Large-Scale Midlatitude–Polar Flow Interactions Leading to Rapid Surface Ice Melt over Greenland and Sea Ice Volume Loss over the Arctic Ocean in June 2019

Lance F. Bosart, Kevin A. Biernat, and Daniel Keyser

Department of Atmospheric and Environmental Sciences
University at Albany, State University of New York

American Geophysical Union
Fall Meeting 2019
San Francisco, CA 94103
Thursday 12 December 2019
Session A43B-06

Research Supported by ONR Grant N00014-18-1-2200

Purpose

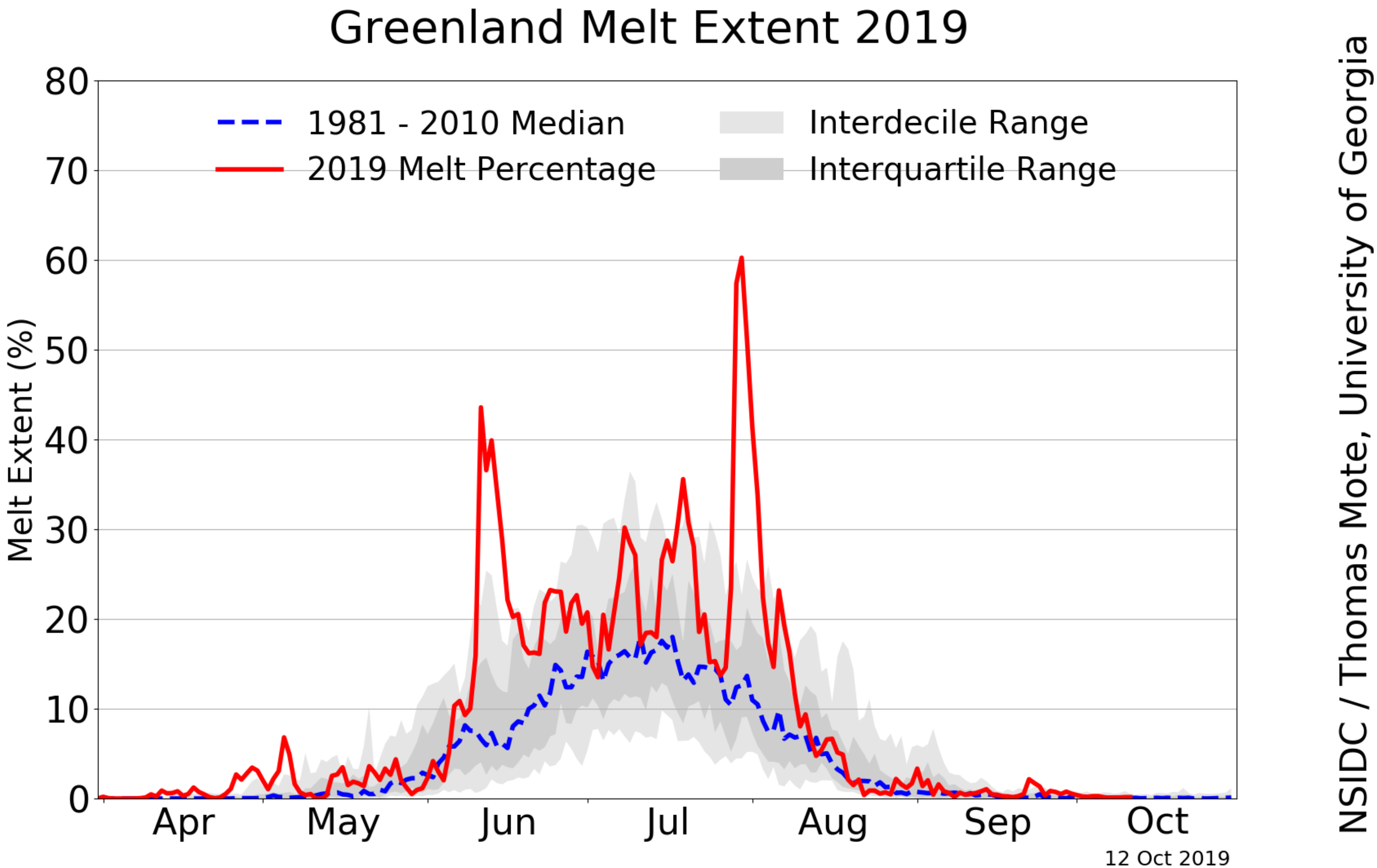
- **Investigate upstream antecedent atmospheric conditions associated with massive Greenland surface ice melt event of June 2019**

Data

- **CFSR gridded analyses at 0.5° resolution (Saha et al. 2010)**

- **GFS forecasts at 0.5° resolution (NOAA/NCEP Central Operations)**

Motivation

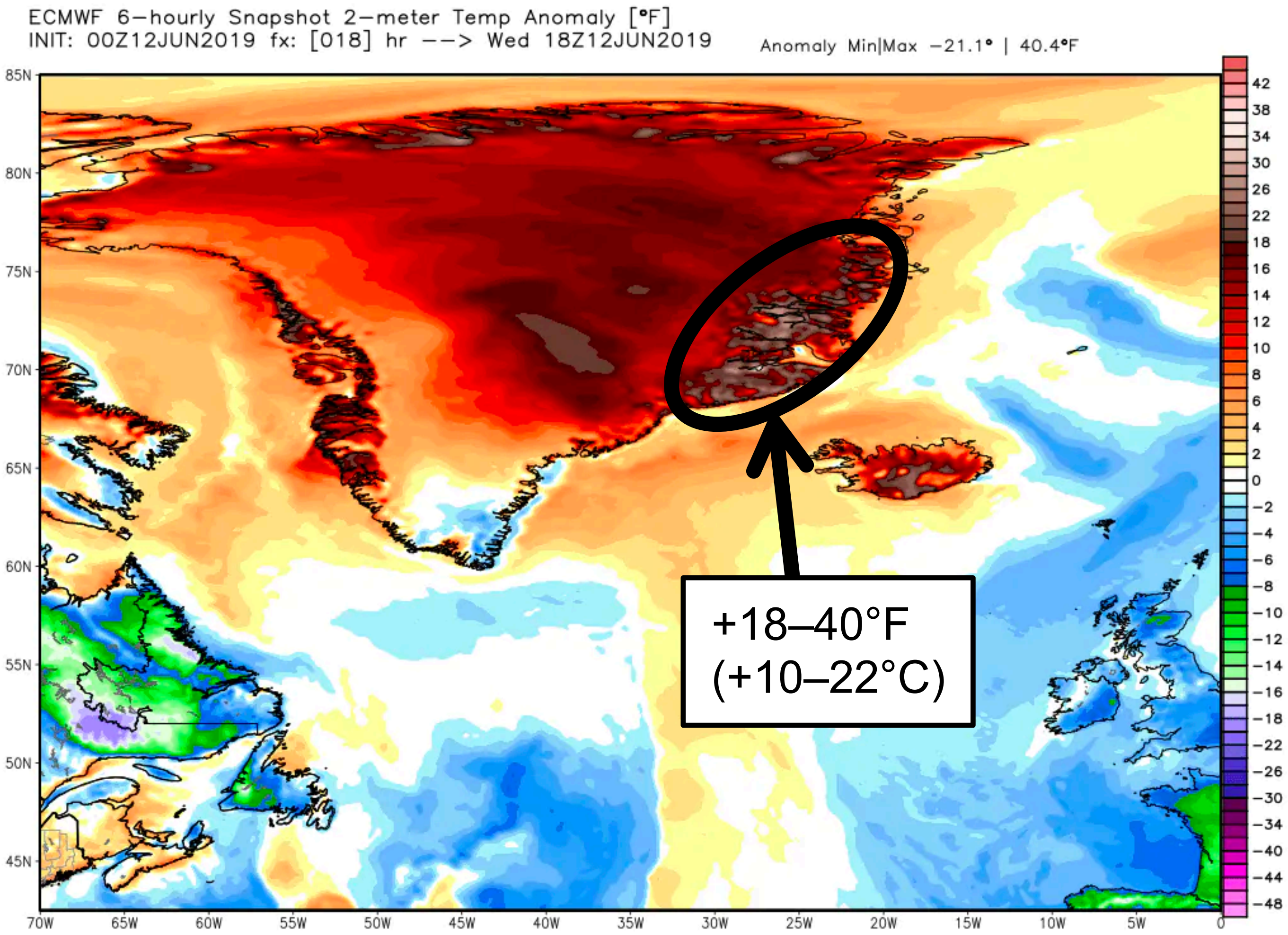


Source: NSIDC/Thomas Mote, University of Georgia; http://nsidc.org/greenland-today/

Motivation

“Steffen Olsen, an Arctic researcher with the Danish Meteorological Institute, and dogs set out to retrieve oceanographic moorings and a weather station over meltwater topping sea ice in northwest Greenland on Thursday.” (Photo credit: Steffen Olsen). Source: Jason Samenow, Washington Post, 14 June 2019; https://www.washingtonpost.com/weather/2019/06/14/arctic-ocean-greenland-ice-sheet-have-seen-record-june-ice-loss/

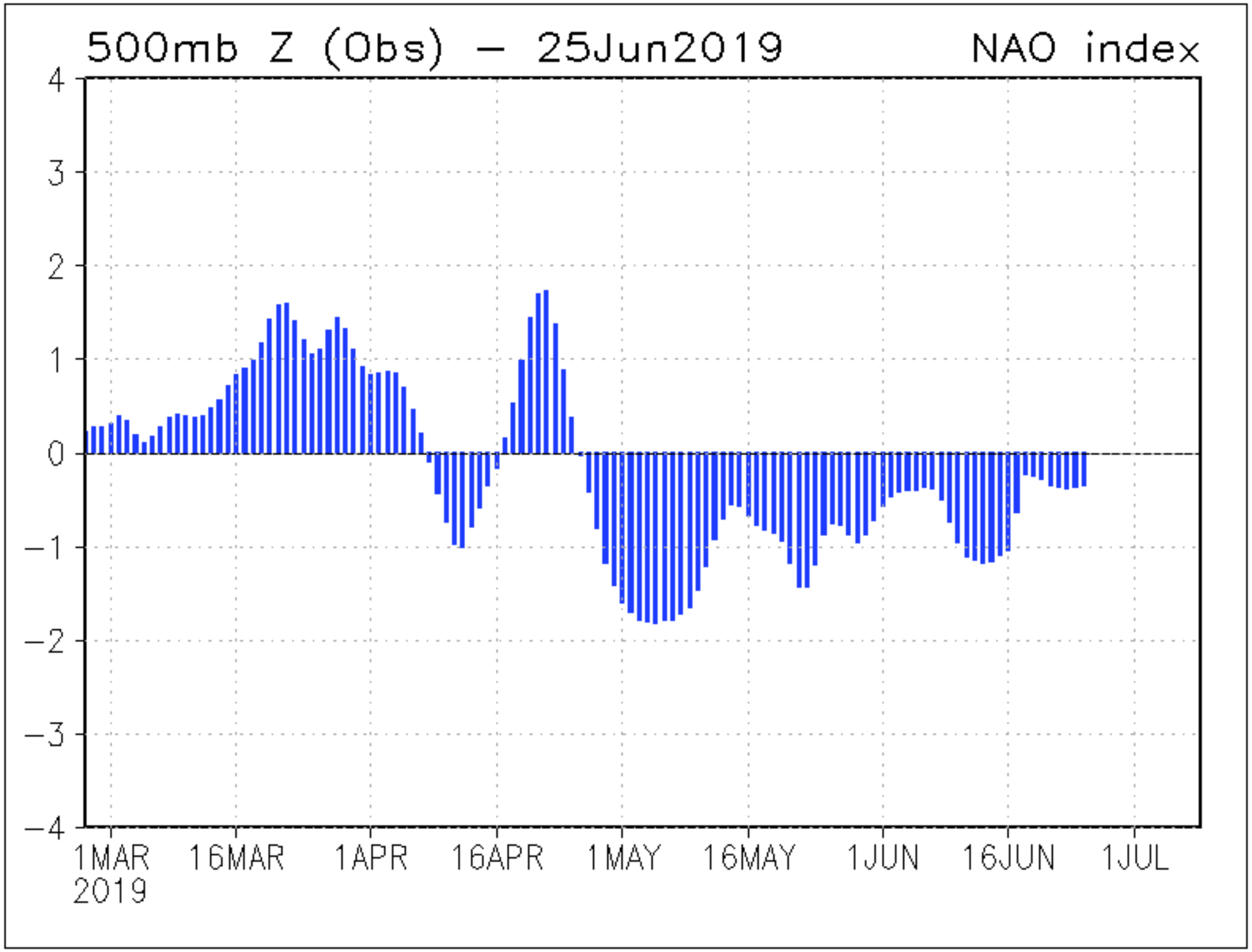
Motivation



18-h forecast of 2-m temperature anomaly (°F) valid at 1800 UTC 12 June 2019 from ECMWF model initialized at 0000 UTC 12 June 2019.

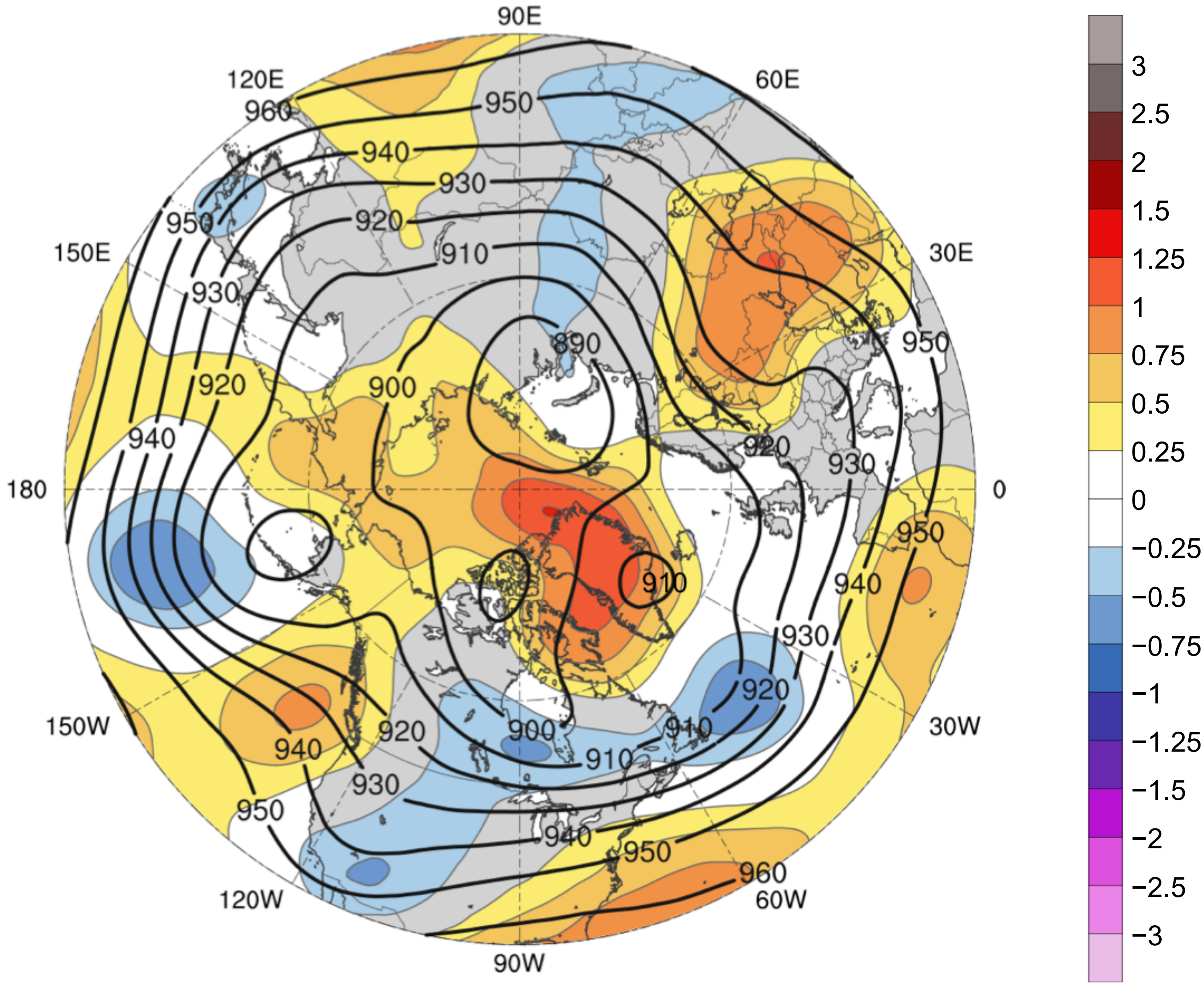
Source: Jason Samenow, Washington Post, 14 June 2019; https://www.washingtonpost.com/weather/2019/06/14/arctic-ocean-greenland-ice-sheet-have-seen-record-june-ice-loss/

Negative NAO (26 Apr–23 Jun 2019)



Source: NOAA Climate Prediction Center

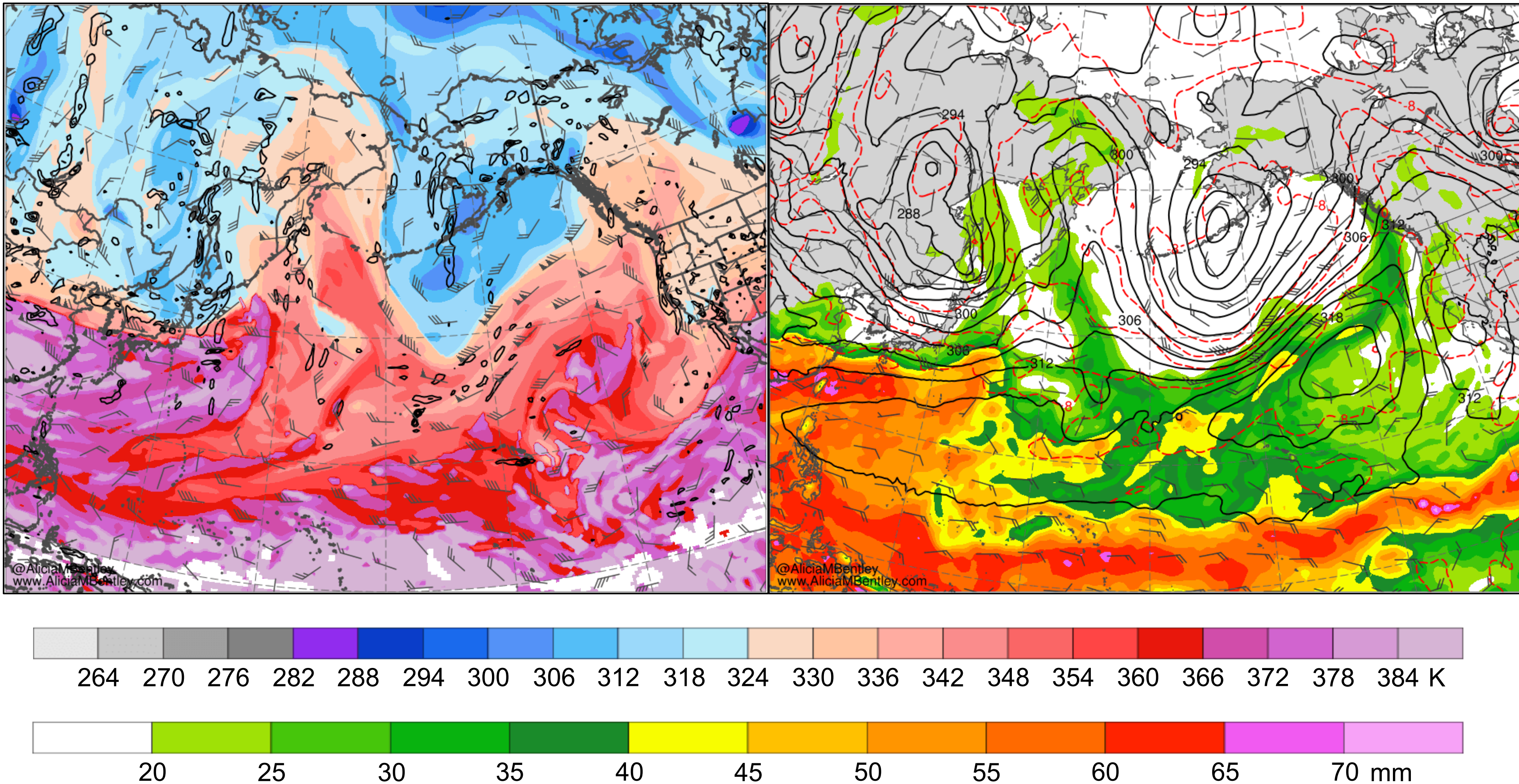
Negative NAO (26 Apr–23 Jun 2019)



26 Apr–23 Jun 2019 time-mean 300-hPa geopotential height (dam, black) and time-mean standardized anomalies of geopotential height (σ, shaded)

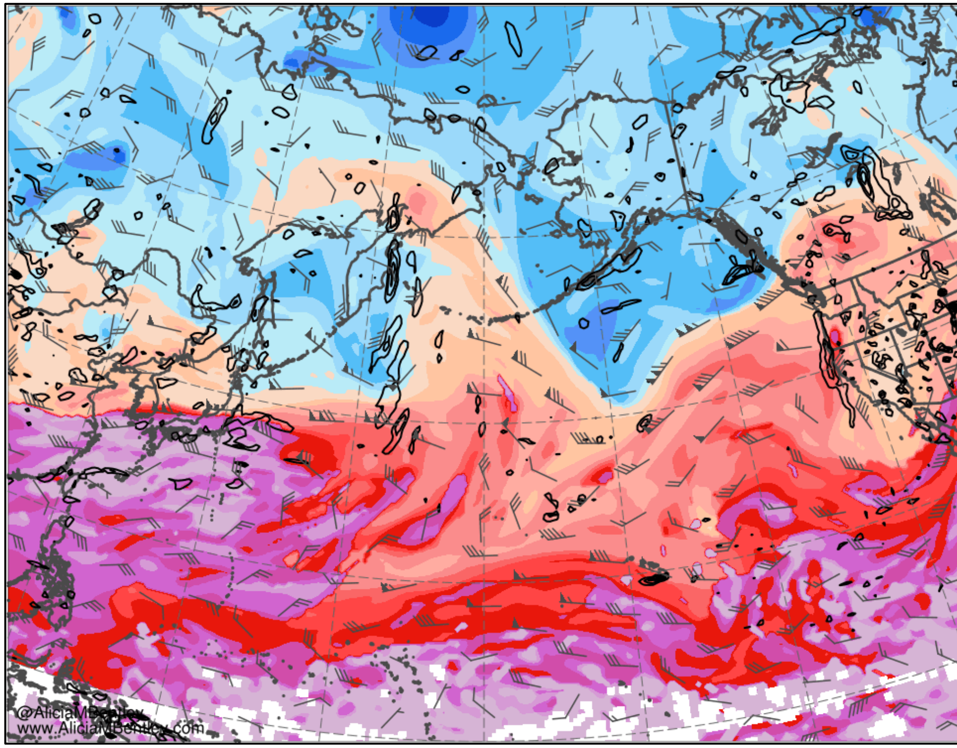
Upstream Antecedent North Pacific Circulation Regime Evolution 1–9 Jun 2019

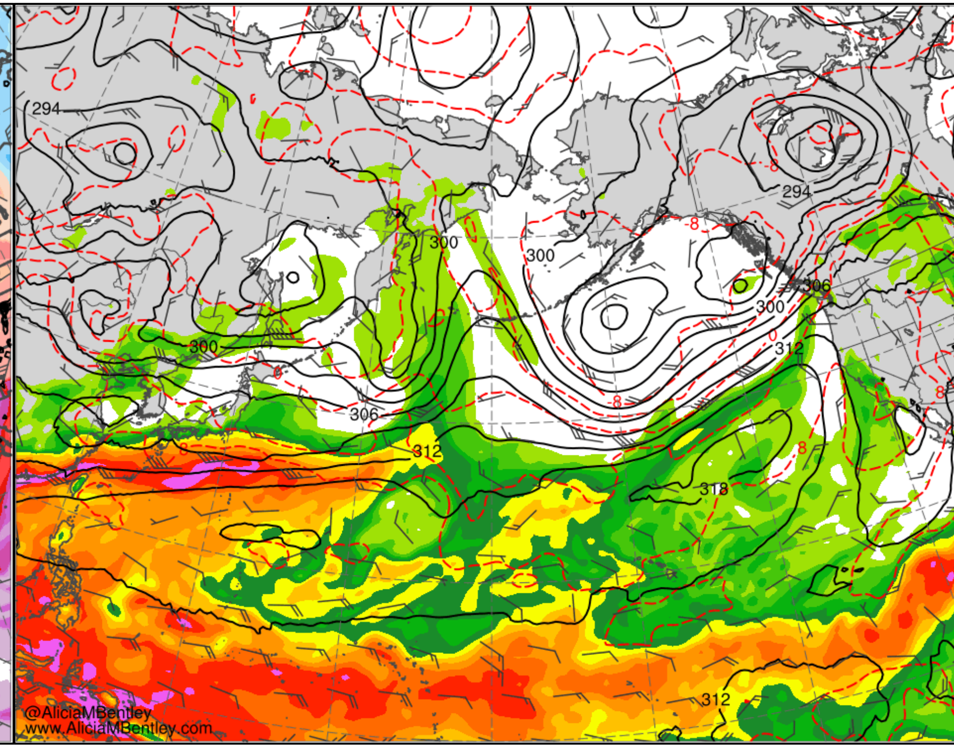
0000 UTC 1 Jun 2019



Potential temperature (K, shaded) and wind (kt, flags and barbs) on 2-PVU surface; 925–850-hPa cycl. rel. vort. (0.5 × 10^{-4} s^{-1}; black)	700-hPa geo. height (dam, black), wind (kt, flags and barbs), and temperature (°C, red), and PW (mm, shaded)

0000 UTC 3 Jun 2019



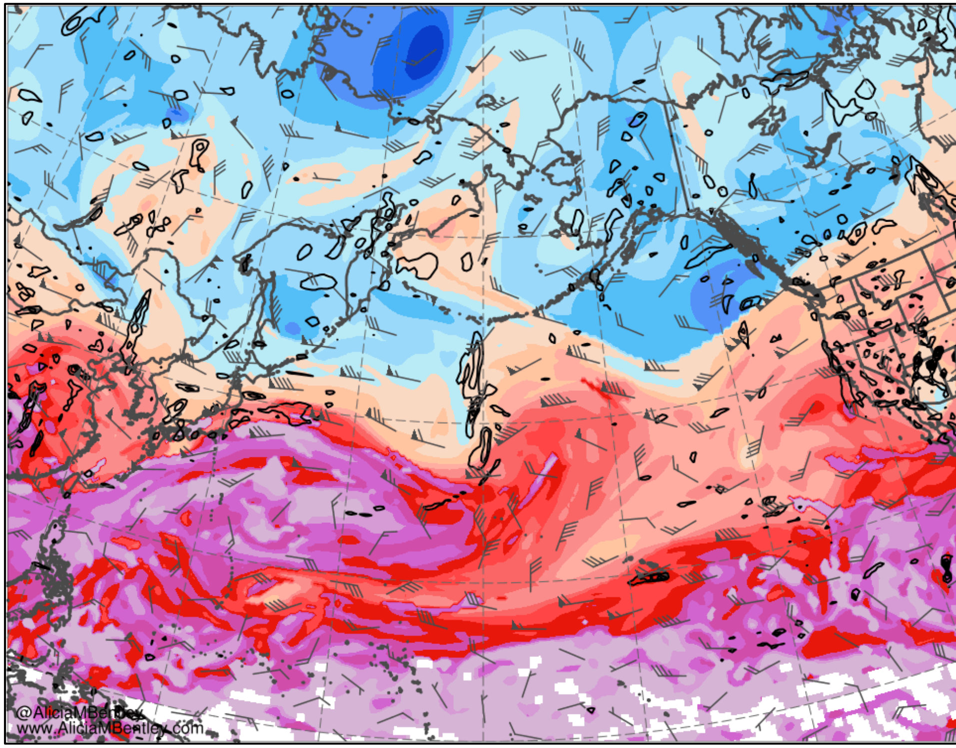


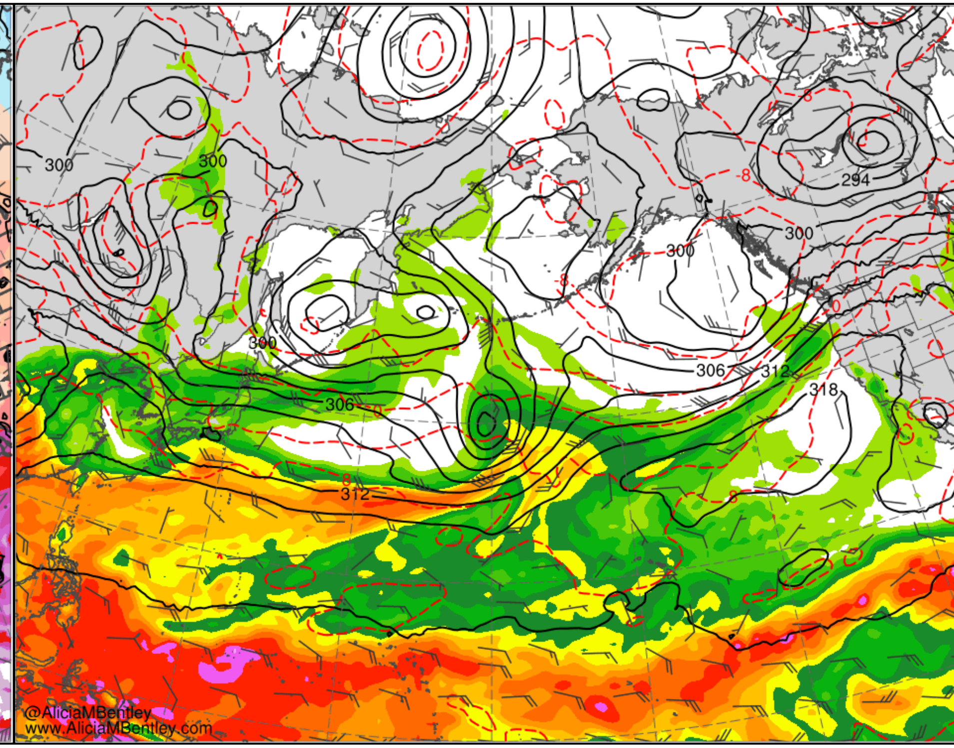
264 270 276 282 288 294 300 306 312 318 324 330 336 342 348 354 360 366 372 378 384 K

