The Contributions of Atmospheric Rivers to Extreme Weather Events Arising from the Interactions of Tropical Disturbances with Tropospheric Jet Streams

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Overview and motivation

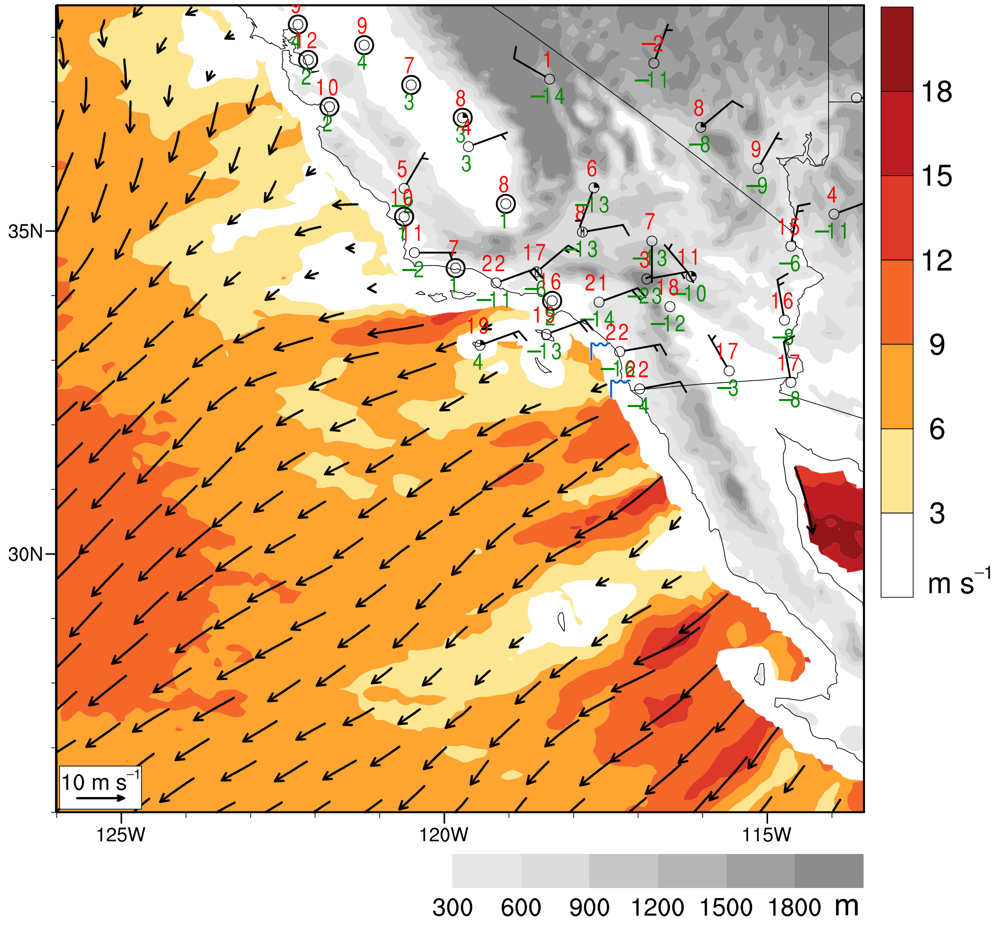
- Four geographically separate, dynamically linked, high-impact extreme weather events (EWEs) occurred over North America in October 2007
- EWEs occurred subsequent to large-scale flow amplification across the North Pacific arising from interacting tropical, midlatitude, and polar disturbances
- Flow amplification culminated in a synoptic-scale flow pattern supportive of atmospheric rivers (ARs) and the occurrence of multiple EWEs

Wildfires in Southern California

14 fatalities, >1500 homes destroyed, ~3900 km^2 burned, ~1 million people displaced

NASA Terra visible sattelite image
1938 UTC 22 Oct

QuikSCAT wind, surface observations
~1400 UTC 22 Oct

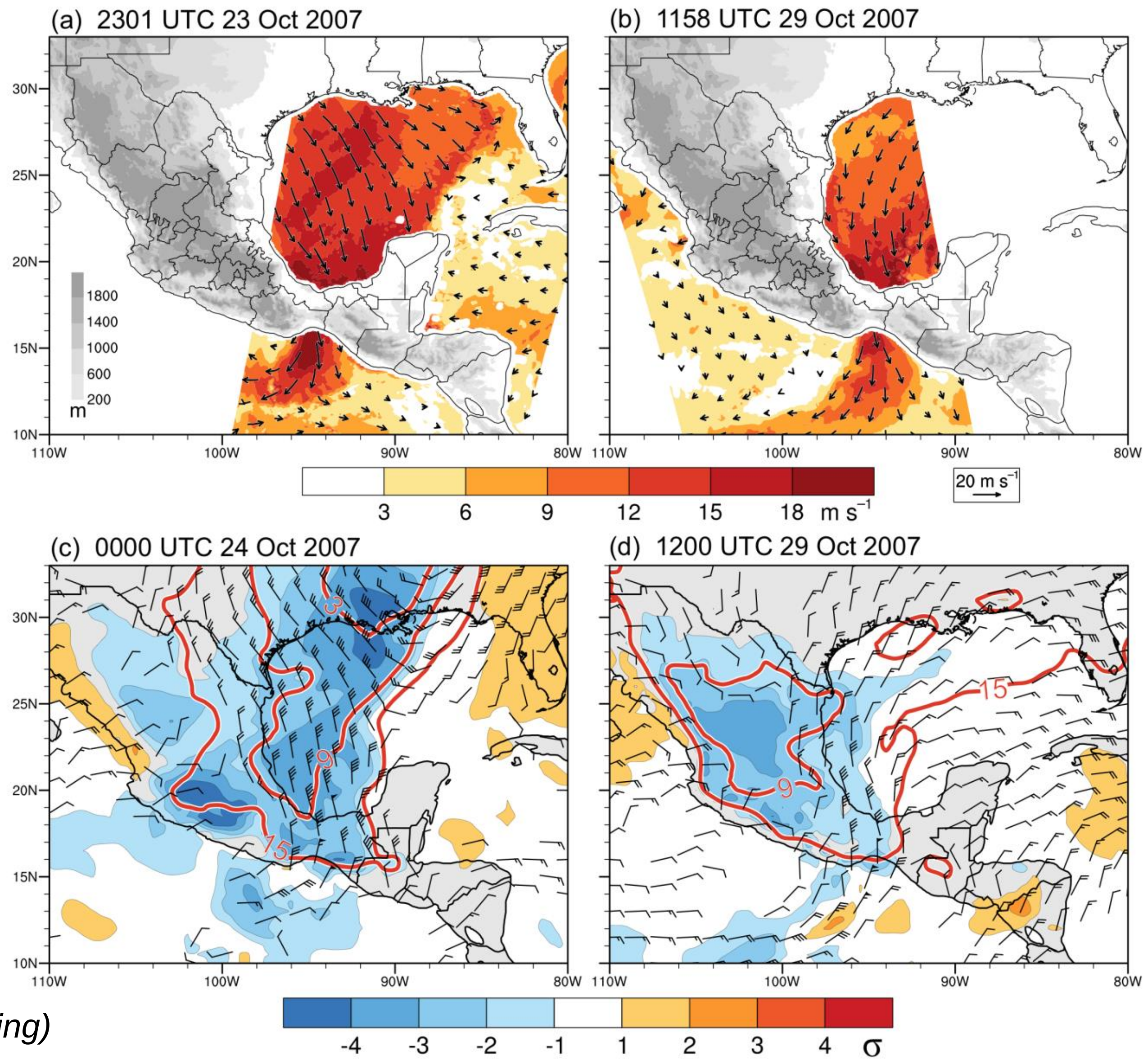


Cold Surges into Mexico

Temperatures far below normal, establish baroclinic zone later associated with heavy rain

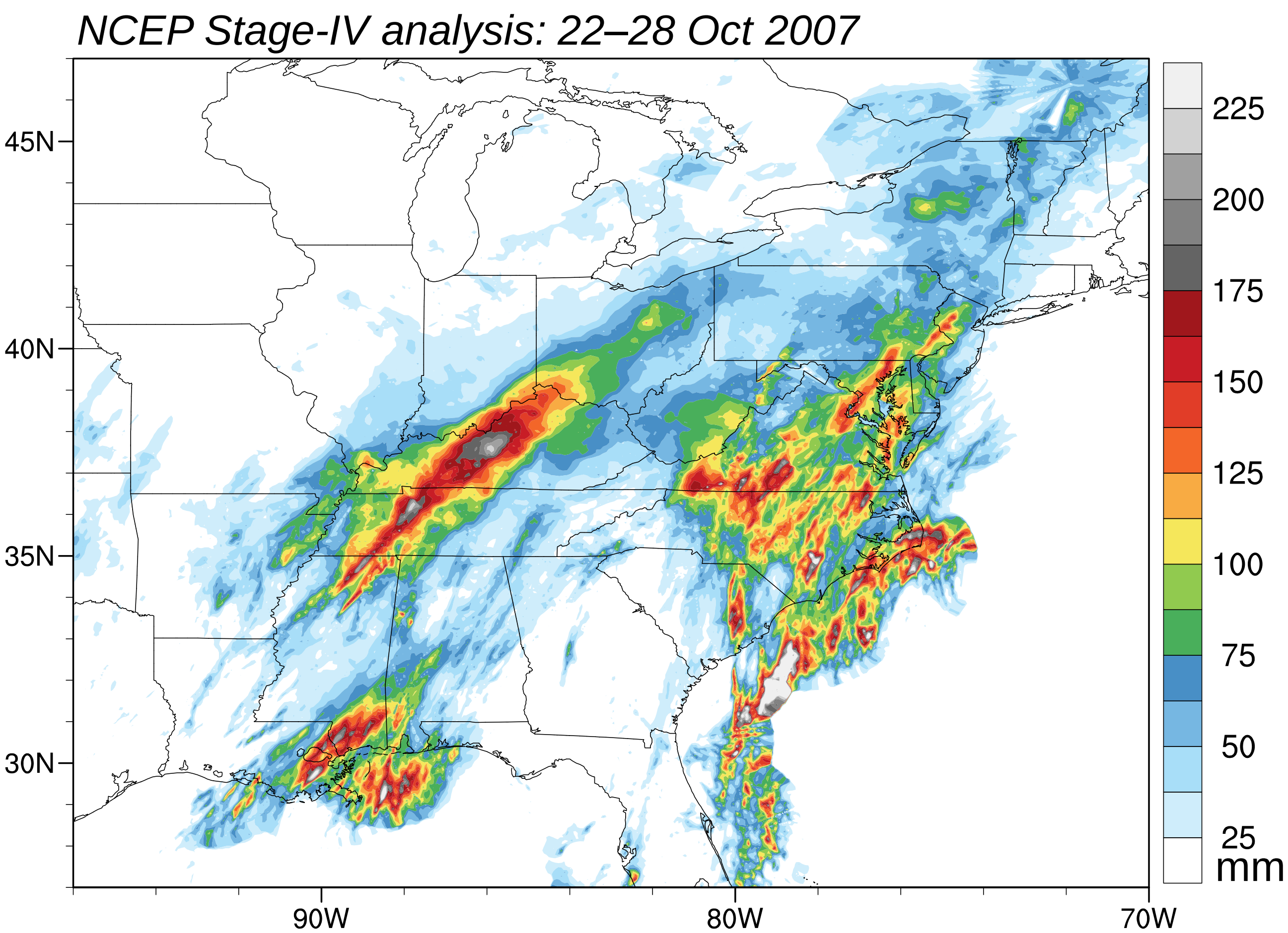
QuikSCAT winds

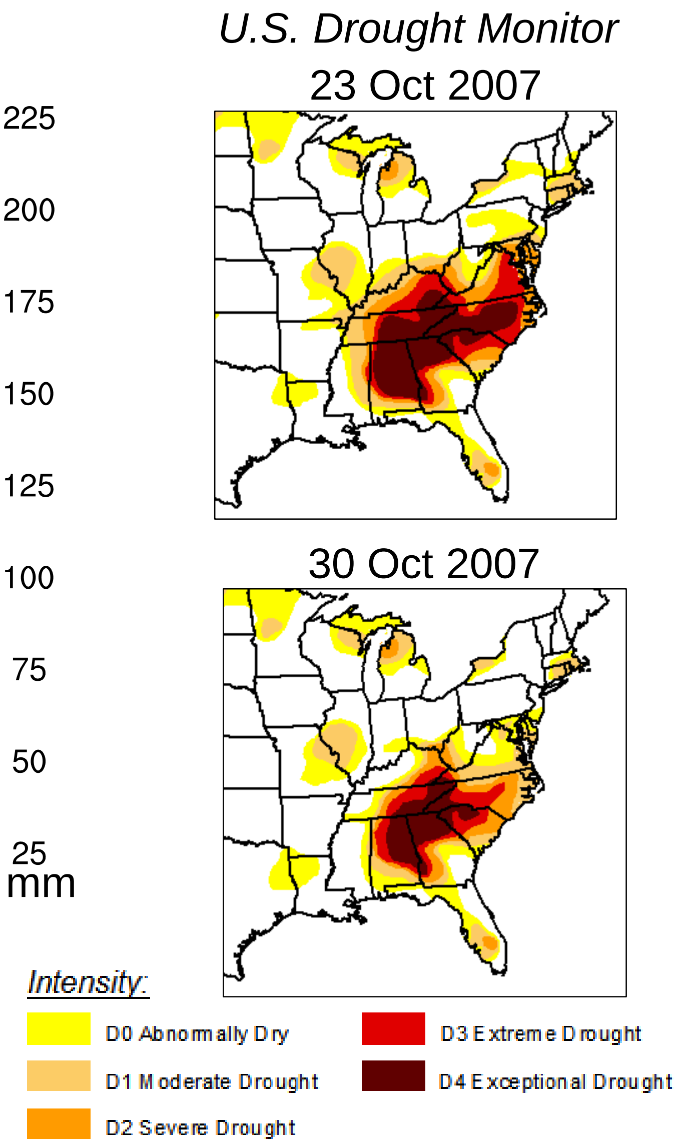
850-hPa T (K, red)
T anomaly (σ, shading)



Heavy Rainfall in the Eastern U.S.

Widespread heavy rainfall mitigates drought conditions in portions of eastern U.S.





http://droughtmonitor.unl.edu/

Heavy Flooding Rainfall in Tabasco and Chiapas

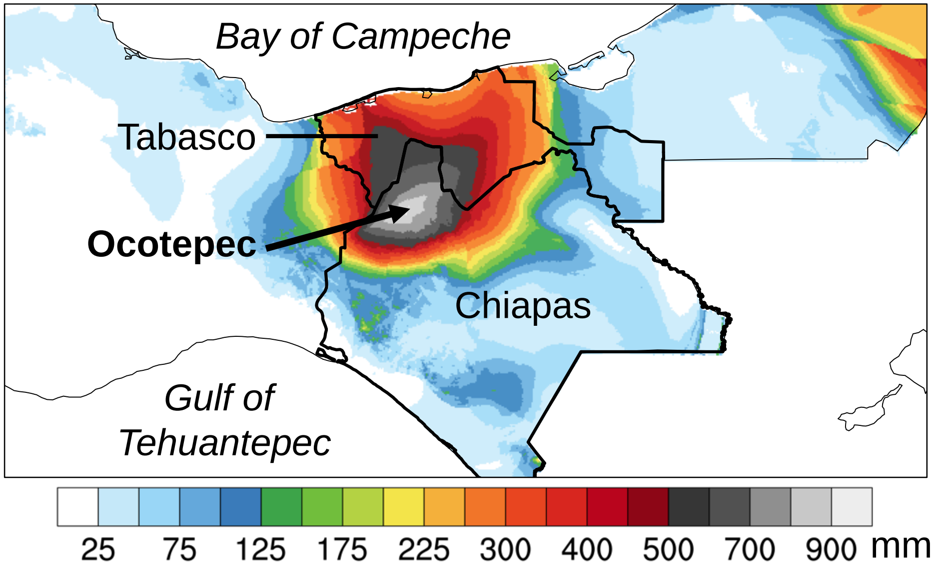
Devastating widespread flooding: ~1 million people displaced, massive damage to crops, property, and infrastructure, food shortages, social unrest

Maximum rainfall totals

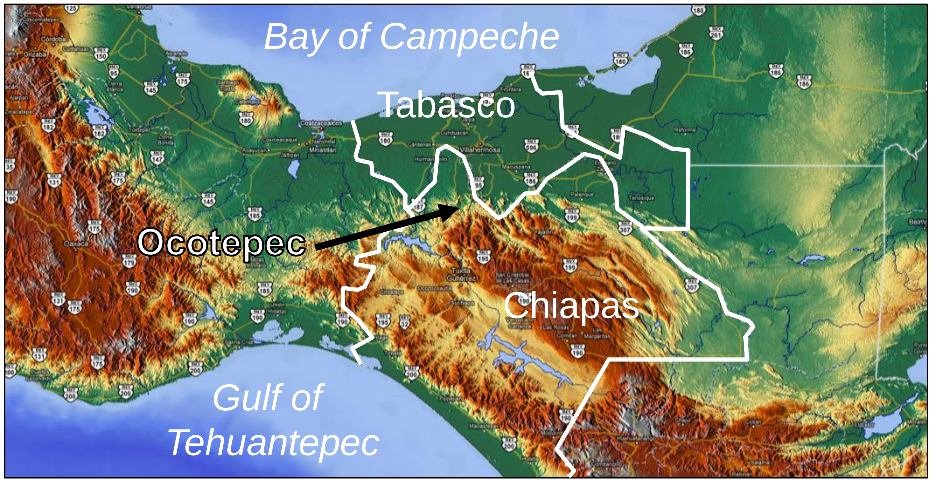
	28–29 Oct	*29–30 Oct*	*30–31 Oct*
Tabasco	317 mm	195 mm	152 mm
Chiapas	403 mm	308 mm	250 mm

– Ocotepec, Chiapas: 962.8 mm total accumulation –

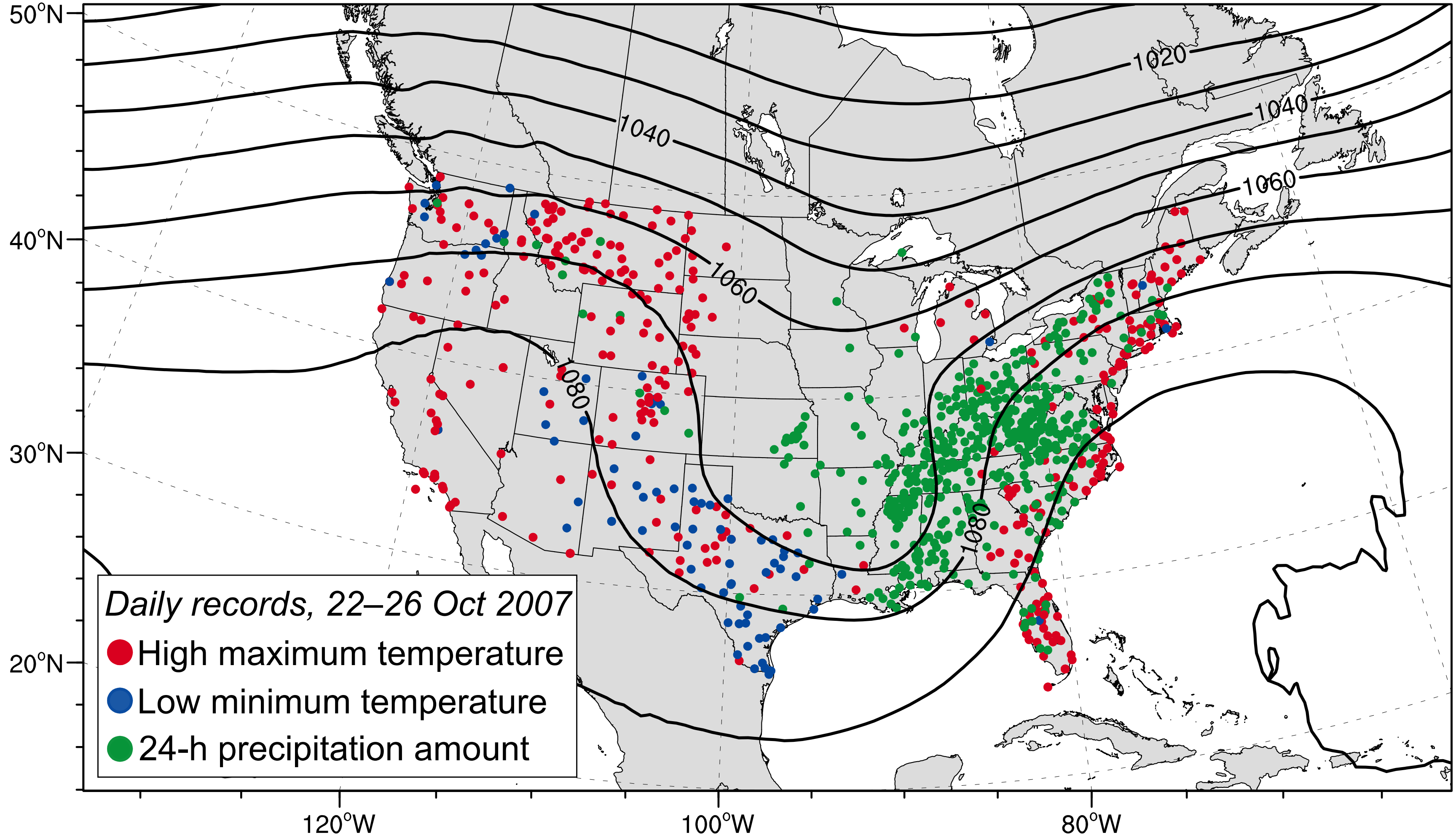
NASA/Oak Ridge National Laboratory DAYMET precipitation: 27–31 Oct 2007



