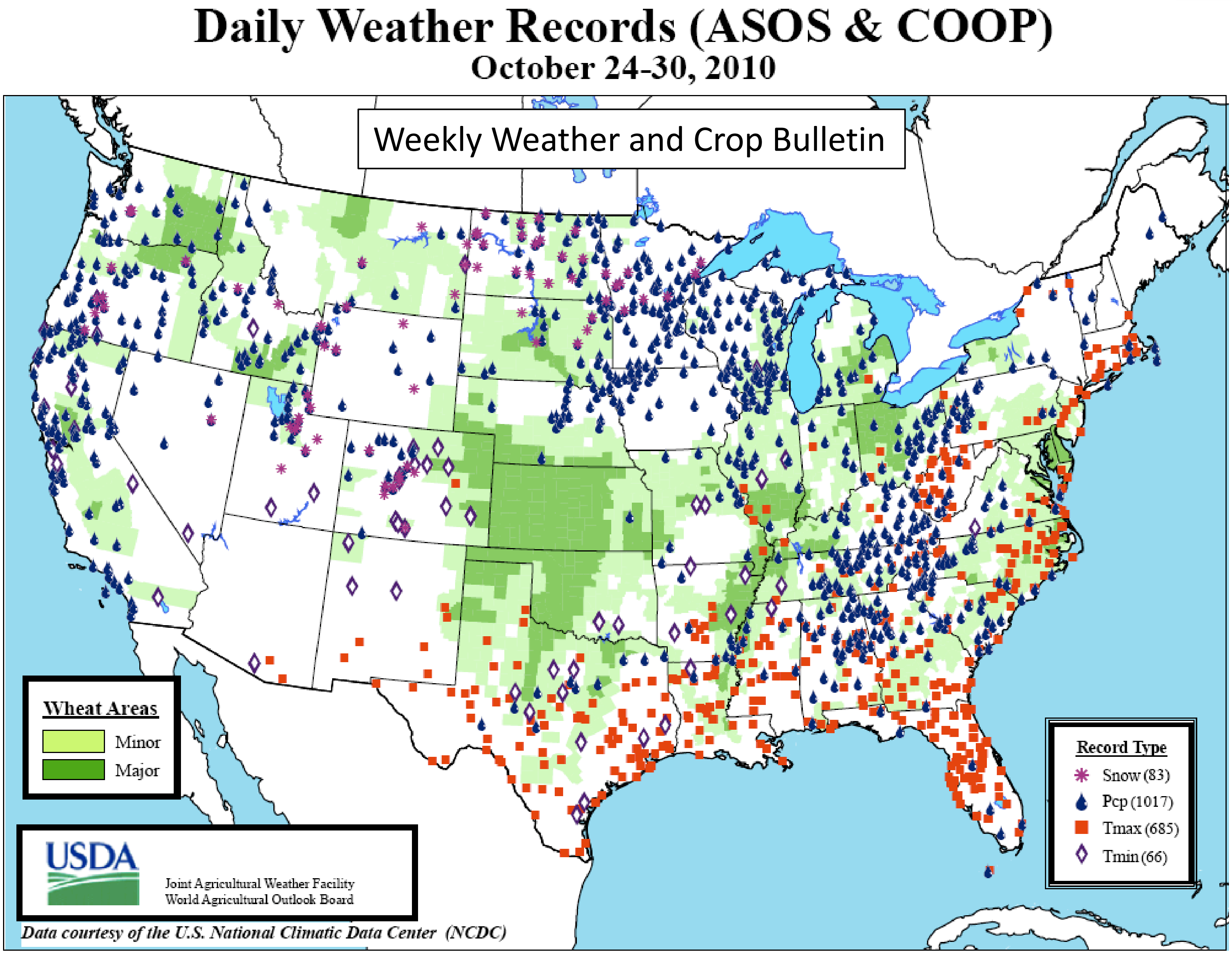
- Strong SLP gradient resulted in 55–65 kt wind gusts

