

Arctic Oscillation and Polar Vortex Analysis and Forecasts

December 2, 2024

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 close to neutral the next two weeks as pressure/geopotential height anomalies across the Arctic are currently mostly negative and are predicted to turn mixed to mostly positive over the next two weeks. The North Atlantic Oscillation (NAO) is currently near neutral with mixed to weakly negative pressure/geopotential height anomalies across Greenland and the NAO is predicted to remain near neutral to positive the next two weeks as pressure/geopotential height anomalies are predicted to remain mostly mixed to negative across Greenland.
- This week support troughing/negative geopotential height anomalies across Greenland will favor ridging/positive geopotential height anomalies across Europe however next week ridging/positive geopotential height anomalies in the Central North Atlantic will support troughing/negative geopotential height anomalies across Western Europe with persistent ridging/positive geopotential height anomalies across Eastern Europe. This pattern will support mostly normal to above normal temperatures across much of Europe including the United Kingdom (UK) this week. However next week normal to below normal temperatures will spread across Western Europe including the UK with normal to above normal temperatures continuing across Eastern Europe.
- The next two weeks two areas of ridging/positive geopotential height anomalies are

predicted with one center near the Urals and a second in Eastern Siberia, with troughing/negative geopotential height anomalies first across East Asia and then next week also across Central Asia. This pattern favors widespread normal to above normal temperatures across much of Asia, with regional normal to below normal temperatures first across East Asia and then including Central Asia.

- The general pattern across North America is ridging/positive geopotential height anomalies centered in Alaska, Western Canada and the Western United States (US) and then next week will slide into the Gulf Alaska will support troughing/negative geopotential height anomalies across Eastern Canada and the Eastern US but is predicted to slide west with time. This pattern favors normal to above normal temperatures extending from Alaska across Western Canada and the Western US with normal to below normal temperatures across Central and Eastern Canada and the Eastern US. However next week temperatures are predicted to turn milder across much of the US with normal to below normal temperatures mostly confined to Western Canada
- The battle continues and in the Impacts section I discuss the competing influences of a strong polar vortex (PV) and high latitude blocking on the upcoming weather in the Northern Hemisphere (NH).

Plain Language Summary

Two stretched polar vortices are in the books and a third is looking increasingly likely mid-month. The first we are bringing cold weather to the Eastern US (see **Figures 3 & 6**). An interlude of a strong polar vortex favors a milder pattern mid-month but could bring colder temperatures first to East Asia and then the US. Western Europe will turn colder next week thanks to mid-oceanic ridging of the atmospheric kind in the North Atlantic (see **Figures 6 & 9**). Longer term is it “rinse, lather, repeat” or more durable cold or mild weather?

Impacts

This week I will start of discussing Arctic Sea Ice Extent (SIE). I posted the AER winter forecast in last week’s blog and then posted an update on Saturday night. The update switched out September pan-Arctic SIE with my estimate of October Barents-Kara SIE. The latter index has a stronger relationship with Northern Hemisphere (NH) winter surface temperatures, and I believe is a better indicator of the strength of the polar vortex (PV). Sea ice growth continues to occur preferentially in the North Pacific sector relative to the North Atlantic sector and the large negative anomaly in the North Atlantic sector compared to the North Pacific sector remains clearly dominant, with sea ice in the North Pacific close to normal (see **Figure i**). 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. This resulted in the updated temperature forecast being colder than the initial forecast. The other region where sea ice is below normal is around Greenland and into Hudson Bay. It appears to me that sea ice anomalies

are evolving that are most favorable for supporting colder weather not only across Eurasia but possibly even the US. Whether it be Ural/Barents-Kara Seas or Greenland blocking.

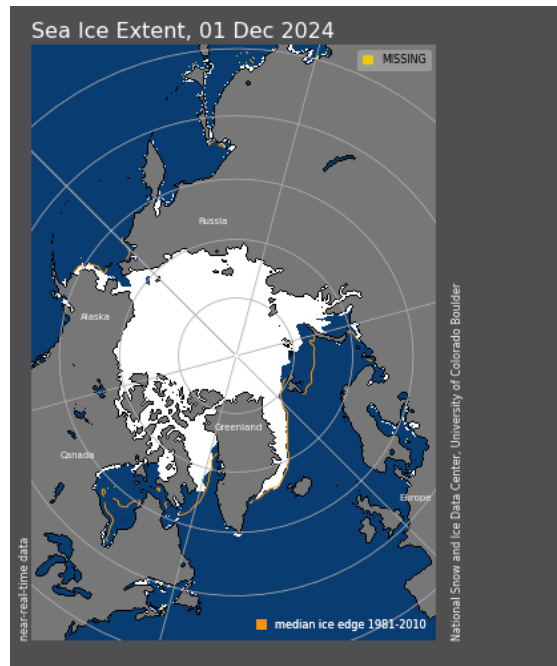


Figure i. Observed Arctic sea ice extent on 02 December 2024 (white). Orange line show climatological extent of sea ice based on the years 1981-2010. Image from the National Snow and Ice Data Center (NSIDC). URL: <https://nsidc.org/sea-ice-today>.

I have been wondering if the low sea ice in the Barents-Kara Seas could contribute to more persistent ridging in the region. So far, any Ural blocking has been transient, enough to trigger a stretched PV but relatively weak ones. So, if Ural blocking does return later this month or even early January, could the low sea ice anchor the blocking/region overhead and force a weaker PV and even an SSW? Models have been playing now you see it, now you don't with both Ural blocking (with the GFS most aggressive with Ural blocking) and Greenland blocking (with the ECMWF most aggressive with Greenland blocking). But to the GFS credit, it has been more consistent with Ural blocking than the ECMWF with Greenland blocking.

In the fall and December months, PV disruptions almost exclusively mean a stretched PV as sudden stratospheric warmings (SSWs) don't really happen until January with some notable exceptions (the last was December 2000). This winter so far, the main theme has been this cycle of repeating stretching and more circular PV. We had our first stretched PV in late November and now a second one in early December and hence the very cold first week predicted in early December for North America (see **Figures 3 and 6**). Stretched PVs bring cold and snow to East Asia and North America while the relationship to Europe is weak. That is why both East Asia and the US have been experiencing cold and snow last and this week while Europe has been overall milder. For those who didn't hear, Seoul, Korea had a record snowstorm late last week (story from [The Guardian](#)).