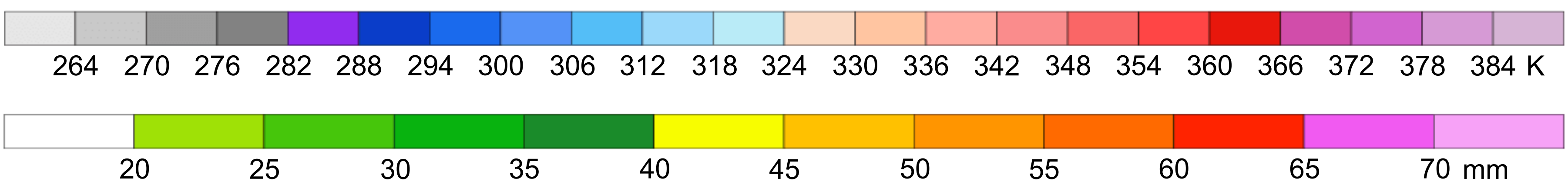
20 25 30 35 40 45 50 55 60 65 70 mm

Potential temperature (K, shaded) and wind (kt, flags and barbs) on 2-PVU surface; 925–850-hPa cycl. rel. vort. (0.5×10^{-4} s^{-1}; black)	700-hPa geo. height (dam, black), wind (kt, flags and barbs), and temperature (°C, red), and PW (mm, shaded)

0000 UTC 5 Jun 2019



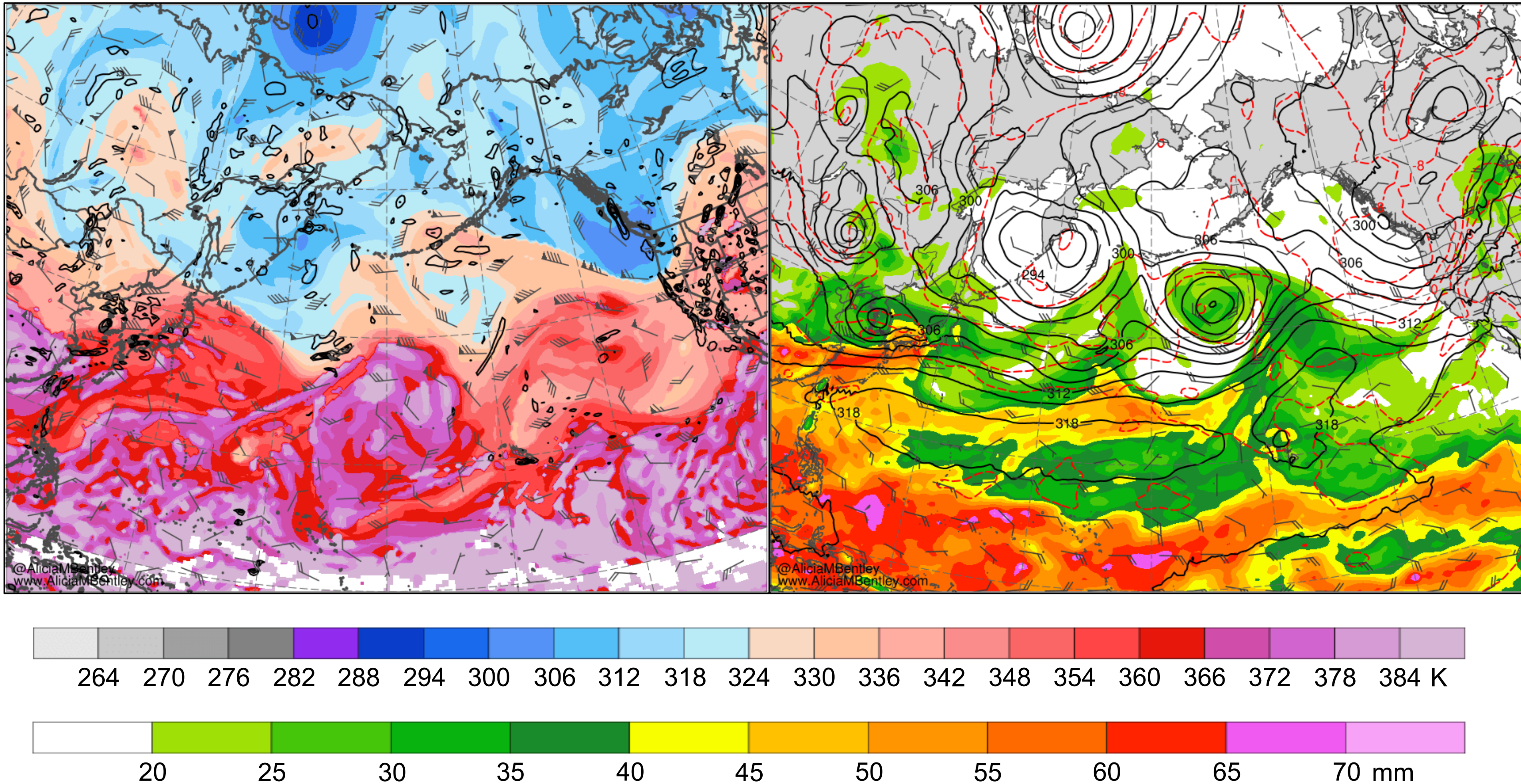




Potential temperature (K, shaded) and wind (kt, flags and barbs) on 2-PVU surface; 925–850-hPa cycl. rel. vort. (0.5×10^{-4} s^{-1}; black)

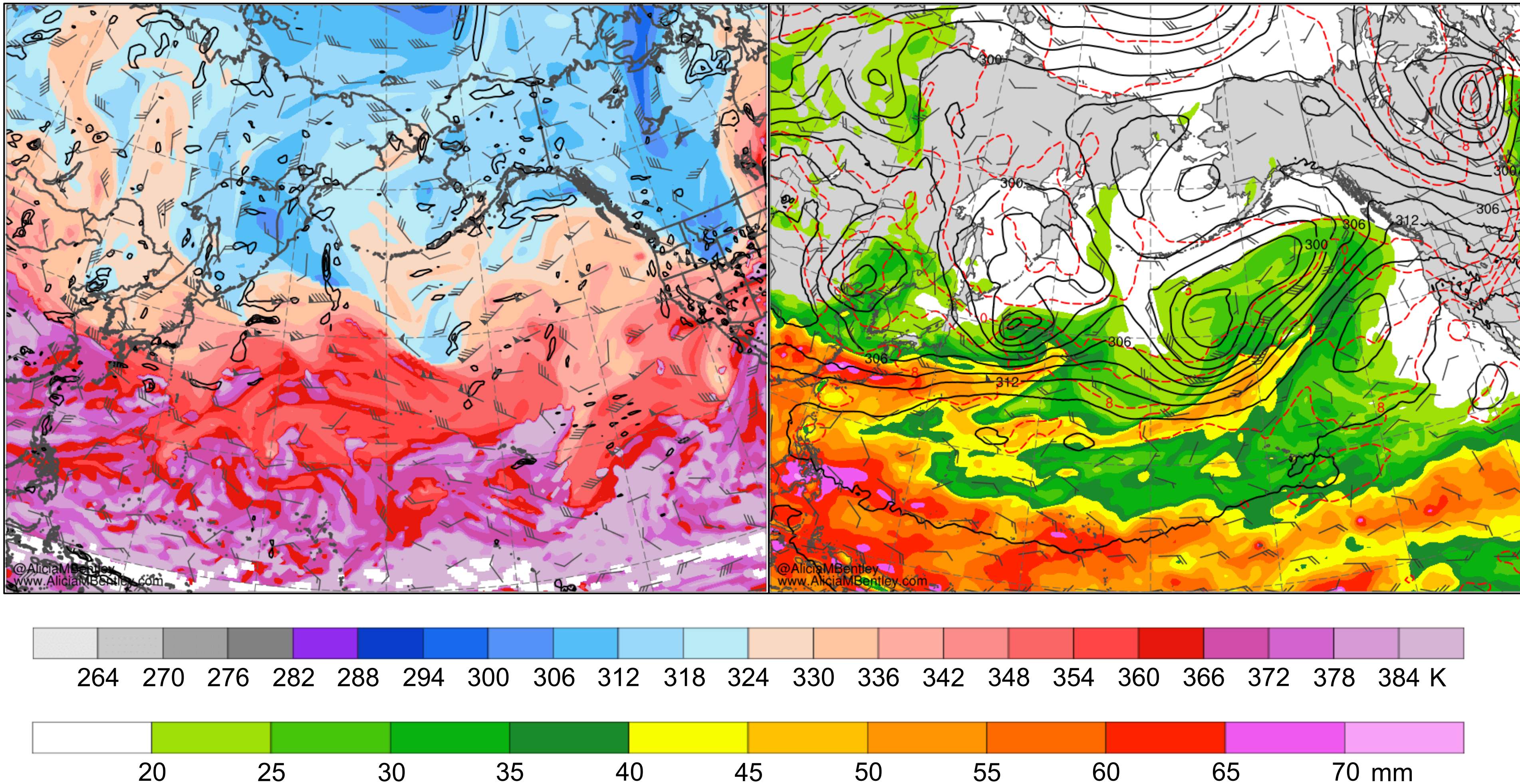
700-hPa geo. height (dam, black), wind (kt, flags and barbs), and temperature (°C, red), and PW (mm, shaded)

0000 UTC 7 Jun 2019



Potential temperature (K, shaded) and wind (kt, flags and barbs) on 2-PVU surface; 925–850-hPa cycl. rel. vort. (0.5×10^{-4} s^{-1}; black)	700-hPa geo. height (dam, black), wind (kt, flags and barbs), and temperature (°C, red), and PW (mm, shaded)

0000 UTC 9 Jun 2019



Potential temperature (K, shaded) and wind (kt, flags and barbs) on 2-PVU surface; 925–850-hPa cycl. rel. vort. (0.5×10^{-4} s^{-1}; black)	700-hPa geo. height (dam, black), wind (kt, flags and barbs), and temperature (°C, red), and PW (mm, shaded)

Summary (1)

- **Tibetan Plateau "heat burst" enables NPAC anticyclonic wave breaking (AWB) and subtropical jet (STJ) extension**

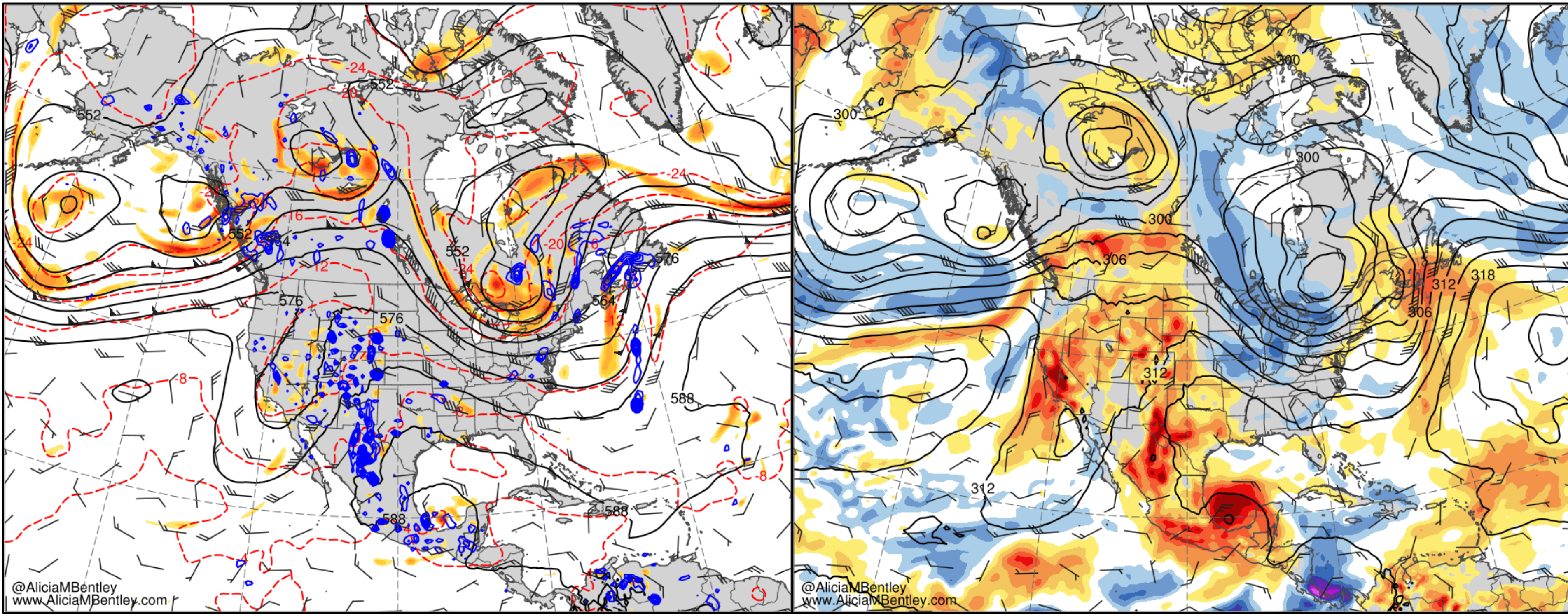
- **AWB allows potential vorticity streamers (PVSs) to form east of the Dateline and poleward of the NPAC STJ corridor**

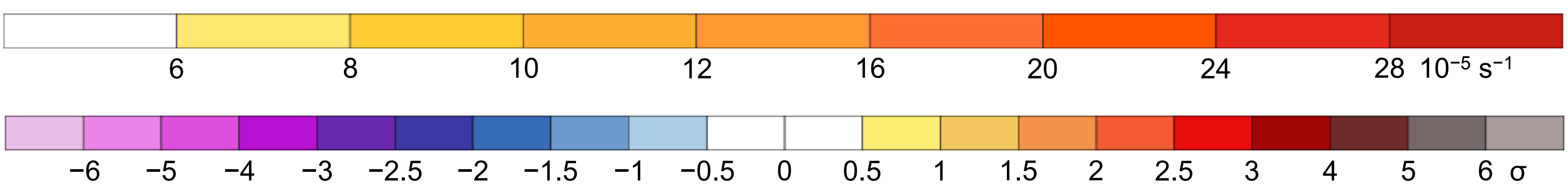
- **Subtropical moisture is advected toward California and Mexico along this NPAC STJ corridor**

- **Cyclonic wave breaking (CWB) events that occur poleward of this STJ corridor facilitate an eastward STJ extension**

North America Circulation Regime Evolution 3–9 Jun 2019

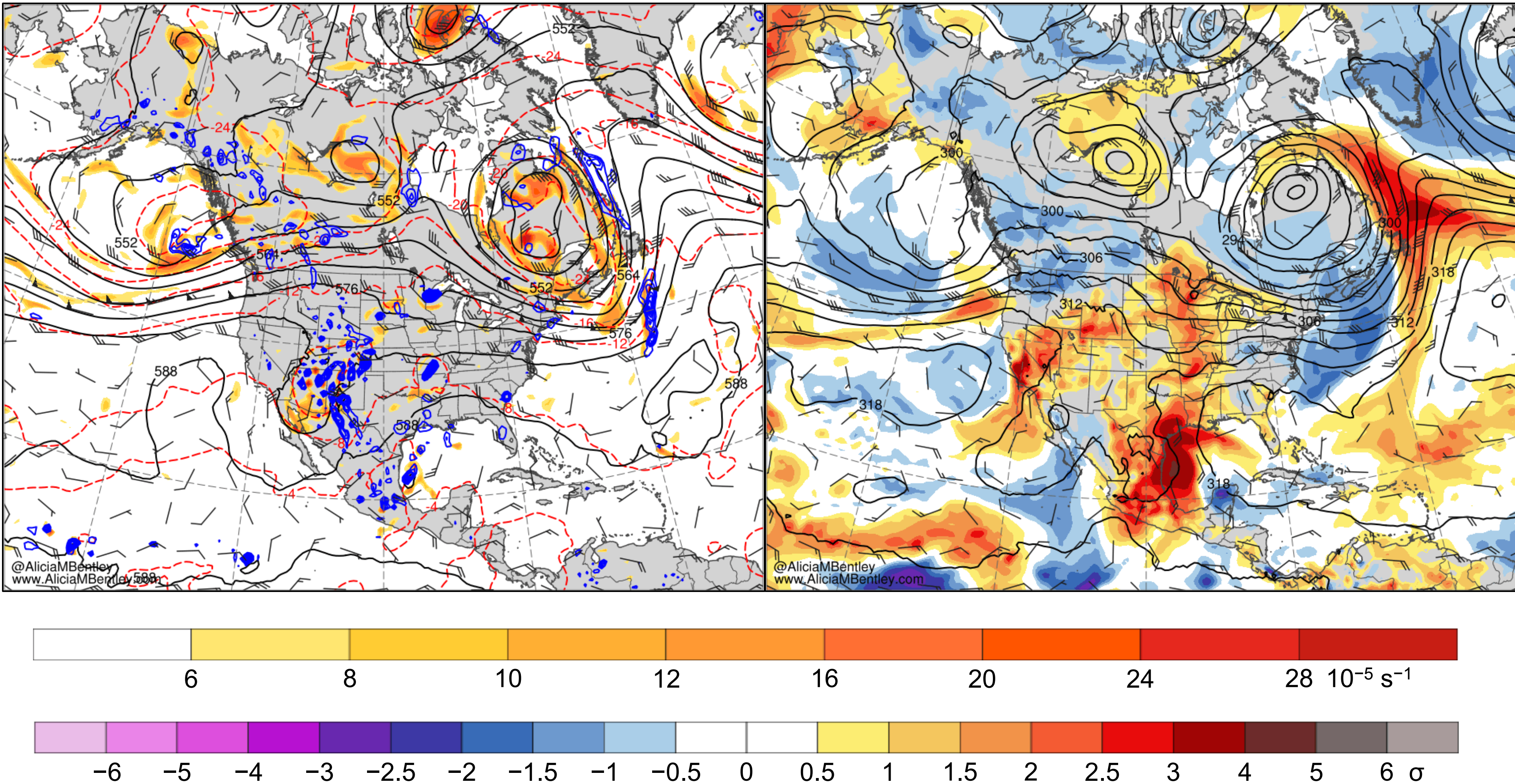
0000 UTC 3 Jun 2019





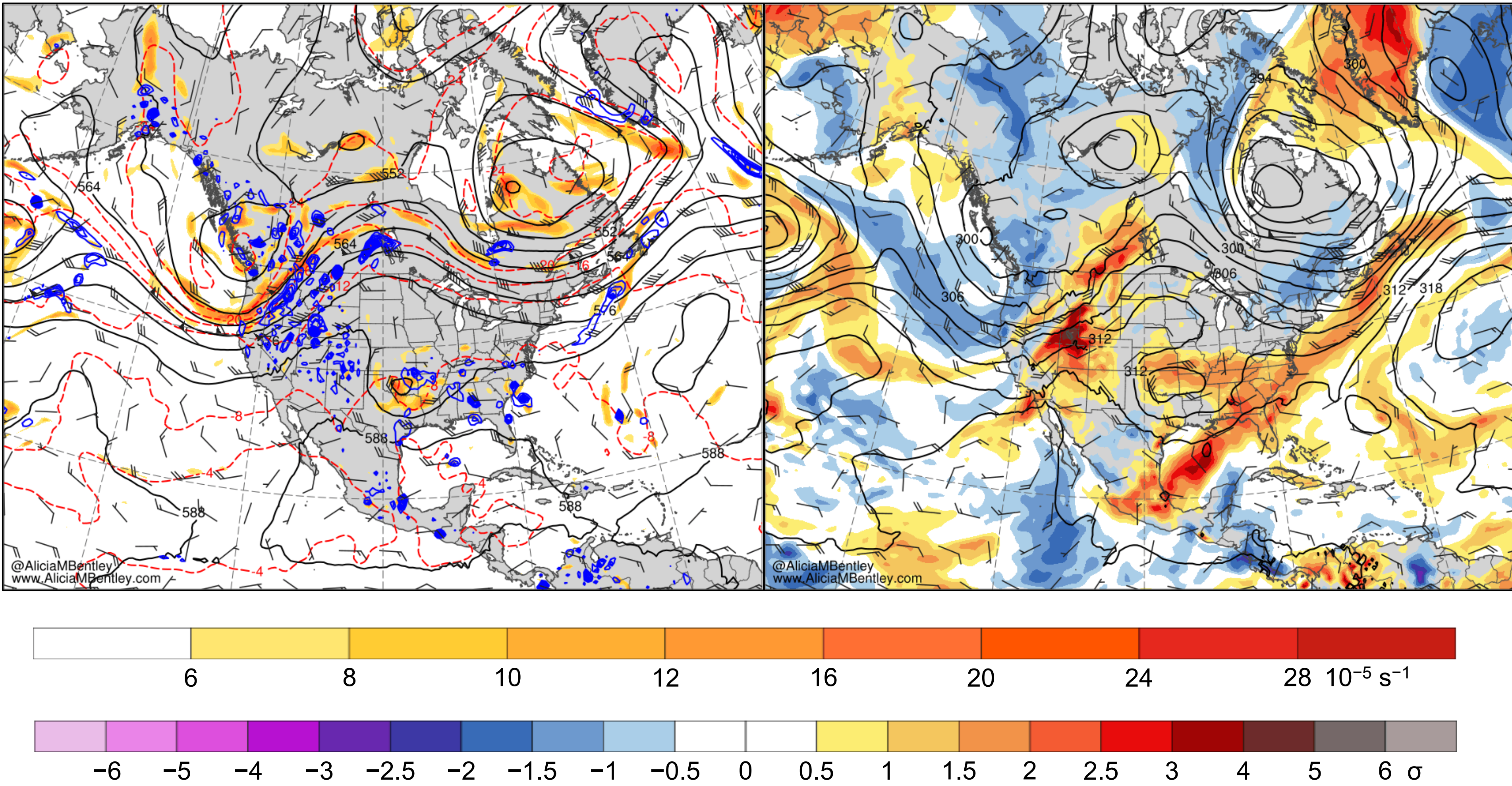
500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5×10^{-3} s^{-1}, blue), and wind (kt, flags and barbs)	700-hPa geo. height (dam, black) and wind (kt, flags and barbs), and standardized anomalies of PW (σ, shaded)

0000 UTC 5 Jun 2019



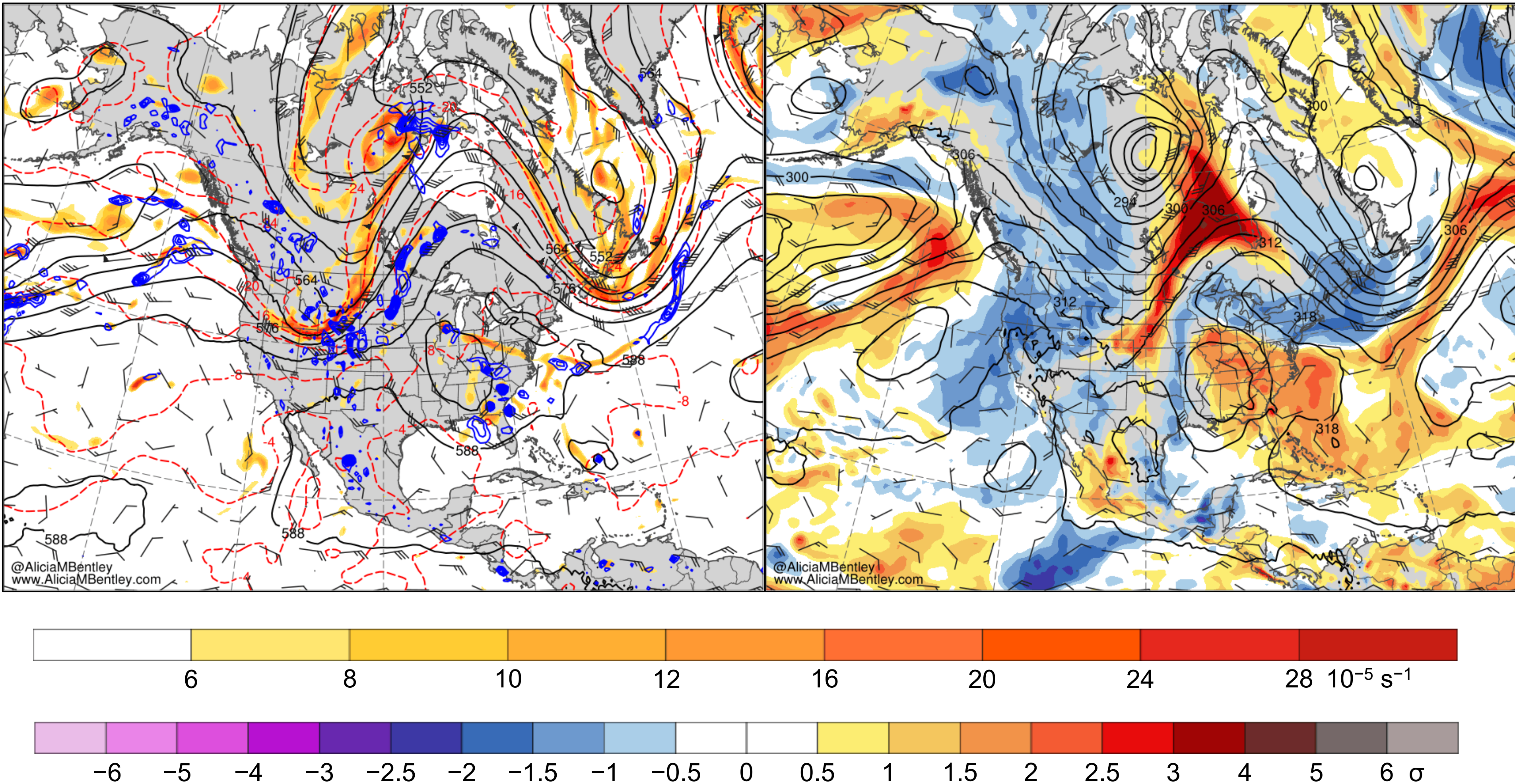
500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5 × 10^{-3} s^{-1}, blue), and wind (kt, flags and barbs)	700-hPa geo. height (dam, black) and wind (kt, flags and barbs), and standardized anomalies of PW (σ, shaded)

0000 UTC 7 Jun 2019



500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5 × 10^{-3} s^{-1}, blue), and wind (kt, flags and barbs)	700-hPa geo. height (dam, black) and wind (kt, flags and barbs), and standardized anomalies of PW (σ, shaded)

