Arctic Oscillation and Polar Vortex Analysis and Forecasts

January 13, 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 neutral and is predicted to remain neutral to positive the next two weeks as pressure/geopotential height anomalies across the Arctic are currently mostly mixed and are predicted to remain mostly negative to mixed over the next two weeks. The North Atlantic Oscillation (NAO) is currently negative with mostly positive pressure/geopotential height anomalies across Greenland and the NAO is predicted to trend positive the next two weeks as pressure/geopotential height anomalies are predicted to reverse to negative across Greenland.
- The next two weeks troughing/negative geopotential height anomalies across Greenland will support ridging/positive geopotential height anomalies across much of Europe with the exception of troughing/negative geopotential height anomalies in the western Mediterranean. This pattern will support mostly normal to above normal temperatures across much of Europe including the United Kingdom (UK) with the exception of normal to below normal temperatures across Southwestern Europe this week under northerly flow.
- The next two weeks ridging/positive geopotential height anomalies are predicted to dominate Asia. However strengthening European ridging the next two weeks will support deepening troughing/negative geopotential height anomalies across Siberia. This pattern favors widespread normal to above normal temperatures across much of Asia,

with normal to below normal temperatures spreading across Eastern Siberia the next two weeks.

- The general pattern across North America the next two weeks is amplifying ridging/positive geopotential height anomalies centered in Alaska, and the Gulf of Alaska supporting troughing/negative geopotential height anomalies first across Central Canada and the Central United States (US) and then Eastern Canada and the Eastern US. This pattern favors normal to above normal temperatures across Alaska and much of Canada with normal to below normal temperatures across the US this week. However, next week below normal temperatures will become more widespread across Canada and the US with normal to above normal temperatures for Alaska.
- This winter has been all about the polar vortex (PV) alternating among strong, a Canadian warming but most of all a stretched PV. This pattern looks to continue but for how long? Also still watching the battle between high latitude blocking and a strong PV, which has been at a stalemate all winter long. Models are predicting near record strong PV but is it really?

Plain Language Summary

What you see is what you get seems to be the theme of the week in the weather. Overall looks mild for Europe and East Asia but turning much colder in Canada and the US (see **Figure 6**). I don't see any reason why the weather ride of January 2025 should end as we head in February but clearly the weather models do with a milder pattern in the Eastern US.

Impacts

The theme of the winter of stretched polar vortex (PV) events in quick succession and seemingly in an infinite loop of "lather, rinse repeat" continues with the PV alternating between a stretched PV and a relaxation to a more circular shape or a Canadian Warming. Regardless the transition to different PV phases or modes at breakneck speed continues through the end of January. The rapid transitions of the PV to different modes or phase can be seen in the latest PV animation in **Figure i**. There is the sixth stretched PV of the season on the 15-16 January (fairly short) and then the seventh stretched PV 20 January through the end of the animation on 28 January.

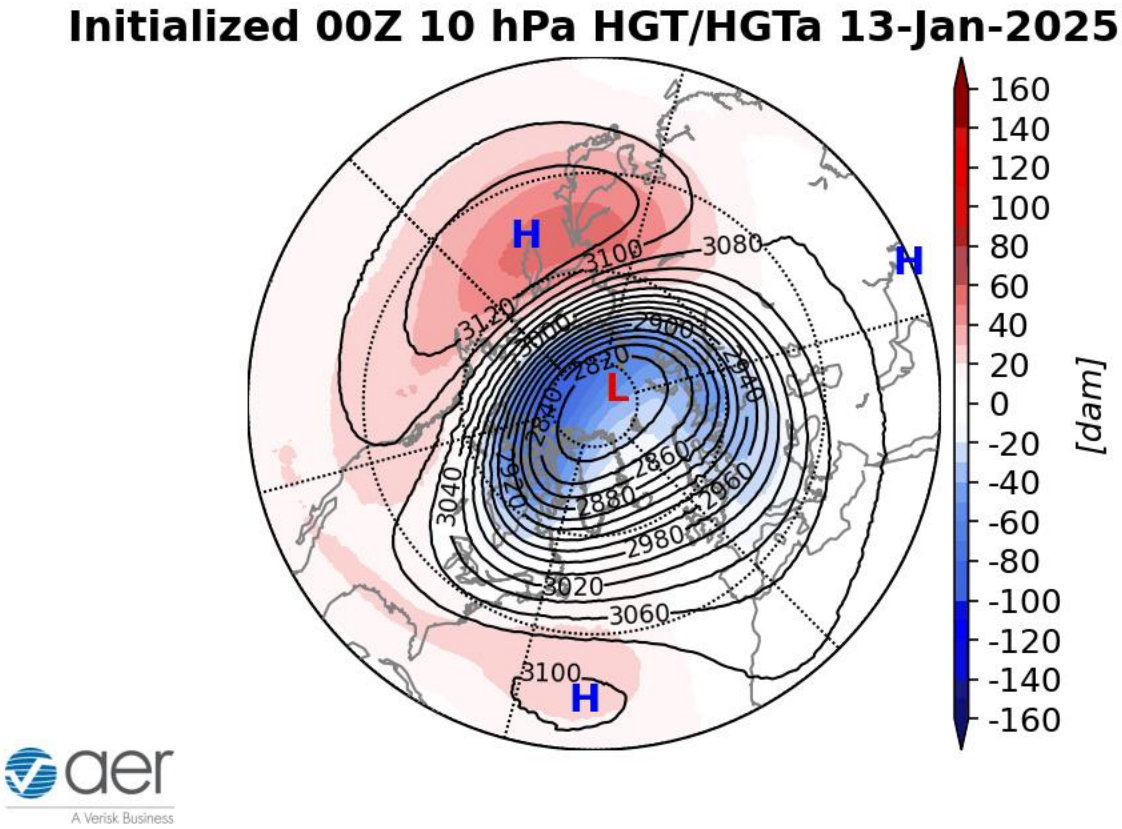

Figure i. Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 13 January 2025 and forecasted from 14 January to 28 January 2025. The forecasts are from the 00Z 13 January 2025 GFS model ensemble.

The next stretched PV (sixth of the season) mid-month looks to be sandwiched between two more impressive, stretched PVs this month one at the beginning and one a the end of the month. In the blog over the past several weeks I have been focusing on the wave reflection diagnostics and show it again in today's blog. 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**). Once again, the wave reflection seems to never quit this month and my diagnostics show wave reflection uninterrupted for the next two weeks. As can be seen in **Figure ii**, the wave reflection for the first event (this week) is more modest compared to the wave reflection for next week. And I believe this is contributing to more impressive cold for the US, including the Eastern US, starting next week.

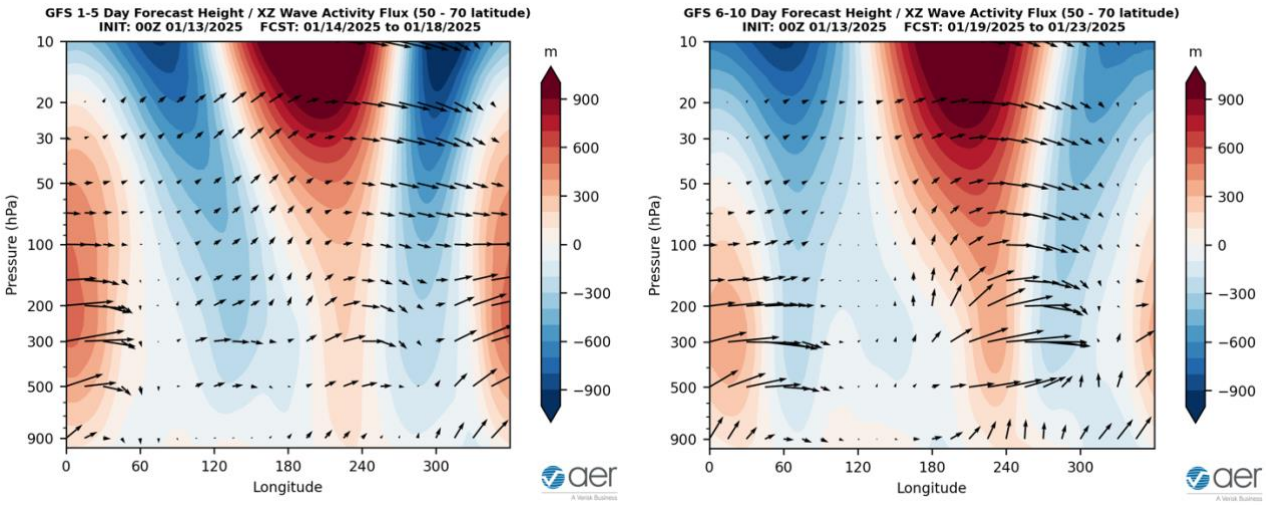

Figure ii. Longitude-height cross section of geopotential eddy height anomalies (shading) and wave activity flux (vectors) forecasted for a) 14 January through 18 January 2025 and b) 24 January through 28 January 2025. The forecasts are from the 00Z 13 January 2025 GFS ensemble.