- Long-lived squall line was associated with 400+ severe reports on 26 Oct

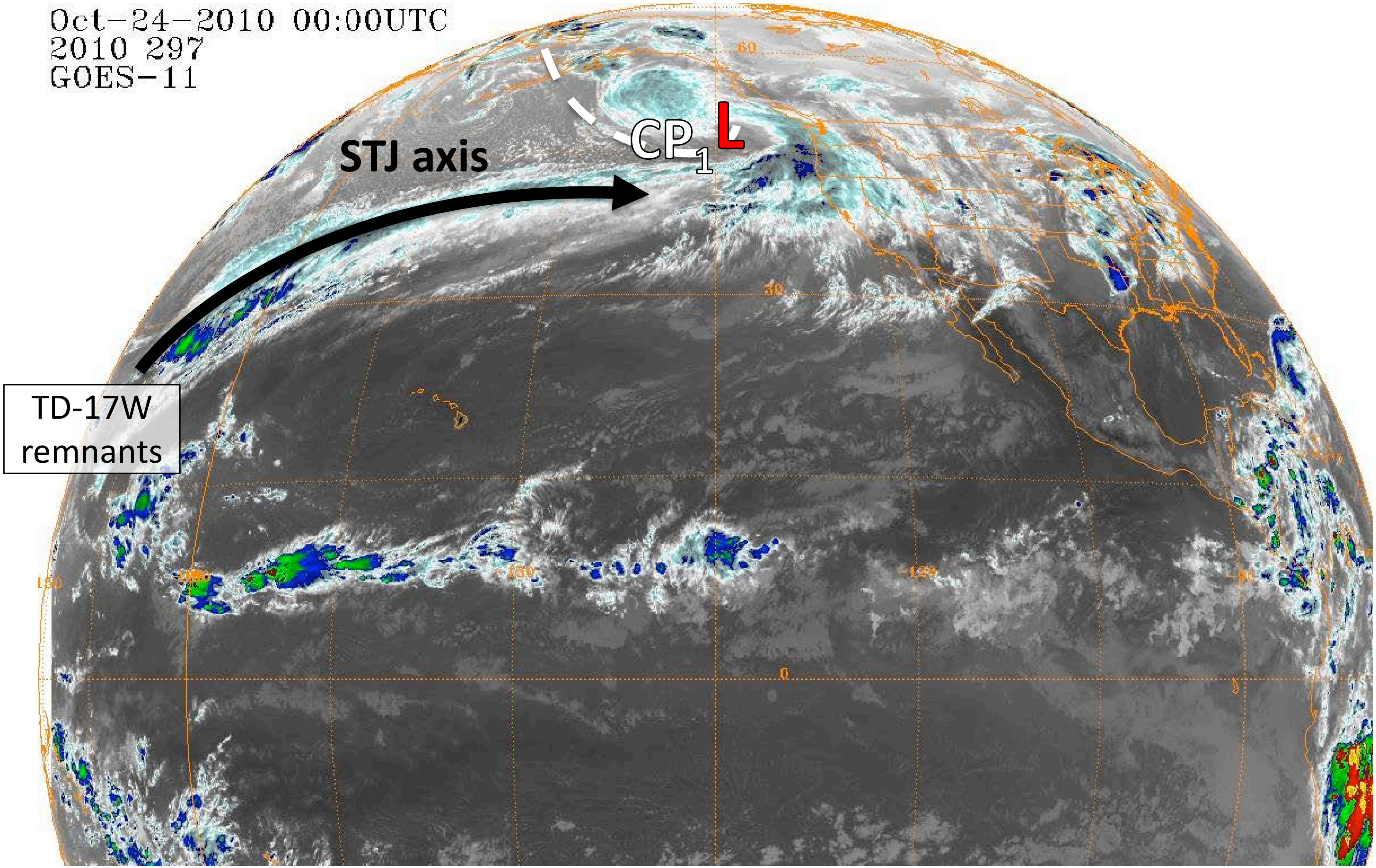


SPC Storm Reports: 26 Oct 2010

Cyclone statistics: High-impact weather

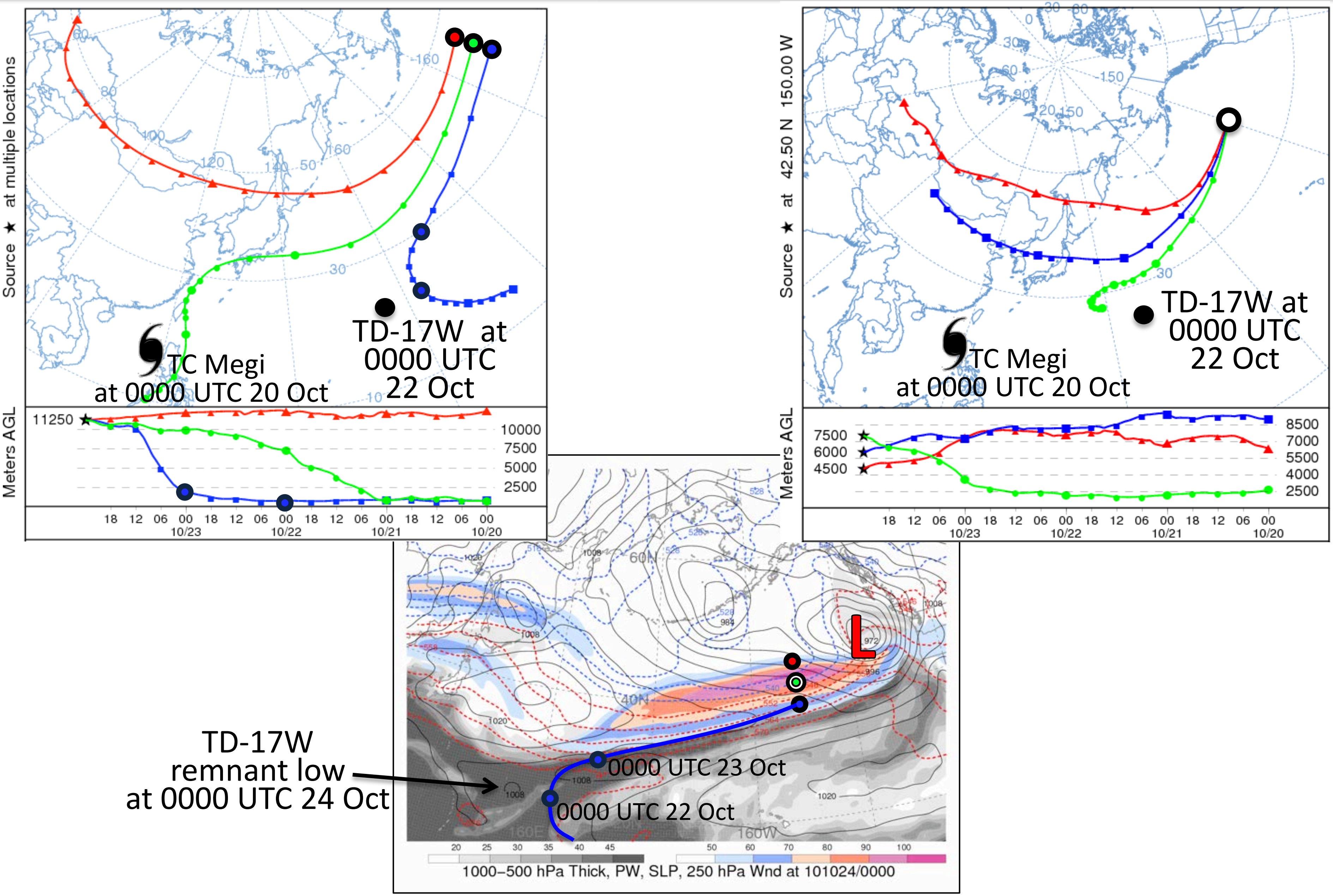