Physical geography of Chiapas and Tabasco



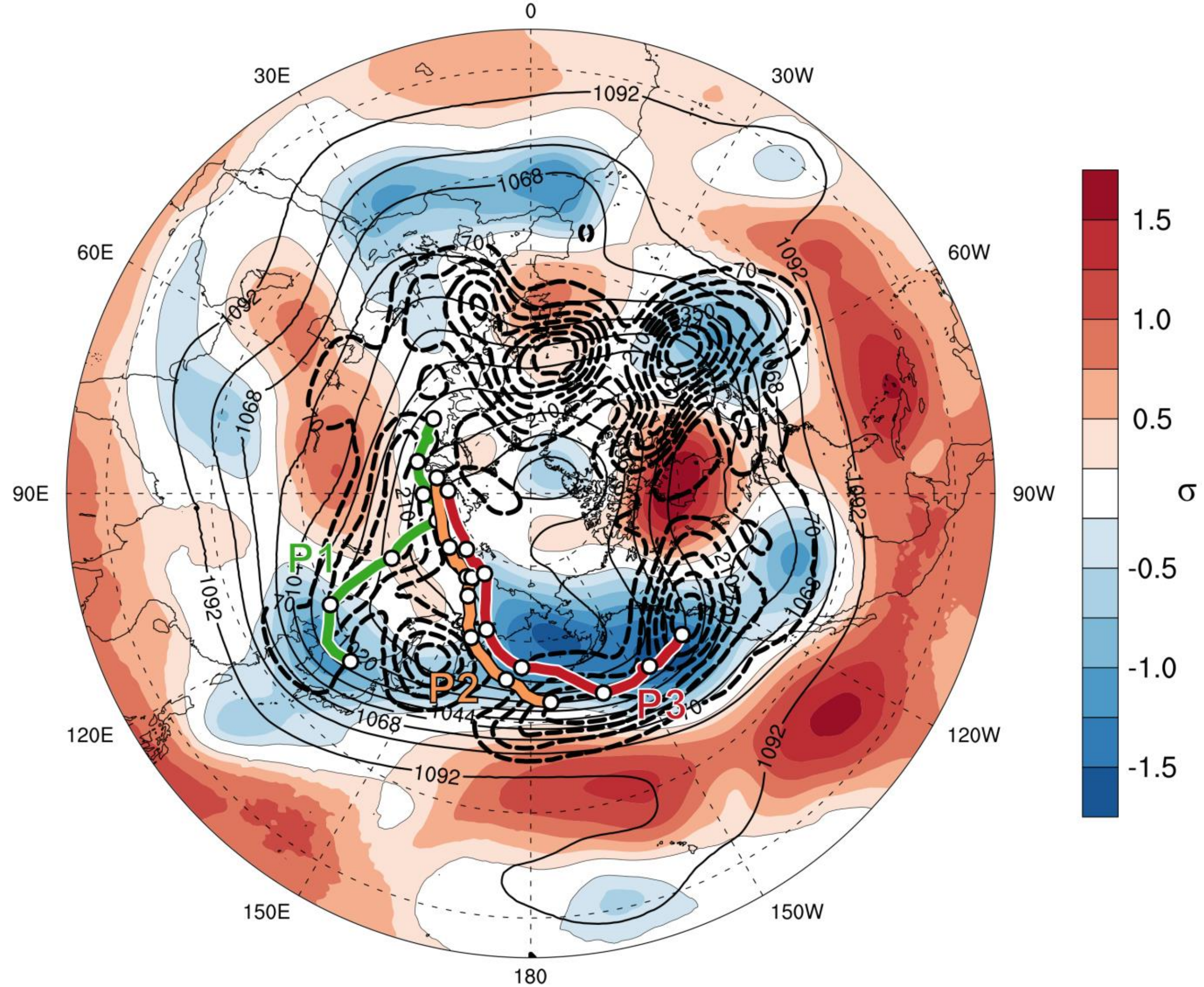
Record-Breaking Weather Conditions across the U.S. during 22–26 Oct 2007



250-hPa time-mean Z (dam, black contours) and daily temperature and precipitation records during 22–26 Oct

Antecedent large-scale conditions

13–20 October 2007

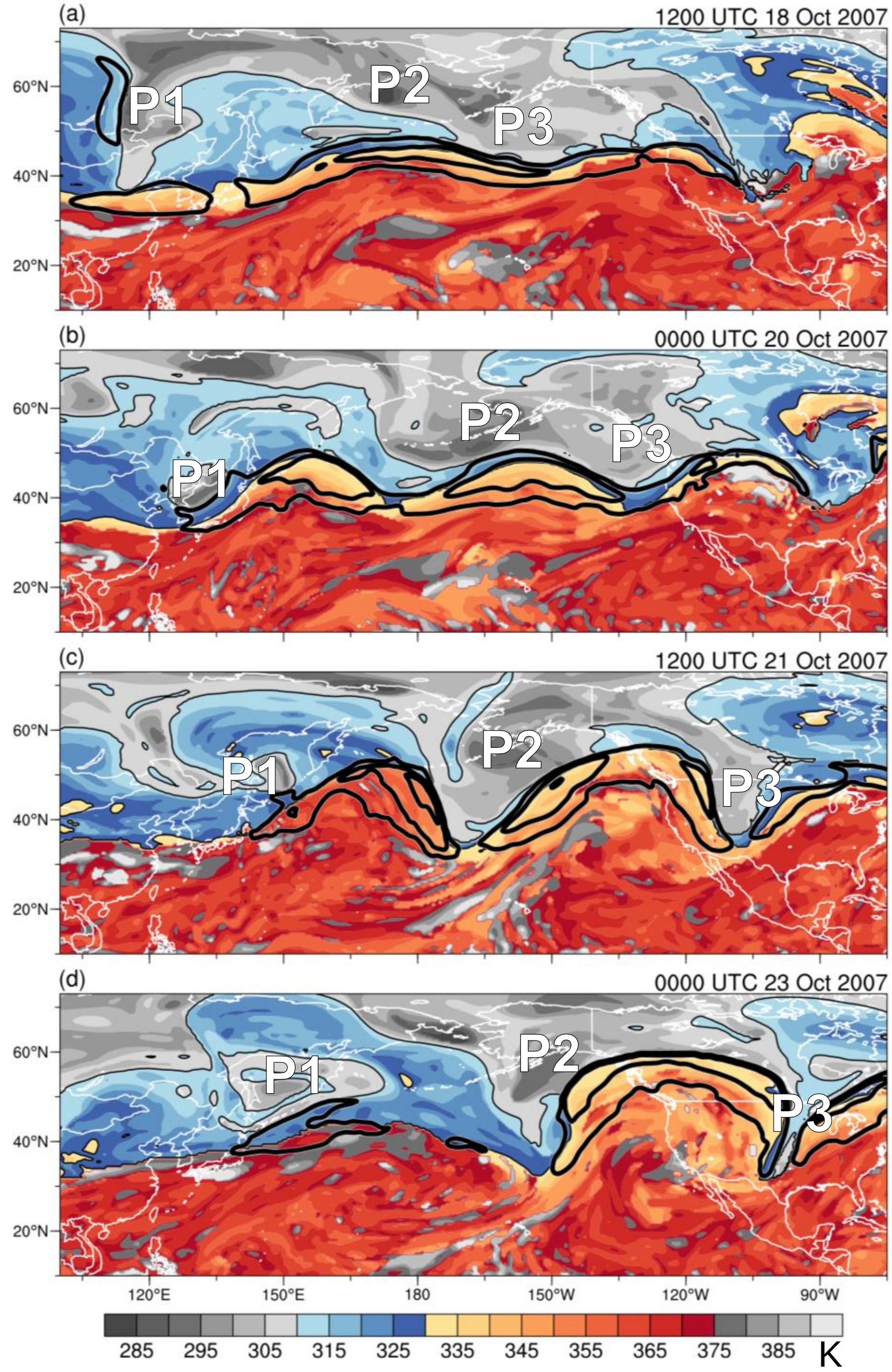


Time-mean 250-hPa geopotential height (dam, thin black), variance (dam², dashed black), normalized anomalies (σ, shading)

Large-scale flow evolution

18–23 Oct 2007

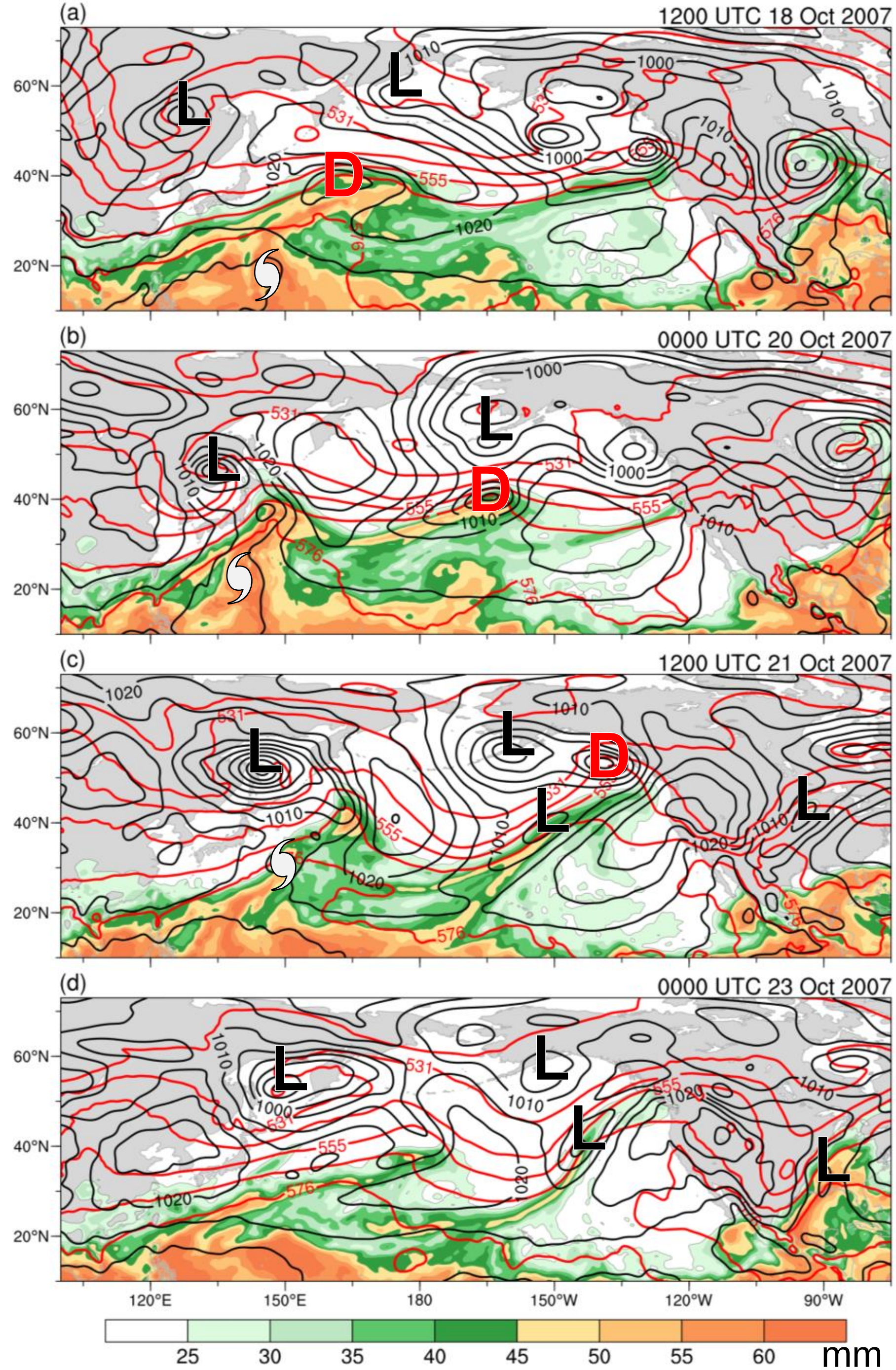
DT θ (K, shading), wind speed (every 20 m s^{-1} starting at 50 m s^{-1}, black)



Large-scale flow evolution

18–23 Oct 2007

PW (mm, shading), SLP (hPa, black),1000–500-hPa thickness (dam, red)



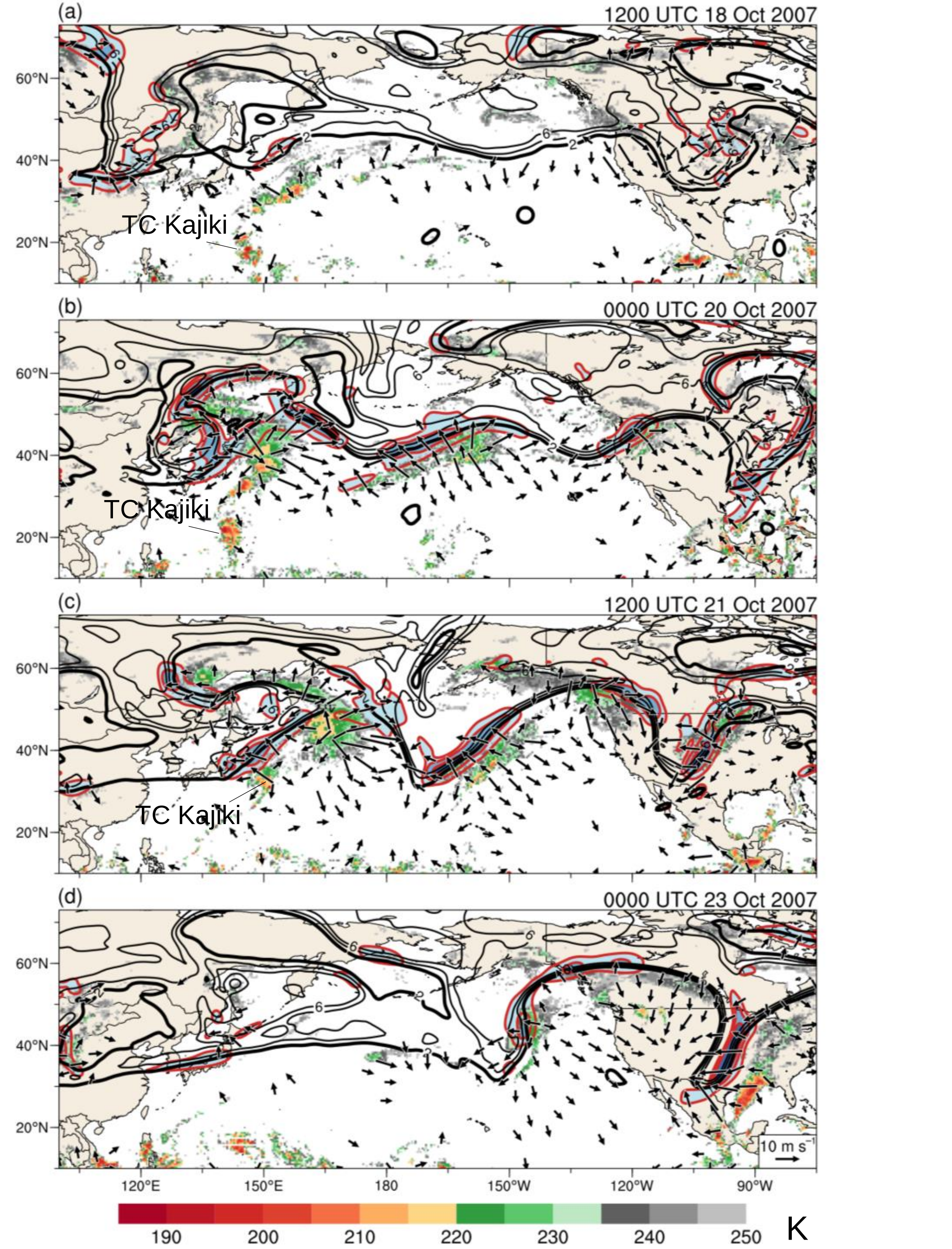
 = TC Kajiki

D = diabatic Rossby vortex

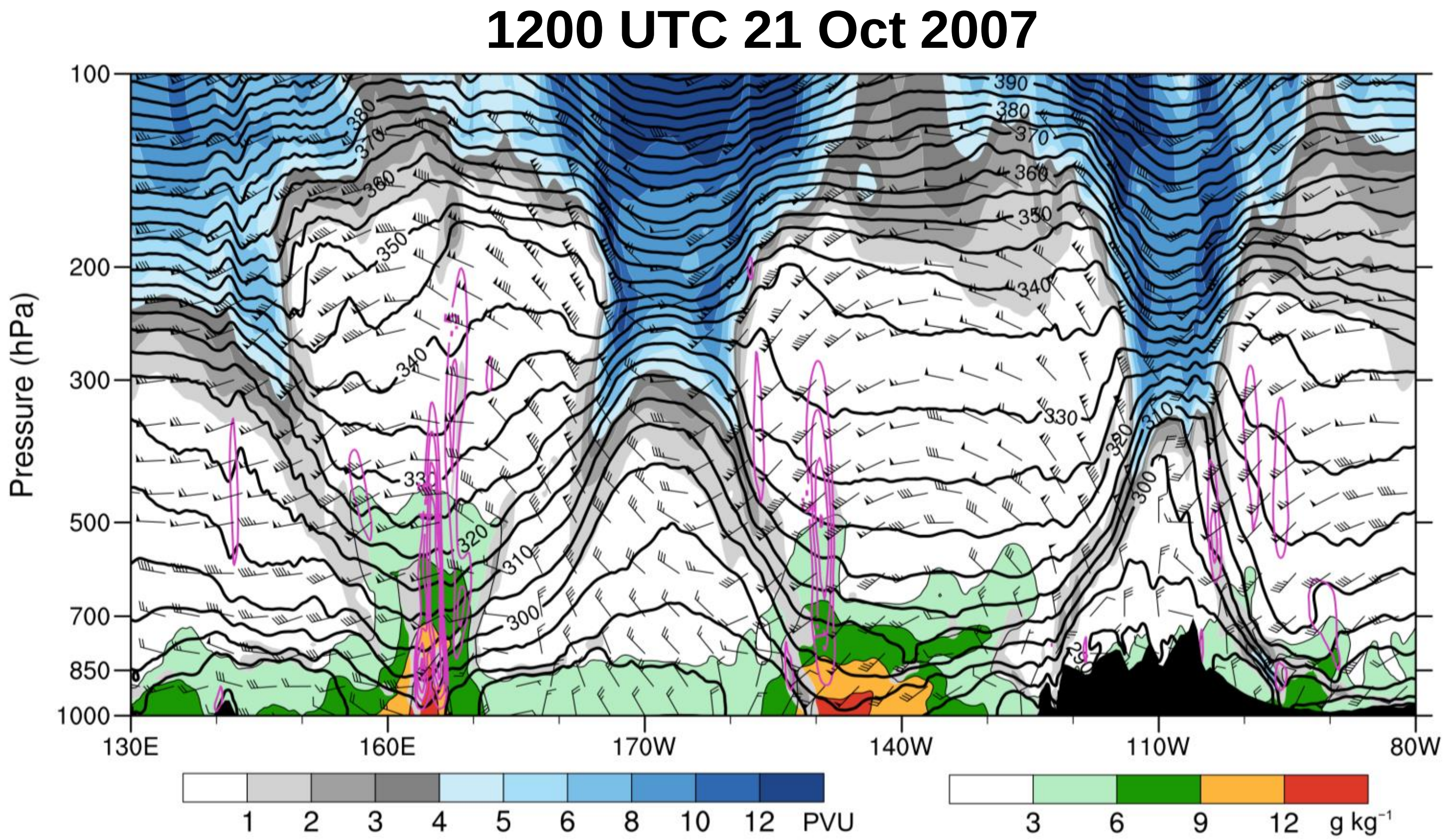
Large-scale flow evolution

18–23 Oct 2007

IR brightness temp (K, shading), 250-hPa PV (PVU, black), V_χ vectors (m s^{-1}), negative PV advection by V_χ [PVU (6 h)$^{-1}$, red with blue shading]



