The Polar Vortex and Rotating Tank Experiments

Differential heating leads to density differences

(salty vs. fresh in tank)

Poleward rising light air and equatorward sinking cold air

- causes a poleward heat transport
- lowers the center of mass → kinetic energy of wind

Conservation of angular momentum creates

- A cyclonic vortex aloft (westerlies)
- An anticyclonic vortex at the surface (easterlies)

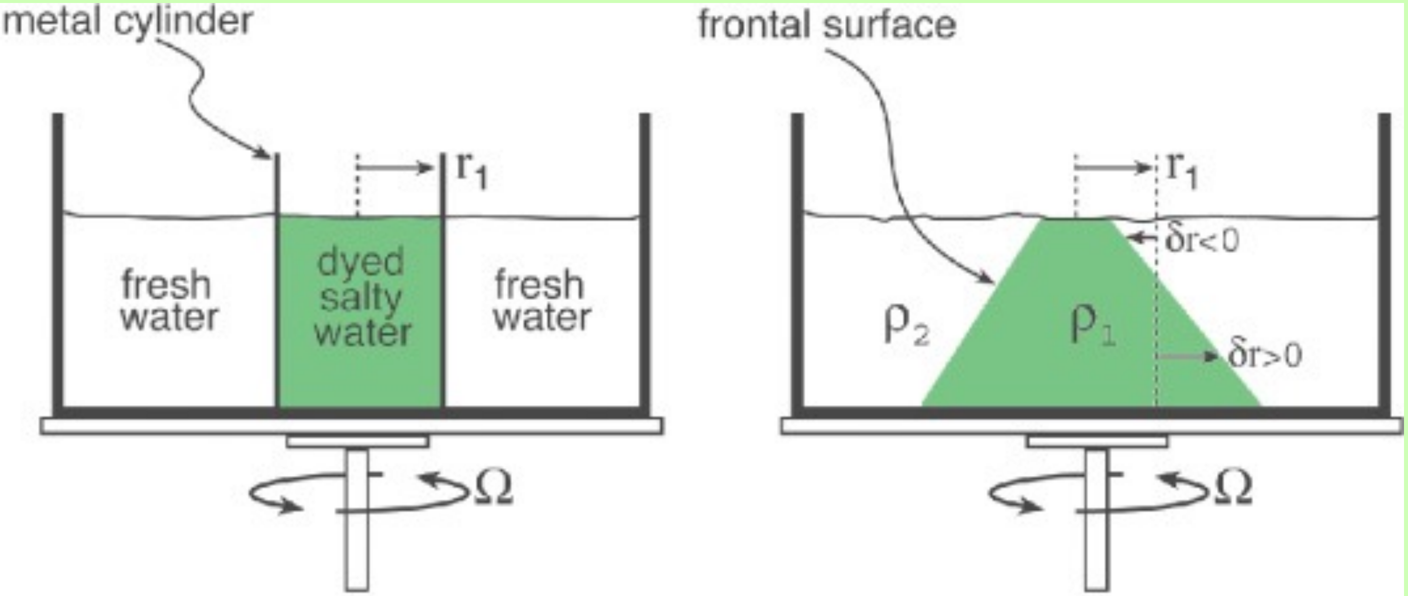


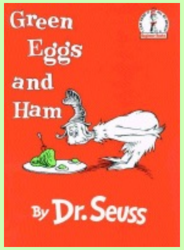
Figure 7.15: We place a large tank on our rotating table, fill it with water to a depth of 10 cm or so, and place in the center of it a hollow metal cylinder of radius $r_1 = 6$ cm, which protrudes slightly above the surface. The table is set into rapid rotation at 10 rpm and allowed to settle down for 10 minutes or so. While the table is rotating, the water within the cylinder is carefully and slowly replaced by dyed, salty (and hence dense) water delivered from a large syringe. When the hollow cylinder is full of colored saline water, it is rapidly removed to cause the least disturbance possible—practice is necessary! The subsequent evolution of the dense column is charted in Fig. 7.16. The final state is sketched on the right: the cylinder has collapsed into a cone whose surface is displaced a distance dr relative to that of the original upright cylinder.

Figure 7.18: The dome of cold air over the north pole shown in the instantaneous slice across the pole on the left (shaded green) is associated with strong upper-level winds, marked and and contoured in red. On the right we show a schematic diagram of the column of salty water studied in GFD Lab IX (cf. Figs. 7.15 and 7.16). The column is prevented from slumping all the way to the bottom by the rotation of the tank. Differences in Coriolis forces acting on the spinning column provide a “torque” which balances that of gravity acting on salty fluid trying to pull it down.

The Northern Annular Mode

- Variations in the strength of the north polar vortex on weekly to interannual time scales
- Deep vertical structure into the stratosphere
- High index NAM → warm eastern U.S. and Europe
- Low index NAM → cold eastern U.S. and eastern Europe
- North Atlantic Oscillation (NAO), Arctic Oscillation (AO) or Northern Annular Mode (NAM)
- What about the SAM?

NAM I LIKE AND SAM I AM BUT
CAN I PLEASE HAVE SOME GREEN EGGS AND NAM?



