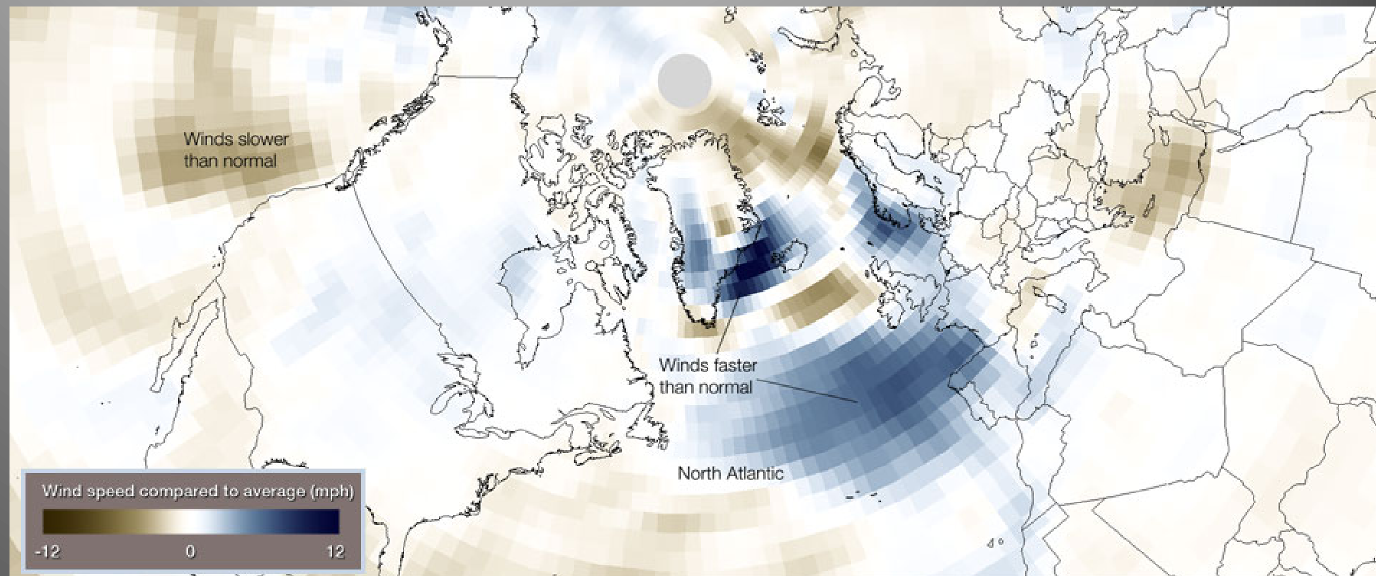
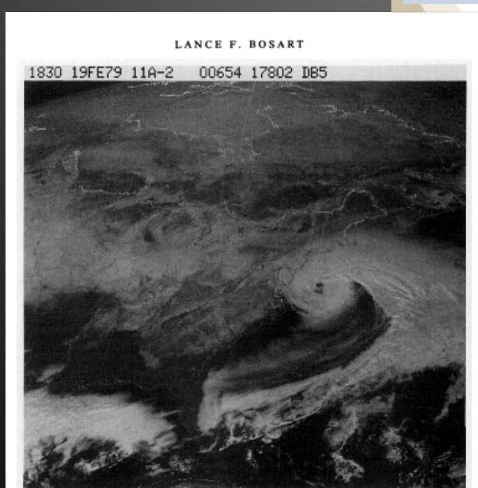
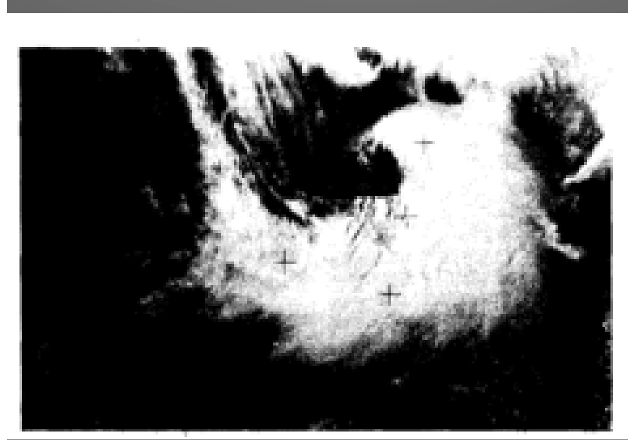
Cyclogenesis: Then (1979) and Now (2014)







http://oceanservice.noaa.gov/facts/bombogenesis.html

Sanders and Gyakum (1980)

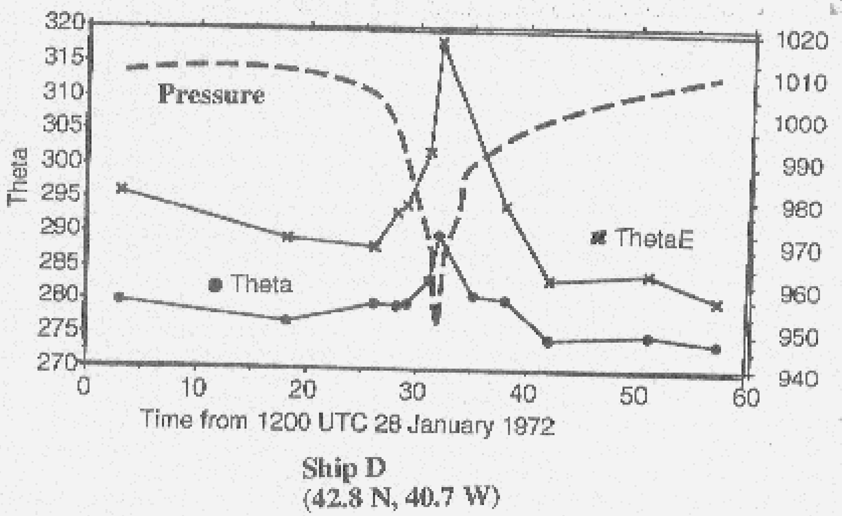
Bosart (1981)

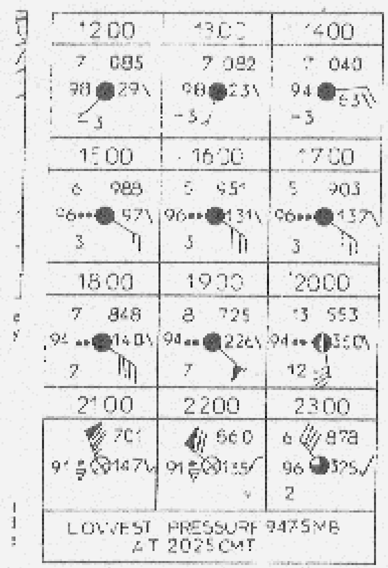
Authors

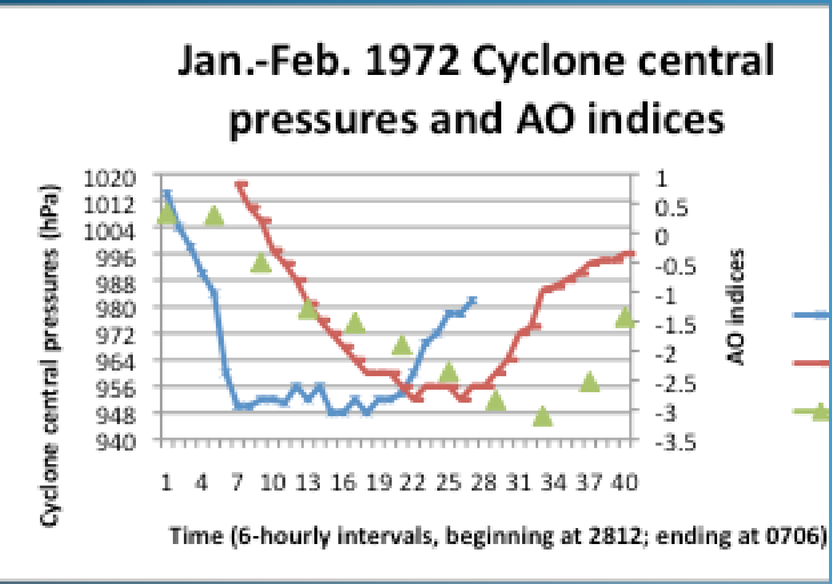
John R. Gyakum[1]
Bryn Ronalds[1]
Lance F. Bosart[2]
Shawn M. Milrad[3]
Eyad H. Atallah[1]
Melissa Gervais[1]

[1]Department of Atmospheric and Oceanic Sciences, McGill University, Montreal, QC
[2]Department of Atmospheric and Environmental Sciences, University at Albany, NY
[3]Applied Aviation Sciences Department, Embry-Riddle Aeronautical University, Daytona Beach, FL

Pressure, potential temperature, and equivalent potential temperature time series at weather ship 'D' for 28-30 January 1972 (Stubbs 1975)







First cyclone's maximum deepening of 2.6 bergerons!

Motivation:

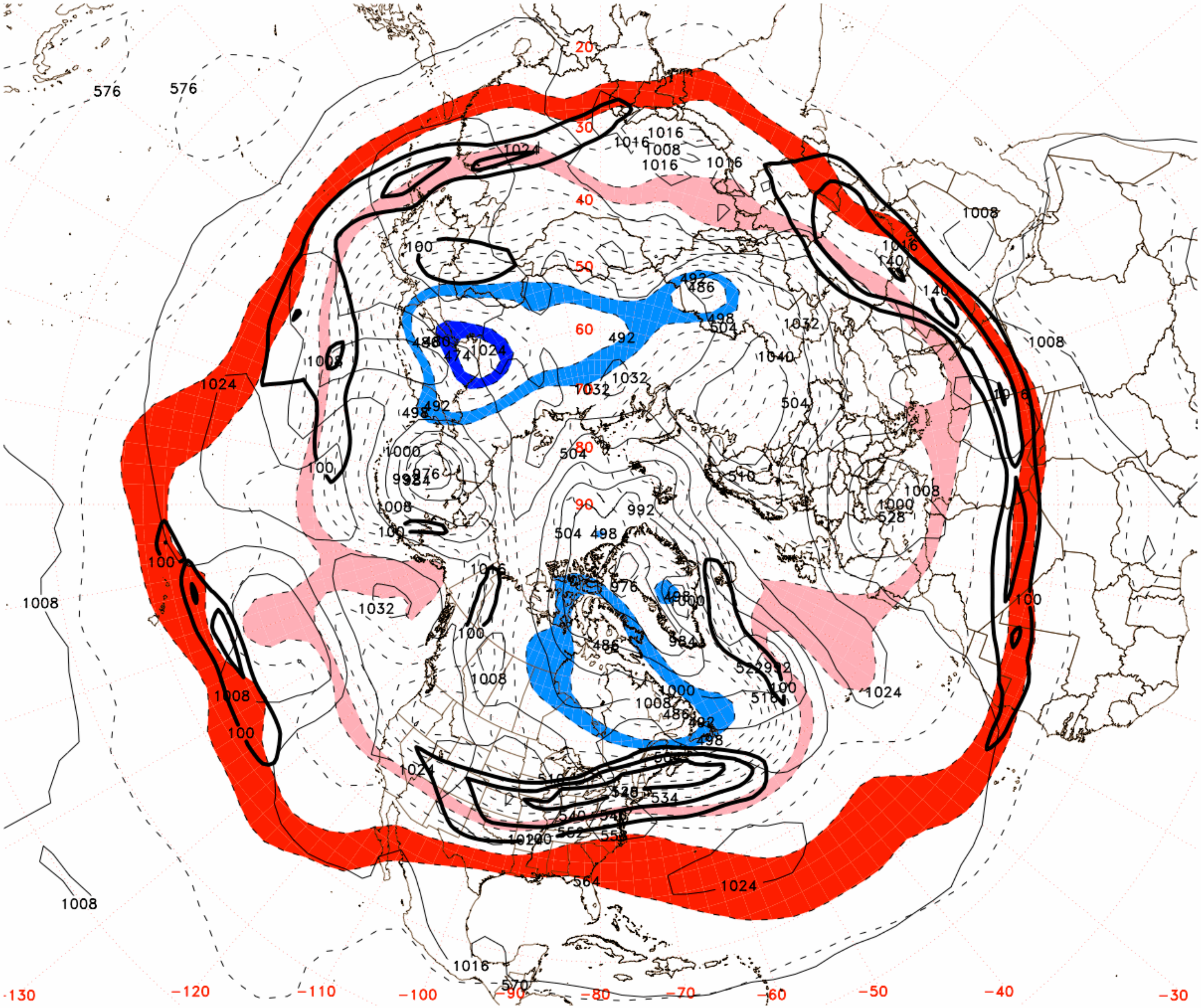
The January 1972 surface cyclogenesis processes were associated with a regime change in the North Atlantic Basin

Sanders and Gyakum (1980) noted the clustering of explosive cyclogeneses during 11-17 February 1979

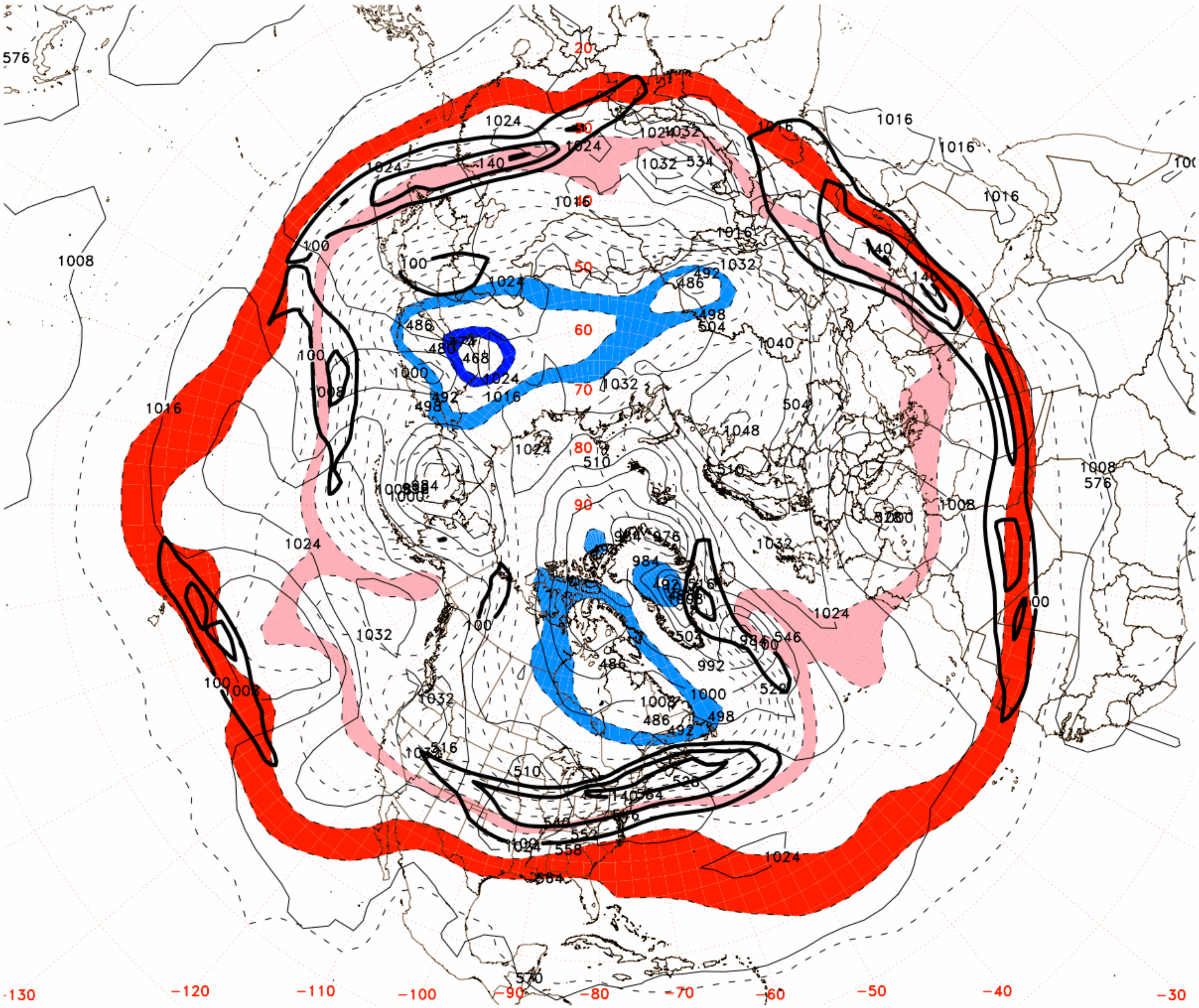
At the end of this clustering was the Presidents' Day cyclone

Six-hourly SLP, 1000-500 hPa thickness, Dynamic Tropopause (2 PVU level) jet (>100 knots) for 28 Jan-3 Feb 1972

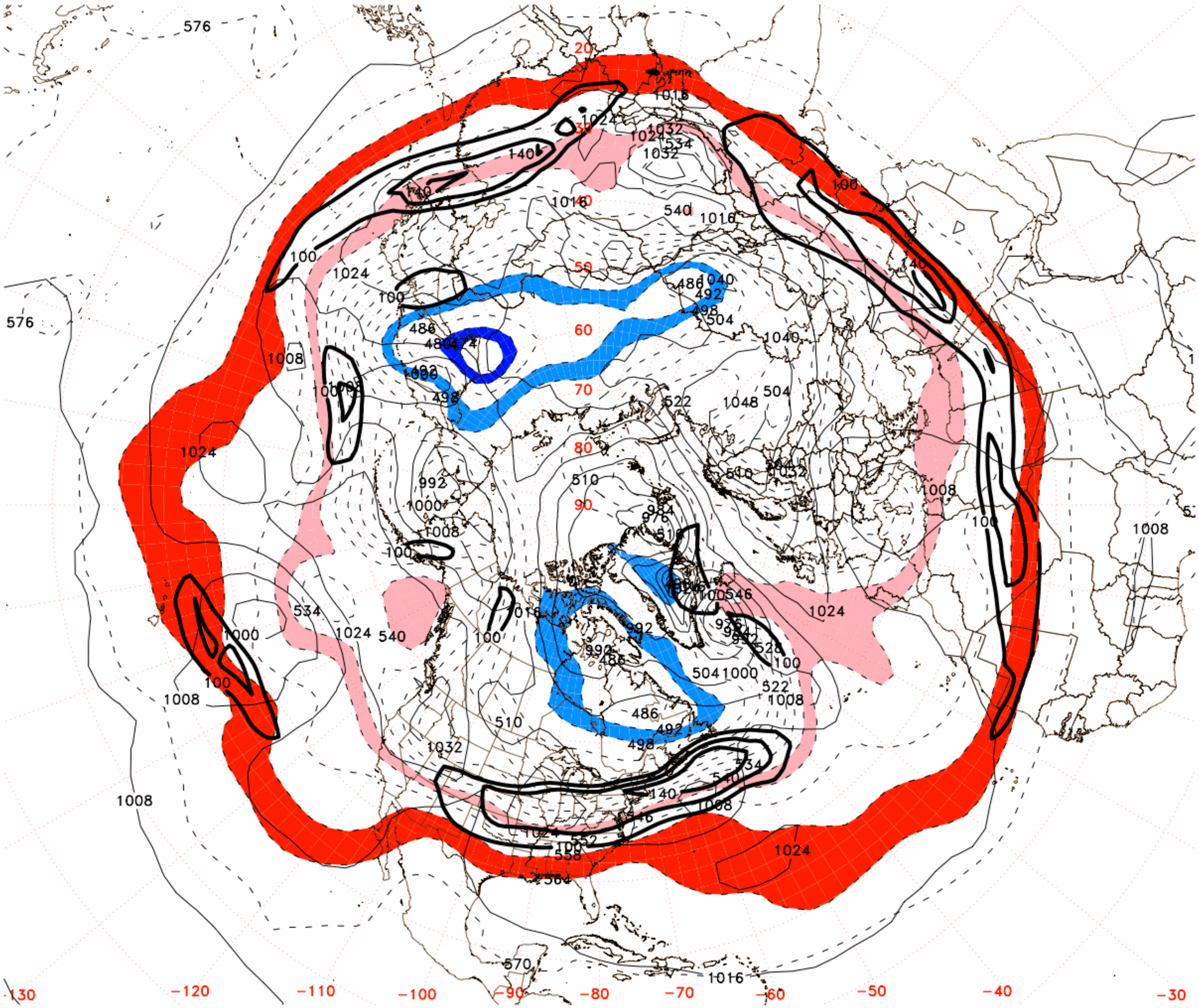
Dark Blue: 474-480 dam
Blue: 492-498 dam
Pink: 540-546 dam
Red: 558-564 dam