I will admit to being confused about how to interpret in between stretched PV events six and seven (see **Figure i**). The sixth event winds down on 17 January and the seventh event doesn't seem to get going until around 20 January. This works well with the timing of the cold air into the Eastern US, with the stretched PV about one day ahead of the cold push into the Eastern US but the cold air comes into the Western US a couple of days earlier.

In between the two stretched events is some hybrid looking stretched event/Canadian warming. But no matter how I think about it I have hard time explaining the timing of the cold air into the Western US around 18 January. But it could simply be that what matters most is the wave reflection or possibly some other forcing such as tropical or even just random weather noise.

Stretched PVs deliver severe winter weather not only to North America but also East Asia. There seems to be some cold air predicted for East Asia around 15 January with the stretched PV at that time and maybe even some post 20 January with the following stretched PV event but clearly nothing as impressive as what is predicted for North America.

Greenland blocking brought cold and snow to Northern Europe last week, but Greenland blocking is predicted to slowly transition to Greenland troughing this week and next week (see **Figure iii**). This should allow more high pressure ridging over Europe and an overall milder pattern. For now, I don't see much evidence for a return to colder weather, unless models are too quick to break down the Greenland blocking.

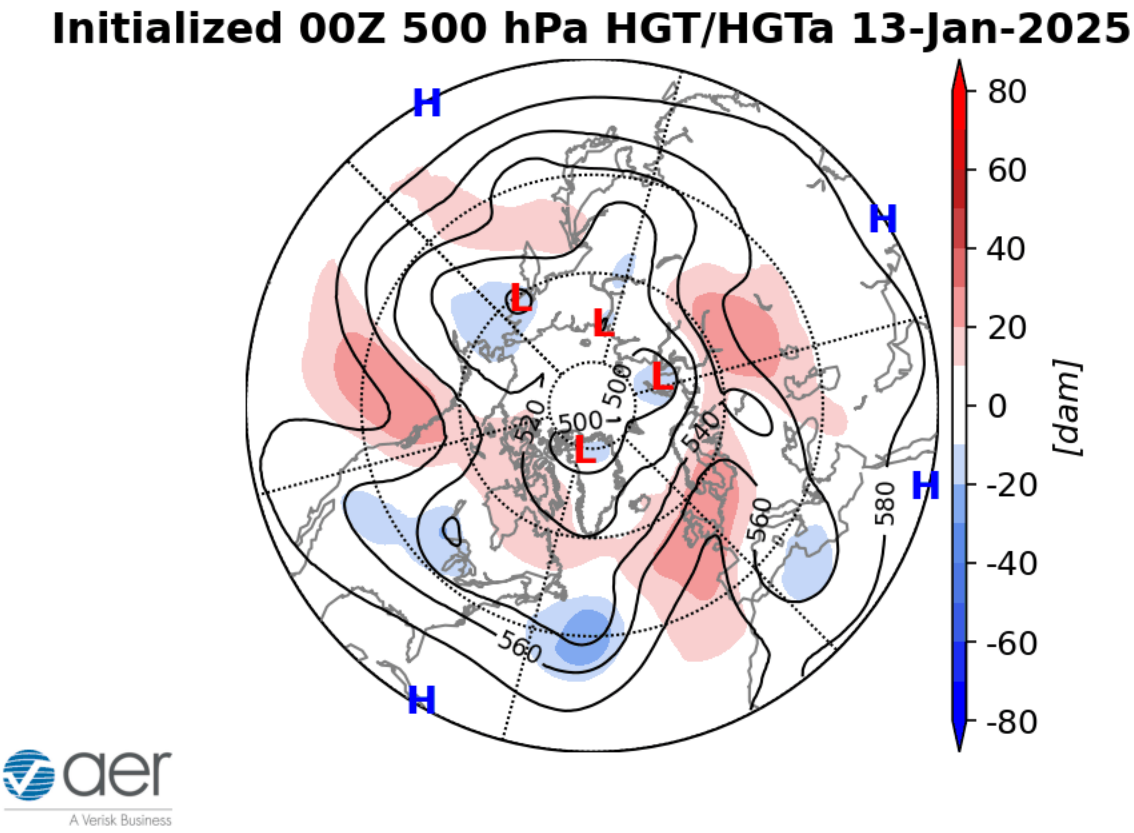

Figure iii. Initialized 500 mb geopotential heights (dam; contours) and decameter anomalies (dam; shading) across the Northern Hemisphere for 13 January 2025 and forecasted from 14 January to 28 January 2025. The forecasts are from the 00Z 13 January 2025 GFS model ensemble.

Heading into the last days of January the models are in good agreement on a relaxation of the cold pattern in the US and that makes sense to me as the cold weather associated with stretched PVs when the PV is overall strong is about a week or so and typically not longer. However, one curiosity is that in the PV forecast through two weeks still no sign of the PV snapping back to a more circular shape (see **Figures i** and **13b**). The models at the end of their runs are suggestive (but it is subtle for now) of maybe some more cold air making it into the Eastern US as January comes to a close. We will have to see if this becomes more significant with time.

Looking ahead into February, I believe that the forecast remains complicated and challenging. There are two major factors that are making the forecast of US temperatures heading into February especially challenging. Both the GFS and European ensembles are predicting a near record strong PV (see **Figure 1**). It is very difficult to get cold in the Eastern US with a PV that strong instead, if there is cold it is much likely to be in the Western US. However, when I look certainly at the operational models and to a lesser extent even the ensembles, that just doesn't look like a record strong PV (see **Figure iv**). Winter 2019/20 comes to my mind as the typical strong PV.

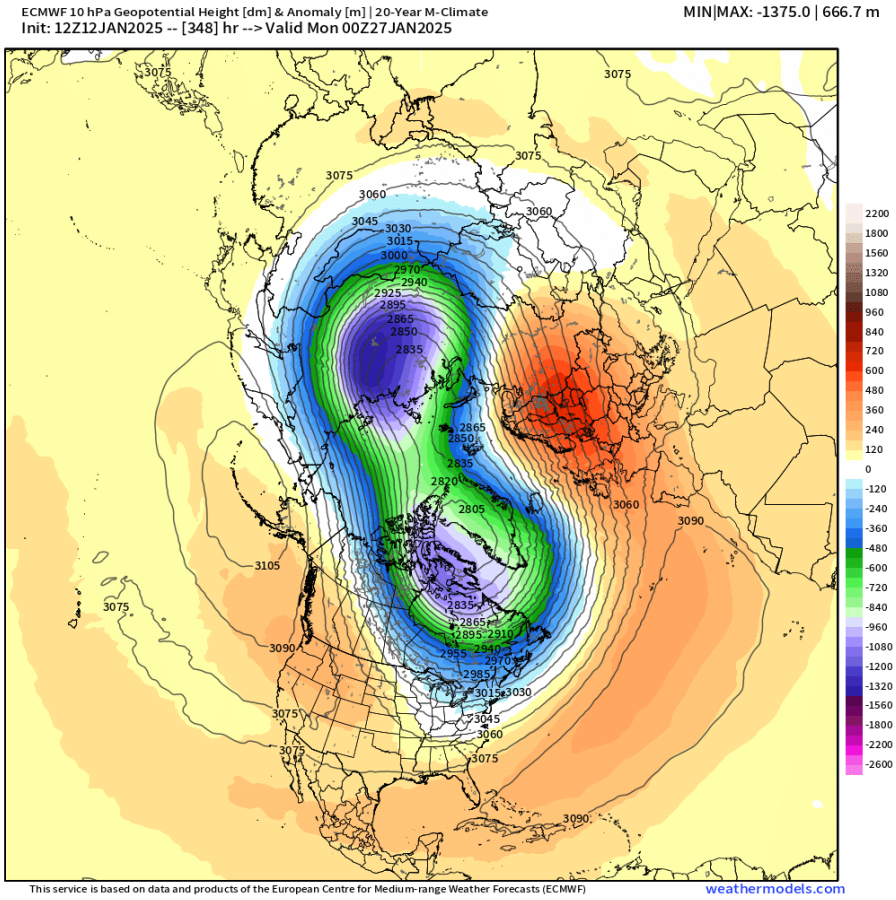

Figure iv. Forecasted 10 mb geopotential heights (dam; contours) and anomalies (meters; shading) across the Northern Hemisphere for 27 January 2025. The forecasts are from the 12Z 12 January 2025 ECMWF operational model. Plot taken from https://weathermodels.com.