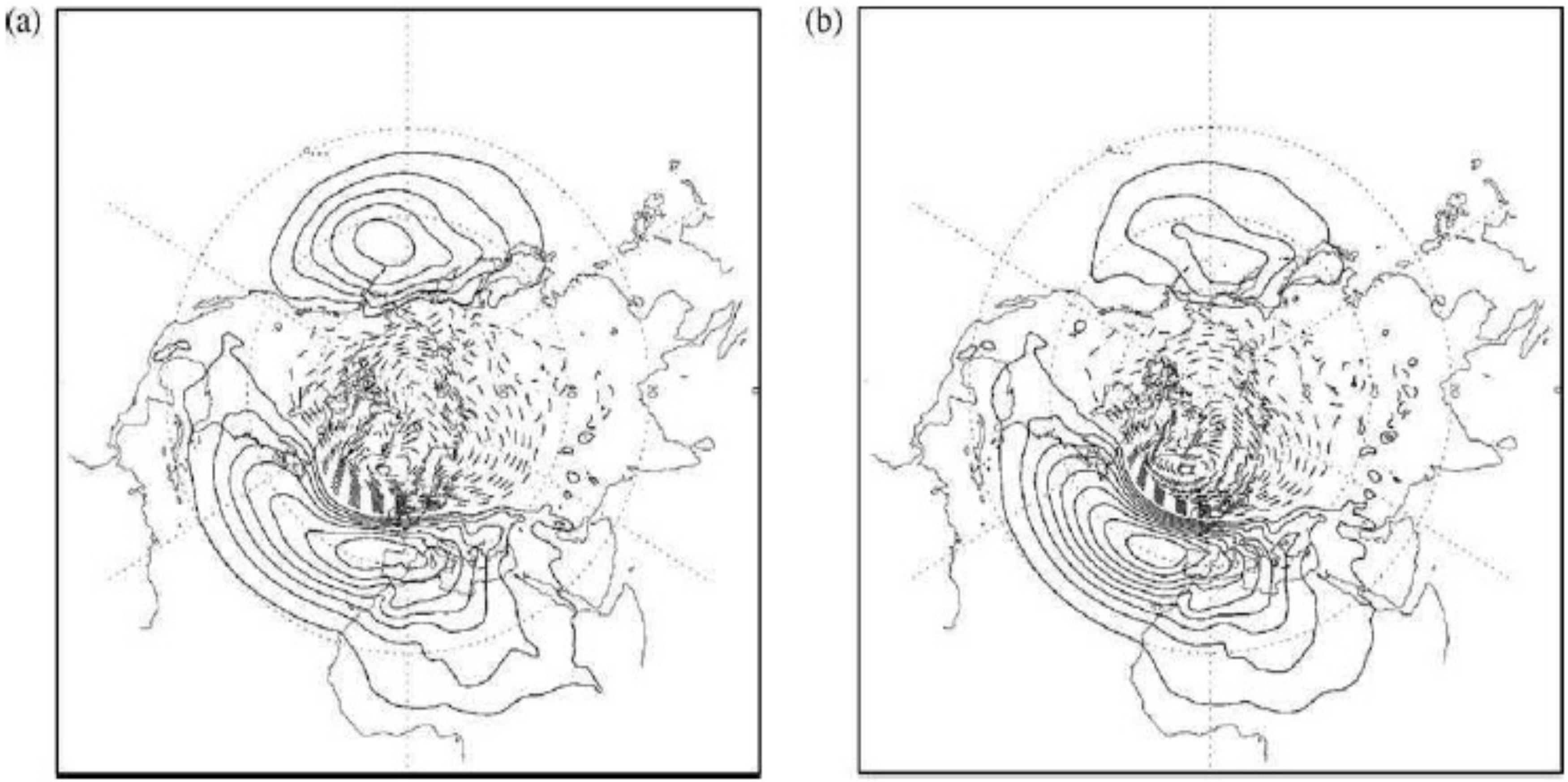


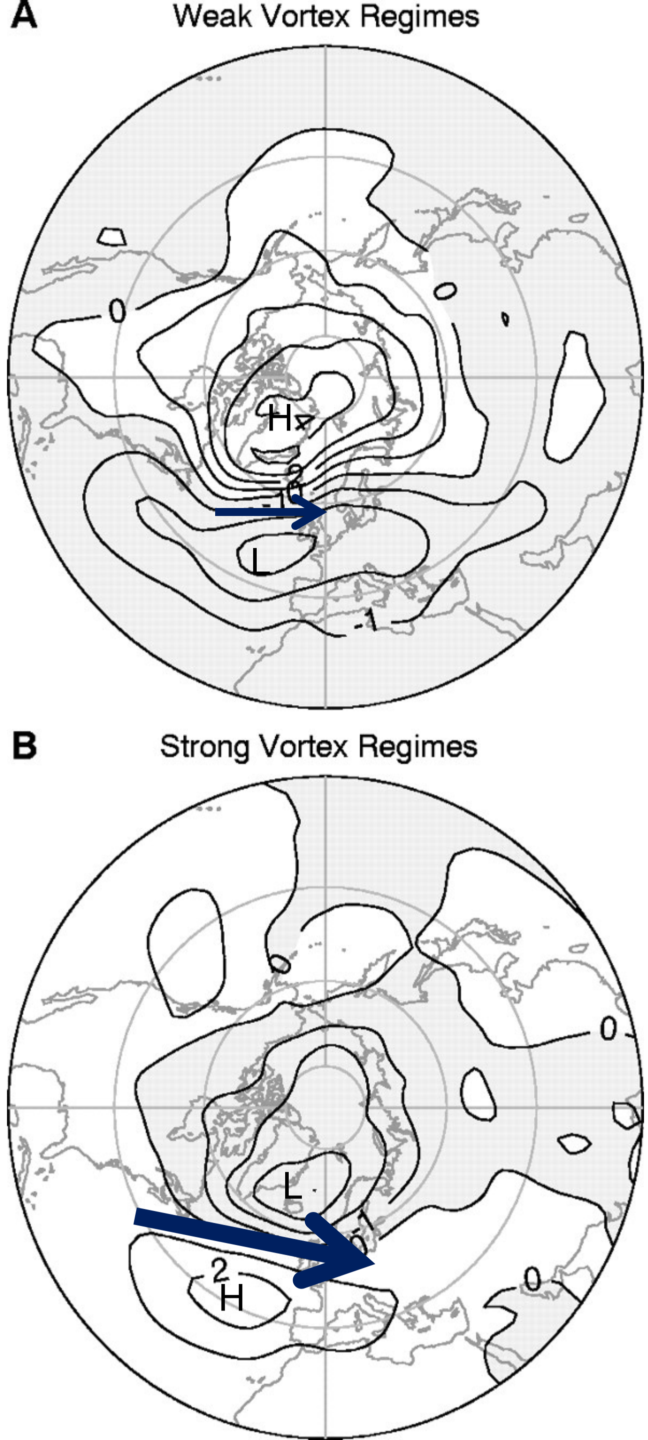
Fig. 1. Left: First EOF of winter (DJFM) sea level pressure (accounting for 25% of the variance). Right: first EOF of winter sea level pressure, based on variability in the Euro-Atlantic sector only. (Adapted from Ambaum et al., 2001.).

Vallis and Gerber 2007, adapted from Anbaum et al. 2001

Baldwin and Dunkerton (2001)
Science

Northern Annular Mode
(~NAO, AO)