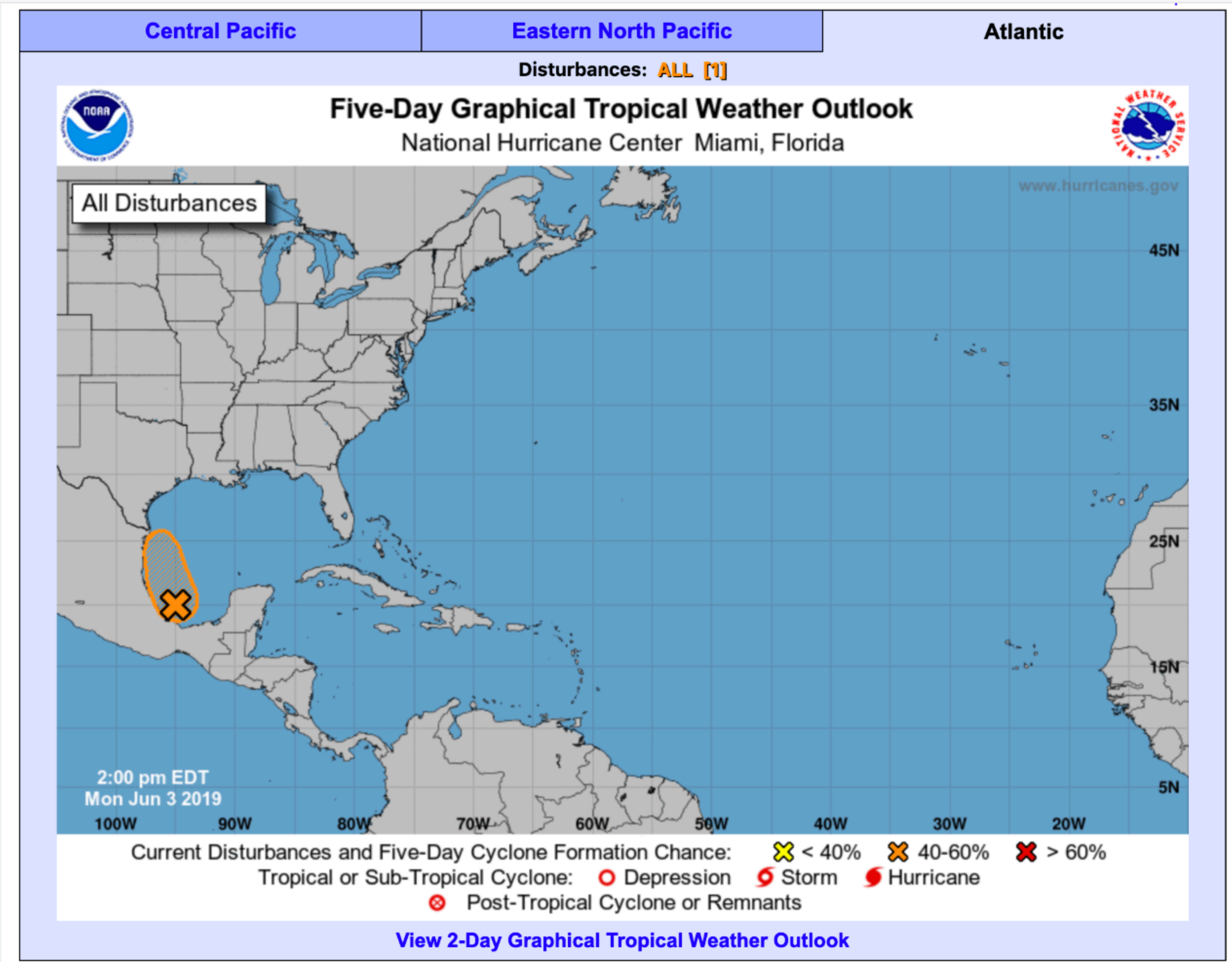
0000 UTC 9 Jun 2019



500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5×10^{-3} s^{-1}, blue), and wind (kt, flags and barbs)

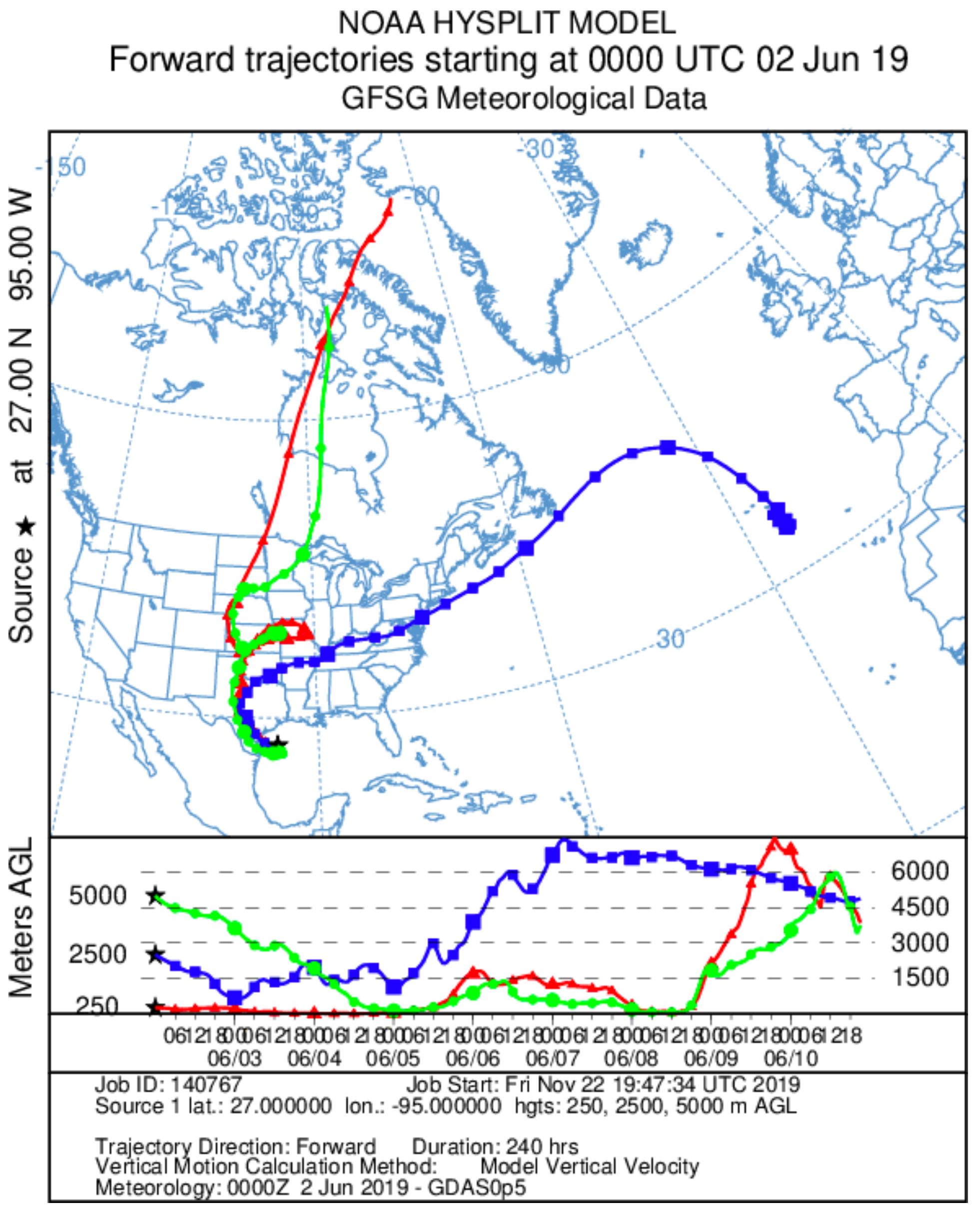
700-hPa geo. height (dam, black) and wind (kt, flags and barbs), and standardized anomalies of PW (σ, shaded)

Tropical Disturbance



NHC Graphical Tropical Weather Outlook from 1800 UTC 3 June

Trajectories



NOAA HYSPLIT forward trajectories starting at 0000 UTC 2 Jun 2019

Summary (2)

- **North Pacific AWB enables western North America ridging, Southwest troughing, and Gulf of Mexico moisture pooling**

- **Southwest trough draws tropical moisture poleward from the southern Gulf of Mexico after it reaches Texas**

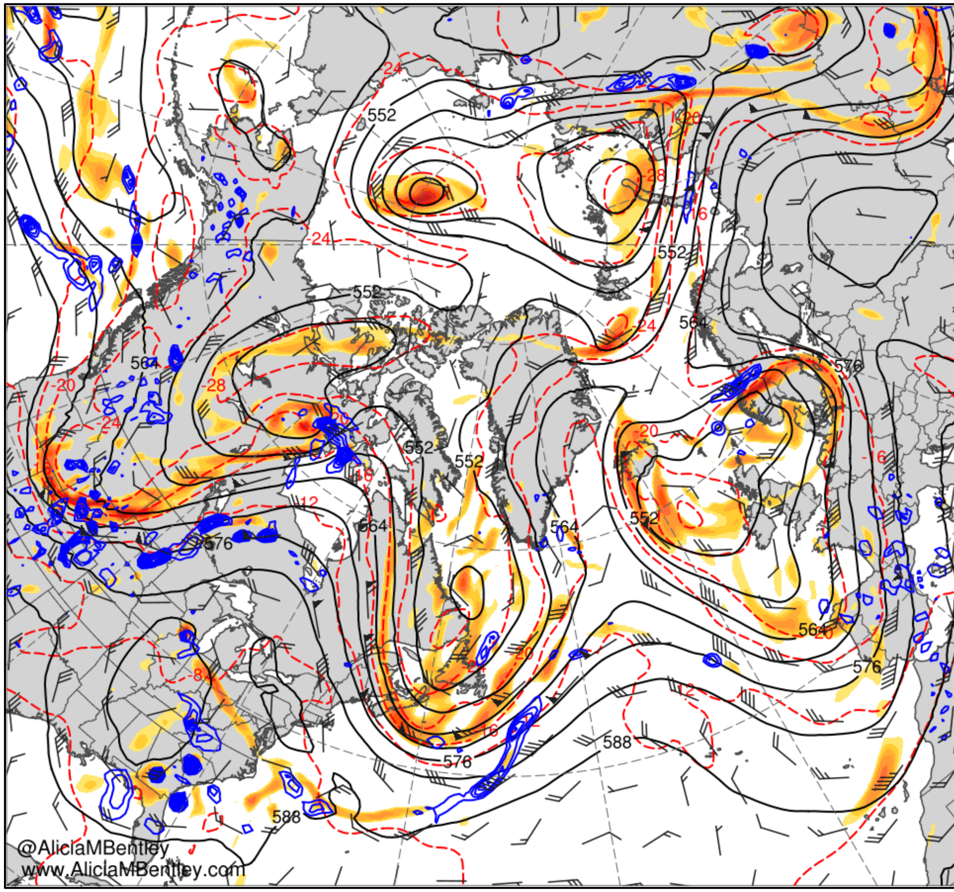
- **A Gulf of Mexico tropical system enhances moisture over the Mississippi Valley as the Texas trough upscales and cuts off**

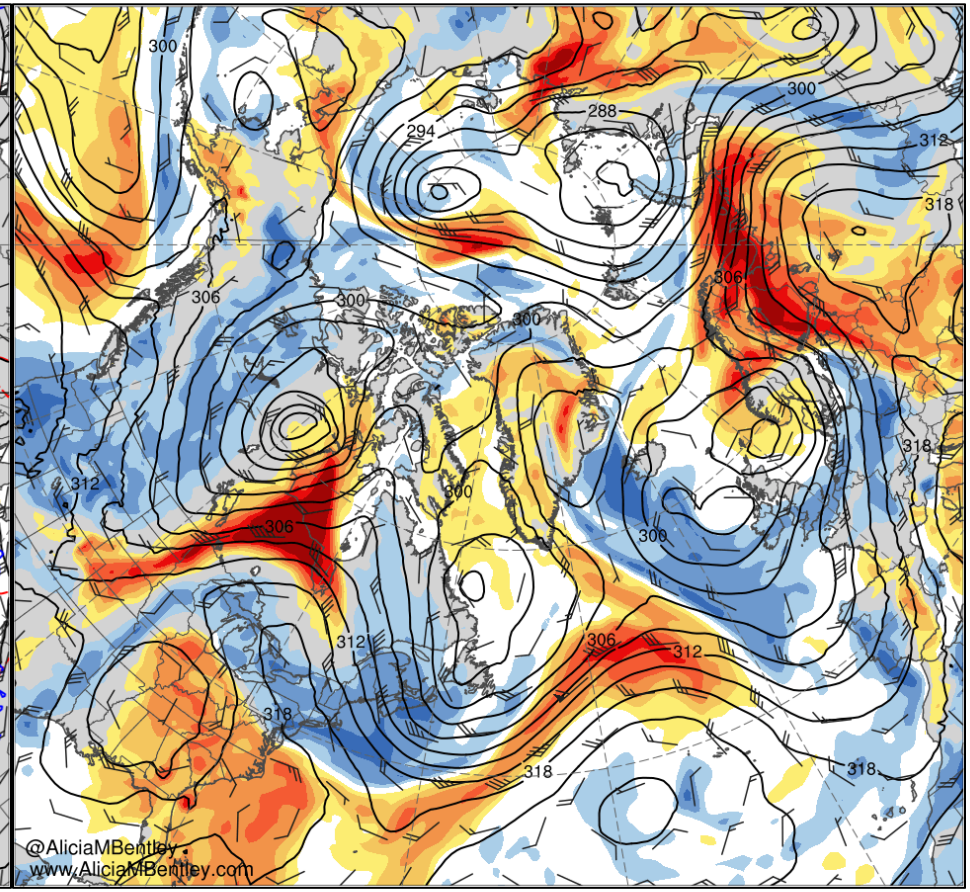
- **Western North American ridging allows a deepening downstream trough to phase with the Texas trough**

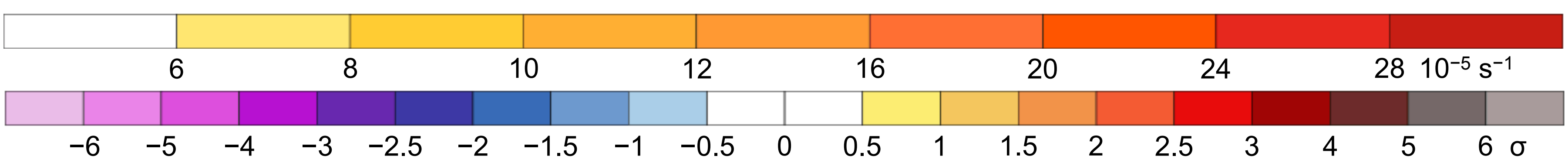
- **A deep moist southerly flow ahead of this phased trough allows deep tropical moisture to reach the Arctic**

Northeast (NE) Canada and Northern Greenland Ridging 10–14 Jun 2019

0000 UTC 9 Jun 2019



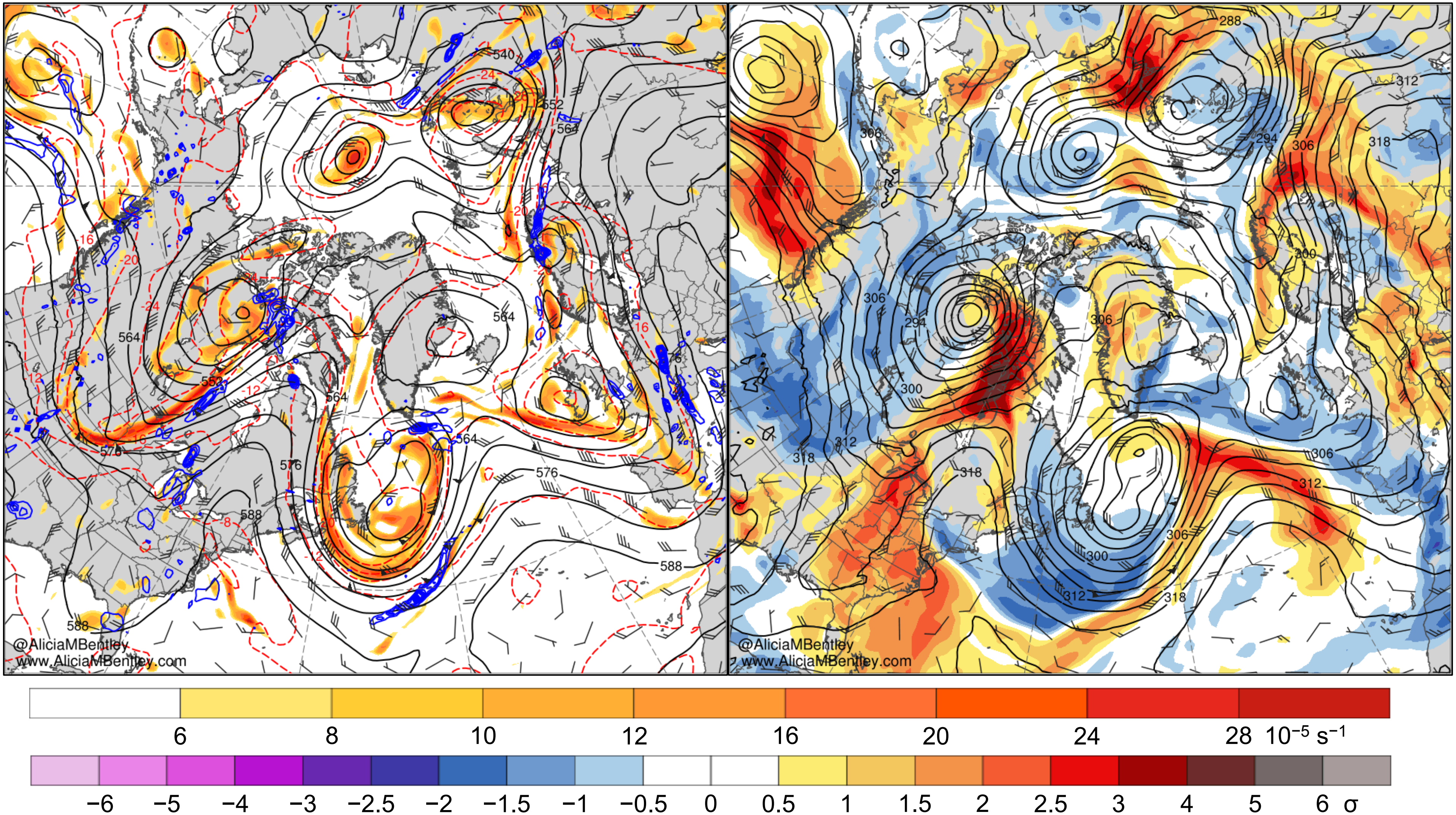




500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5×10^{-3} s^{-1}, blue), and wind (kt, flags and barbs)

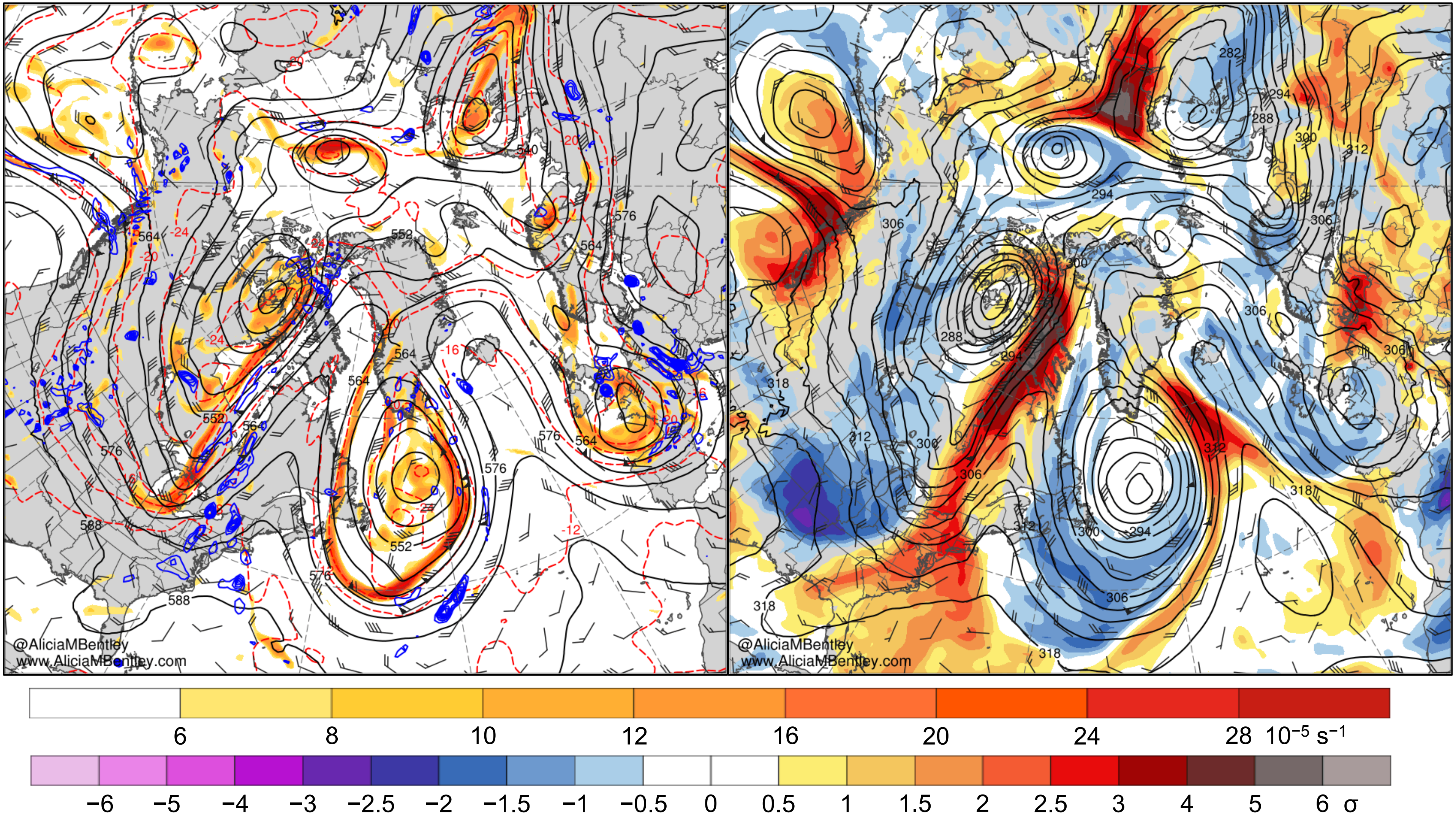
700-hPa geo. height (dam, black) and wind (kt, flags and barbs), and standardized anomalies of PW (σ, shaded)

0000 UTC 10 Jun 2019



500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5 × 10^{-3} s^{-1}, blue), and wind (kt, flags and barbs)	700-hPa geo. height (dam, black) and wind (kt, flags and barbs), and standardized anomalies of PW (σ, shaded)

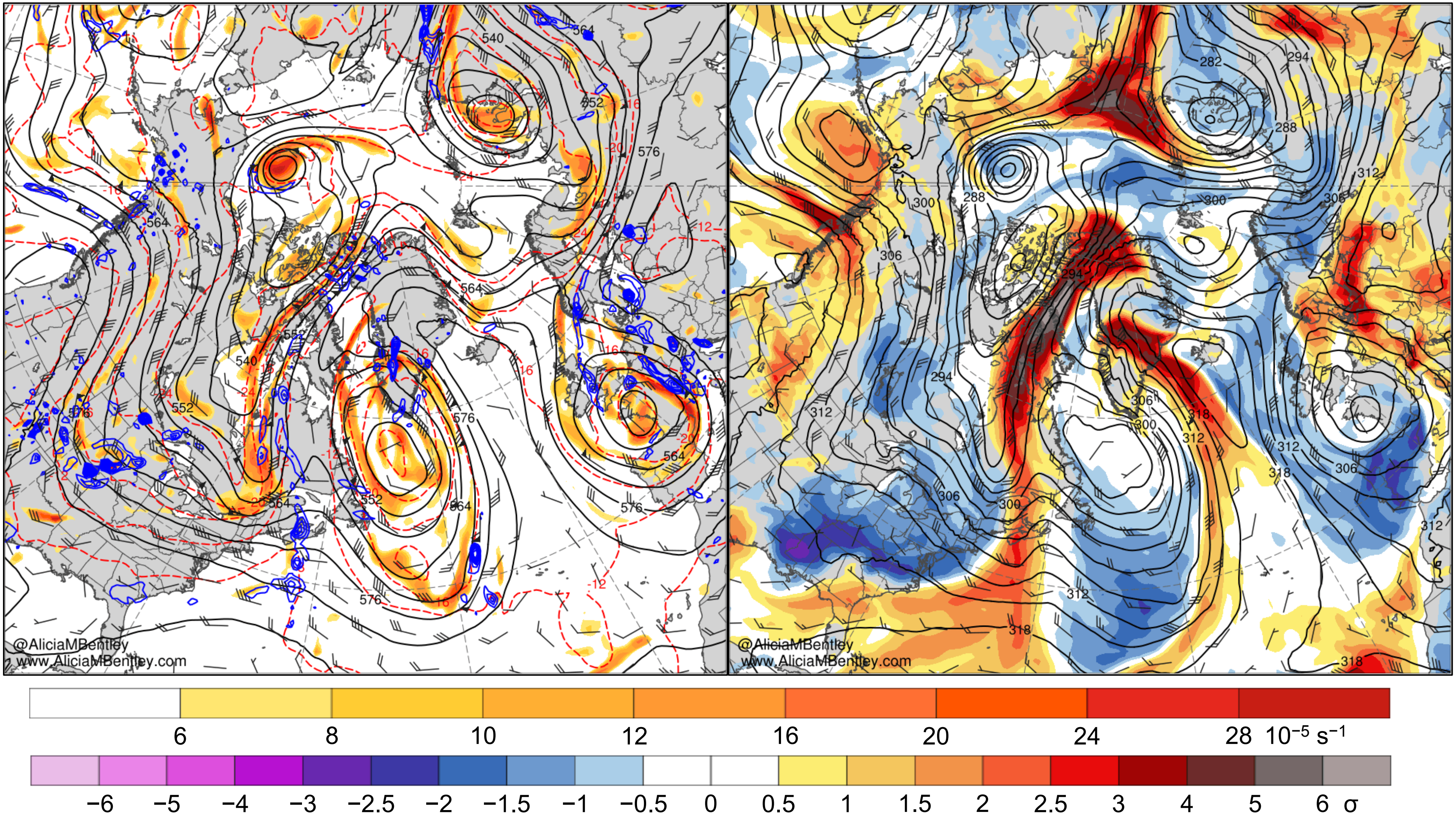
0000 UTC 11 Jun 2019



500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5×10^{-3} s^{-1}, blue), and wind (kt, flags and barbs)

700-hPa geo. height (dam, black) and wind (kt, flags and barbs), and standardized anomalies of PW (σ, shaded)

