Arctic Oscillation and Polar Vortex Analysis and Forecasts

February 3, 2025

Dr. Judah Cohen from Atmospheric and Environmental Research (AER) embarked on an experimental process of regular research, review, and analysis of the Arctic Oscillation (AO) and Polar Vortex (PV). This analysis is intended to provide researchers and practitioners real-time insights on one of North America's and Europe's leading drivers for extreme and persistent temperature patterns.

During the winter schedule the blog is updated once every week. Snow accumulation forecasts replace precipitation forecasts. Also, there is renewed emphasis on ice and snow boundary conditions and their influence on hemispheric weather. In late Spring, we transition to a spring/summer schedule, which is once every two weeks. Snow accumulation forecasts will be replaced by precipitation forecasts. Also, there will be less emphasis on ice and snow boundary conditions and their influence on hemispheric weather.

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Summary

- The Arctic Oscillation (AO) is currently positive and is predicted to trend negative to neutral and then negative the next two weeks as pressure/geopotential height anomalies across the Arctic are currently mostly negative and are predicted to slowly become increasingly positive over the next two weeks. The North Atlantic Oscillation (NAO) is currently positive with negative pressure/geopotential height anomalies across Greenland and the NAO is predicted to slowly trend negative the next two weeks as pressure/geopotential height anomalies are predicted to become increasingly positive across Greenland.
- This week ridging/positive geopotential height anomalies across Scandinavia and the Barents-Kara Seas will support troughing/negative geopotential height anomalies across Southern Europe. The starting next week, strengthening ridging/positive geopotential height anomalies across Greenland will support deepening troughing/negative geopotential height anomalies across Europe. This pattern will support mostly normal to above normal temperatures across Northern and Eastern Europe with normal to below normal temperatures across Western Europe including the United Kingdom (UK) this week. The next week normal to below normal temperatures will become more widespread across Europe.
- The next two weeks ridging/positive geopotential height anomalies across Northern and

Eastern Asia will support troughing/negative geopotential height anomalies across Eastern and Southern Asia. This pattern favors widespread normal to above normal temperatures across Western and Northern Asia, with normal to below normal temperatures across Central and East Asia the next two weeks.

- The general pattern across North America the next two weeks is strengthening ridging/positive geopotential height anomalies across Alaska and the Gulf of Alaska supporting deepening troughing/negative geopotential height anomalies much of Canada and the United States (US) with more ridging/positive geopotential height anomalies across the Southeastern US. Though this week much of the US will be mild, this pattern favors normal to below normal temperatures spreading across much of Canada and the US with normal to above normal temperatures limited to Alaska, and the Southeastern US.
- This winter has been all about the polar vortex (PV) alternating among three different states: strong, a Canadian warming but most of all a stretched PV. This pattern looks to continue into February, but the PV is also weakening. Also still watching the battle between high latitude blocking and a strong PV, which has been at a stalemate all winter long. But it certainly looks like high latitude blocking is getting the upper hand but is it really?

Plain Language Summary

In January the cold anomalies were clearly focused in the US but were also in Canada, Northern Europe and Northern Siberia (see **Figure**). Another stretched polar vortex starting this week should bring more relative cold first to East Asia and then the Eastern US. But Europe should also get in on the cold as high pressure blocking in the Barents-Kara Seas morphs into Greenland blocking. Impressive high latitude blocking should continue the cold in these three regions beyond the two week forecast period.

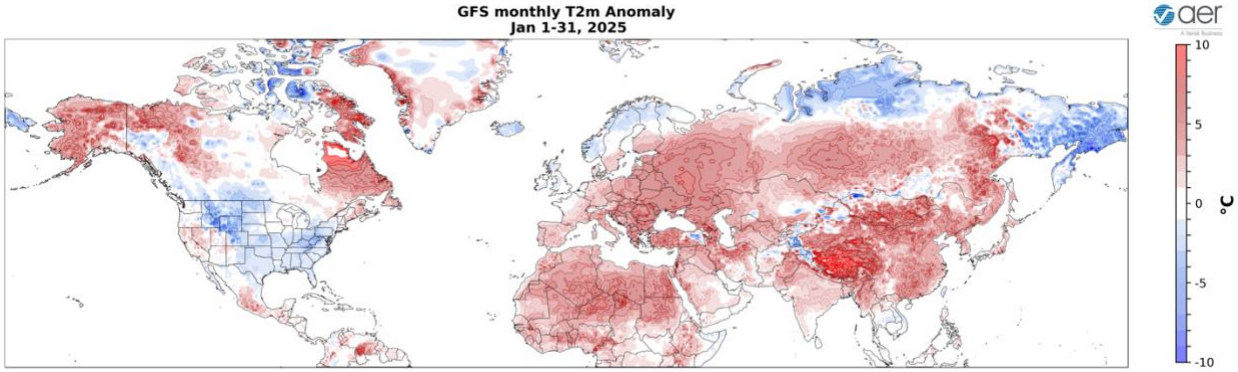

Figure. Estimate of the observed surface temperatures (°C; shading) from 1 January 2025 – 31 January 2025 based on GFS initializations and the GFS forecast from the 1 February 2025 forecast.

Impacts

There has been excitement on social media about a bigger polar vortex (PV) disruption even a full PV split but I think we are still in this seemingly infinite loop of "lather, rinse repeat," The difference is with a bigger load of laundry this time. The stretched PV events or periods have been punctuated by a more circular or strong PV, and I think only once by a Canadian warming. We last had a stretched PV at the end of January and currently the PV has relaxed to a more circular shape for this week allowing for a milder pattern across the Eastern United States (US). The next stretched PV is predicted for the second week of February, and this would bring the total of nine for the season according to my count. The next installment (but coming in two parts) of the stretched PV can be seen in the latest PV animation in **Figure i**. The ninth stretched PV 8-12th of February and should continue beyond that. However, it looks to me to disjointed or coming in two parts. So maybe a relaxation of the stretched PV between 13-15th of February and then a re-intensification of the stretched PV. The initial PV stretch looks to be only the appetizer with the main course after the 15th of February. The Eastern US could be in for a bit of a temperature roller coaster first mild then cold, mild again and then even colder.

Two PV centers are predicted in all the models with this next stretched PV and in **Figure i** it shows up starting on the 11th of February. This is not a PV split that occurs with sudden stratospheric warmings (SSWs) but rather what I would consider a larger PV stretch, certainly larger than any of the previous eight PV stretched this winter so far. Some of the GFS and European operational runs were predicting a full PV split but the ensembles never did and certainly as of today, I do think a stretched PV is most likely. The impacts therefore are most felt in East Asia and North America east of the Rockies and less so in Europe. However, Europe will feel the impacts of high latitude blocking.

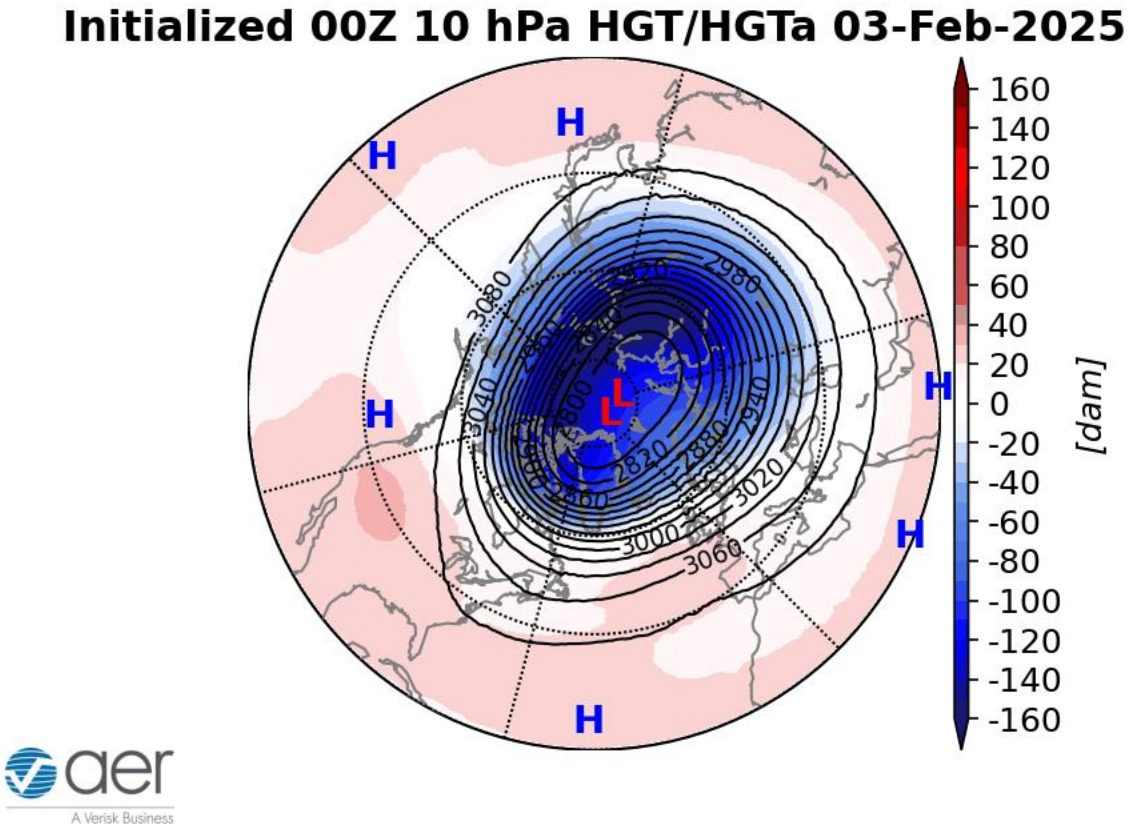

Figure i. Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 3 February 2025 and forecasted from 4 February to 18 February 2025. The forecasts are from the 00Z 27 January 2025 GFS model ensemble.