Sea Level Pressure - Mean



Low index NAM

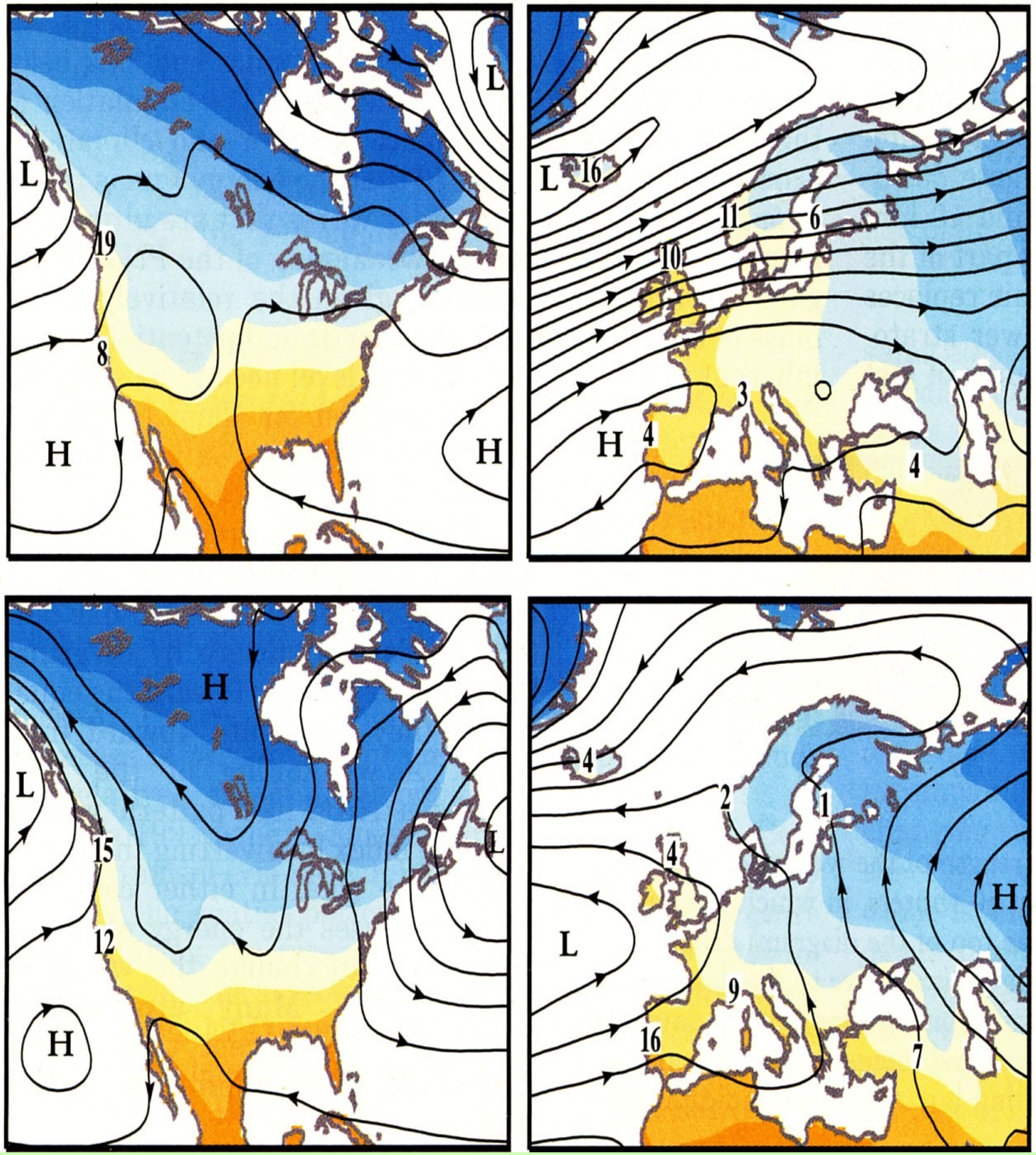
High index NAM

Volcanic eruptions
Tend to excite
Positive NAM

NAM

JFM 1958-1997

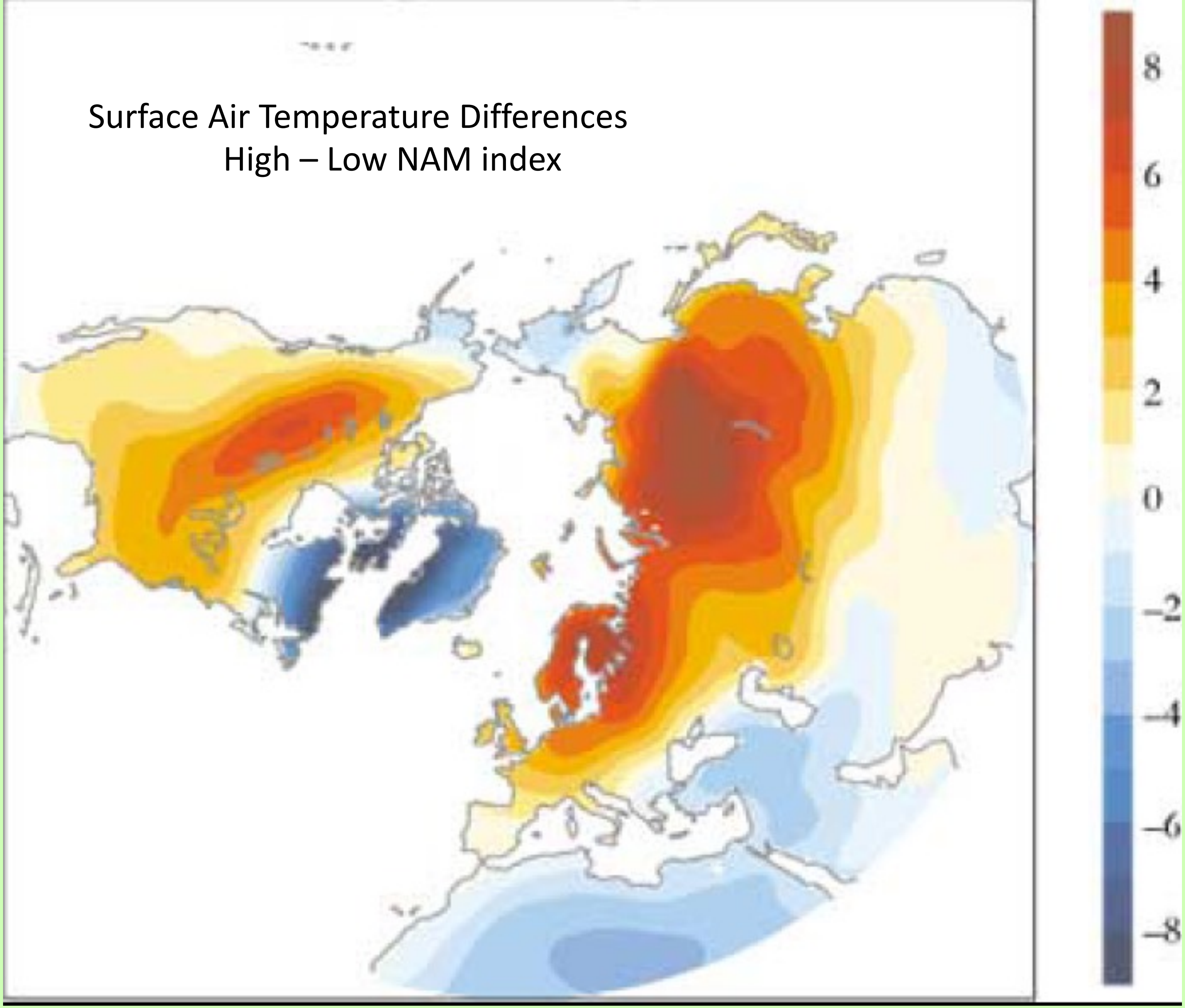
3 hPa SLP
5 K blue < O^{o}C
precipitation cm/mo



High Index

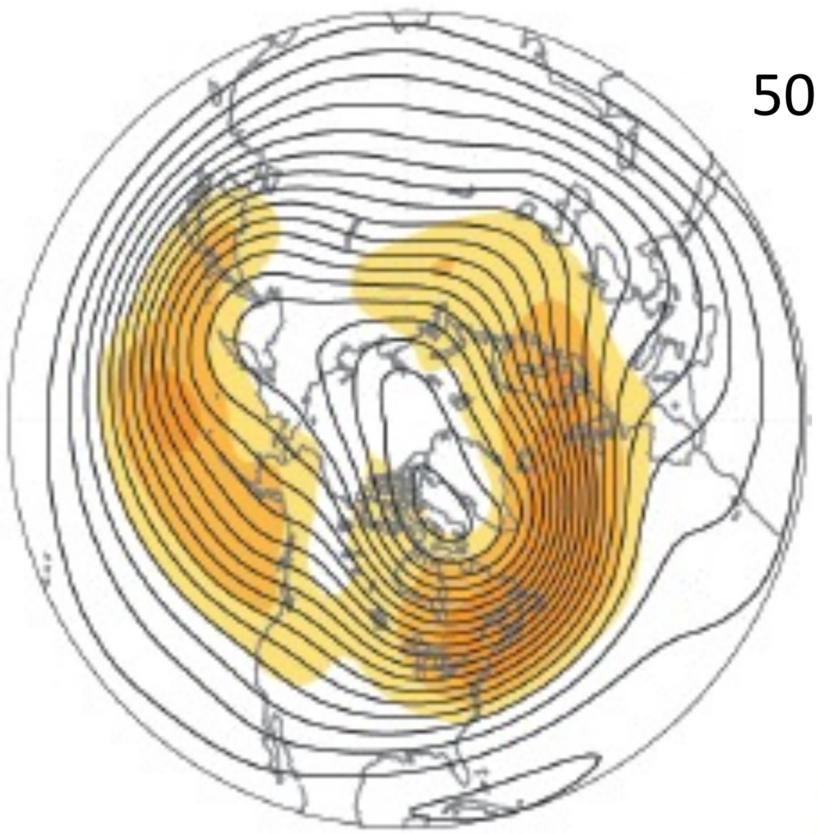
Low Index

FIGURE 2. COMPOSITE MAPS of surface air temperature (shading), sea-level pressure (contours) and precipitation (the numbers indicate cm/month) for (top) high Northern Hemisphere annular mode–index days, as defined in the text, and (bottom) low NAM-index days. The maps are based on data collected from January to March over the 40-year period, 1958–1997. Contour intervals are 5°C for temperature (blue shades indicate temperatures below 0°C) and 3 hectopascals for sea-level pressure. (Adapted from ref. 2.)