Antecedent conditions: 0000 UTC 24 Oct IR

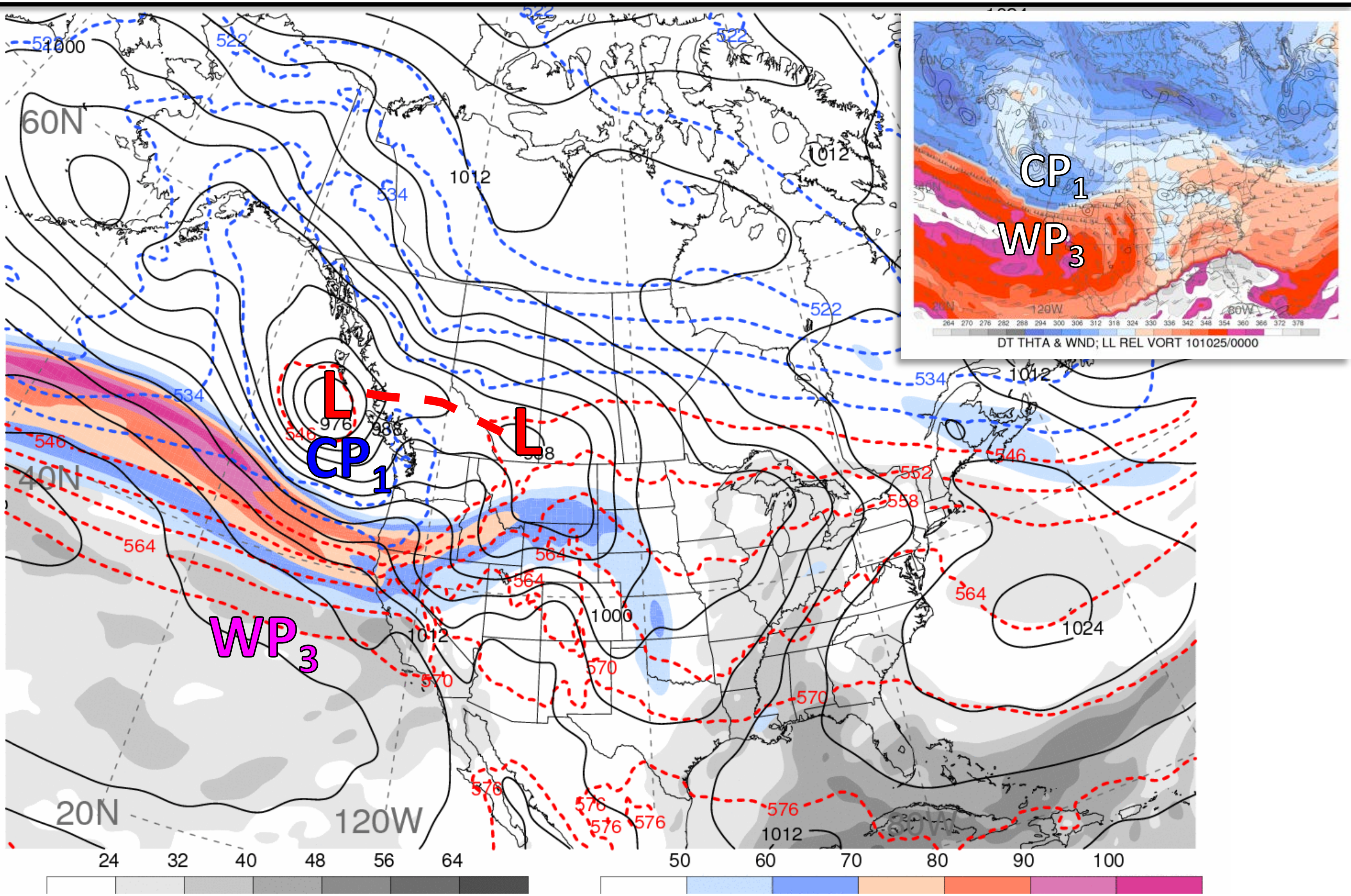


GOES-11 satellite

Antecedent conditions: 96-h trajectories ending 0000 UTC 24 Oct

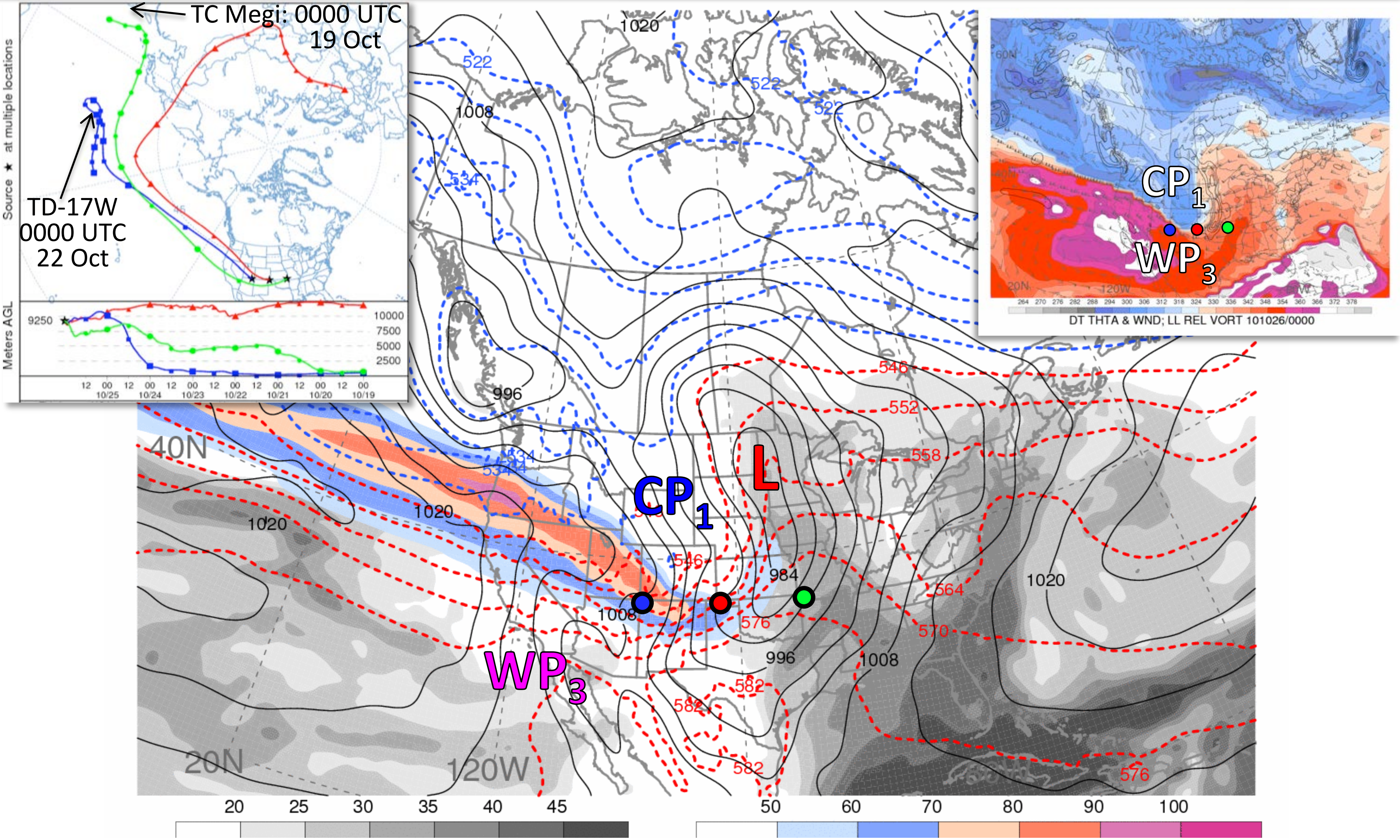