Once again, I present the wave reflection diagnostics. Wave reflection is the physical underpinning of stretched PV events, and it has seemed it has occurred continuously throughout the month of January. During wave reflection, wave energy goes up over Asia, bouncing off the stratospheric PV and then downward over North America. The downward wave energy amplifies the ridge-trough wave over North America and determines the strength or amplitude of the North American wave and the axis or position (see **Figure ii**). Currently there is no wave reflection (see **Figure iia**). This is supportive of a more damped pattern across North America and a milder US for much of this week.

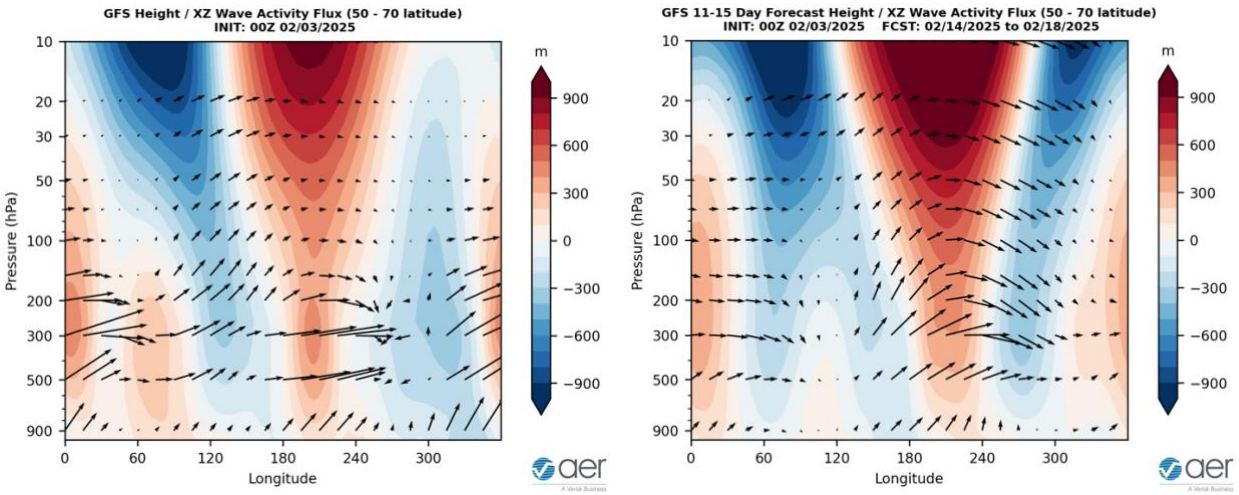

Figure ii. Longitude-height cross section of geopotential eddy height anomalies (shading) and wave activity flux (vectors) a) initialized for 3 February 2025 and b) forecasted for 14 February through 18 February 2025. The forecasts are from the 00Z 3 February 2025 GFS ensemble.

But the wave reflection is clearly back for the second week of February and even stronger for mid-month with the ridge is centered near 140°W and the trough centered on 80°W (see **Figure iib**). I do think the GFS is showing a westward bias and the cold will be further east as predicted by the European. I am leaning toward the colder European solution in the Eastern US. All the models have struggled but the European is clearly performing the best. Interestingly late last week the GFS lost wave reflection for the second week of February and into the third week. This has important implications for the cold returning to the Eastern US.

Stretched PVs is related to severe winter weather not only to North America but also East Asia. And from **Figure i**, you can see how the stretched PV in February first stretches or elongates into Asia the first week of February starting around the 3rd of February before subsequently stretching into North America the following week (see **Figure i**). And as can be seen in the animation of 500hPa geopotential heights shown in **Figure iii**, the high latitude blocking is predicted to strengthen across the Urals and near the Dateline forcing a deepening trough in East Asia. This will favor East Asia for an Arctic outbreak for this week (see **Figure 3**) and into next week. I do believe that this is the biggest cold air outbreak into East Asia since December. However, as the high latitude blocking returns to Alaska and Northwestern Canada the second week of February, troughing deepens across North America setting up the next Arctic outbreak into the US the second week of February (see **Figures 6** and **9**).

While wintry weather opportunities present themselves in the first half of February for East Asia, Canada and the US, the same can now be said for Europe. The weather models are predicting the Ural blocking will slide east to near Greenland mid-month (see **Figure iii**). But even before the formation of Greenland blocking, the Ural ridging has pushed north into the Barents-Kara Seas. This has allowed cold air to flow from east to west under the high-pressure ridging (see **Figure 6**). After that the predicted return of Greenland blocking (see below **Figure i**) could

intensify the cold in Northern Europe mid-month. I haven't seen any impressive cold predicted for Europe but if the Greenland blocking materializes, I expect that to change. And for those who absolutely can't wait for the next stretched PV (would be double digits!), Greenland blocking is a precursor for a stretched PV in about two weeks' time.

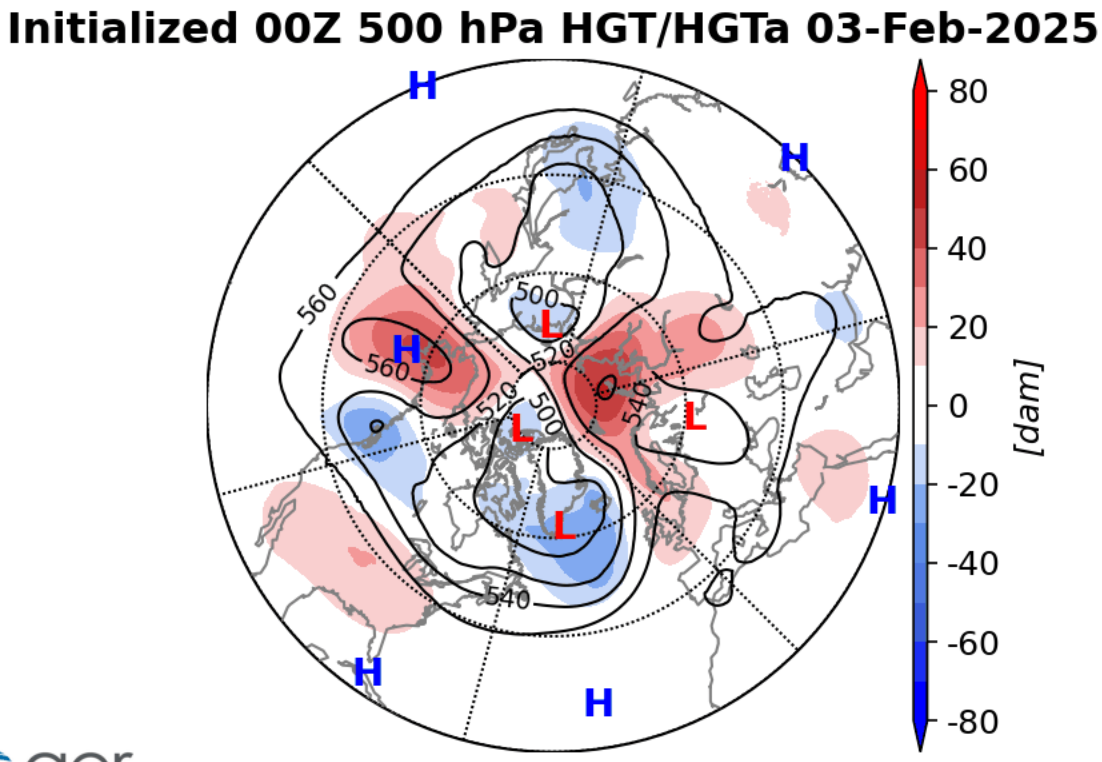

Figure iii. Initialized 500 mb geopotential heights (dam; contours) and decameter anomalies (dam; shading) across the Northern Hemisphere for 3 February 2025 and forecasted from 4 February to 18 February 2025. The forecasts are from the 00Z 3 February 2025 GFS model ensemble.

The European operational has predicted at times over the weekend a stretched PV that would be supportive of more intense cold in the Eastern US. However, the 12z hot off the press looks lackluster (see **Figure iv**). Not sure if the European operational is on to a trend of a more benign stretched PV or not, but regardless of how robust the next stretched PV is in the end, the high latitude blocking looks impressive, probably the most impressive of the winter.