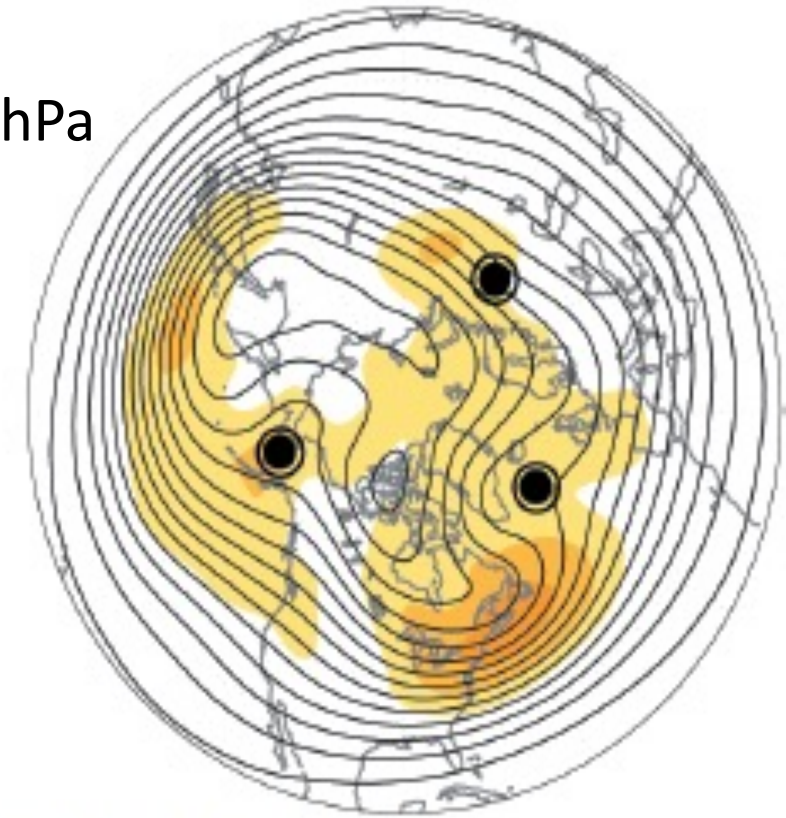


Wallace and Thompson, 2002, Phys Today,
Figure 3

High Index NAM



Low Index NAM



500 hPa

Fig. 3. As in Fig. 2, but for composite maps of 500-hPa height (contours) and the SD of band-pass filtered 500-hPa height field (shading) (18). Blocking regions (14) used in Table 2 are marked by black dots. Contour intervals are 50 m for 500-hPa height (the lowest contour is 4950 m in the high-index composite and 5150 m in the low-index composite). Shading is drawn for SD values of 50, 60, and 70 m.

Thompson and Wallace 2001

Table 2. Significant weather events associated with high and low NAM–index days. Total, the total number of events; NAM+ and NAM−, the number of events falling on high- and low-index days, respectively; ΔT_{mean}, the ratio attributable to shifts in mean temperature induced by fluctuations in the NAM (*19*); Trend NAM and Trend Gl. Wm., the estimated trends in the frequency of occurrence of cold events between 1958–1967 and 1988–1997 that are attributable to trends in the frequency distribution of the NAM and global-mean temperature, respectively (*28*). All results for NAM+ and NAM− exceed the 95% confidence level (*15*). Results are based on daily data, JFM 1958–1997, except buoy data, which are available 1981–1997.

Event type and location	Total	NAM+	NAM−	ΔT_{mean}	Trend NAM	Trend Gl. Wm.
Cold daily minimum temperature (*29*)						
<−15°C in Juneau, AK	352	32	84	1:1.5	−23%	−10%
<−18°C in Chicago, IL	330	29	84	1:2.3	−31%	−9%
<3°C in Orlando, FL	267	31	68	1:2.3	−29%	−12%
<−3°C in Paris, France	298	23	97	1:2.7	−39%	−15%
<−29°C in Novosibirsk, Russia	268	21	85	1:2.6	−31%	−7%
<−19°C in Beijing, China	212	21	55	1:1.9	−17%	−10%
<−1°C in Tokyo, Japan	304	20	93	1:1.8	−37%	−21%
Frozen precipitation (*29*)						
>Trace snow in Dallas, TX	56	1	17			
>Trace snow in Memphis, TN	130	7	36			
>Trace snow in Atlanta, GA	67	4	19			
>5 cm snow in Baltimore, MD	119	11	31			
>0.5 cm snow in Paris, France	182	11	63			
>0 cm snow in Tokyo, Japan	109	8	25			
Winds/waves (*30*)						
>25 knots, Seattle, WA	333	78	27			
>35 knots, Astoria, OR	251	55	20			
Offshore waves >6.5 m, WA	144	30	12			
>30 knots with snow, Boston, MA	206	22	45			
Offshore waves >5 m, MA	122	10	36			
>50 knots, Keflavik, Iceland	276	81	19			
Blocking days (*14*, *31*)						
Alaska (170°E–150°W; 60°N–75°N)	385	53	98			
North Atlantic (50°W–0°; 60°N–75°N)	439	1	225			
Russia (40°E–70°E; 60°N–75°N)	412	29	82			

Thompson and Wallace 2001

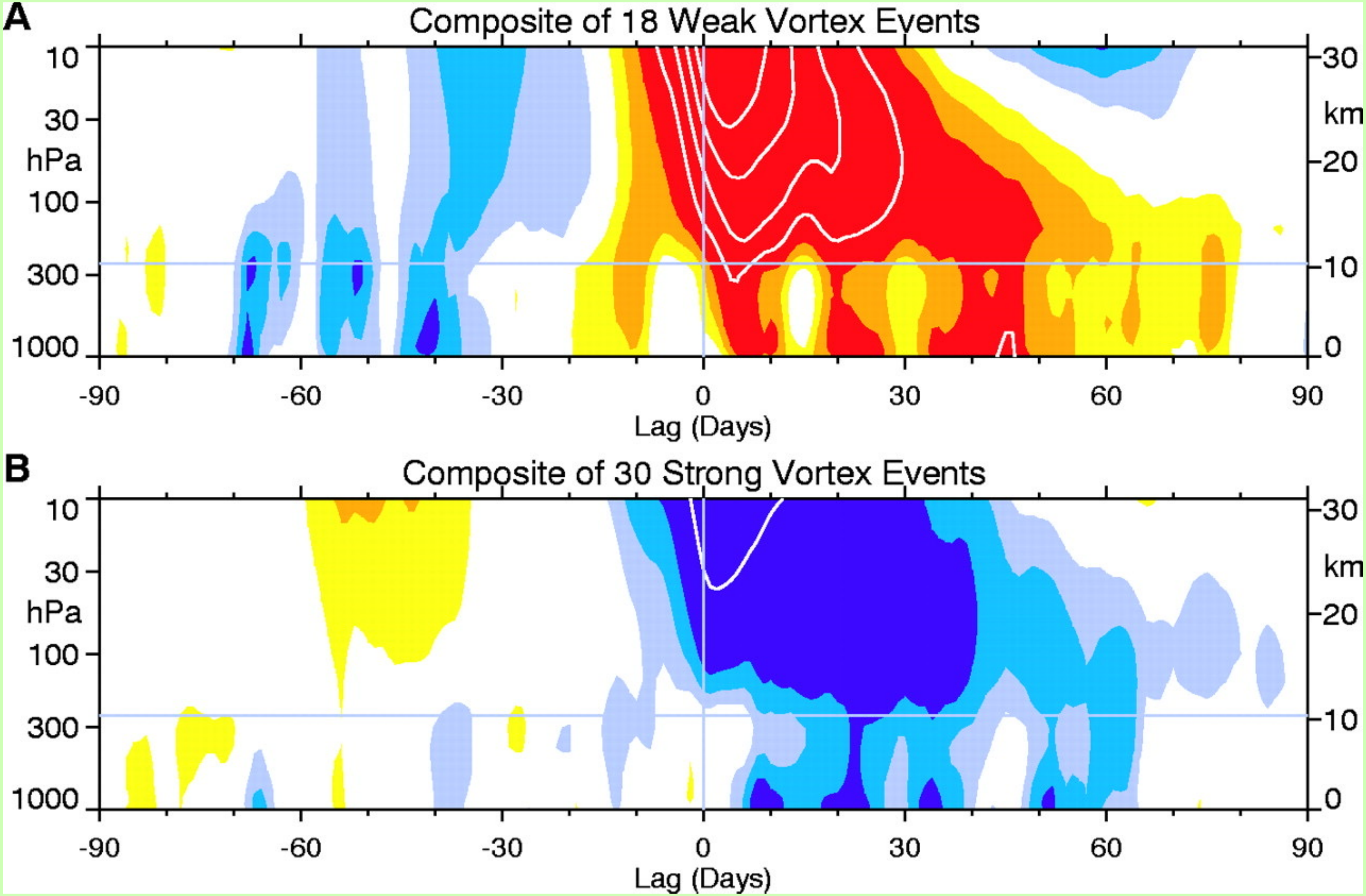
Table 3. As in Table 2, but for cold events at select stations over the northwestern United States. All results are based on daily station data, JFM 1958–1997.