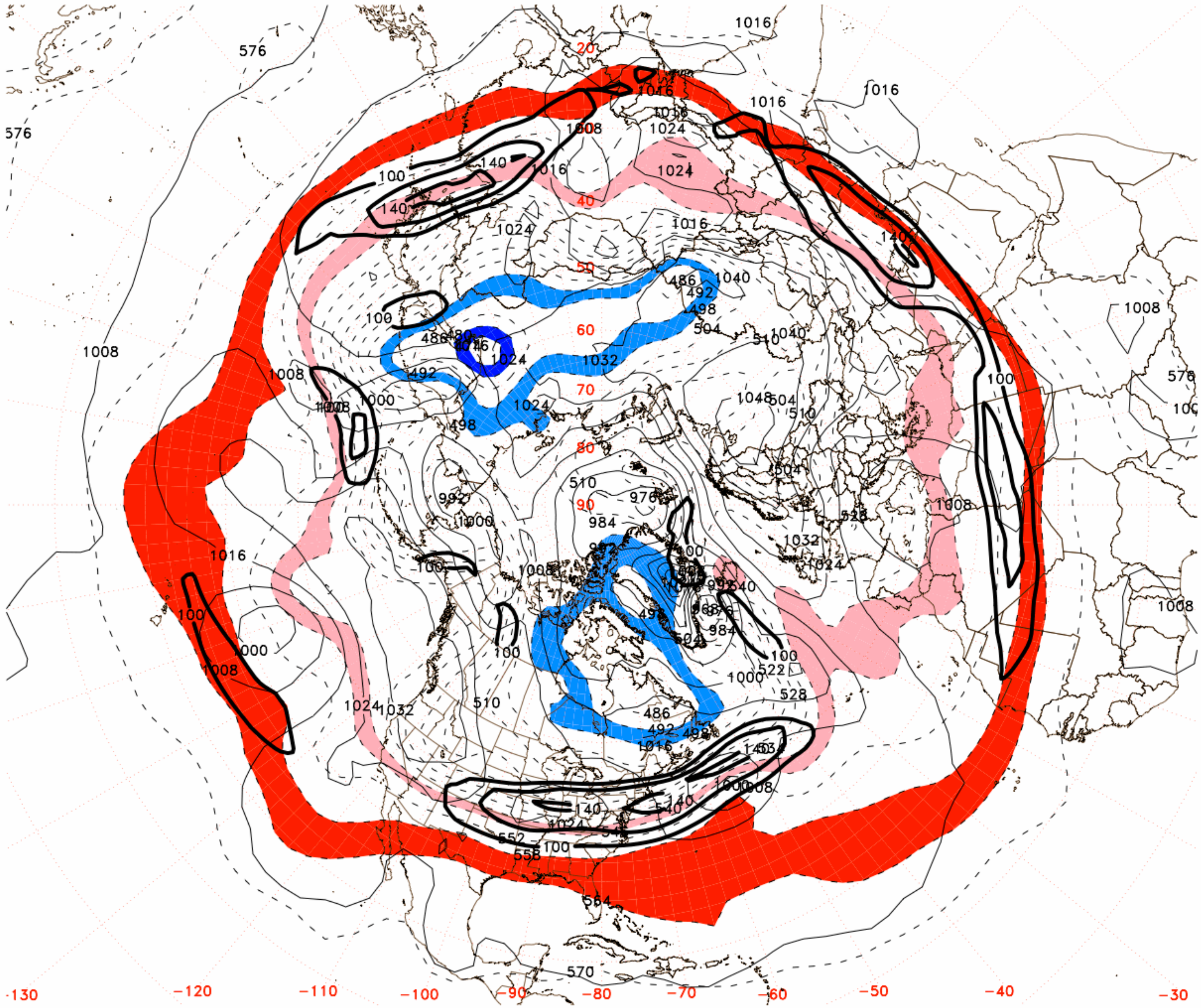
720128/1200V000 2 POTV KNTSPED



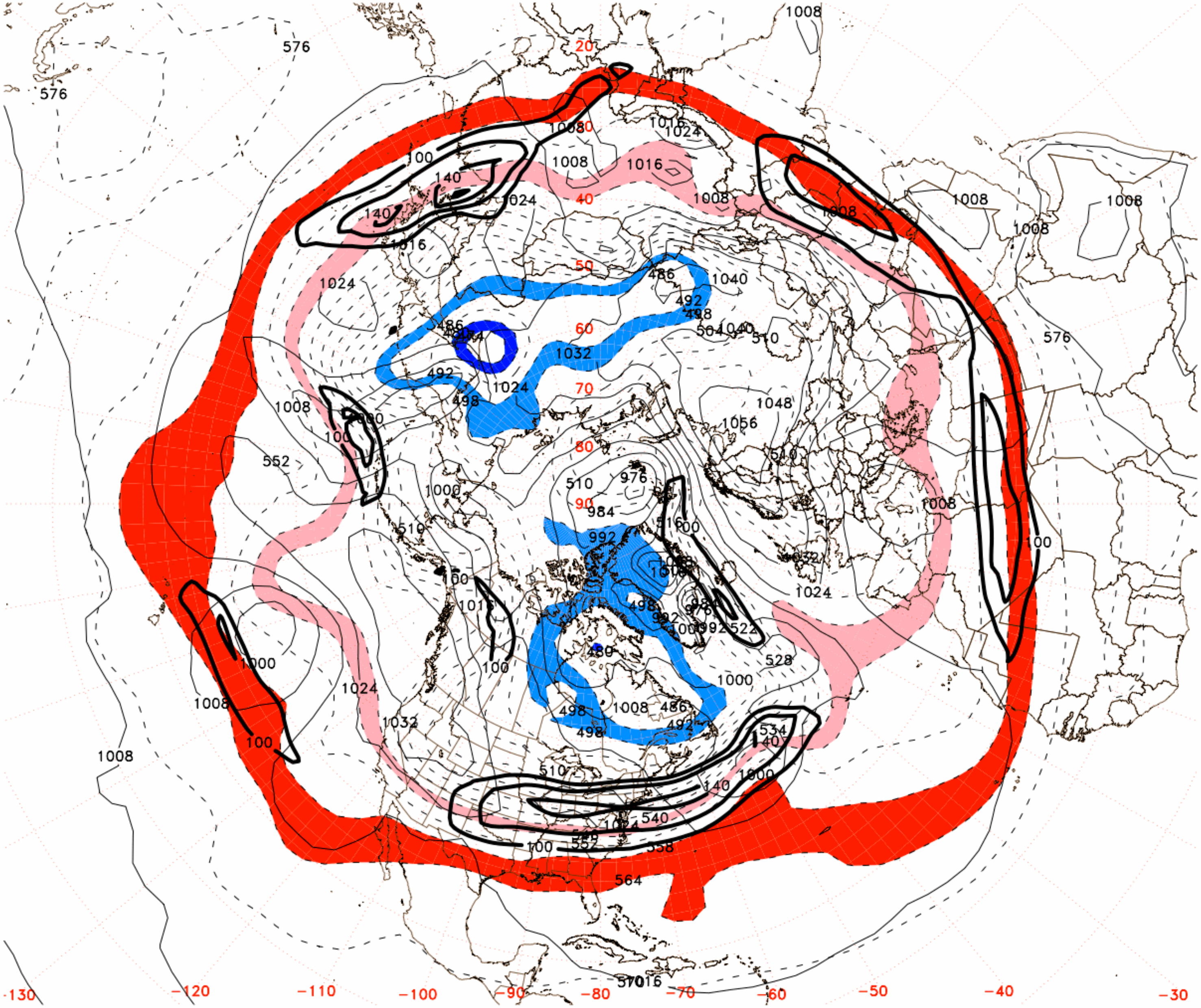
720128/1800V000 2 POTV KNTSPED



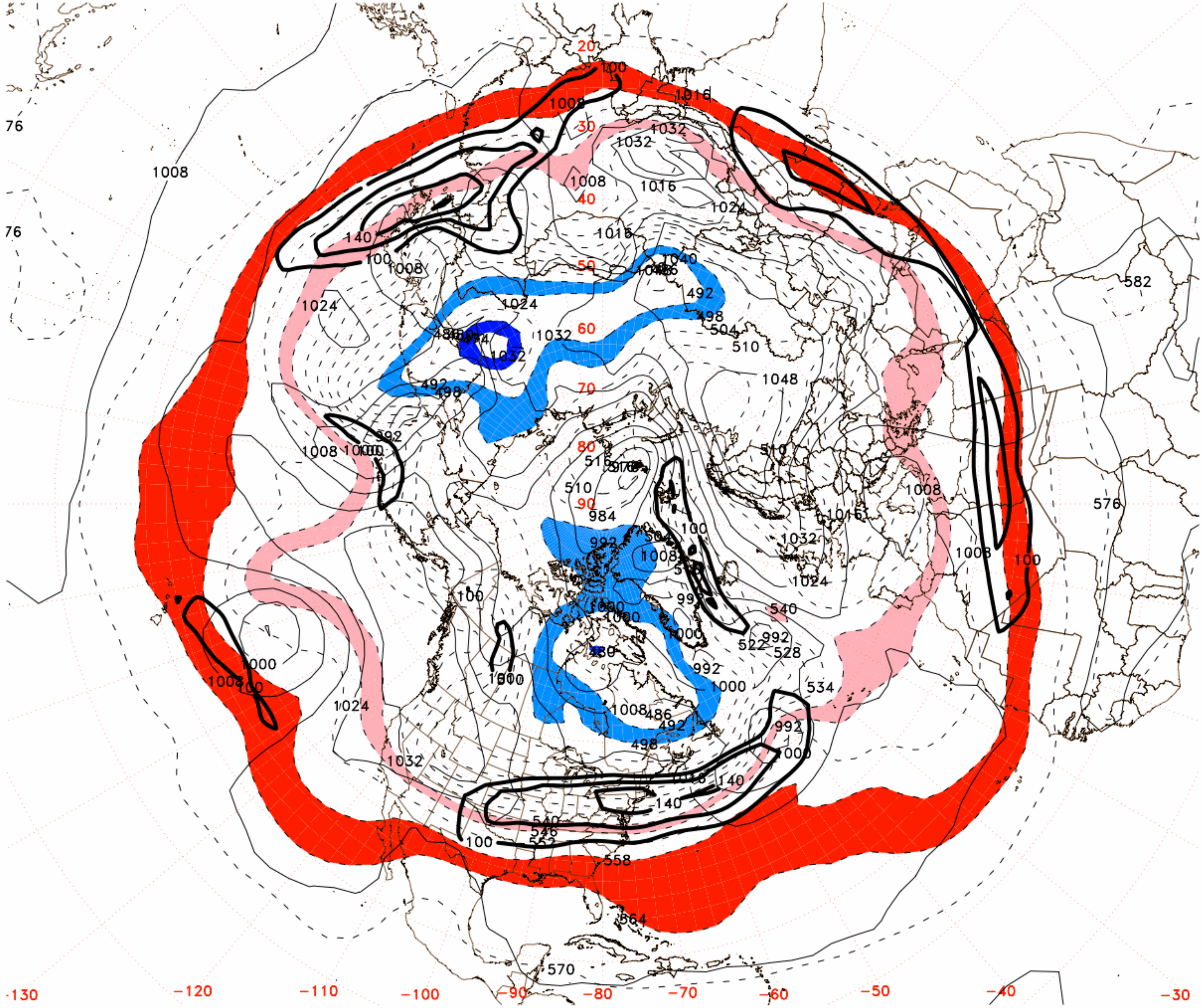
720129/0000V000 2 POTV KNTSPED



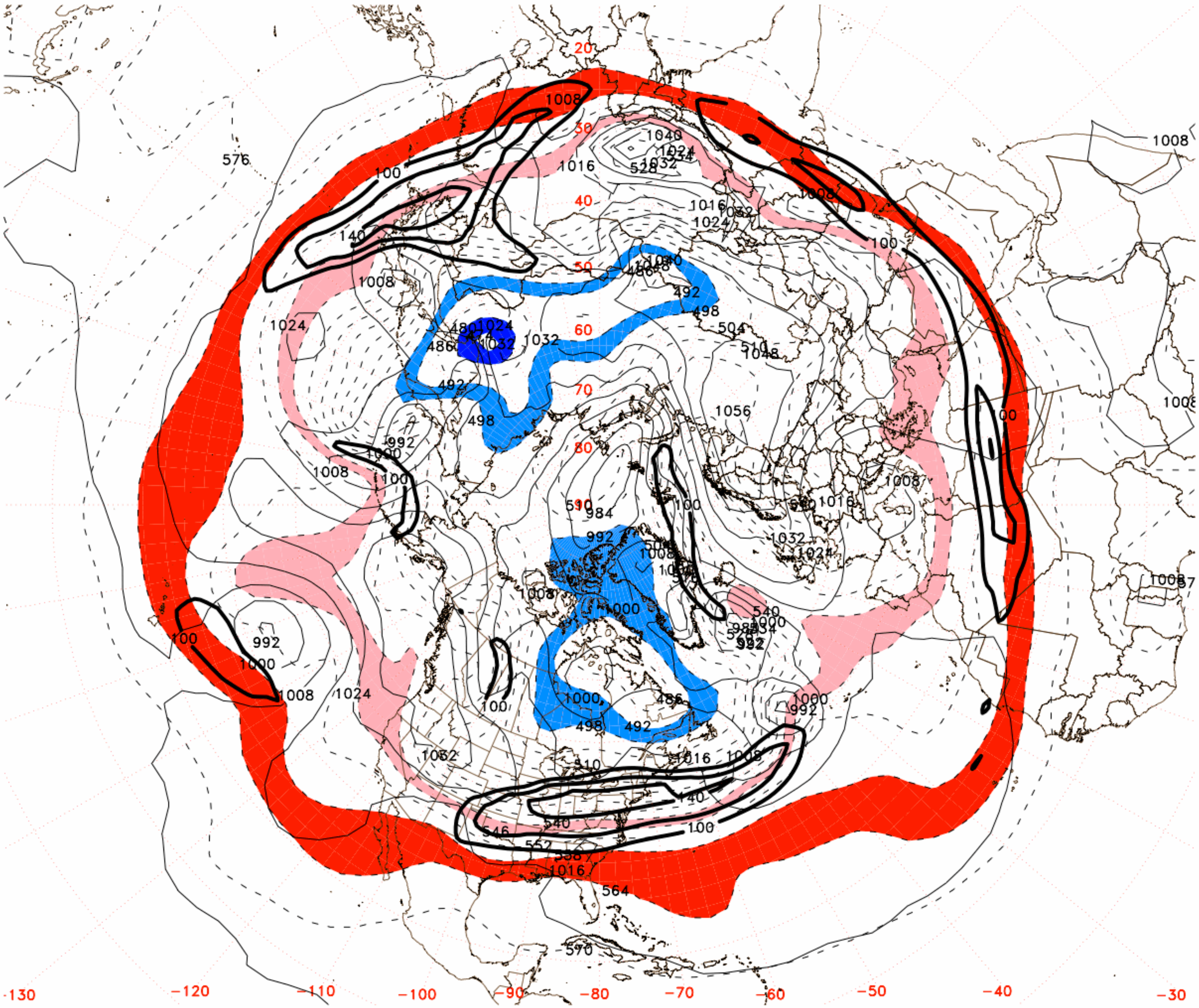
720129/0600V000 2 POTV KNTSPED



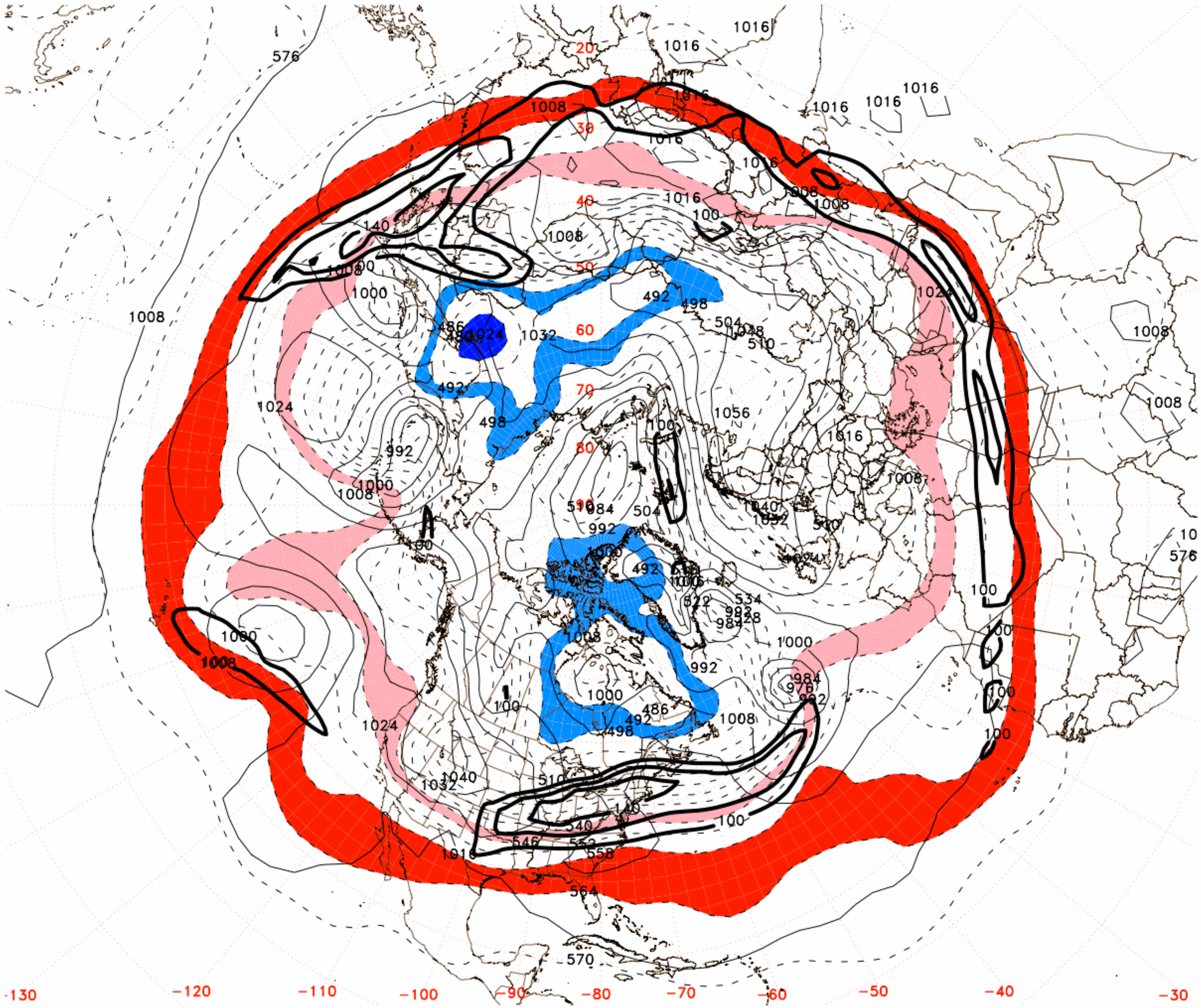
720129/1200V000 2 POTV KNTSPED



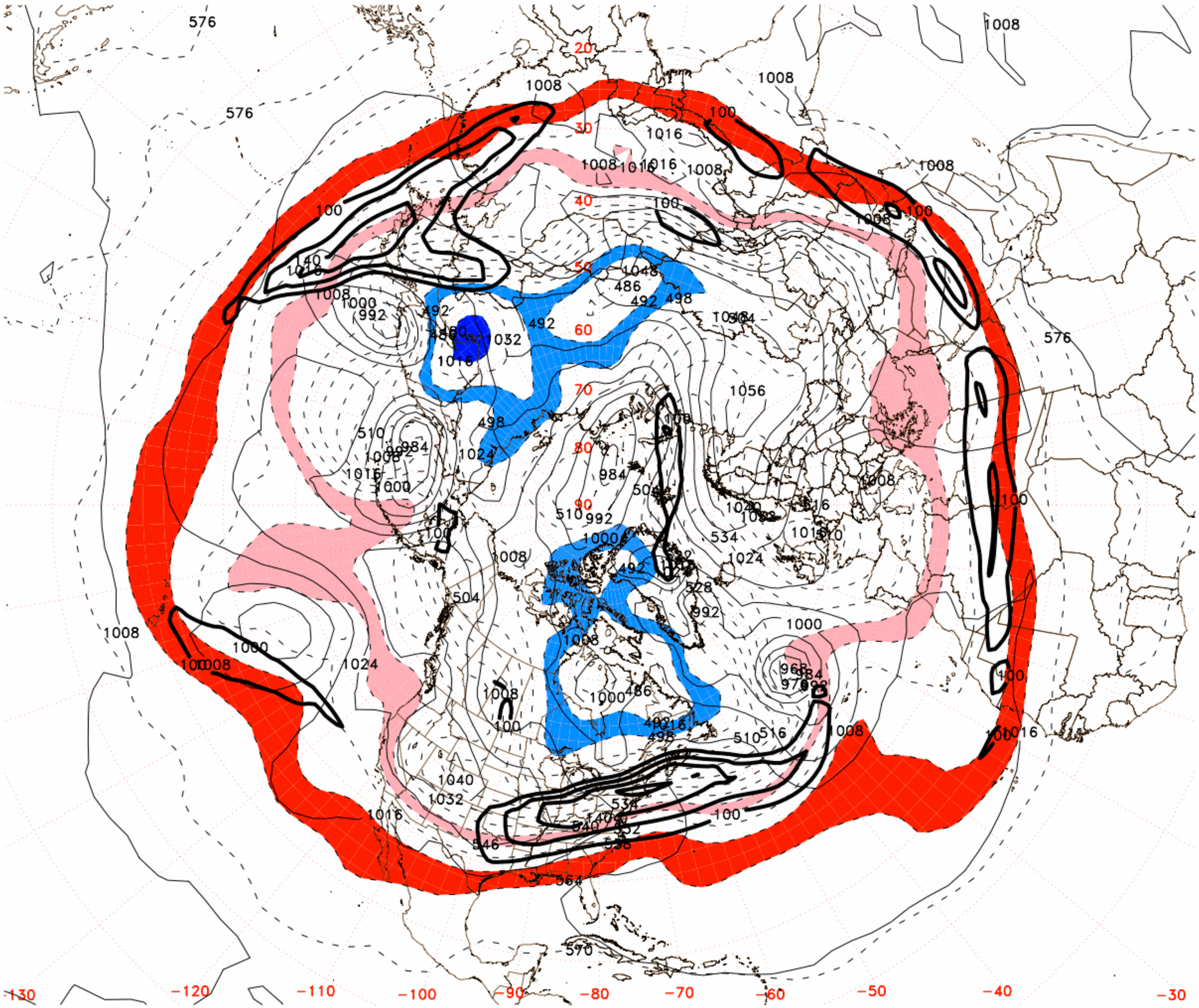
720129/1800V000 2 POTV KNTSPED



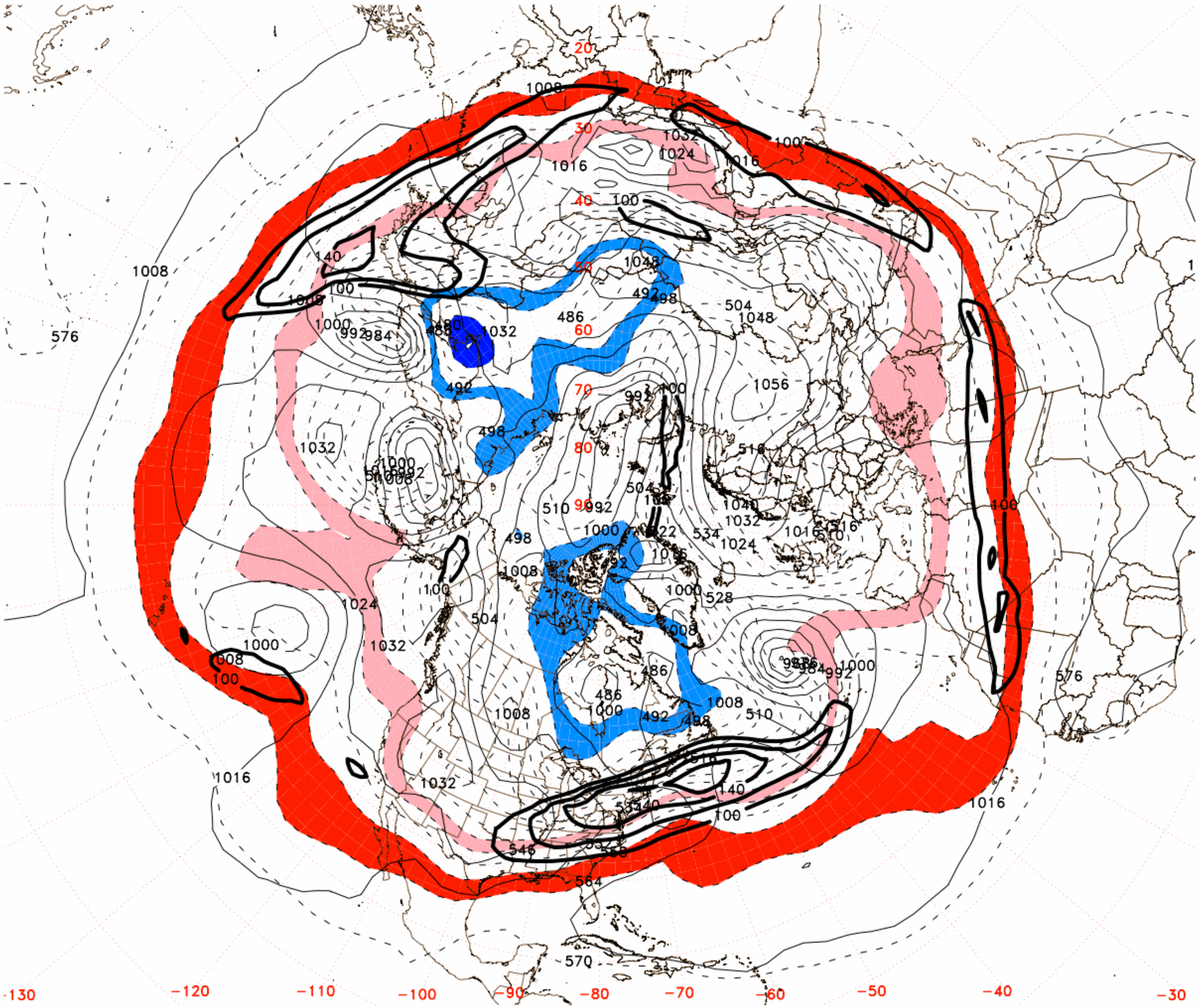
720130/0000V000 2 POTV KNTSPED



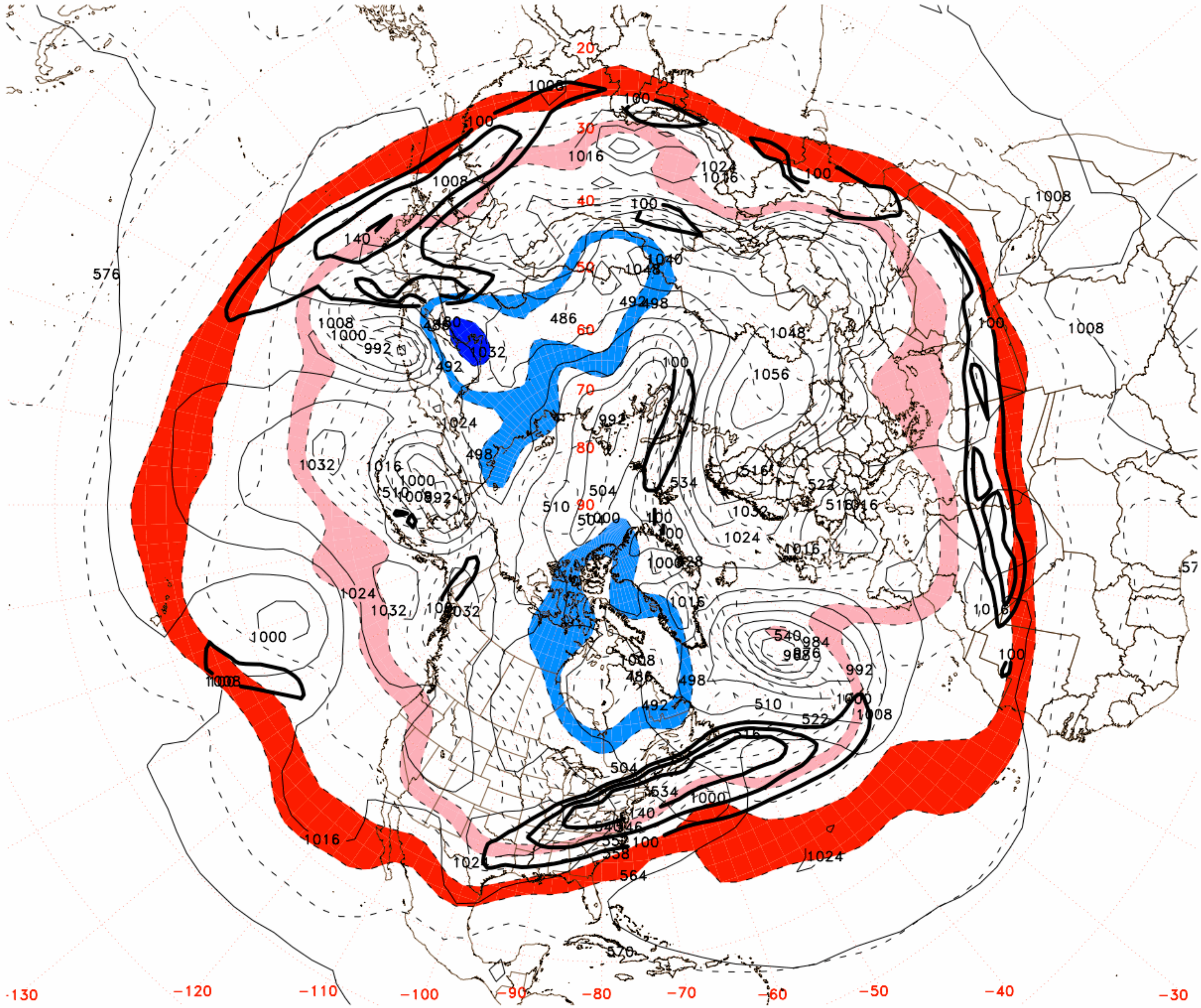
720130/0600V000 2 POTV KNTSPED



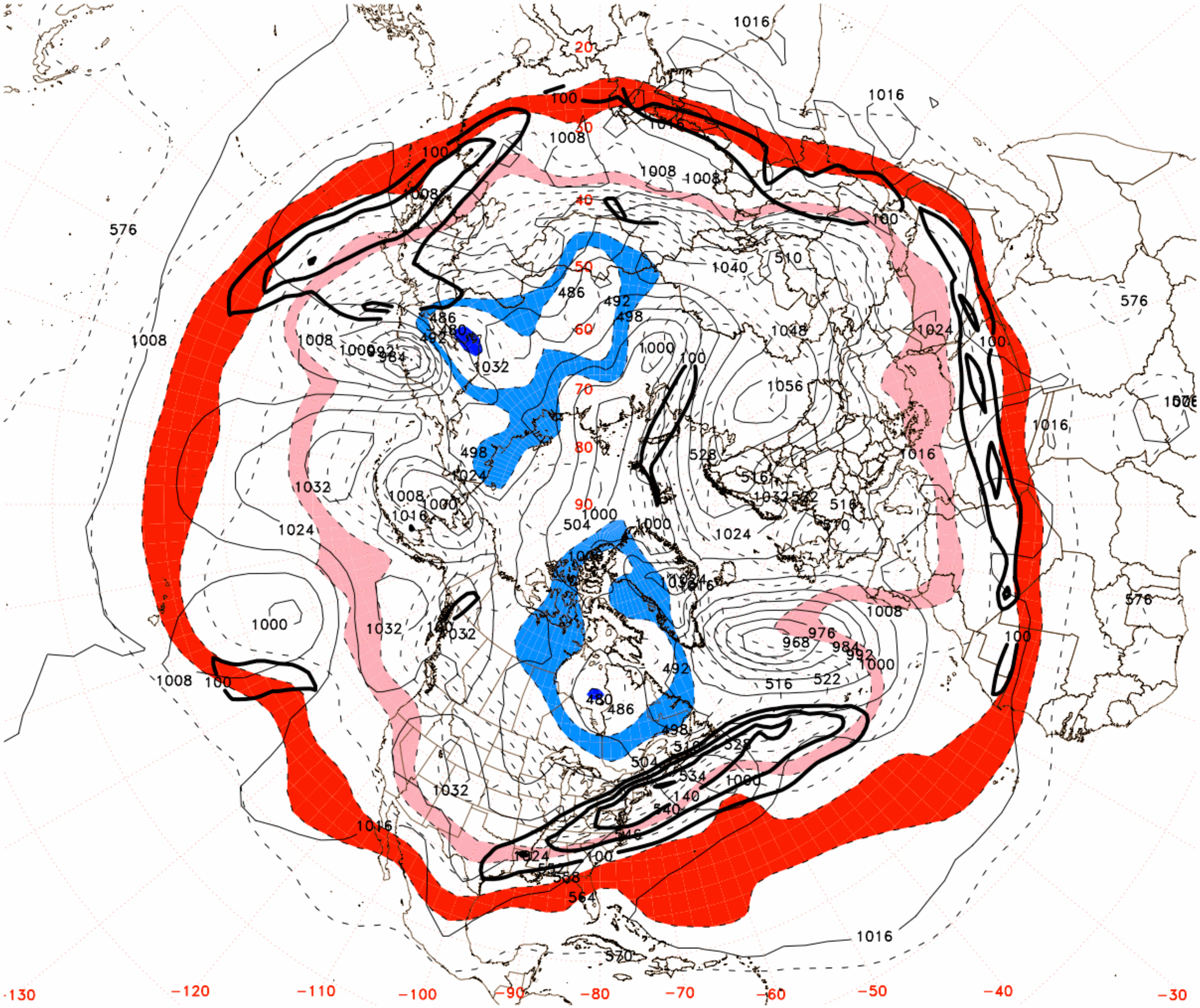
720130/1200V000 2 POTV KNTSPED



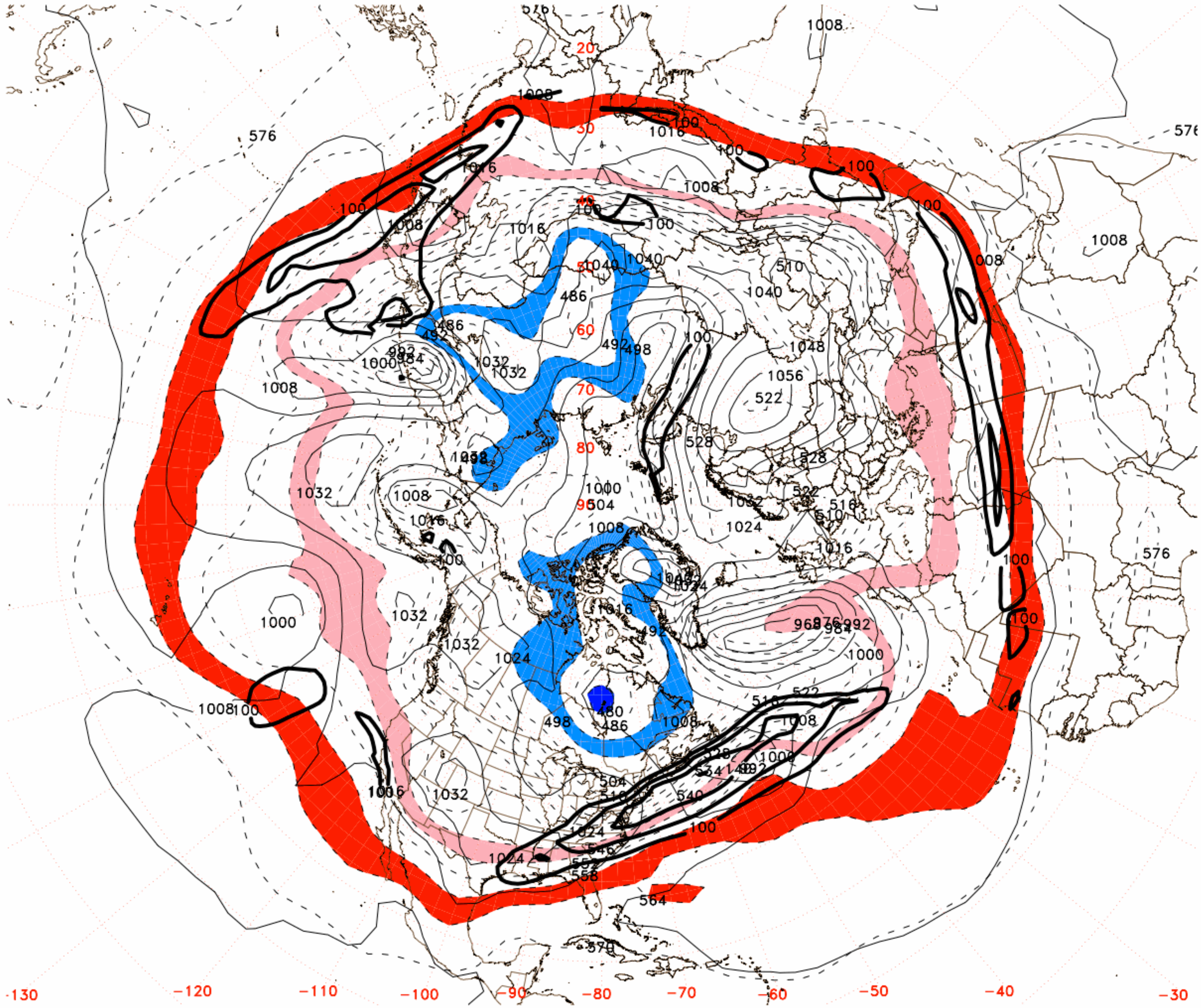
720130/1800V000 2 POTV KNTSPED