Cyclone evolution: 0000 UTC 25 Oct



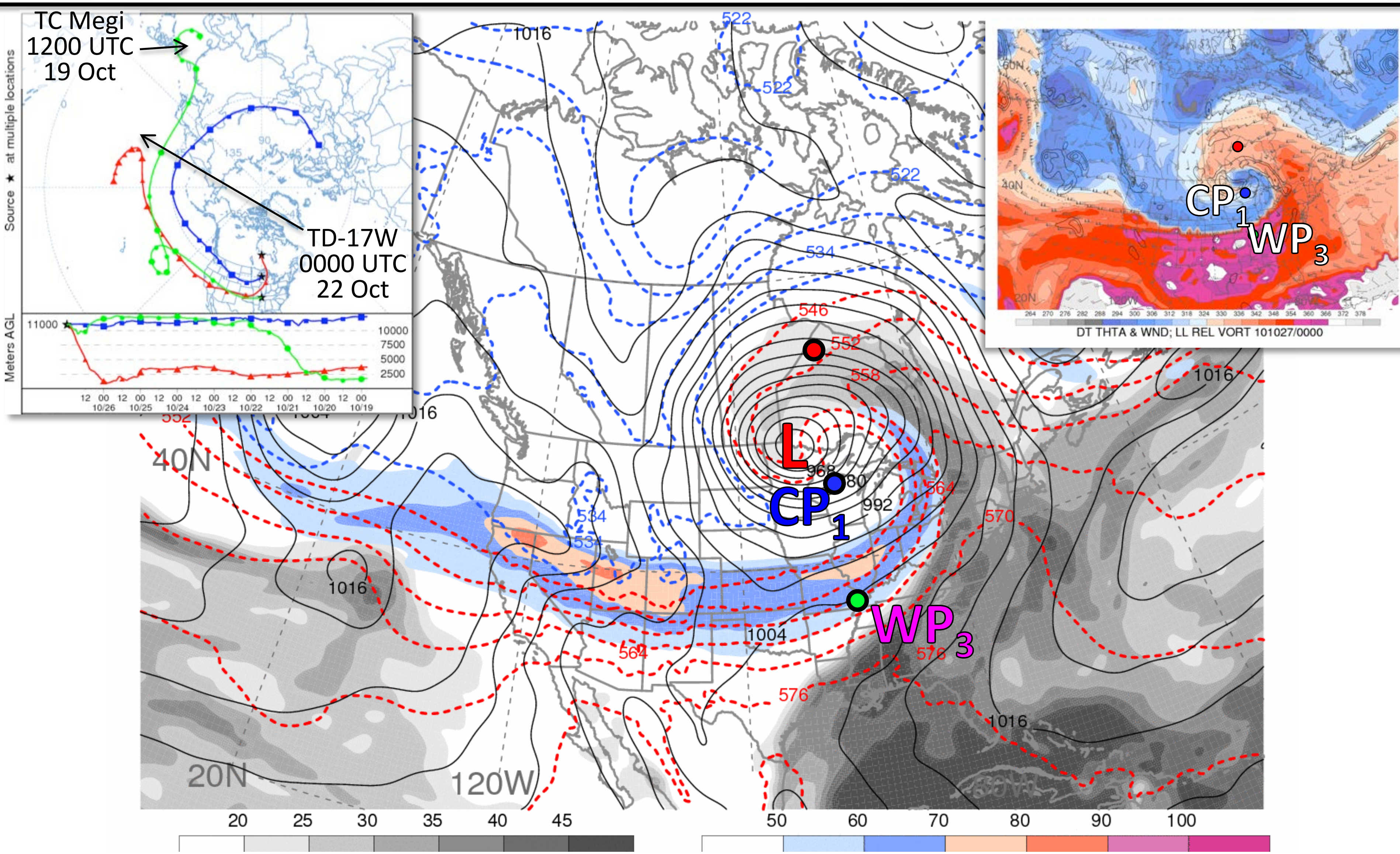
250-hPa wind speed (color shading, m s^{-1}), precipitable water (gray shading, mm), SLP (black, hPa) and 1000–500-hPa thickness (dashed, dam)