Event type and location	Total	NAM+	NAM–	ΔT_{mean}	Trend NAM	Trend Gl. Wm.
Cold daily minimum temperature						
<-5°C in Bellingham, WA	218	25	58	1:1.7	−13%	−15%
<-3°C in Portland, OR	271	29	73	1:1.5	−18%	−16%
<-11°C in Yakima, WA	304	38	99	1:1.6	−24%	−12%
<-10°C in Wenatchee, WA	309	39	91	1:1.8	−18%	−12%
<-12°C in Spokane, WA	330	44	92	1:1.6	−14%	−11%
<-11°C in Moscow, ID	306	39	82	1:1.5	−12%	−11%
<-16°C in Missoula, MT	324	41	82	1:1.7	−18%	−10%
<-23°C in Great Falls, MT	304	31	90	1:2.1	−32%	−7%
Frozen precipitation						
>Trace snow in Seattle, WA	146	15	36			
>Trace snow in Portland, OR	135	12	43			

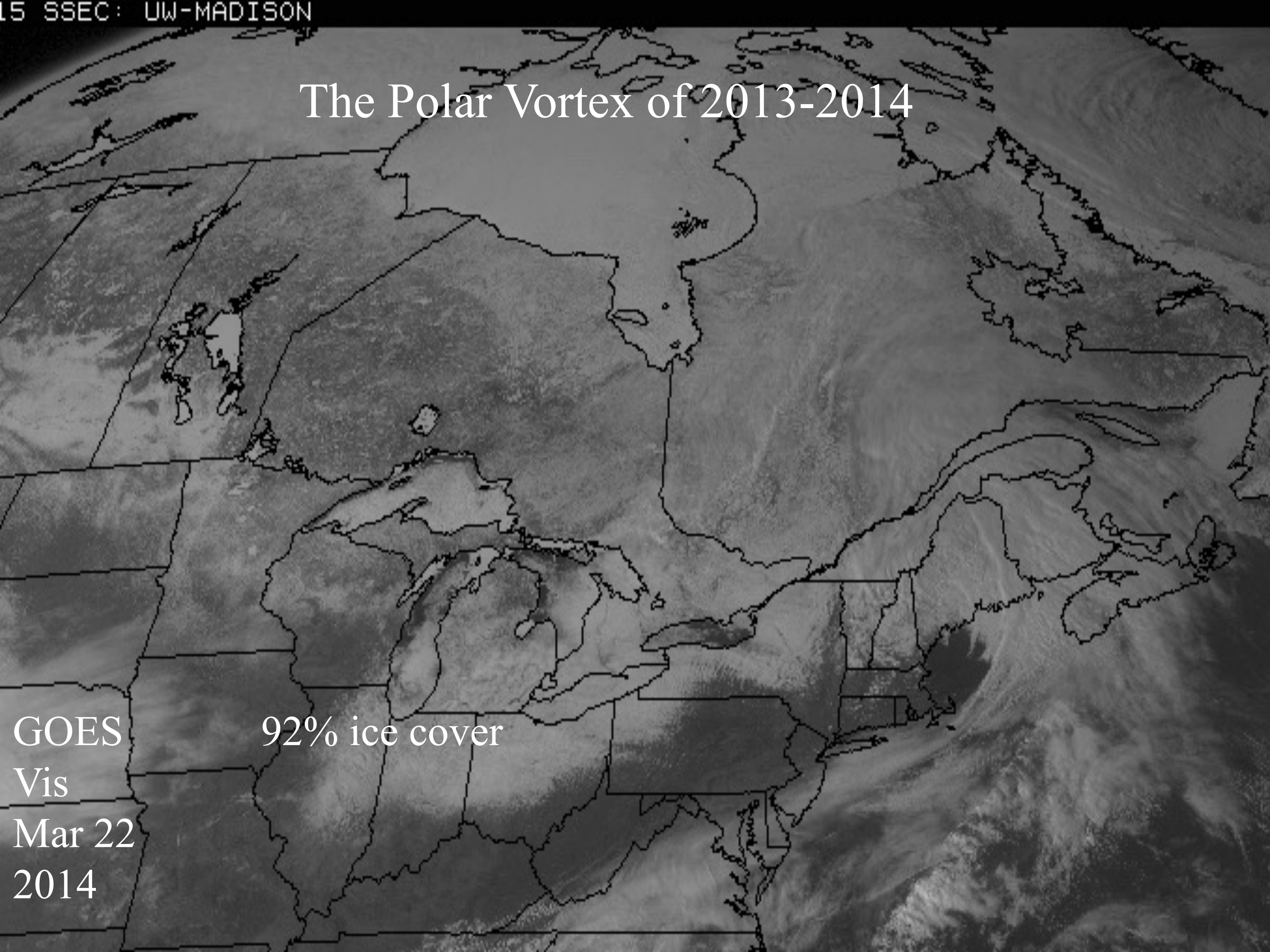
Thompson and Wallace 2001

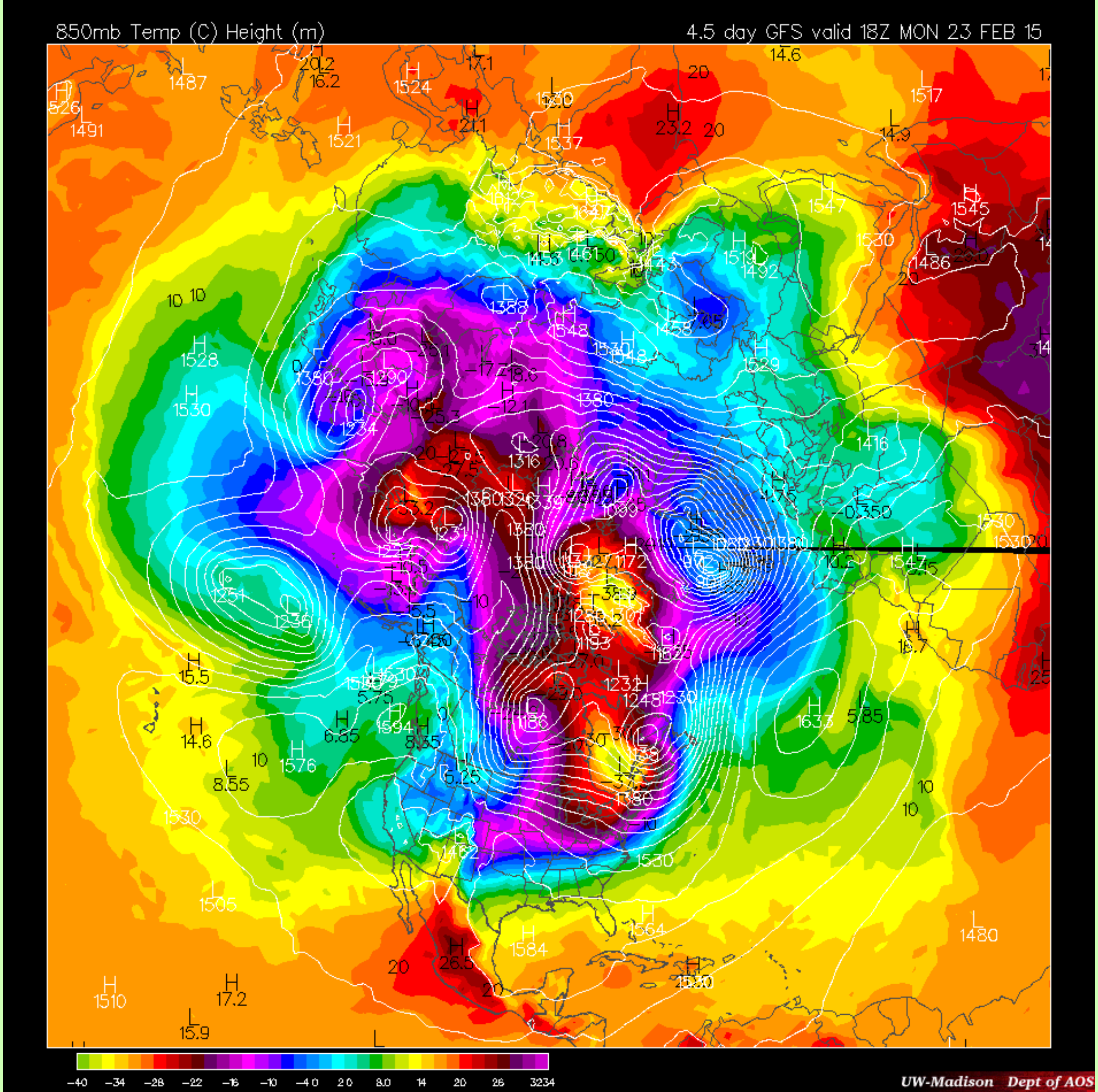
Baldwin and Dunkerton (2001) Science

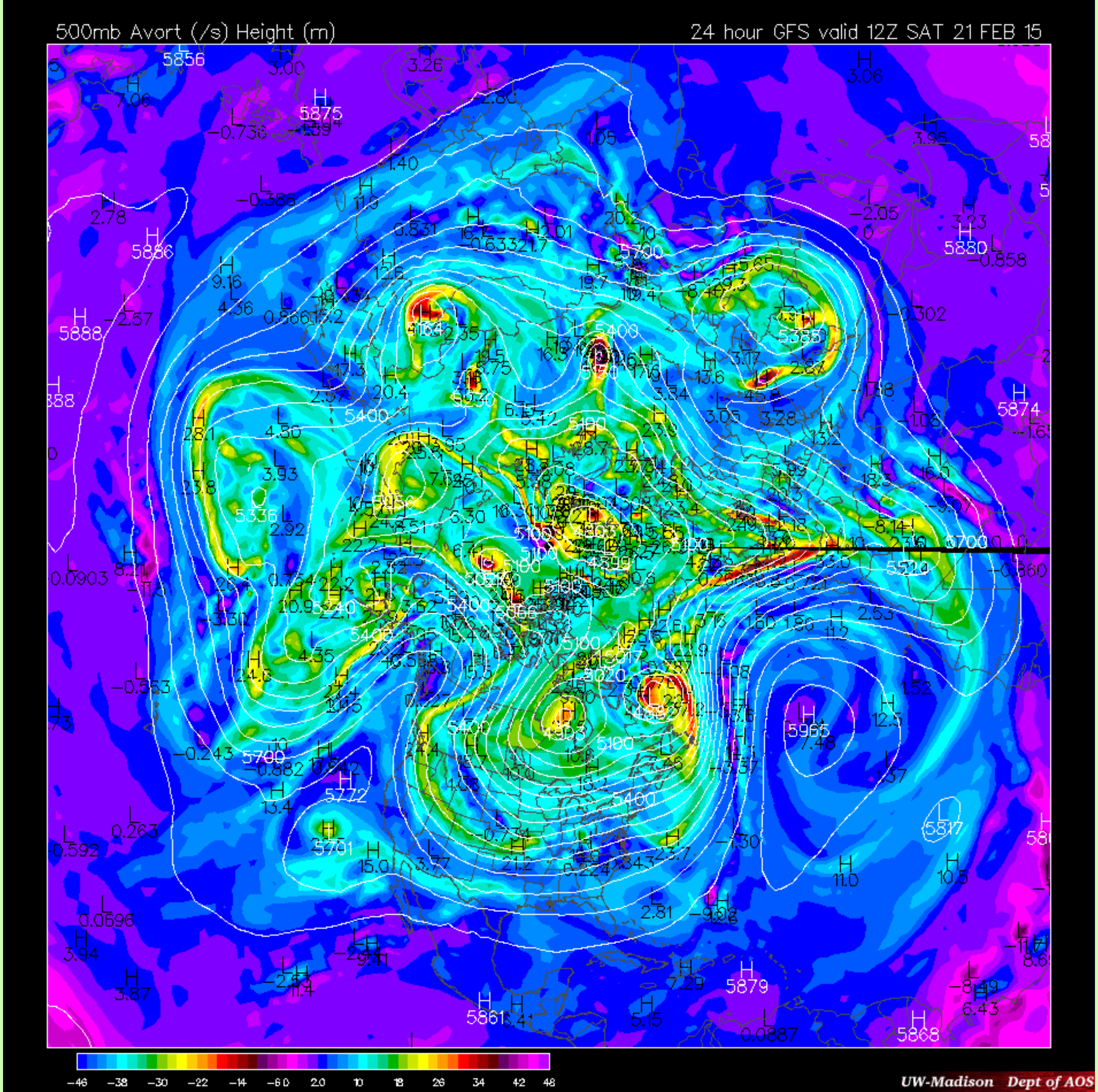