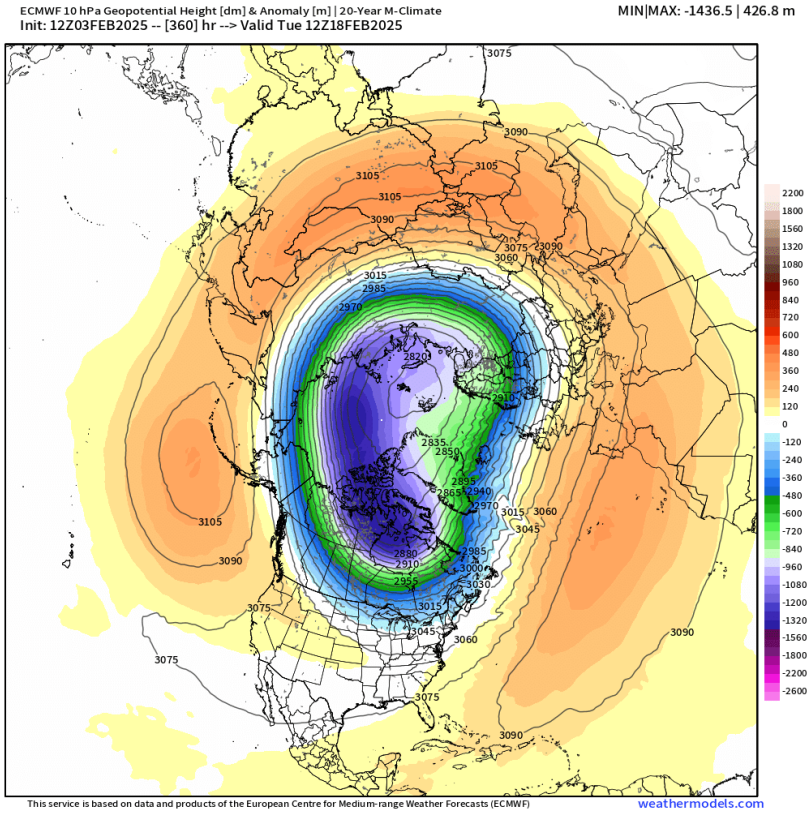

Figure iv. Forecasted 10 mb geopotential heights (dam; contours) and anomalies (meters; shading) across the Northern Hemisphere for 18 February 2025. The forecasts are from the 12Z 3 February 2025 ECMWF operational model. Plot taken from https://weathermodels.com.

But as I have been saying all winter this is a very challenging forecast environment, and I think that is still true. Models seem in fairly good agreement this afternoon, but I will say that this next stretched PV coming in two parts or installments makes me very uneasy, seems really bizarre to me. Seems to me that would be tricky for the models to handle. So still need to expect the unexpected.

Near-Term

This week

The AO is predicted to be mostly positive this week **(Figure 1**) with mostly negative geopotential height anomalies across the Arctic and with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 2**). With predicted negative geopotential height anomalies across Greenland (**Figure 2**), the NAO is predicted to be positive this week.

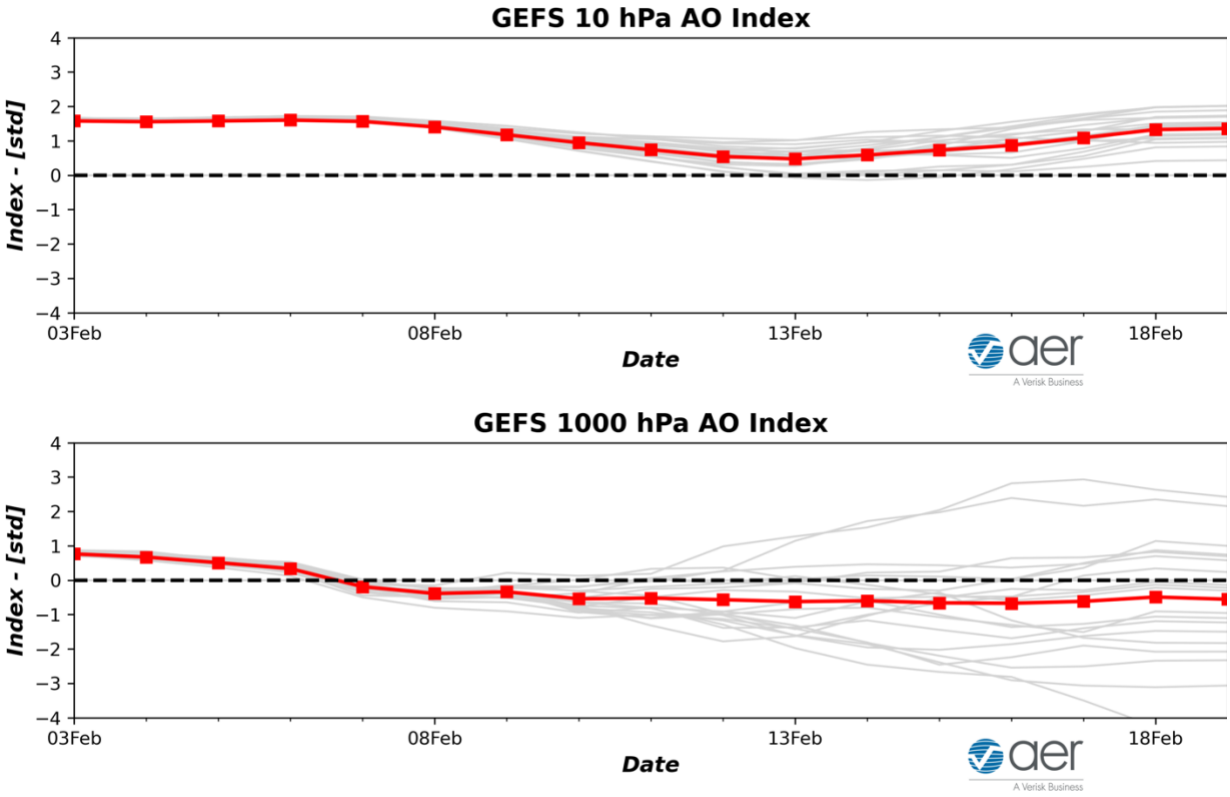

Figure 1. a) The predicted daily-mean AO at 10 hPa from the 00Z 3 February 2025 GFS ensemble. b) The predicted daily-mean AO at 1000 hPa from the 00Z 3 February 2025 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble mean AO index given by the red line with squares.

This week ridging/positive geopotential height anomalies across Scandinavia and the Barents-Kara Seas will support troughing/negative geopotential height anomalies across Southern Europe (**Figures 2).** This pattern will favor widespread normal to above normal temperatures across Northern and Eastern Europe with normal to below normal temperatures mostly limited to Western Europe including the UK and Turkey under low heights this period (**Figure 3**). This week the predicted pattern across Asia is widespread ridging/positive geopotential height anomalies across Western Asia and far Eastern Siberia forcing troughing/negative geopotential height anomalies across Siberia but especially Northeast Asia (**Figure 2**). This pattern favors normal to above normal temperatures widespread across much of Western Asia with normal to below normal temperatures across Southwest and Central Asia, Southern and Eastern Siberia and extending into East Asia **(Figure 3**).

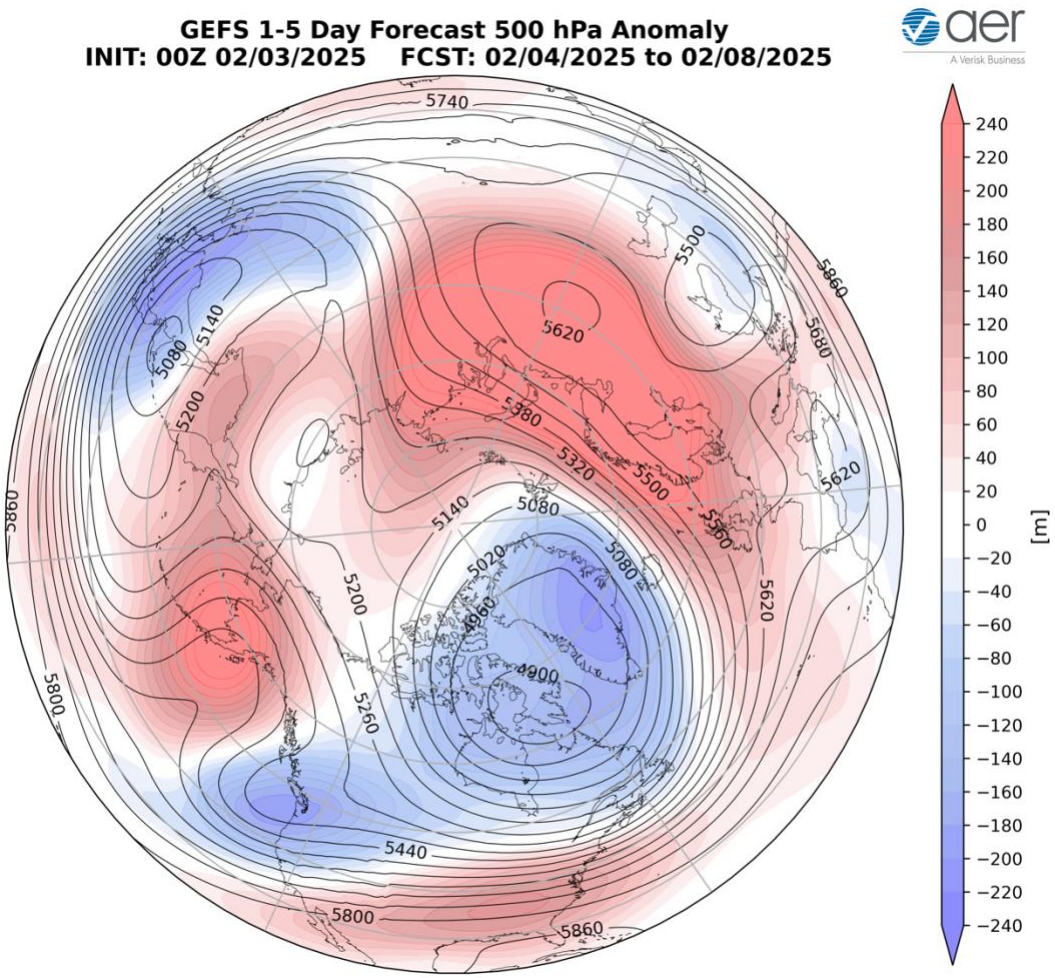

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 4 Feb to 8 Feb 2025. The forecasts are from the 00Z 3 February 2025 GFS ensemble.