Cyclone evolution: 0000 UTC 26 Oct



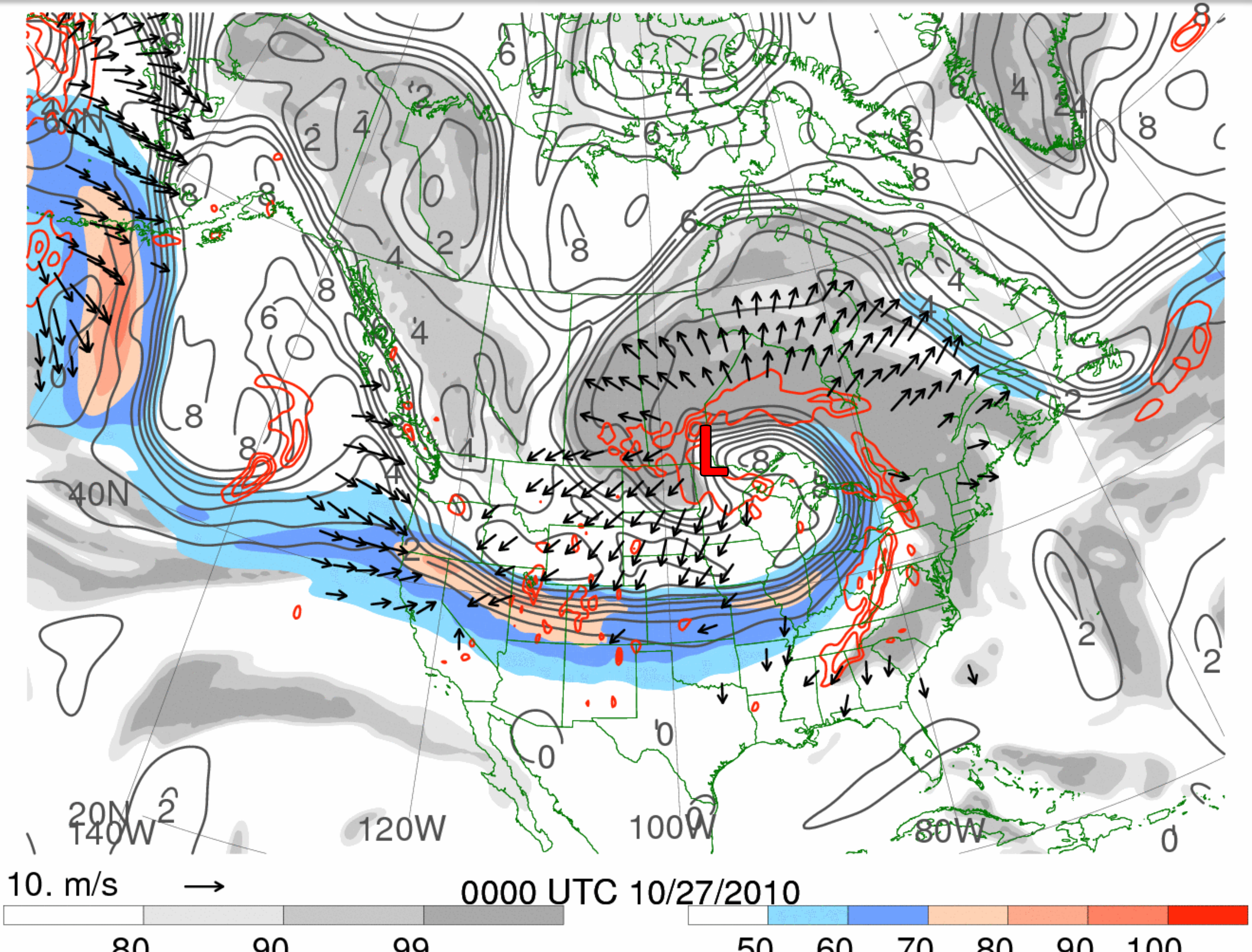
250-hPa wind speed (color shading, m s^{-1}), precipitable water (gray shading, mm), SLP (black, hPa) and 1000–500-hPa thickness (dashed, dam)

Cyclone evolution: 0000 UTC 27 Oct



250-hPa wind speed (color shading, m s^{-1}), precipitable water (gray shading, mm), SLP (black, hPa) and 1000–500-hPa thickness (dashed, dam)

Cyclone evolution: Irrotational wind, jet – 0000 UTC 27 Oct

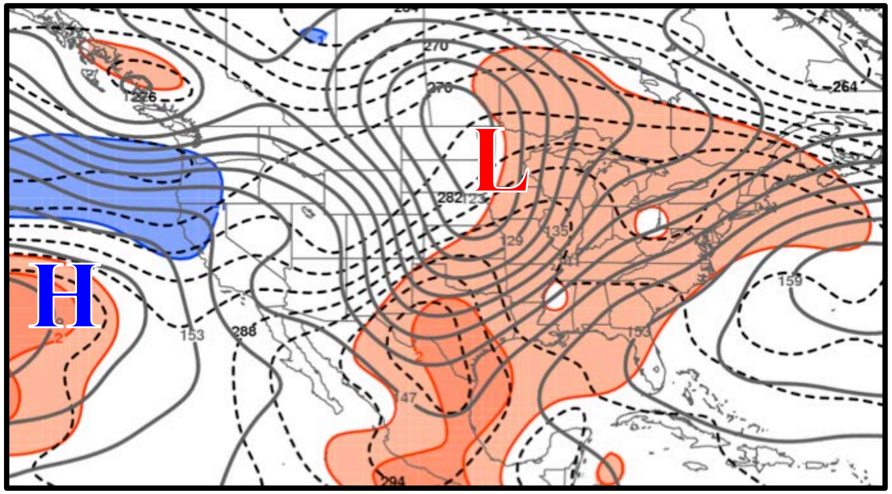


250-hPa WND (m s^{-1}, color shading), PV (PVU, gray), REL HUM (%, gray shading); 300–200-hPa IRROT WND (vectors, m s^{-1}), 600–400-hPa OMEG (red, every 5 x 10^{-3} hPa s^{-1}, neg. values only)