The second complicating factor is the tropical convection. Starting mid-week, tropical convection will be supportive of cold in the Western US and mild in the Eastern US. The models keep predicting the cold to shift into the Western US and for it to turn milder in the Eastern US. It is hard to know if this is real or a model bias.

At least for the foreseeable, I still think that the PV is supportive of cold in the Eastern US, at least when it stretches. Longer term I still favor a continuation of the pattern we have seen all winter, stretched PVs that most likely favor cold in the Eastern US and some kind of relaxation, which for the past month has been in the form of one to two Canadian warmings and one circular PV. When I look at the tropospheric pattern in the ensembles, that does not look supportive of a record strong PV. Instead, should at least keep the PV tap dancing and not settle into a nice circular rhythm. Instead, the predicted pattern looks very supportive of stretched PVs with an especially nice-looking wave-2 pattern across the Northern Hemisphere (see **Figure 8**).

Near-Term

This week

The AO is predicted to be mostly positive this week **(Figure 1**) with mixed to 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 mostly negative geopotential height anomalies across Greenland (**Figure 2**), the NAO is predicted to be neutral to positive this week.

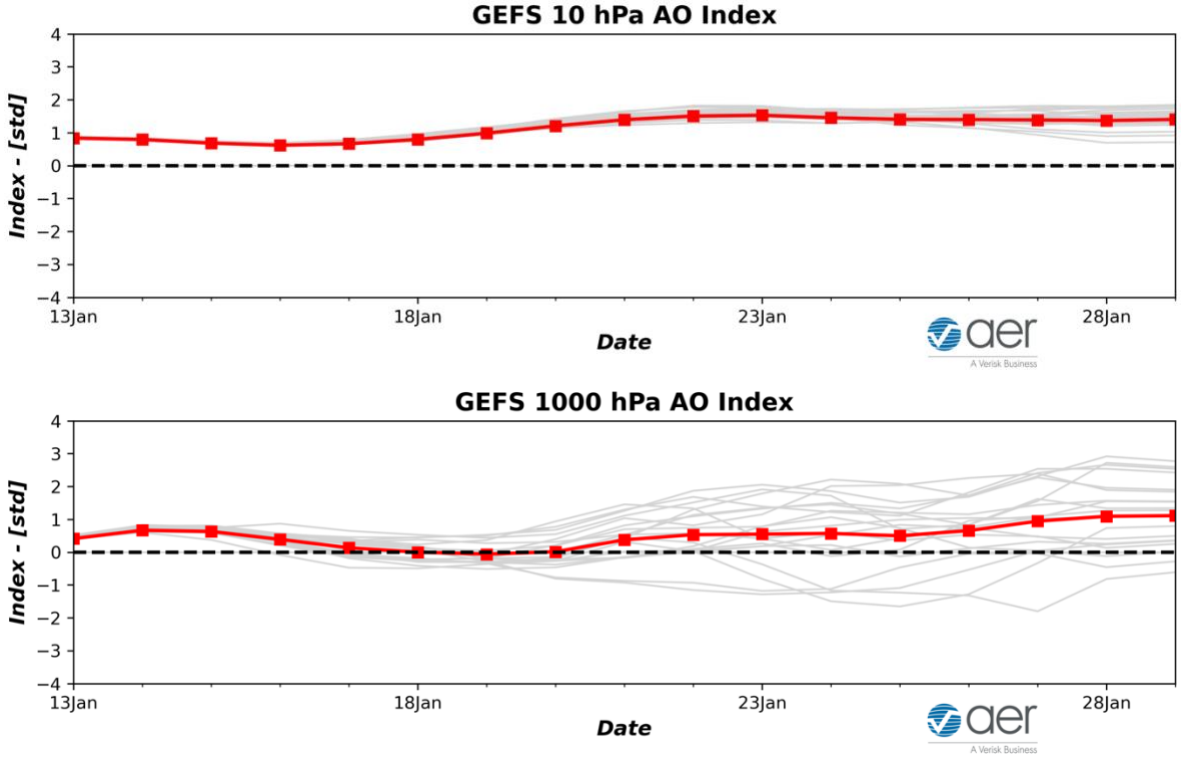

Figure 1. a) The predicted daily-mean AO at 10 hPa from the 00Z 13 January 2025 GFS ensemble. b) The predicted daily-mean AO at 1000 hPa from the 00Z 13 January 2025 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble mean AO index given by the red line with squares.

This week, deepening troughing/negative geopotential height anomalies across Greenland will support strengthening ridging/positive geopotential height anomalies across much of Europe with the exception of troughing/negative geopotential height anomalies in the western Mediterranean (**Figures 2).** This pattern will favor widespread normal to above normal temperatures across Europe including the UK with normal to below normal temperatures across Southwestern Europe due ot induced northerly flow this period (**Figure 3**). This week the predicted pattern across Asia is widespread ridging/positive geopotential height anomalies with troughing/negative geopotential height anomalies mostly confined to Siberia and Northeastern Asia (**Figure 2**). This pattern favors normal to above normal temperatures widespread across much of Asia with normal to below normal temperatures limited to far Northern Siberia **(Figure 3**).

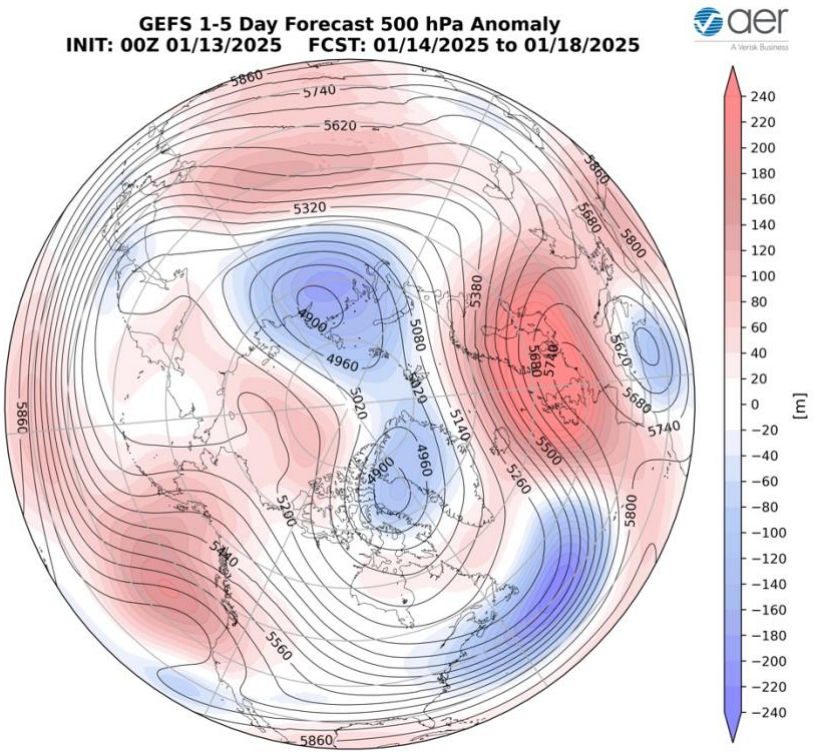

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 14 Dec to 18 Jan 2025. The forecasts are from the 00Z 13 January 2025 GFS ensemble.

This week ridging/positive geopotential height anomalies spread across much of Alaska and Northeastern Canada will support troughing/negative geopotential height anomalies across the US. (**Figure 2**). This pattern favors normal to above normal temperatures across Alaska and much of Canada with normal to below normal temperatures across most of the US (**Figure 3**).