This week strengthening ridging/positive geopotential height anomalies across Alaska and the Gulf of Alaska and the Southern US will support troughing/negative geopotential height anomalies across much of Canda and the Northwestern US. (**Figure 2**). This pattern favors normal to above normal temperatures across Alaska, Eastern Canada and most of the US with normal to below normal temperatures across Western Canada and the Northwestern US (**Figure 3**).

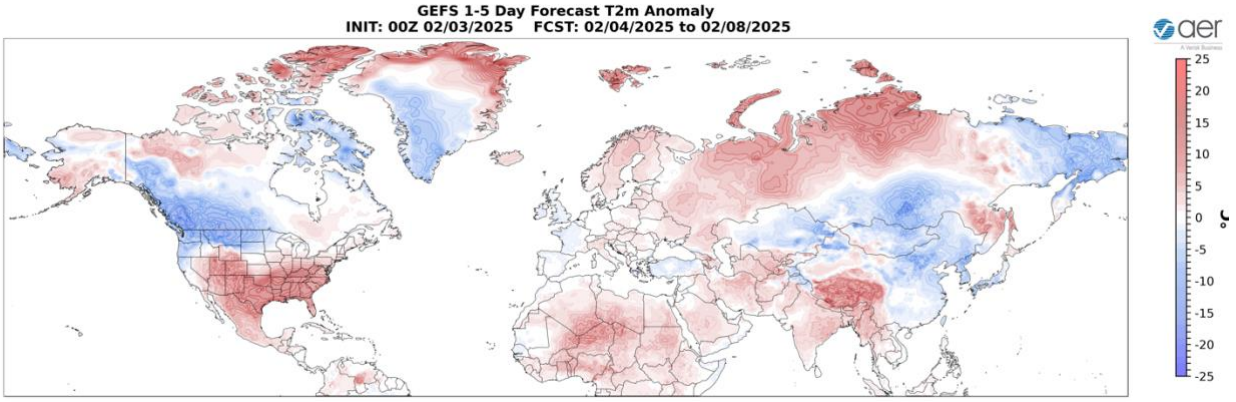

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 4 Feb to 8 Feb 2025. The forecasts are from the 00Z 3 February 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall in Norway, the Caucuses, parts of Siberia, Central and Northeast Asia (especially Japan) and the Tibetan Plateau while warm temperatures will support snowmelt in Sweden, the Alps and Western Russia this week (**Figure 4**). Troughing and/or cold temperatures will support new snowfall across northern Alaska, Northern and Eastern Canada, the higher elevations of the Northwestern US and along the US Canadian border while warm temperatures will support snowmelt in Southern Alaska, Western and Central Canada, the Northeastern US this week (**Figure 4**).

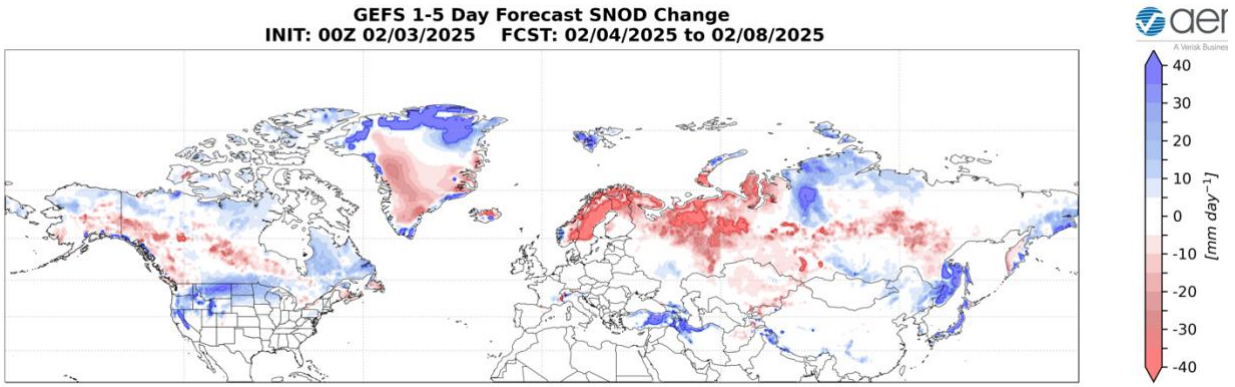

Figure 4. Forecasted snow depth changes (mm/day; shading) from 4 Feb to 8 Feb 2025. The forecasts are from the 00Z 3 February 2025 GFS ensemble.

Near-Mid Term

Next week

With geopotential height anomalies remaining becoming more mised across the Arctic and with mixed geopotential height anomalies across the mid-latitudes this period (**Figure 5**), the AO will likely be near neutral this period (**Figure 1**). With predicted mostly negative pressure/geopotential height anomalies across Greenland (**Figure 5**), the NAO will likely be positive this period.

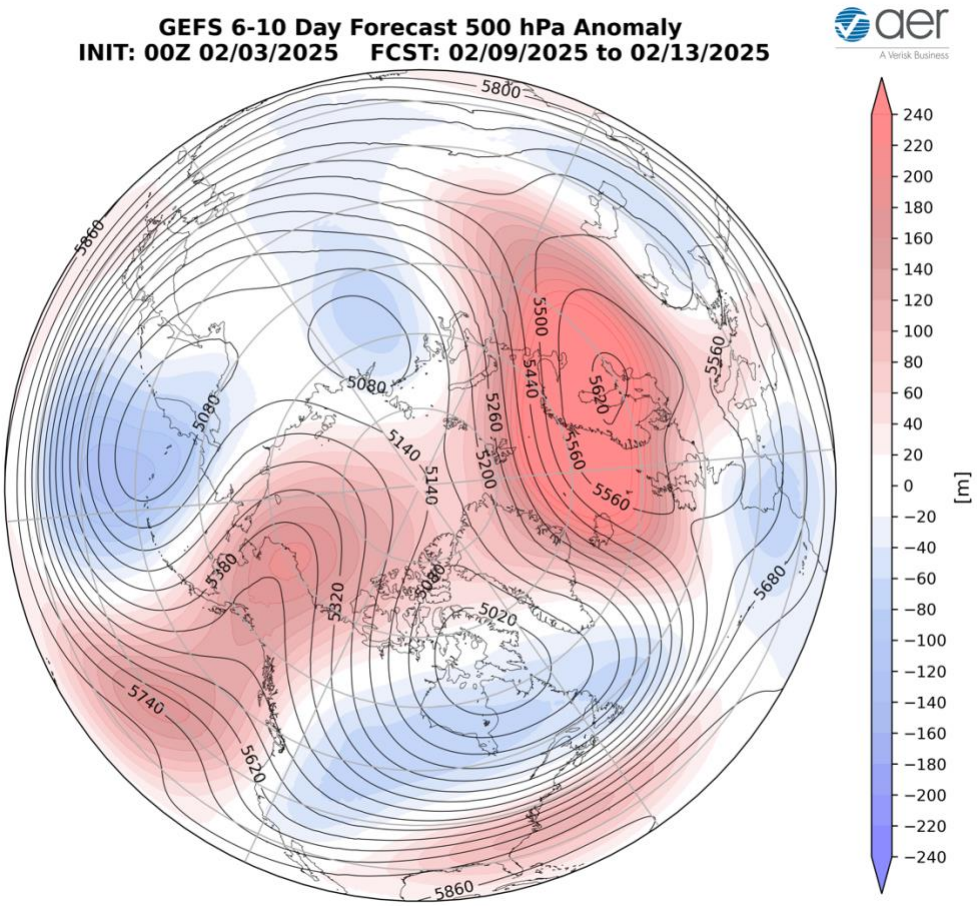

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 09 Feb to 13 Feb 2025. The forecasts are from the 00Z 3 February 2025 GFS ensemble.