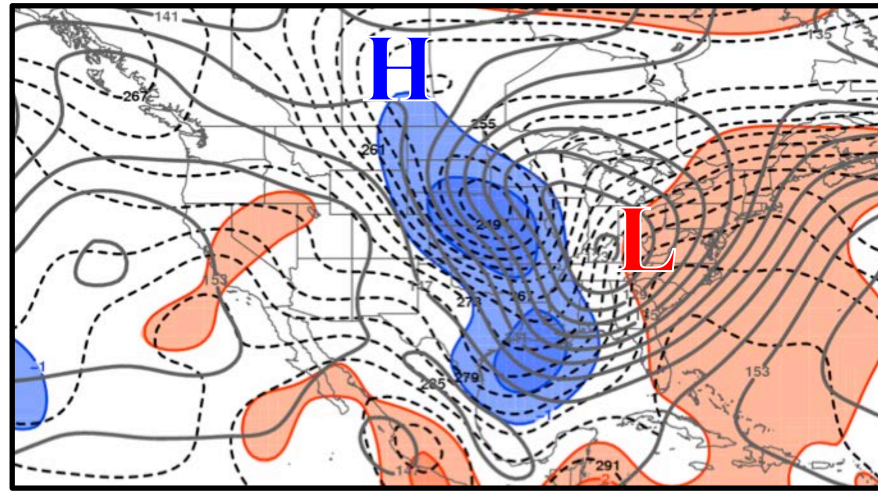
A Comparison of the CONUS bomb of 25-26 October 2010 with the "Cleveland Superbomb" of 25-26 January 1978