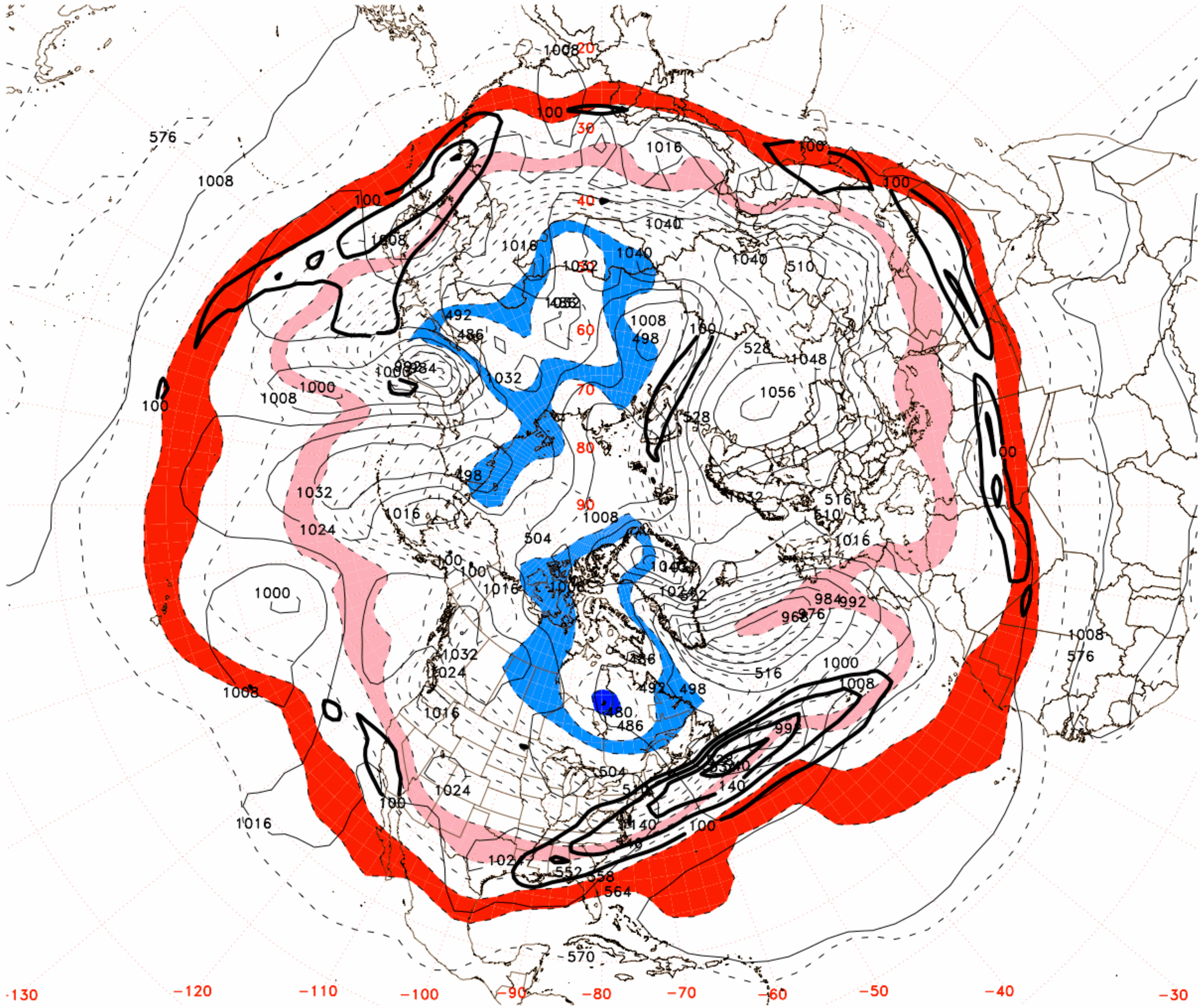
720131/0000V000 2 POTV KNTSPED



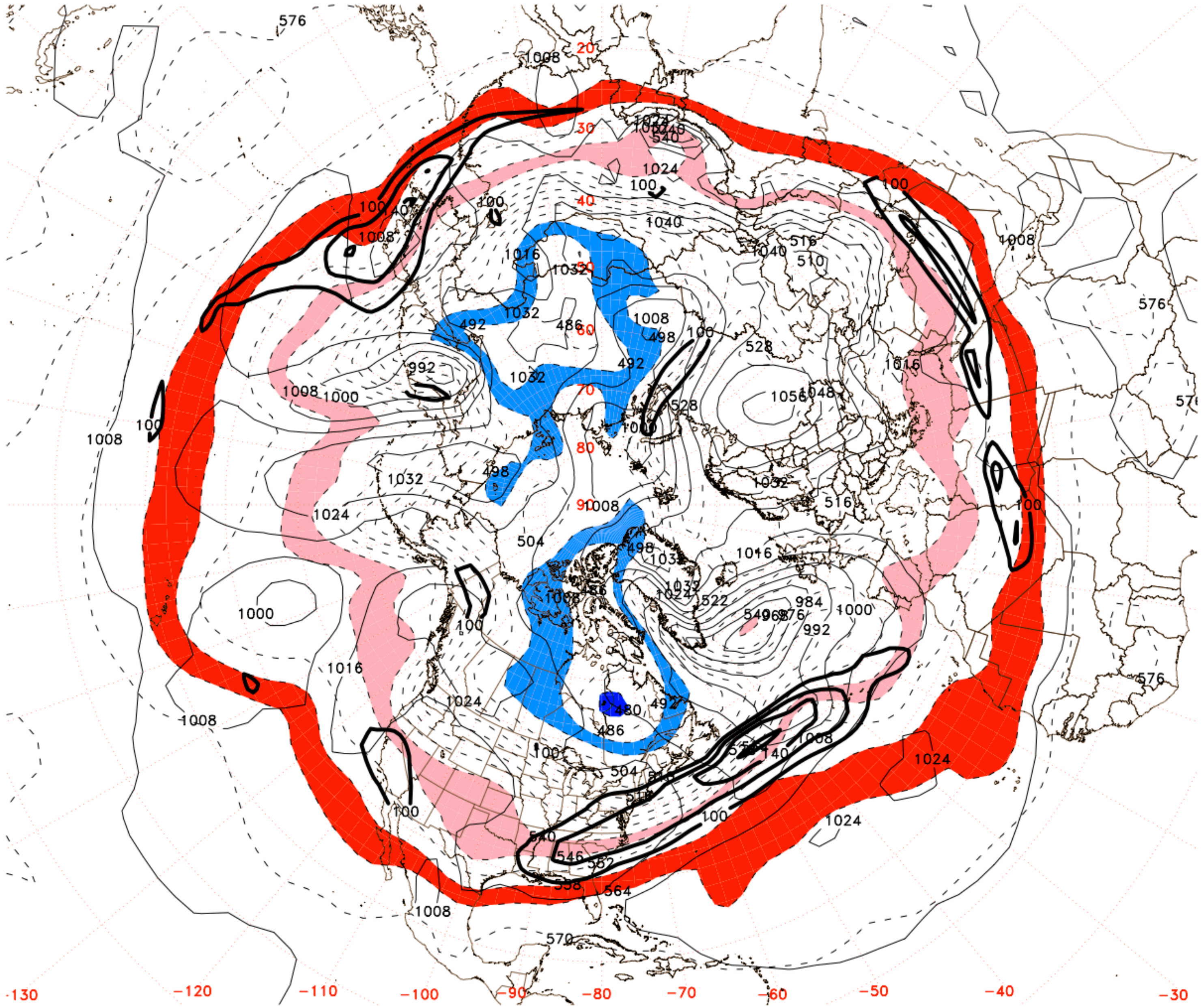
720131/0600V000 2 POTV KNTSPED



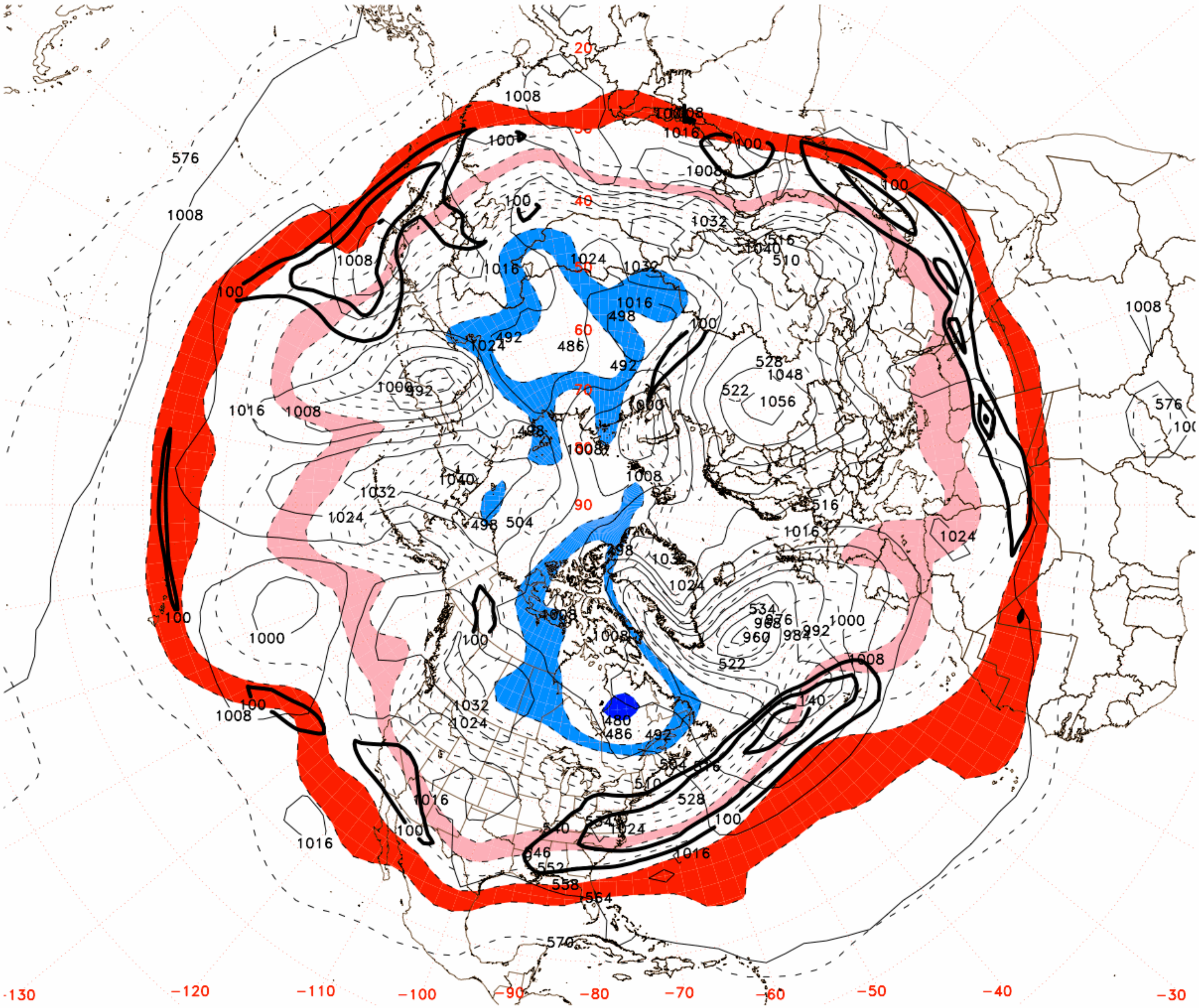
720131/1200V000 2 POTV KNTSPED



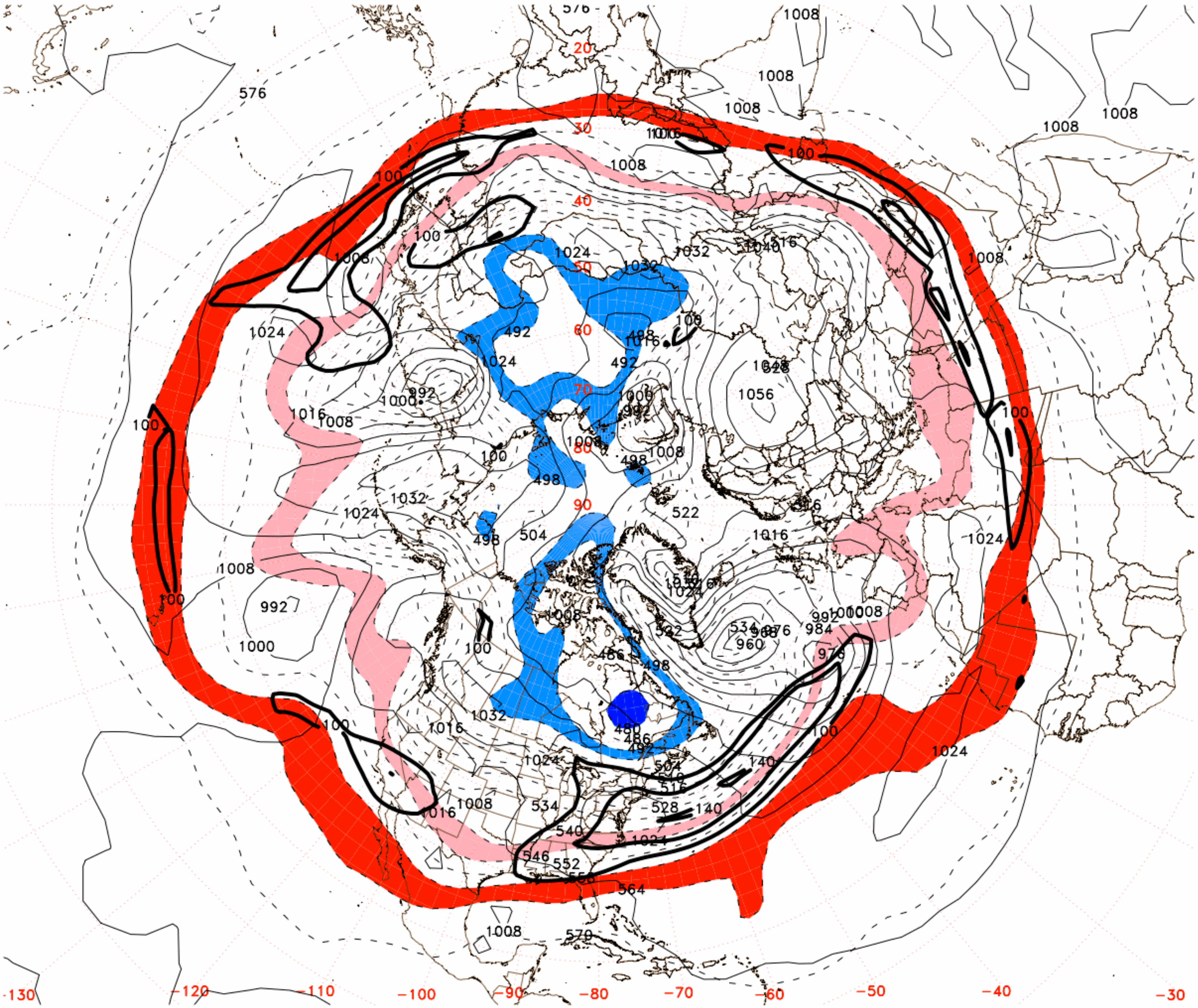
720131/1800V000 2 POTV KNTSPED



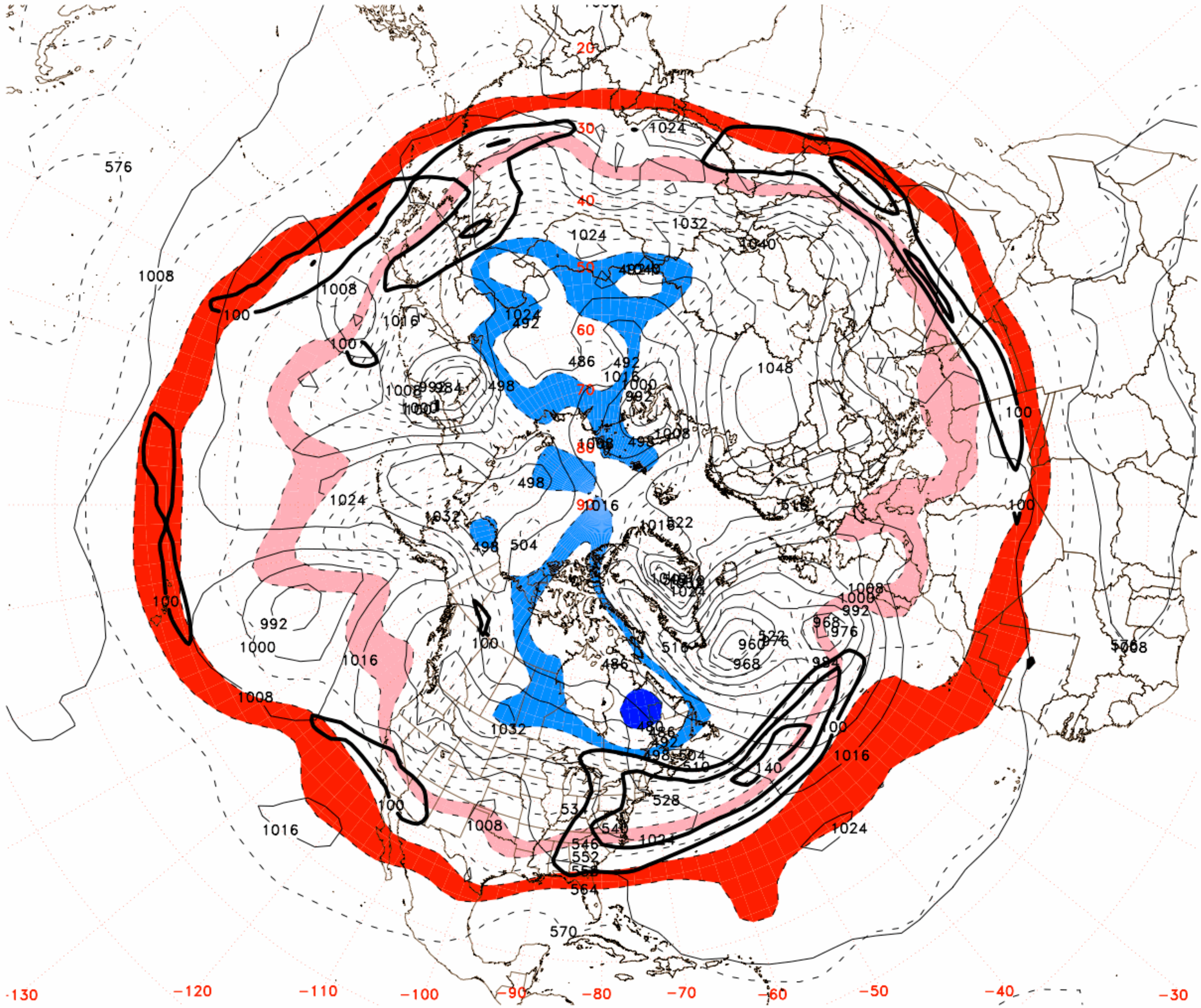
720201/0000V000 2 POTV KNTSPED



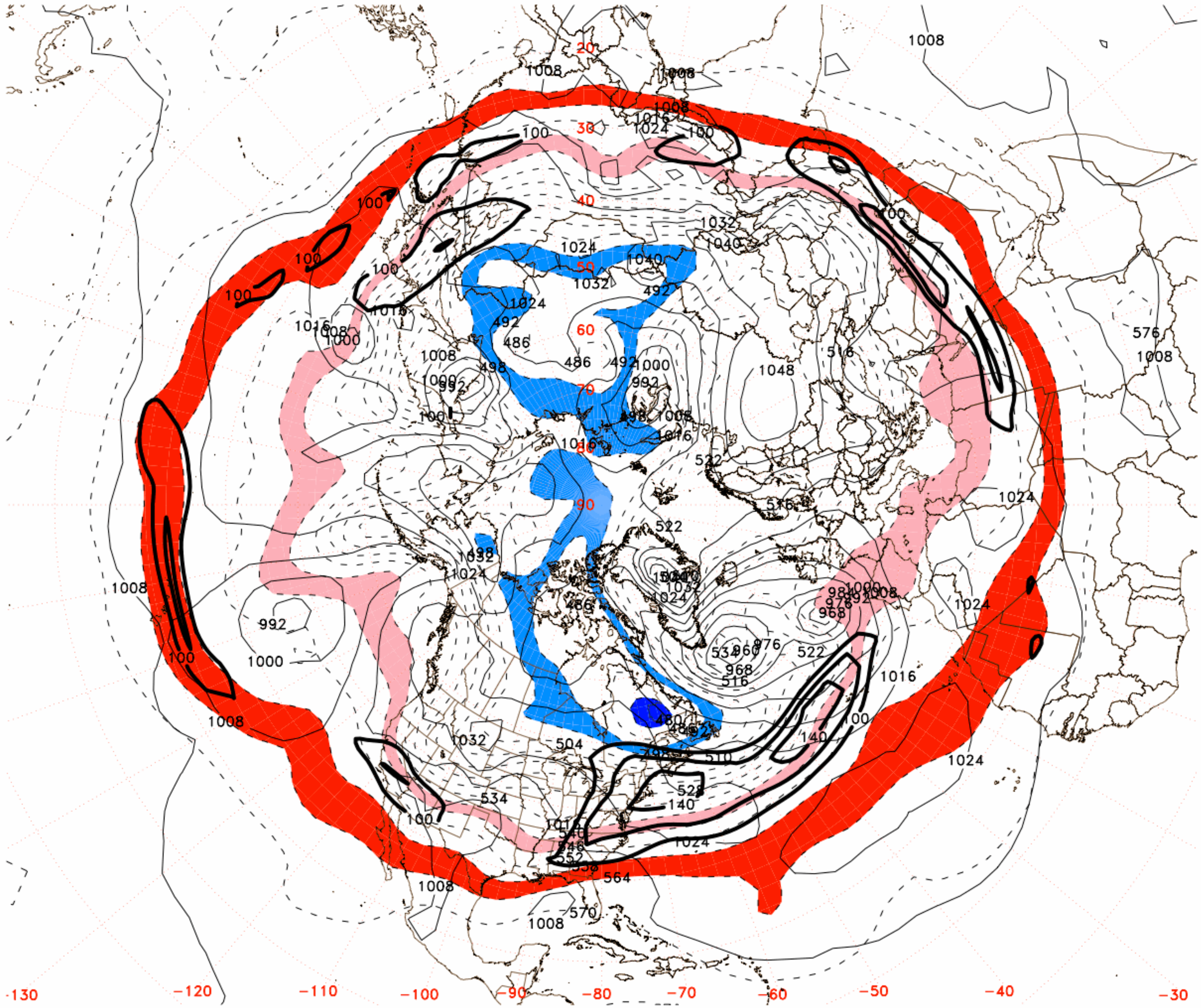
720201/0600V000 2 POTV KNTSPED



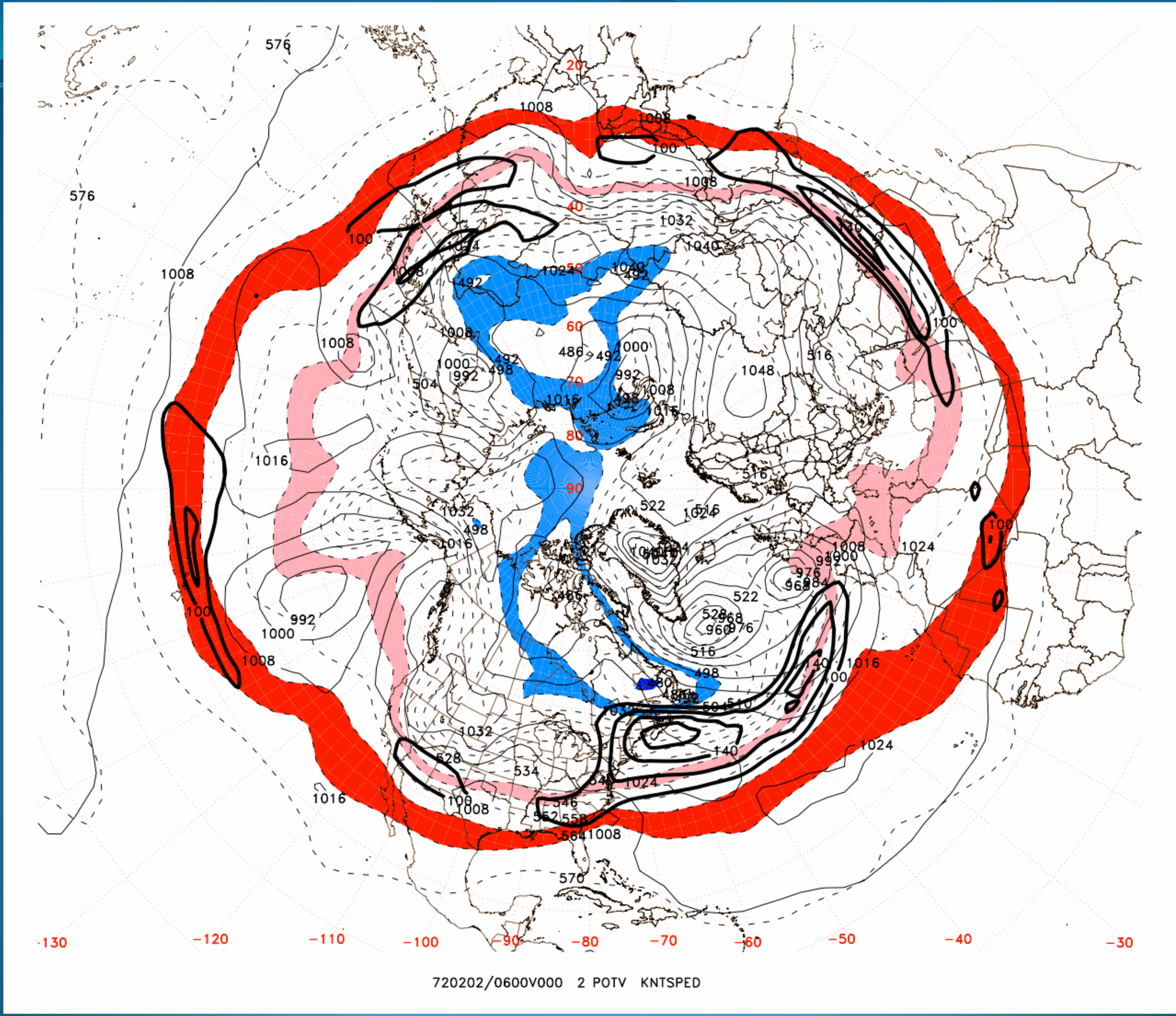
720201/1200V000 2 POTV KNTSPED

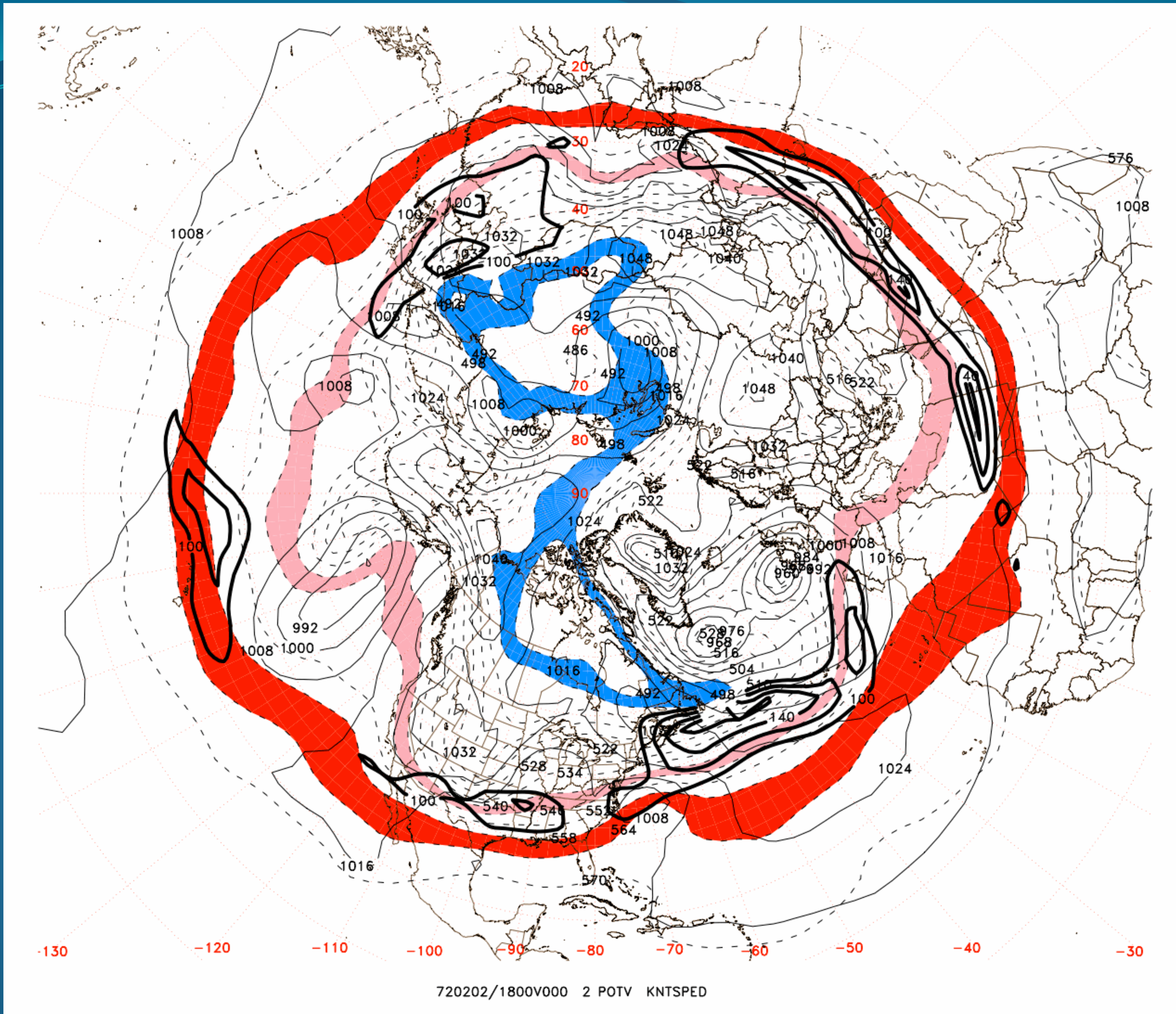


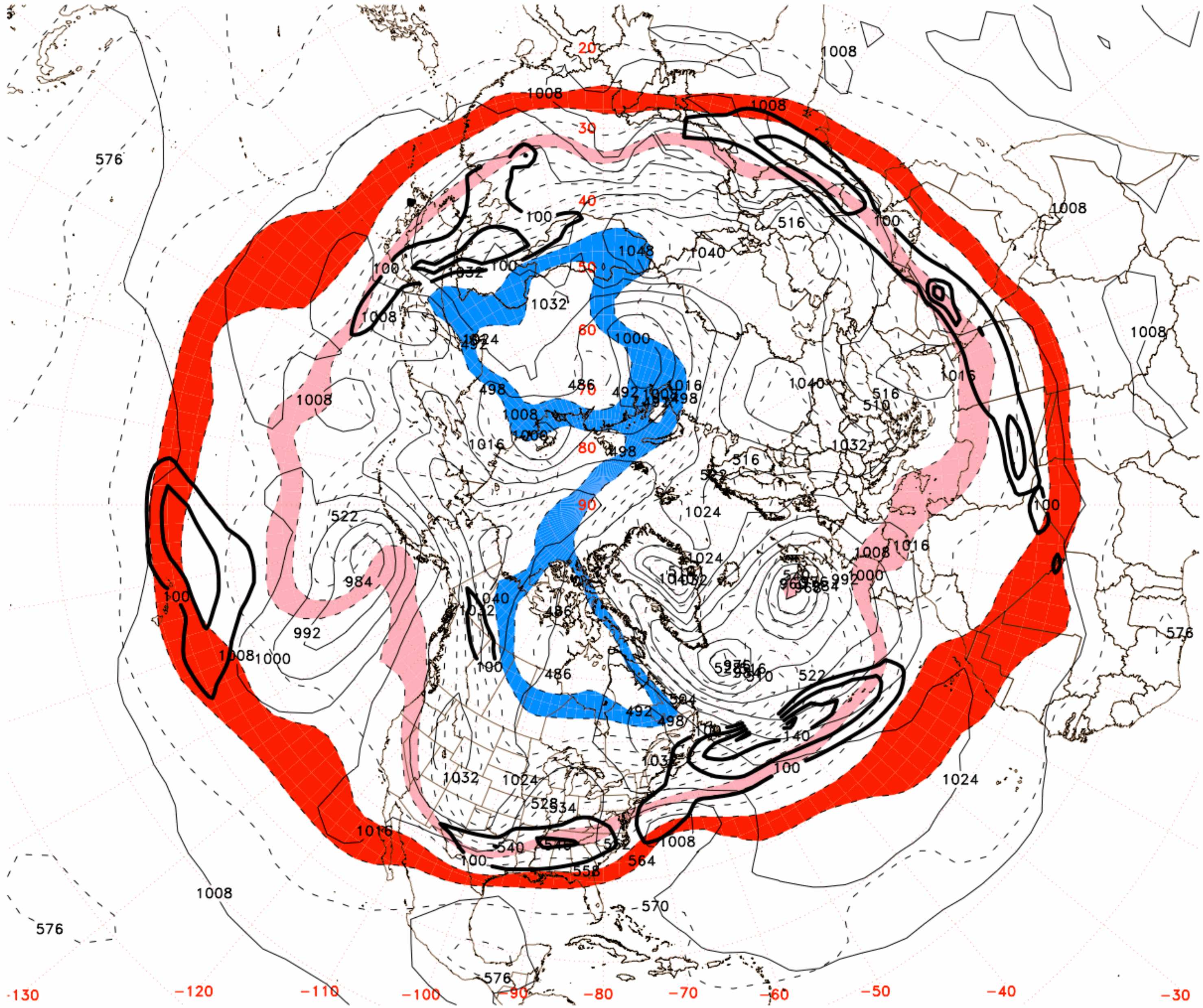
720201/1800V000 2 POTV KNTSPED



720202/0000V000 2 POTV KNTSPED


720202/0600V000 2 POTV KNTSPED

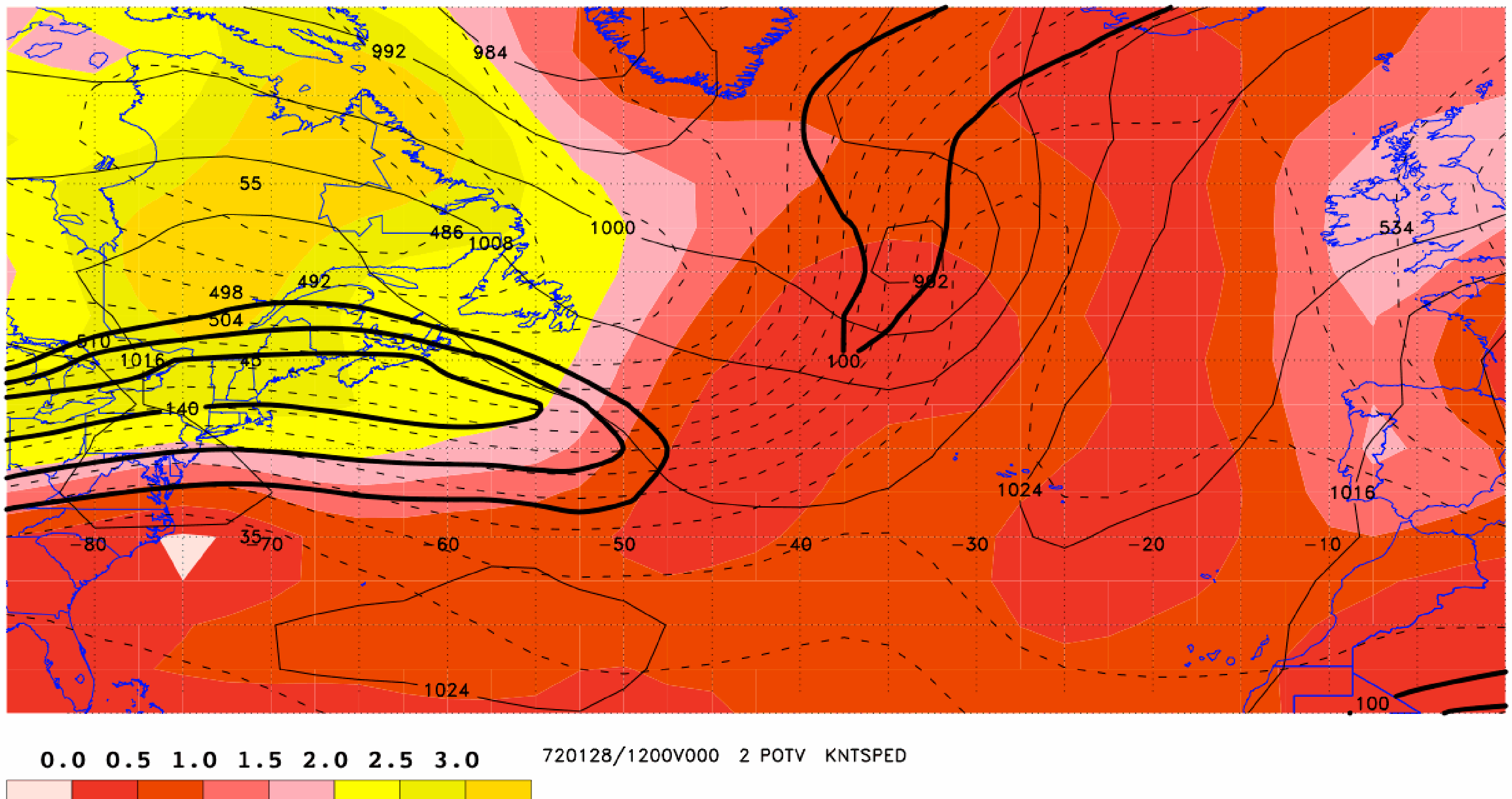

20
30
40
60
70
80
90
-130
-120
-110
-100