For Europe, the biggest driver of severe winter weather is Greenland blocking. The models are predicting ridging in the North Atlantic to emerge next week that will bring some colder air to Western Europe (see **Figures 5** and **6**). North Atlantic ridging might be a relative of Greenland blocking but does not deliver the same level of cold and snow as Greenland blocking.

We have one stretched PV ongoing and then at the very end of the latest PV animation it does appear, yet another stretched PV predicted will occur the third week of December (see **Figure ii**). This is bringing the colder air into the US in waves with lots of large swings in the temperatures. As I have been saying the impact from stretched PVs is relatively short on the order of days to up to two weeks, especially when the PV remains strong during the stretch, and the PV is strong (see **Figure 1**). So, the cold should abate in the Eastern US next week with a milder pattern setting up for mid-month. Usually, the cold in East Asia precedes the cold in the US and therefore we can already see the reloading of cold air in East Asia but not the US in the 11-15 day forecast (see **Figure 9**).

Initialized 00Z 10 hPa HGT/HGTa 02-Dec-2024

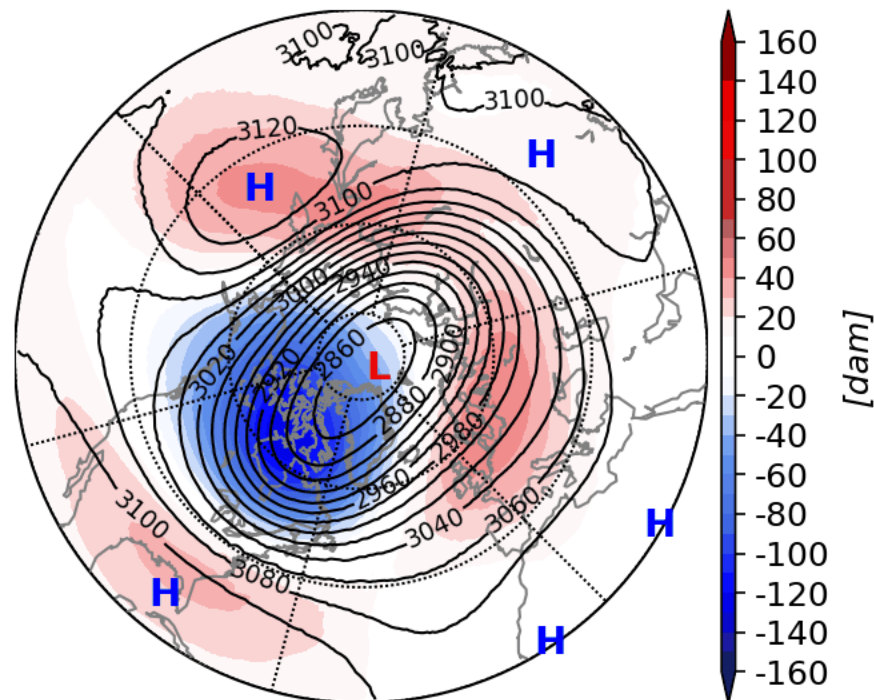


Figure ii. Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere for 02 December 2024 and forecasted from 03 December to 17 December 2024. The forecasts are from the 00Z 02 December 2024 GFS model ensemble.

What happens in the US as we approach the holiday season is highly uncertain. As far as I can tell the weather models are predicting the remainder of December to remain mild with any cold air entering the US the second half of December remaining in the Western US. Our research (not published but currently under review) shows two flavors of stretched PVs one where the cold is focused in the Central and Eastern US (the more classical type) and one where the cold is focused in the Western US. Based on the model forecasts it seems to me that the weather models are predicting the mid-December stretched PV to be the type where the cold is focused in the Western US. But by comparing the polar stratosphere forecasts with our own analysis, I do think that the stretched PV will eventually evolve or transition to a stretched PV that does deliver the cold air to the US east of the Mississippi (all the way to the East Coast I have greater doubts but could) during the holiday season.

This next bit is somewhat esoteric, but I have shown the energy propagation diagnostics during past stretched PV events. One of the more classical signs of a stretched PV is wave reflection where the wave energy goes up over Asia, reflects off the polar vortex (and helps build a ridge both in the stratosphere and the troposphere near Alaska (near 150°W) and then goes down over North America helping to deepen a trough near 80-70°W (or the Eastern Canada and US see **Figure iii**). Hence stretched PVs are also referred to as wave reflection events. The energy diagnostics can be quite volatile so certainly plausible the observed energy diagnostics turn out to be a lot different, but to me that forecast plot looks classical.