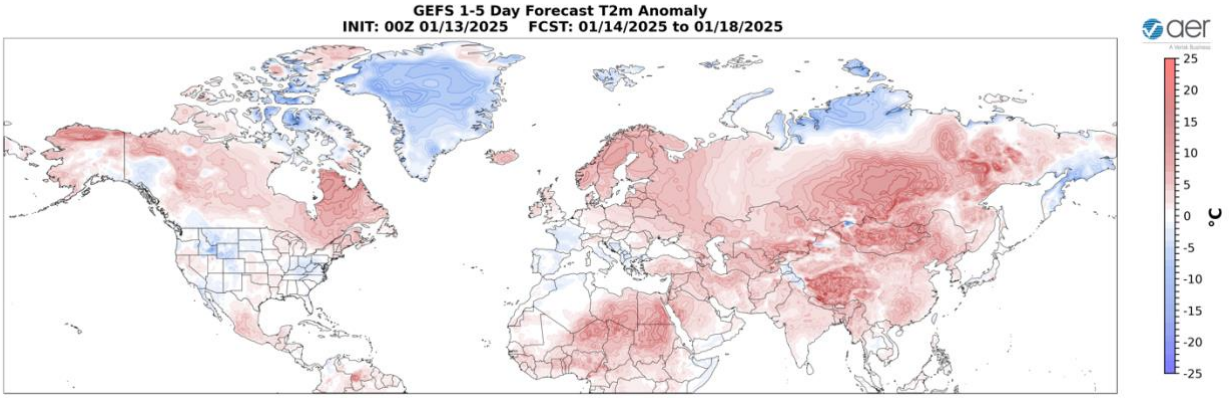

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 14 Jan to 18 Jan 2025. The forecast is from the 00Z 13 January 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall in parts of Siberia, Northeast Asia and the Tibetan Plateau while warm temperatures will support snowmelt in Scandinavia, the Baltic States, the Alps and Western Russia this week (**Figure 4**). Troughing and/or cold temperatures will support new snowfall across western Alaska, Northern and Eastern Canada, the higher elevations of the Canadian West Coast and New England while warm temperatures will support snowmelt in Western Canada, the Western and Southeastern US this week (**Figure 4**).

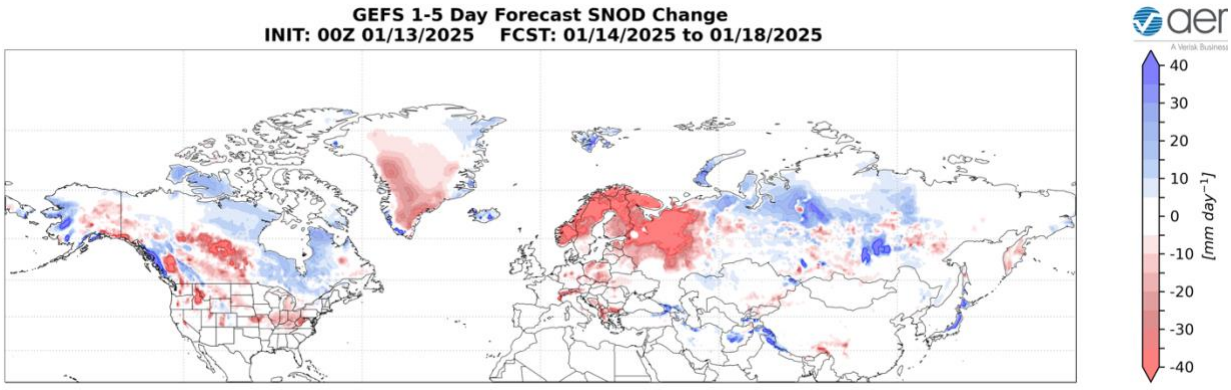

Figure 4. Forecasted snow depth changes (mm/day; shading) from 14 Jan 2025 to 18 Jan 2025. The forecast is from the 00Z 13 January 2025 GFS ensemble.

Near-Mid Term

Next week

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

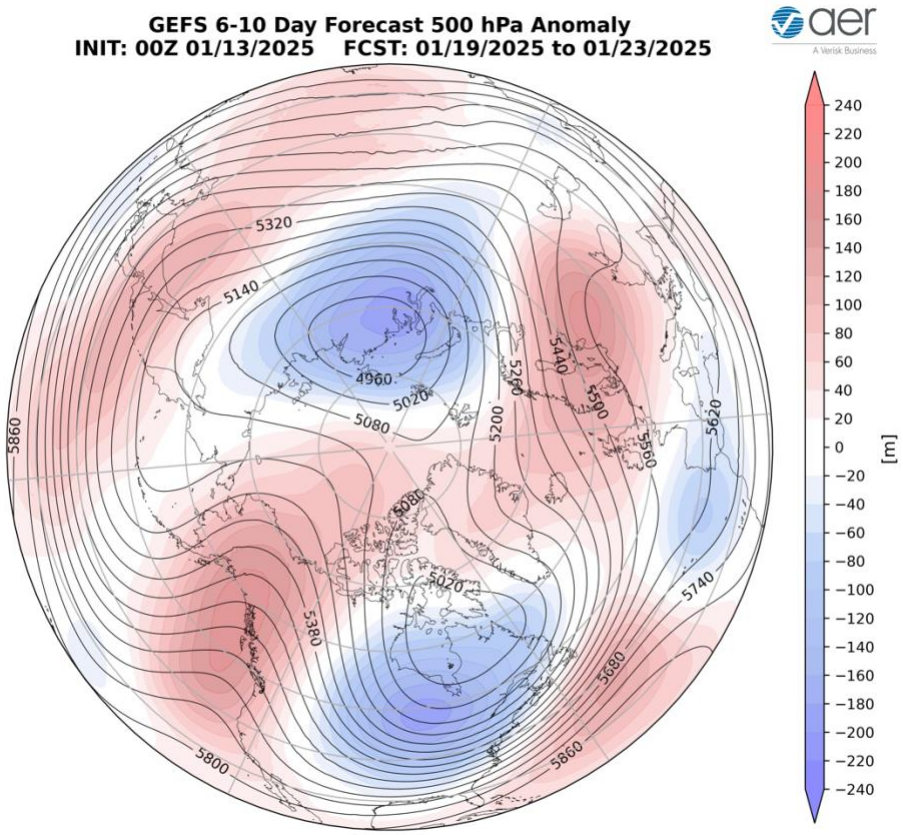

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 19 Jan to 23 Jan 2025. The forecasts are from the 00Z 13 January 2025 GFS ensemble.

Troughing/negative geopotential height anomalies across Greenland will continue to support ridging/positive geopotential height anomalies across much of Europe with the exception of troughing/negative geopotential height anomalies in the western Mediterranean this period (**Figure 5**). This pattern favors normal to above normal temperatures across much of Europe including the UK with normal to below normal temperatures limited to France and Spain under northerly this period (**Figure 6**). Once again ridging/positive geopotential height anomalies are predicted to dominate Asia with troughing/negative geopotential height anomalies limited to Siberia (**Figure 5**). This pattern

favors widespread normal to above normal temperatures across Asia with normal to below normal temperatures mostly limited to Northern Siberia this period (**Figure 6**).

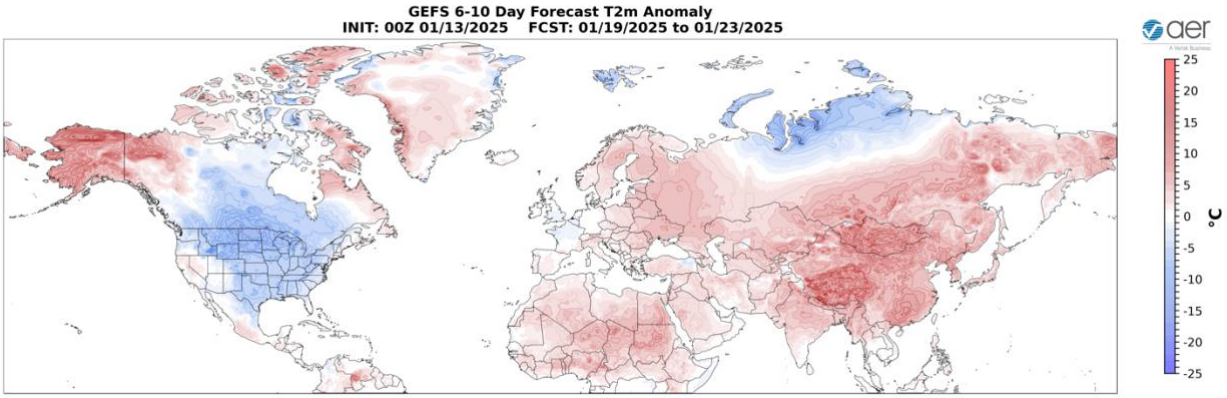

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 19 Jan to 23 Jan 2025. The forecast is from the 00Z 13 January 2025 GFS ensemble.