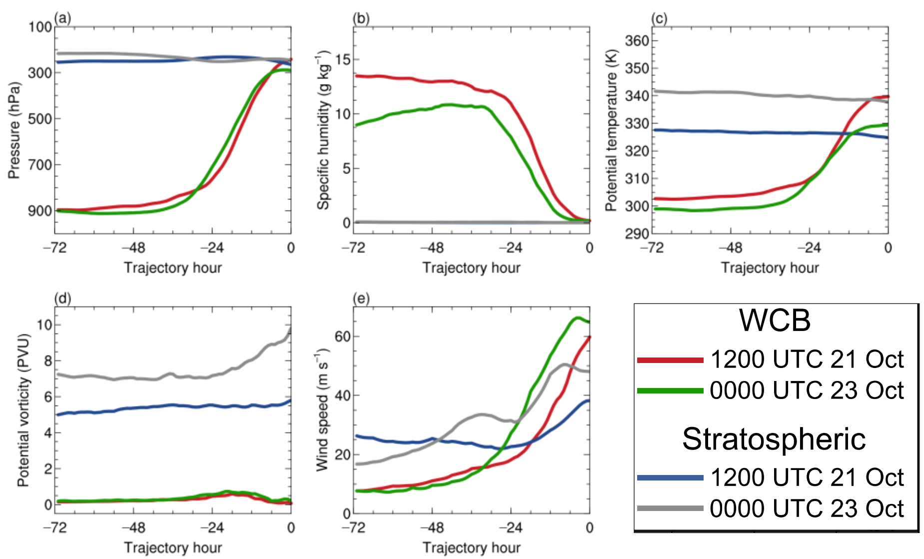
Cross section along 40°N through the wave train



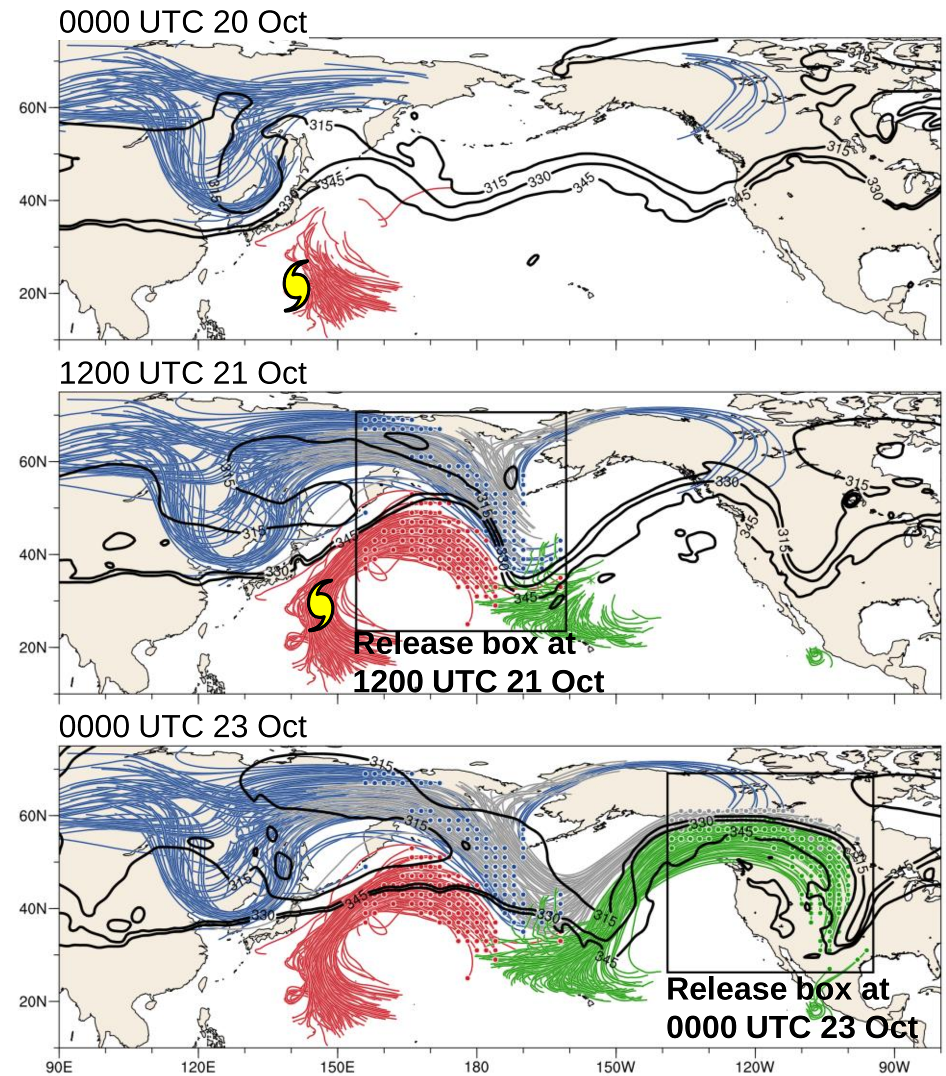
PV (PVU, gray/blue shading), specific humidity (g kg^{-1}, green/yellow/red shading), θ (K, black), upward vertical velocity (Pa s^{-1}, magenta), and wind barbs (m s^{-1})

Lagrangian perspective on flow amplification

Average time series for groups of trajectories



Evolution of groups of 72-h backward trajectories released from points in jet stream (>30 m s^{-1} wind speed in 350–175-hPa layer) with 300-, 315-, 330-K isentropes on DT overlaid

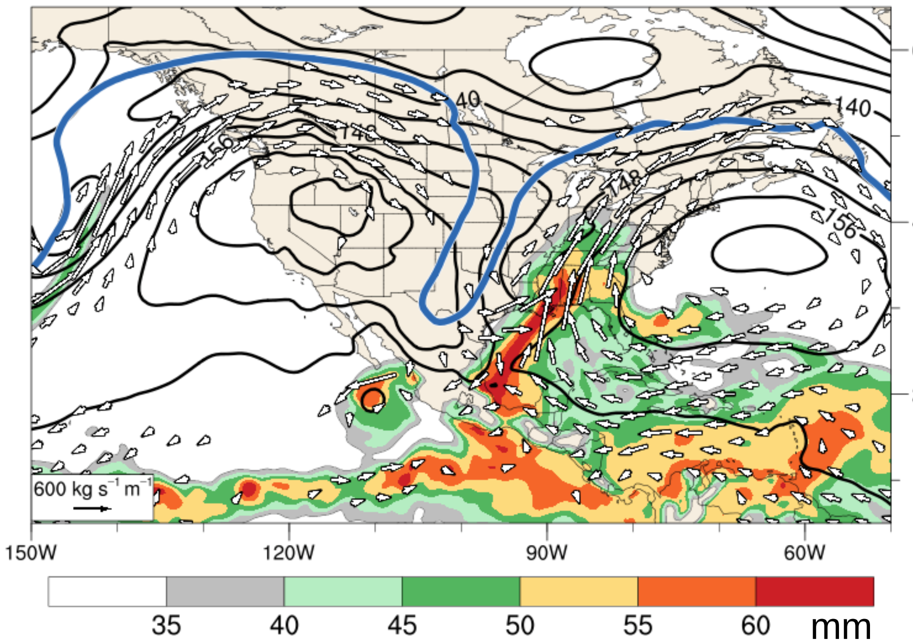


warm conveyor belt (WCB) trajectories:
>600 hPa ascent in 48 h

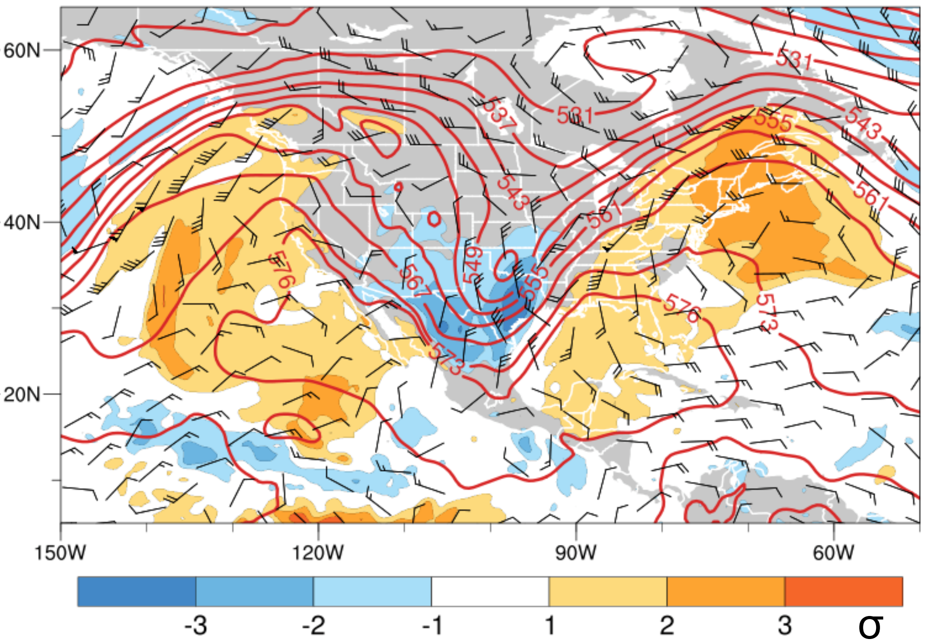
stratospheric trajectories:
PV >2 PVU and pass poleward of 60°N

Synoptic-scale conditions supporting wildfires, first cold surge, and eastern U.S. heavy rainfall

0000 UTC 23 Oct 2007



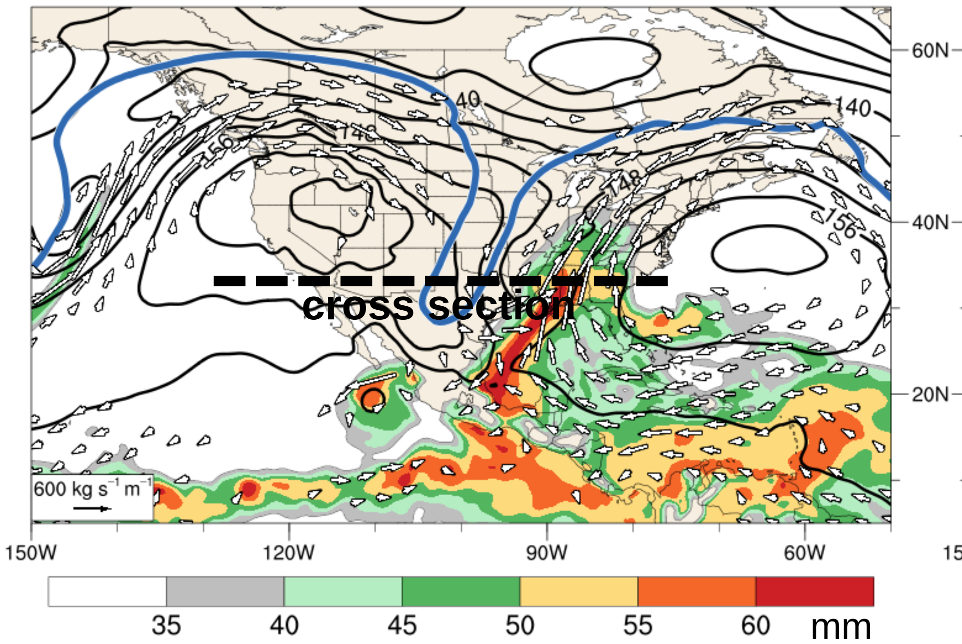
PW (mm, shading)
850-hPa Z (dam, black contours)
1000–200-hPa IVT vectors (kg m^{-1} s^{-1})
2-PVU contour on 330-K surface (blue)



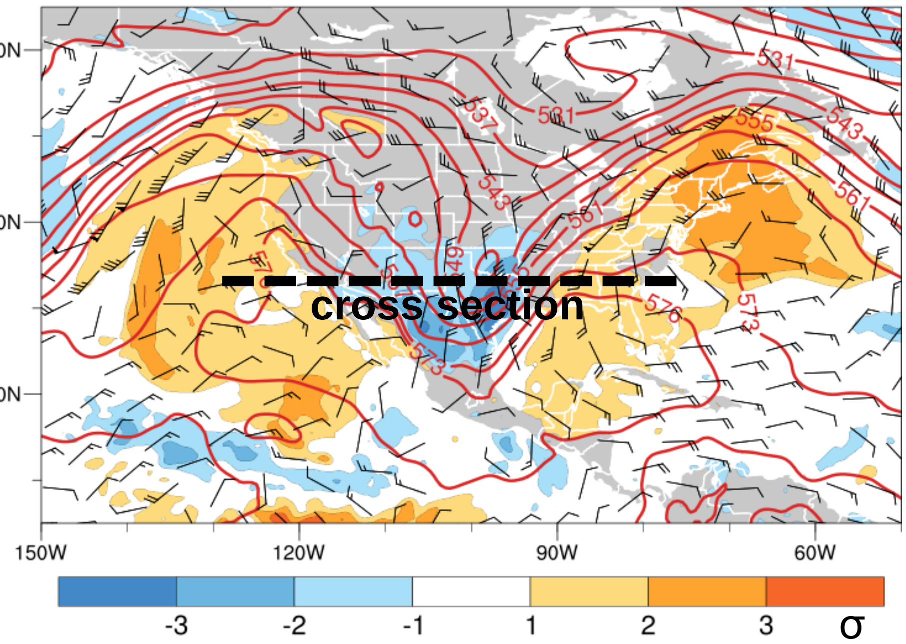
850-hPa T anomalies (σ, shading)
1000–500-hPa thickness (dam, red contours)
850-hPa wind (m s^{-1}, barbs)

Synoptic-scale conditions supporting wildfires, first cold surge, and eastern U.S. heavy rainfall

0000 UTC 23 Oct 2007



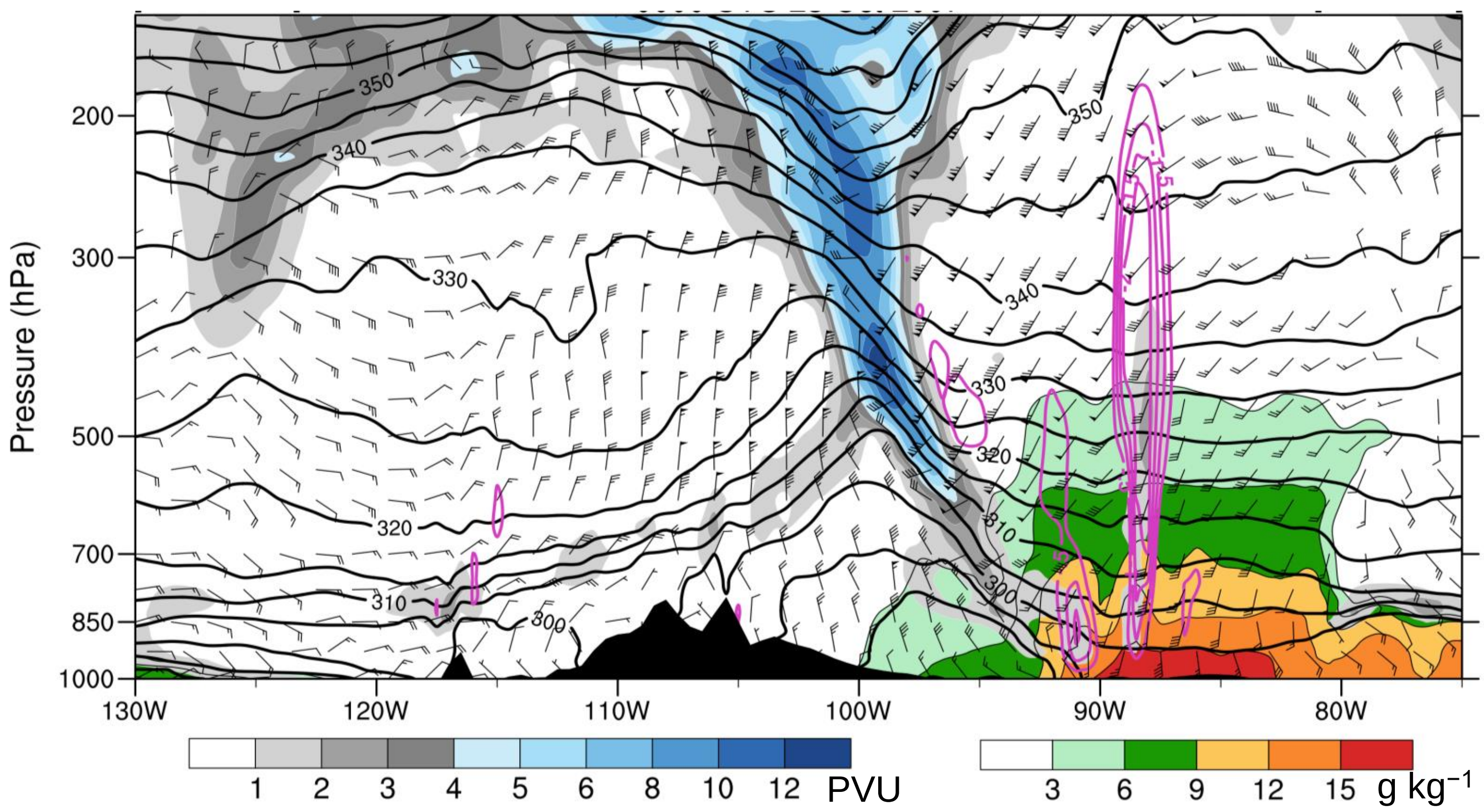
PW (mm, shading)
850-hPa Z (dam, black contours)
1000–200-hPa IVT vectors (kg m^{-1} s^{-1})
2-PVU contour on 330-K surface (blue)



850-hPa T anomalies (σ, shading)
1000–500-hPa thickness (dam, red contours)
850-hPa wind (m s^{-1}, barbs)

Synoptic-scale conditions supporting wildfires, first cold surge, and eastern U.S. heavy rainfall