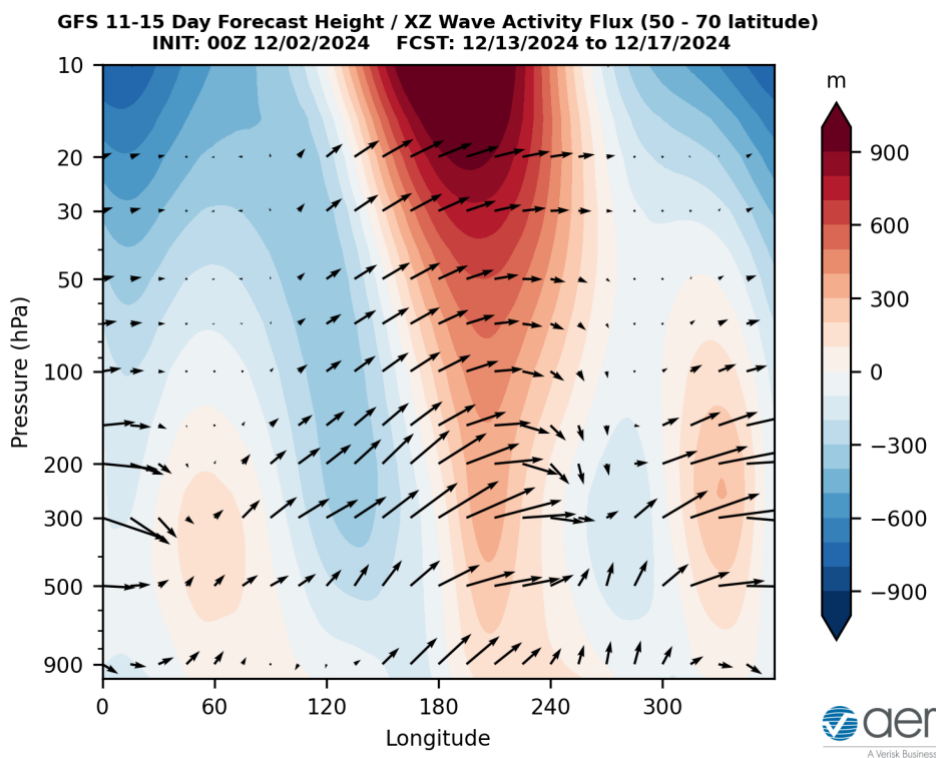


Figure iii. Longitude-height cross section of geopotential eddy height anomalies (shading) and wave activity flux (vectors) forecasted for 13 December through 17 December 2024. The forecasts are from the 00z 2 December 2024 GFS ensemble.

Besides the question if there is cold air in Western Canada the third week of December (ECMWF is most aggressive and the GFS is what cold air?) does it dump into the Western US and hang out there or moves steadily eastward or does it enter into the Northern Plains and then steadily slides east from there are important unanswered questions. But even longer term what happens next? Is it just more of “rinse, lather repeat” and we continue this merry go-round of strong circular PV and mild weather quickly followed by a strong elongated PV and colder weather. Or alternatively do we eventually transition to a much larger PV disruption and eventually a more durable cold more akin to a sudden stratospheric warming or yet a third possibility of a runaway strong PV a positive surface AO and a long duration mild pattern? I think this is strongly dependent on high latitude blocking especially near the Urals and Barents-Kara seas. For now, we have to patiently wait and see as the models are struggling mightily with correctly resolving the high latitude blocking so far this winter. And yet for one more week the stratosphere and troposphere appear to be uncoupled (see **Figure 11**) at least from a framework of polar cap geopotential heights.

Near-Term

This week

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

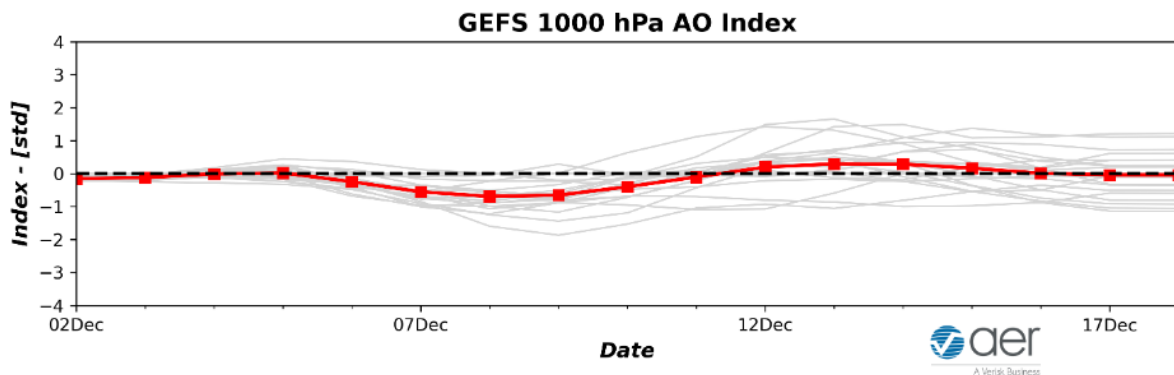
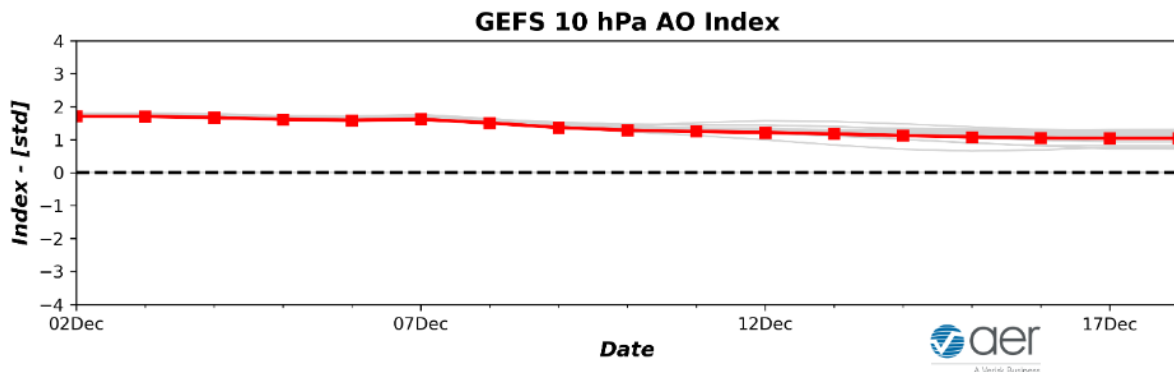


Figure 1. a) The predicted daily-mean AO at 10 hPa from the 00Z 02 December 2024 GFS ensemble. b) The predicted daily-mean AO at 1000 hPa from the 00Z 02 December 2024 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble mean AO index given by the red line with squares.

This week, weak toughing/negative geopotential height anomalies across Greenland will support ridging/positive geopotential height anomalies across much of Europe (**Figure 2**). This pattern will favor normal to above normal temperatures across much of Europe including the UK with the possible exception of normal to below normal temperatures in Norway due to some weak troughing across the region (**Figure 3**). This week the predicted pattern across Asia is ridging/positive geopotential height anomalies centered over Western Russia and Eastern Siberia with toughing/negative geopotential height anomalies across East Asia and the eastern Mediterranean (**Figure 2**). This pattern favors normal to above normal temperatures widespread across much of Asia with normal to below normal temperatures limited to parts of China and the Middle East (**Figure 3**).