-90
-80
-70
-60
-50
-40
-30
720202/1800V000 2 POTV KNTSPED



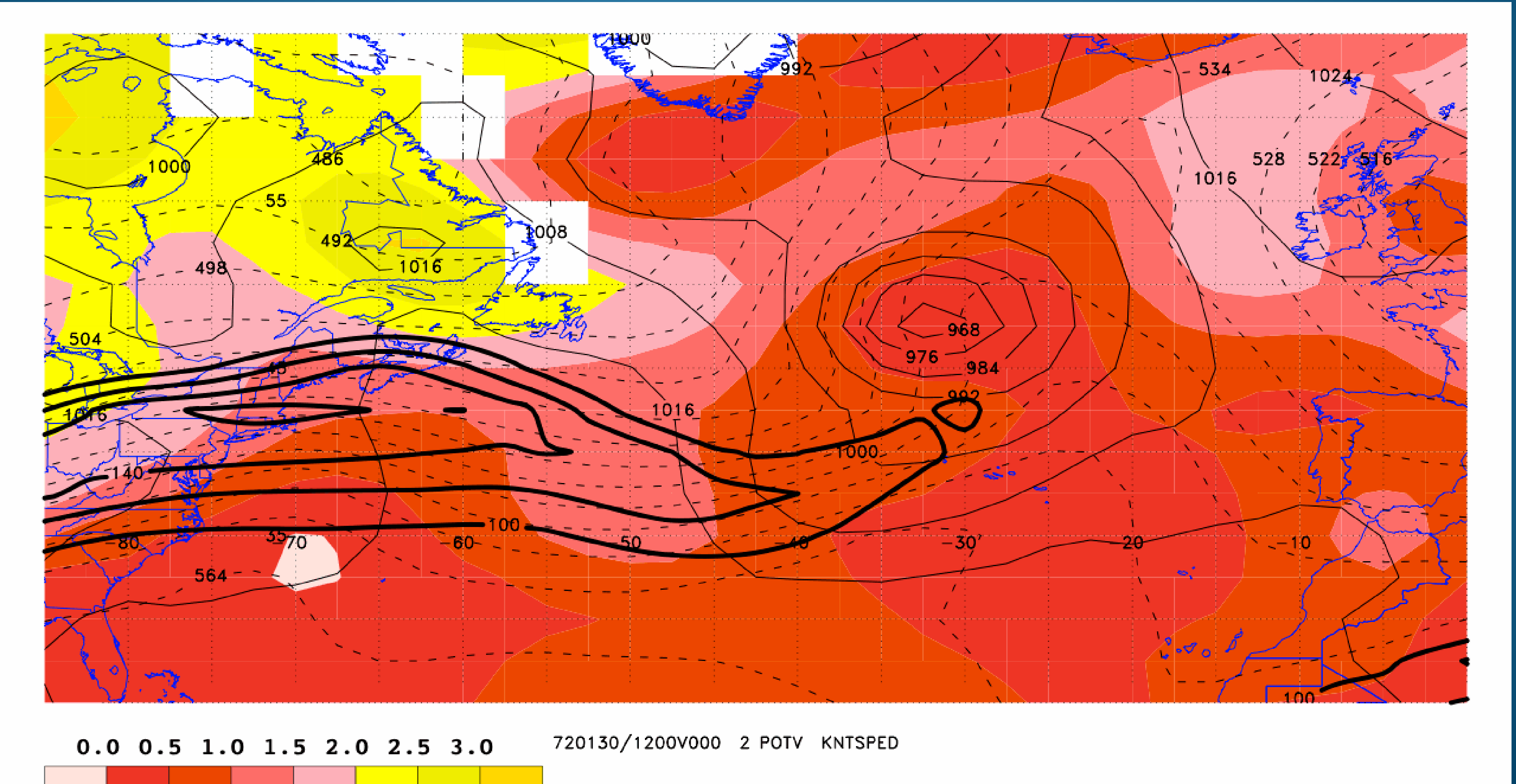
720203/0000V000 2 POTV KNTSPED

Previous slides illustrate the upscale growth of surface cyclonic coverage throughout the North Atlantic basin

The initial cyclogenesis (1200 UTC, 28 Jan) occurs on the equatorward side of the jet, where the moist Brunt-Väisälä frequency $(N_m)^2 = (g/T)(\partial T/\partial z + \Gamma_m)$ is near zero (units of $10^{-4}\ s^{-2}$)



At 1200 UTC, 30 January 1972, the cyclone has migrated to the left exit region of the jet, while a new surface cyclogenesis is occurring on the equatorward side of the jet in near zero effective stability:



Consider that the more extreme of the N. Atlantic cyclones deepened at 2.6 bergerons).