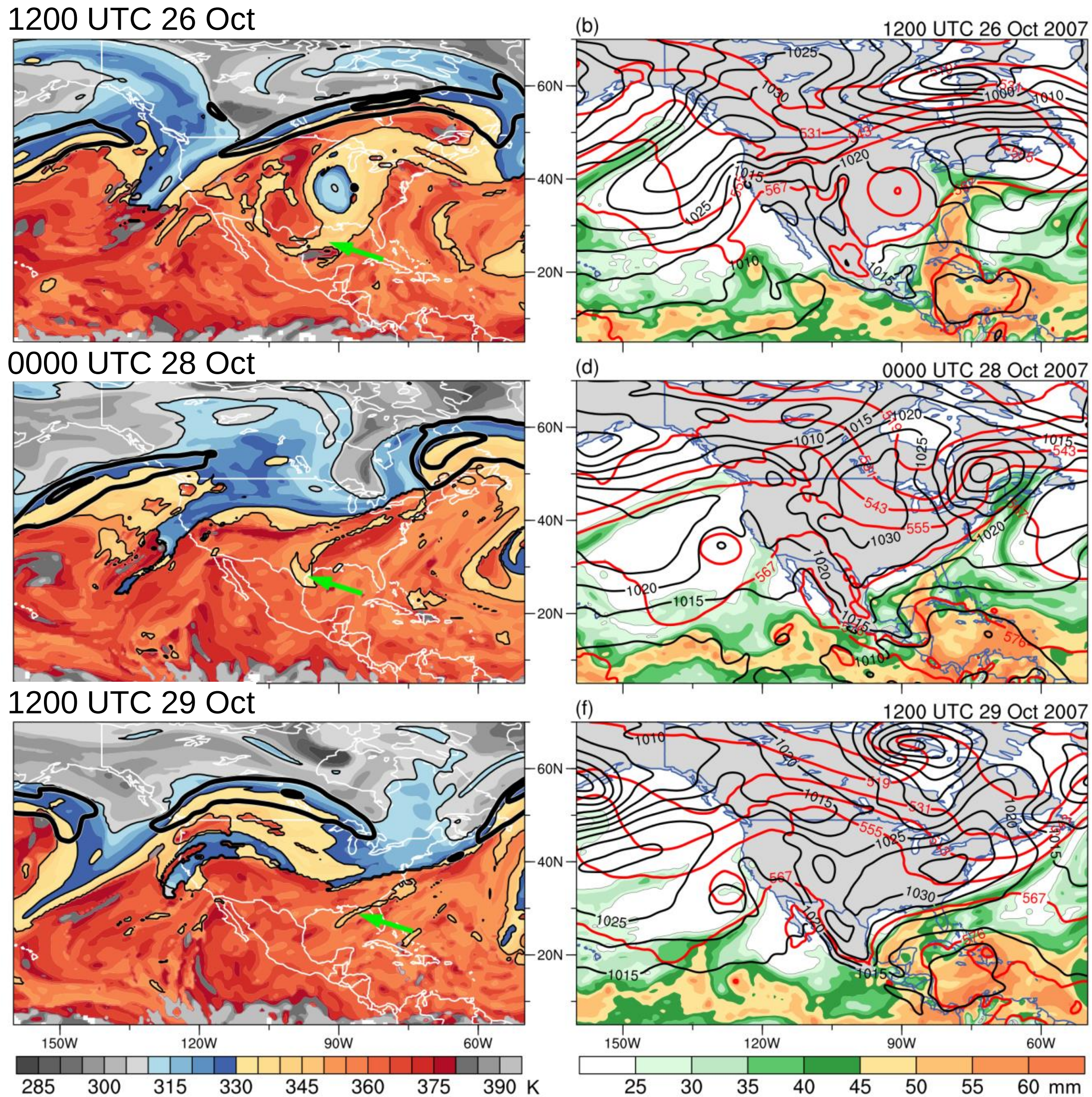
Cross section along 33°N from 130°W to 75°W at 0000 UTC 23 Oct 2007



PV (PVU, gray/blue shading), specific humidity (g kg^{-1}, green/yellow/red shading), θ (K, black), upward vertical velocity (Pa s^{-1}, magenta), and wind barbs (m s^{-1})

Flow evolution culminating in Mexican heavy rainfall

26–29 Oct 2007

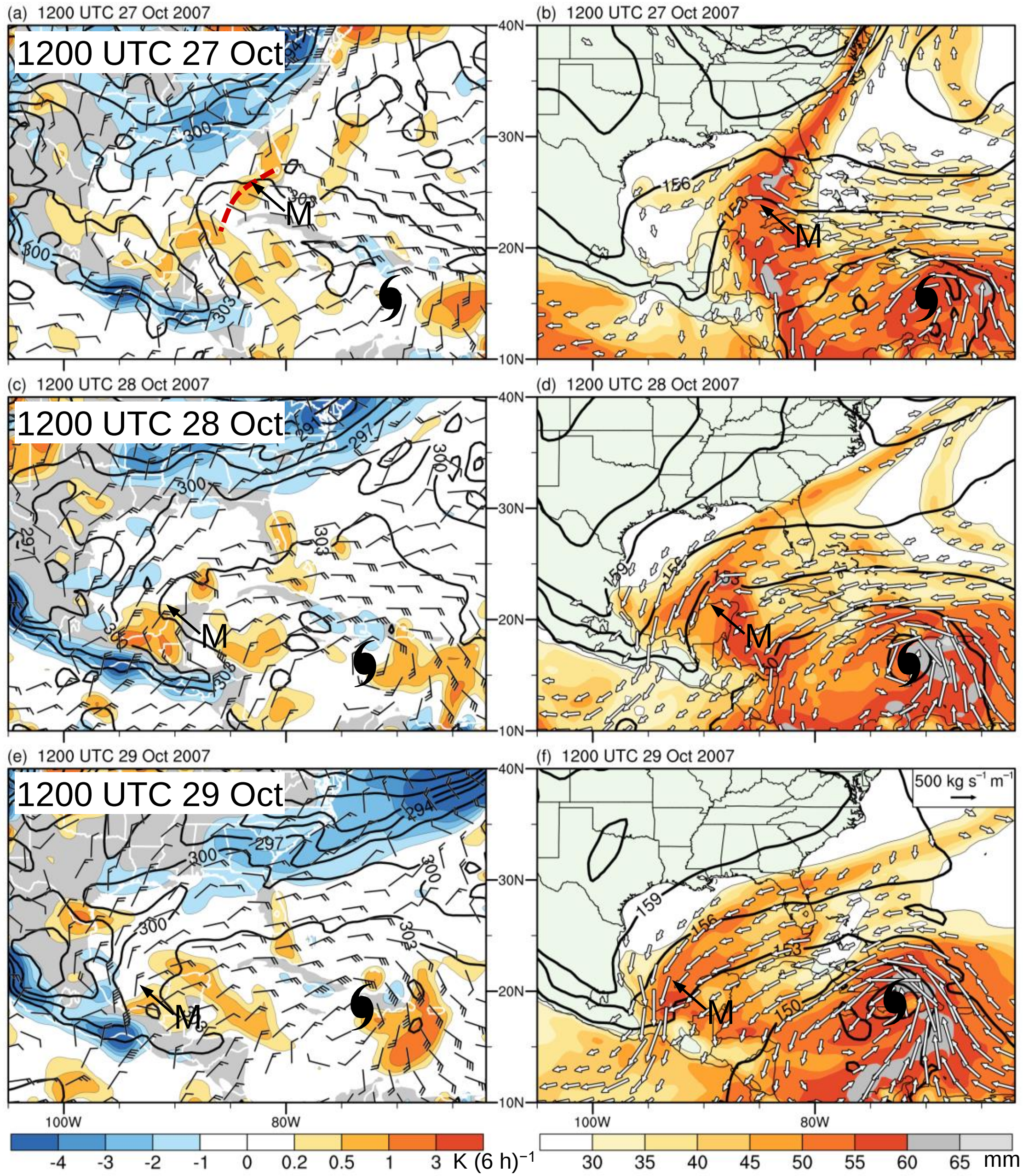


left: *DT θ (K, shading), wind speed (every 20 m s^{-1} starting at 50 m s^{-1}, black)*

right: *PW (mm, shading), SLP (hPa, black),1000–500-hPa thickness (dam, red)*

Processes linked to Mexican heavy rainfall

27–29 Oct 2007



***left:** 1000–800-hPa layer-averaged θ advection [K (6 h)$^{-1}$, shading], 850-hPa θ (K, black), wind barbs (m s^{-1})*

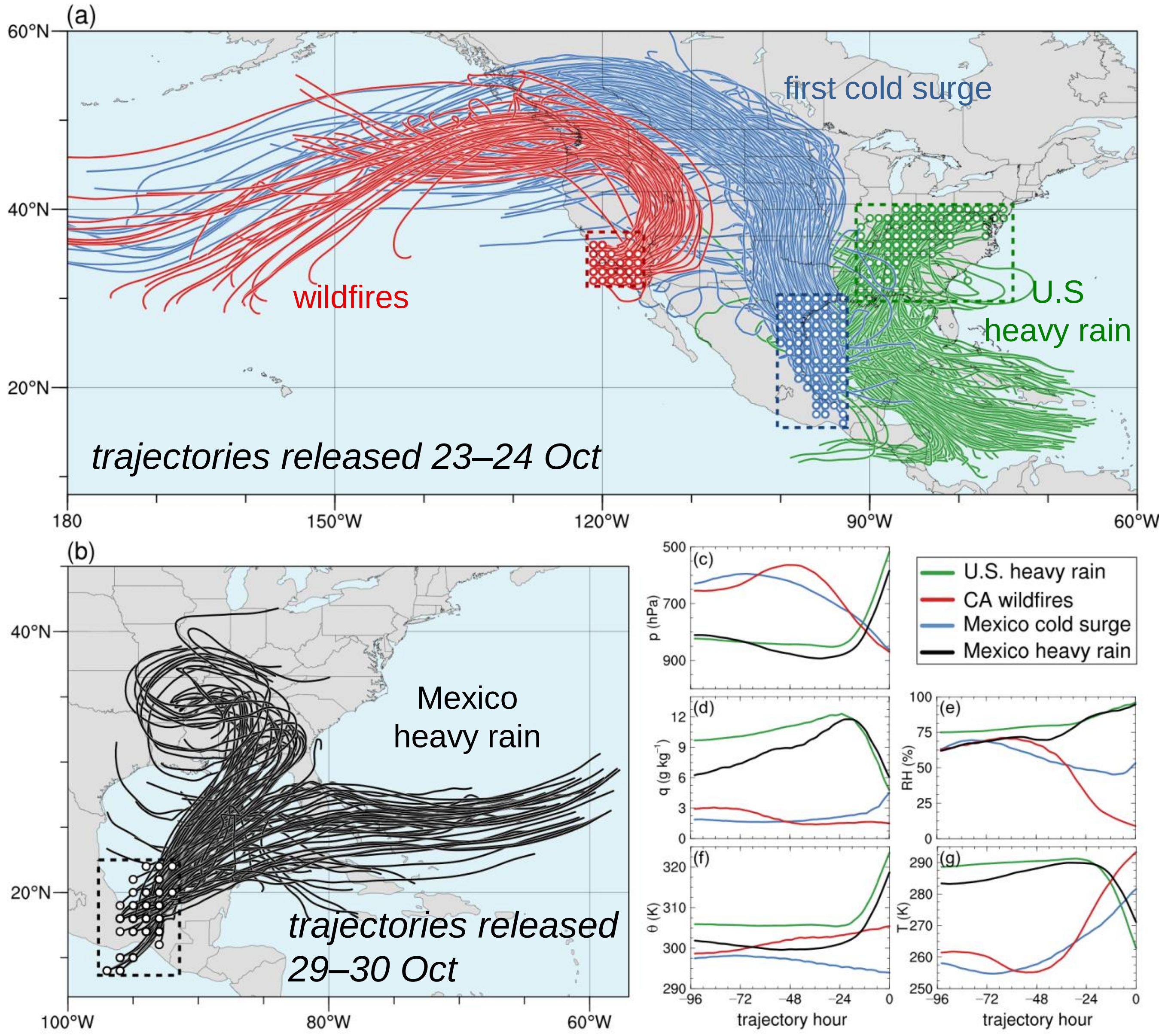
***right:** PW (mm, shading), 1000–200-hPa IVT vectors (kg m^{-1} s^{-1}), 860-hPa geopotential height (dam, black)*

= TC Noel

M = mesoscale disturbance

Lagrangian perspective on four EWEs

Coherent groups of backward 96-h trajectories corresponding to air streams linked to the four EWEs



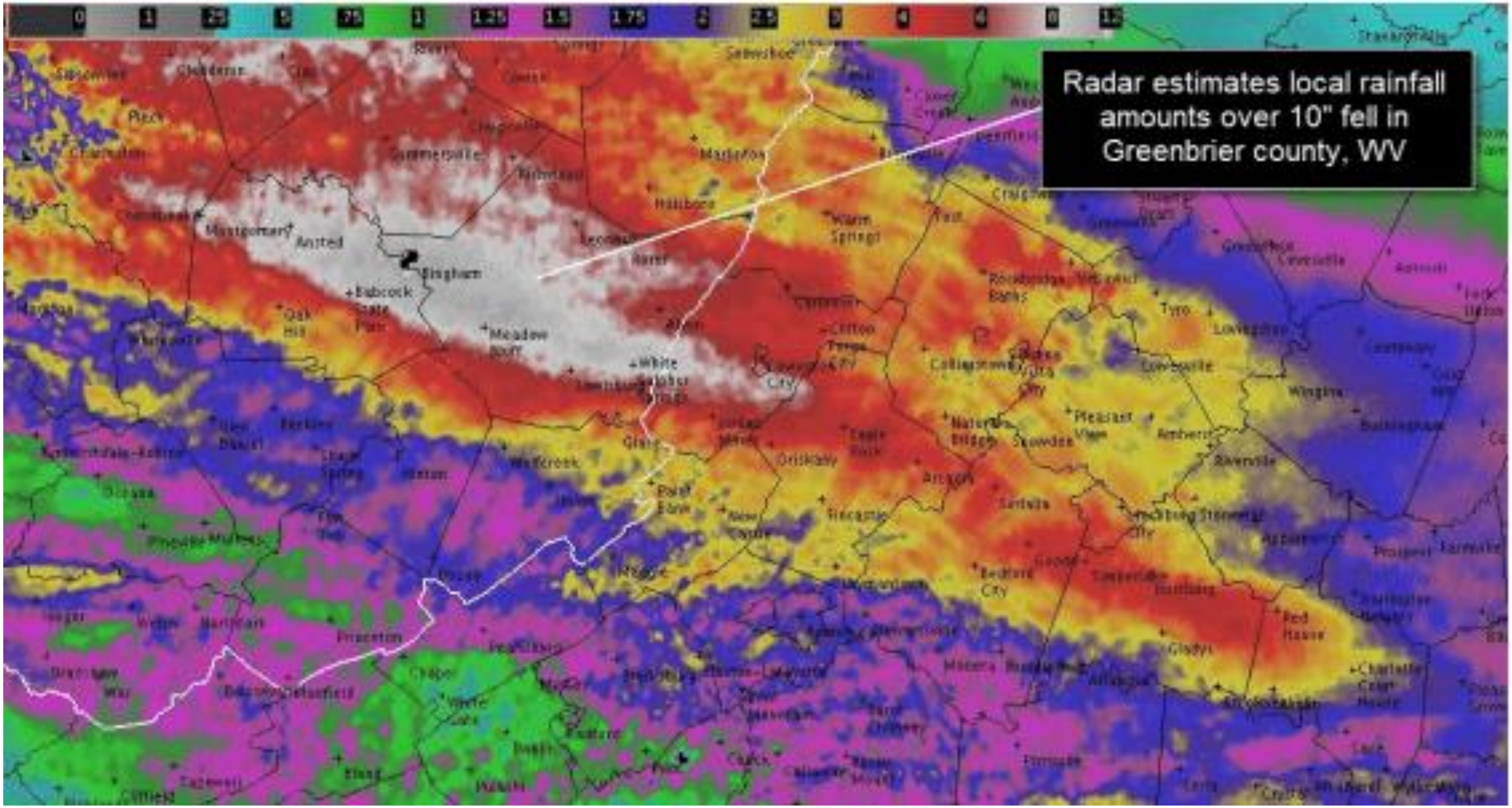
Conclusions

- **North Pacific jet stream was perturbed by tropical, midlatitude, and polar disturbances prior to EWE formation**
- **Jet perturbations culminated in the formation of a Rossby wave train (RWT) across the North Pacific and North America**
- **RWT-related ridge amplification was enhanced by latent heating in WCBs emanating from atmospheric rivers (ARs)**
- **Heating along WCBs further amplified downstream ridges and contributed to anticyclonic wave breaking (AWB)**
- **AWB facilitated the downstream occurrence of multiple geographically separate, but dynamically linked EWEs**

A Postscript: West Virginia Flooding Event of 23–24 June 2016

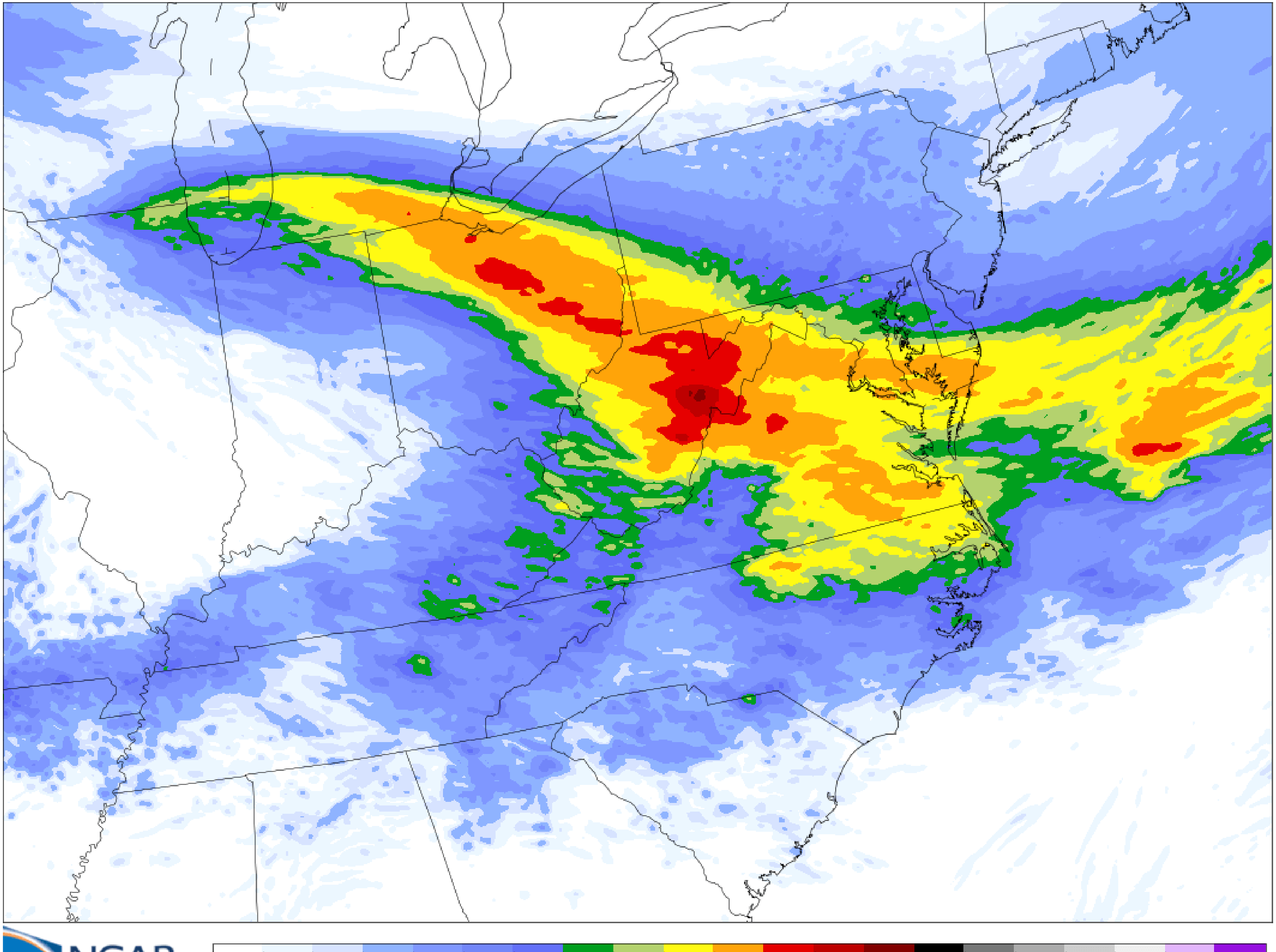
- Rains > 250 mm produced flooding that killed 23 people
- Training echoes occurred along a WNW-ESE frontal zone
- Tropical moisture converged along this frontal zone
- W. Atlantic and Gulf of Mexico were moisture sources
- Remnant atmospheric river reactivated by upstream front