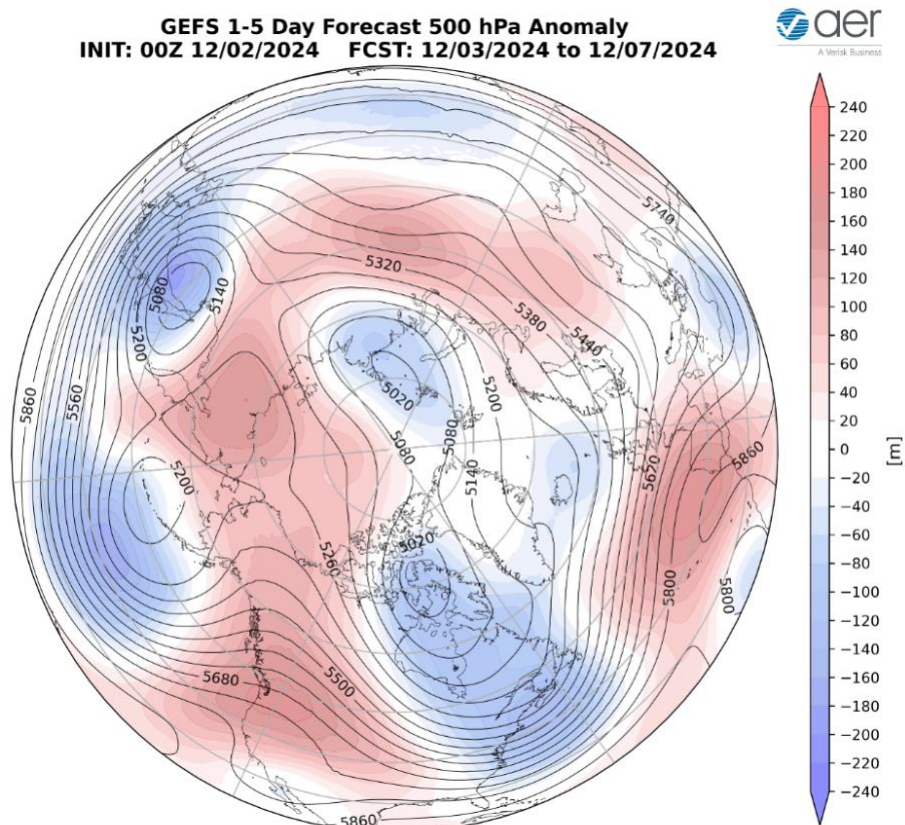


Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 03 Dec to 07 Dec 2024. The forecasts are from the 00Z 02 December 2024 GFS ensemble.

This week ridging/positive geopotential height anomalies across Alaska, Western Canada and the Western US will force troughing/negative geopotential height anomalies across Central and Eastern Canada and the Eastern US. (**Figure 2**). This pattern will favor normal to above normal temperatures across Alaska, Western Canada and the Western US with normal to below normal temperatures across Central and Eastern Canada and the Eastern US (**Figure 3**).

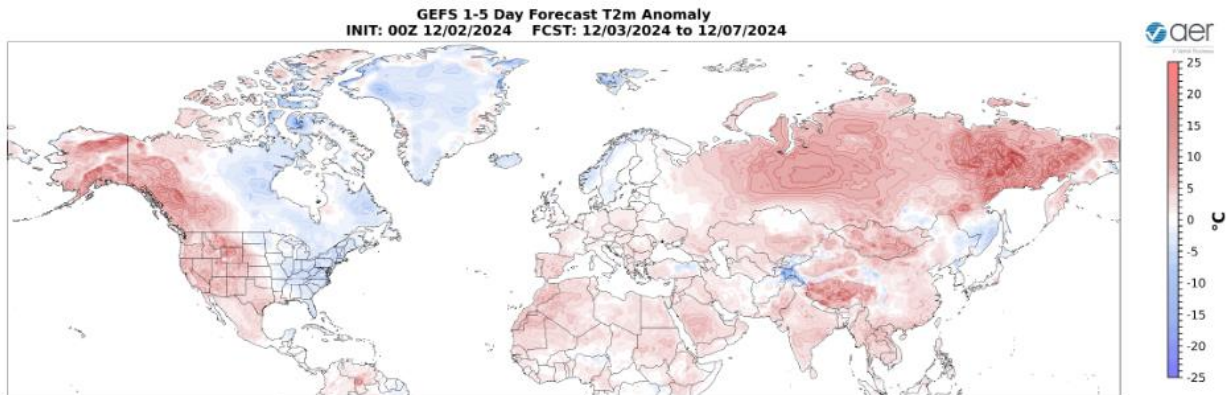


Figure 3. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 03 Dec to 07 Dec 2024. The forecast is from the 00Z 02 December 2024 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across Norway, the Urals, parts of Siberia and Northeast China while warm temperatures will support snowmelt in Western Siberia this week (**Figure 4**). Troughing and/or cold temperatures will support new snowfall across Northern and Eastern Canada and the Northeastern US while warm temperatures will support snowmelt in Western Canada and the higher elevations of the Western US this week (**Figure 4**).