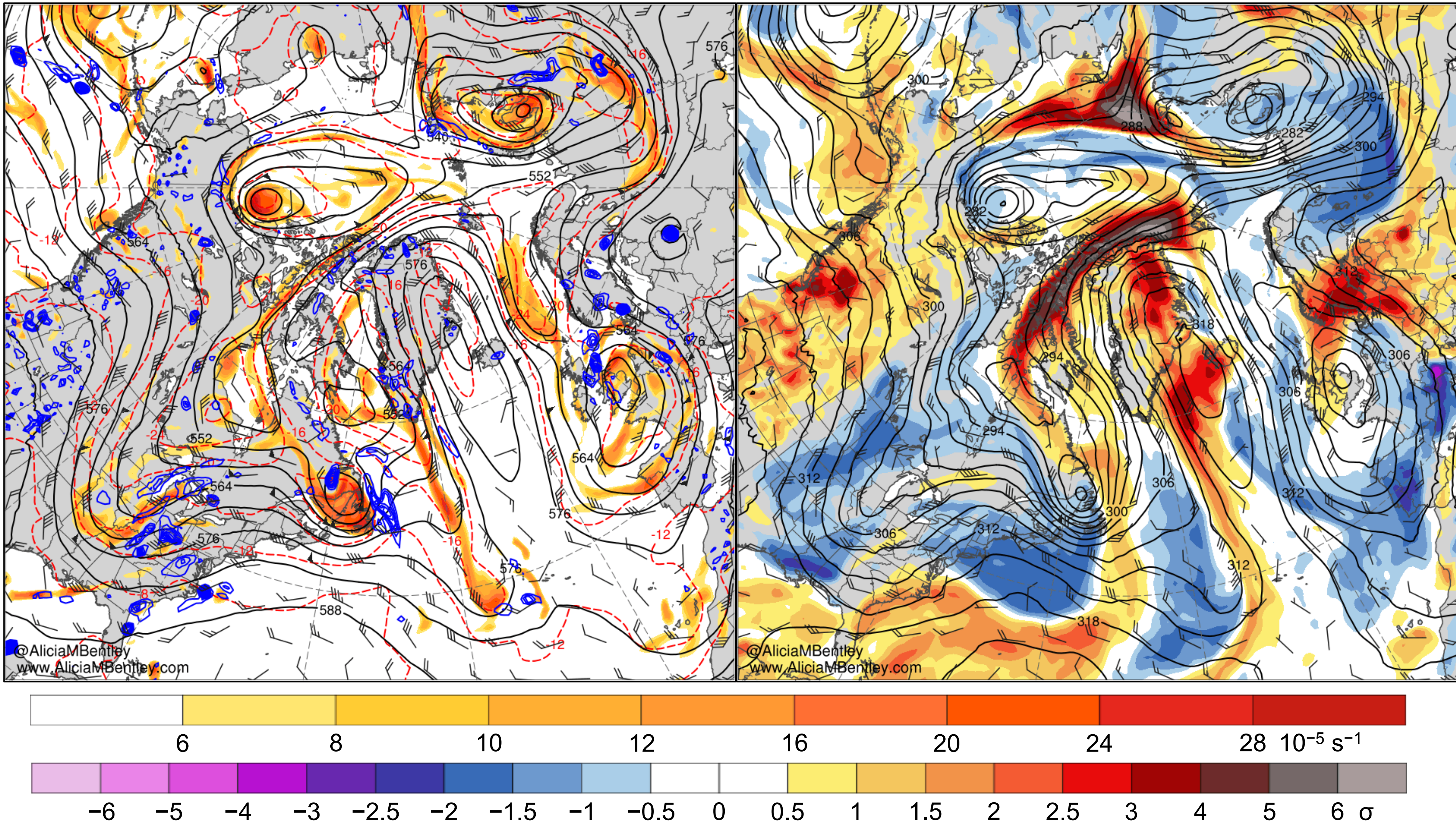
0000 UTC 12 Jun 2019



500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5×10^{-3} s^{-1}, blue), and wind (kt, flags and barbs)

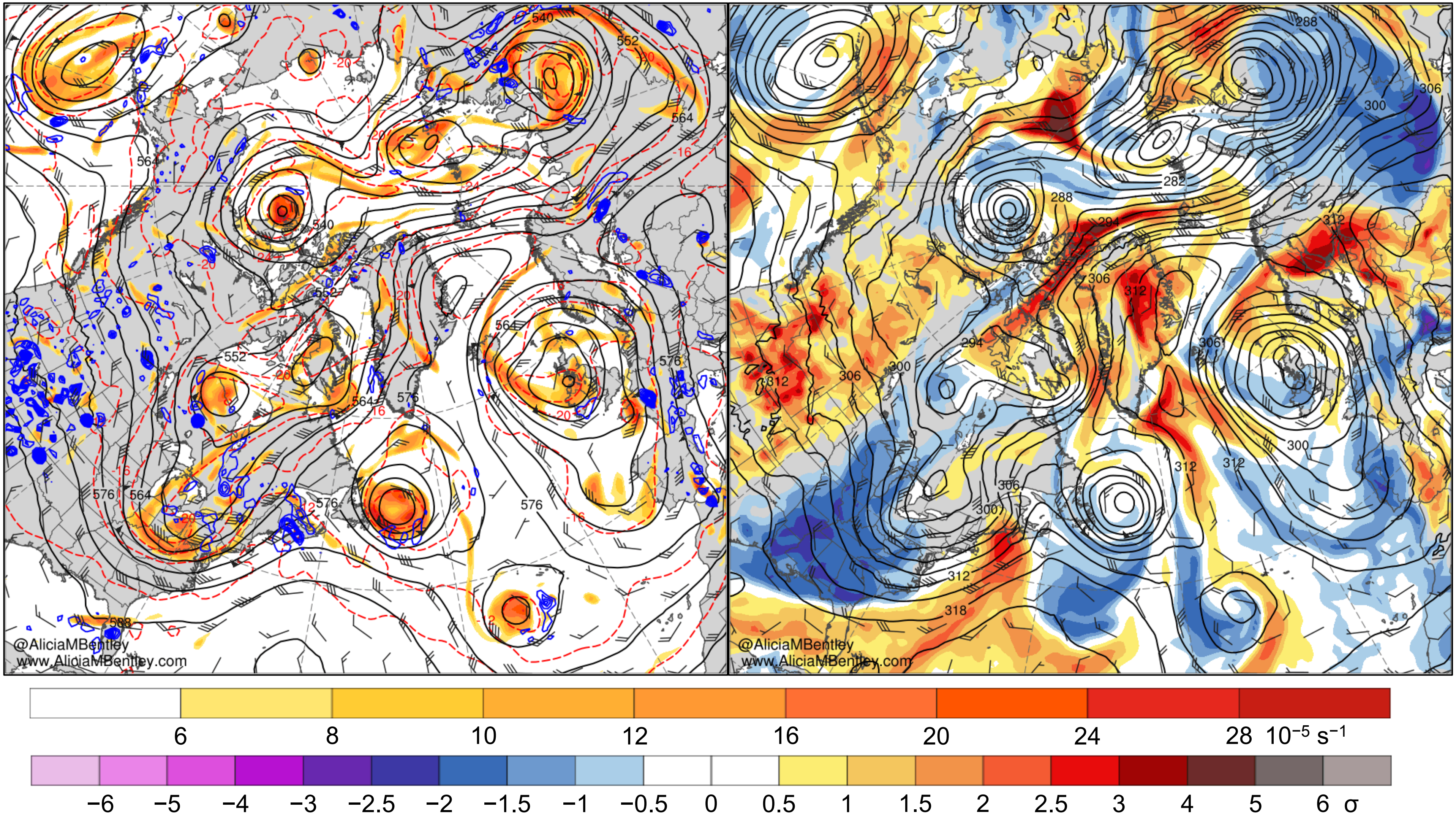
700-hPa geo. height (dam, black) and wind (kt, flags and barbs), and standardized anomalies of PW (σ, shaded)

0000 UTC 13 Jun 2019



500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5×10^{-3} s^{-1}, blue), and wind (kt, flags and barbs)	700-hPa geo. height (dam, black) and wind (kt, flags and barbs), and standardized anomalies of PW (σ, shaded)

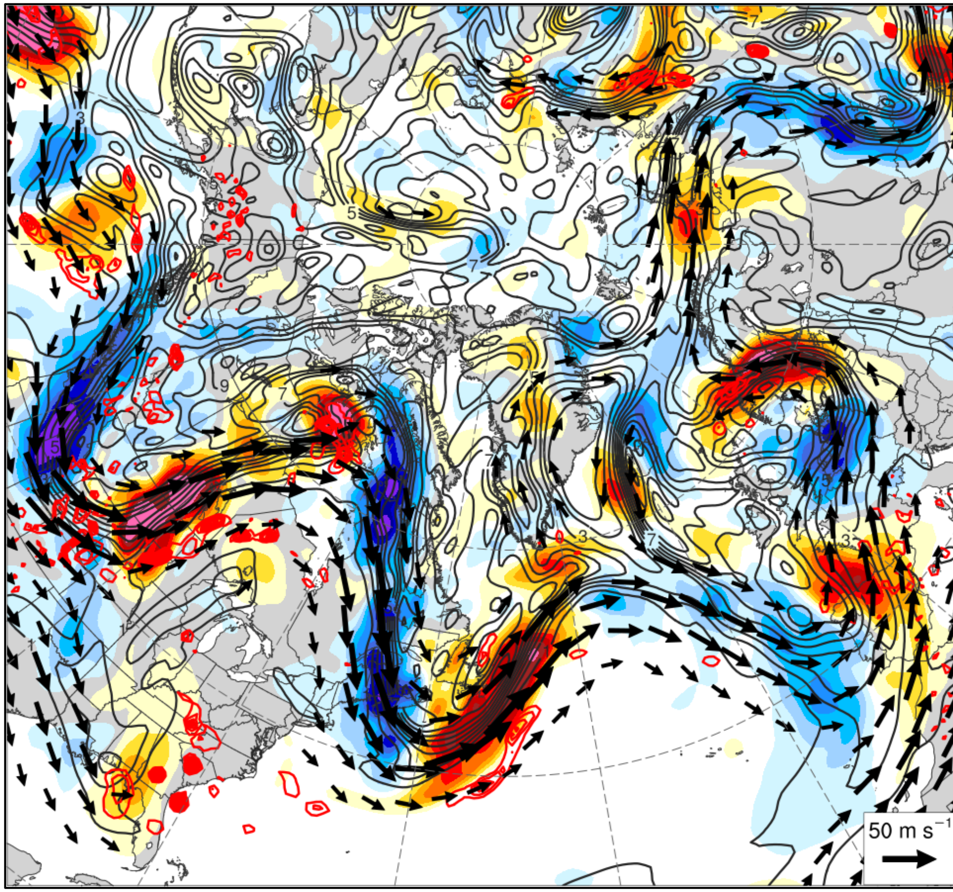
0000 UTC 14 Jun 2019

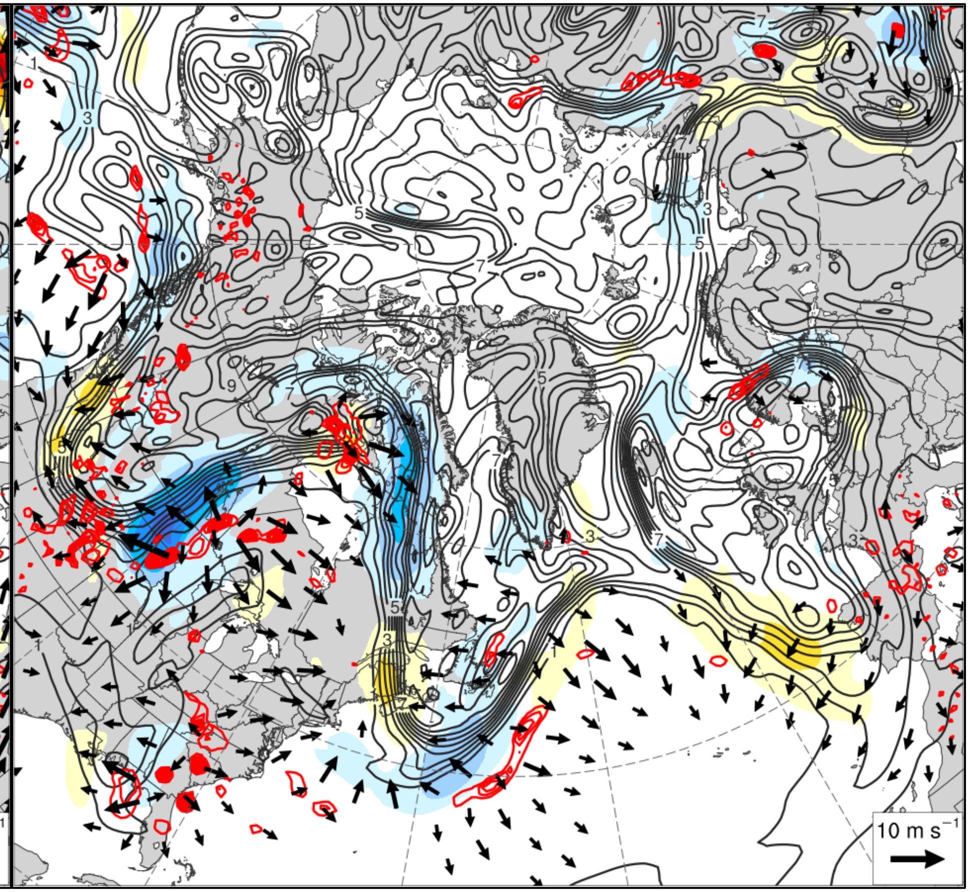


500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5×10^{-3} s^{-1}, blue), and wind (kt, flags and barbs)

700-hPa geo. height (dam, black) and wind (kt, flags and barbs), and standardized anomalies of PW (σ, shaded)

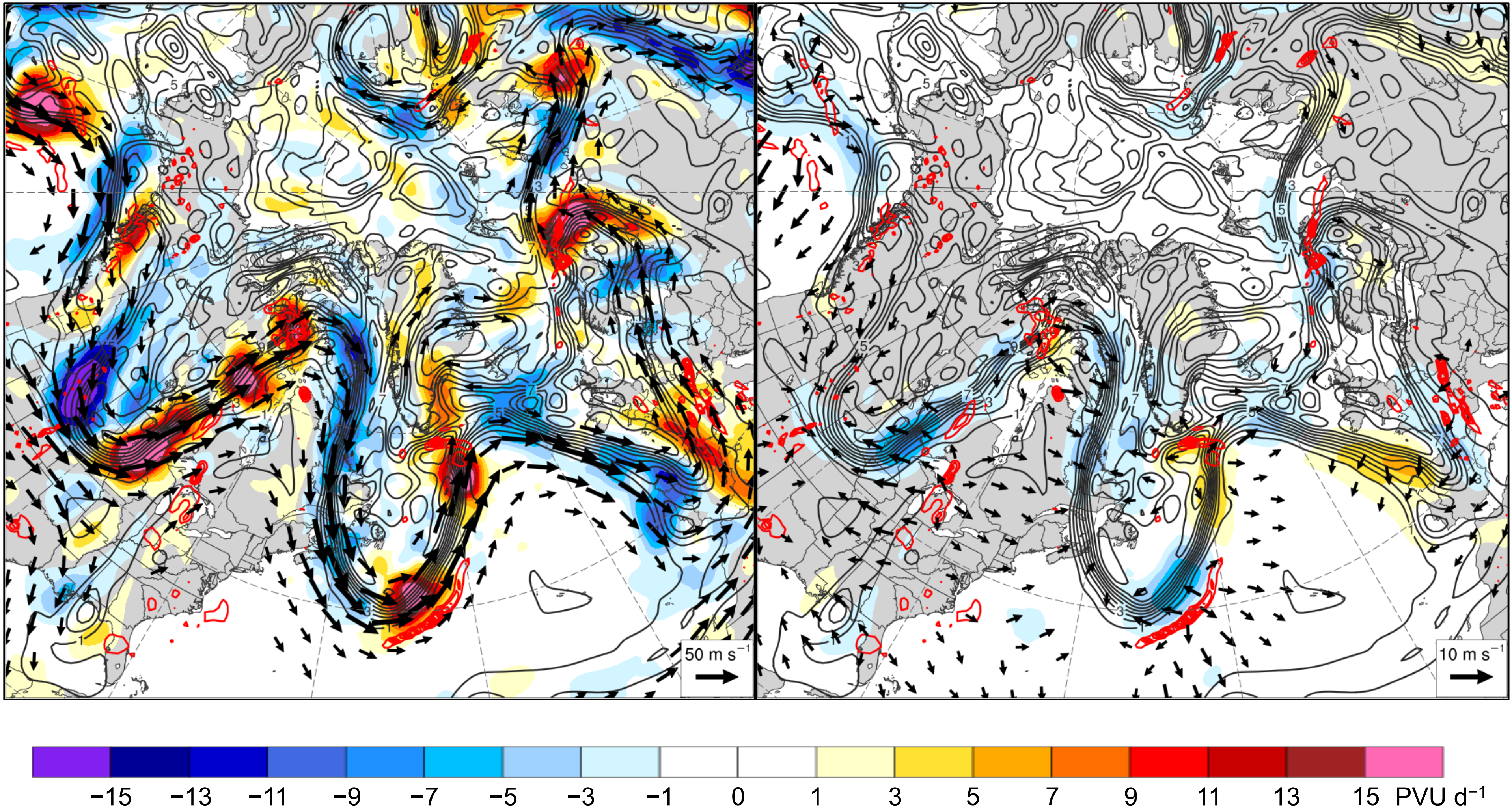
0000 UTC 9 Jun 2019





300–200-hPa PV (PVU, gray), nondivergent wind (m s^{-1}, vectors), and PV advection by nondivergent wind (PVU d^{-1}, shading), and 600–400-hPa ω (5 × 10^{-3} s^{-1}, red)	300–200-hPa PV (PVU, gray), irrotational wind (m s^{-1}, vectors), and PV advection by irrotational wind (PVU d^{-1}, shading), and 600–400-hPa ω (5 × 10^{-3} s^{-1}, red)

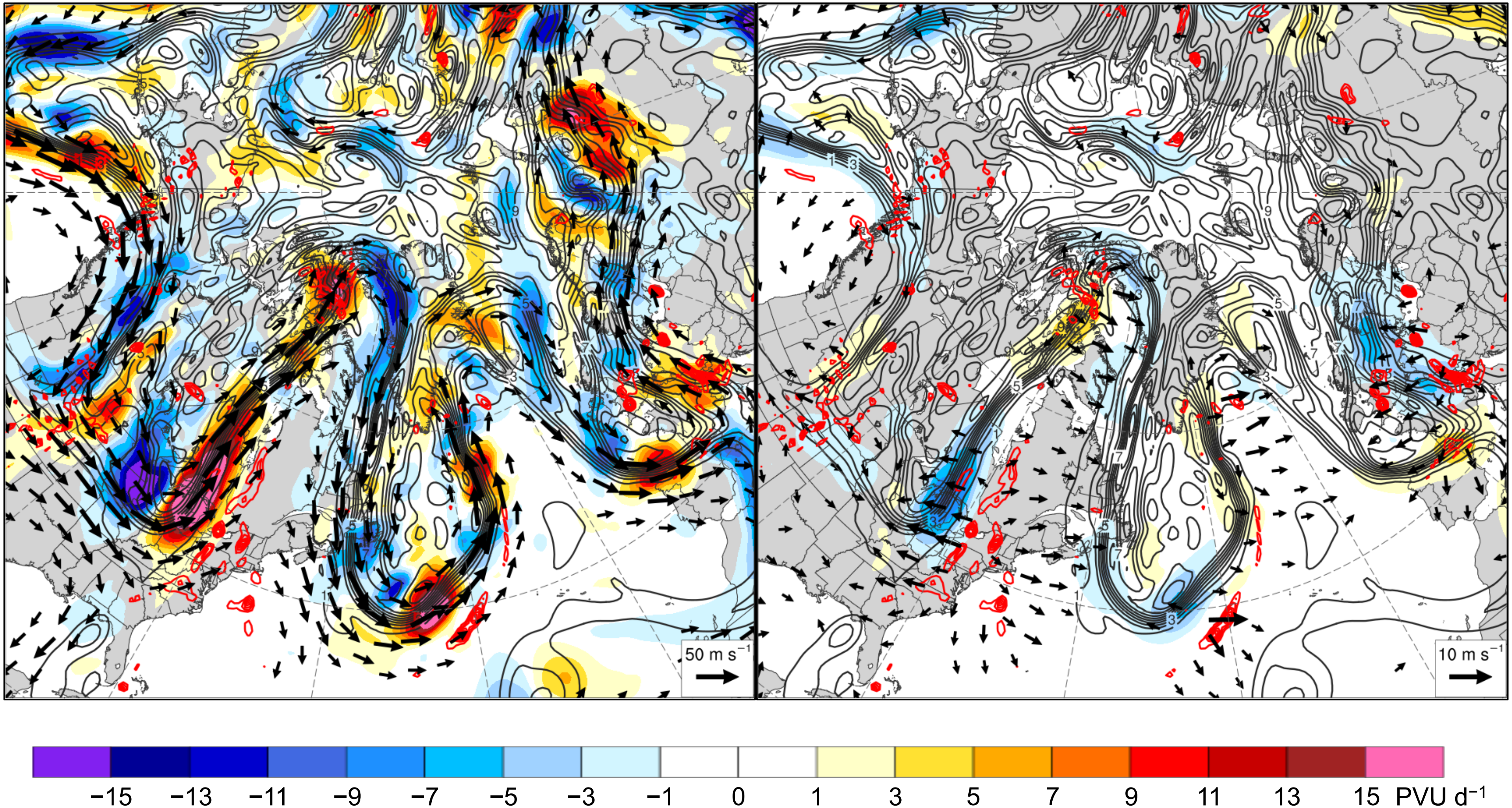
0000 UTC 10 Jun 2019



300–200-hPa PV (PVU, gray), nondivergent wind (m s^{-1}, vectors), and PV advection by nondivergent wind (PVU d^{-1}, shading), and 600–400-hPa ω (5 × 10^{-3} s^{-1}, red)

300–200-hPa PV (PVU, gray), irrotational wind (m s^{-1}, vectors), and PV advection by irrotational wind (PVU d^{-1}, shading), and 600–400-hPa ω (5 × 10^{-3} s^{-1}, red)

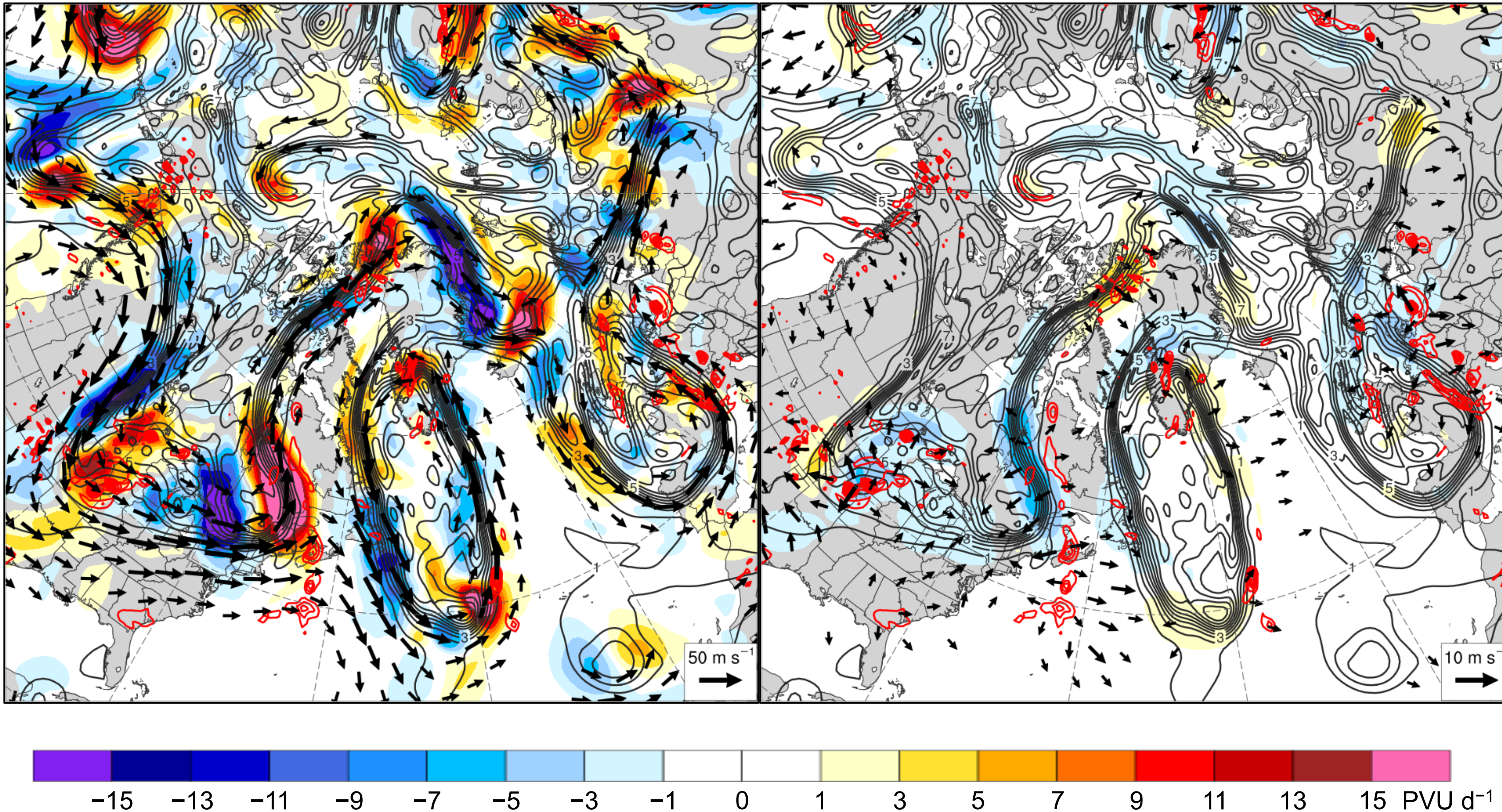
0000 UTC 11 Jun 2019



300–200-hPa PV (PVU, gray), nondivergent wind (m s^{-1}, vectors), and PV advection by nondivergent wind (PVU d^{-1}, shading), and 600–400-hPa ω (5 × 10^{-3} s^{-1}, red)

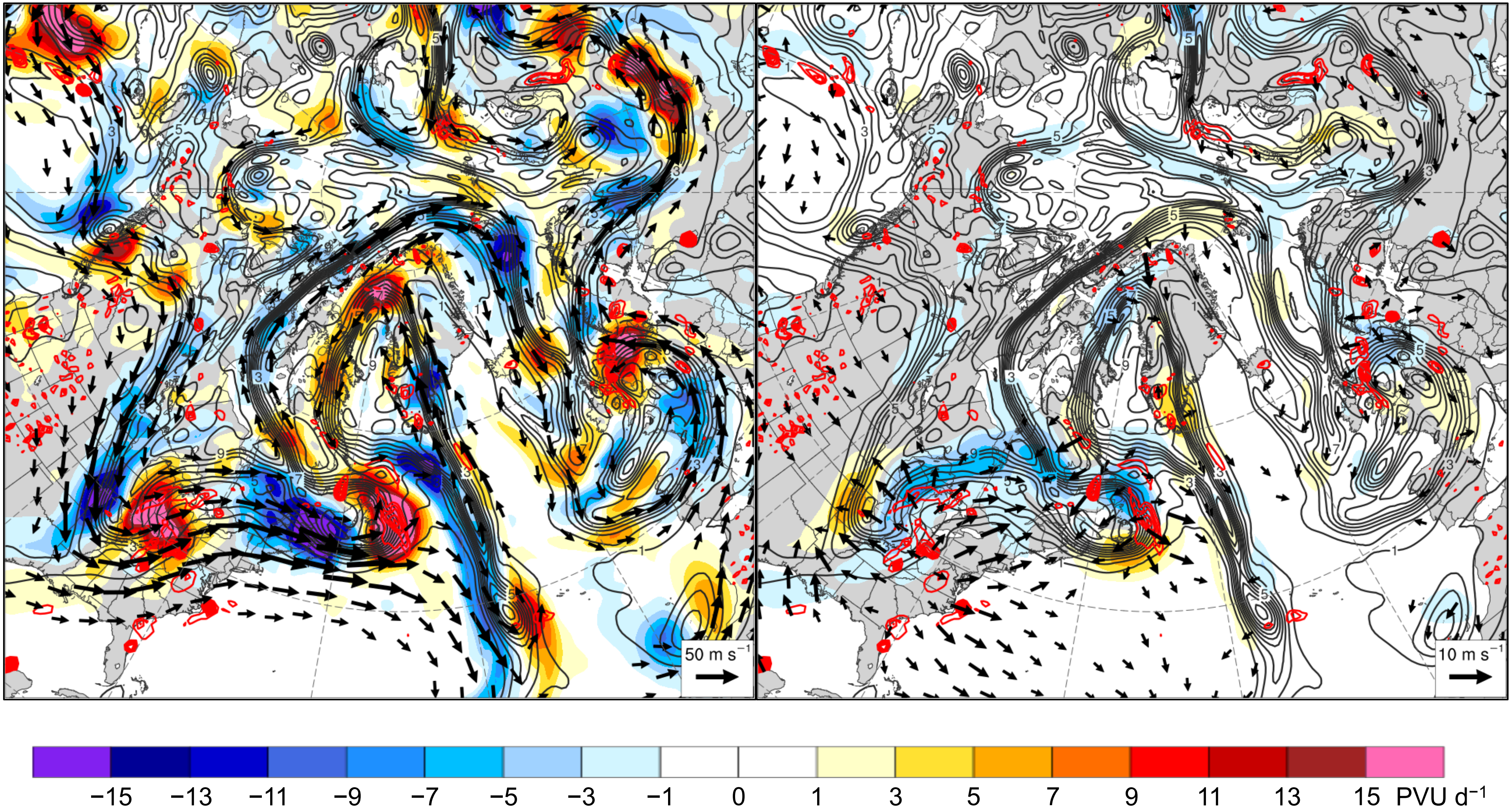
300–200-hPa PV (PVU, gray), irrotational wind (m s^{-1}, vectors), and PV advection by irrotational wind (PVU d^{-1}, shading), and 600–400-hPa ω (5 × 10^{-3} s^{-1}, red)