From Roebber (1984):

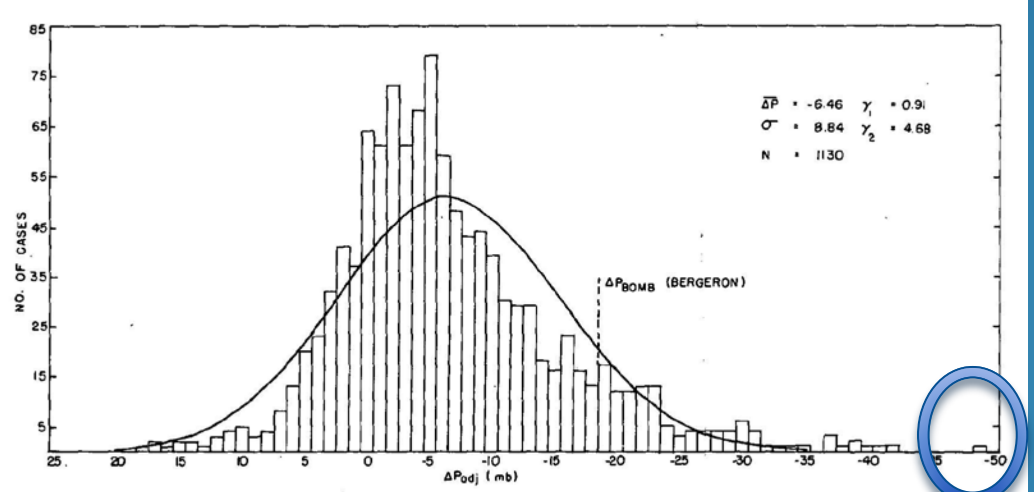


FIG. 2. Twenty-four hour deepening distribution, one-year data. The dashed line indicates the Bergeron definition of a bomb; points to the right of the line are bombs.

An index for North Atlantic Basin Storm Activity: Its relationship to explosive cyclogenesis

- Theory
- Observations
- Surface cyclogenesis
- Concluding discussion

Theory

Eady growth rate maximum:

$\sigma = 0.31\, f\, |\, \partial \mathbf{v}/\partial z\, |\, N^{-1}$, where N is the dry Brunt-Väisälä frequency

$N^2 = (g/T)(\partial T/\partial z + \Gamma_d)$

and the moist baroclinic growth rate:

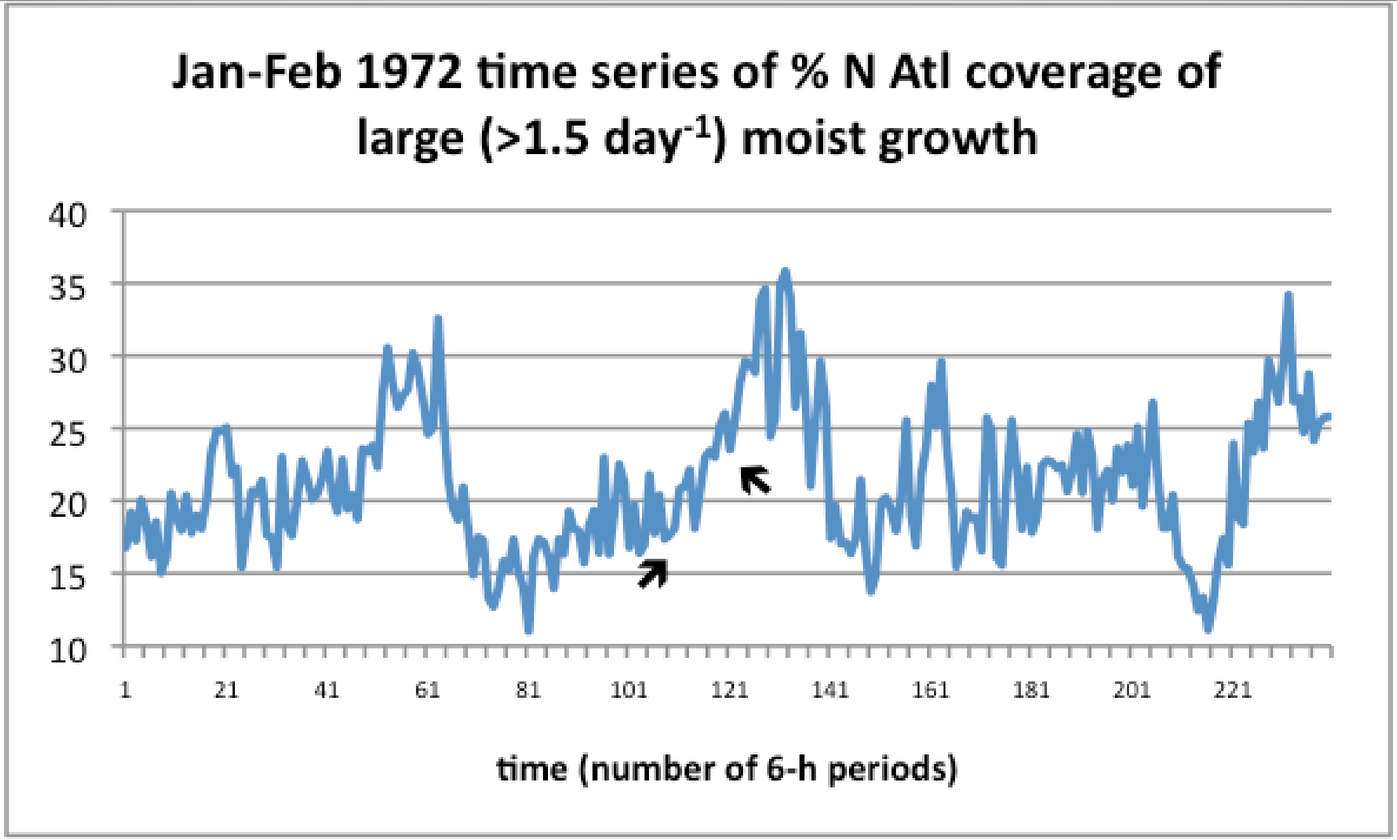
$\sigma_m = 0.31\, f\, |\, \partial \mathbf{v}/\partial z\, |\, N_m^{-1}$, where N_m is the moist Brunt-Väisälä frequency

$(N_m)^2 = (g/T)(\partial T/\partial z + \Gamma_m)$

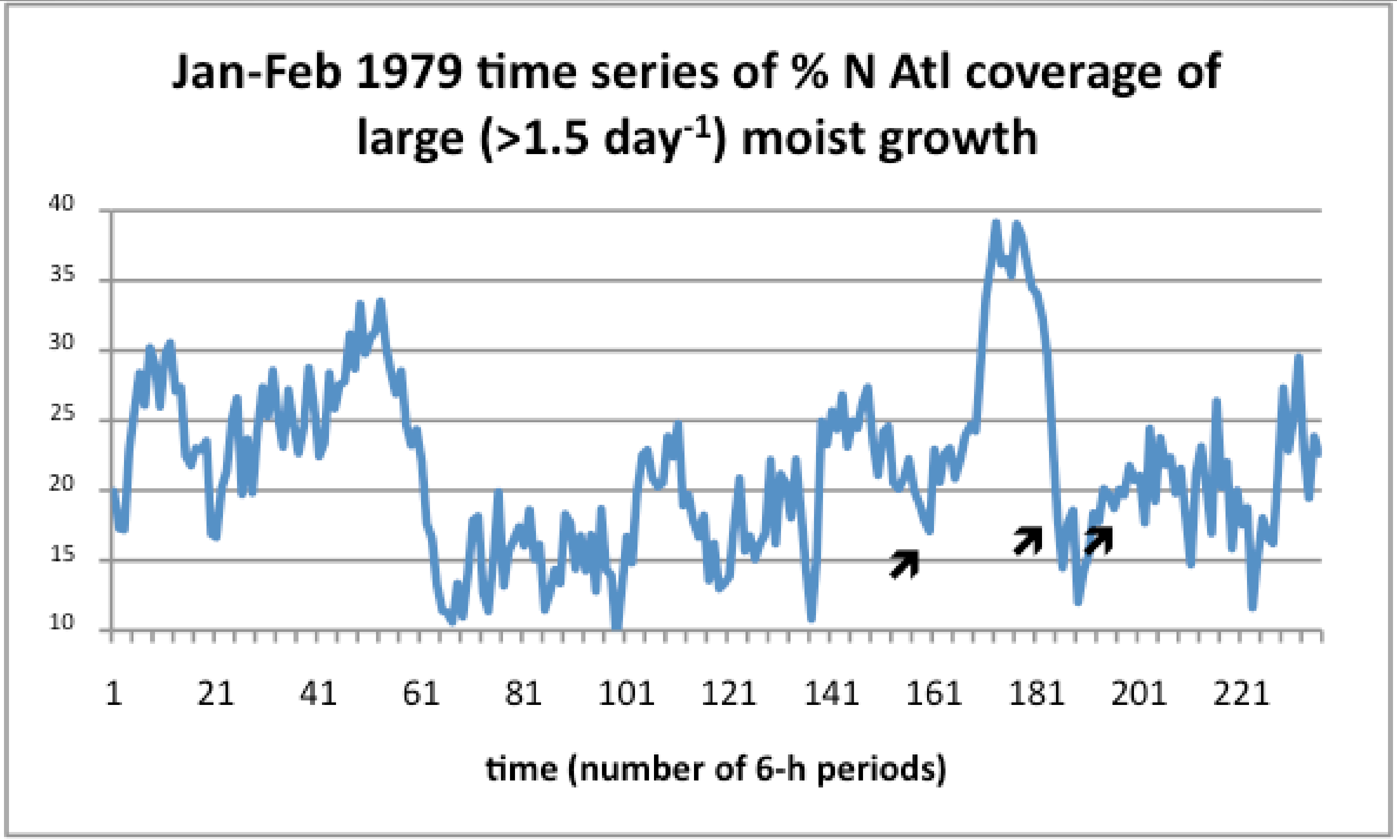
The North Atlantic Storm Index (NASTI):

The count of events during which the areal coverage (%) in the North Atlantic basin (25-60 deg N; 80-0 deg W) of moist baroclinic growth exceeding 1.5/day exceeds 2 standard deviations from a 30-year running mean climatology

Observations

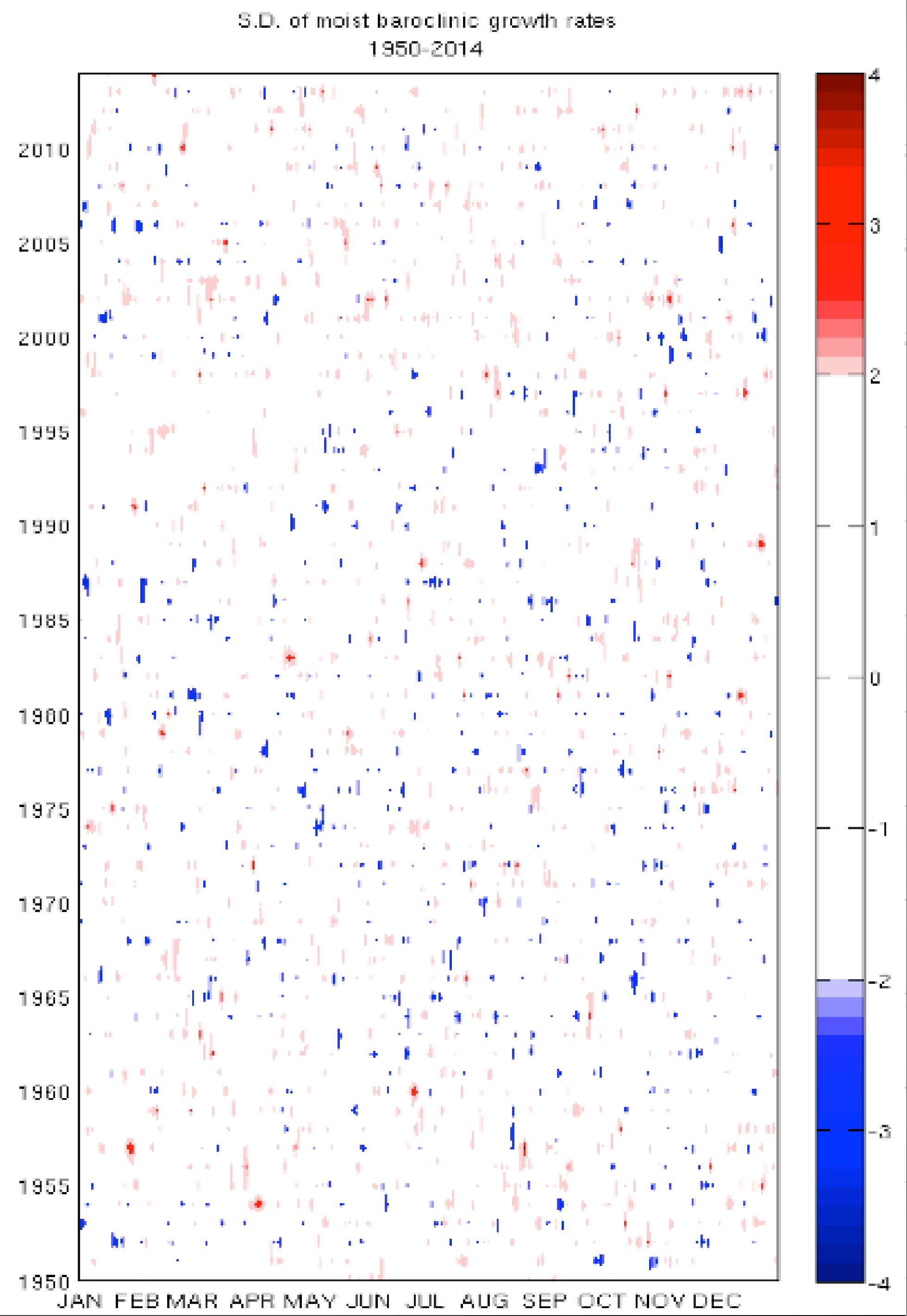


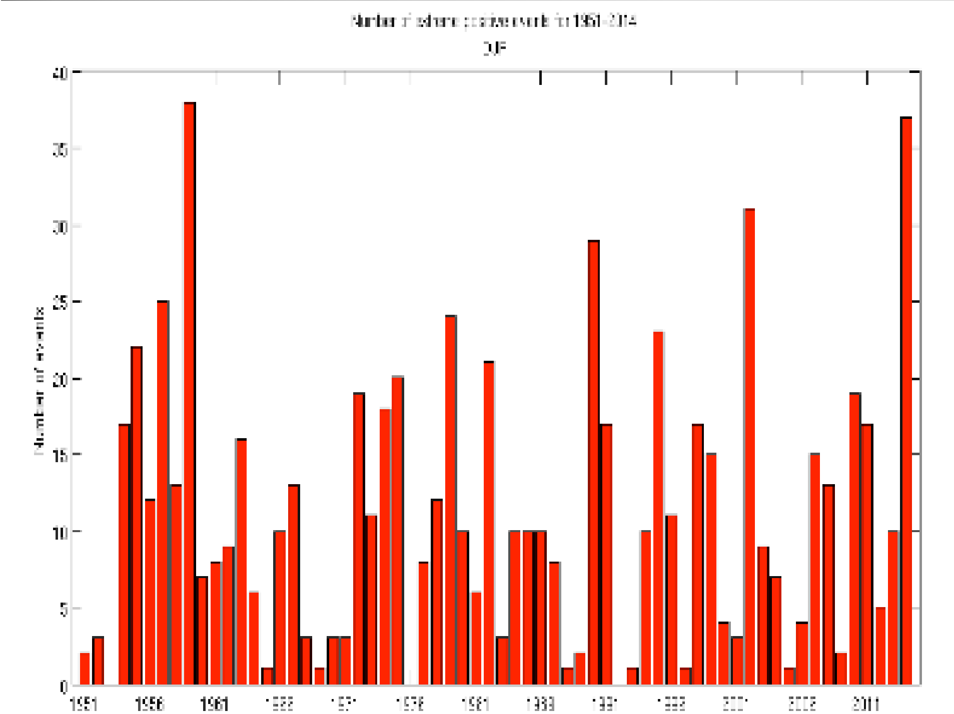
The left-most arrow points to the time of first appearance of explosive cyclone 1 (1200 UTC, 28 January 1972). The right most arrow points to the time of the completion of explosive cyclogenesis (1800 UTC, 31 January 1972) of cyclone 2.



The left-most arrow points to the initial time (0000 UTC, 10 February 1979) of the week-long sequence of 'cluster' bomb events discussed in the Sanders-Gyakum (1980) paper. The second arrow points to the completion (1800 UTC, 16 February 1979) of the week. The third arrow points to the first appearance (1800 UTC, 18 February 1979) of the Presidents' Day cyclone (Bosart 1981).

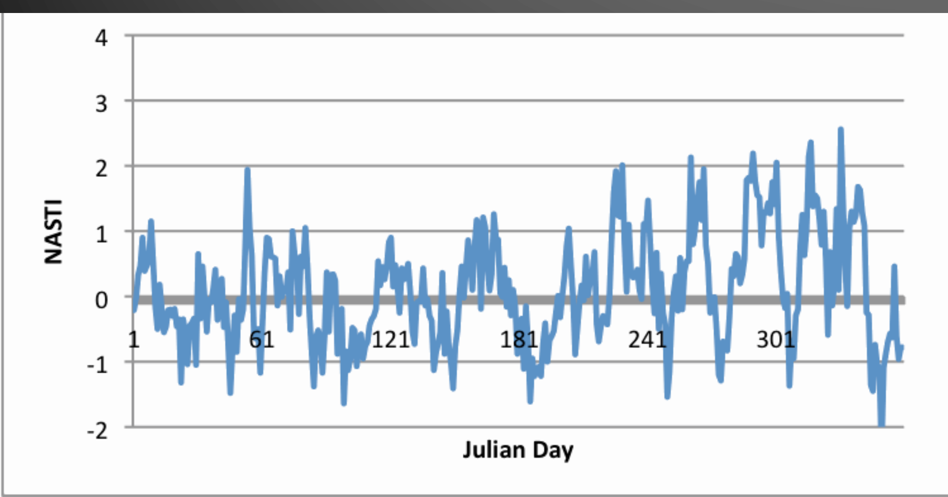
North Atlantic Storm Index from 1950 through February 2014 (counts of normalized standard deviations with absolute values exceeding 2.0)



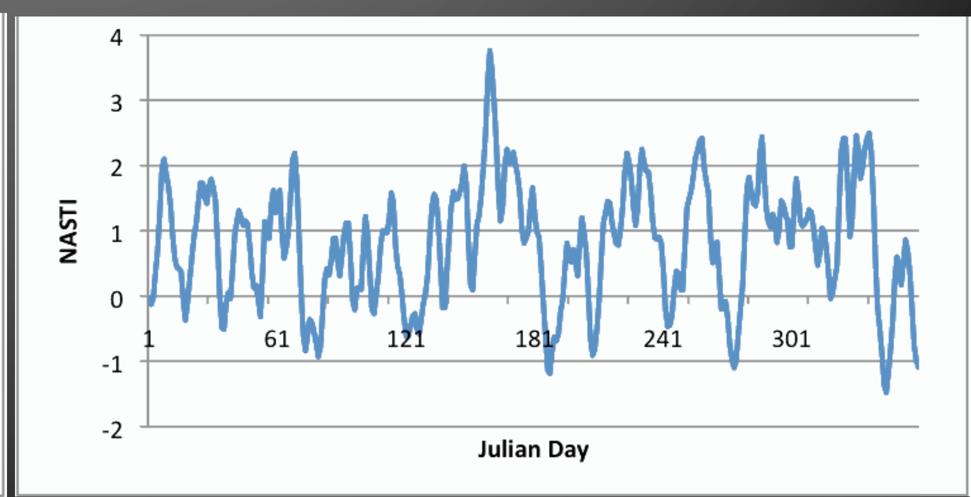


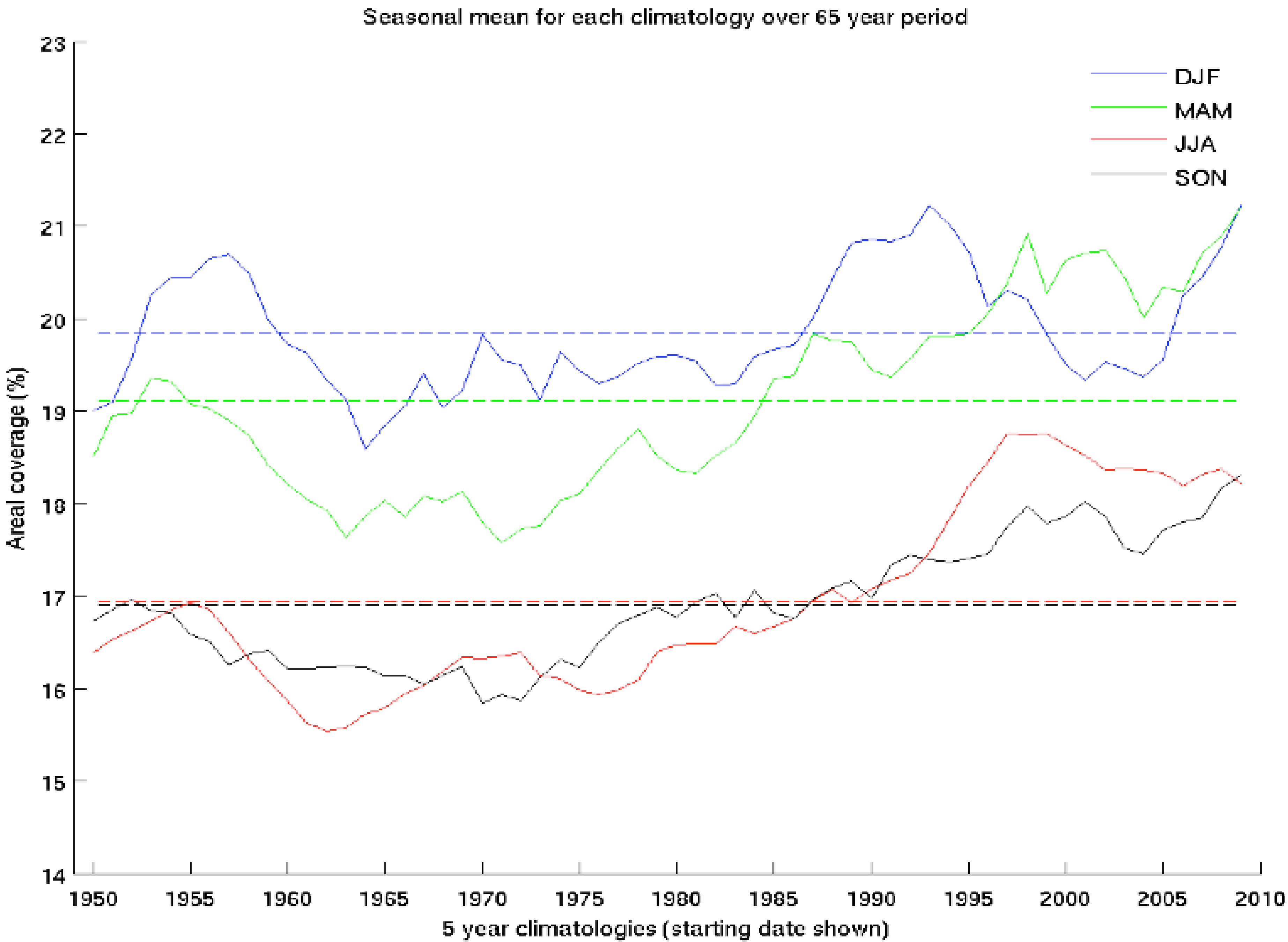
Counts of NASTI events (DJF) from Dec. 1950 through February 2014

JFM 1992:



JFM 2014:



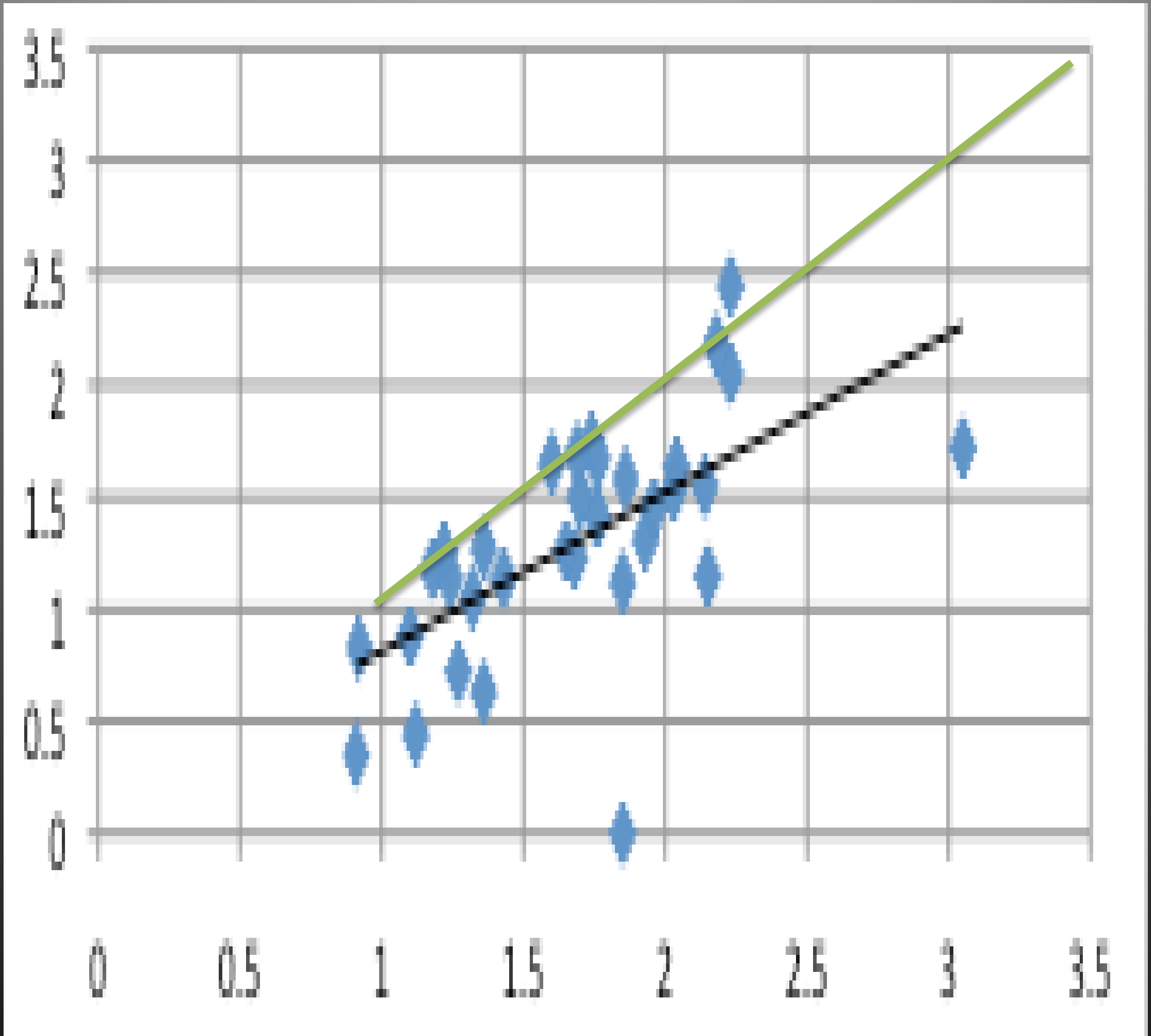

Seasonal mean for each climatology over 65 year period
DJF
MAM
JJA
SON
Areal coverage (%)
5 year climatologies (starting date shown)
23
22
21
20
19
18
17
16
15
14
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

Surface cyclogenesis

Cyclone intensifications (observed versus forecasted)

Deep low (<960 hPa) maximum deepenings vs forecasted (Bergerons)
(of the 37 960 hPa cases during Dec. 2013-March 2014, 31 qualified as ‘bombs’)

Forecasted



Synoptic-Dynamic Climatology of the "Bomb"

FREDERICK SANDERS AND JOHN R. GYAKUM

Department of Meteorology, Massachusetts Institute of Technology, Cambridge 02139

(Manuscript received 24 March 1980, in final form 12 June 1980)

ABSTRACT

By defining a "bomb" as an extratropical surface cyclone whose central pressure fall averages at least 1 mb h^{-1} for 24 h, we have studied this explosive cyclogenesis in the Northern Hemisphere during the period September 1976–May 1979. This predominantly maritime, cold-season event is usually found ~400 n mi downstream from a mobile 500 mb trough, within or poleward of the maximum westerlies, and within or ahead of the planetary-scale troughs.

A more detailed examination of bombs (using a 12 h development criterion) was performed during the 1978–79 season. A survey of sea surface temperatures (SST's) in and around the cyclone center indicates explosive development occurs over a wide range of SST's, but, preferentially, near the strongest gradients. A quasi-geostrophic diagnosis of a composite incipient bomb indicates instantaneous pressure falls far short of observed rates. A test of current National Meteorological Center models shows these products also fall far short in attempting to capture observed rapid deepening.

1. Introduction

Tor Bergeron is reputed to have characterized a rapidly deepening extratropical low as one in which the central pressure at sea level falls at the rate of at least 1 mb h^{-1} for 24 h. An extreme example of the development of a storm of this type appears in Fig. 1. The extraordinary deepening occurred during an interval of unfortunately sparse coverage of ship observations near the center, so that we know the central intensity only at the initial and final times. Note that nearly the strongest winds occur only ~60 n mi from the center, and that the radial profile of wind near the center must resemble that of a tropical cyclone. Note further that the storm develops along the leading edge of an outbreak of bitterly cold air over the western Atlantic, but that the cold air does not penetrate to the center of the low.

A Defense Meteorological Satellite view (Fig. 2), about midway through the illustrated period, shows a major "head cloud" mass of great meridional extent, considered by Jalu (1973) and by Böttger *et al.* (1975) to be characteristic of intense deepening on a small scale. Note also the indication of deep convection along the rear edge of the main cloud mass, corresponding to the cold front, and the eyelike circular clear area perhaps 40 n mi in diameter near 43°N, 43°W, near the estimated position of the surface center. These characteristics also appear to be typical.

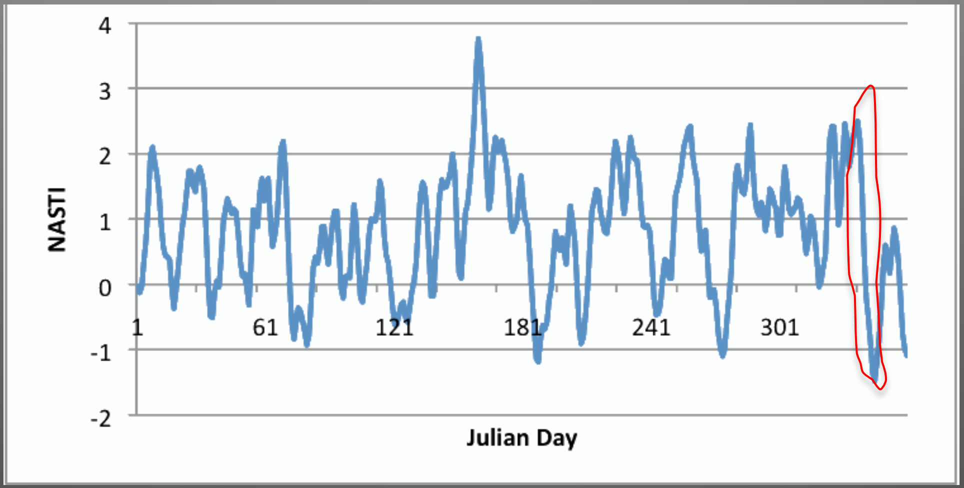
We are interested in this phenomenon because of its great practical importance to shipping and to coastal regions. Even pleasure craft are endangered by these storms; the tragic loss of life in the 1979 Fastnet yacht race was attributable to a rare summer example of the meteorological "bomb" (Rice, 1979). We are also interested in these storms because (as will be shown later) deepening rates predicted by current operational dynamical models fall far short of the observed ones, implying that some physical effect other than the commonly understood large-scale baroclinic mechanism may play an important role. Finally, the rapid deepening process may be a necessary component in a realistic model simulation of the general circulation. We have tested the notion that most of the hemisphere's deepest cyclones (which usually track toward their final resting places in the vicinity of the Icelandic and Aleutian lows) have deepened explosively. Of the 37 deep lows (960 mb or lower) found during the 9-month period beginning 1 September 1978, 31 qualified as a bomb (using the criteria defined in Section 4) during their development. Thus, explosive deepening is a characteristic of the vast majority of the deepest cyclones.

2. A three-year data sample

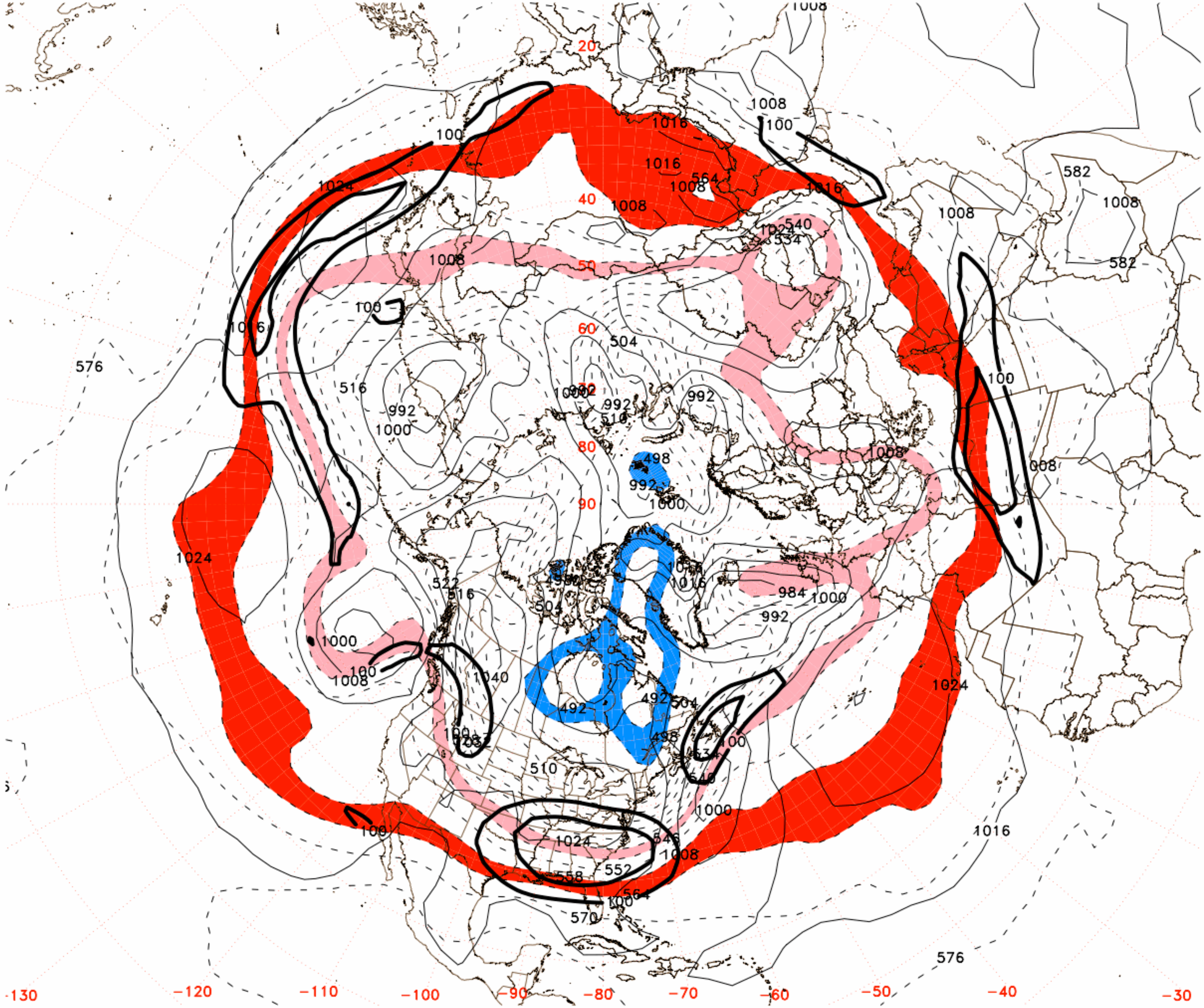
For three recent cold seasons we have studied this class of explosively intensifying cyclones in the Northern Hemisphere from longitude 130°E eastward to 10°E. As Bergeron's characterization probably referred to the latitude of Bergen (60°N), a geostrophically equivalent rate was obtained for arbitrary latitude ϕ by multiplying his rate by

0027-0644/80/101589-18$08.50

The large decrease in NASTI in late March 2014:

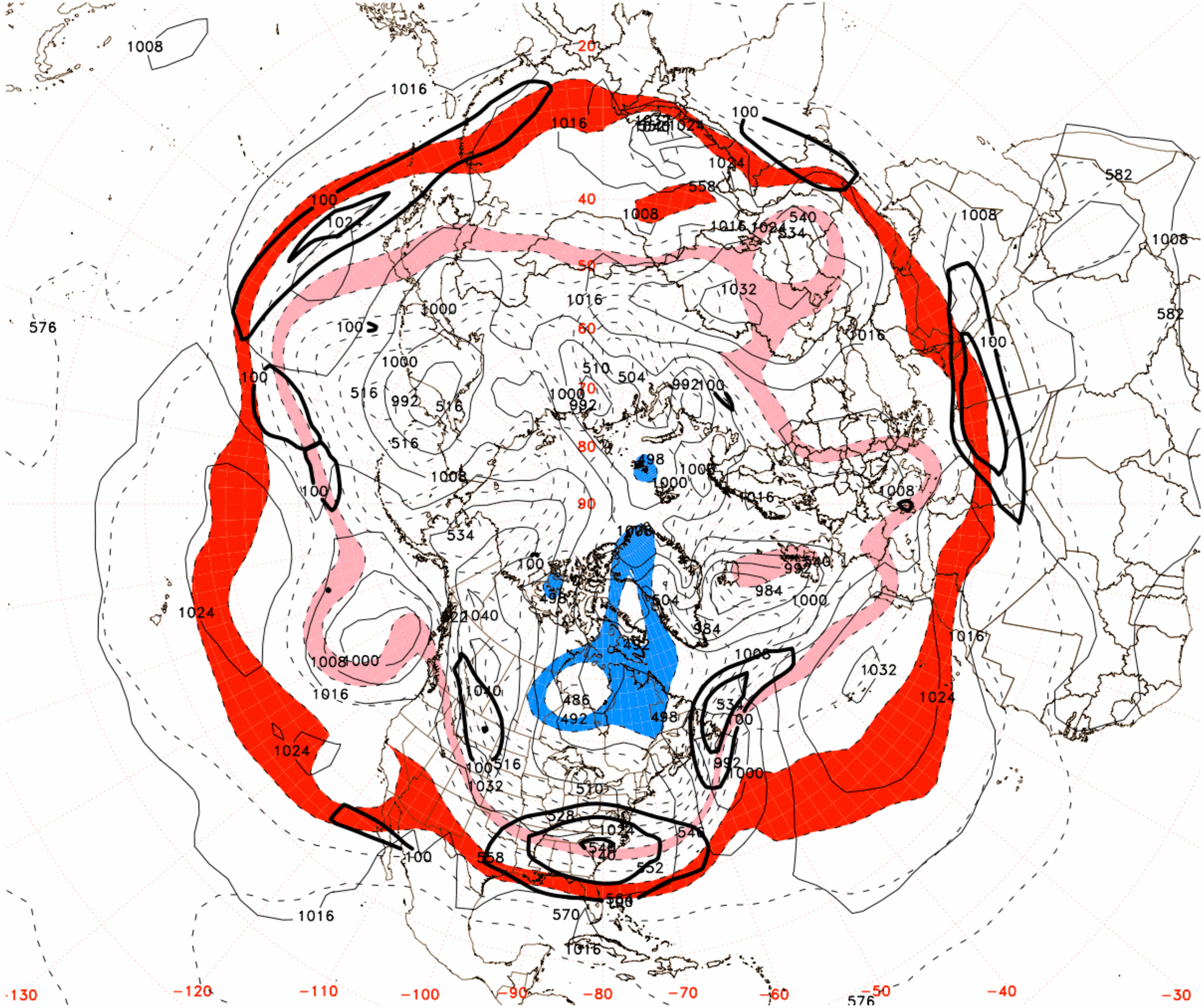


2.46



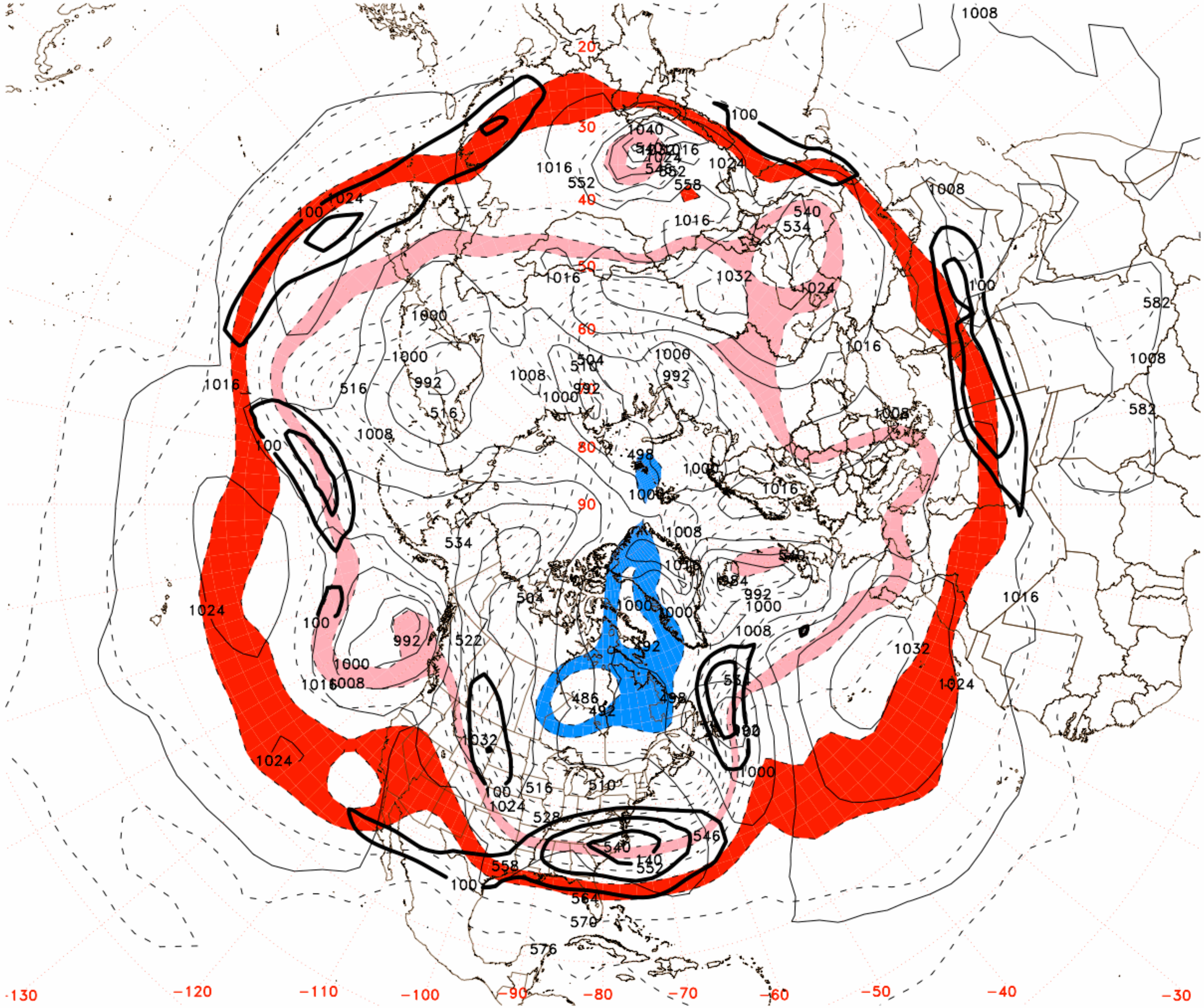
140324/1200V000 250 MB KNTSPED

2.23



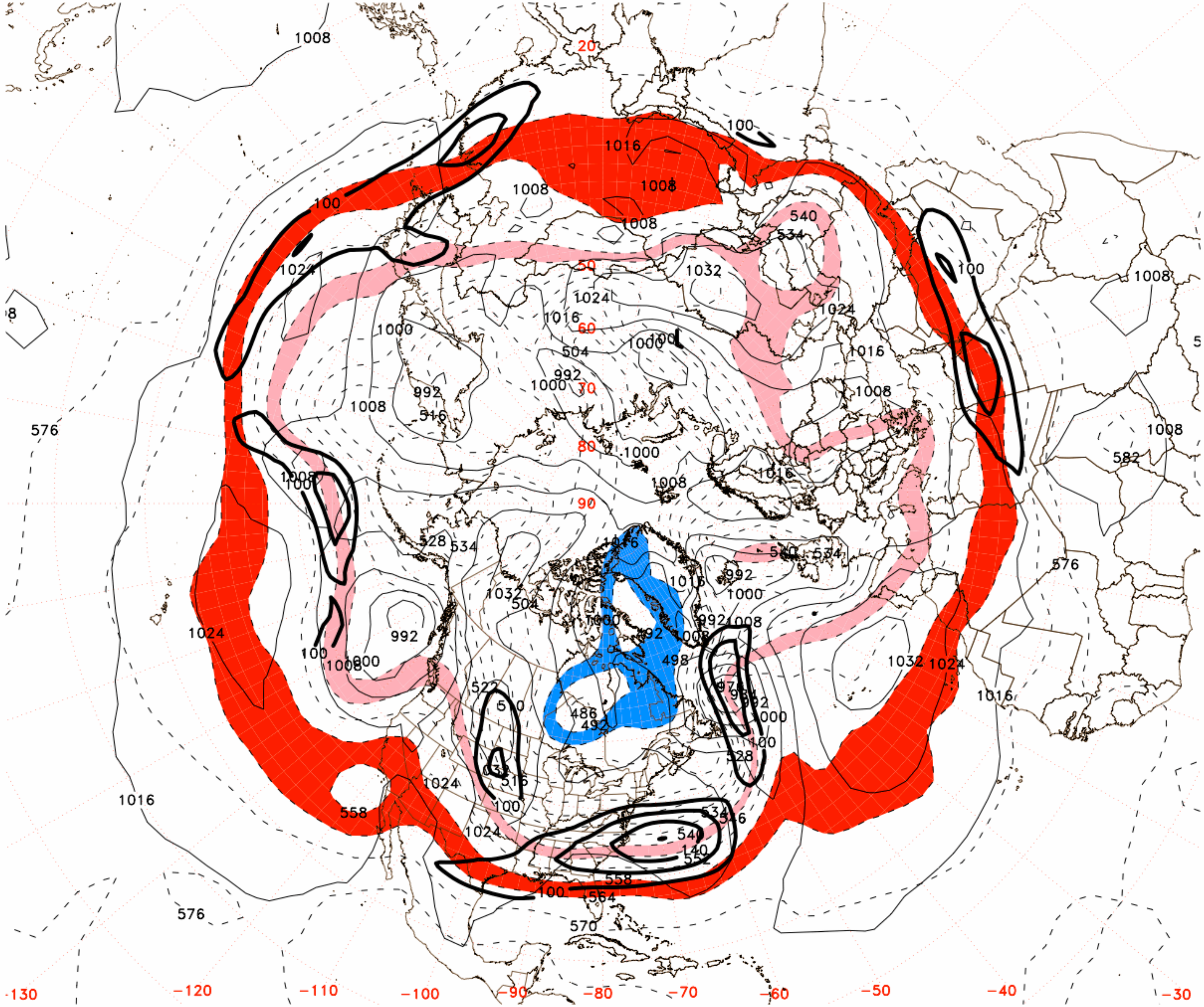
140324/1800V000 250 MB KNTSPED

1.80



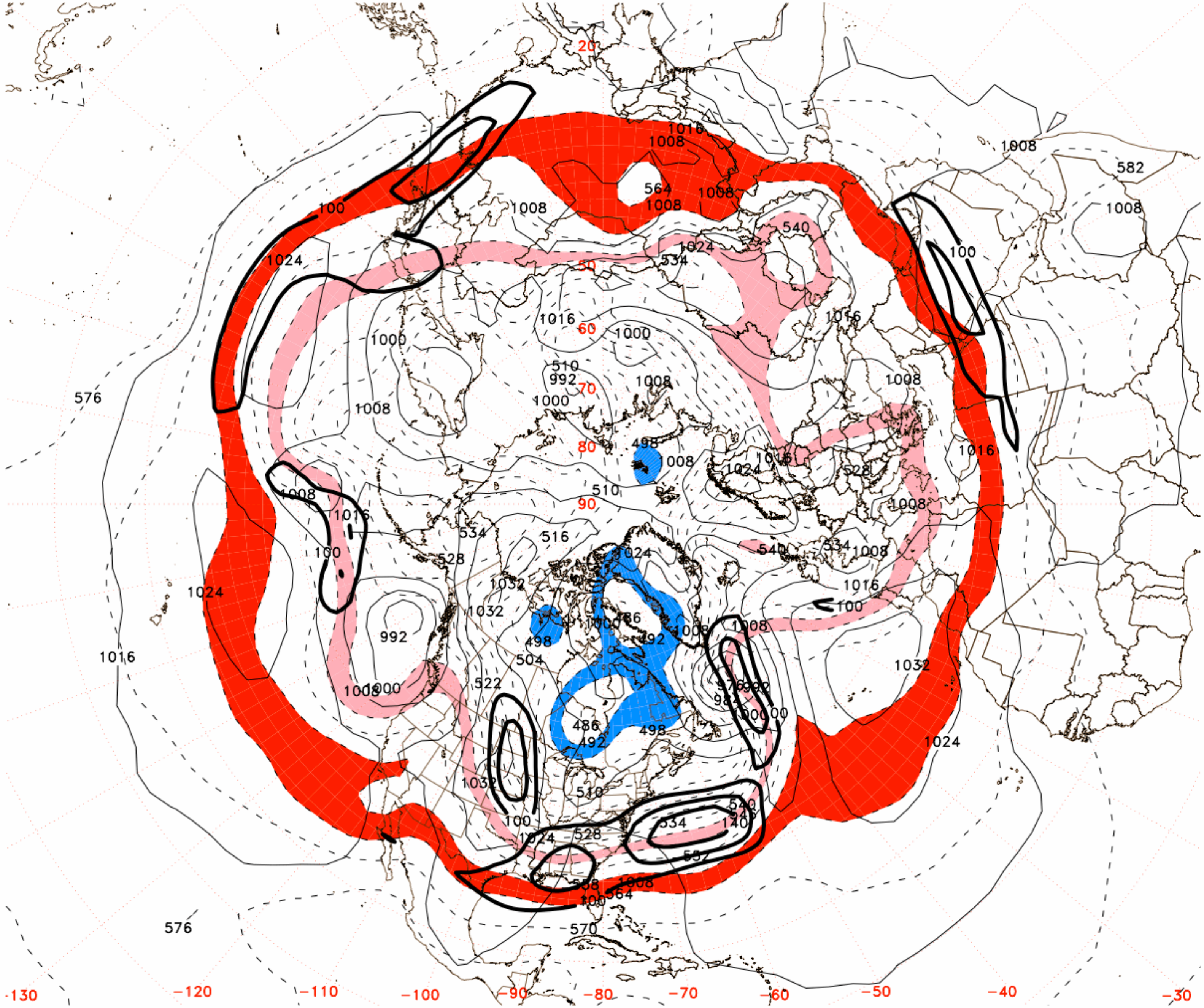
140325/0000V000 250 MB KNTSPED

1.98



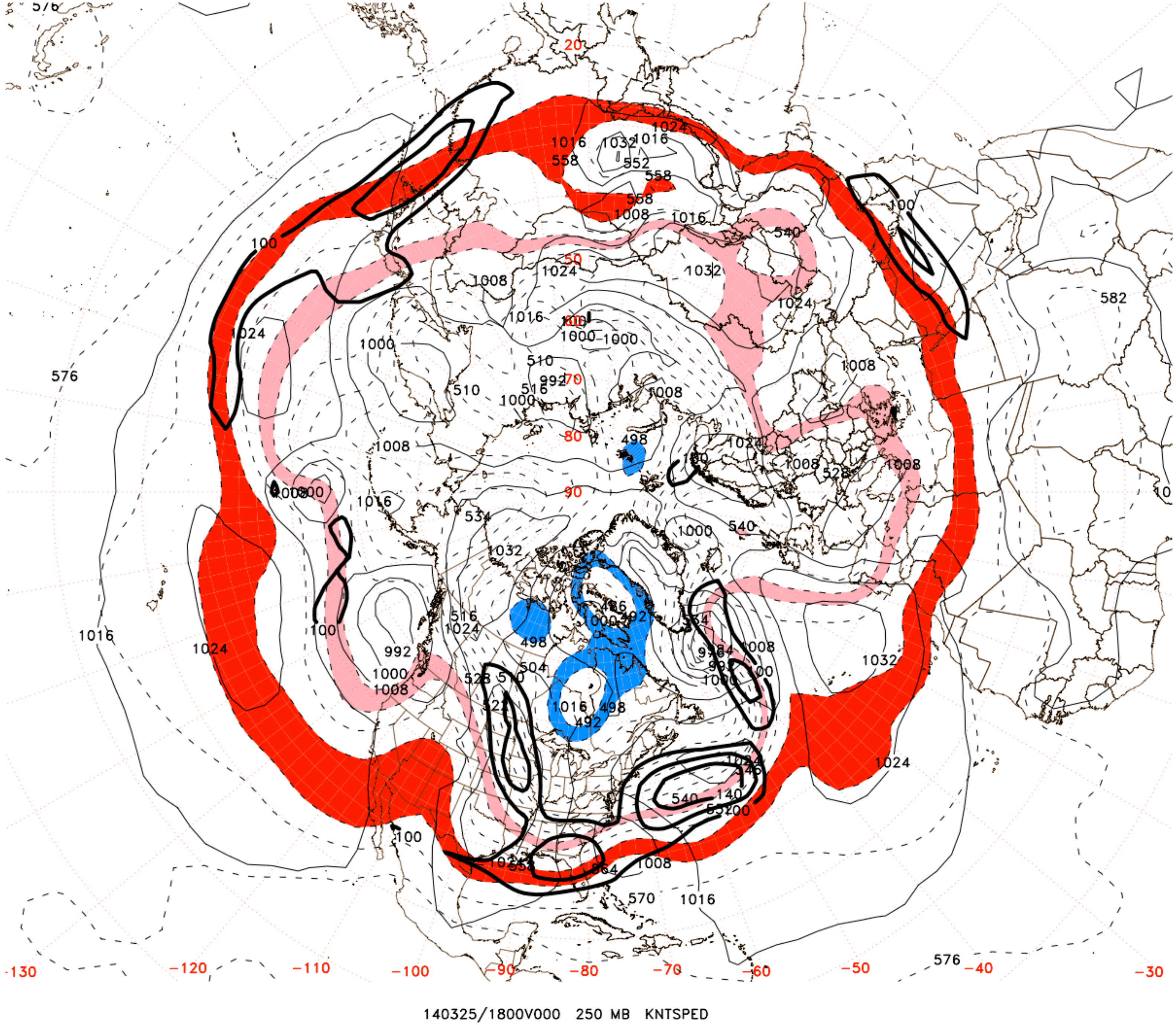
140325/0600V000 250 MB KNTSPED

2.26



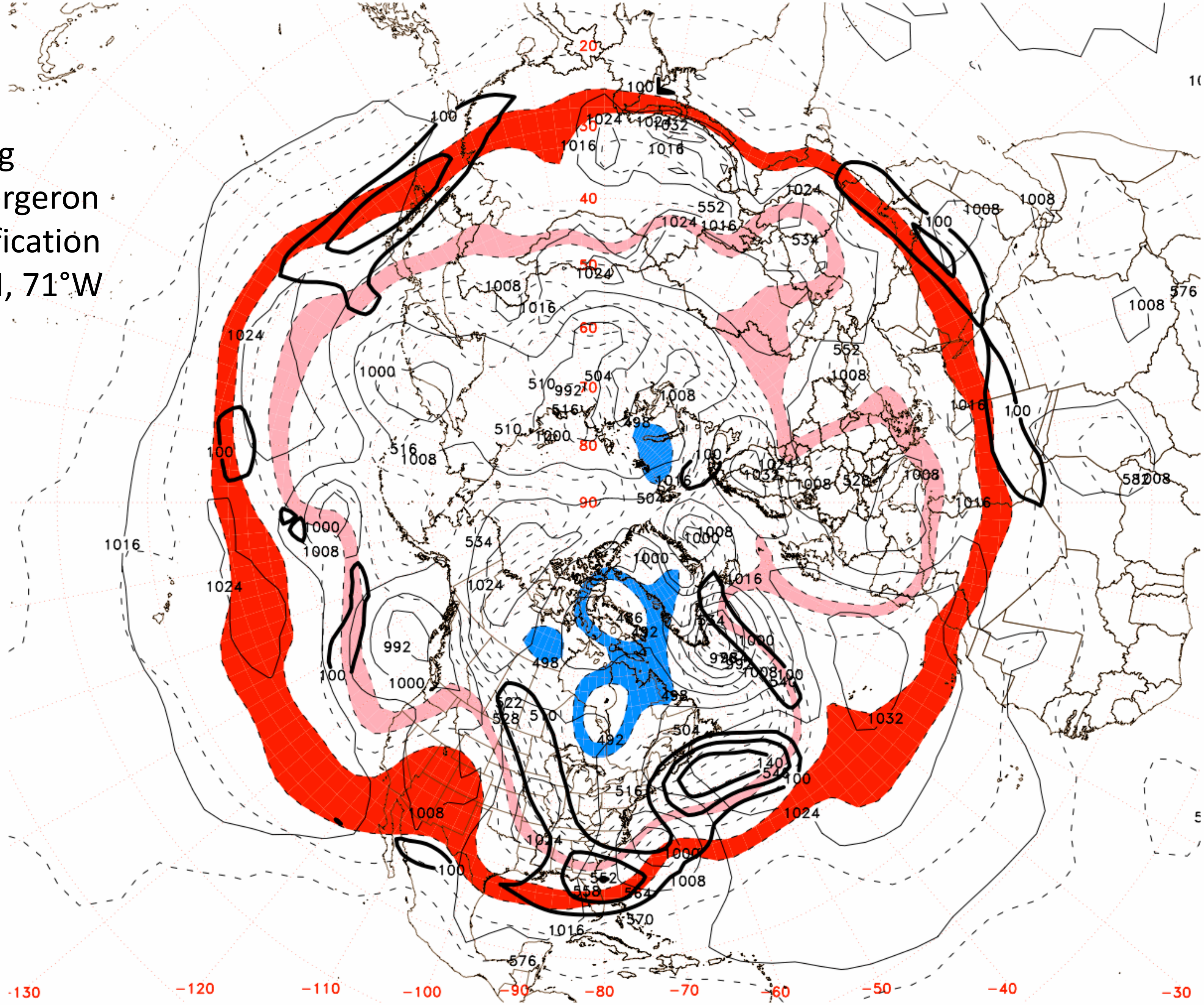
140325/1200V000 250 MB KNTSPED

2.41



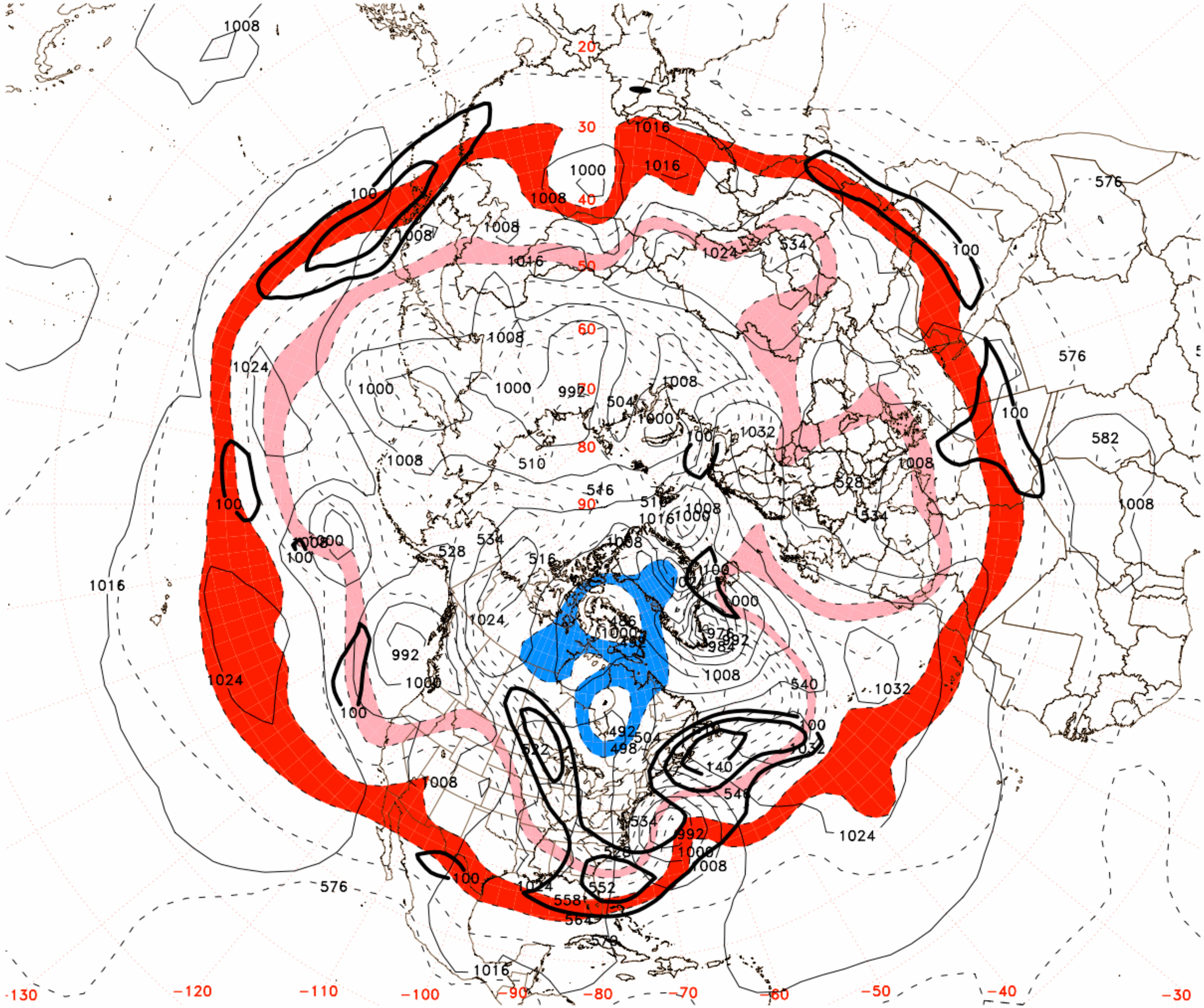
2.50

Ongoing
3.05 Bergeron
Intensification
At 33°N, 71°W



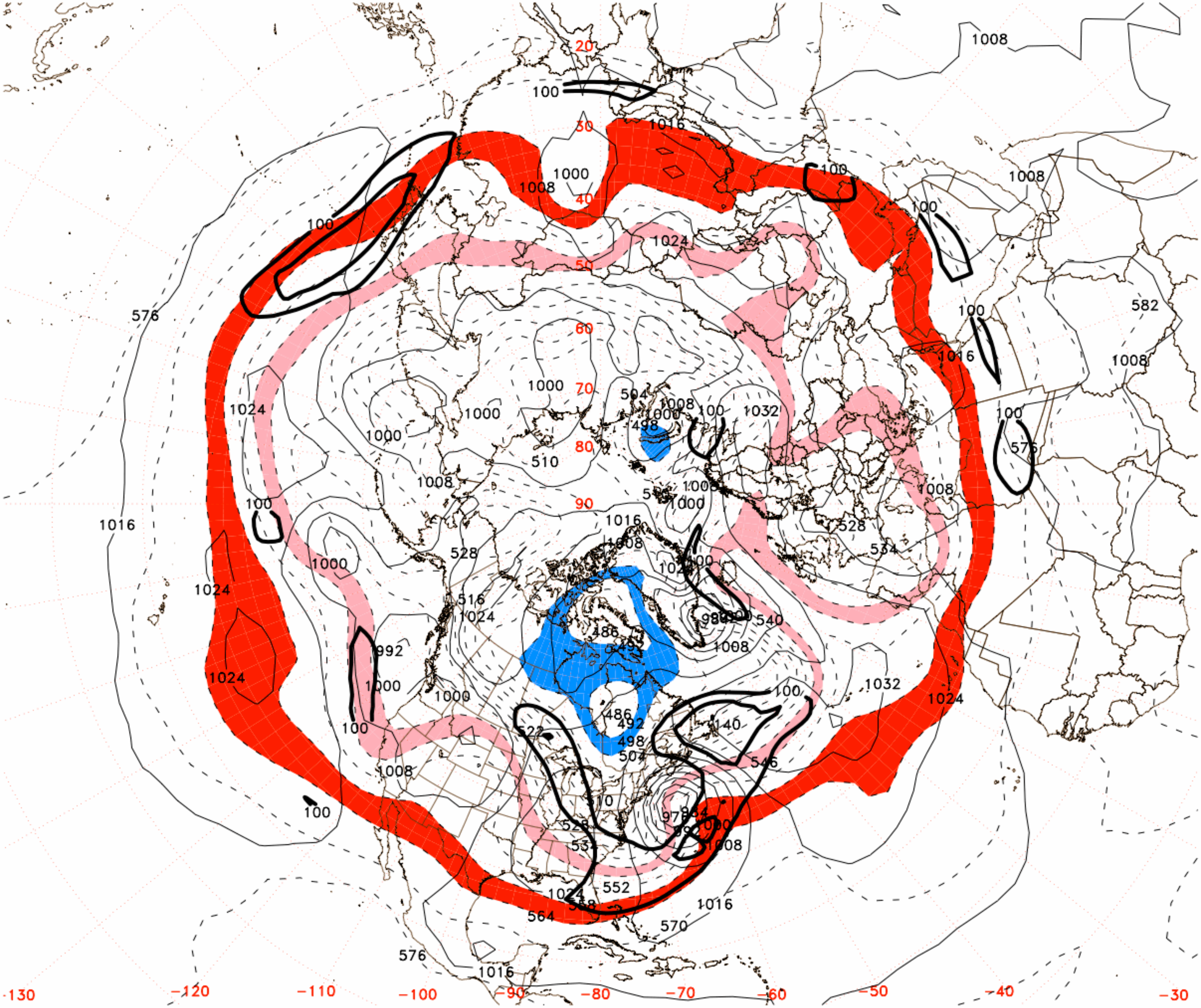
140326/0000V000 250 MB KNTSPED

2.22



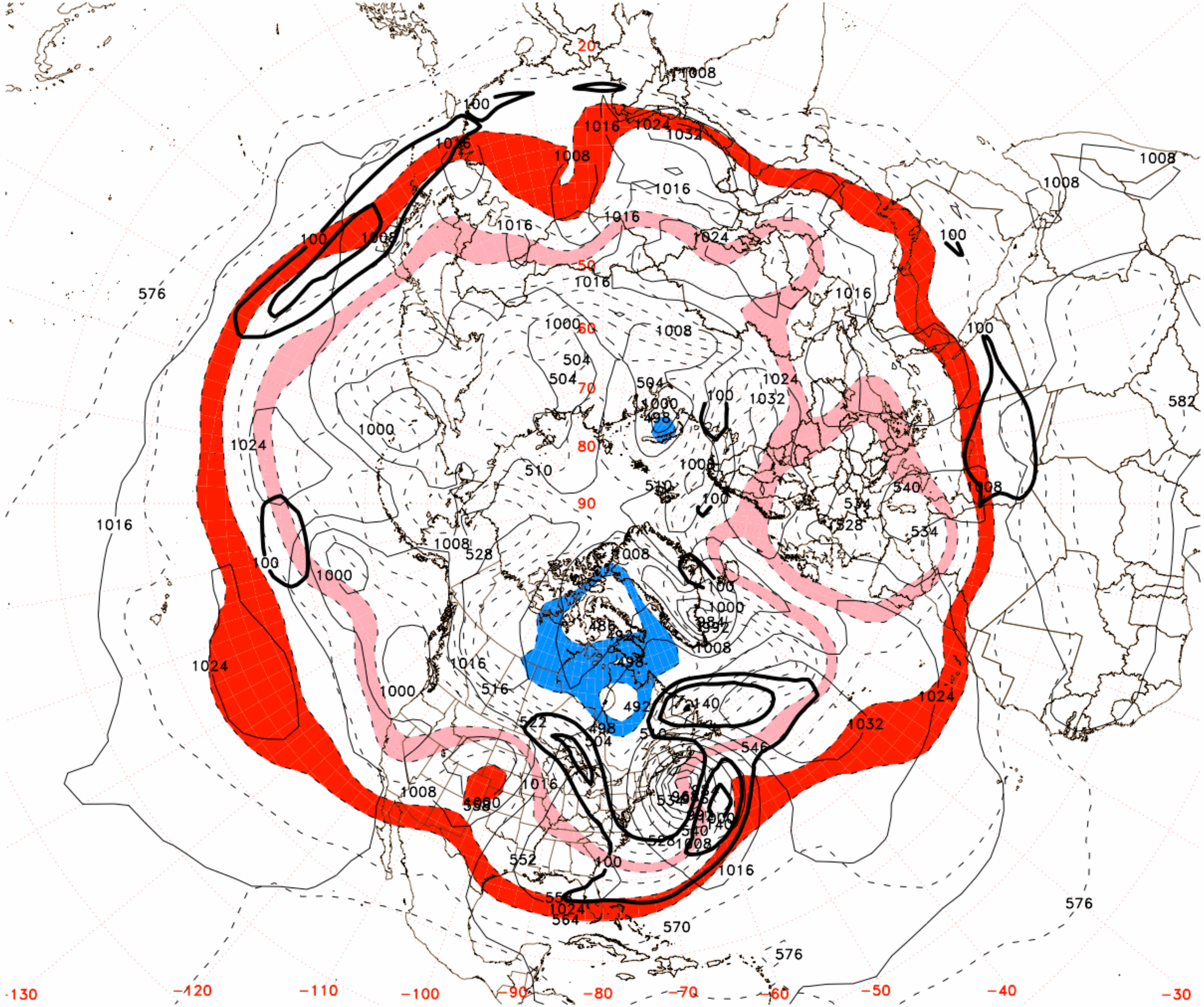
140326/0600V000 250 MB KNTSPED

1.50



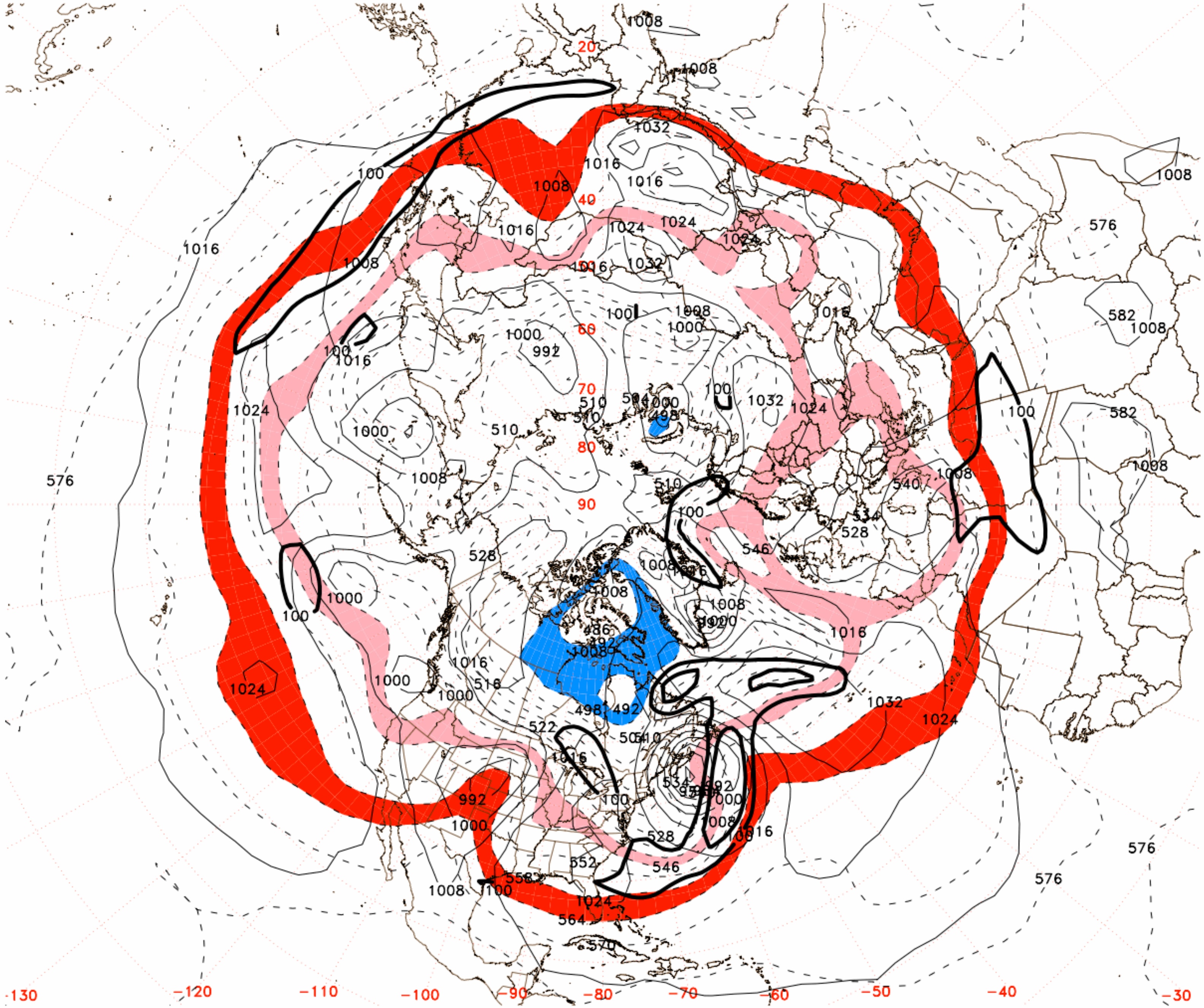
140326/1200V000 250 MB KNTSPED

0.50



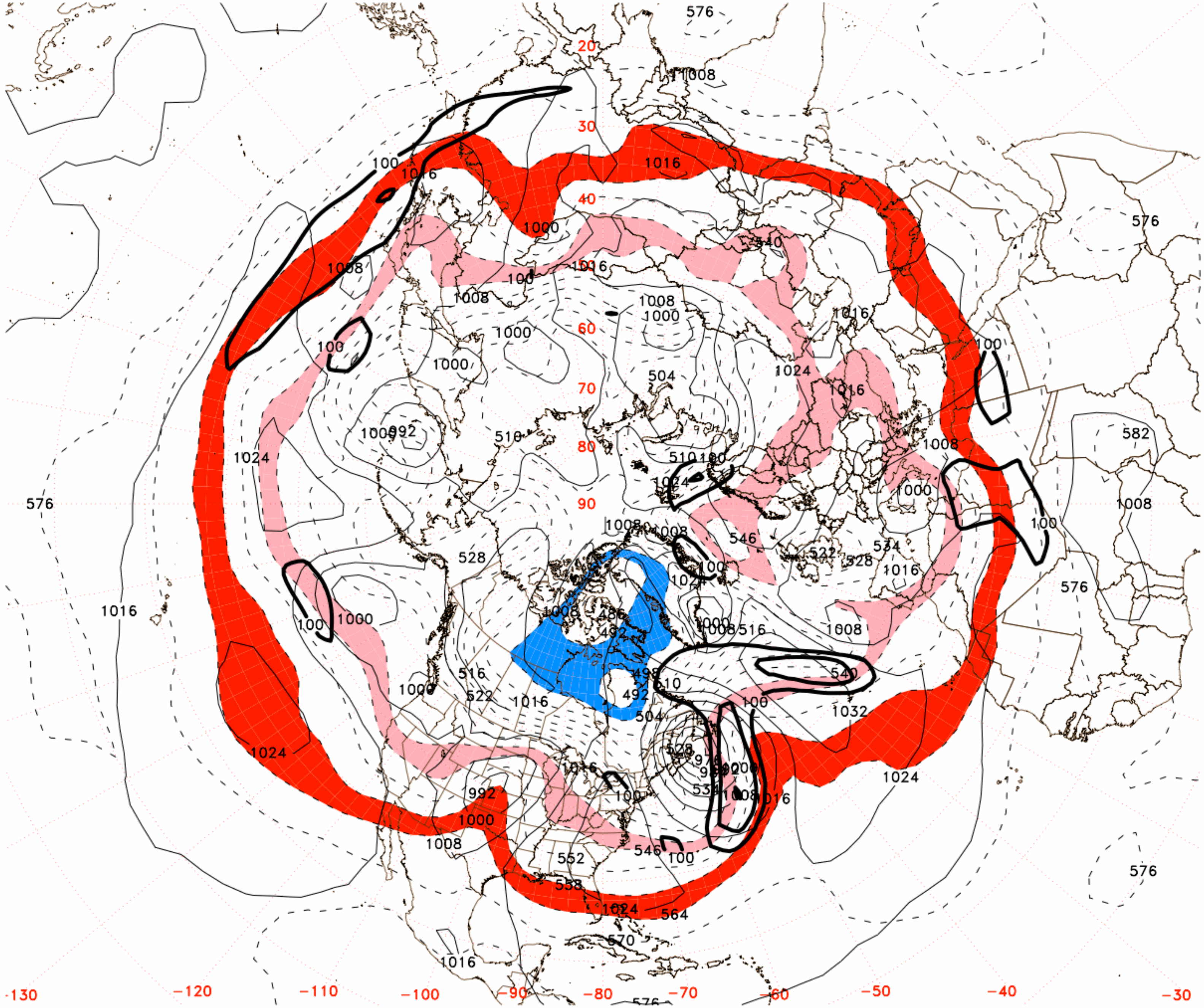
140326/1800V000 250 MB KNTSPED

-0.20



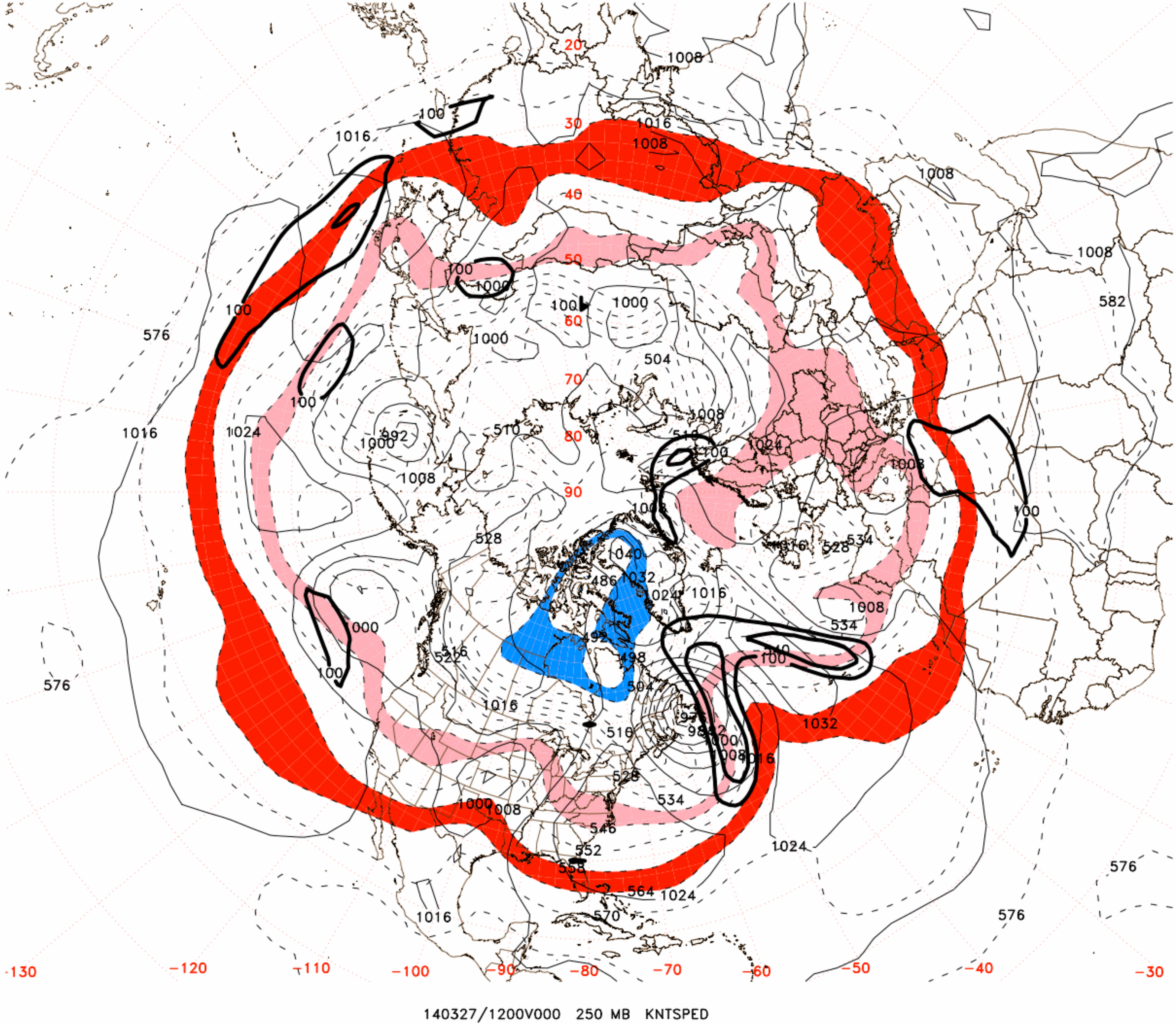
140327/0000V000 250 MB KNTSPED

-0.51

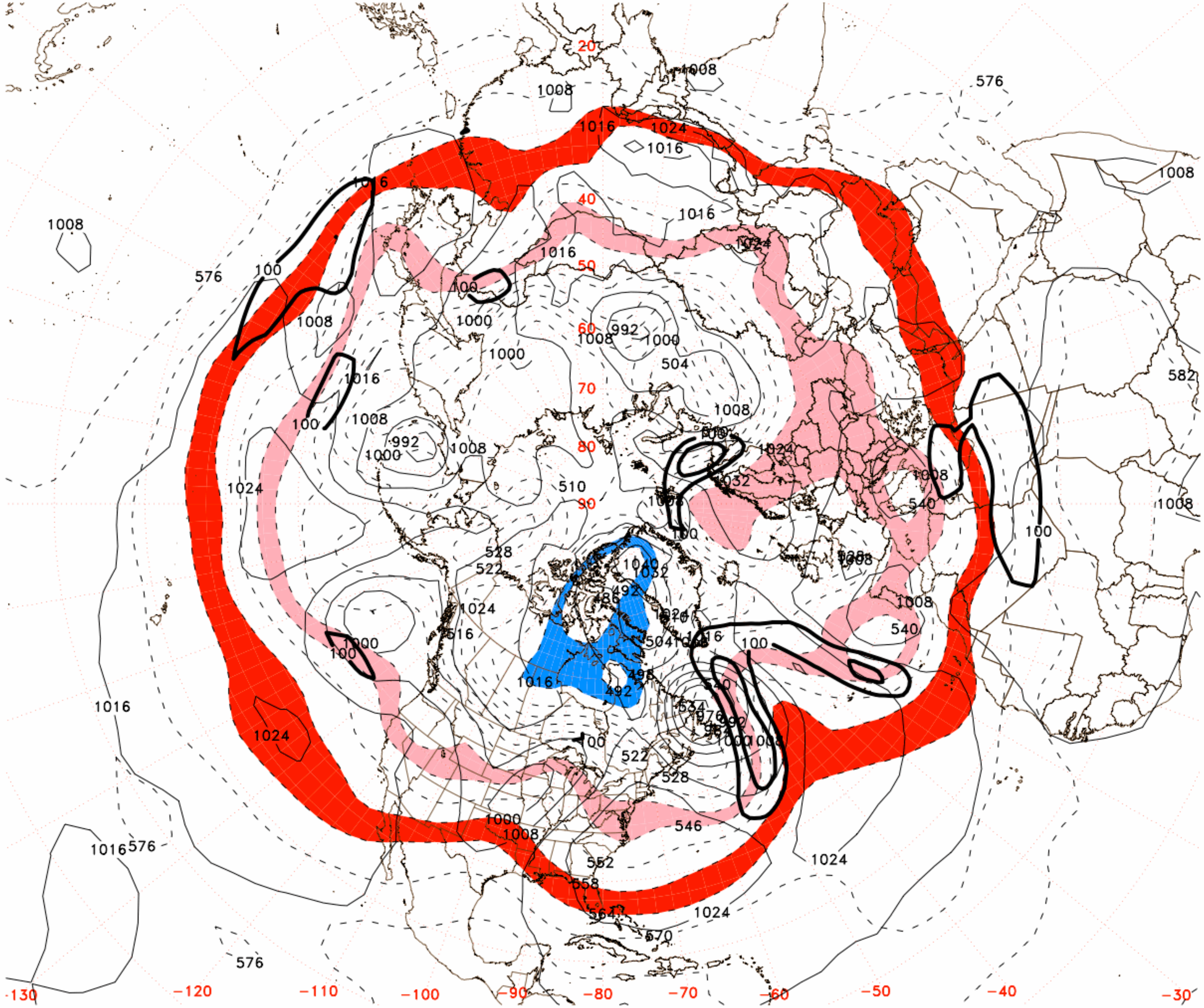


140327/0600V000 250 MB KNTSPED

-0.90

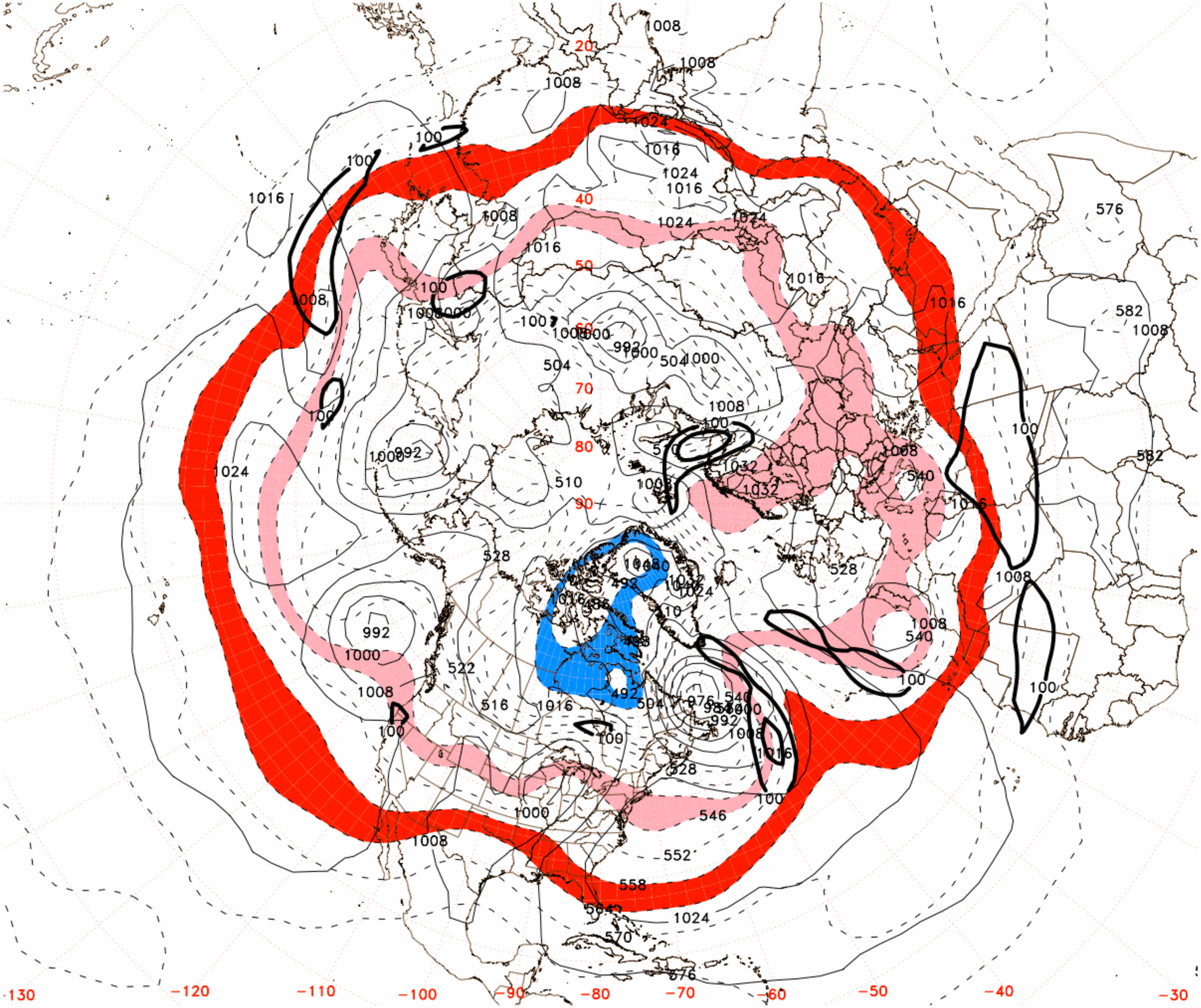

20
30
40
50
60
70
80
90
-130
-120
-110
-100
-90
-80
-70
-60
-50
-40
-30
140327/1200V000 250 MB KNTSPED

-1.36



140327/1800V000 250 MB KNTSPED

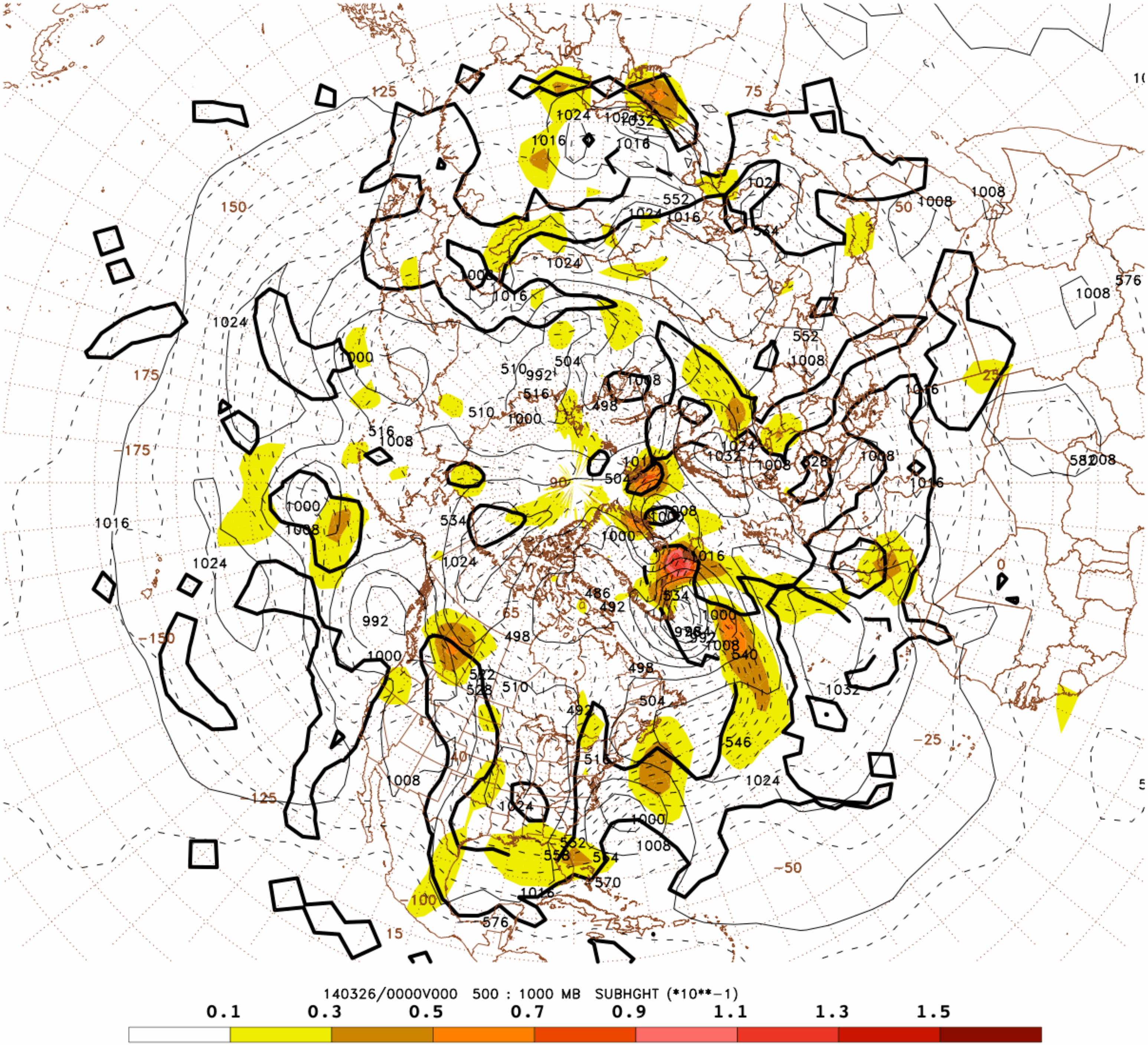
-1.48



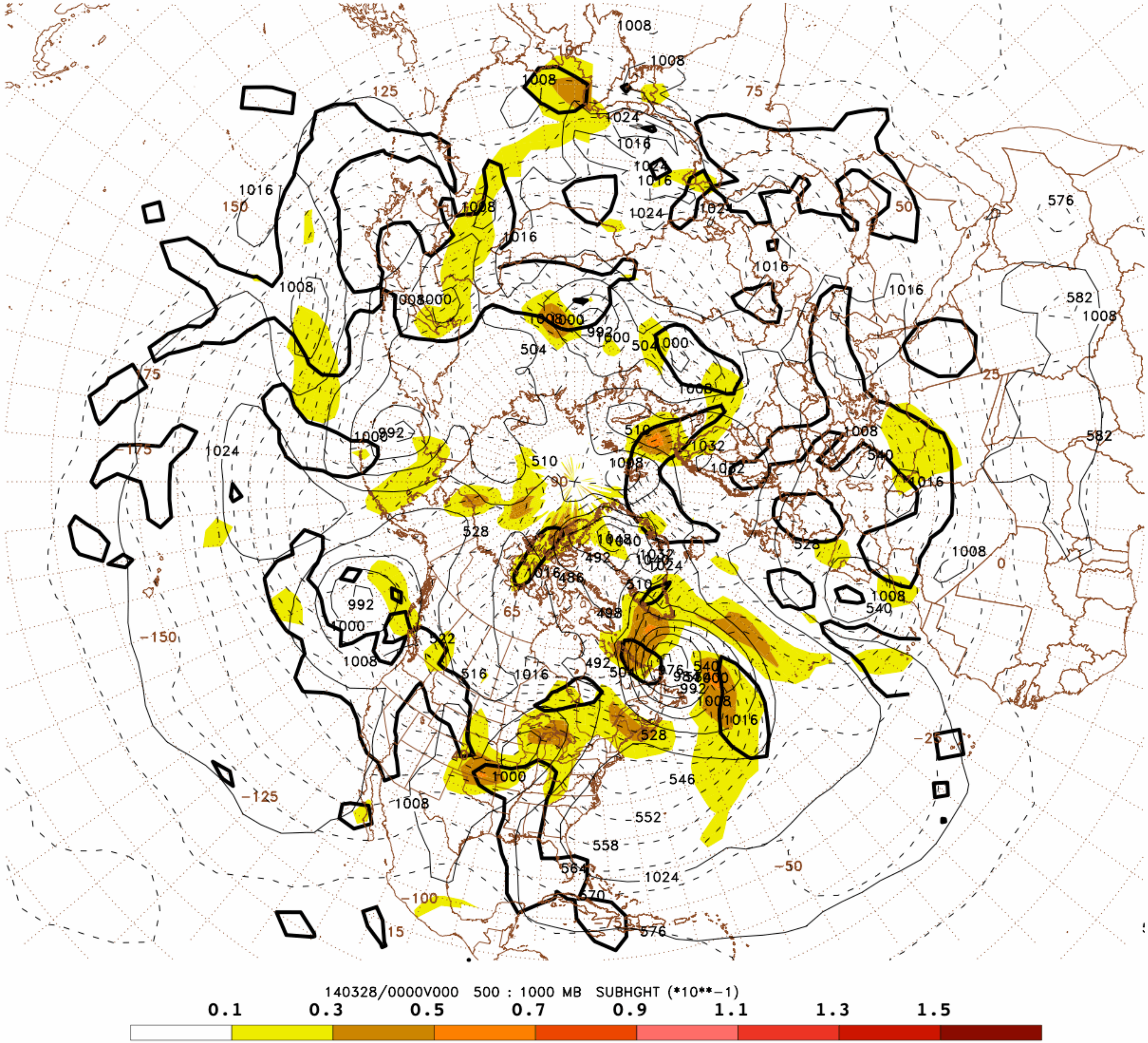
140328/0000V000 250 MB KNTSPED

The following two figures show the areal coverage of large moist baroclinic growth rates, along with 850-hPa frontogenesis for extreme values of NASTI

+2.50



-1.48



Concluding discussion

- Cyclogenesis is often a ‘regime changer’.

- Moist baroclinic growth rate coverage is a useful metric for basin-wide weather regimes.

- There is a suggestion that this metric (NASTI) has been increasing in recent decades.