Troughing/negative geopotential height anomalies across Greenland will continue to support ridging/positive geopotential height anomalies across Northern Europe with troughing/negative geopotential height anomalies across Southern Europe this period (**Figure 5**). This pattern favors normal to above normal temperatures across Northern Europe with normal to below normal temperatures across Central and Southern Europe including the UK this period (**Figure 6**). Ridging/positive geopotential height anomalies are

predicted to dominate Western and Northern Asia forcing troughing/negative geopotential height anomalies across Southern and Eastern Asia (**Figure 5**). This pattern favors widespread normal to above normal temperatures across Western and Northern Asia and the Indian subcontinent with normal to below normal temperatures across much of Central and Eastern Asia this period (**Figure 6**).

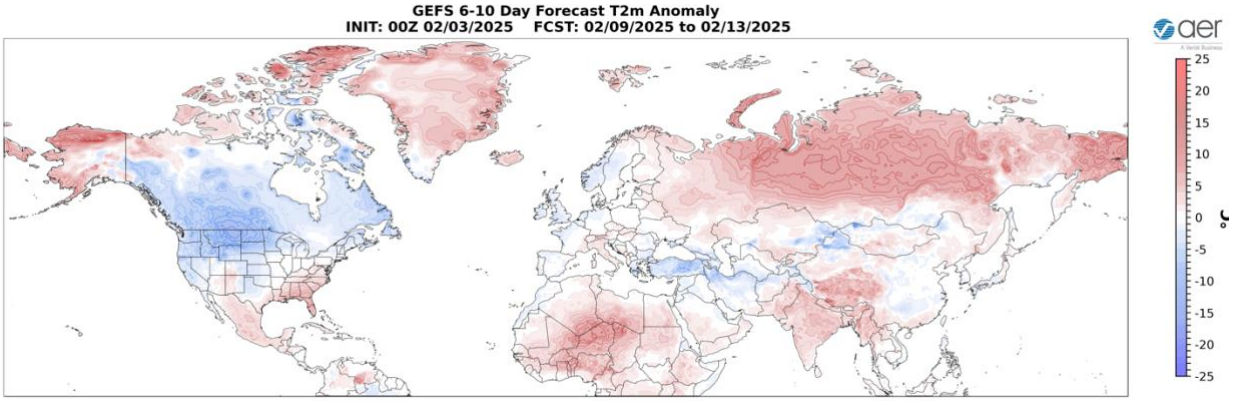

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 09 Feb to 13 Feb 2025. The forecasts are from the 00Z 3 February 2025 GFS ensemble.

Amplifying ridging/positive geopotential height anomalies predicted across the Gulf of Alaska and Alaska and the Southeastern US will support troughing/negative geopotential height anomalies across much of Canada and the Western US this period (**Figure 5**). This pattern will favor normal to above normal temperatures across Alaska and the Southern and Eastern US with normal to below normal temperatures across much of Canada and the Western and Northern US (**Figure 6**).

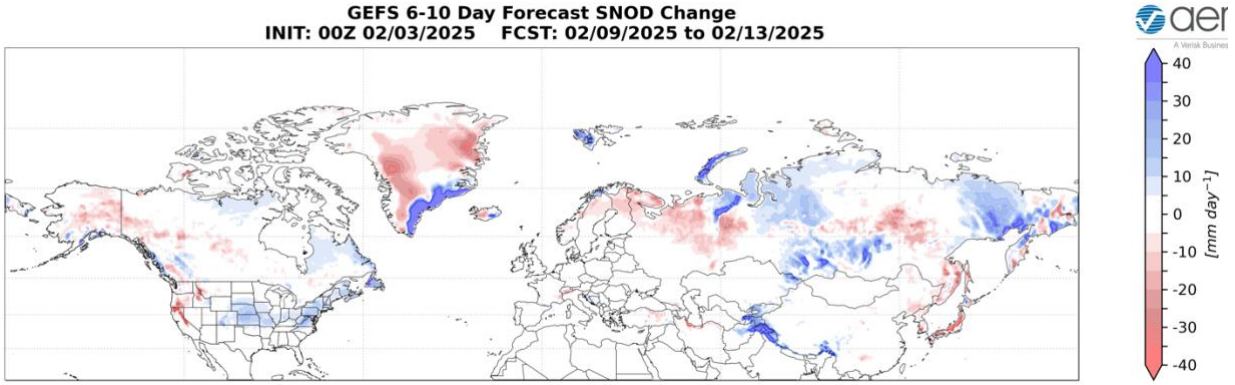

Figure 7. Forecasted snow depth changes (mm/day; shading) from 09 Feb to 13 Feb 2025. The forecasts are from the 00Z 3 February 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across the Balkans, eastern Turkey, parts of Siberia and the Tibetan Plateau while warm temperatures will support snowmelt in parts of Scandinavia, Western Russia and Northeast Asia this period (**Figure 7**). Troughing and/or cold temperatures will support new snowfall across the Plains into the

Northeastern US while warm temperatures will support snowmelt in southern Alaska, Western Canada and the Western US this period (**Figure 7**).

Mid Term

Week Two

With predicted persistent mixed to positive geopotential height anomalies across the Arctic and mixed geopotential height anomalies across the mid-latitudes this period (**Figure 8**), the AO will likely remain dip negative this period (**Figure 1**). With predicted weak but positive pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO will likely dip negative this period.

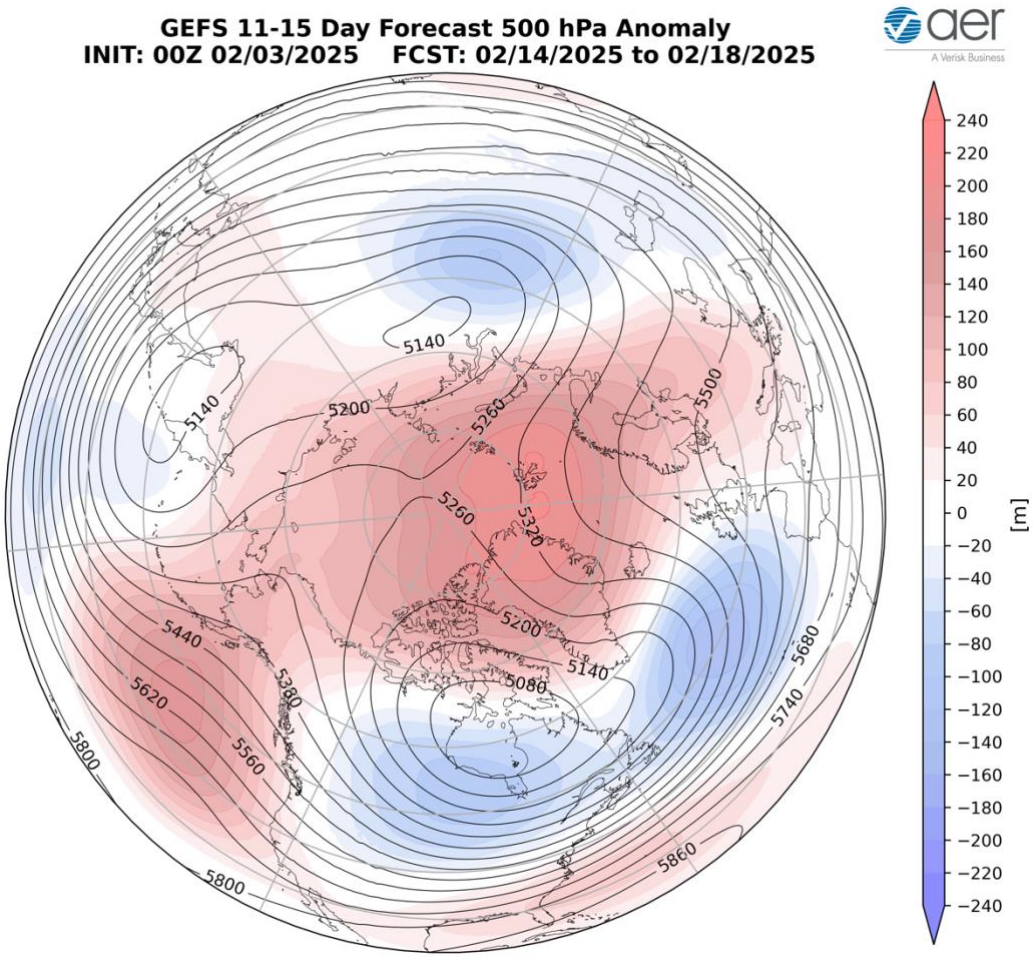

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 14 Feb to 18 Feb 2025. The forecasts are from the 00Z 3 February 2025 GFS ensemble.

Strengthening ridging/positive geopotential height anomalies across Greenland is predicted to support troughing/negative geopotential height anomalies across Western Europe with ridging/positive geopotential height anomalies across Eastern Europe (**Figure 8**). This pattern should favor normal to below normal temperatures across Northern Europe including the UK with normal to above normal temperatures across Southern and Central Europe this period (**Figures 9**). The persistent ridging/positive geopotential height anomalies across Western Asia is predicted to persist supporting troughing/negative geopotential height anomalies across Northern and Eastern Asia this period (**Figure 8**). The predicted pattern favors widespread normal to above normal temperatures across Western and Eastern Asia and the Indian subcontinent with normal to below normal temperatures across Central Asia this period (**Figure 9**).