A more amplified pattern is predicted to return to North America with ridging/positive geopotential height anomalies predicted across Alaska, the Gulf of Alaska and along the Canadian Maritimes with troughing/negative geopotential height anomalies across Central Canada and the Eastern US this period (**Figure 5**). This pattern will favor widespread normal to below normal temperatures across much of Canada and the US with normal to above normal temperatures mostly limited to Alaska and the Canadian Maritimes (**Figure 6**).

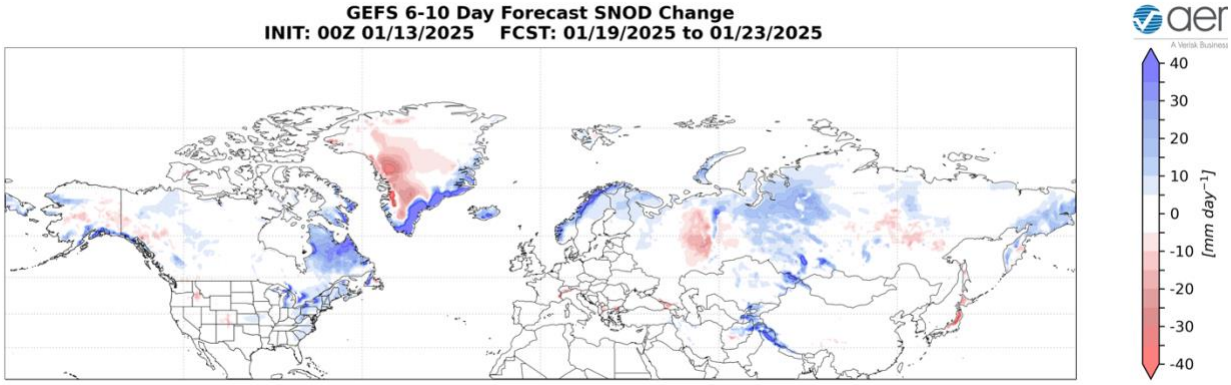

Figure 7. Forecasted snow depth changes (mm/day; shading) from 19 Jan to 23 Jan 2025. The forecast is from the 00Z 13 January 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across Norway, Siberia and the Tibetan Plateau while warm temperatures will support snowmelt in parts of Western Russia and Japan this period (**Figure 7**). Troughing and/or cold temperatures will support new snowfall across western Alaska, Western and Eastern Canada and the Northeastern US while warm temperatures will support snowmelt in southern Alaska and the Western US this period (**Figure 7**).

Mid Term

Week Two

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

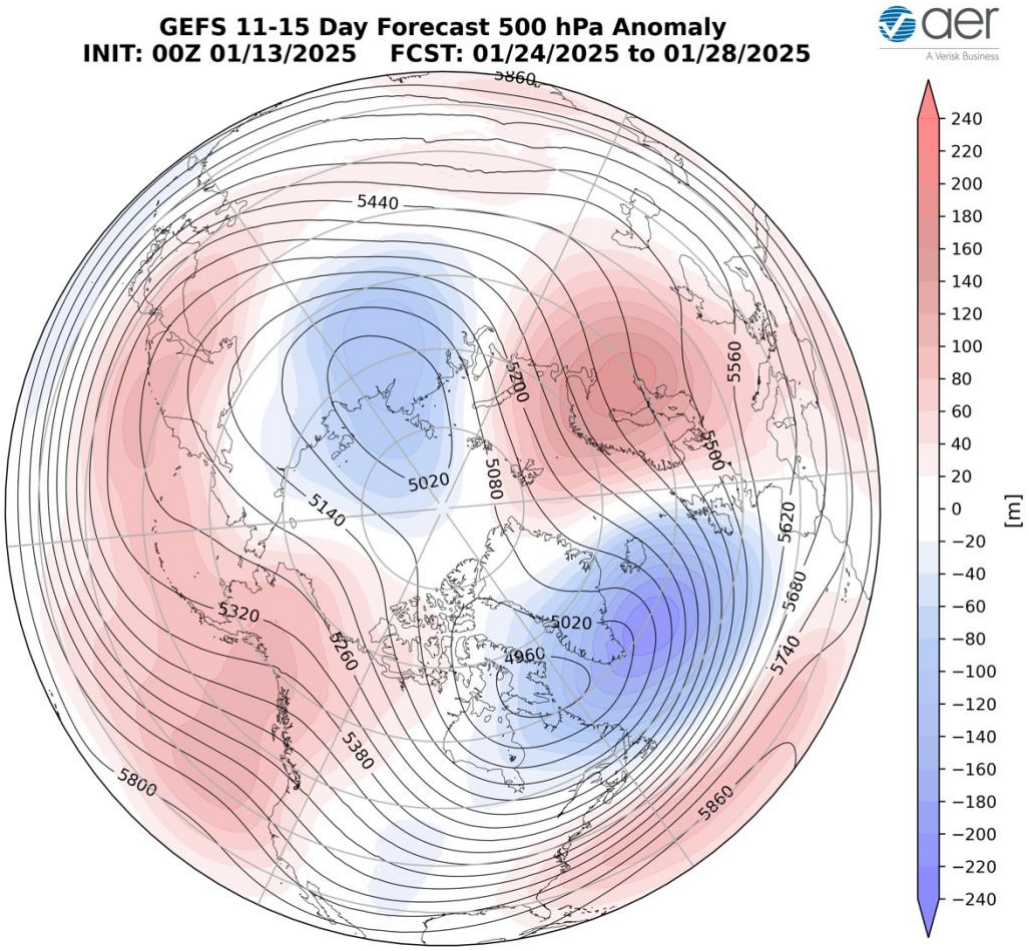

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 24 Jan to 28 Jan 2025. The forecasts are from the 00Z 13 January 2025 GFS ensemble.

Persistent troughing/negative geopotential height anomalies across Greenland is predicted to continue supporting ridging/positive geopotential height anomalies across Europe (**Figure 8**). This pattern should favor widespread normal to above normal temperatures across much of

Europe including the UK this period (**Figures 9**). The persistent ridging/positive geopotential height anomalies across Europe is predicted support deepening troughing/negative geopotential height anomalies across Siberia with ridging/positive geopotential height anomalies across Southern Asia this period (**Figure 8**). The predicted pattern favors widespread normal to above normal temperatures across much of Asia with normal to below normal temperatures expanding across Siberia this period (**Figure 9**).

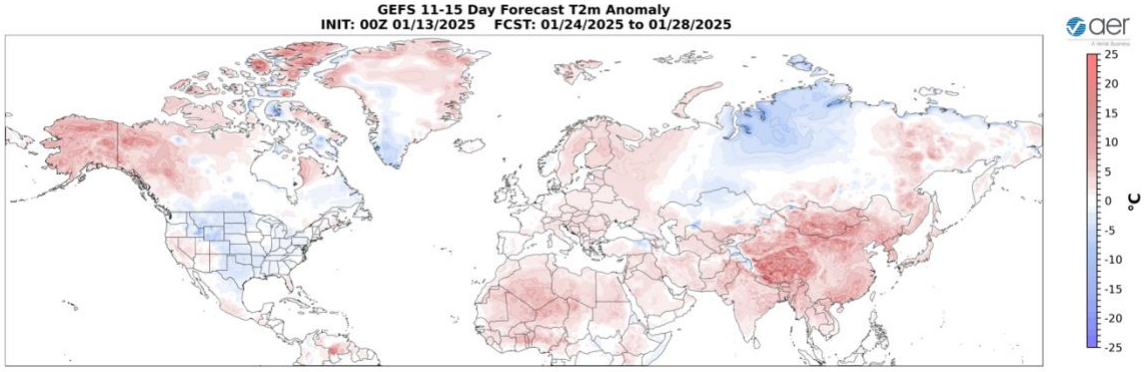

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 24 Jan to 28 Jan 2025. The forecast is from the 00Z 13 January 2025 GFS ensemble.