0000 UTC 12 Jun 2019



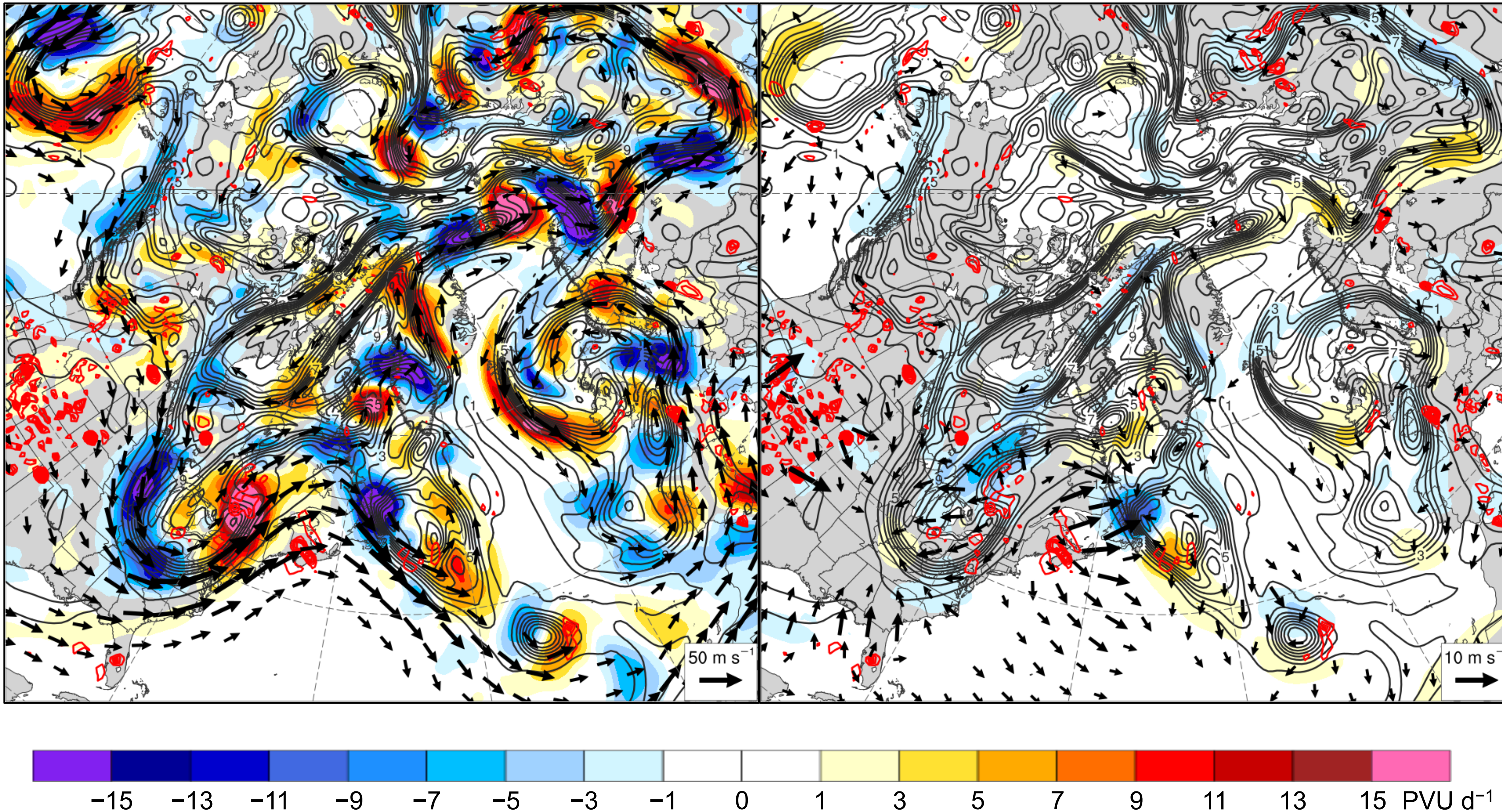
300–200-hPa PV (PVU, gray), nondivergent wind (m s^{-1}, vectors), and PV advection by nondivergent wind (PVU d^{-1}, shading), and 600–400-hPa ω (5 × 10^{-3} s^{-1}, red)	300–200-hPa PV (PVU, gray), irrotational wind (m s^{-1}, vectors), and PV advection by irrotational wind (PVU d^{-1}, shading), and 600–400-hPa ω (5 × 10^{-3} s^{-1}, red)

0000 UTC 13 Jun 2019



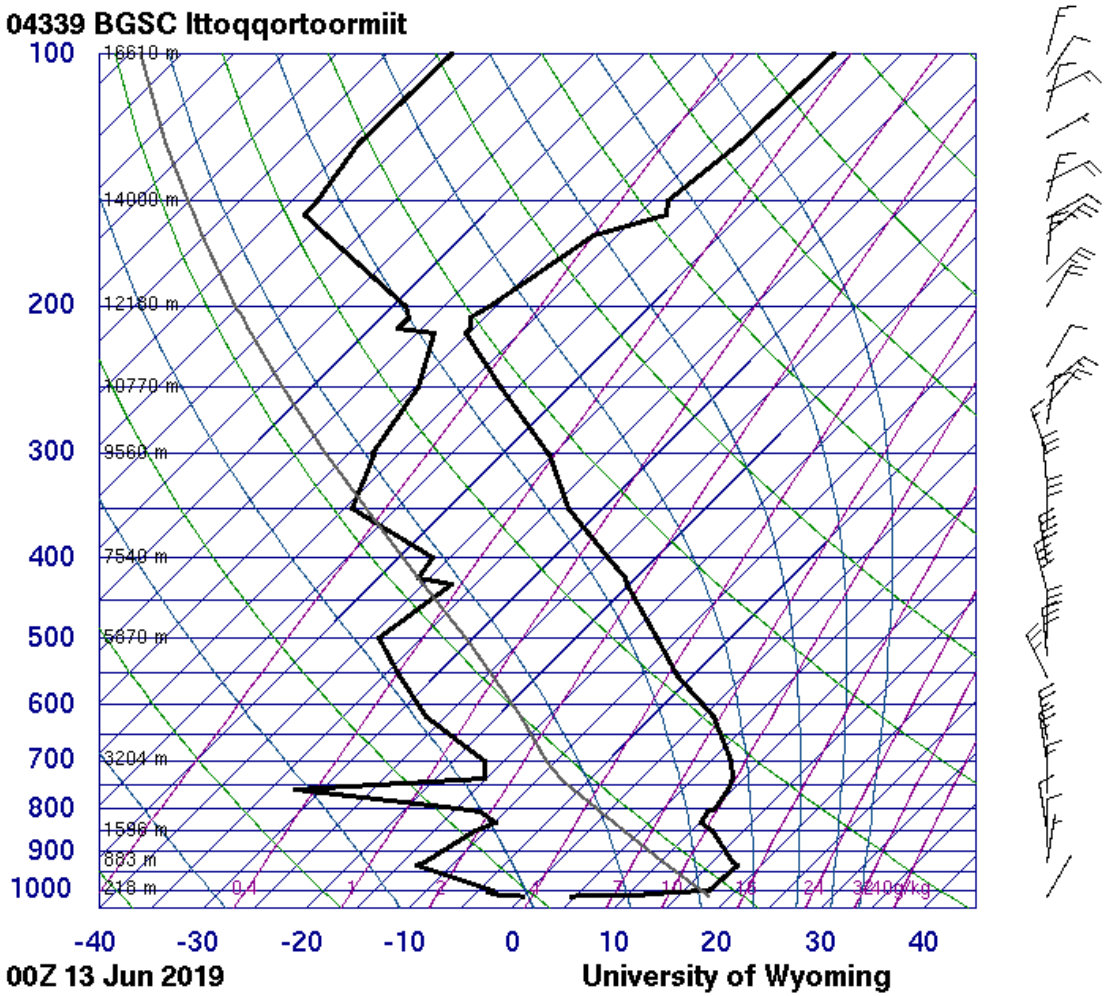
300–200-hPa PV (PVU, gray), nondivergent wind (m s^{-1}, vectors), and PV advection by nondivergent wind (PVU d^{-1}, shading), and 600–400-hPa ω (5 × 10^{-3} s^{-1}, red)	300–200-hPa PV (PVU, gray), irrotational wind (m s^{-1}, vectors), and PV advection by irrotational wind (PVU d^{-1}, shading), and 600–400-hPa ω (5 × 10^{-3} s^{-1}, red)

0000 UTC 14 Jun 2019

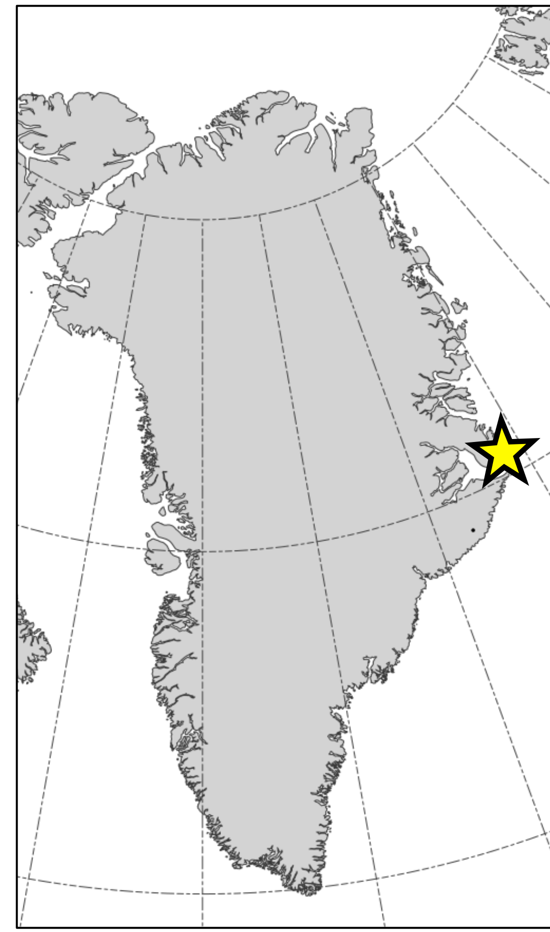


300–200-hPa PV (PVU, gray), nondivergent wind (m s^{-1}, vectors), and PV advection by nondivergent wind (PVU d^{-1}, shading), and 600–400-hPa ω (5 × 10^{-3} s^{-1}, red)	300–200-hPa PV (PVU, gray), irrotational wind (m s^{-1}, vectors), and PV advection by irrotational wind (PVU d^{-1}, shading), and 600–400-hPa ω (5 × 10^{-3} s^{-1}, red)

Sounding (0000 UTC 13 Jun 2019)

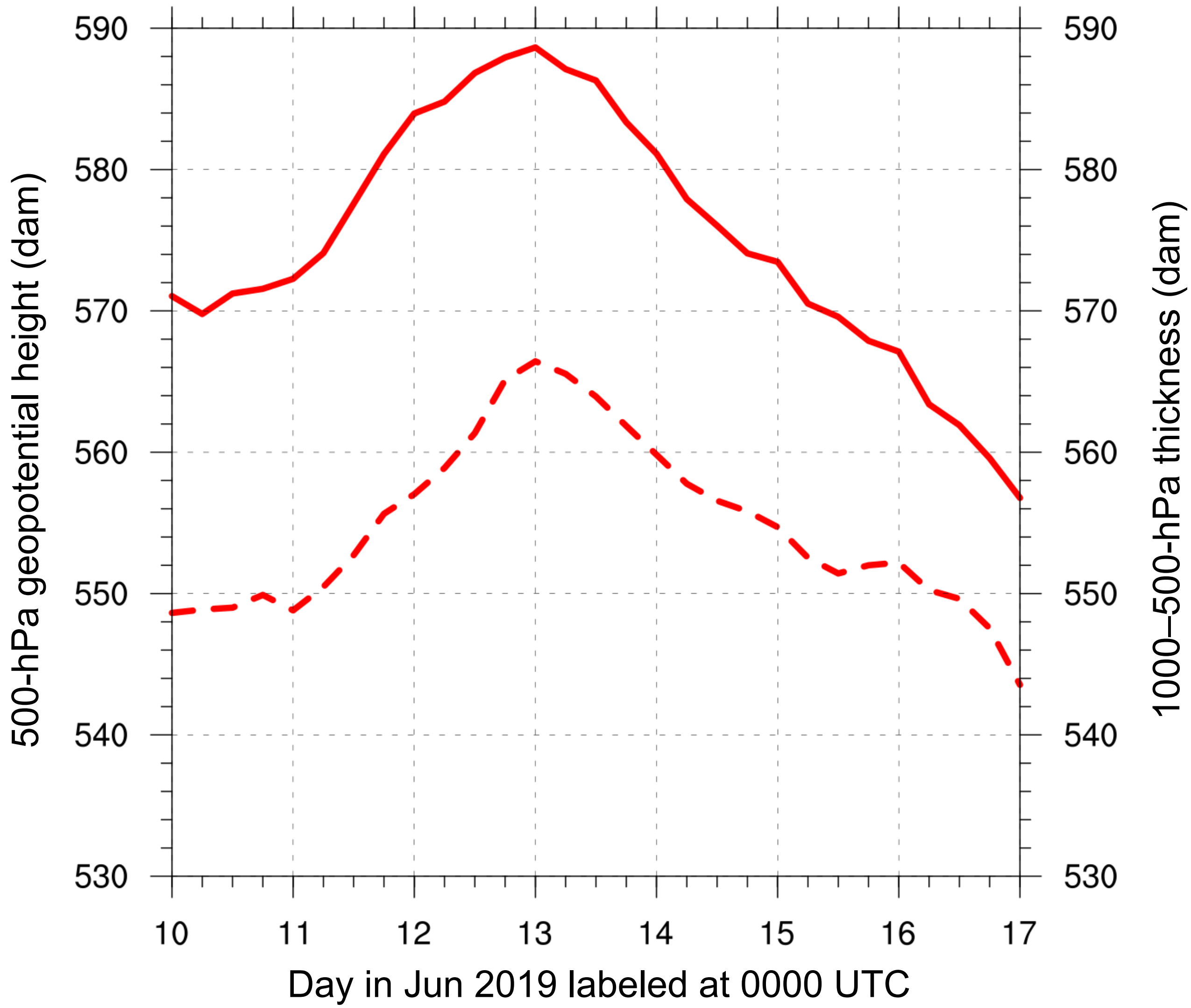


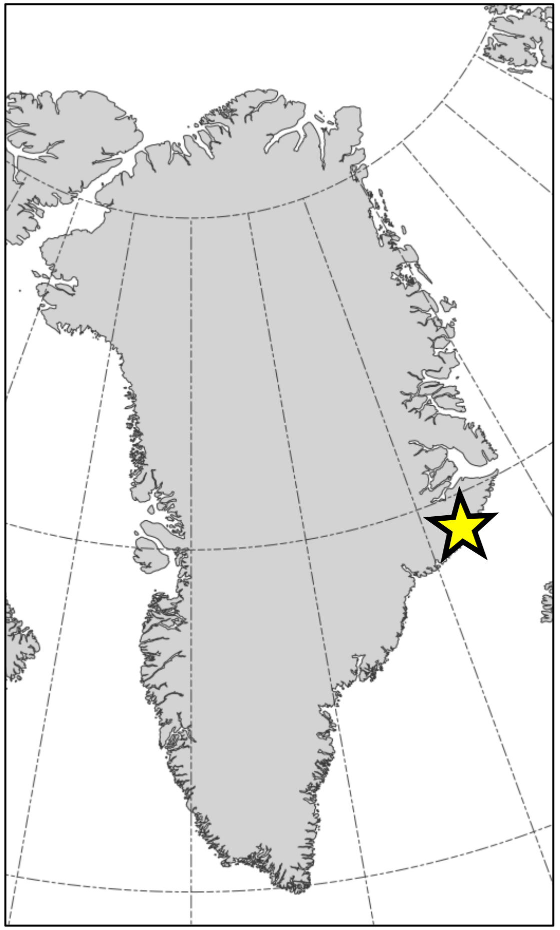
SLAT	70.48
SLON	-21.95
SELV	69.00
SHOW	13.53
LIFT	18.55
LFTV	18.50
SWET	51.01
KINX	-10.9
CTOT	1.10
VTOT	24.10
TOTL	25.20
CAPE	0.00
CAPV	0.00
CINS	0.00
CINV	0.00
EQLV	-9999
EQTV	-9999
LFCT	-9999
LFCV	-9999
BRCH	0.00
BRCV	0.00
LCLT	263.6
LCLP	719.1
MLTH	289.7
MLMR	2.67
THCK	5652.
PWAT	7.58



Source: University of Wyoming

Time Series

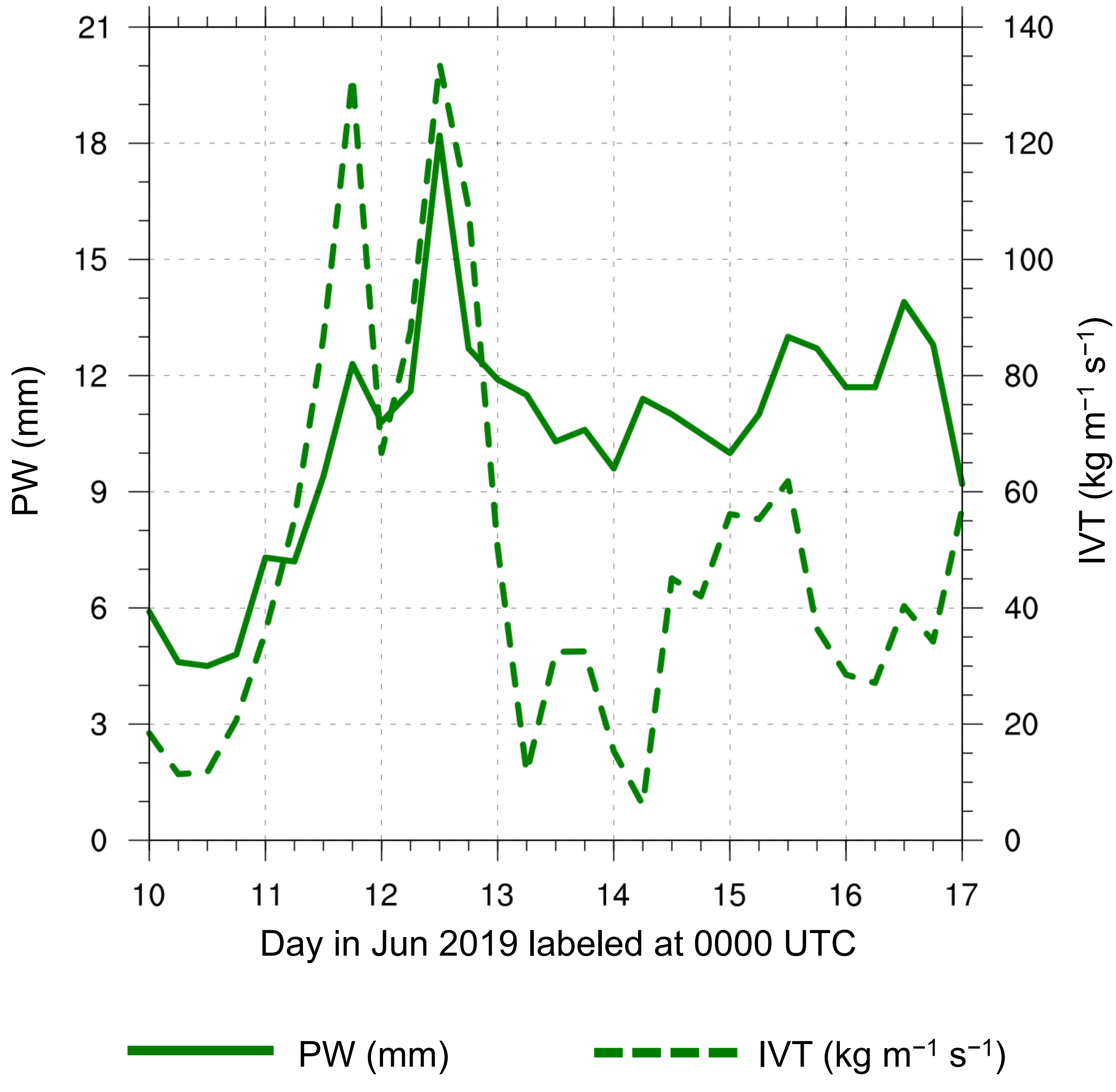




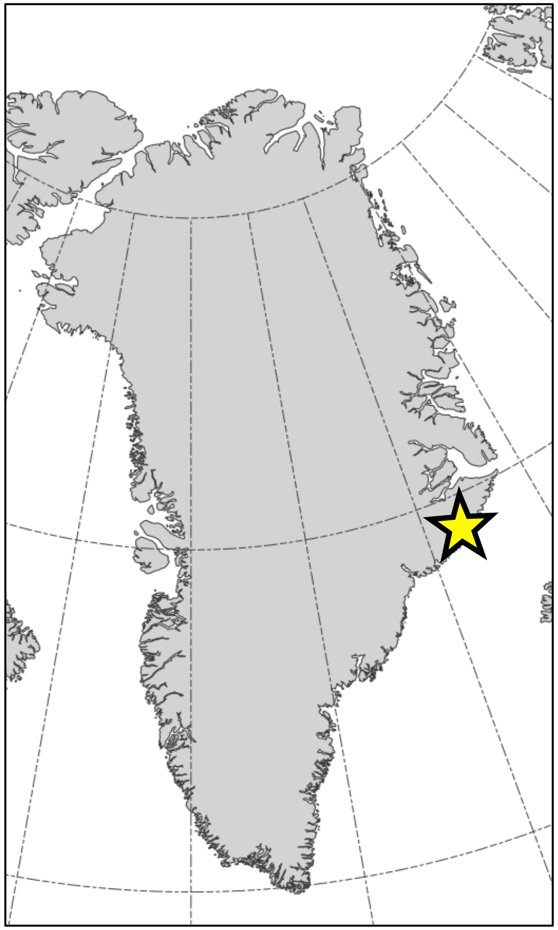
500-hPa geopotential height (dam)

1000–500-hPa thickness (dam)

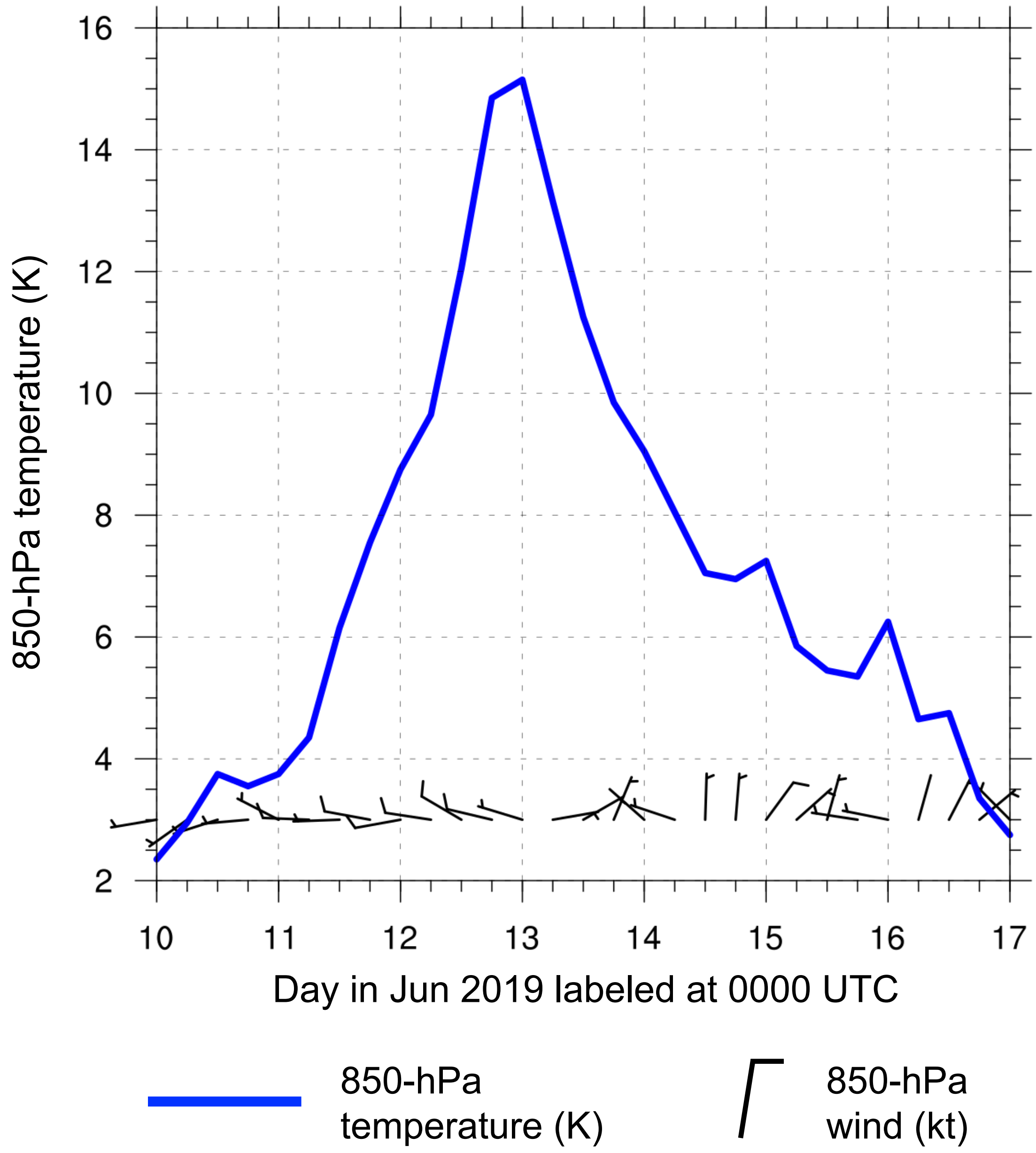
Time Series



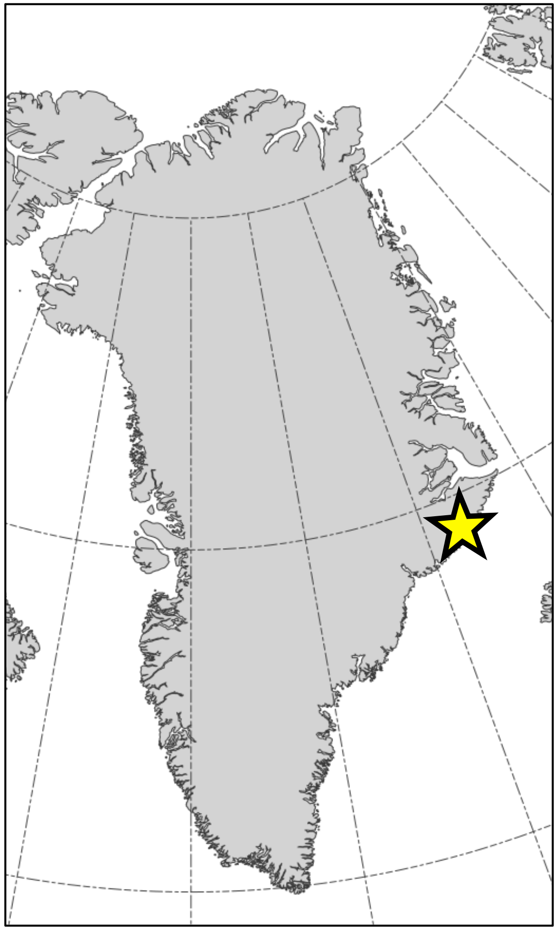
PW (mm)
IVT (kg m−1 s−1)
Day in Jun 2019 labeled at 0000 UTC
0
3
6
9
12
15
18
21
0
20
40
60
80
100
120
140
10
11
12
13
14
15
16
17
PW (mm)
IVT (kg m−1 s−1)