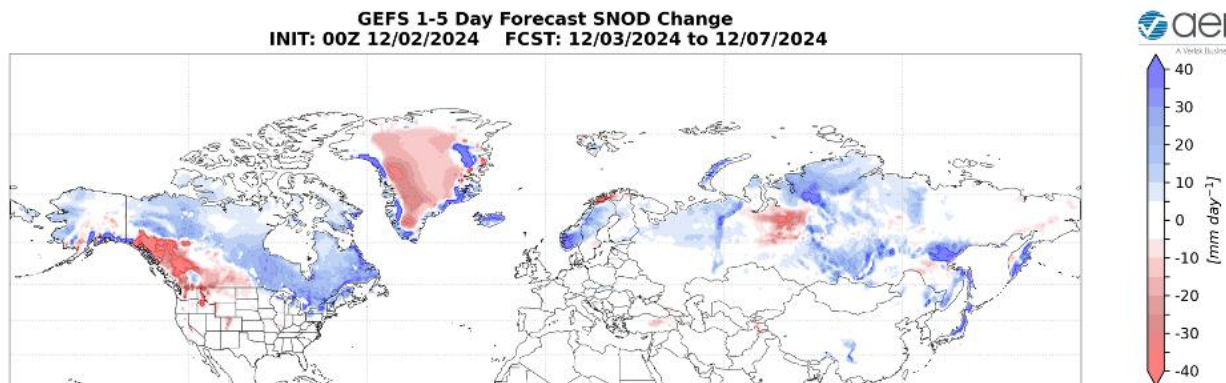


Figure 4. Forecasted snow depth changes (mm/day ; shading) from 03 Dec to 07 Dec 2024. The forecast is from the 00Z 02 December 2024 GFS ensemble.

Near-Mid Term

Next week

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

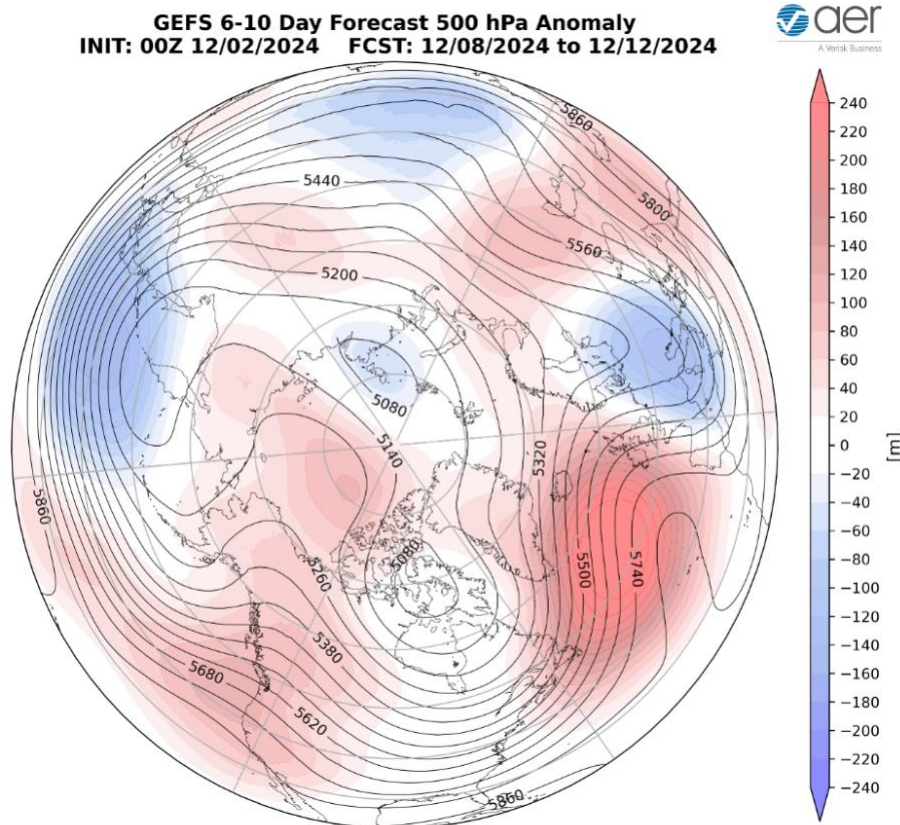


Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 08 Dec to 12 Dec 2024. The forecasts are from the 00Z 02 December 2024 GFS ensemble.

Predicted ridging/positive geopotential height anomalies centered in the North Atlantic will support troughing/negative geopotential height anomalies across Western Europe with ridging/positive geopotential height anomalies across far Eastern Europe this period (**Figure 5**). This pattern will favor normal to below normal temperatures across Western Europe including the southern UK with normal to above normal temperatures across Eastern Europe this period (**Figure 6**). The predicted pattern across Asia is ridging/positive geopotential centered over Western Asia and Eastern Siberia forcing troughing/negative geopotential height anomalies across Central and far East Asia (**Figure 5**). This pattern favors widespread normal to above normal temperatures across much of Asia with normal to below normal temperatures limited to parts of Central and East Asia (**Figure 6**).

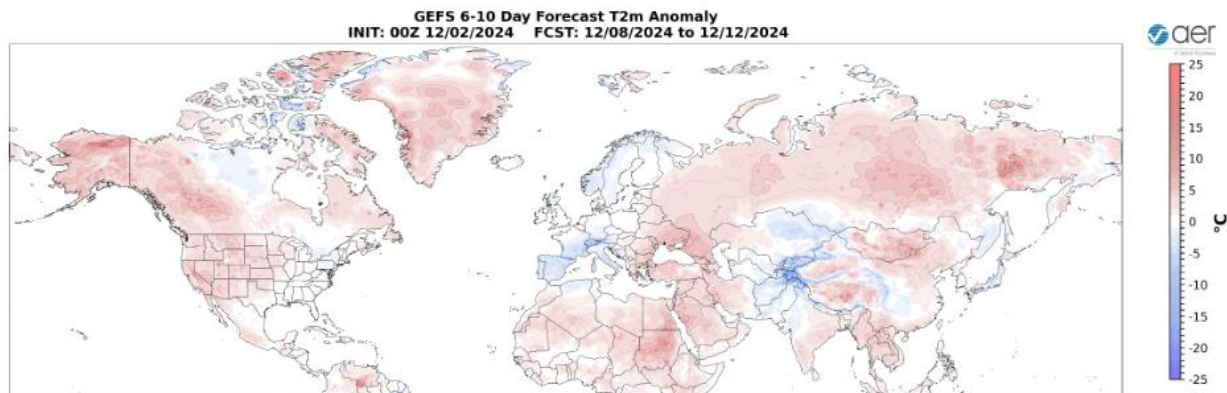


Figure 6. Forecasted surface temperature anomalies (°C; shading) from 08 Dec to 12 Dec 2024. The forecast is from the 00Z 02 December 2024 GFS ensemble.