Ridging/positive geopotential height anomalies are predicted to persist across Alaska and the Gulf of Alaska supporting troughing/negative geopotential height anomalies across Eastern Canada and the Eastern US this period (**Figure 8**). Above normal temperatures will spread south and east out of Alaska into Western Canada and the Western US with normal to below normal temperatures will dominate across Canada and the US east of the Rockies this period (**Figure 9**).

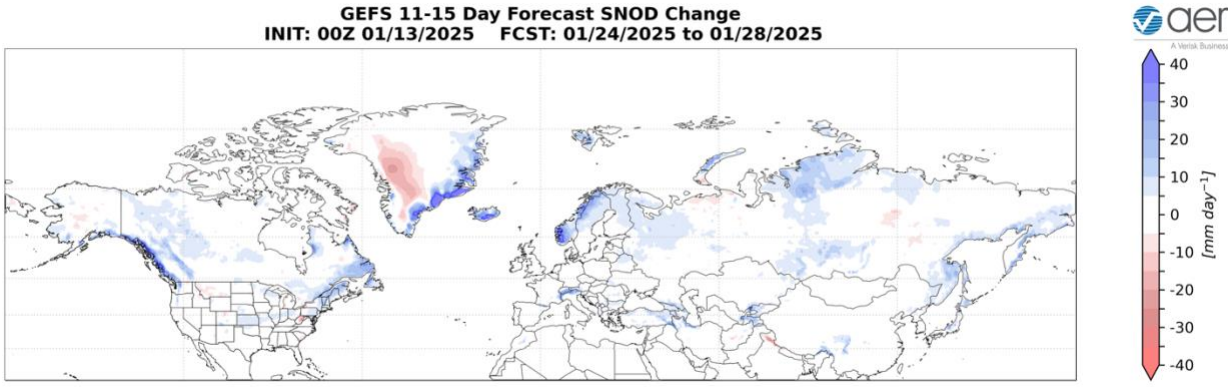

Figure 10. Forecasted snow depth changes (mm/day; shading) from 24 Jan to 28 Jan 2025. The forecast is from the 00Z 13 January 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across Scandinavia, Siberia, the Tibetan Plateau and Northeastern Asia while warm temperatures will support snowmelt in Southern Siberia this period (**Figure 10**). Troughing and/or cold temperatures will support new

snowfall across Western and Eastern Canada and the Northeastern US while warm temperatures will support snowmelt in the Appalachians 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 from the stratosphere are predicted to persist and strengthen the next two weeks while the warm/positive PCHs in the troposphere are predicted to alternate with cold/negative PCHs. 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 once again the strong PV is dominating high latitude blocking.

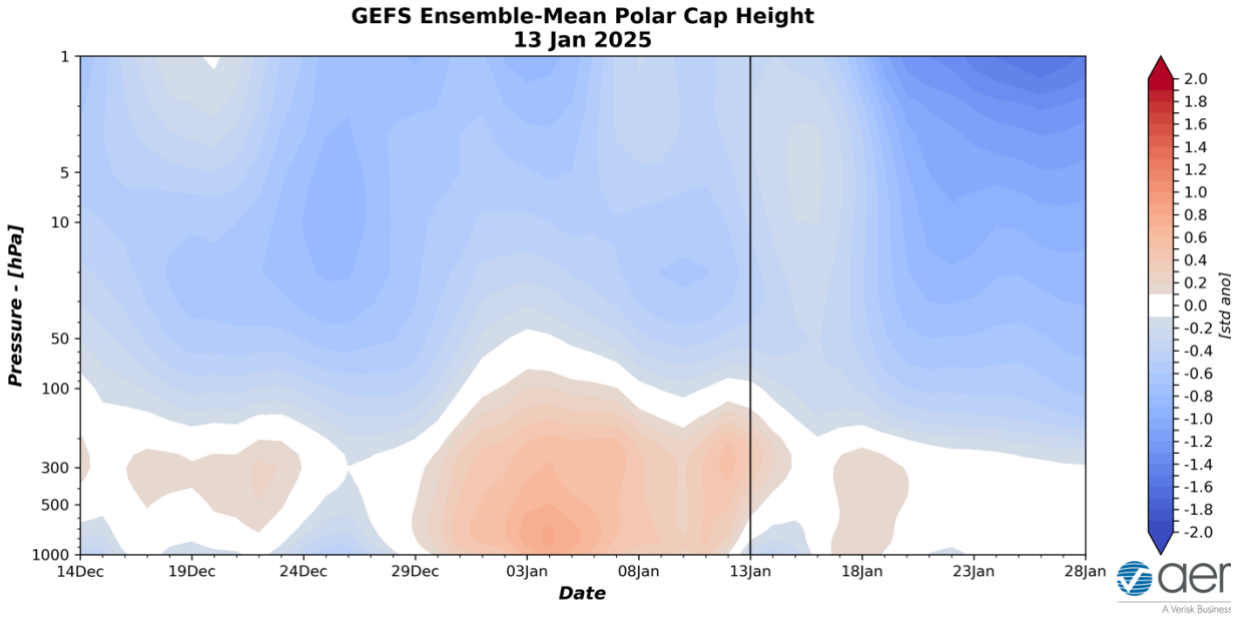

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 13 January 2025 GFS ensemble.

The predicted alternating warm/positive and cold/negative PCHs in the lower troposphere the next two weeks (**Figure 11**) are consistent with the predicted neutral to positive surface AO this week and next week (**Figure 1**). 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.

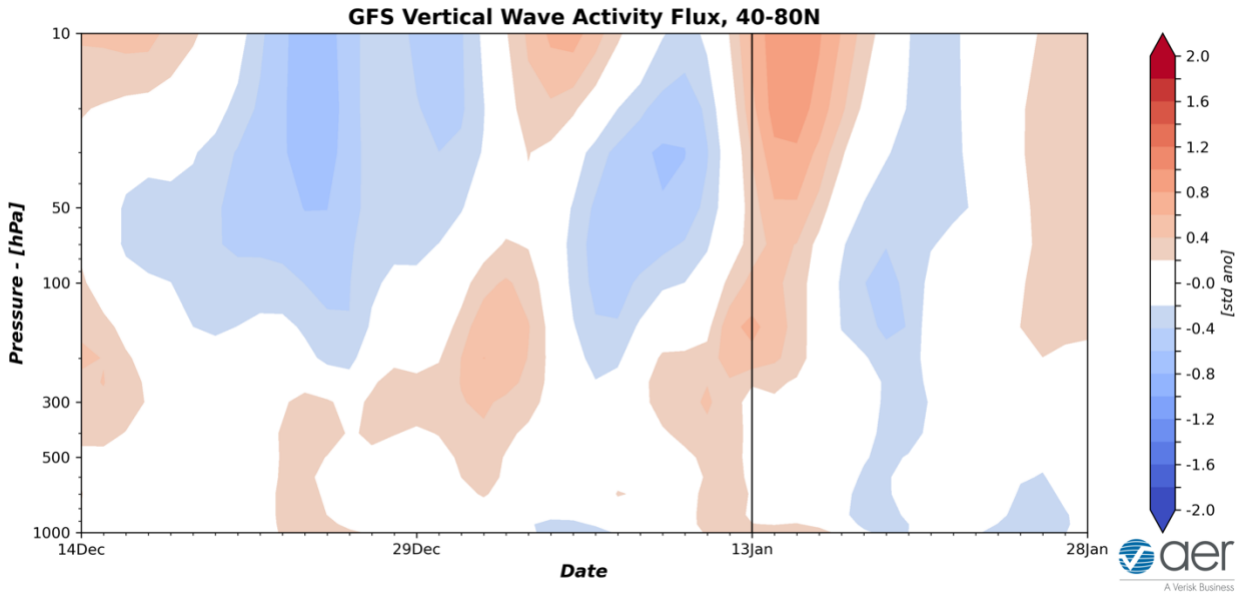

Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 13 January 2025 GFS ensemble.

Vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere has been relatively quiet this season (**Figure 12**). However, the alternating positive (red) and negative (blue) WAFz anomalies is predicted to continue for another two weeks and is characteristic of wave reflection associated with stretched PVs (**Figure 12**). What is unusual is the rapidity of the changes. The alternating anomalies of WAFz are predicted to continue through the end of January, signaling to me, at least two more stretched PVs for the second half of January.

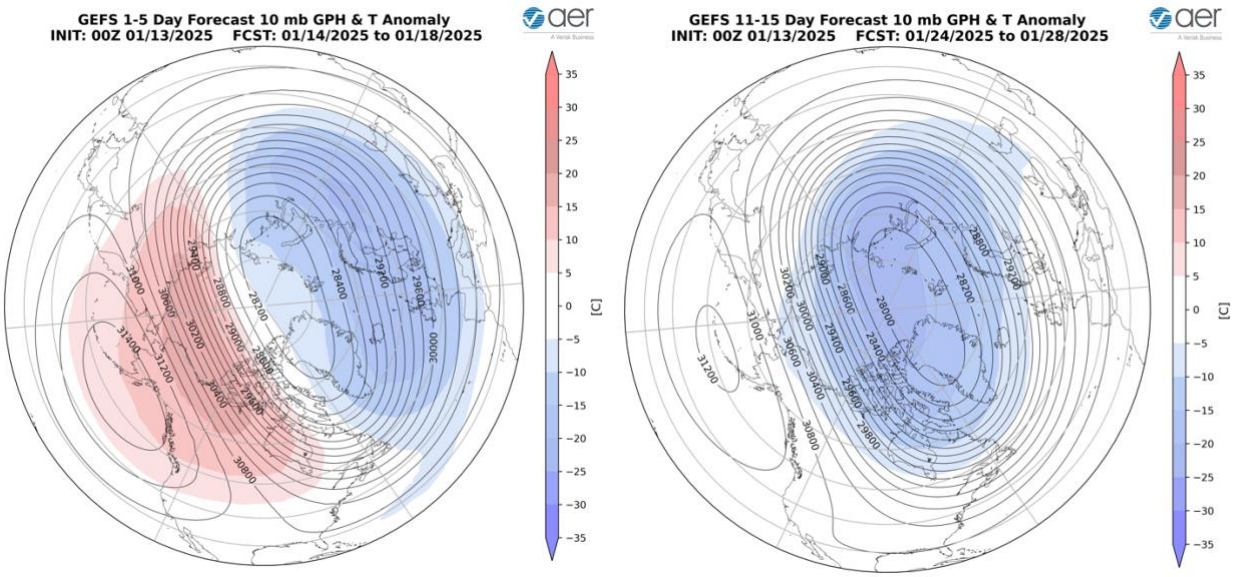

Figure 13. (a) Forecasted 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 19 Jan to 23 Jan 2025. (b) Same as (a) except forecasted averaged from 24 Jan to 28 Jan 2025. The forecasts are from the 00Z 13 January 2025 GFS model ensemble.

This week the polar vortex (PV) is predicted to move closer to Svalbard and become more elongated in shape with relatively coldest temperatures across the North Atlantic and Europe and across East Asia, the North Pacific and western North America in the polar stratosphere (**Figure 13a**). This is consistent with a yet another stretched PV (for those keeping score at home, the sixth of the season). The next week the PV is becoming more circular in shape as the PV comes out of the most recent stretched PV of mid-January. Then the PV is predicted yet again to become more elongated in shape with relatively coldest temperatures across the Arctic in the stratosphere (**Figure 13b**). For those keeping score at home, the seventh 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, and any cold air outbreaks should remain brief with each individual stretched PV event, on the order of a week or so.

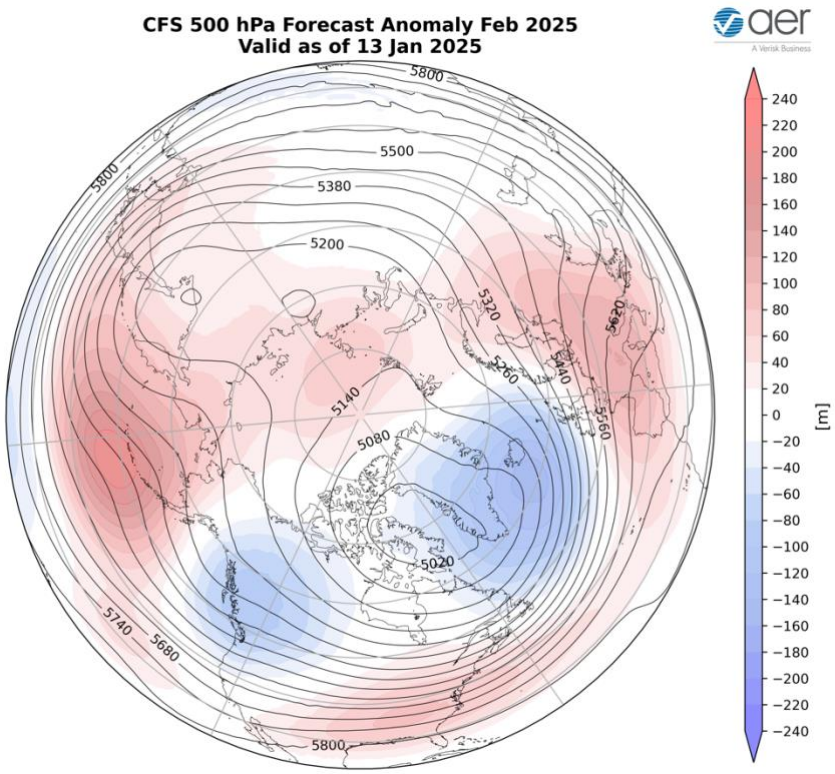

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for February 2025. The forecasts are from the 00Z 13 January 2025 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and surface temperatures for February (**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 Europe, the Laptev Sea, centered on the Dateline and into Eastern Siberia and the Southeastern US with troughing across Baffin Bay and Greenland, Northern and Eastern Asia, Western and the Western US (**Figure 14**). This pattern favors seasonable to relatively warm temperatures across Europe, much of Asia but especially Western and Northern Asia, Eastern Siberia and the Southern US with seasonable to relatively cold temperatures across Western Siberia, East Asia, Alaska, Western Canada and the Northwestern US (**Figure 15**).

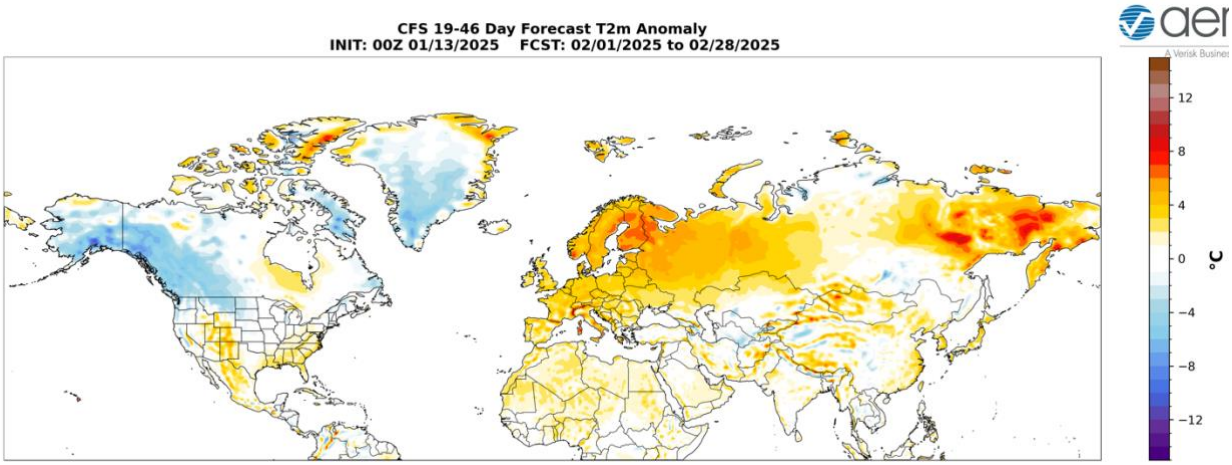

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for February 2025. The forecasts are from the 00Z 13 Jan 2025.