WV Doppler-Estimated Rainfall (inches) 23–24 June 2016

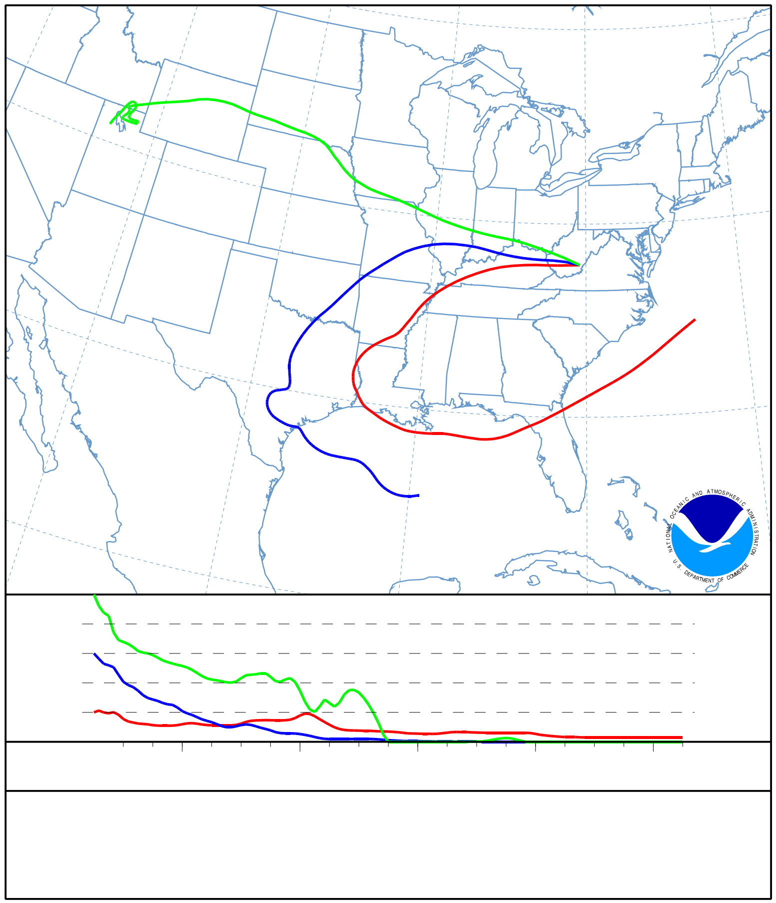


Ensemble mean 48-hr accumulated precipitation (in)

Init: Thu 2016-06-23 00 UTC
Valid: Sat 2016-06-25 00 UTC

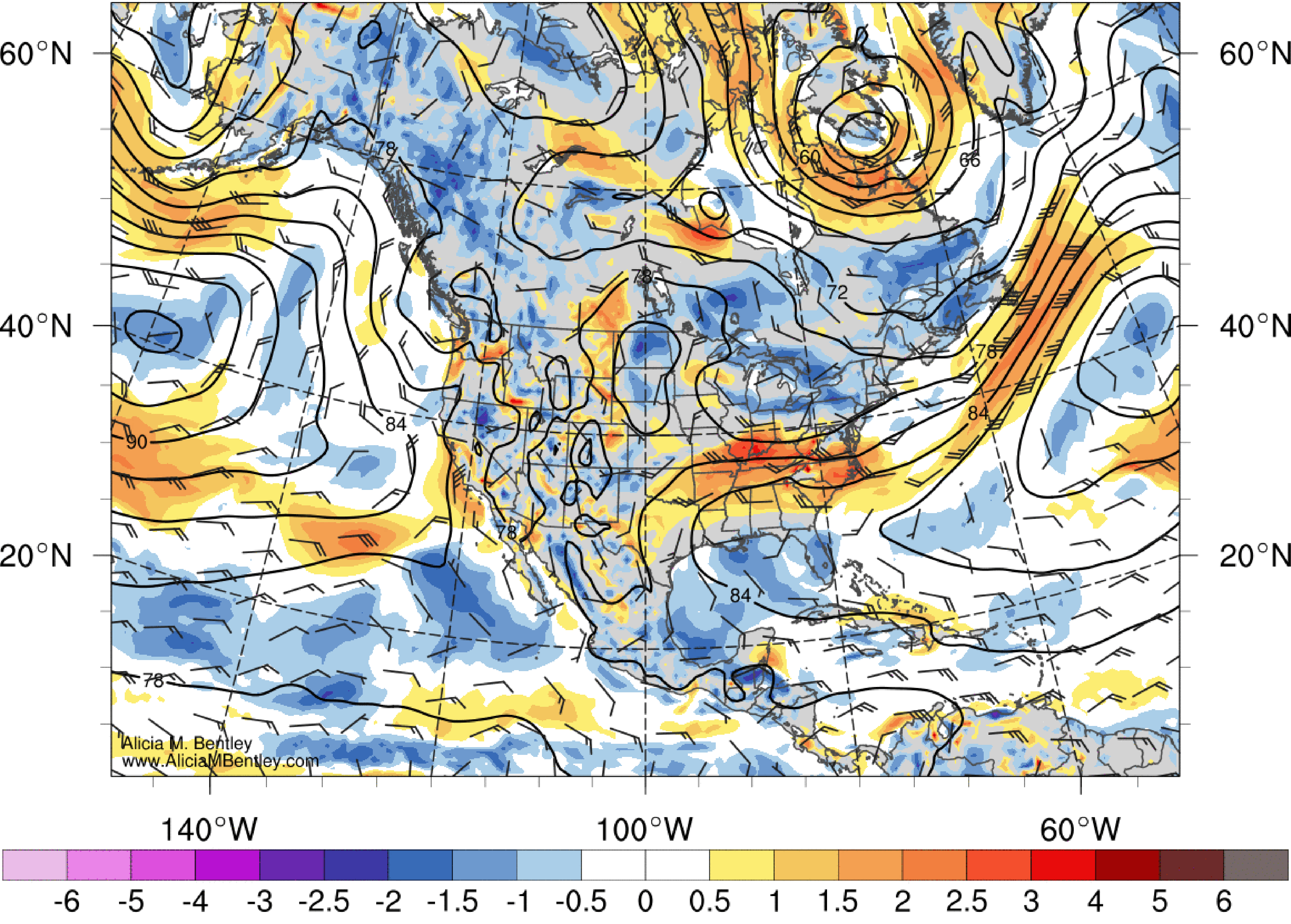


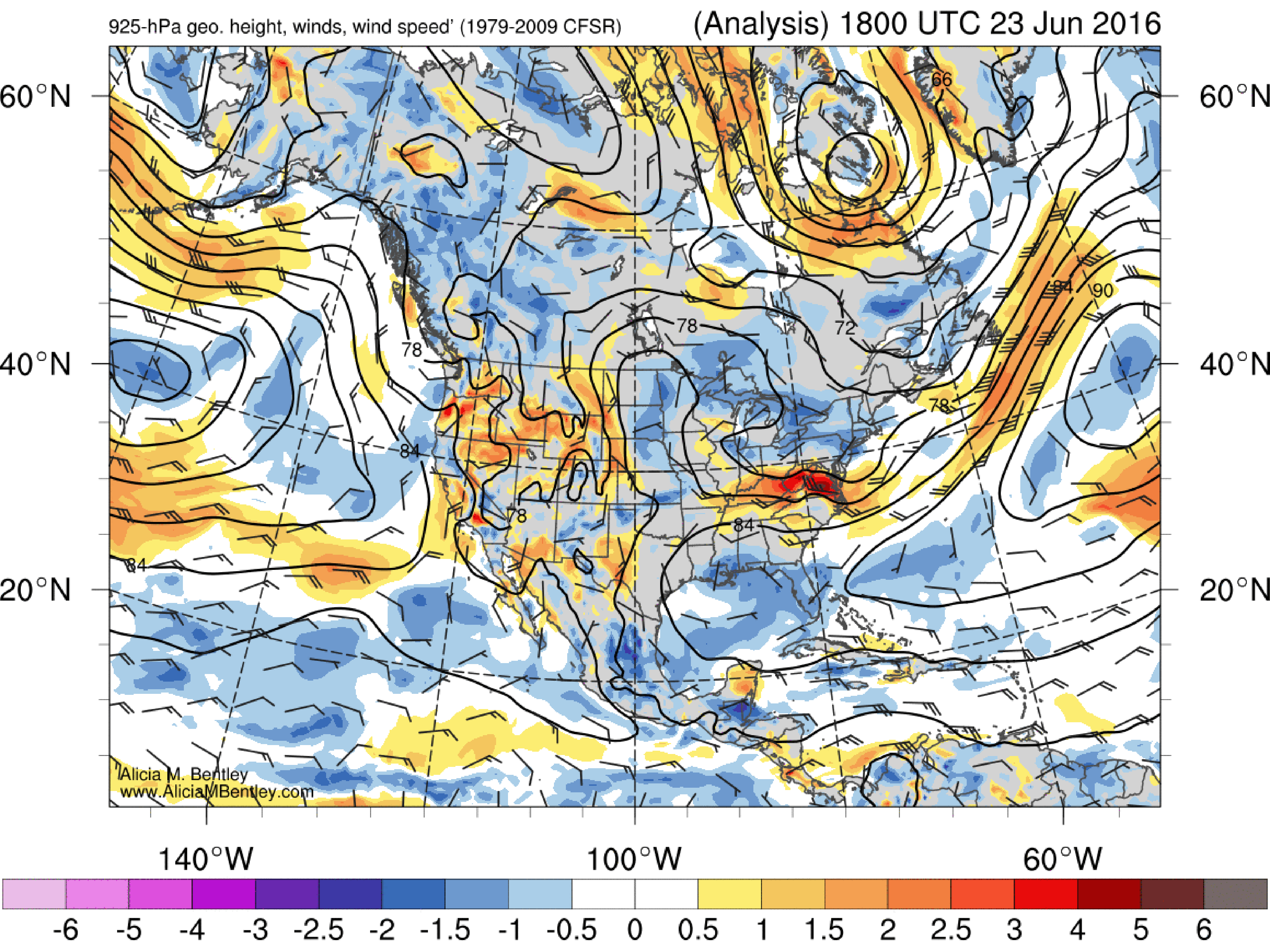
NCAR
ensemble.ucar.edu



925-hPa geo. height, winds, wind speed' (1979-2009 CFSR)

(Analysis) 1200 UTC 23 Jun 2016





925-hPa geo. height, winds, wind speed' (1979-2009 CFSR)
(Analysis) 1800 UTC 23 Jun 2016
60°N
40°N
20°N
140°W
100°W
60°W
66
72
78
84
90
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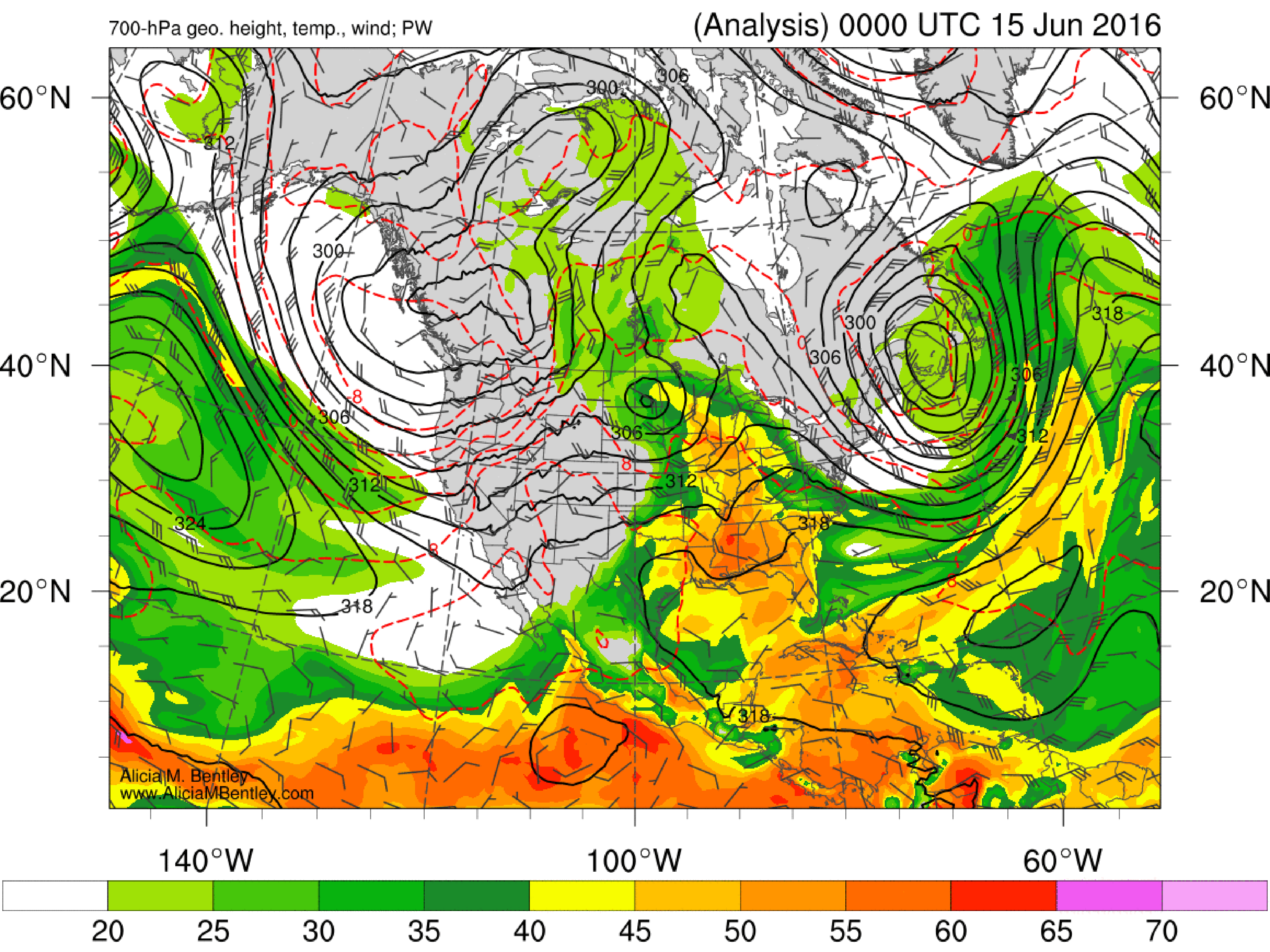
700-hPa geo. height, temp., wind; PW
(Analysis) 0000 UTC 15 Jun 2016
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140°W
100°W
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318
324
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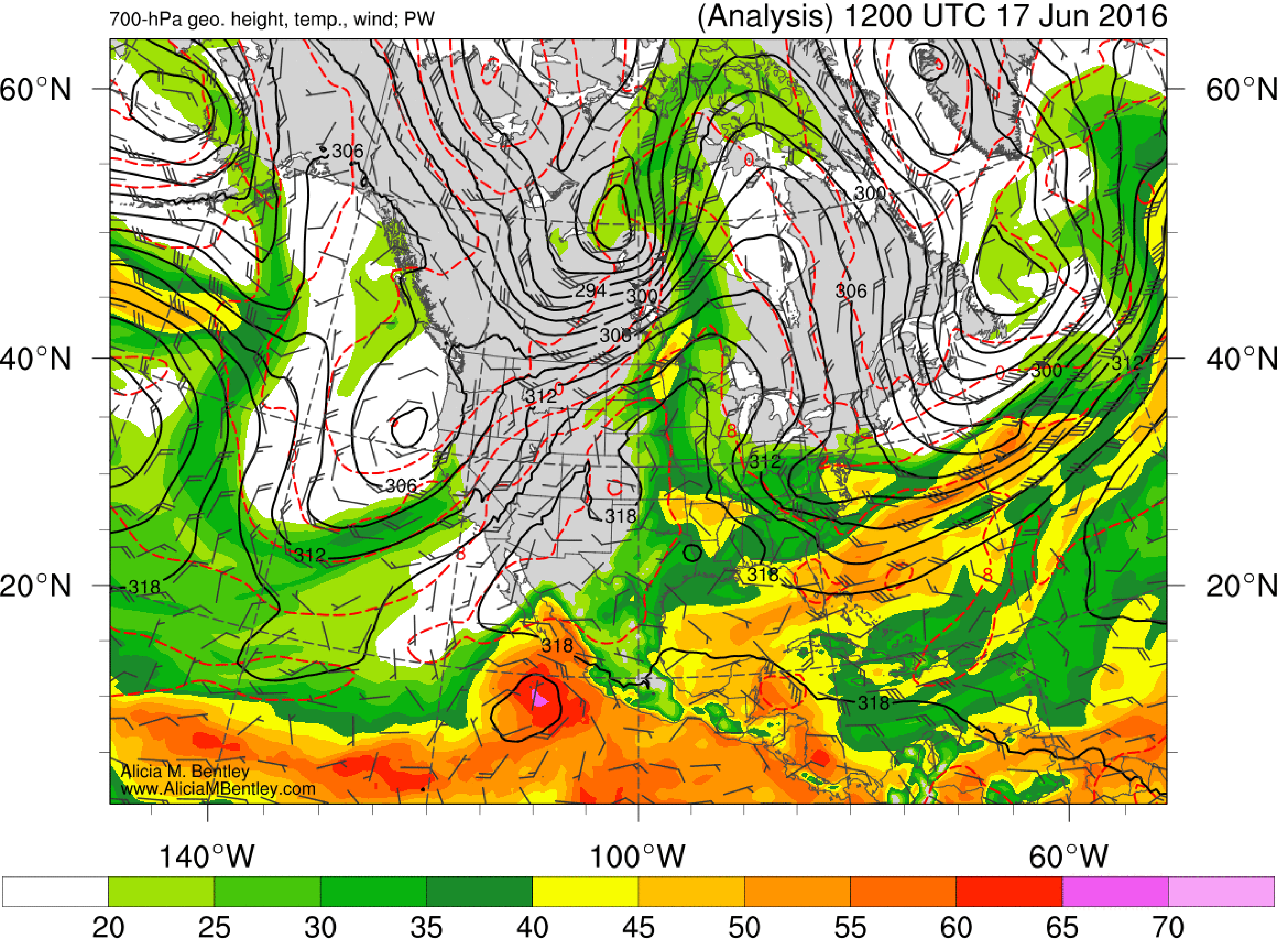
700-hPa geo. height, temp., wind; PW
(Analysis) 1200 UTC 17 Jun 2016
60°N
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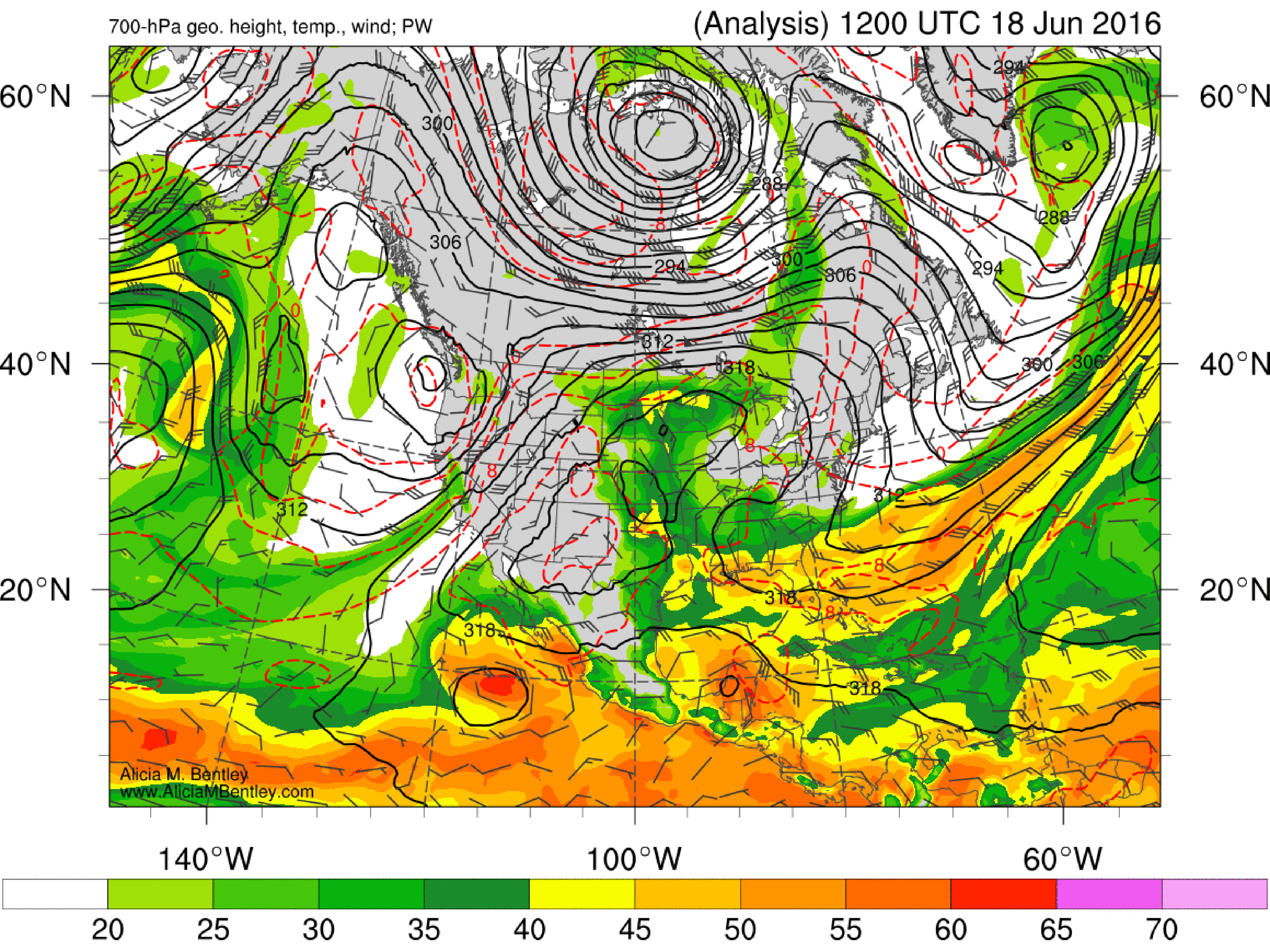
700-hPa geo. height, temp., wind; PW
(Analysis) 1200 UTC 18 Jun 2016
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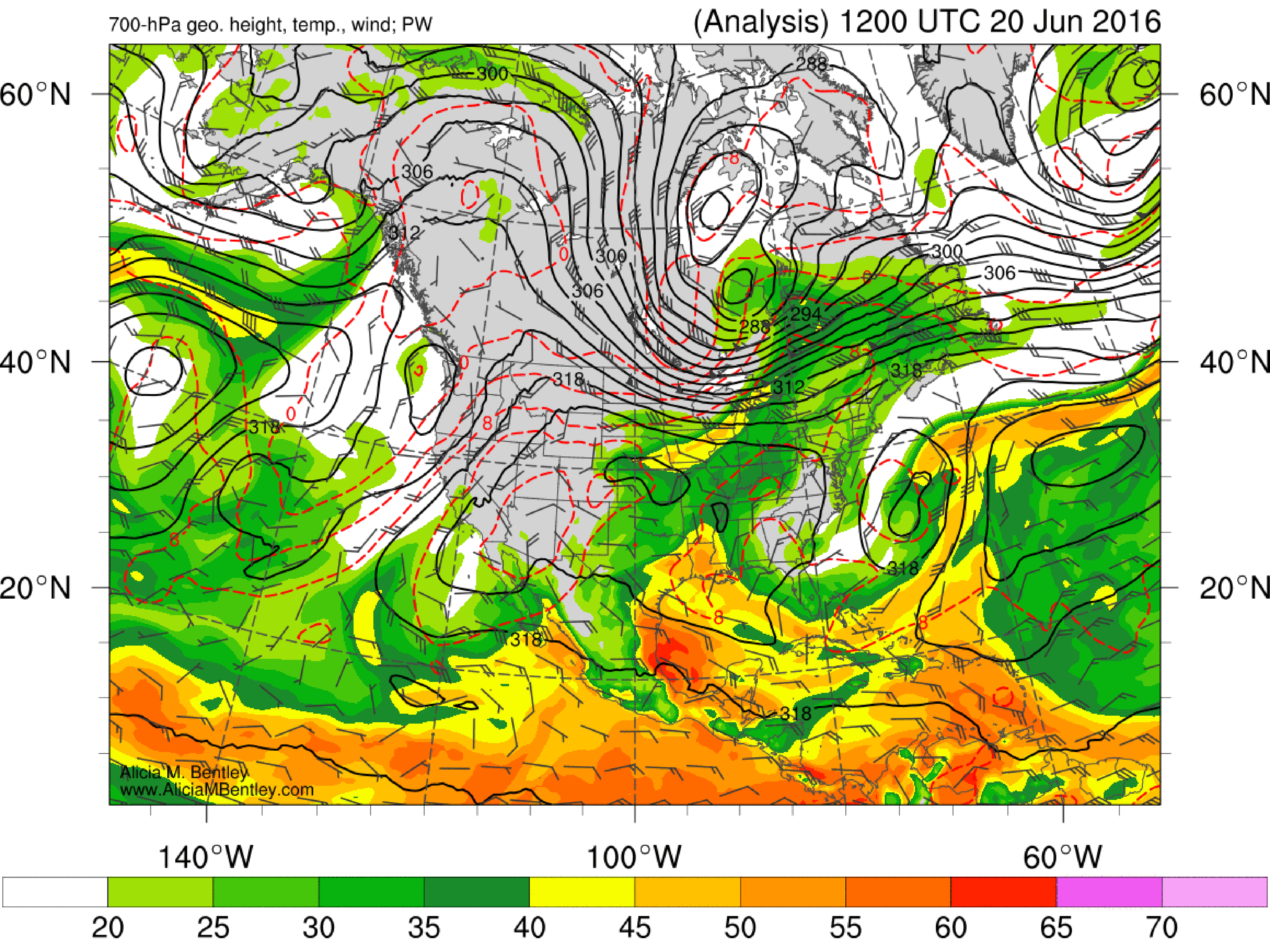