Persistent ridging/positive geopotential height anomalies across Alaska, Western Canada and the Western US will continue to support troughing/negative geopotential height anomalies across Eastern Canada and the Eastern US with more ridging/positive geopotential height anomalies across Northeastern Canada and Baffin Bay this period (**Figure 5**). This pattern will favor normal to above normal temperatures across Alaska, Western and Northeastern Canada and the Western US with normal to below normal temperatures across Central Canada and the Eastern US (**Figure 6**).

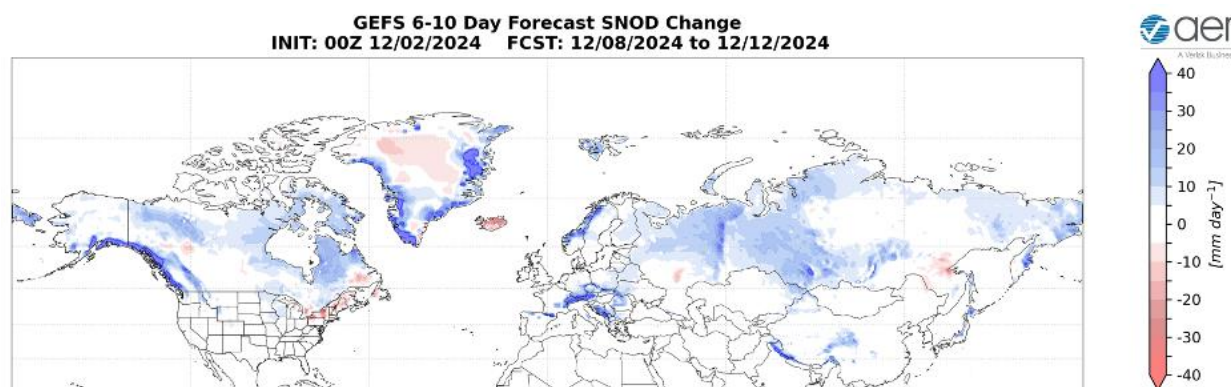


Figure 7. Forecasted snow depth changes (mm/day; shading) from 08 Dec to 12 Dec 2024. The forecast is from the 00Z 02 December 2024 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across Norway, the Alps, the Pyrenees, the Balkans, the Urals, Western and Eastern Siberia, the Tibetan Plateau and Hokkaido while warm temperatures will support snowmelt in southeastern Siberia this period (**Figure 7**). Troughing and/or cold temperatures will support new snowfall across southern Alaska, the West coast mountains of Canada, Northern and Eastern Canada and the Northwestern US while warm temperatures will support snowmelt in the Northeastern US this period (**Figure 7**).

Mid Term

Week Two

With predicted mostly mixed geopotential height anomalies across the Arctic and mixed geopotential height anomalies across the mid-latitudes this period (**Figure 8**), the AO will likely persist near neutral (**Figure 1**). With predicted weak and mixed pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO will likely remain relatively close to neutral this period.

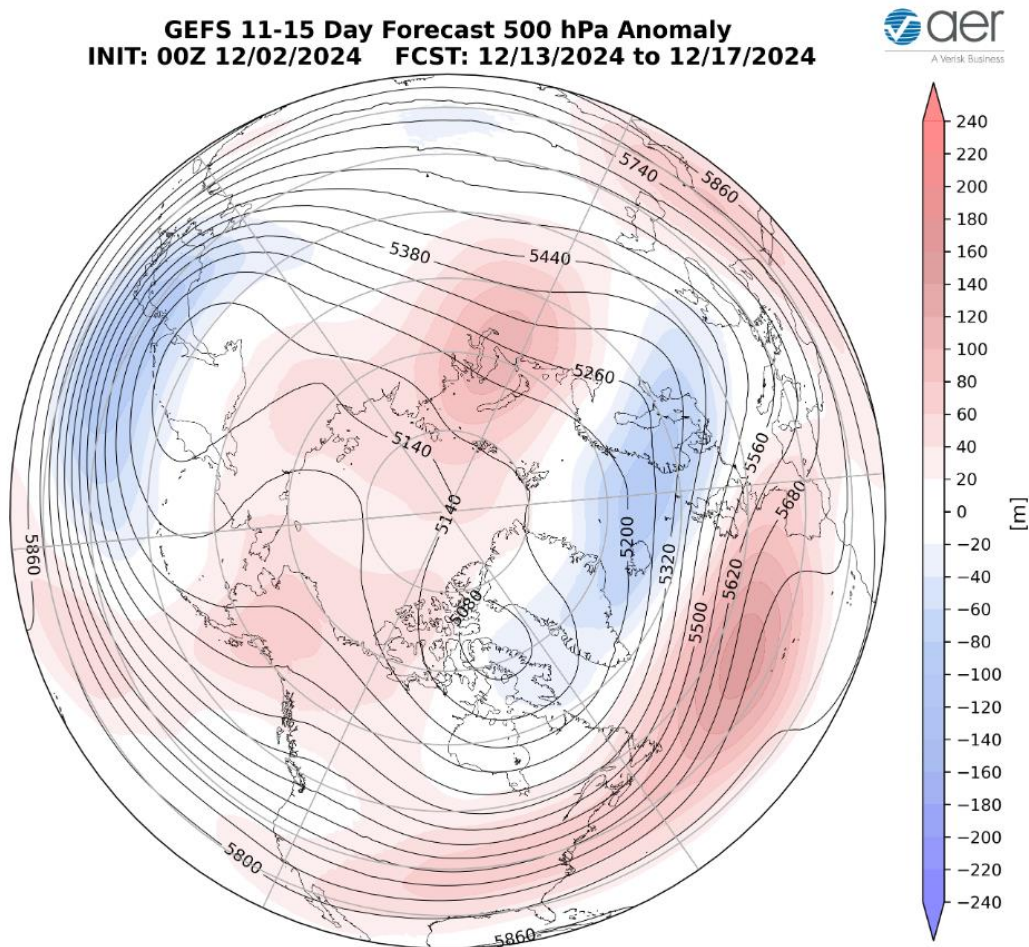


Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 13 Dec to 17 Dec 2024. The forecasts are from the 00Z 02 December 2024 GFS ensemble.