Blue = Stronger westerly vortex



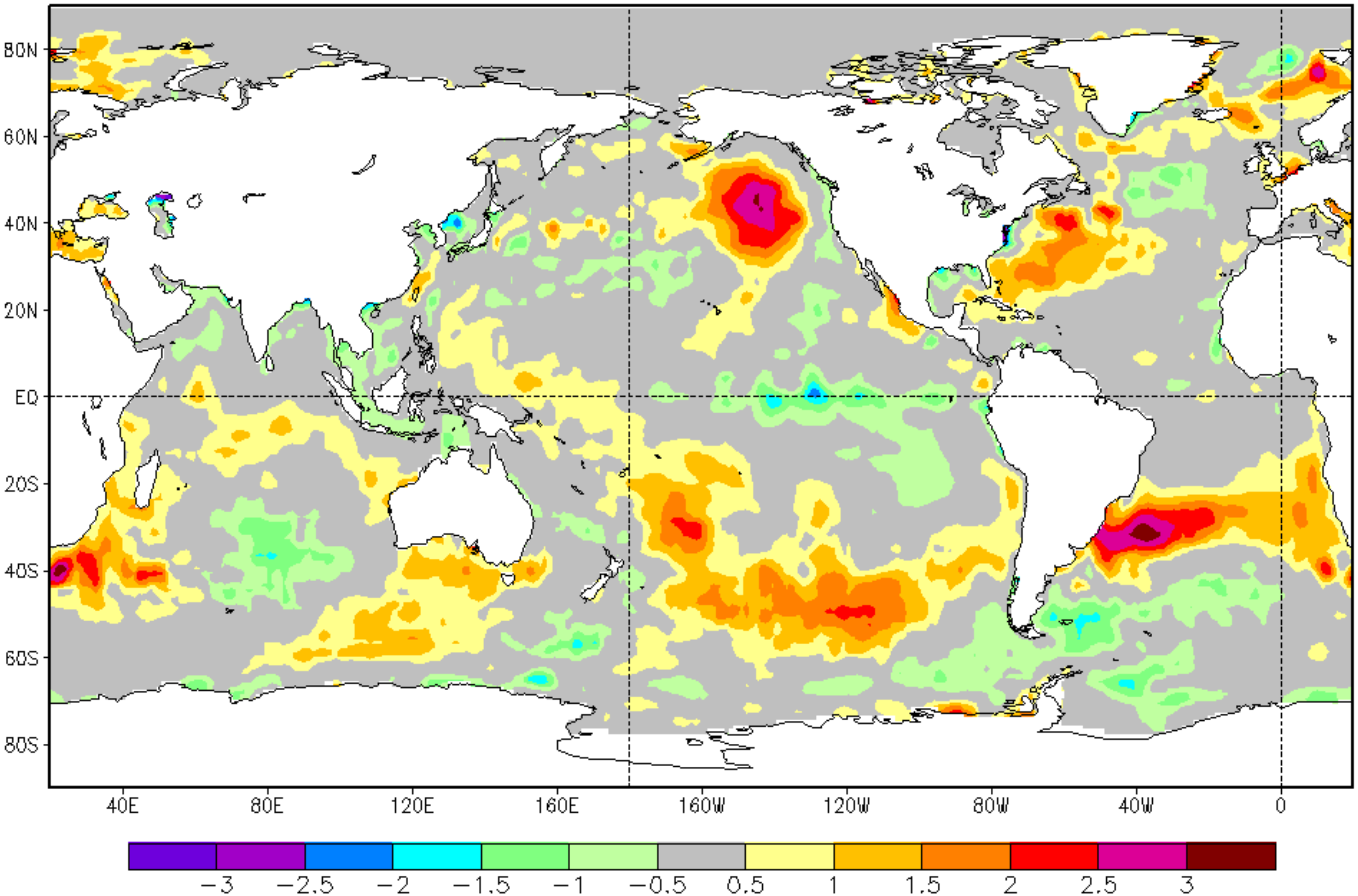
The Polar Vortex of 2013-2014



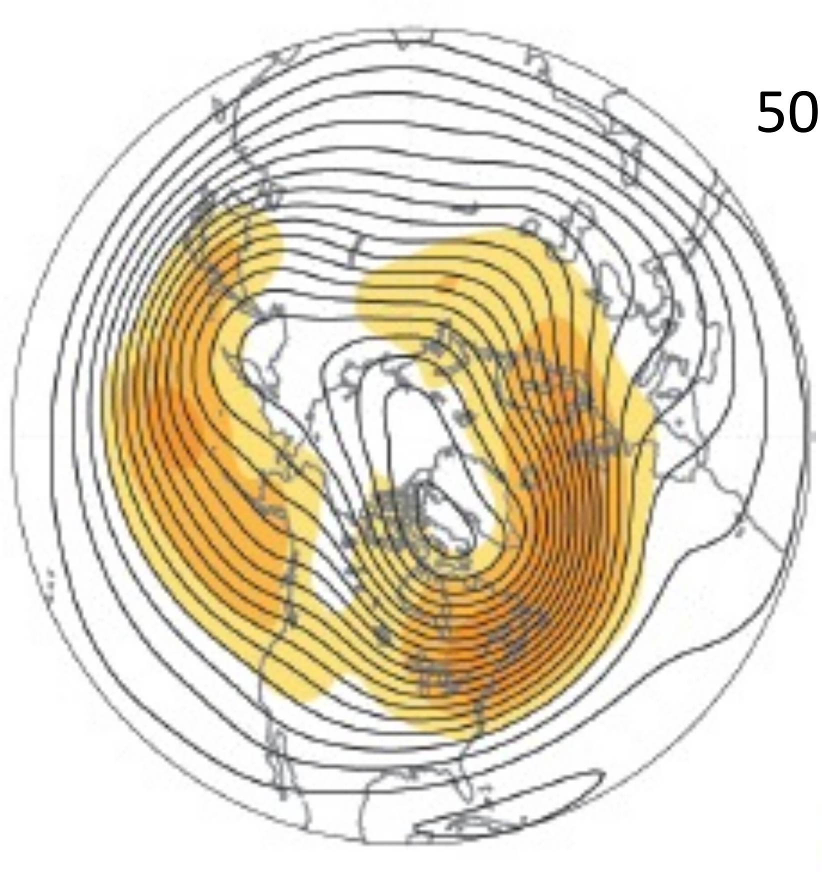

850mb Temp (C) Height (m)
4.5 day GFS valid 18Z MON 23 FEB 15
-40 -34 -28 -22 -16 -10 -4.0 2.0 8.0 14 20 26 32 34
UW-Madison Dept of AOS


500mb Avort (/s) Height (m)
24 hour GFS valid 12Z SAT 21 FEB 15
−46 −38 −30 −22 −14 −6.0 2.0 10 18 26 34 42 48
UW-Madison Dept of AOS