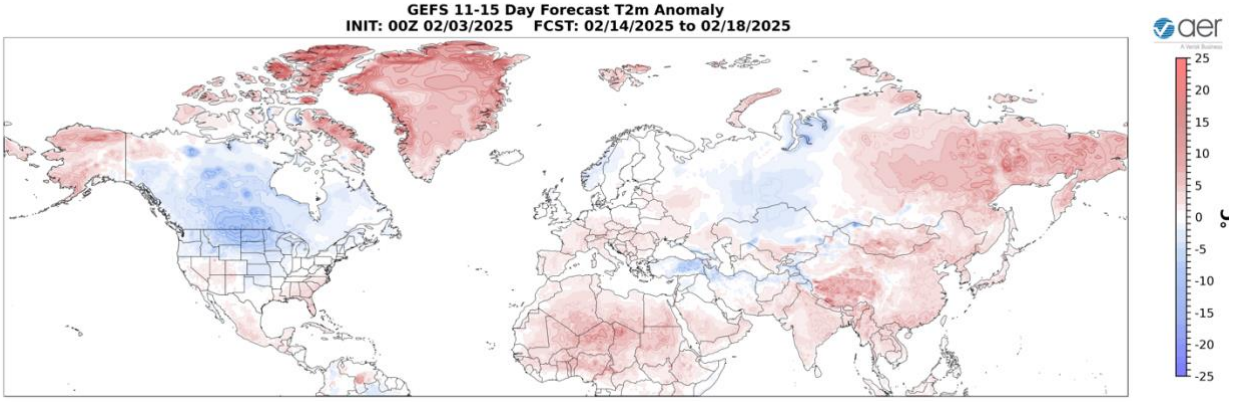

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 14 Feb to 18 Feb 2025. The forecasts are from the 00Z 3 February 2025 GFS ensemble.

Ridging/positive geopotential height anomalies in the Gulf of Alaska and Alaska will support troughing/negative geopotential height anomalies across much of Canada and the Interior US with more ridging/positive geopotential height anomalies across the Southeastern US this period (**Figure 8**). Below normal temperatures will continue to spread south and east across much of Canada and across the US with normal to above normal temperatures limited to Alaska and the Southeastern US this period (**Figure 9**).

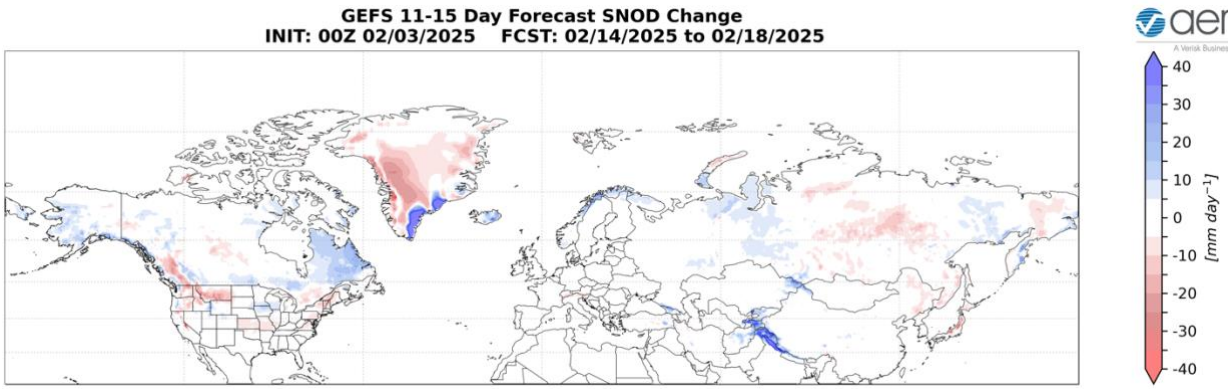

Figure 10. Forecasted snow depth changes (mm/day; shading) from 14 Feb to 18 Feb 2025. The forecasts are from the 00Z 3 February 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across Norway, parts of Siberia, the Caucuses, the Tibetan Plateau and Central Asia while warm temperatures will support snowmelt in parts of Siberia this period (**Figure 10**). Troughing and/or cold temperatures will support new snowfall across western Alaska, Ontario and Quebec while warm temperatures will support snowmelt in Southwestern Canada and the Northwestern US this period (**Figure 10**).

Longer Term

30–day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows warm/positive PCHs in the troposphere with cold/negative PCHs in the stratosphere (**Figure 11**). The cold/negative PCHs in the stratosphere are predicted to persist but weaken the next two weeks while the warm/positive PCHs in the troposphere are predicted to also mostly persist. The contrast between cold/negative PCHs in the stratosphere and warm/positive PCHs in the troposphere continues for yet another two weeks (**Figure 11**). For now, this suggests that the stratosphere and troposphere are mostly uncoupled. At least in the models, it looks like this time high latitude blocking is finally weakening the PV.

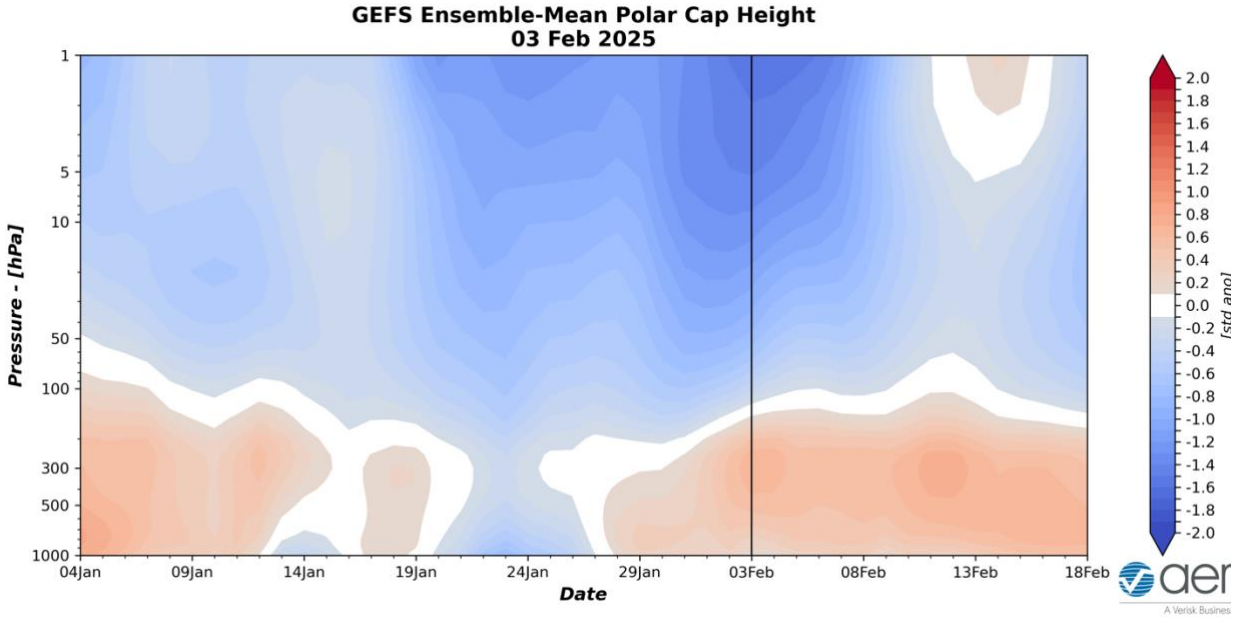

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 3 February 2025 GFS ensemble.

The predicted weak but warm/positive and cold/negative PCHs in the lower troposphere the next two weeks (**Figure 11**) are consistent with the predicted near neutral surface AO this week and next week (**Figure 1**). I do wonder if maybe the GFS is a bit too zealous with the positive AO predictions given the lack of cold/negative PCHs in the troposphere. Still waiting to see if the warm/positive PCHs in the troposphere could force a larger polar vortex disruption or the cold/negative PCHs in the stratosphere consistently couple to the surface. Still, lots of questions and no definitive signs.