Persistent ridging/positive geopotential height anomalies in the North Atlantic is predicted to support weak troughing/negative geopotential height anomalies persisting in Western Europe with weak ridging/positive geopotential height anomalies in Eastern Europe (**Figure 8** but I did follow the ECMWF forecast here). This pattern should favor normal to below normal temperatures across Western Europe including the UK with normal to above normal

temperatures across Eastern Europe this period (**Figure 9**). The predicted pattern across Asia this period is ridging/positive geopotential height anomalies centered on the Urals forcing troughing/negative geopotential height anomalies across East 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 limited to Western Siberia and extending into parts of East Asia this period (**Figure 9**).

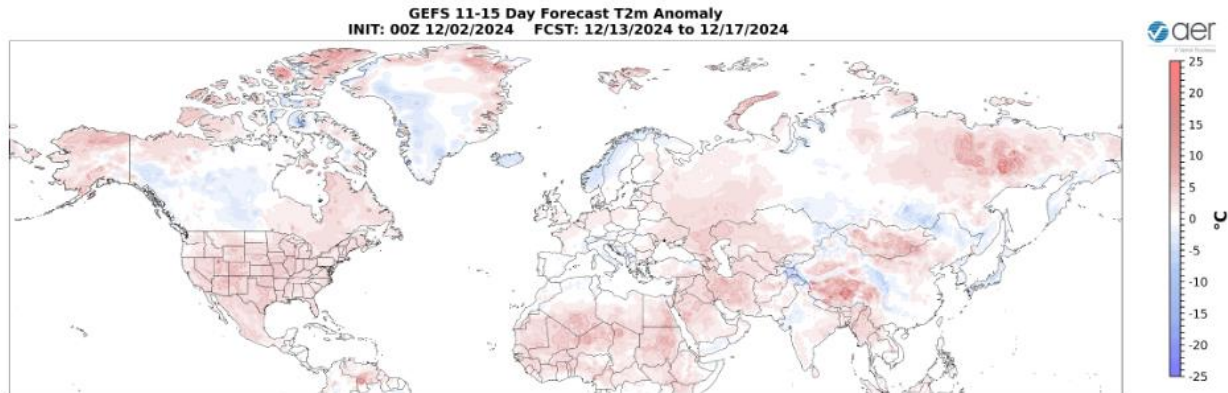


Figure 9. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 13 Dec to 17 Dec 2024. The forecast is from the 00Z 02 December 2024 GFS ensemble.

Ridging/positive geopotential height anomalies are predicted to persist across Alaska and the Gulf of Alaska and for much of the US supporting troughing/negative geopotential height anomalies across Western Canada this period (**Figure 8**). This pattern will favor widespread normal to above normal temperatures across much of Alaska, Eastern Canada and the much of the US with normal to below normal temperatures mostly limited to Western Canada this period (**Figure 9**). Though it does seem that the cold air in Western Canada is poised to move south into the US Northern Plains.

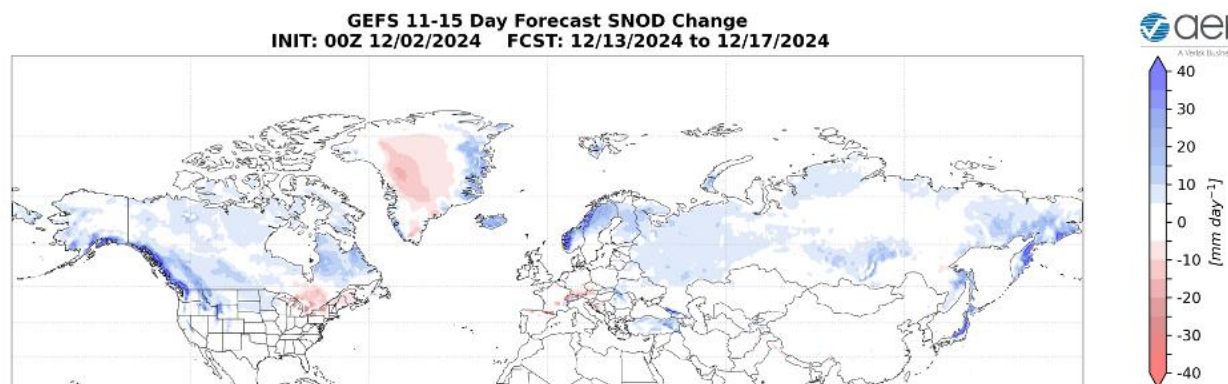


Figure 10. Forecasted snow depth changes (mm/day ; shading) from 13 Dec to 17 Dec 2024. The forecast is from the 00Z 02 December 2024 GFS ensemble.

Trouching and/or cold temperatures will support new snowfall across Scandinavia, the Caucasus, Western Russia, Eastern Siberia and parts of Northeast Asia this period (**Figure 10**). Trouching and/or cold temperatures will support new snowfall across Alaska, much of Canada and the US Northern Plains while warm temperatures will support snowmelt in Ontario and the Northeastern US in this period (**Figure 10**).

Longer Term

30-day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows normal to warm/positive PCHs in the troposphere with cold/negative PCHs in the stratosphere (**Figure 11**). This contrast between cold/negative PCHs in the stratosphere and warm/positive PCHs are predicted in the troposphere is predicted to last at least for the next two weeks (**Figure 11**). For now, this suggests that the stratosphere and troposphere are uncoupled but that could change with time.