700-hPa geo. height, temp., wind; PW
(Analysis) 1200 UTC 20 Jun 2016
60°N
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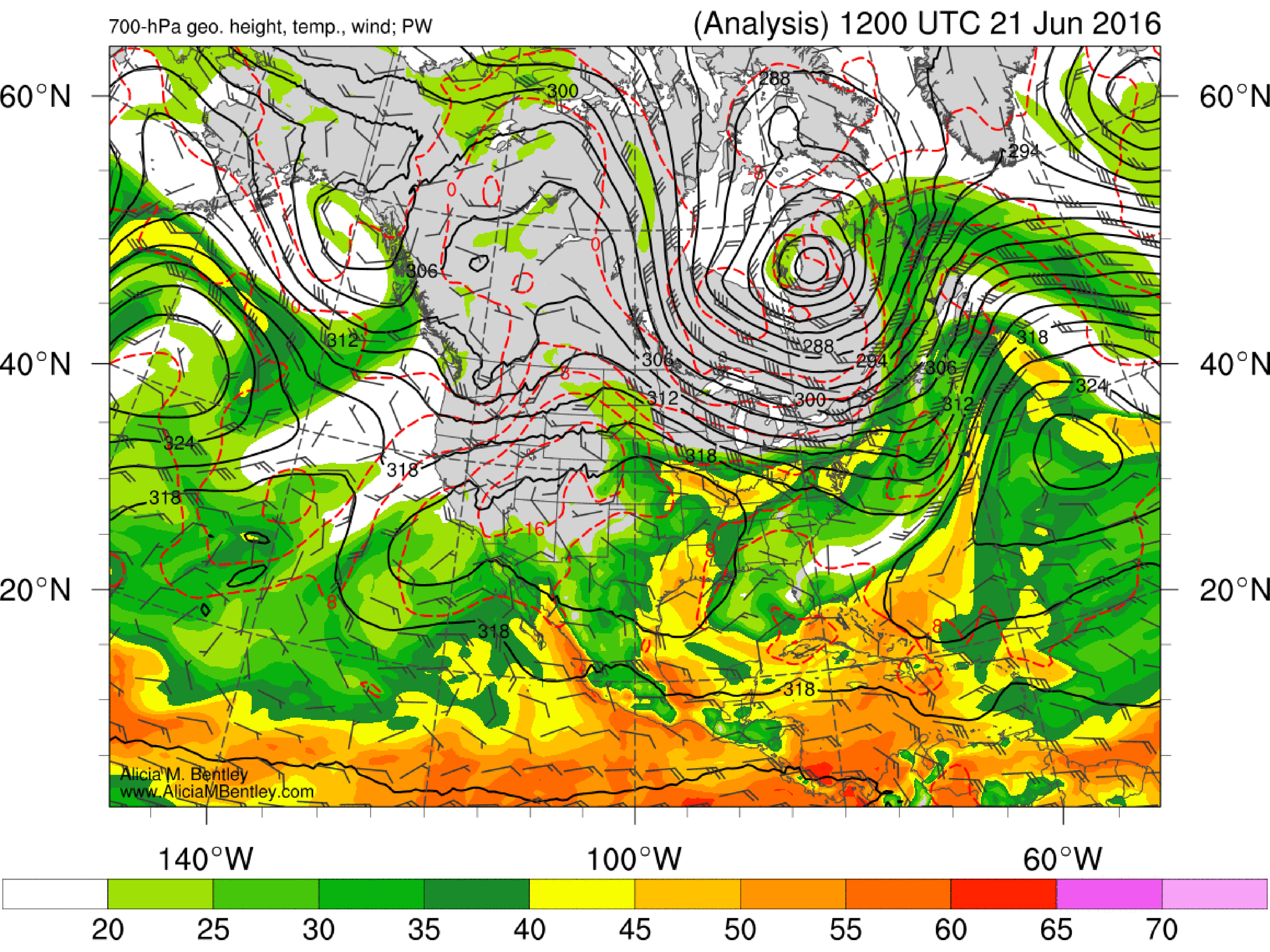
700-hPa geo. height, temp., wind; PW
(Analysis) 1200 UTC 21 Jun 2016
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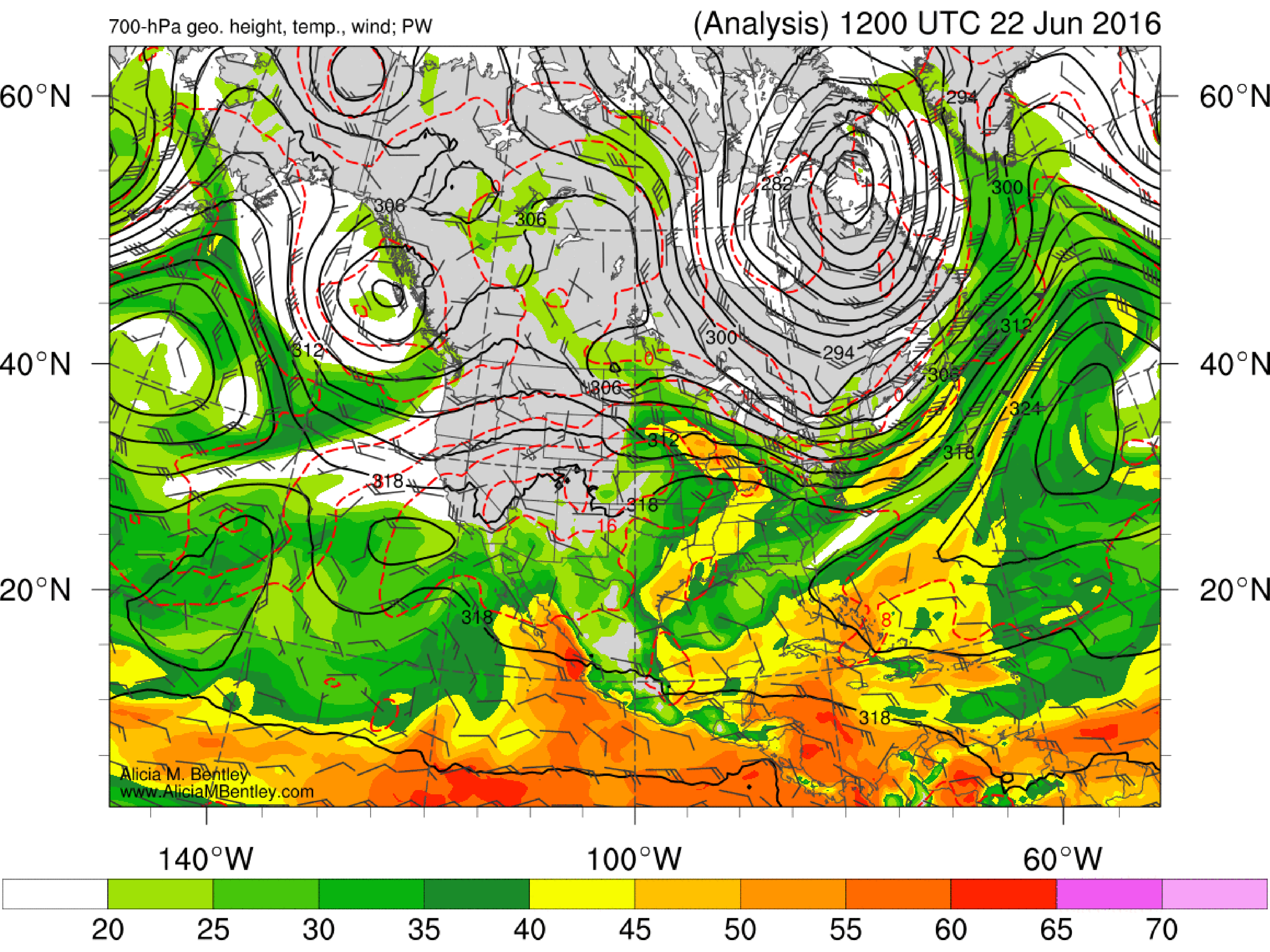
700-hPa geo. height, temp., wind; PW
(Analysis) 1200 UTC 22 Jun 2016
60°N
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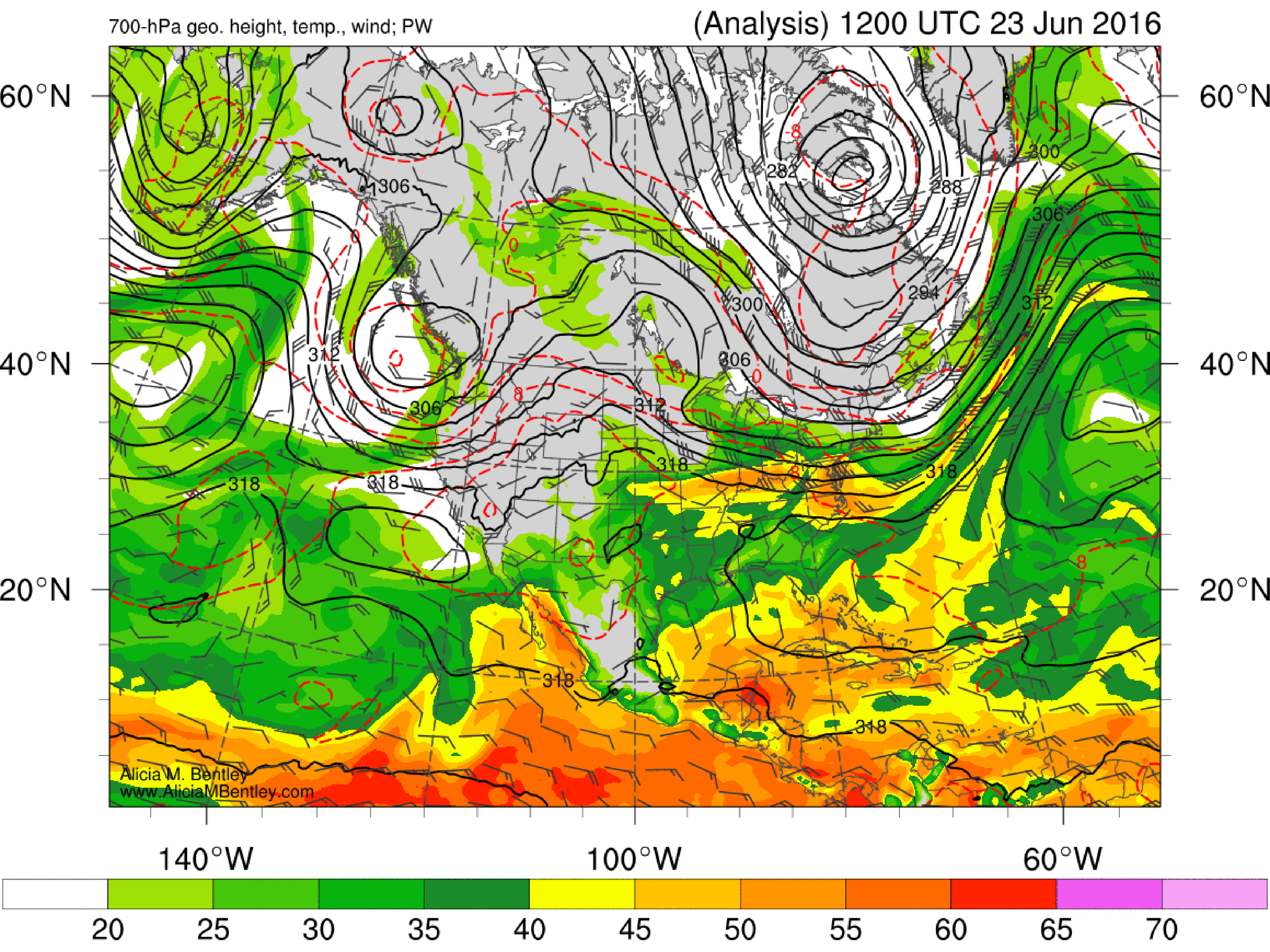
700-hPa geo. height, temp., wind; PW
(Analysis) 1200 UTC 23 Jun 2016
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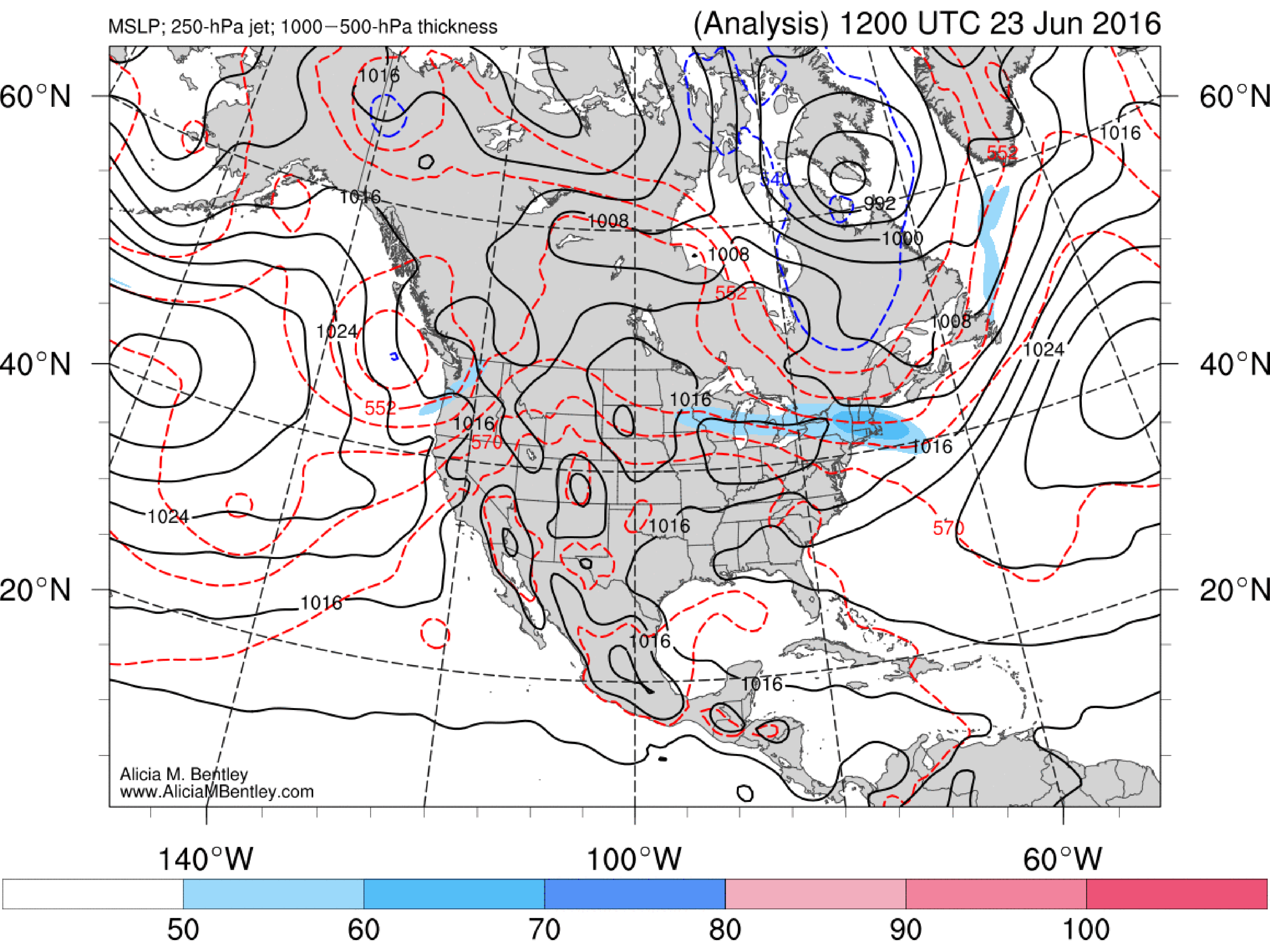
Conclusions: WV Flooding Event