Boundary Forcings

Arctic Sea Ice

Sea ice growth continues relatively slowly with a larger negative anomaly in the North Atlantic sector compared to the North Pacific sector though reduced from during the fall (see **Figure 16**). This is important because it is the lack of sea ice in the Barents-Kara Seas that favors a weak PV and colder temperatures across the interior of the NH continents. The other region where sea ice is below normal is the Labrador Sea. The influence of sea ice on remote weather is likely waning.

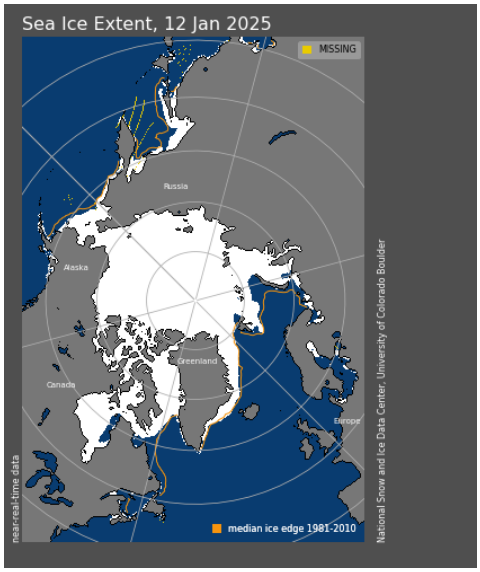

Figure 16. Observed Arctic sea ice extent on 12 January 2025 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image from the National Snow and Ice Data Center (NSIDC). URL: https://nsidc.org/sea-ice-today

SSTs/El Niño/Southern Oscillation

According to Jennifer Francis this plot has stopped updating.

Equatorial Pacific sea surface temperatures (SSTs) anomalies are below normal, between the Dateline and the South America coast, indicating that a La Niña event is emerging (**Figure 17**) and weak La Niña conditions are expected through the 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 do wonder 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.

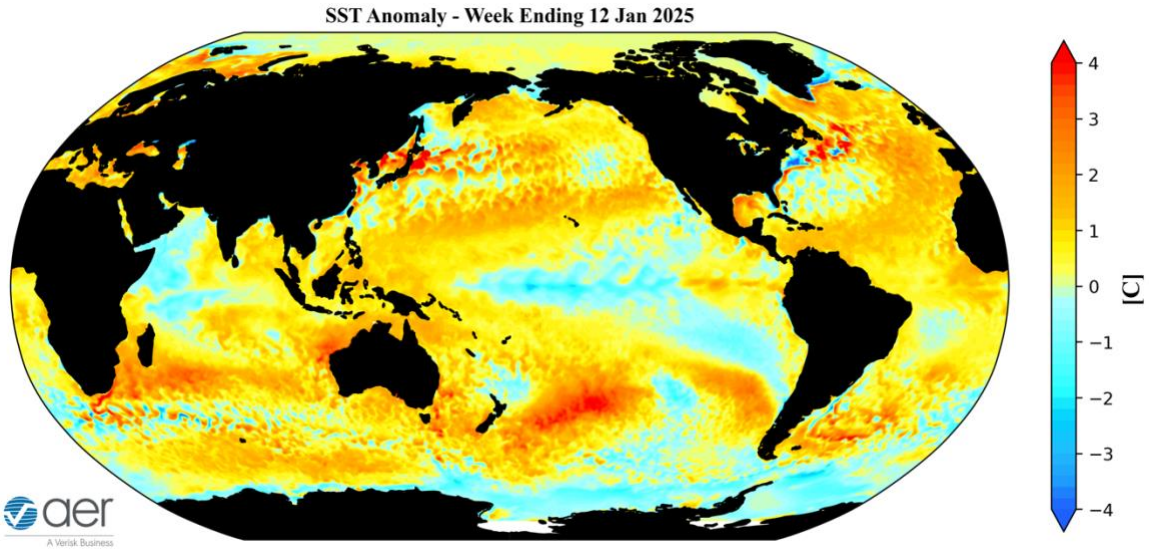

Figure 17. The latest daily-mean global SST anomalies (ending 12 Jan 2025). Data from NOAA OI High-Resolution dataset. Source https://psl.noaa.gov/map/clim/sst.shtml

Madden Julian Oscillation

Currently the Madden Julian Oscillation (MJO) is in phase one (**Figure 18**). The forecasts are for the MJO to through phases one, two and three and then weaken to where no phase is favored. Phase one favors ridging in the Western US and troughing in the Eastern US. However, phases two and three favor the opposite with ridging in the Eastern US and troughing in the Western US. 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.

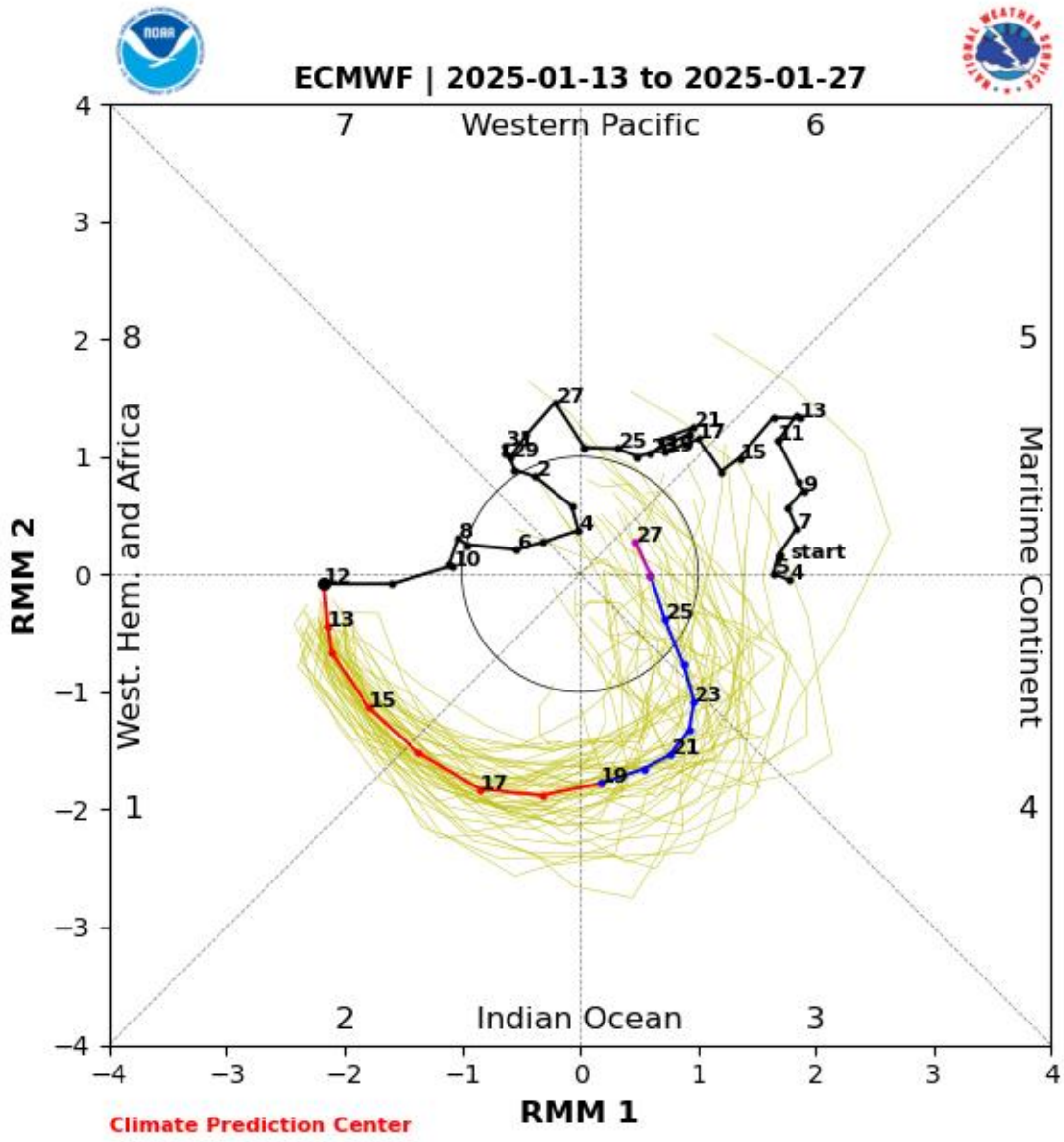

Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 06 January 2025 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model 'spread' is denoted by the gray shading. Sector numbers indicate 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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