Comparison with 1978 Superbomb: 850 hPa

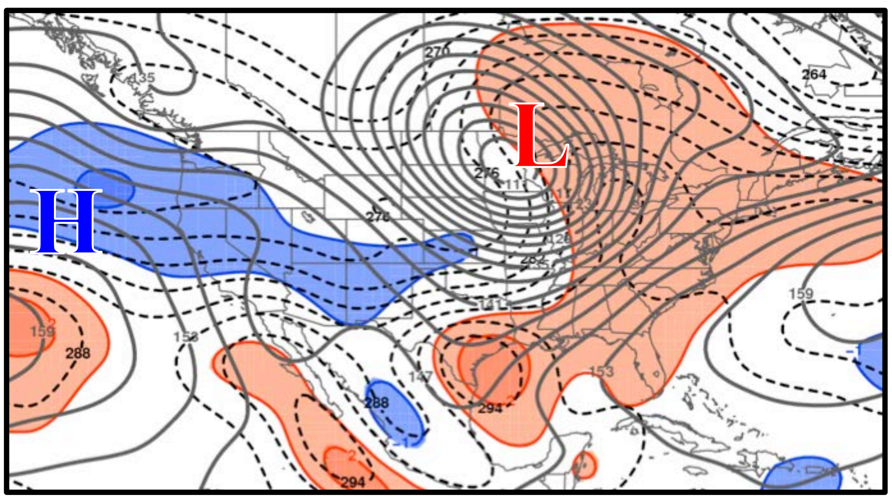
0000 UTC 26 October 2010



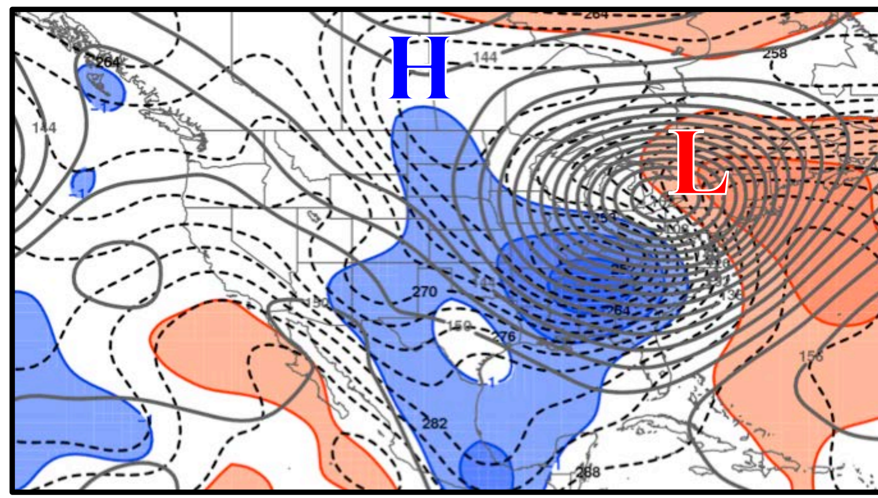
0000 UTC 26 January 1978



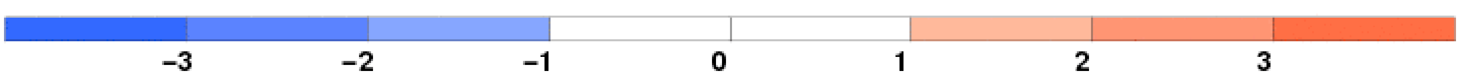
1200 UTC 26 October 2010



1200 UTC 26 January 1978



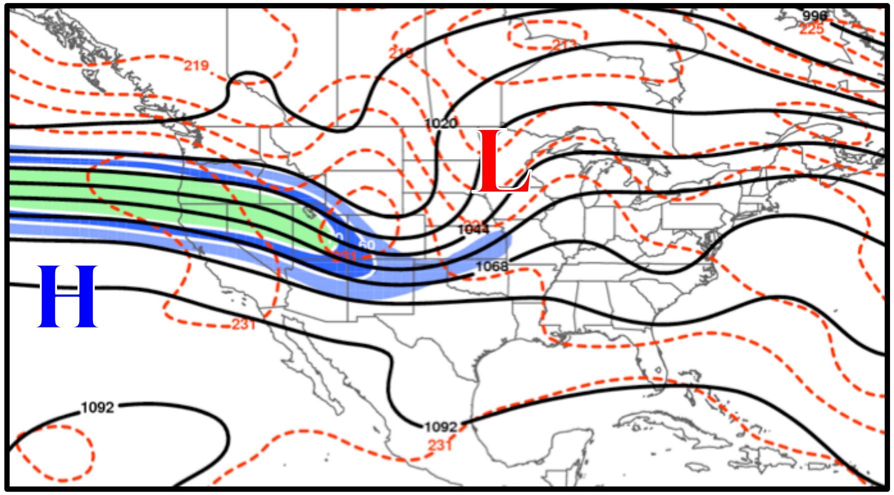
2.5° NCEP–NCAR reanalysis



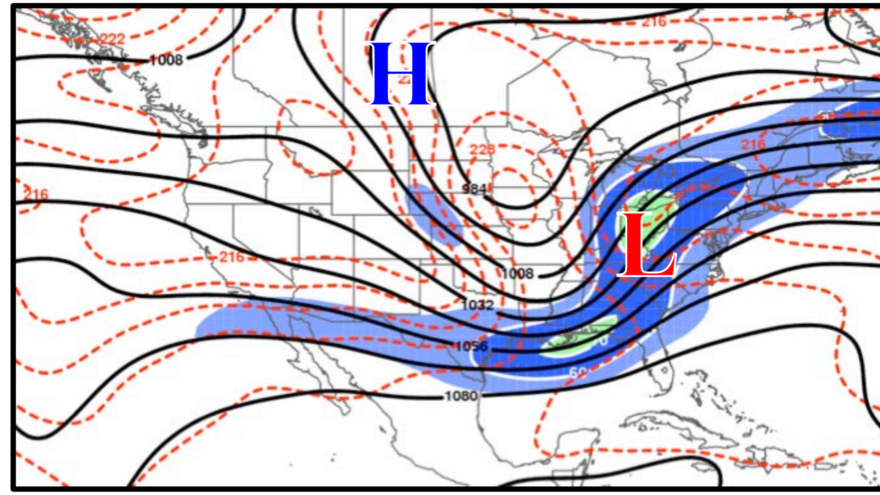
850-hPa temp. (K, dashed), std. temp. anomaly (SD, shaded), and geo. height (dam, solid)