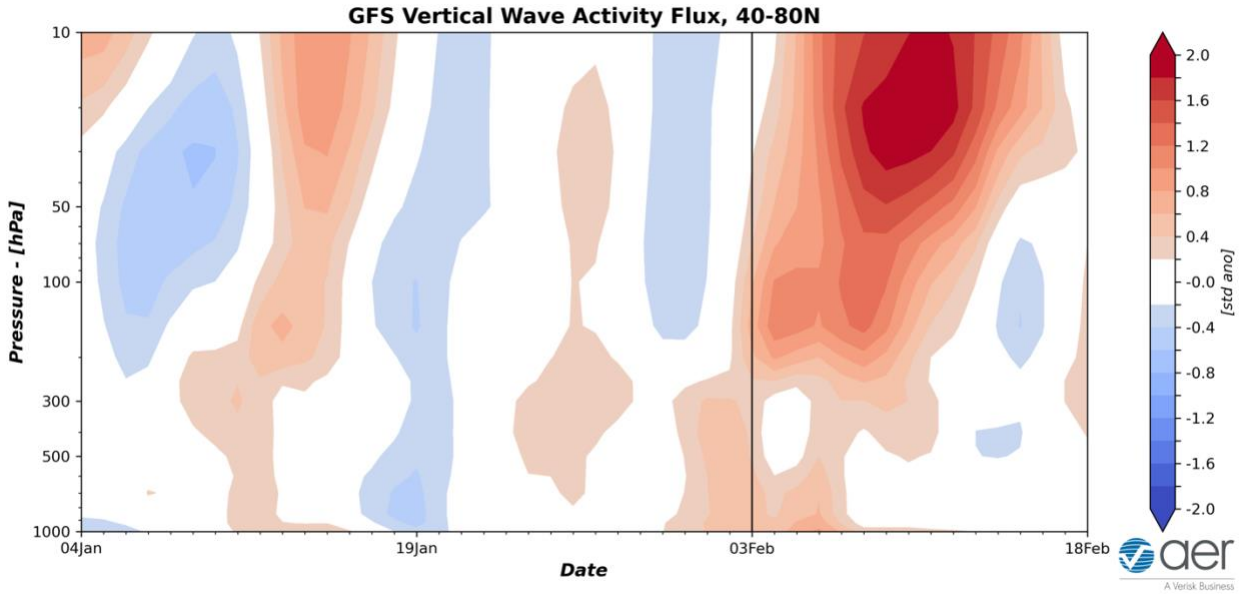

Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 3 February 2025 GFS ensemble.

Vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere has been relatively quiet this entire season (**Figure 12**). However, the strongest pulse of WAFz is predicted this week into next week (**Figure 12**). This larger pulse is supportive of a larger PV disruption in my opinion.

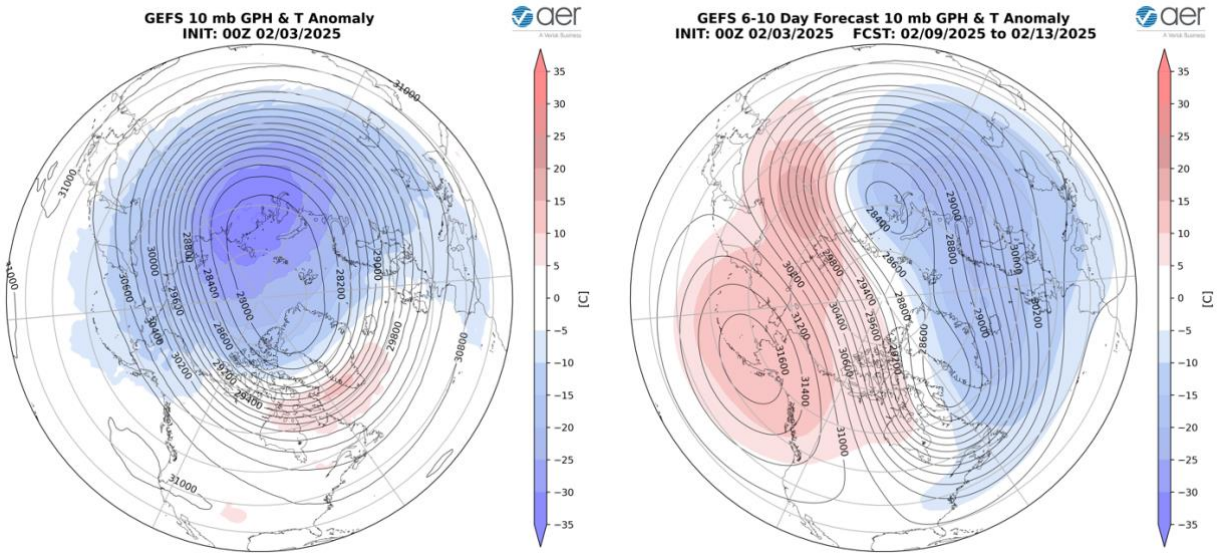

Figure 13. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 03 Feb 2025. (b) Same as (a) except forecasted averaged from 09 Feb to 13 Feb 2025. The forecasts are from the 00Z 3 February 2025 GFS model ensemble.

Currently the polar vortex (PV) is centered near the Nort Pole and more circular in shape with relatively coldest temperatures across northern Eurasia and the Arctic in the polar stratosphere (**Figure 13a**). This is consistent with a strong PV that favors relatively mild temperatures across the mid-latitudes including the US. The next week the PV is predicted to become more elongated in shape with seemingly two PV centers, one over Western Siberia and the other over Baffin Bay. The relatively coldest temperatures of the polar stratosphere are predicted across the North Atlantic side of the Arctic in the stratosphere and the warmest temperatures across the North Pacific side of the Arctic (**Figure 13b**). This event looks most robust of the winter. For those keeping score at home, the ninth (I called it a two part-er but if considered two separate events, would event be the tenth of the season). The stratospheric AO in **Figure 1** this week continues to show that despite the repeated stretched PVs, overall, the PV remains strong and possibly record strong. I think that the PV could weaken more than predicted by the GFS ensembles.

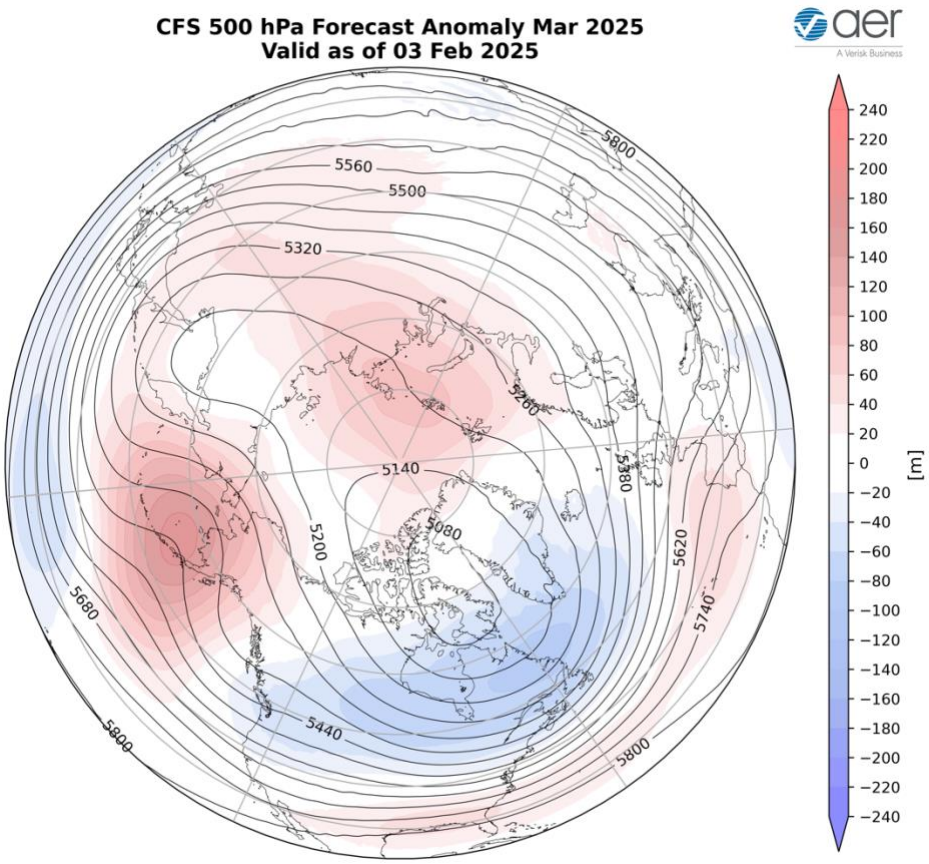

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for March 2025. The forecasts are from the 00Z 3 February 2025 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and surface temperatures for March (**Figure 15**) from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging centered on Western Europe, the Barents-Kara Seas, the Aleutians and the Southeastern US with troughing across Eastern Europe, Northern and Eastern Asia, much of Canada, Baffin Bay and the Northern US (**Figure 14**). This pattern favors seasonable to relatively warm temperatures across Europe, Western and Northern Asia, Eastern Siberia, Alaska and the Southeastern US with seasonable to relatively cold temperatures across Northeast Asia, much of Canada but especially Western Canada and the Western and Northern US but especially the Plains (**Figure 15**).