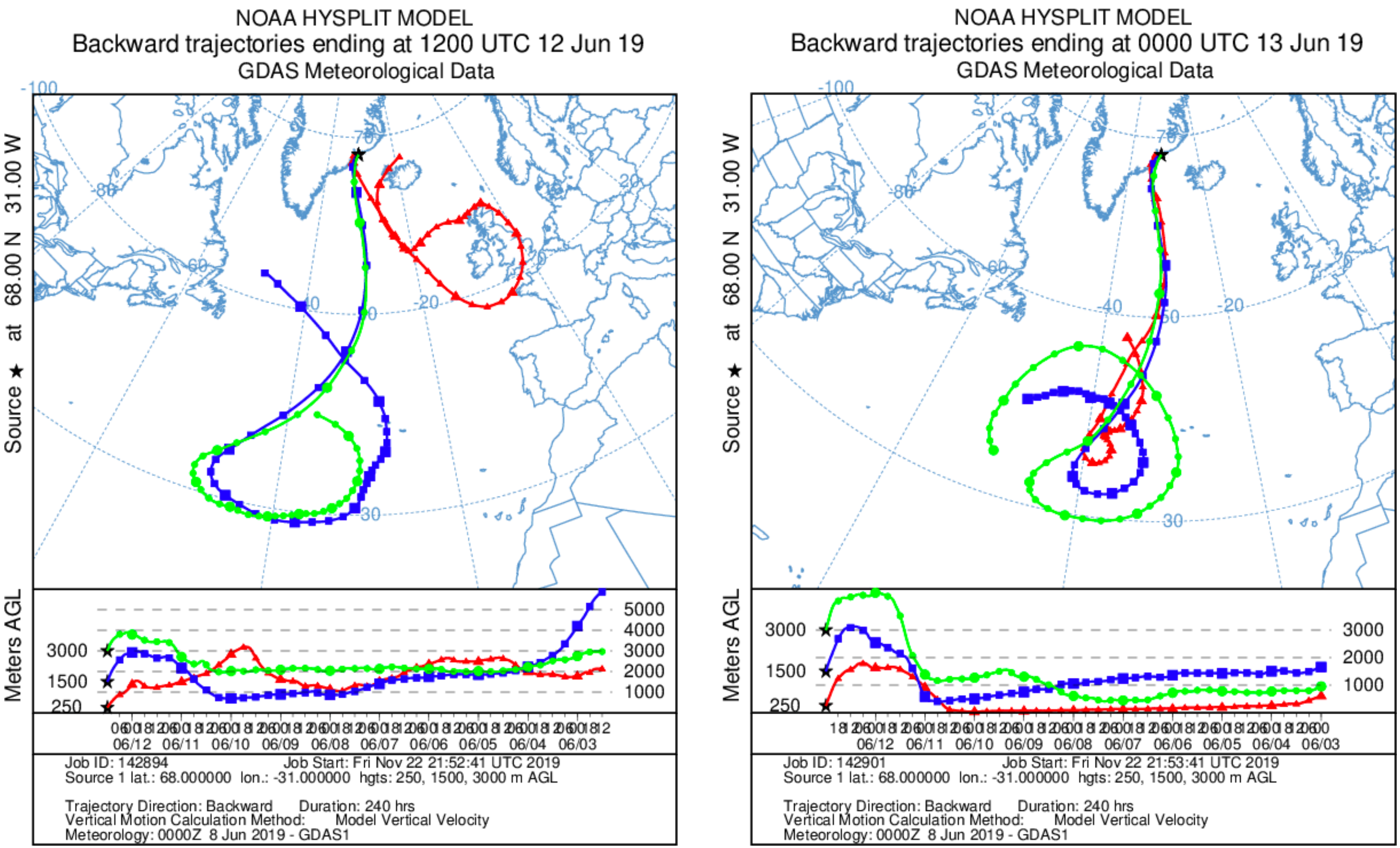
Time Series



16
14
12
10
8
6
4
2
850-hPa temperature (K)
10
11
12
13
14
15
16
17
Day in Jun 2019 labeled at 0000 UTC
850-hPa temperature (K)
850-hPa wind (kt)



Trajectories



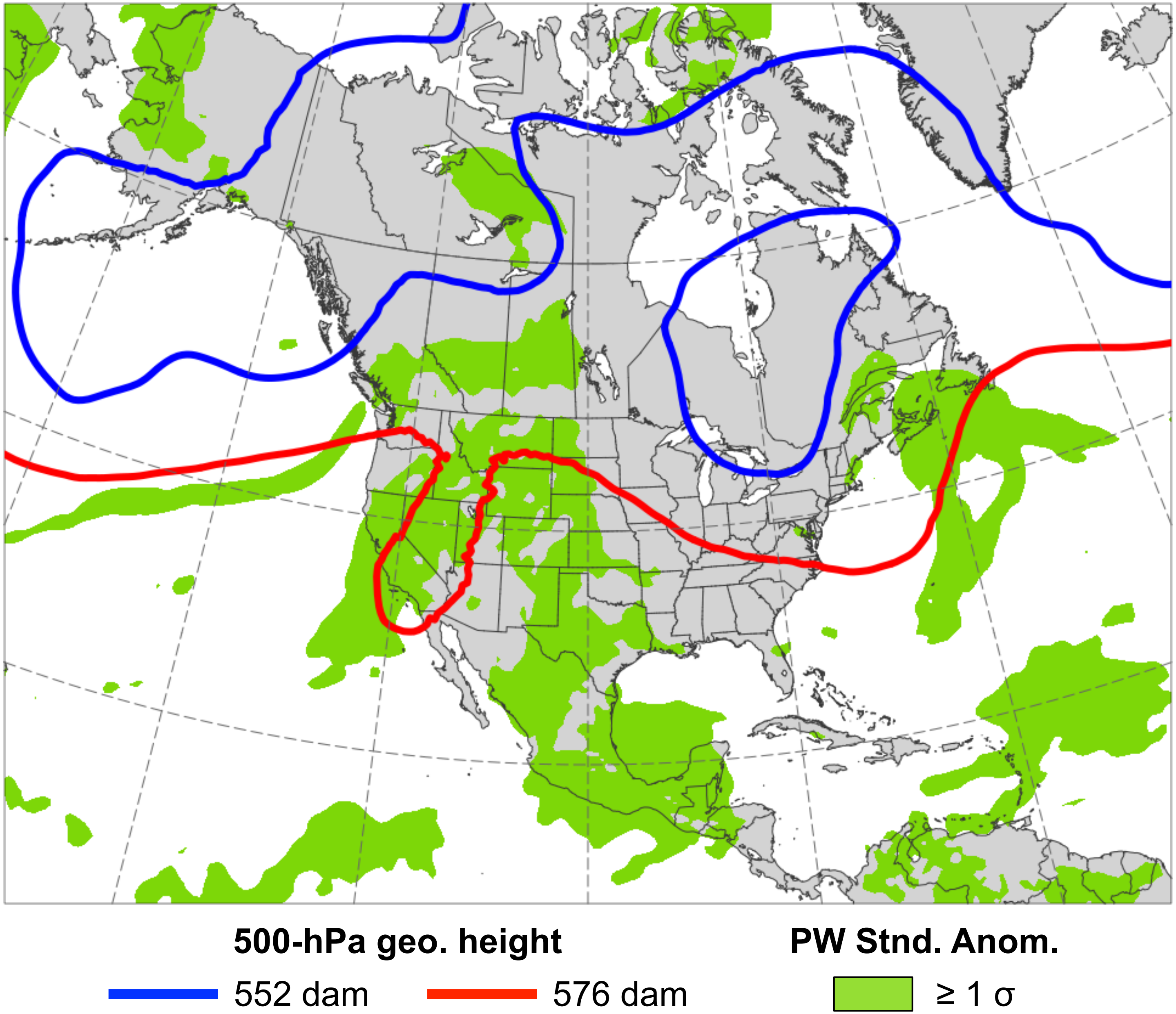
NOAA HYSPLIT backward trajectories ending at
(left) 1200 UTC 12 Jun 2019 and (right) 0000 UTC 13 Jun 2019

Summary (3)

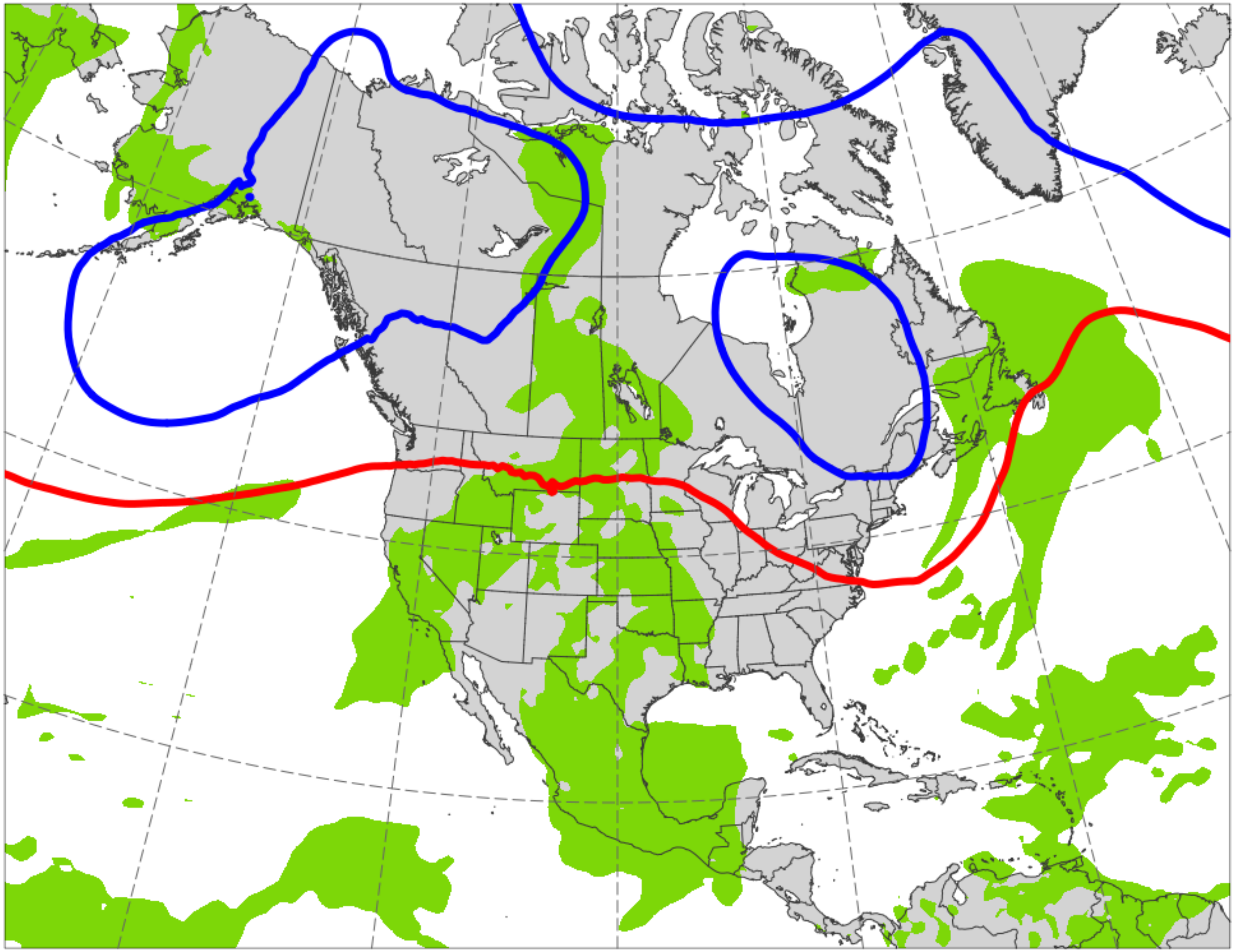
- Initial ridging over northeastern Canada occurs east of a long tropical moisture axis
- Subsequent ridging occurs over northeastern Greenland to the north of a deep cutoff cyclone
- Negative PV advection by the nondivergent and irrotational winds builds Canada and Greenland ridges
- Ridging over Canada and Greenland is further enhanced by diabatically driven ridge building

Summary of Flow Evolution
3–14 June 2019

0000 UTC 3 Jun 2019



0000 UTC 4 Jun 2019



500-hPa geo. height

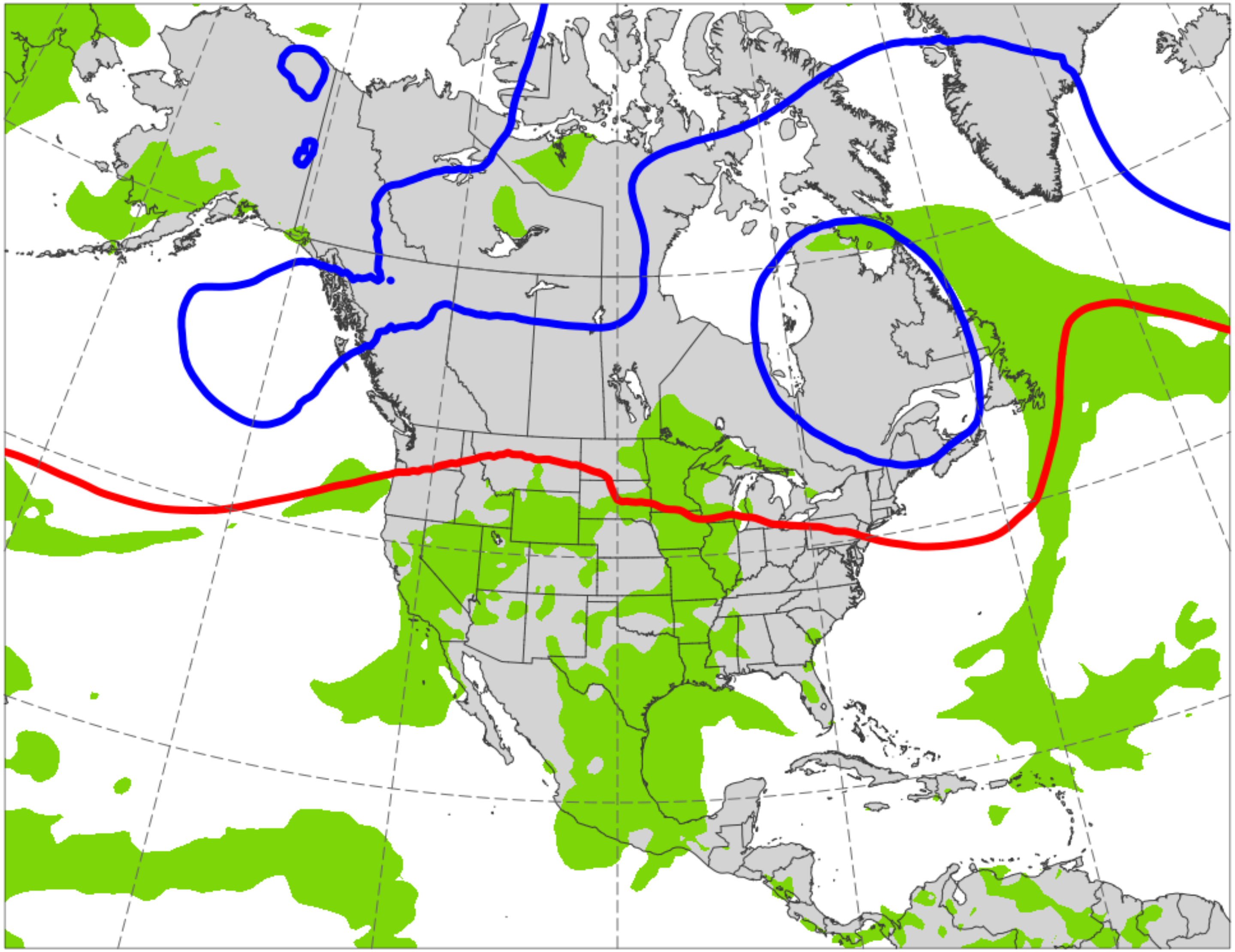
552 dam

576 dam

PW Stnd. Anom.

≥ 1 σ

0000 UTC 5 Jun 2019



500-hPa geo. height

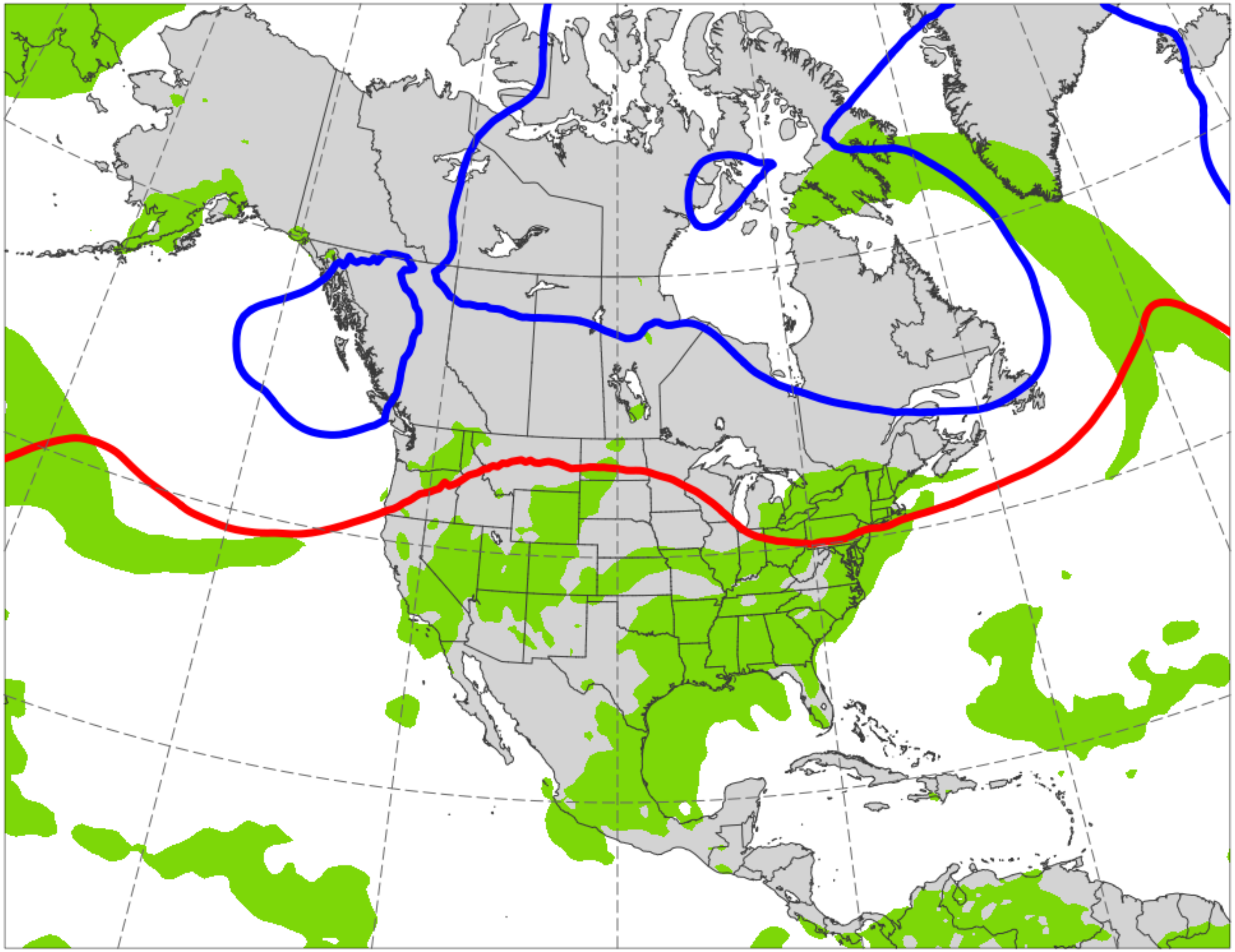
552 dam

576 dam

PW Stnd. Anom.

≥ 1 σ

0000 UTC 6 Jun 2019



500-hPa geo. height

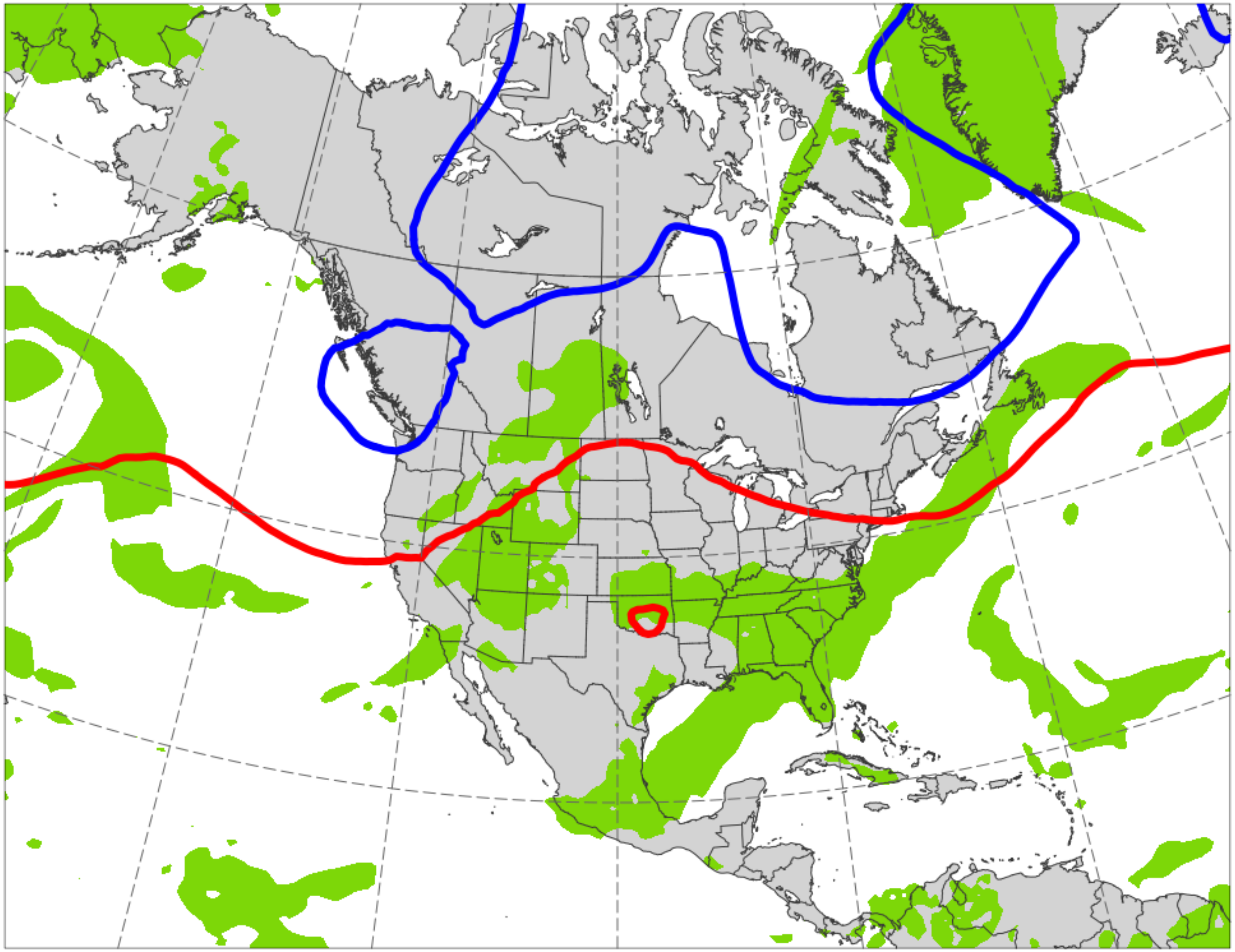
552 dam

576 dam

PW Stnd. Anom.

≥ 1 σ

0000 UTC 7 Jun 2019



500-hPa geo. height

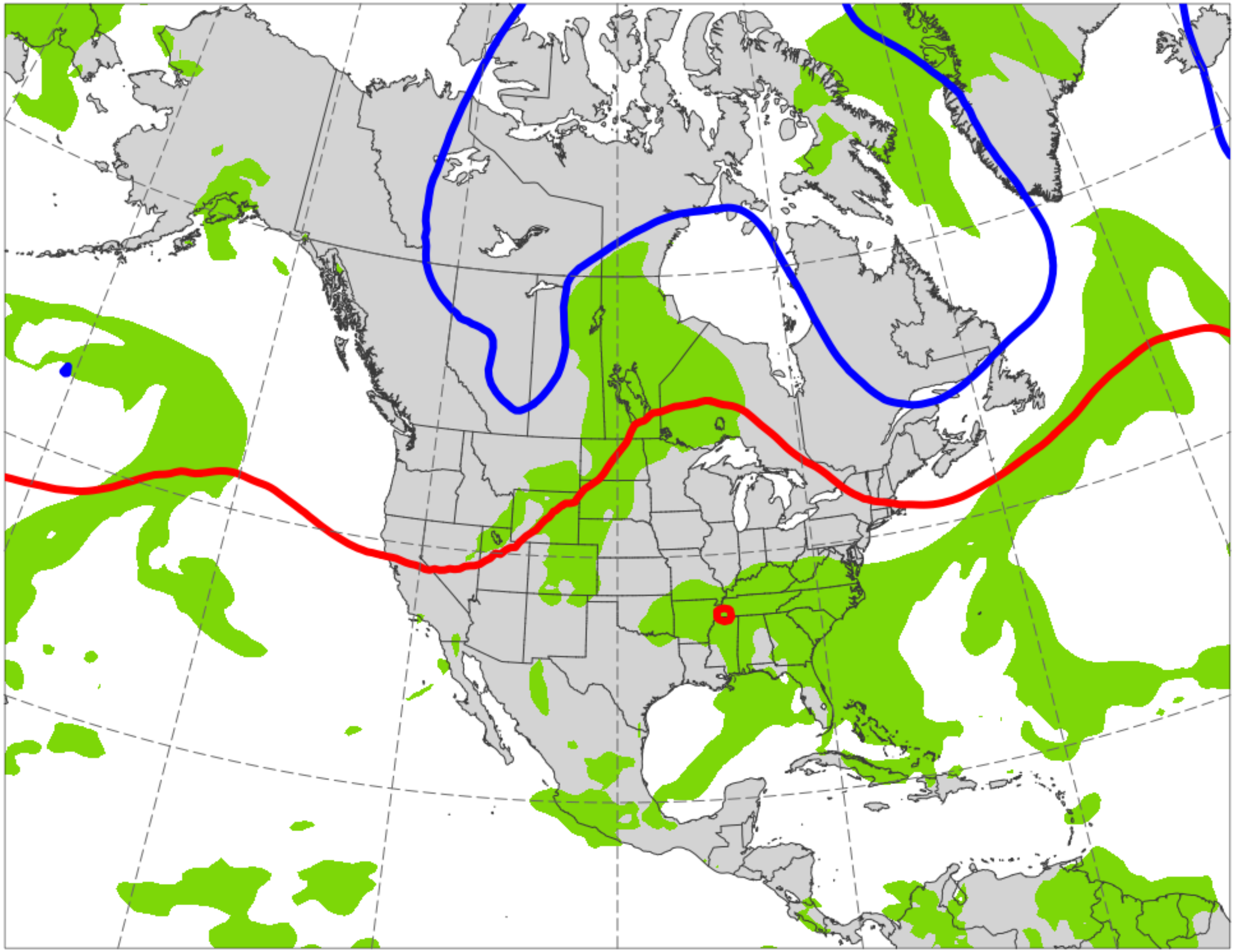
552 dam

576 dam

PW Stnd. Anom.

≥ 1 σ

0000 UTC 8 Jun 2019



500-hPa geo. height

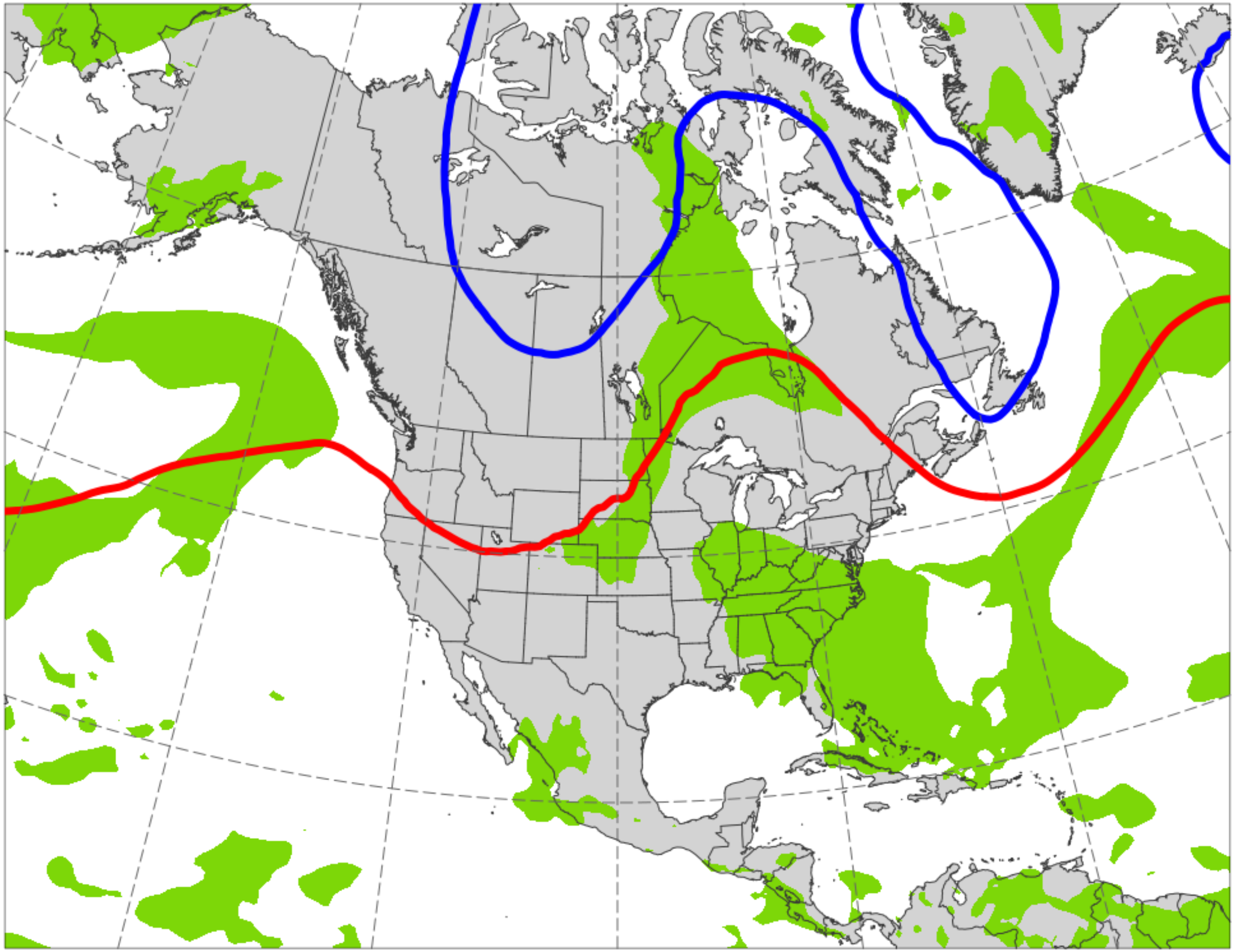
552 dam

576 dam

PW Stnd. Anom.