Comparison with 1978 Superbomb: 250-hPa

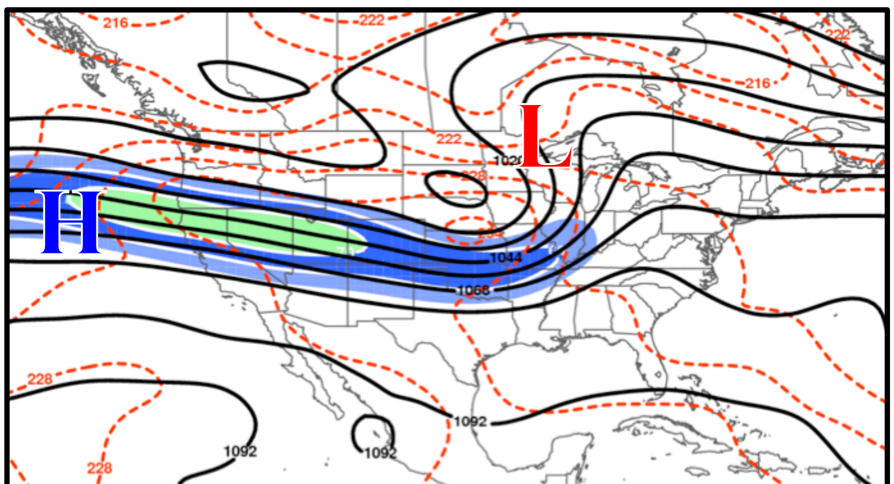
0000 UTC 26 October 2010



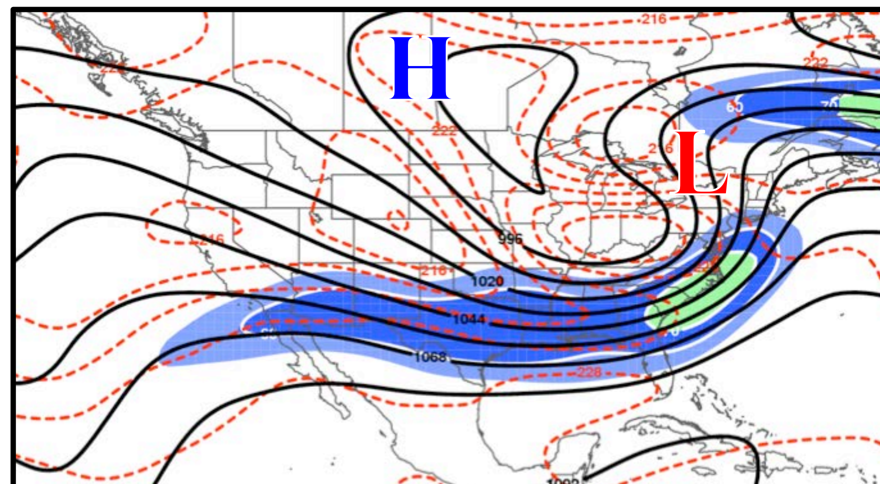
0000 UTC 26 January 1978



1200 UTC 26 October 2010



1200 UTC 26 January 1978

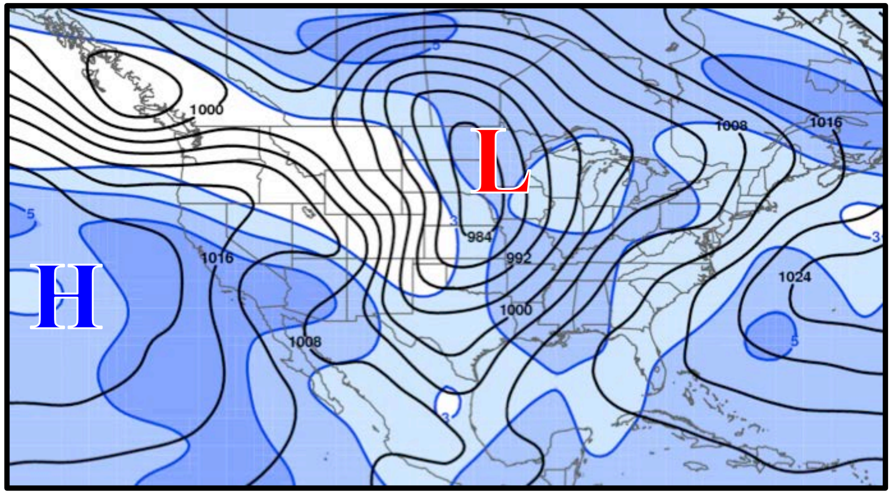


2.5° NCEP–NCAR reanalysis

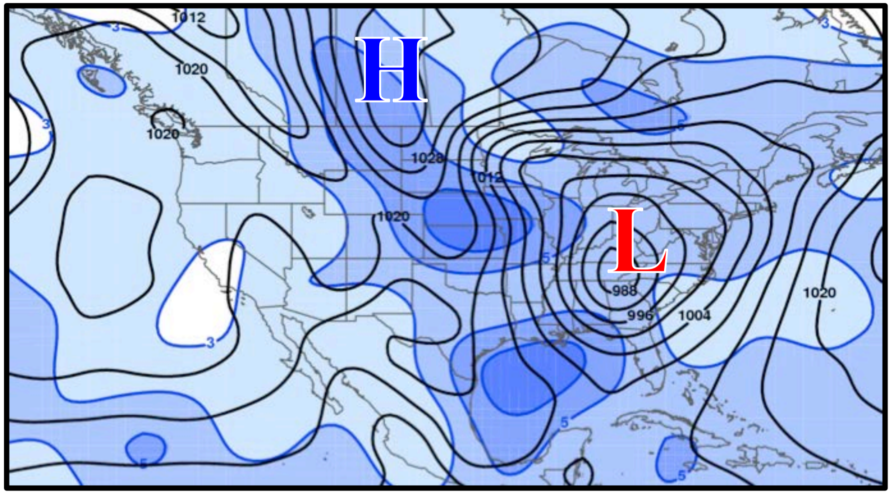
250-hPa temp. (K, dashed), geo. height (dam, solid), and wind speed (m s^{-1}, shaded)

Comparison with 1978 Superbomb: Static stability

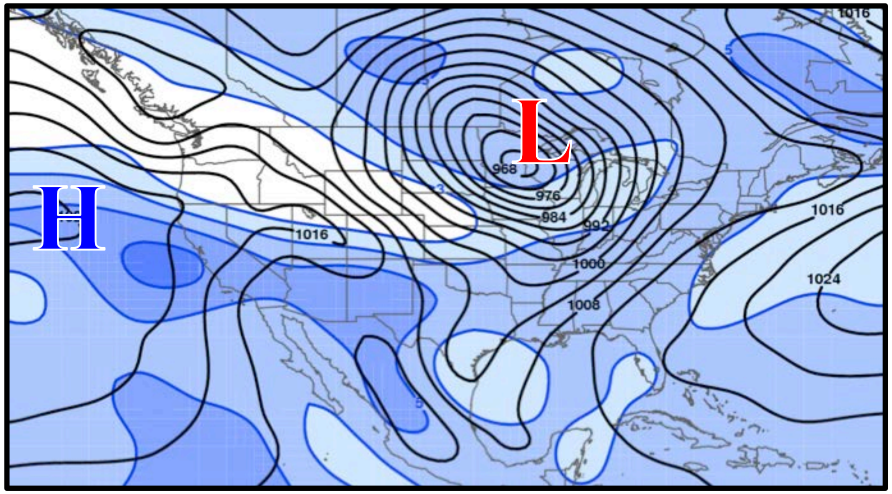
0000 UTC 26 October 2010



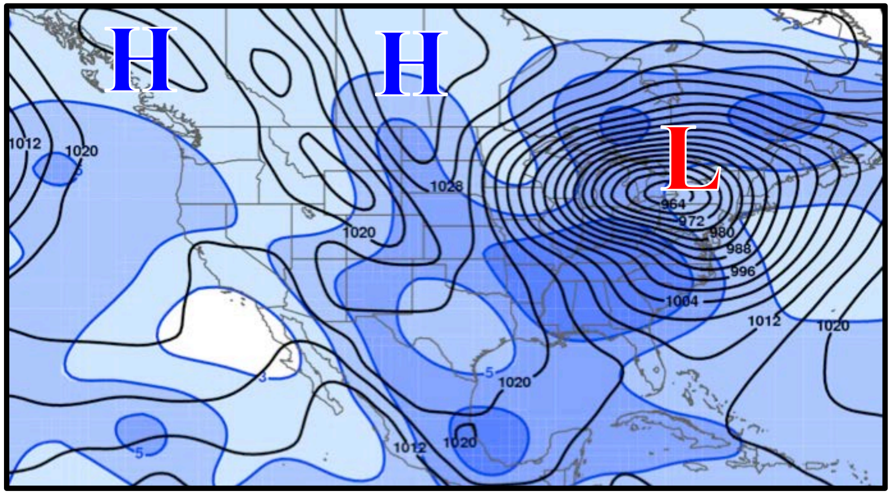
0000 UTC 26 January 1978



1200 UTC 26 October 2010



1200 UTC 26 January 1978



2.5° NCEP–NCAR reanalysis

850–500-hPa static stability parameter (10^{-4} K Pa^{-1}) and sea level pressure (hPa)

Conclusions

- Strong Pacific STJ originated from juxtaposition of TC/TD-related warm pools and trough-related cold pools
- Pacific frontal zone was a focus for deep ascent, increased baroclinicity, and a strengthened STJ
- TC/TD related diabatic outflow strengthened the PV gradient and STJ from Asia eastward across the Pacific
- STJ entrance & exit region dynamics governed the structure & evolution of the surface cyclone from the Pacific to the Midwest
- Oct 2010 intense Midwest cyclone featured a strong STJ, modest low-level baroclinicity, and relatively low stability
- Jan 1978 intense Ohio Valley cyclone featured coupled jets, strong baroclinicity, and relatively high stability