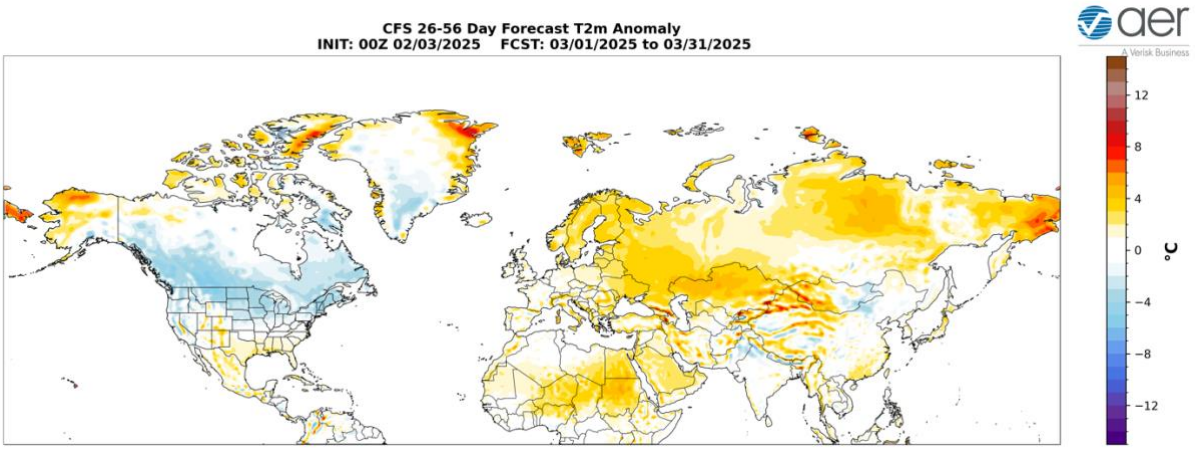

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for March 2025. The forecasts are from the 00Z 3 February 2025.

Boundary Forcings

Arctic Sea Ice

Sea ice growth continues relatively slowly with negative anomalies in the Barents-Kara Seas, the Sea of Okhotsk and the Labrador Sea (see **Figure 16**). The lack of sea ice in the that favors a weak PV, more high latitude blocking and colder temperatures across the interior of the NH continents. The influence of sea ice on remote weather is likely waning.

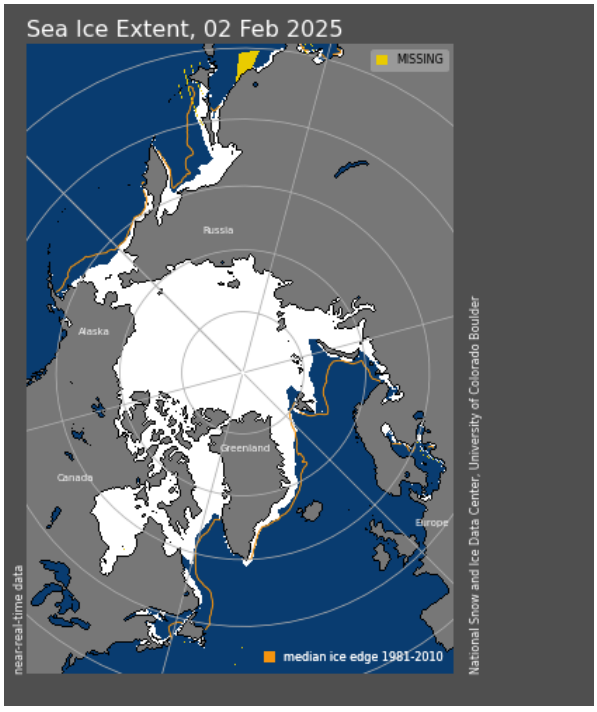

Figure 16. Observed Arctic sea ice extent on 2 February 2025 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image from the National Snow and Ice Data Center (NSIDC). URL: https://nsidc.org/sea-ice-today

SSTs/El Niño/Southern Oscillation

Equatorial Pacific sea surface temperatures (SSTs) anomalies are below normal, between the Dateline and the South America coast, indicating that a La Niña event has emerged but is focused more near the Dateline rather than close to the South American coast (**Figure 17**) and weak La Niña conditions are expected through the end of winter. Observed SSTs across the NH remain well above normal especially in the central North Pacific centered on the Dateline and the western North Pacific, much of the North Atlantic and offshore of the Canadian Maritimes though below normal SSTs exist regionally especially in the South Pacific. I have wondered if the warmer SSTs this year relative to recent years along the west coast of North America is favoring the cold air further to the east this winter compared to the past decade and this was certainly true in January.

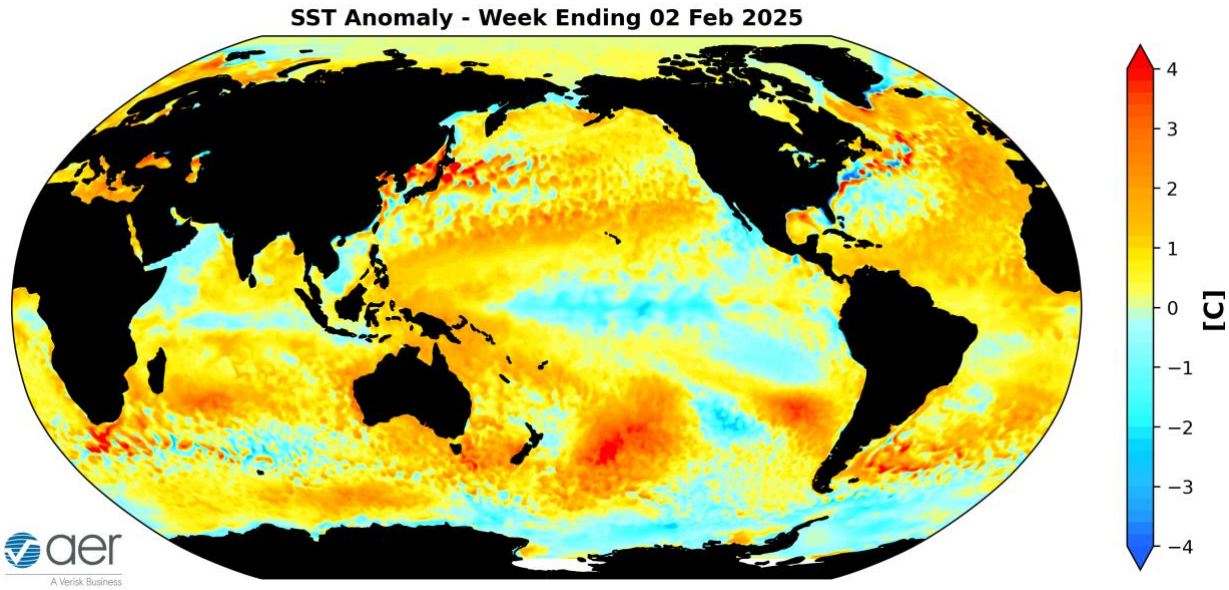

Figure 17. The latest daily-mean global SST anomalies (ending 2 Feb 2025). Data from NOAA OI High-Resolution dataset. Source https://psl.noaa.gov/map/clim/sst.shtml

Madden Julian Oscillation

Currently the Madden Julian Oscillation (MJO) is in phase five (**Figure 18**). The forecasts are for the MJO to quickly rifle through phases six, seven and eight. Phases five, six and seven favor troughing in the Western US and ridging in the Eastern US while phase eight favors Western US ridging and Eastern US troughing. Therefore, it seems that the MJO may be having some influence on North American weather the next couple of weeks. But admittedly this is outside of my expertise.

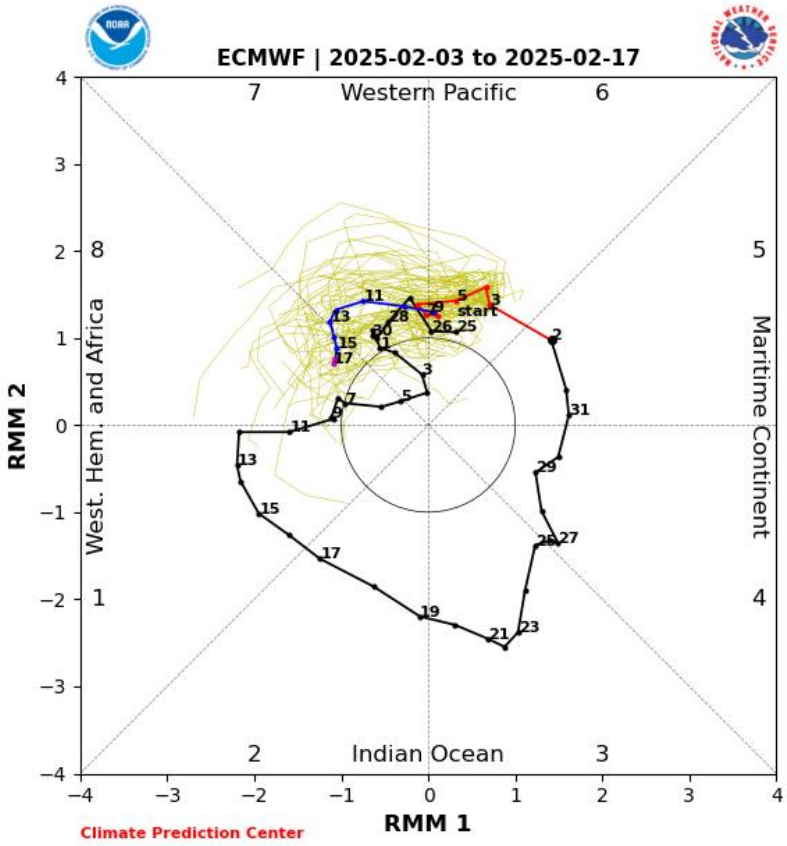

Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 3 February 2025 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model 'spread' is denoted by the gray shading. Sector numbers indicate the phase of the MJO, with geographical labels indicating where anomalous convection occurs during that phase. Image source https://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/CLIVAR/ecmf.shtml

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