- NCAR convection-allowing mresoscale ensemble captured essence of the rainstorm
- Rainstorm was supported by amalgamation of remnant AR and frontal moisture bands
- Band amalgamation along a surface boundary was driven by synoptic and mesoscale processes
- Anomalously strong low-level westerly confluent flow concentrated moisture along surface boundary
- Ascent along boundary was driven by warm-air advection in an equatorward jet-entrance region

Extra Slides


MSLP; 250-hPa jet; 1000−500-hPa thickness
(Analysis) 1200 UTC 23 Jun 2016
60°N
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140°W
100°W
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Alicia M. Bentley
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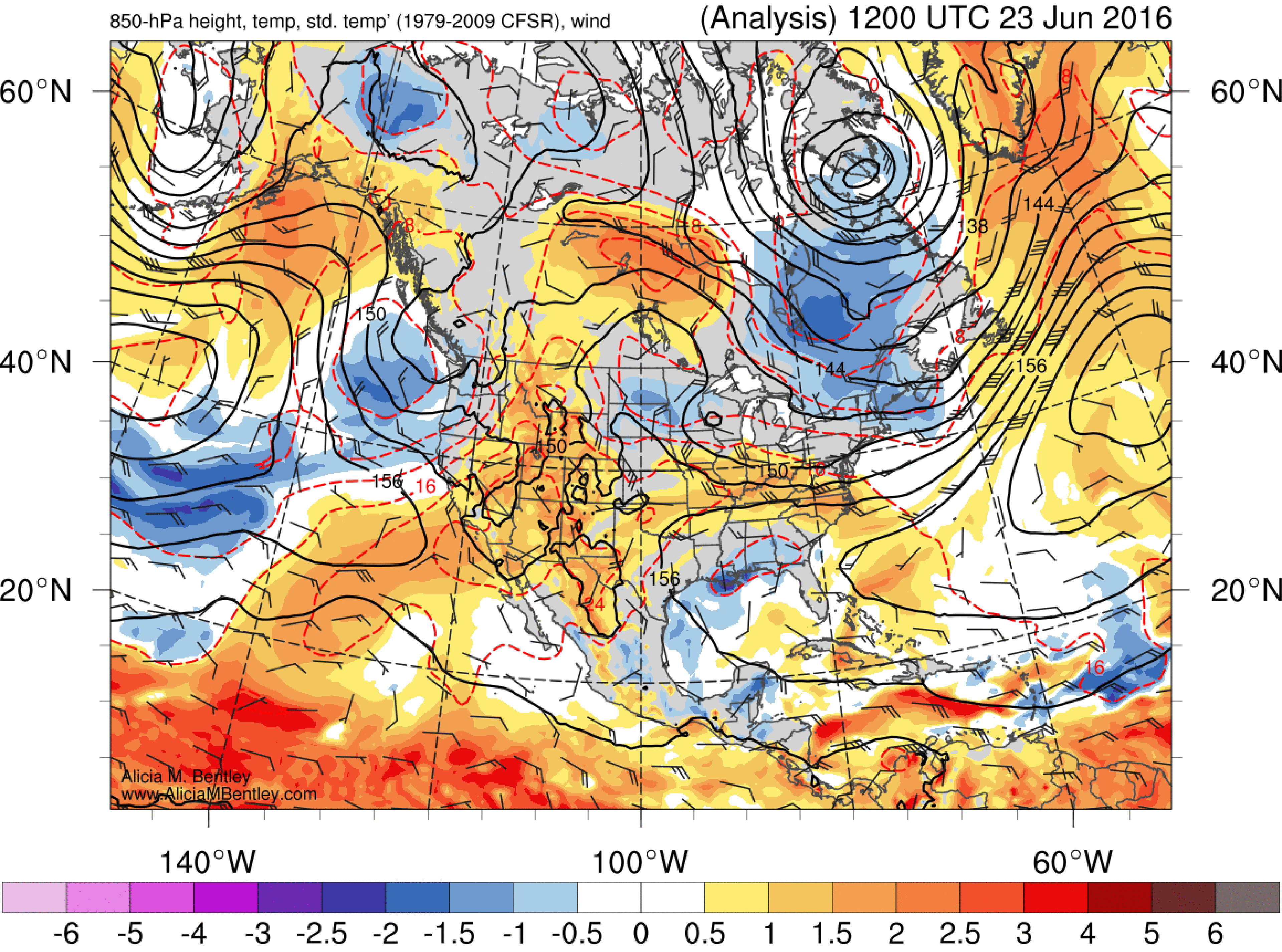
850-hPa height, temp, std. temp' (1979-2009 CFSR), wind
(Analysis) 1200 UTC 23 Jun 2016
60°N
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140°W
100°W
60°W
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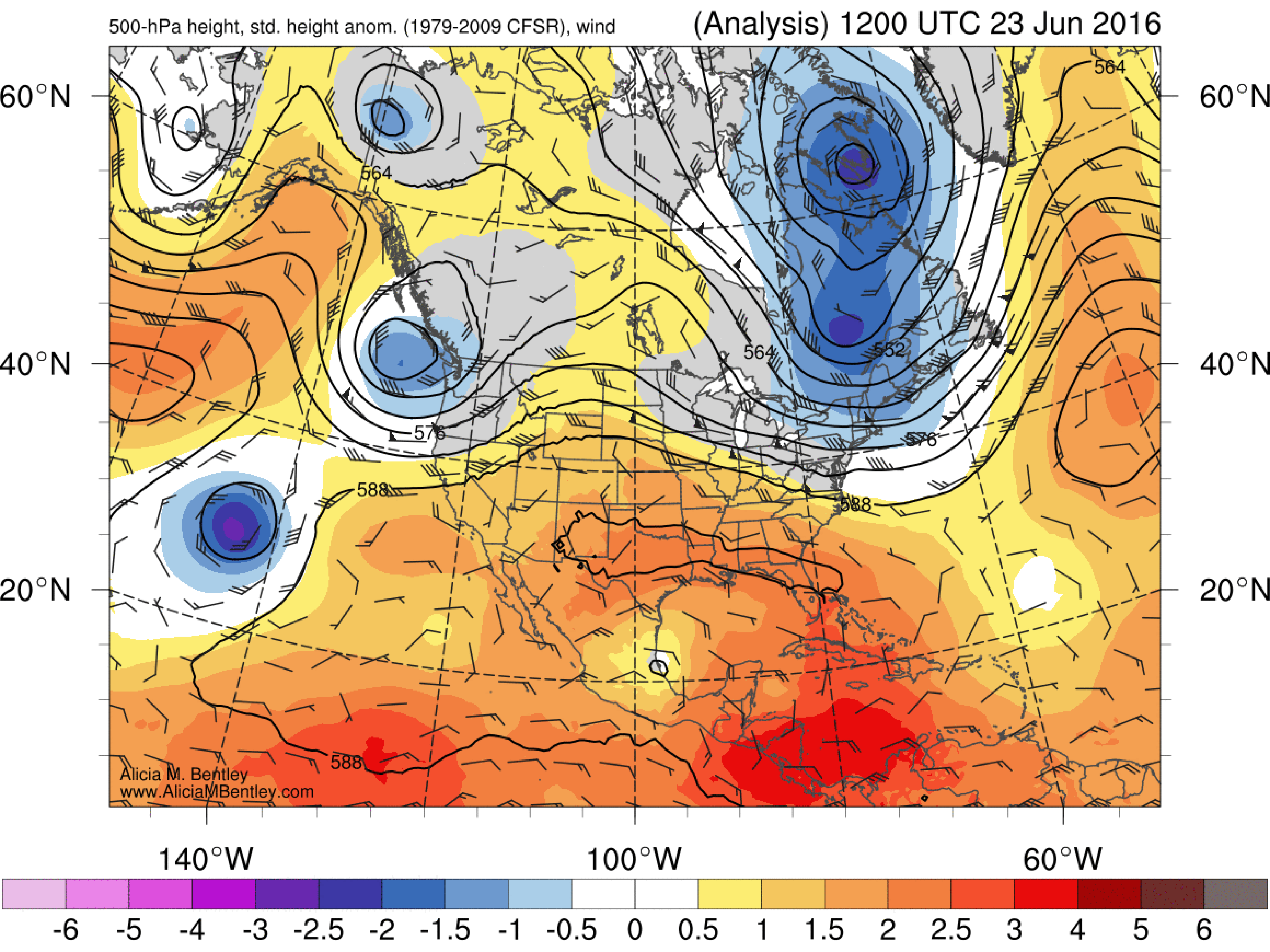
500-hPa height, std. height anom. (1979-2009 CFSR), wind
(Analysis) 1200 UTC 23 Jun 2016
60°N
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140°W
100°W
60°W
564
576
588
552
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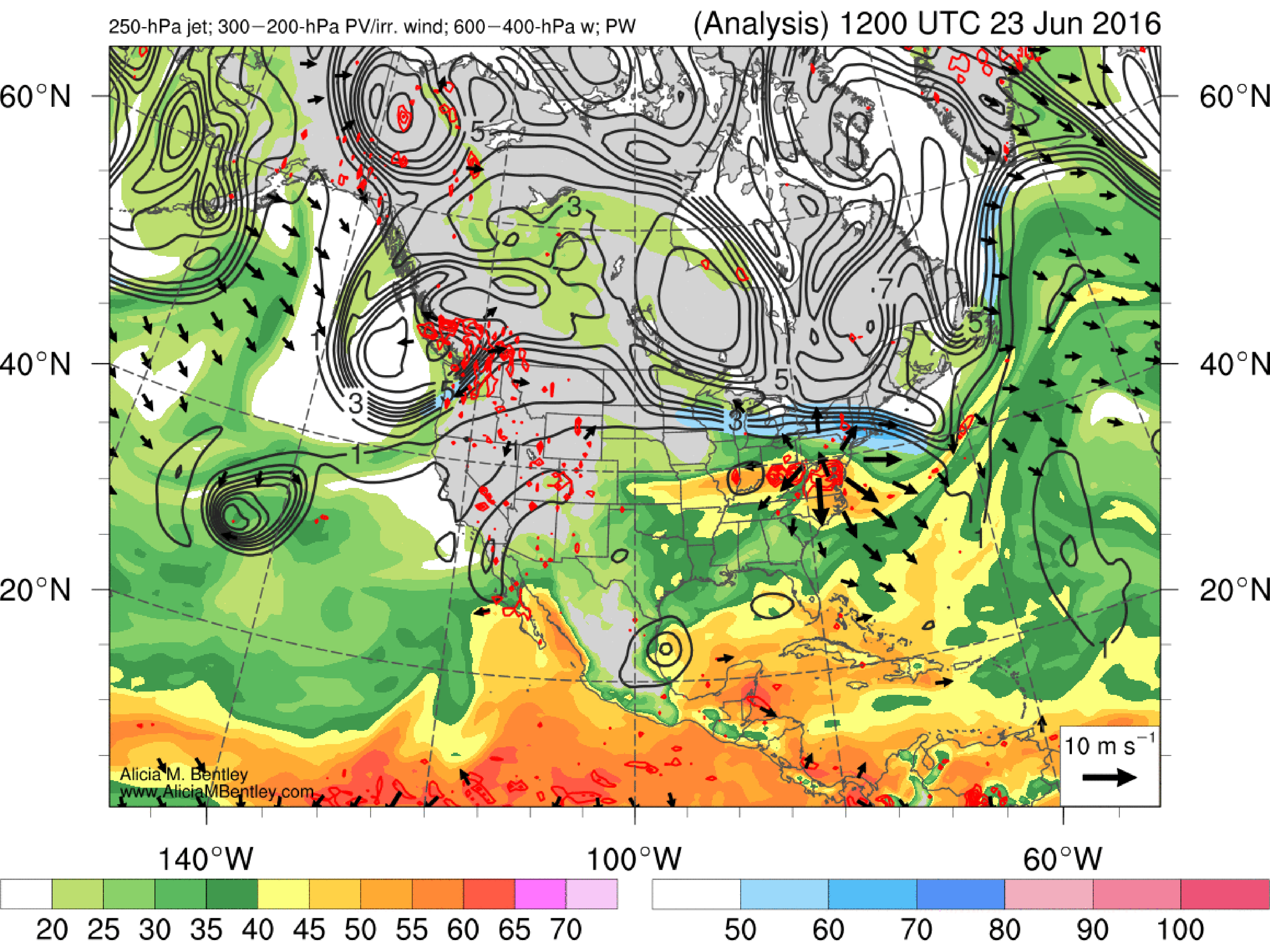

250-hPa jet; 300−200-hPa PV/irr. wind; 600−400-hPa w; PW
(Analysis) 1200 UTC 23 Jun 2016
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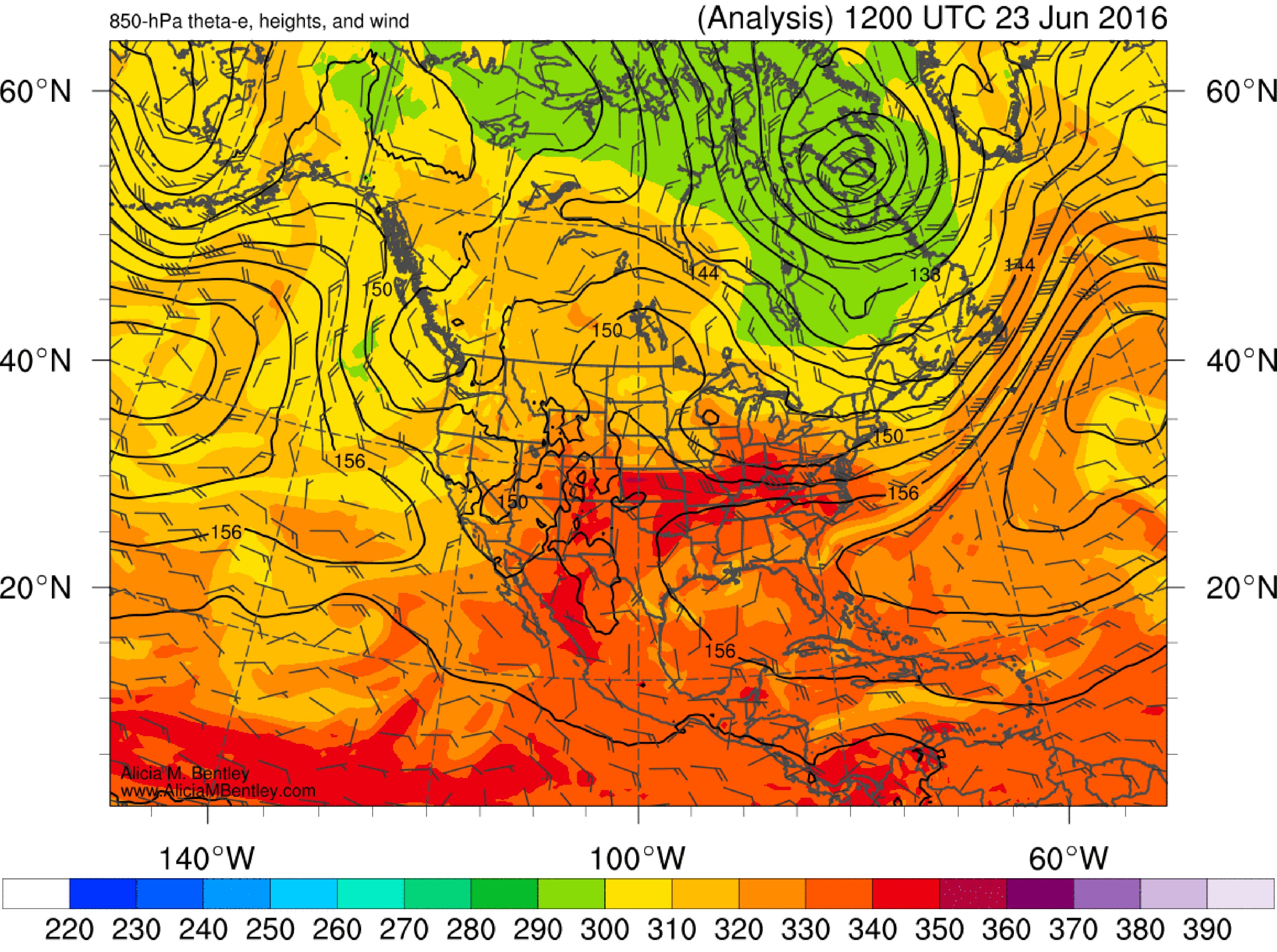
50 60 70 80 90 100