Sea Surface Temperature Anomaly (°C), Base Period 1971–2000
Week of 5 FEB 2014

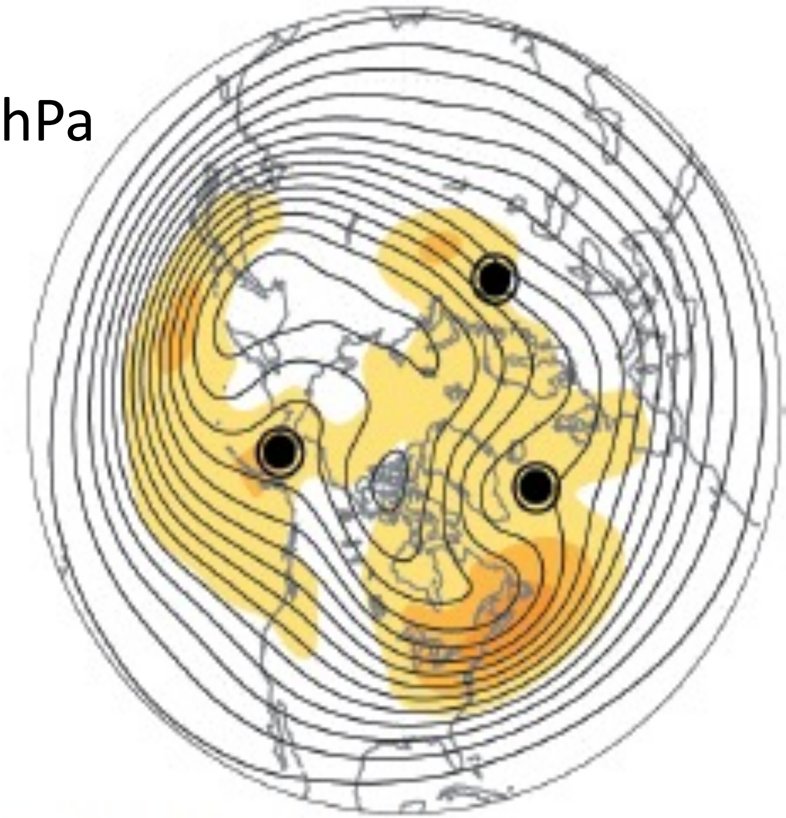


High Index NAM



500 hPa

Low Index NAM



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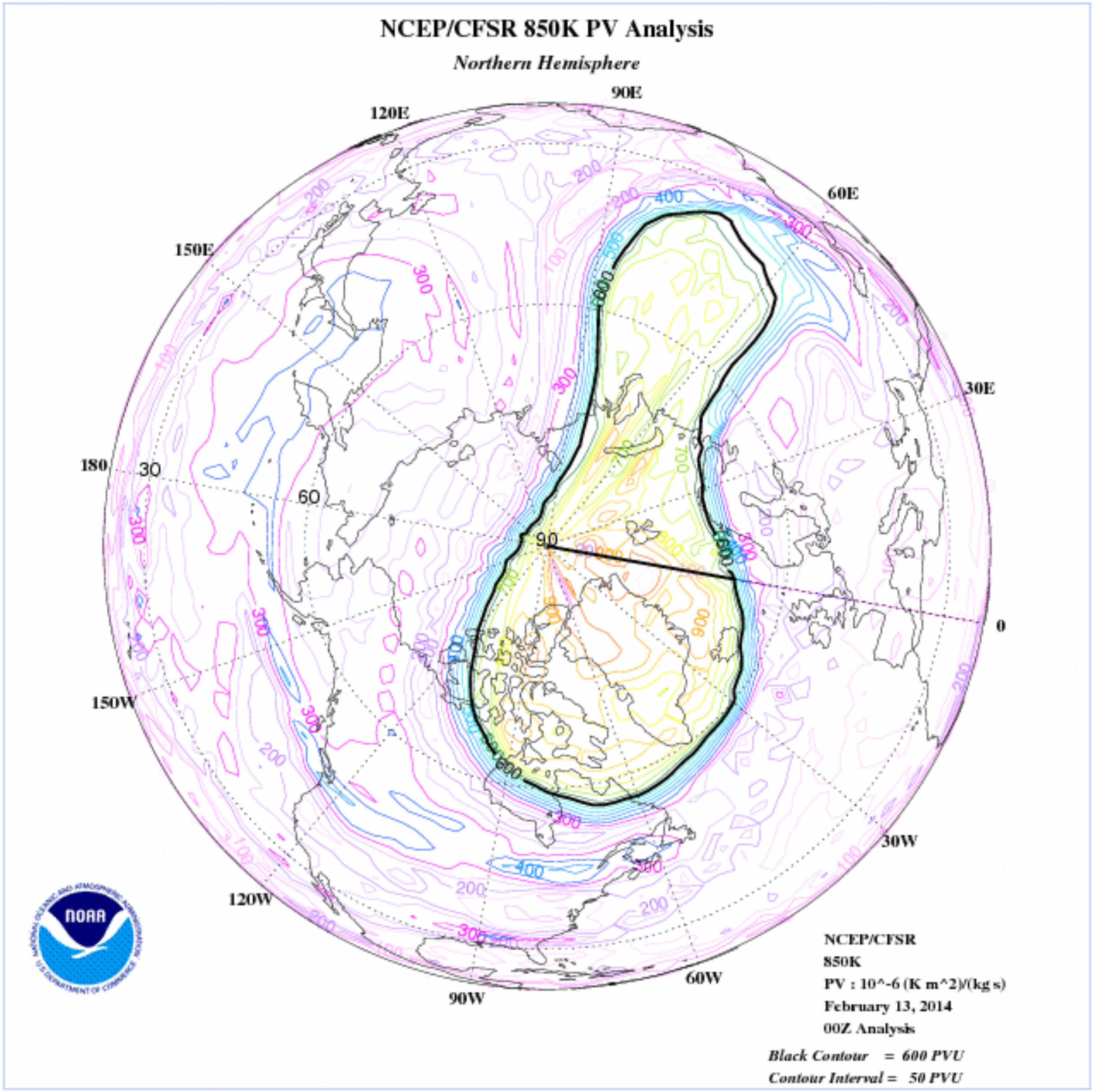
Thompson and Wallace 2001

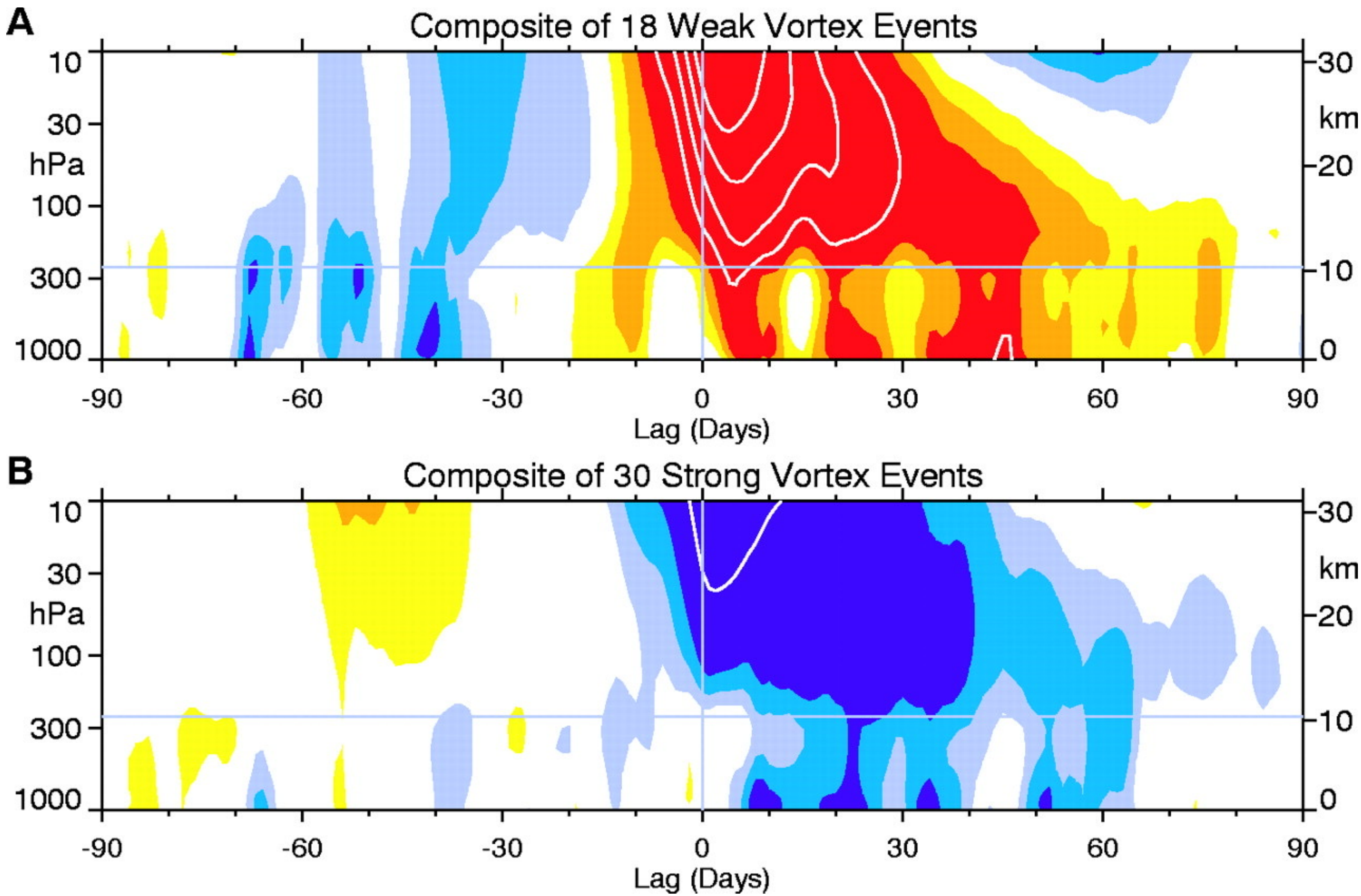
$$P = \frac{1}{\rho}\frac{\partial \theta}{\partial z}(\zeta + f) \quad Ertel's\ Potential\ Vorticity$$



→850 K
PV loop
2014

Baldwin and Dunkerton (2001) Science

Blue = Stronger westerly vortex



- High index NAM → warm eastern U.S. and Europe

  Low index NAM → cold eastern U.S. and eastern Europe

- The state of the stratospheric polar vortex is a useful predictor of surface weather for several weeks thereafter

- A high index NAM tends to be excited by volcanic eruptions, a westerly phase of the QBO, or increased GH gas loading

14. NAM.

What is the Northern Annular Mode / North Atlantic Oscillation?

What is the weather in Europe and Eastern North America like during the weak phase of NAM?

During the strong phase?