≥ 1 σ

0000 UTC 9 Jun 2019



500-hPa geo. height

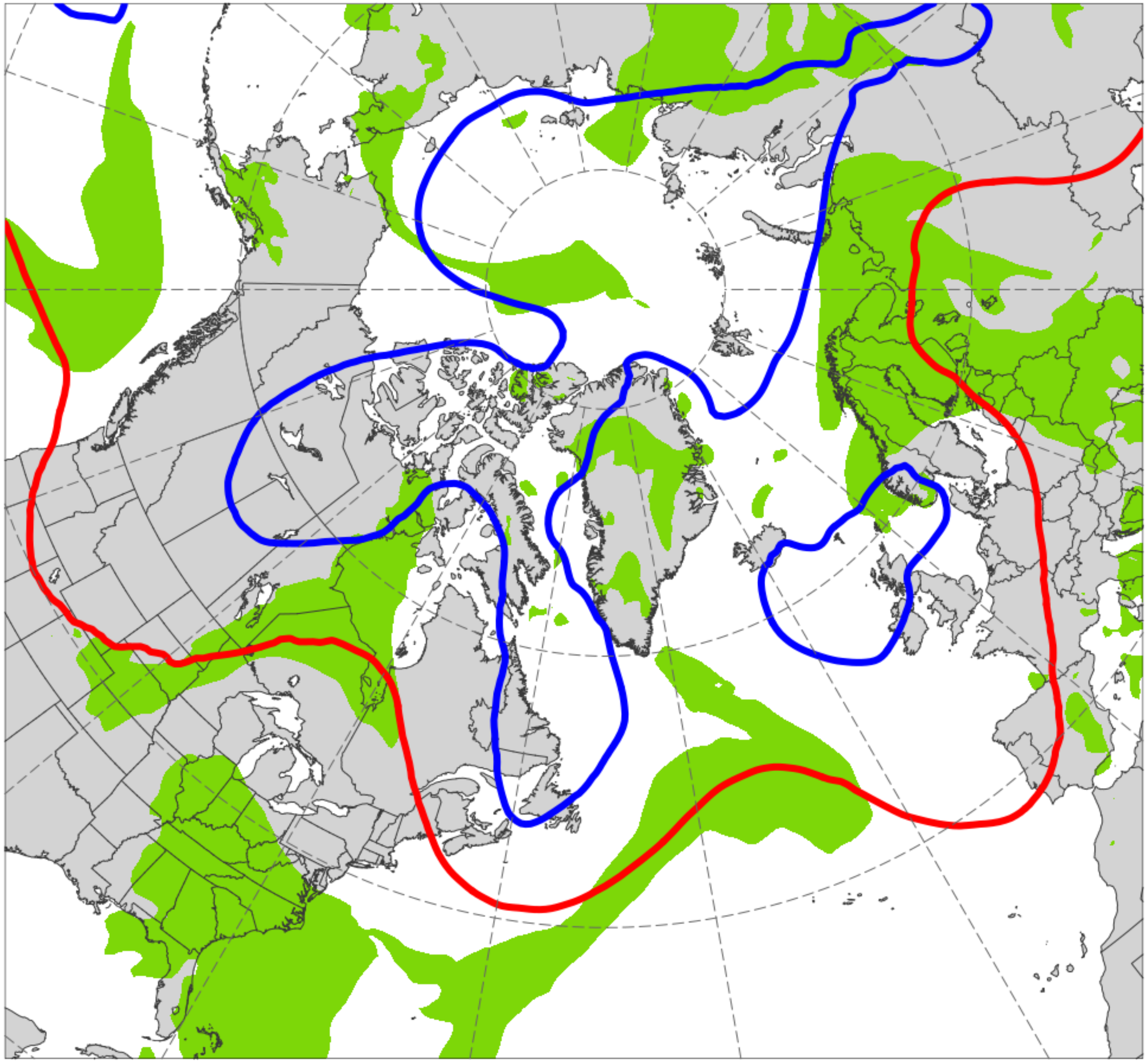
552 dam

576 dam

PW Stnd. Anom.

≥ 1 σ

0000 UTC 9 Jun 2019



500-hPa geo. height

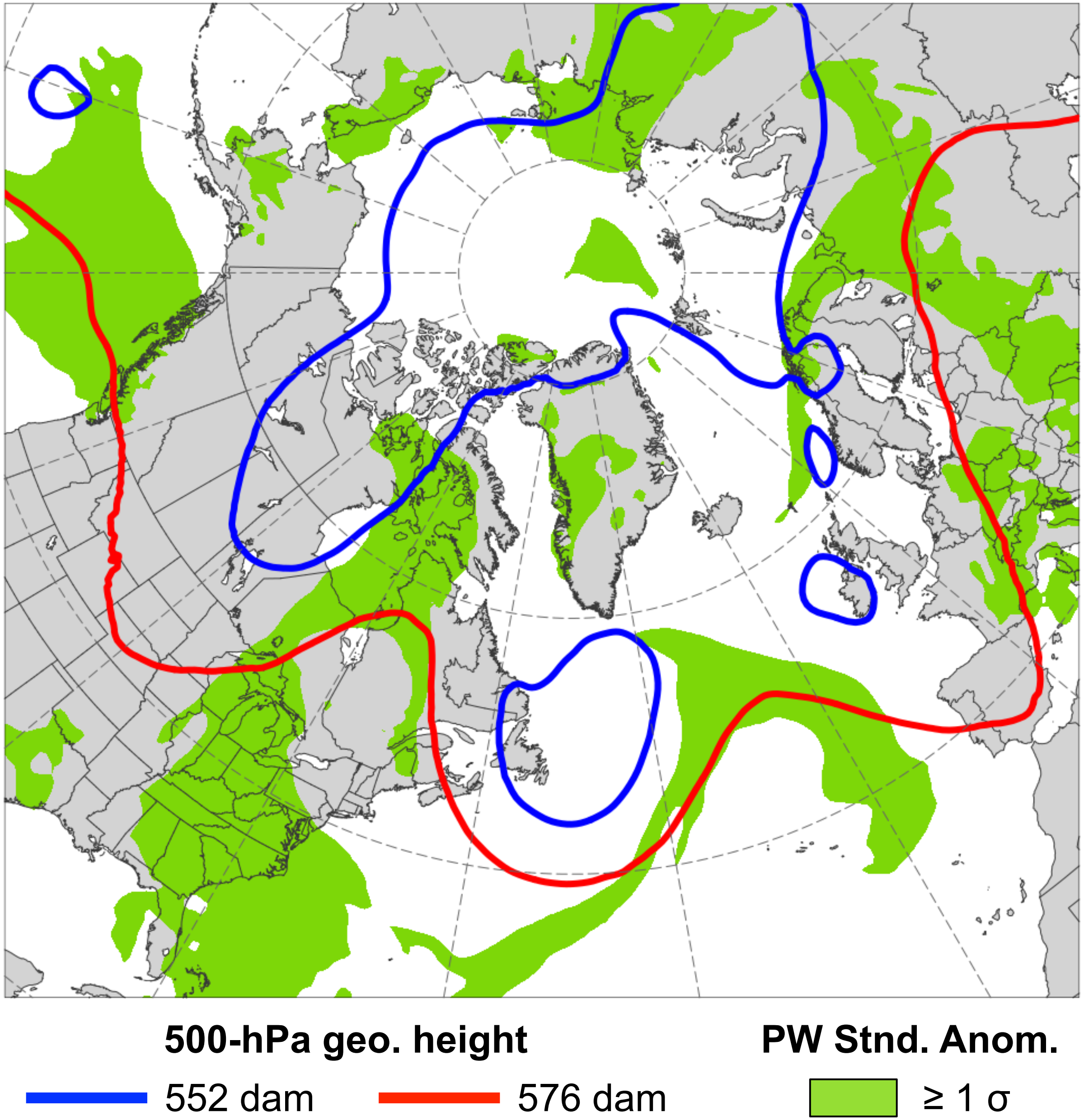
552 dam

576 dam

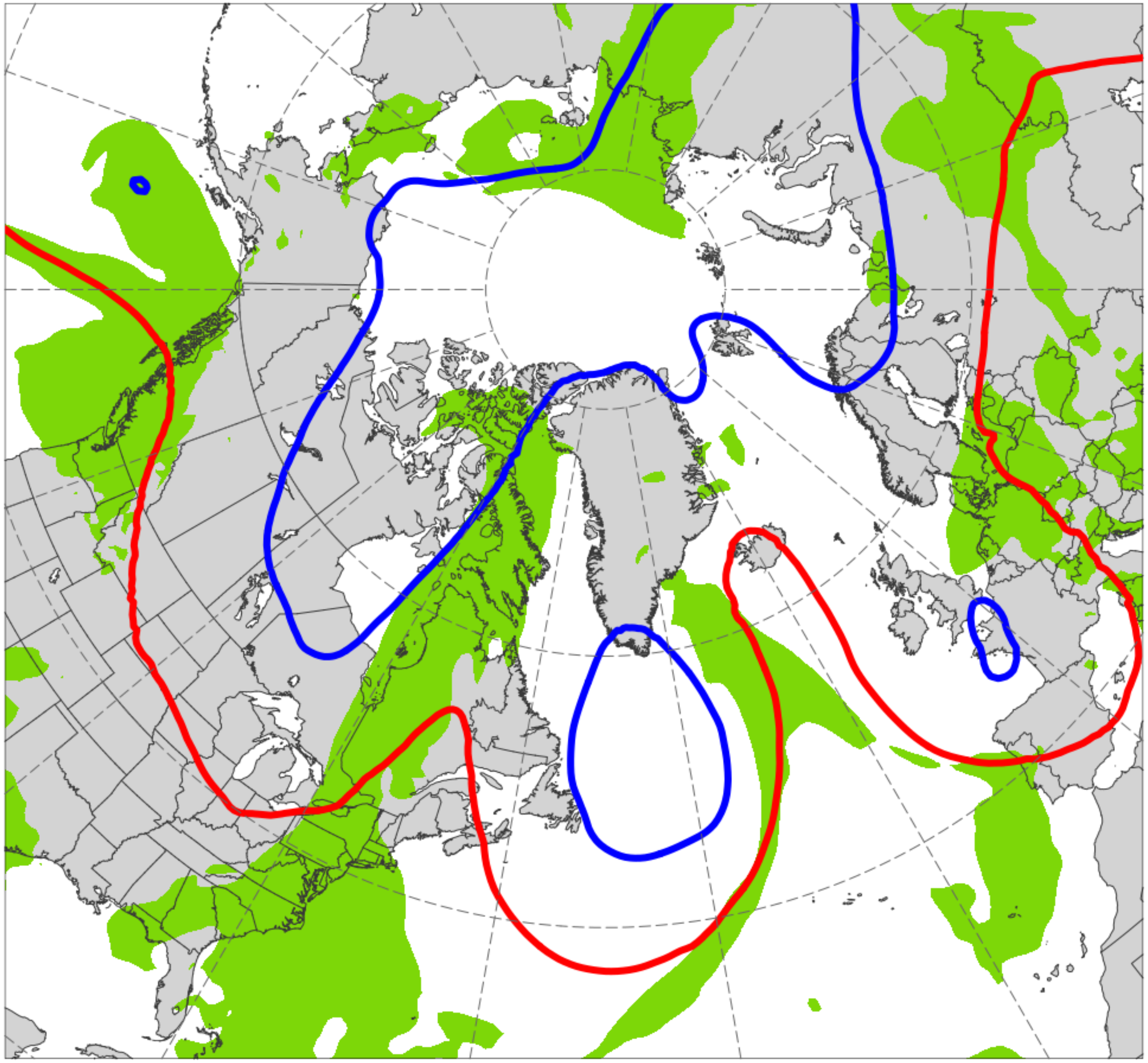
PW Stnd. Anom.

≥ 1 σ

0000 UTC 10 Jun 2019



0000 UTC 11 Jun 2019



500-hPa geo. height

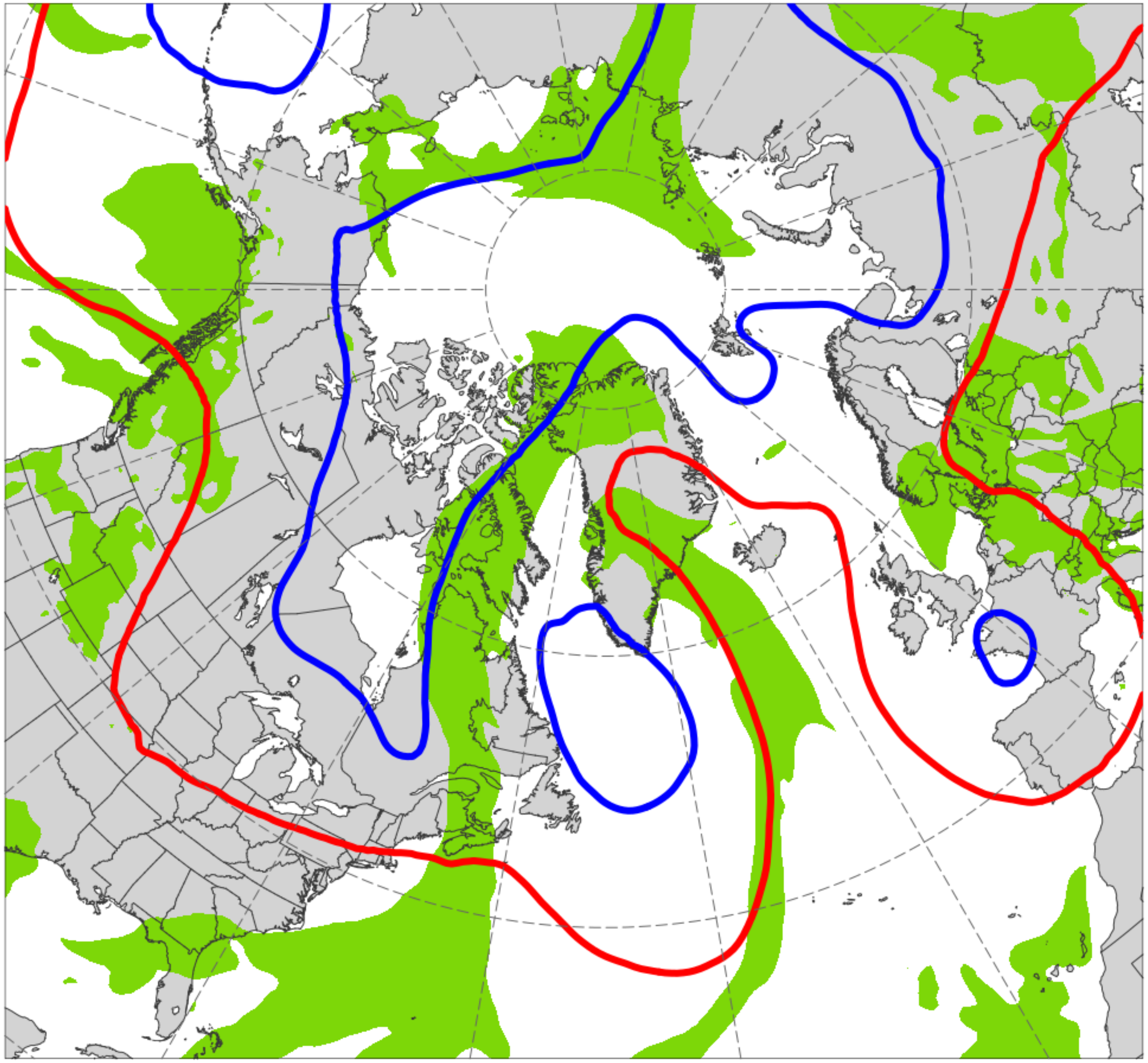
552 dam

576 dam

PW Stnd. Anom.

≥ 1 σ

0000 UTC 12 Jun 2019



500-hPa geo. height

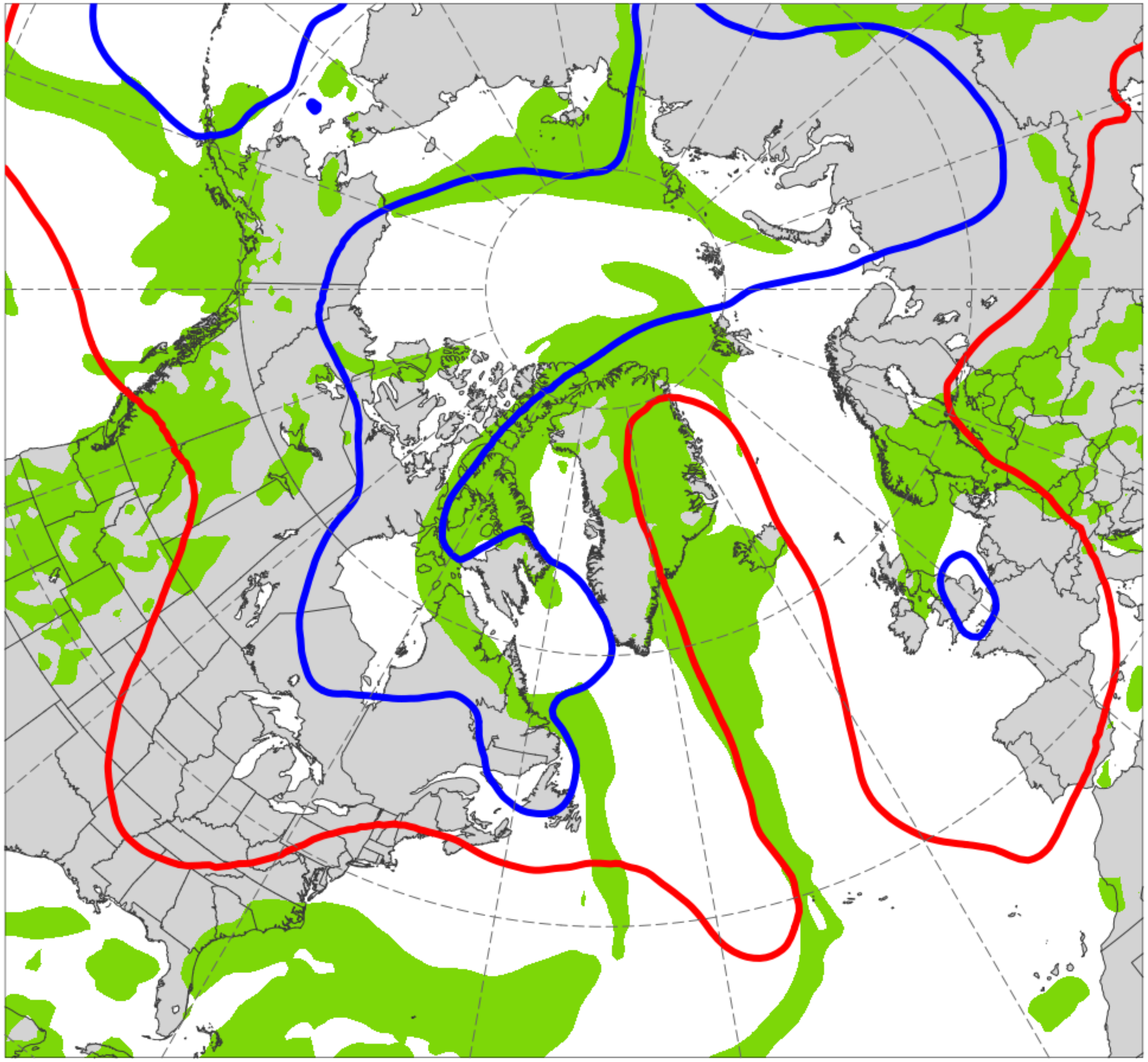
552 dam

576 dam

PW Stnd. Anom.

≥ 1 σ

0000 UTC 13 Jun 2019



500-hPa geo. height

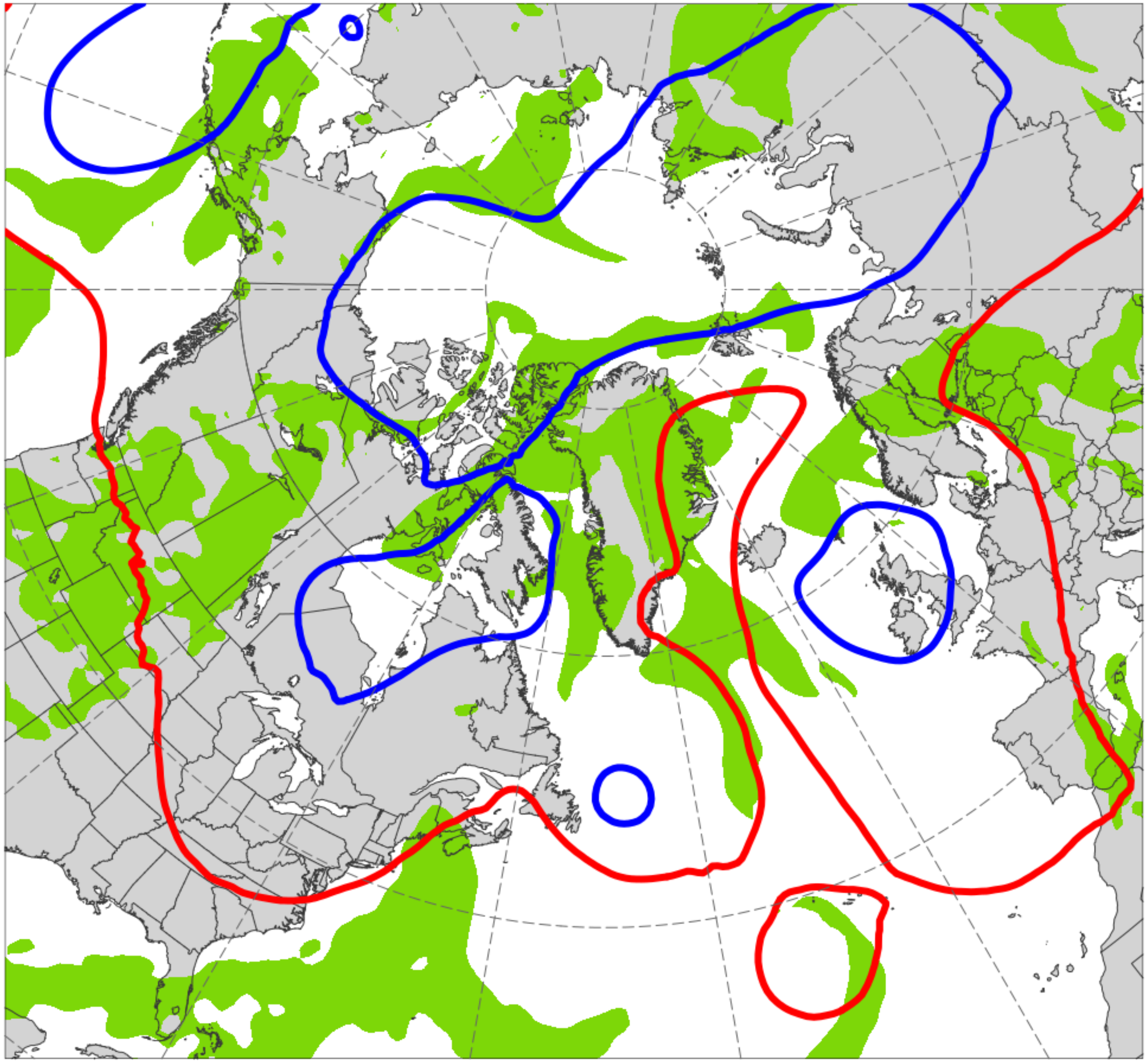
552 dam

576 dam

PW Stnd. Anom.

≥ 1 σ

0000 UTC 14 Jun 2019



500-hPa geo. height

552 dam

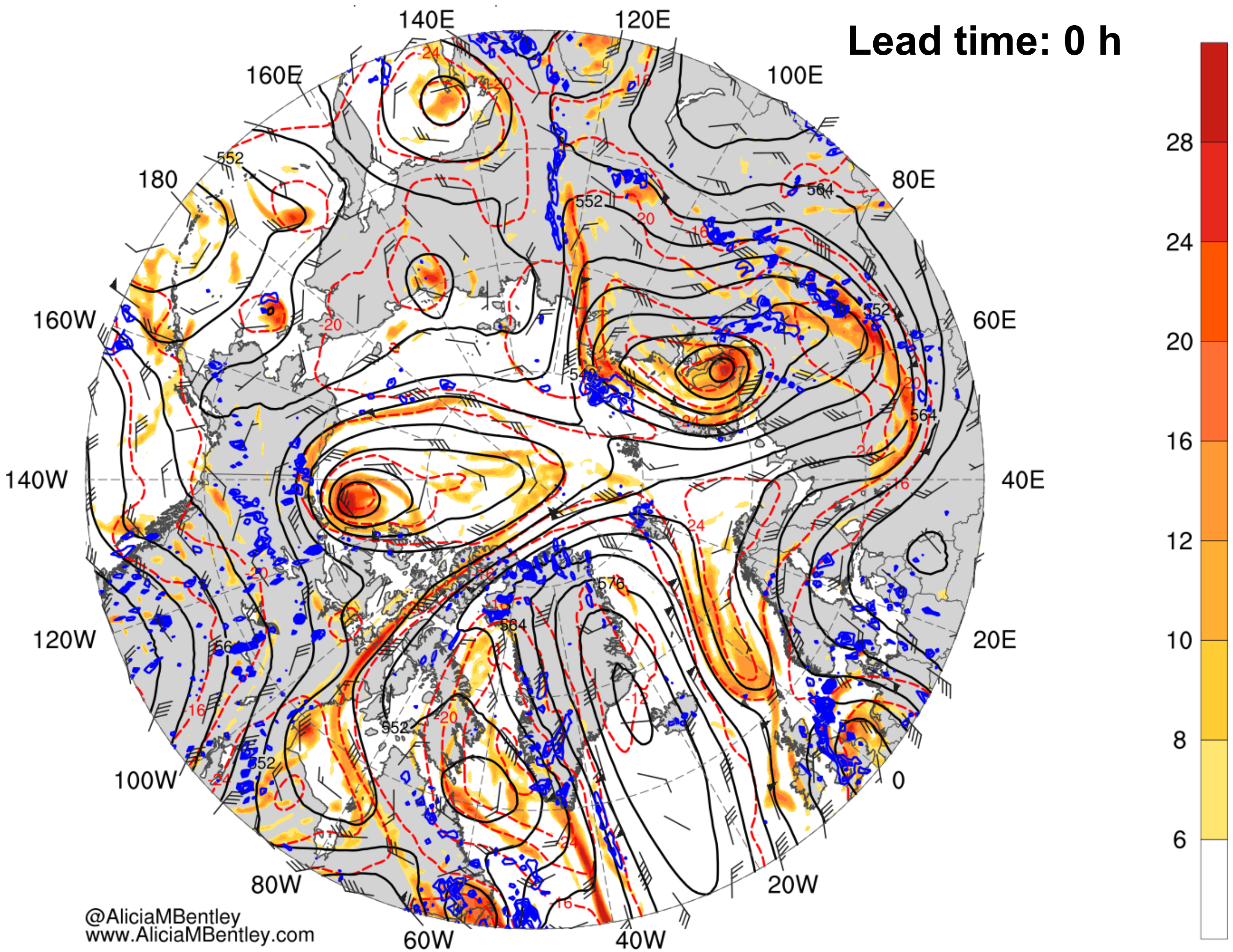
576 dam

PW Stnd. Anom.