850-hPa theta-e, heights, and wind
(Analysis) 1200 UTC 23 Jun 2016
60°N
40°N
20°N
140°W
100°W
60°W
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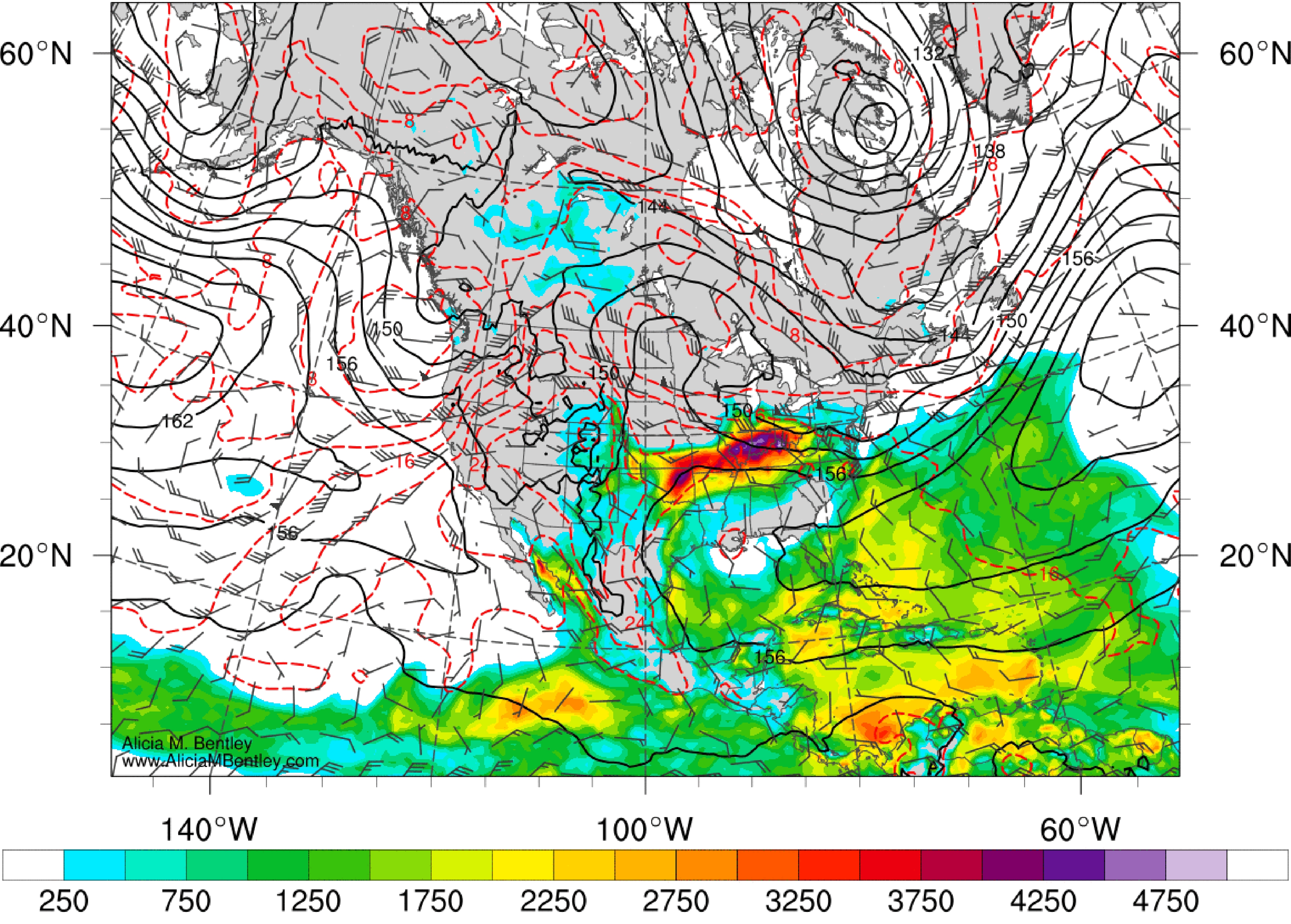
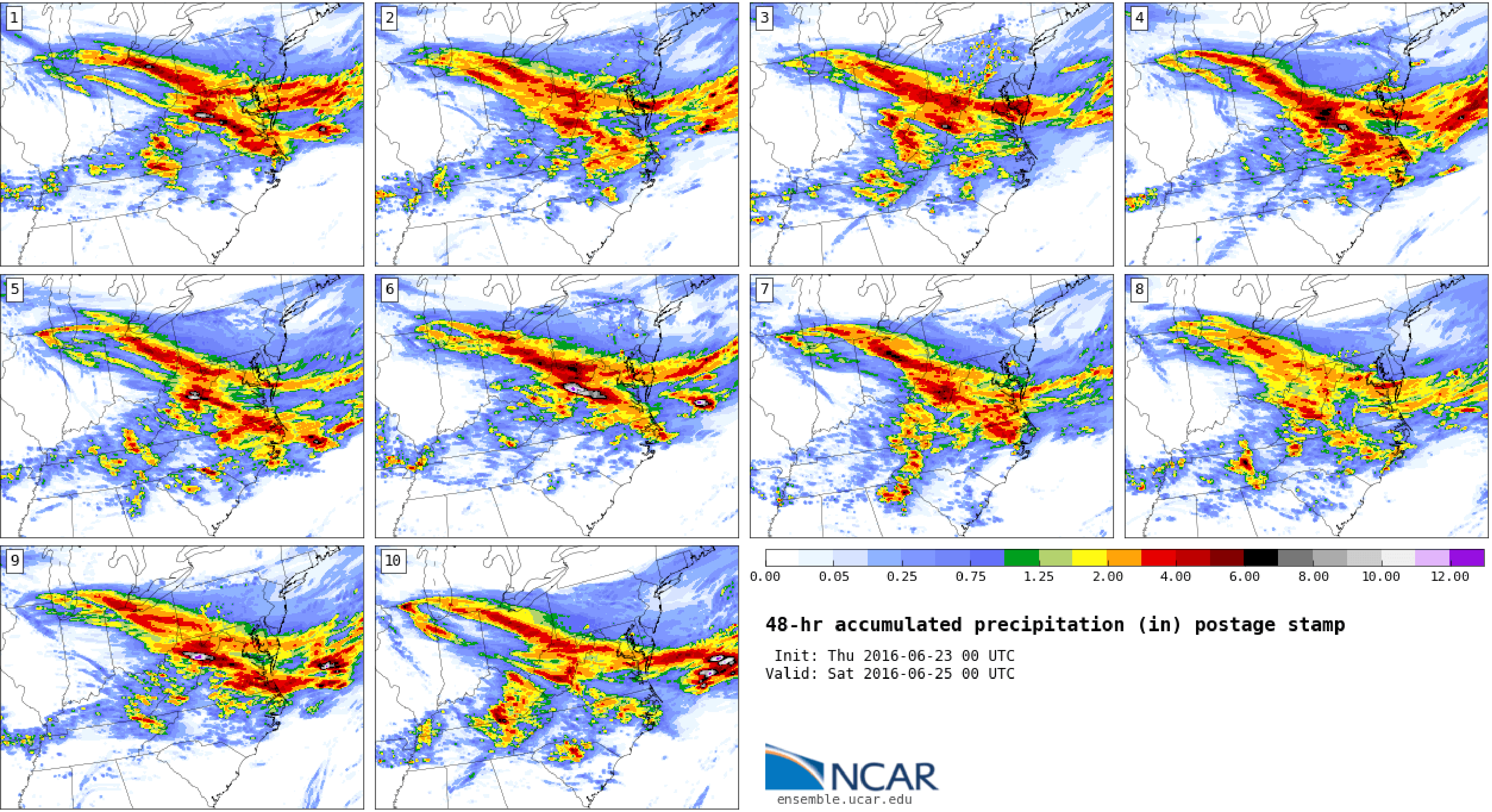
220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 390

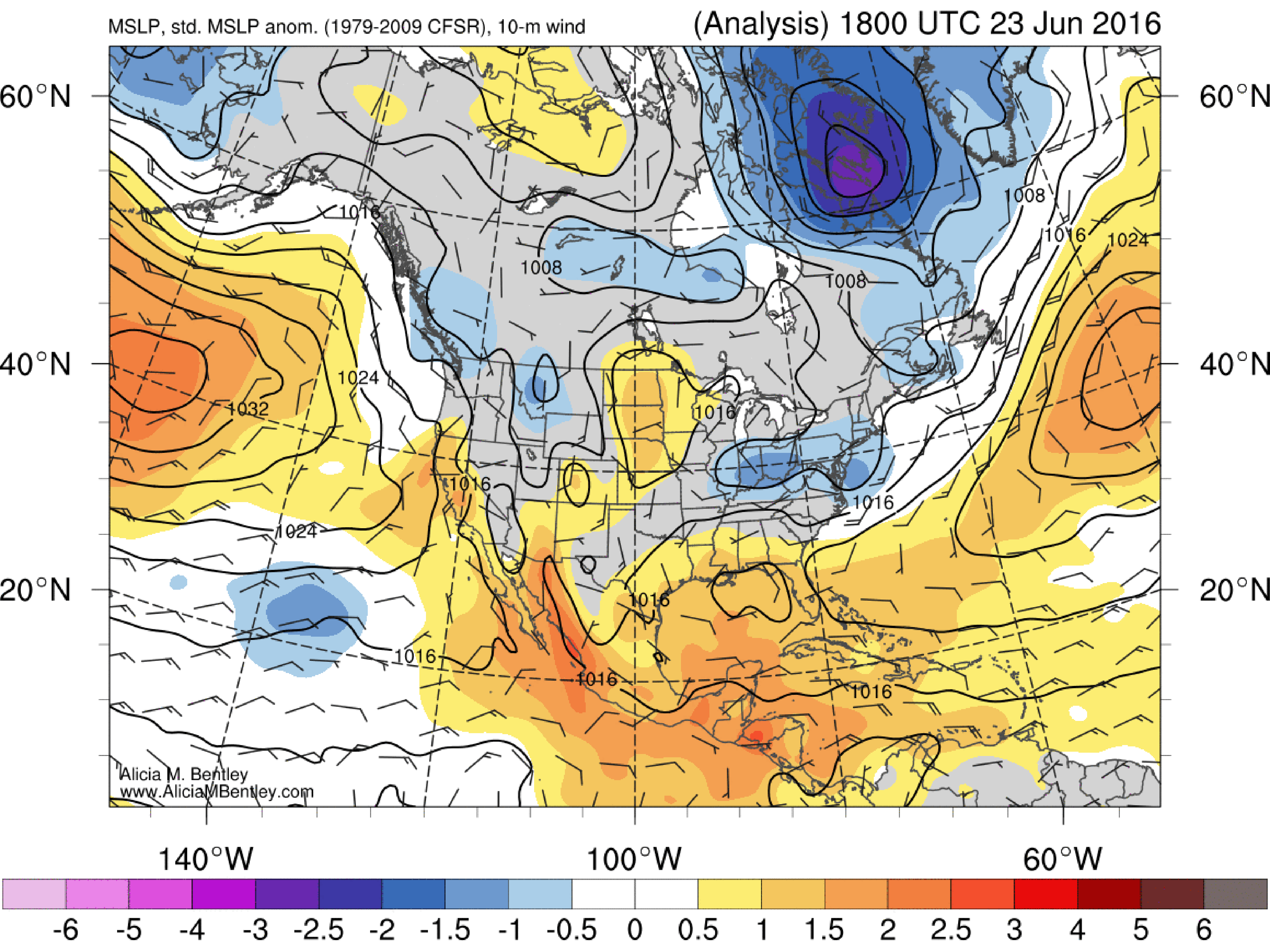
CAPE; 1000-500-hPa shear; 850-hPa heights and temp.

(Analysis) 1800 UTC 23 Jun 2016



NCAR Real-time Mesoscale Ensemble Model Postage Stamps: Accumulated 48 h Rainfall (in) Ending 0000 UTC 25 June 2016

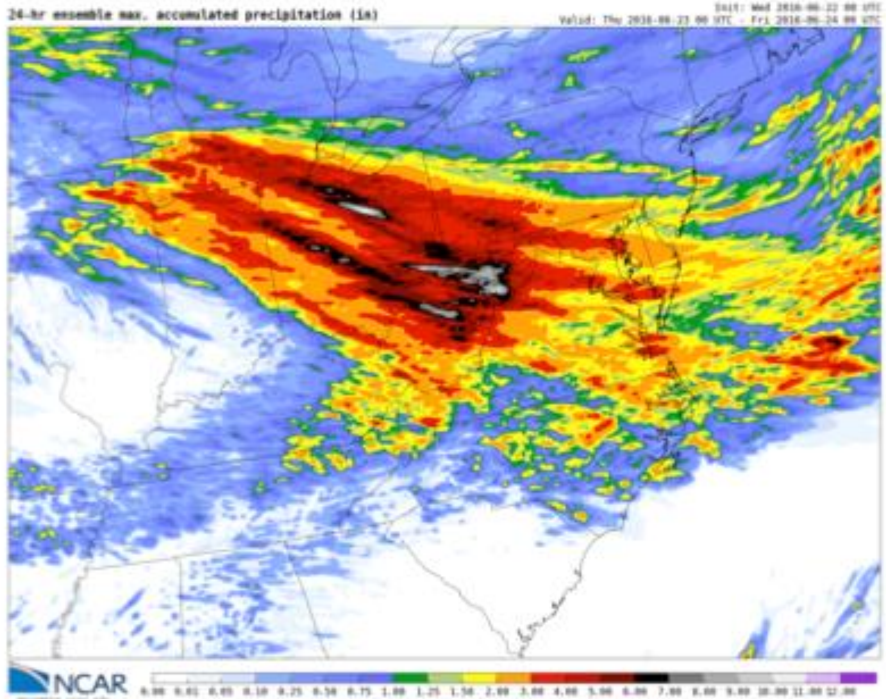



MSLP, std. MSLP anom. (1979-2009 CFSR), 10-m wind
(Analysis) 1800 UTC 23 Jun 2016
60°N
40°N
20°N
140°W
100°W
60°W
1008
1016
1024
1032
-6 -5 -4 -3 -2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3 4 5 6
Alicia M. Bentley
www.AliciaMBentley.com

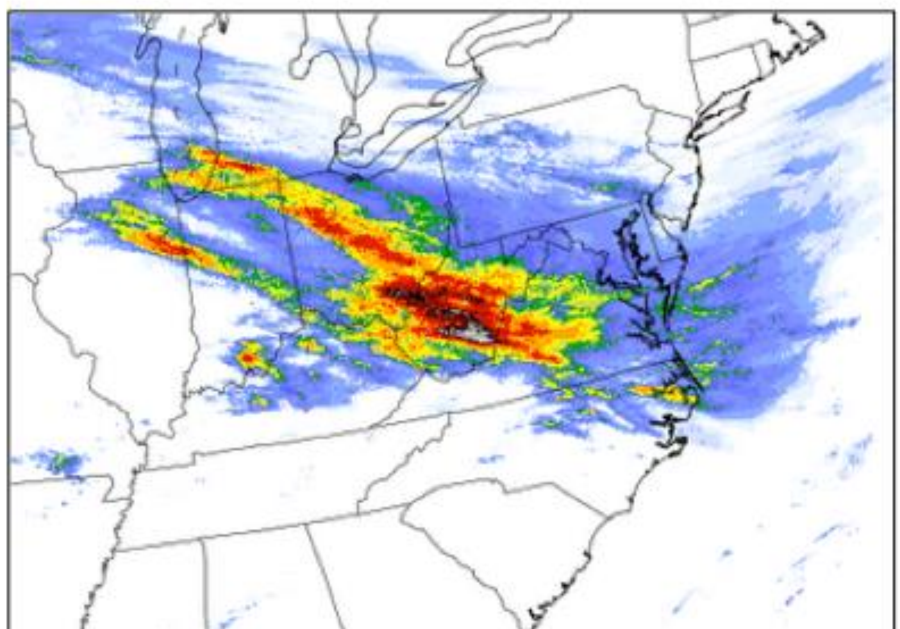
22 June 2016

24 h Precip

***Slight northward bias**

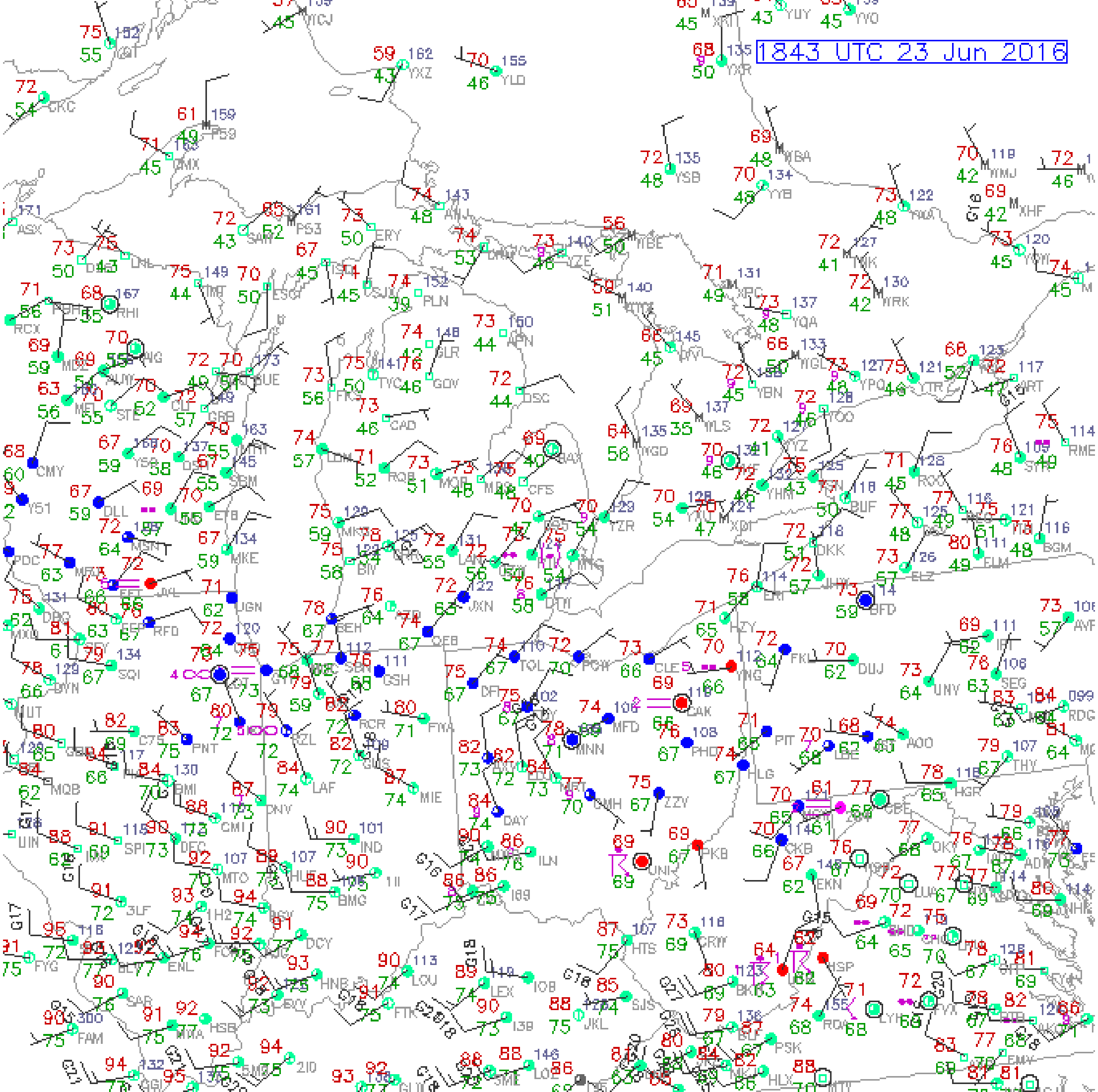


Ensemble Max



Obs (MRMS)

WV Rainstorm Meteorology


1843 UTC 23 Jun 2016

Maps Courtesy of Alicia Bentley

WV Flood Rainfall (inches)
1200 UTC –1200 UTC 23–24 June 2016