- Cyclogenesis forecasts have obviously improved. However, there are still crucial cases that are ‘missed’, which may have impact on medium-range forecasts.

References:

Bosart, L. F., 1981: The Presidents' Day Snowstorm of 18-19 February 1979: A subsynoptic-scale event. *Mon. Wea. Rev.*, **109**, 1542-1566.

Durran, D. R., and J. B. Klemp, 1982: On the effects of moisture on the Brunt-Väisälä frequency. *J. Atmos. Sci.*, **39**, 2152-2158.

Gyakum, J. R., J. R. Anderson, R. Grumm and E. L. Gruner, 1989: North Pacific cold-season surface cyclone activity: 1975 through 1983. *Mon. Wea. Rev.*, **117**, 1141-1155.

Gyakum, J. R., P.J. Roebber and T.A. Bullock, 1992: The role of antecedent surface vorticity development as a conditioning process in explosive cyclone intensification. *Mon. Wea. Rev.*, **120**, 1465-1489.

Hoskins, B. J., and P. J. Valdes, 1990: On the existence of storm tracks. *J. Atmos. Sci.*, **47**, 1854-1864.

Roebber, P. J., 1984: Statistical Analysis and Updated Climatology of Explosive Cyclones. *Mon. Wea. Rev.*, **112, 1577–1589.**

Sanders, F., 1971: Analytic solutions of the nonlinear omega and vorticity equations for a structurally simple model of disturbances in the baroclinic westerlies. *Mon. Wea. Rev.*, **99, 393–407.**

Sanders, F. and J. R. Gyakum, 1980: Synoptic-dynamic climatology of the "bomb." *Mon. Wea. Rev.*, **108**, 1589-1606.

Stubbs, M. W., 1975: An unusually large fall of pressure. *Weather*, **30**, 91-92.

Turner, J. K., J. R. Gyakum, and S. M. Milrad, 2013: A thermodynamic analysis of an intense North American arctic air mass. *Mon. Wea. Rev.*, **141**, 166-181.

Turner, J. K., and J. R. Gyakum, 2011: The development of Arctic air masses in Northwest Canada and their behavior in a warming climate. *J. Climate*, **24**, 4618-4633.