≥ 1 σ

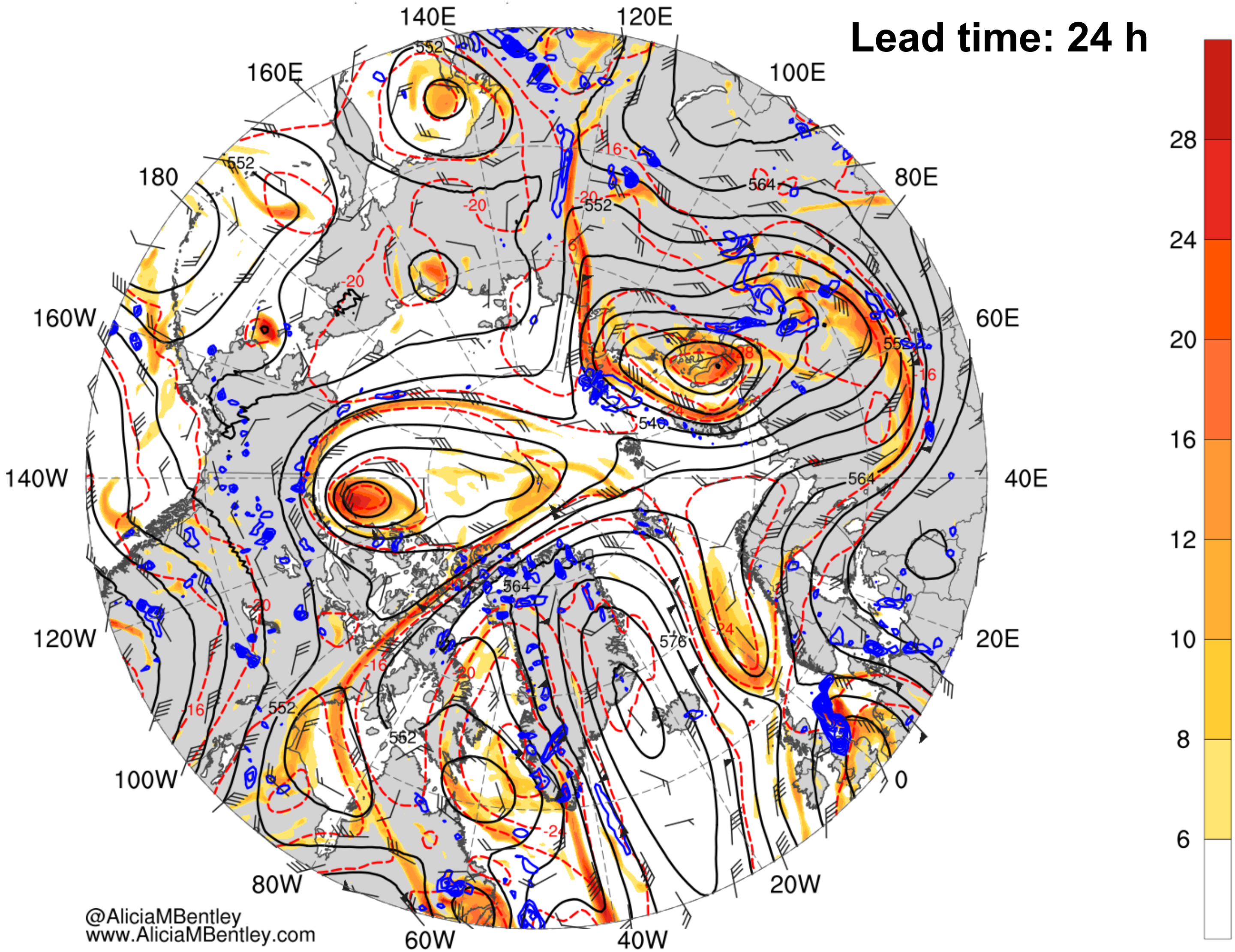
D(prog)/Dt
valid 0000 UTC 13 June 2019

D(prog)/Dt valid 0000 UTC 13 Jun 2019



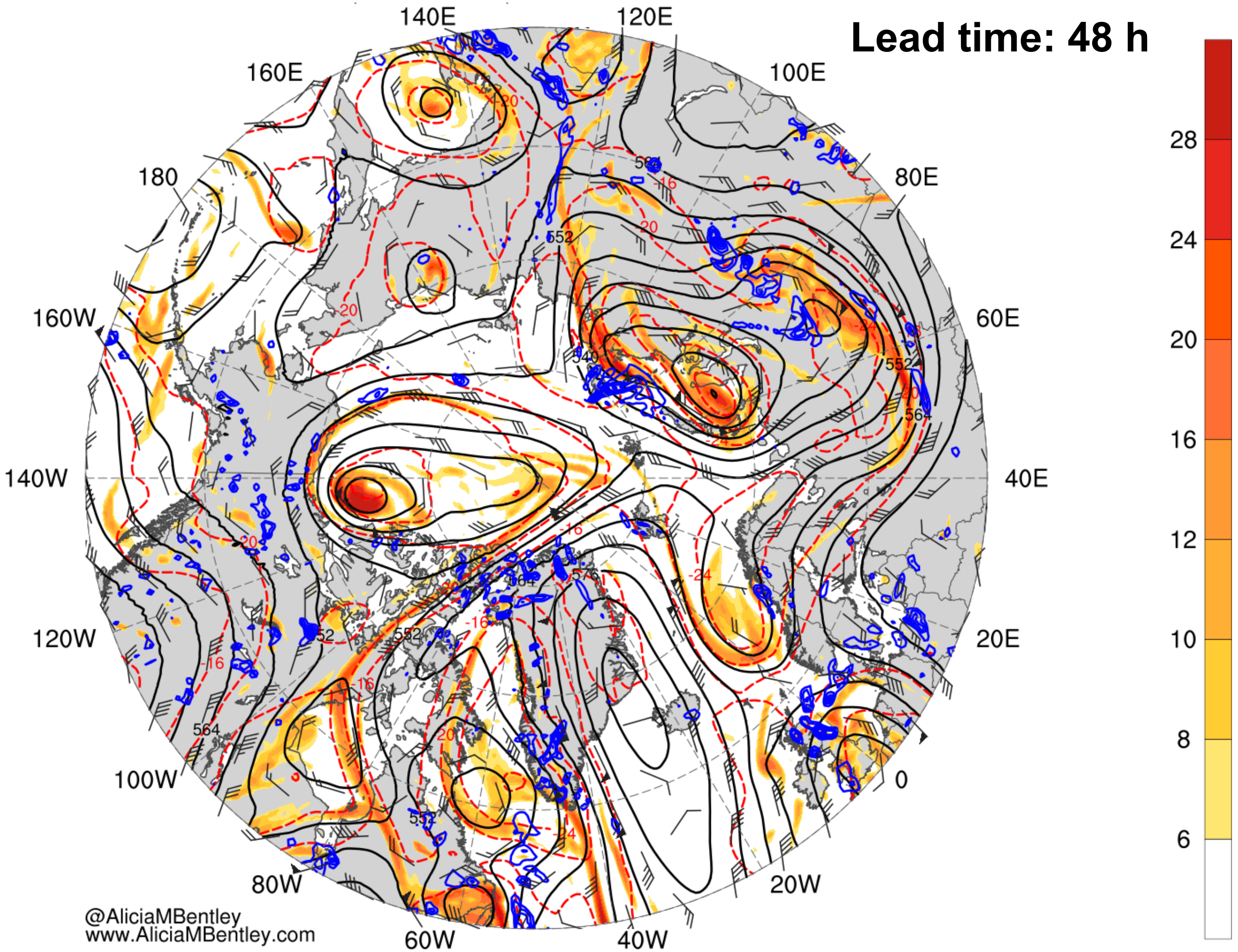
500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5 × 10^{-3} s^{-1}, blue), and wind (kt, flags and barbs) from GFS

D(prog)/Dt valid 0000 UTC 13 Jun 2019



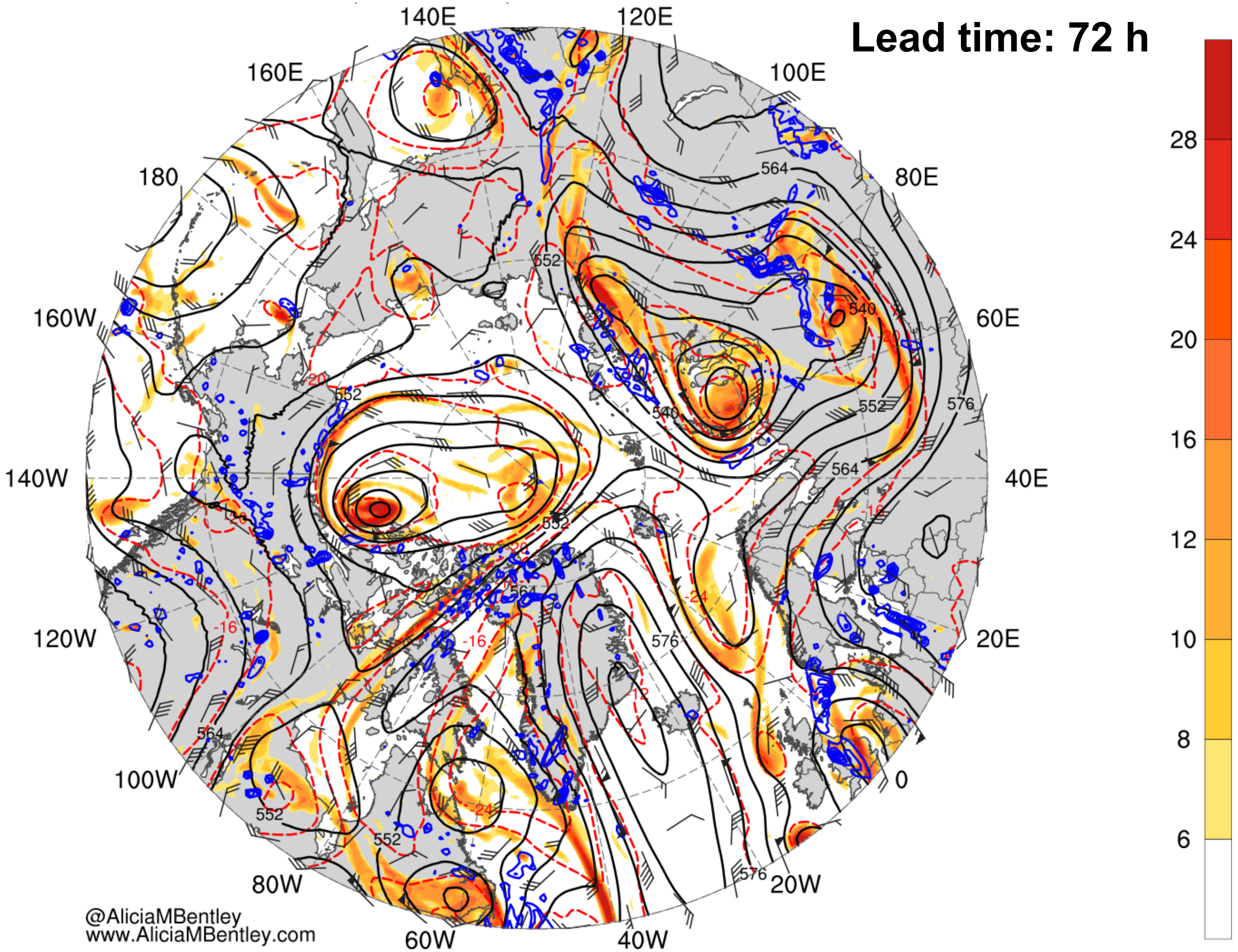
500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5×10^{-3} s^{-1}, blue), and wind (kt, flags and barbs) from GFS

D(prog)/Dt valid 0000 UTC 13 Jun 2019



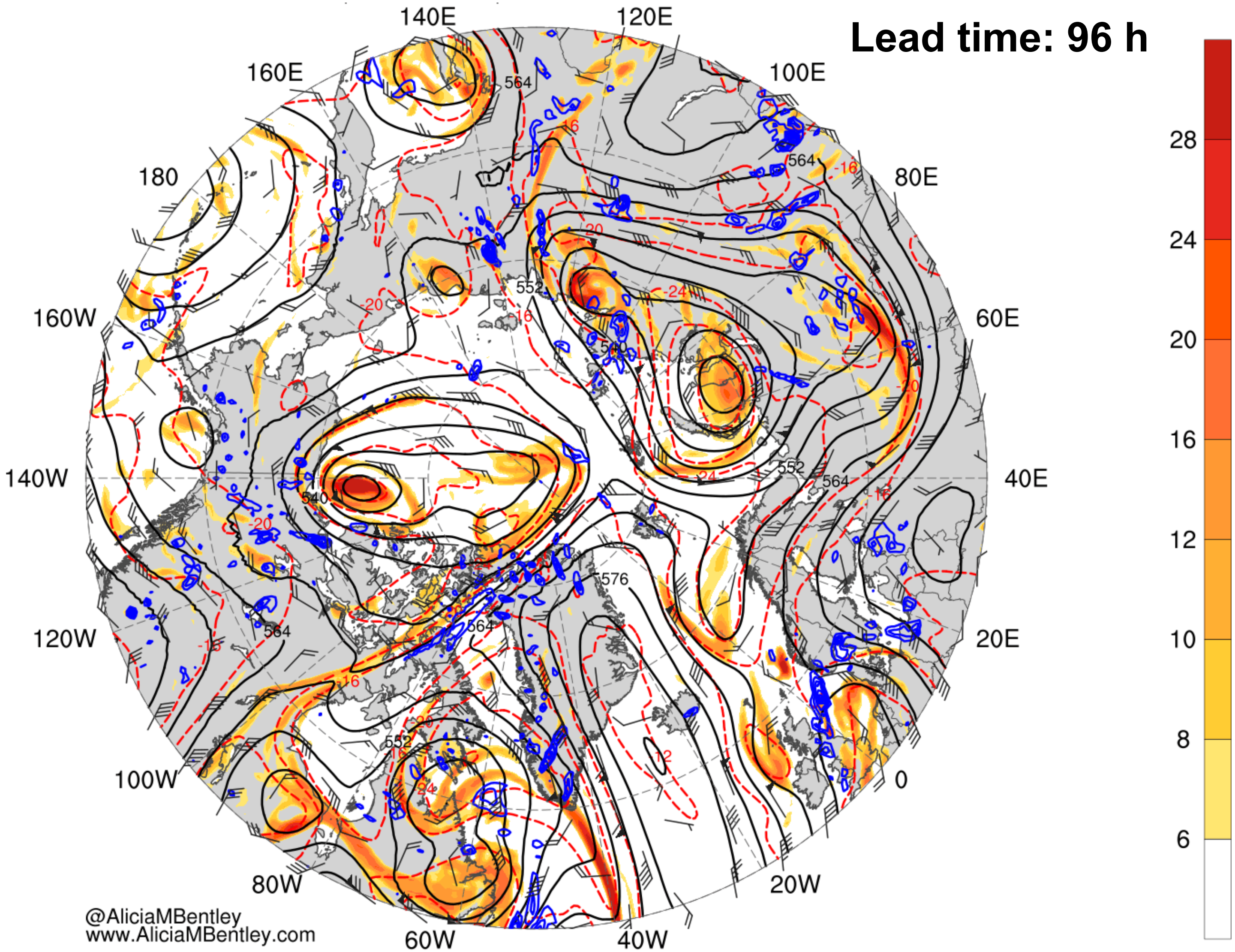
500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5 × 10^{-3} s^{-1}, blue), and wind (kt, flags and barbs) from GFS

D(prog)/Dt valid 0000 UTC 13 Jun 2019



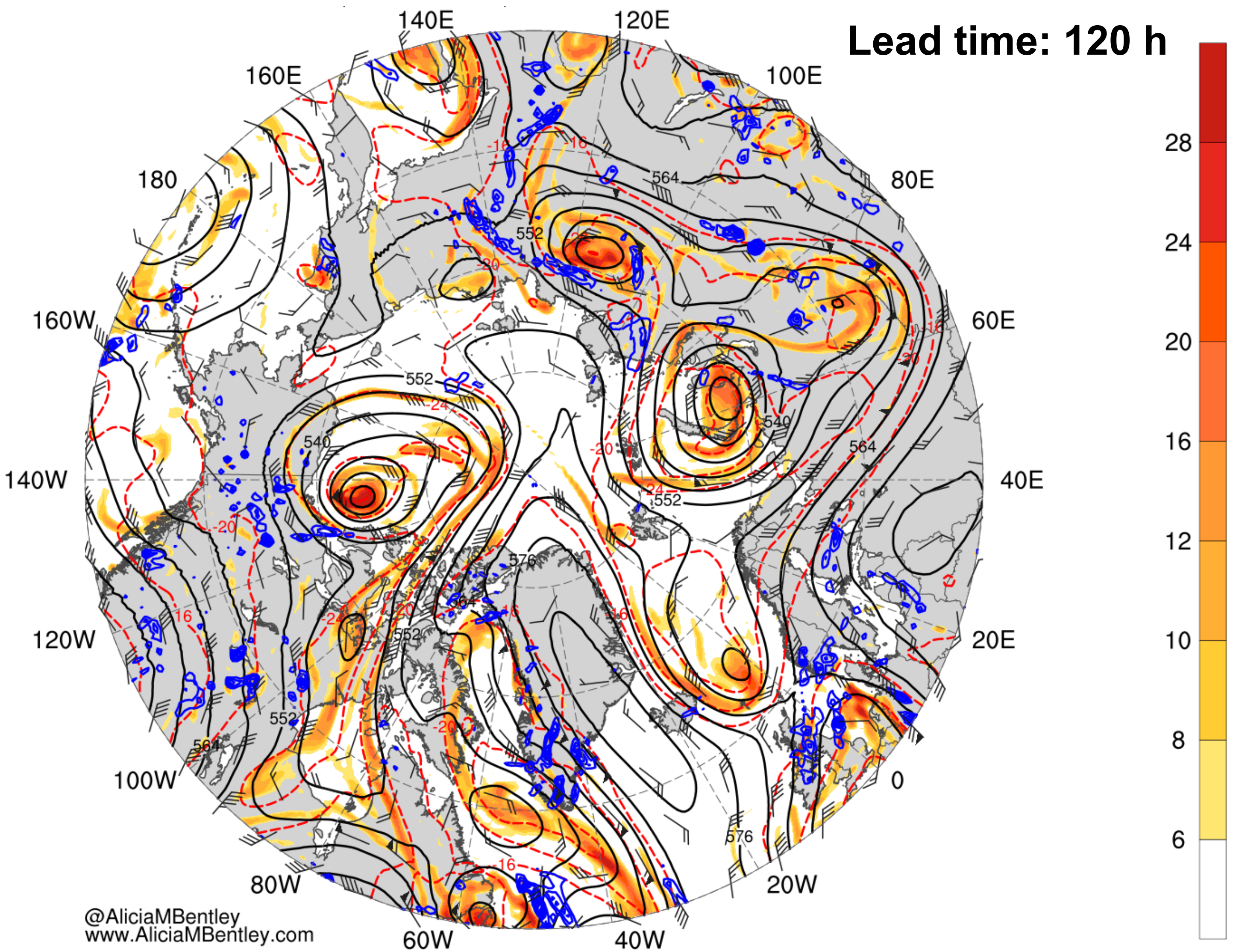
500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5 × 10^{-3} s^{-1}, blue), and wind (kt, flags and barbs) from GFS

D(prog)/Dt valid 0000 UTC 13 Jun 2019



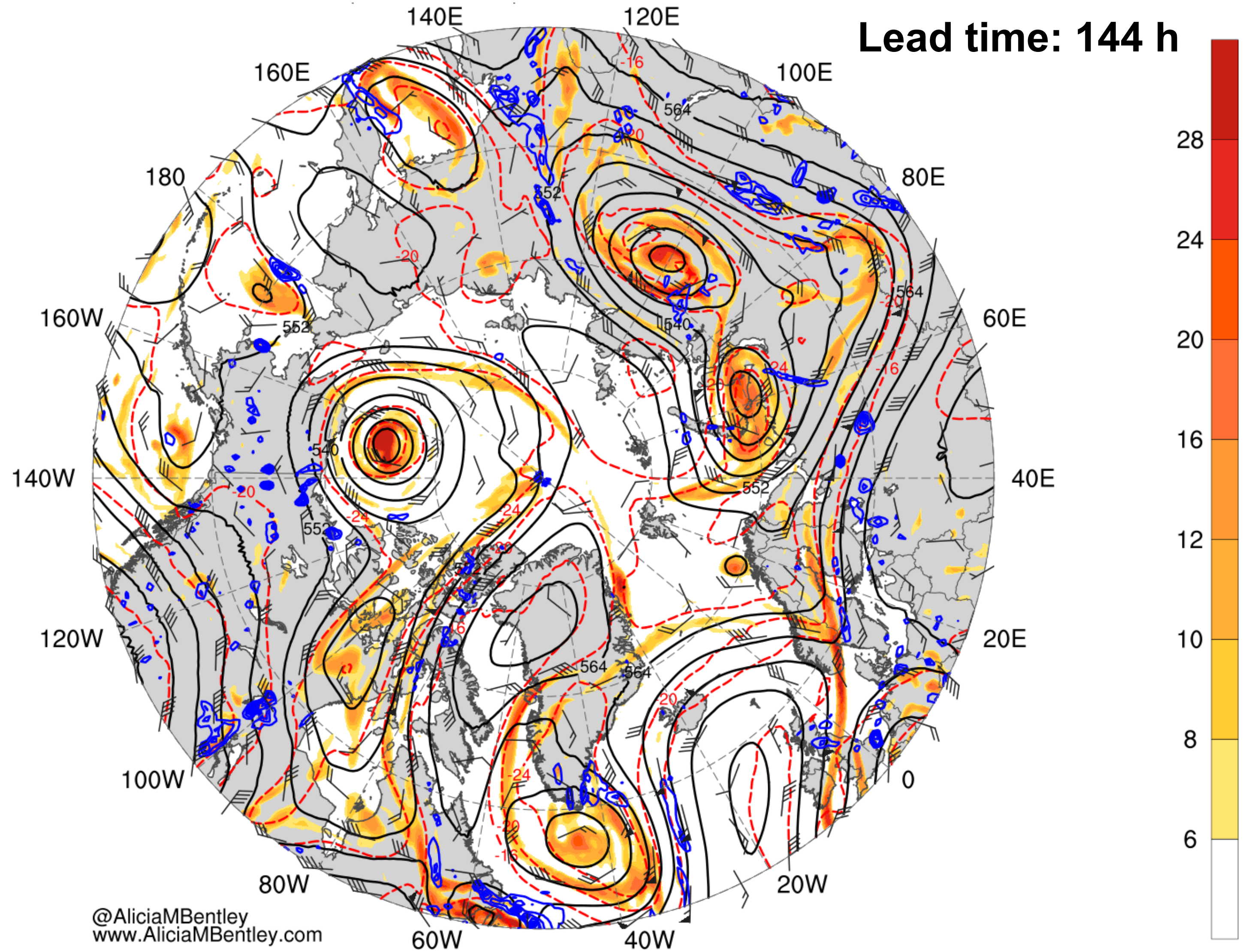
500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5 × 10^{-3} s^{-1}, blue), and wind (kt, flags and barbs) from GFS

D(prog)/Dt valid 0000 UTC 13 Jun 2019



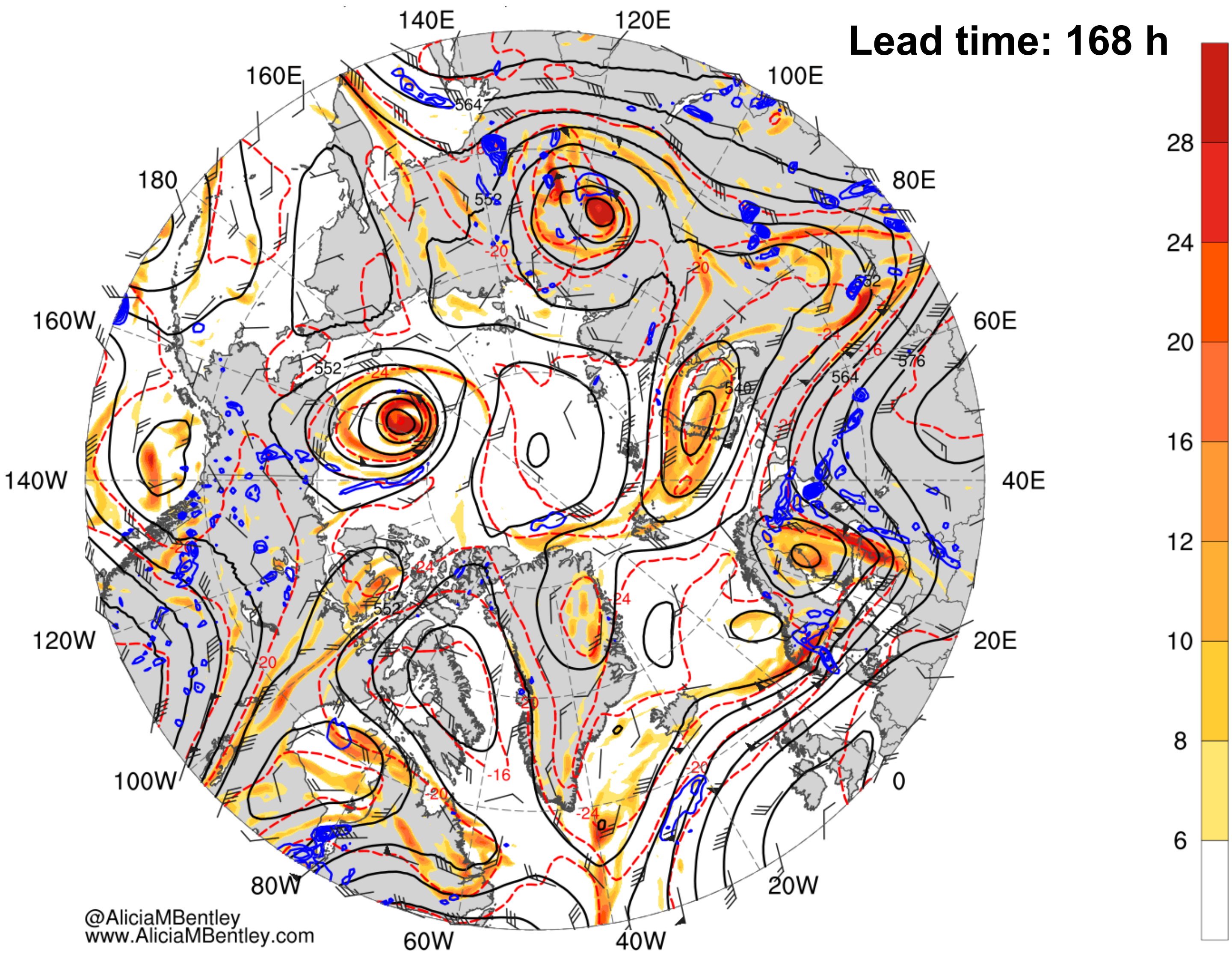
500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5×10^{-3} s^{-1}, blue), and wind (kt, flags and barbs) from GFS

D(prog)/Dt valid 0000 UTC 13 Jun 2019



500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5×10^{-3} s^{-1}, blue), and wind (kt, flags and barbs) from GFS

D(prog)/Dt valid 0000 UTC 13 Jun 2019



500-hPa geo. height (dam, black), temp. (K, red), cycl. rel. vort. (10^{-5} s^{-1}, shaded), ω (5×10^{-3} s^{-1}, blue), and wind (kt, flags and barbs) from GFS

Conclusions:

- **Origins of the Greenland surface ice-melt of June 2019 were over the Tibetan Plateau ("heat burst") and North Pacific**
- **"Heat burst" leads to NPAC anticyclonic wave breaking, a jet extension, and western North America ridging**
- **Western North America ridging leads to trough deepening and trough phasing east of the Rockies**
- **Trough phasing enables a deep southerly flow of moist tropical air to reach the Arctic**
- **Greenland ridging is driven by negative PV advection by the nondivergent and irrotational winds**