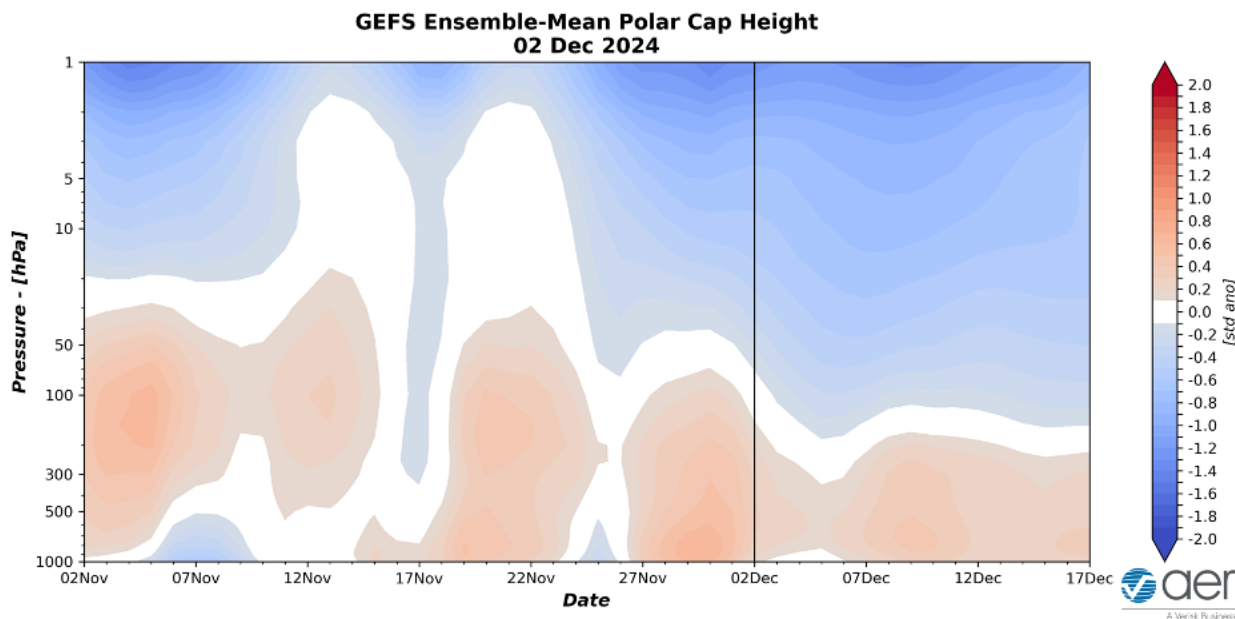


Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 02 December 2024 GFS ensemble.

The predicted neutral to warm/positive PCHs in the lower troposphere the next two weeks (**Figure 11**) are consistent with the predicted neutral to negative surface AO the next two weeks (**Figure 1**). However, as we head into late December, I believe there is much uncertainty and coupling with the cold/negative stratospheric PCHs with the troposphere could force a more positive AO. However based on the latest PCH forecast with the very deep cold/negative PCHs in the stratosphere weakening in mid-December, I do think that this scenario is not as likely as the past several weeks.

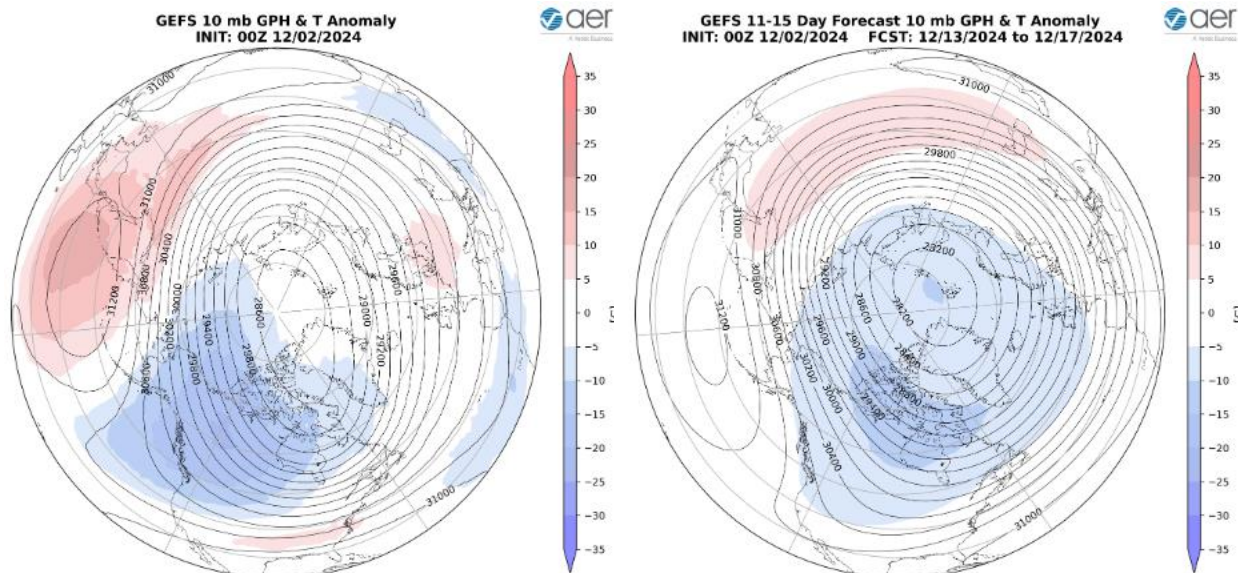


Figure 12. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 02 December 2024. (b) Same as (a) except forecasted averaged from 13 Dec to 17 Dec 2024. The forecasts are from the 00Z 02 December 2024 GFS model ensemble.

This week the polar vortex (PV) is predicted to be elongated in shape with the PV center near the North Pole with relatively cold temperatures focused in Western Canada with warm temperatures sweeping out of Asia towards the Dateline (**Figure 12a**). This is consistent with a stretched PV configuration. This is related to the cold air outbreak and record snowfalls in Northeast Asia and the flow of cold air out of Canada to the US. Then, in mid-December the PV center is predicted to move closer to Svalbard and once again become more elongated in shape with relatively cold temperatures concentrated in Canada in the polar stratosphere (**Figure 12b**). This is consistent with yet another stretched PV (for those keeping score at home, the third of the season). I included the stratospheric AO in **Figure 1** this week to show despite the repeated stretched PVs overall the PV remains strong, and any cold air outbreaks should remain brief with each individual stretched PV event.

**CFS 500 hPa Forecast Anomaly Jan 2025
Valid as of 02 Dec 2024**

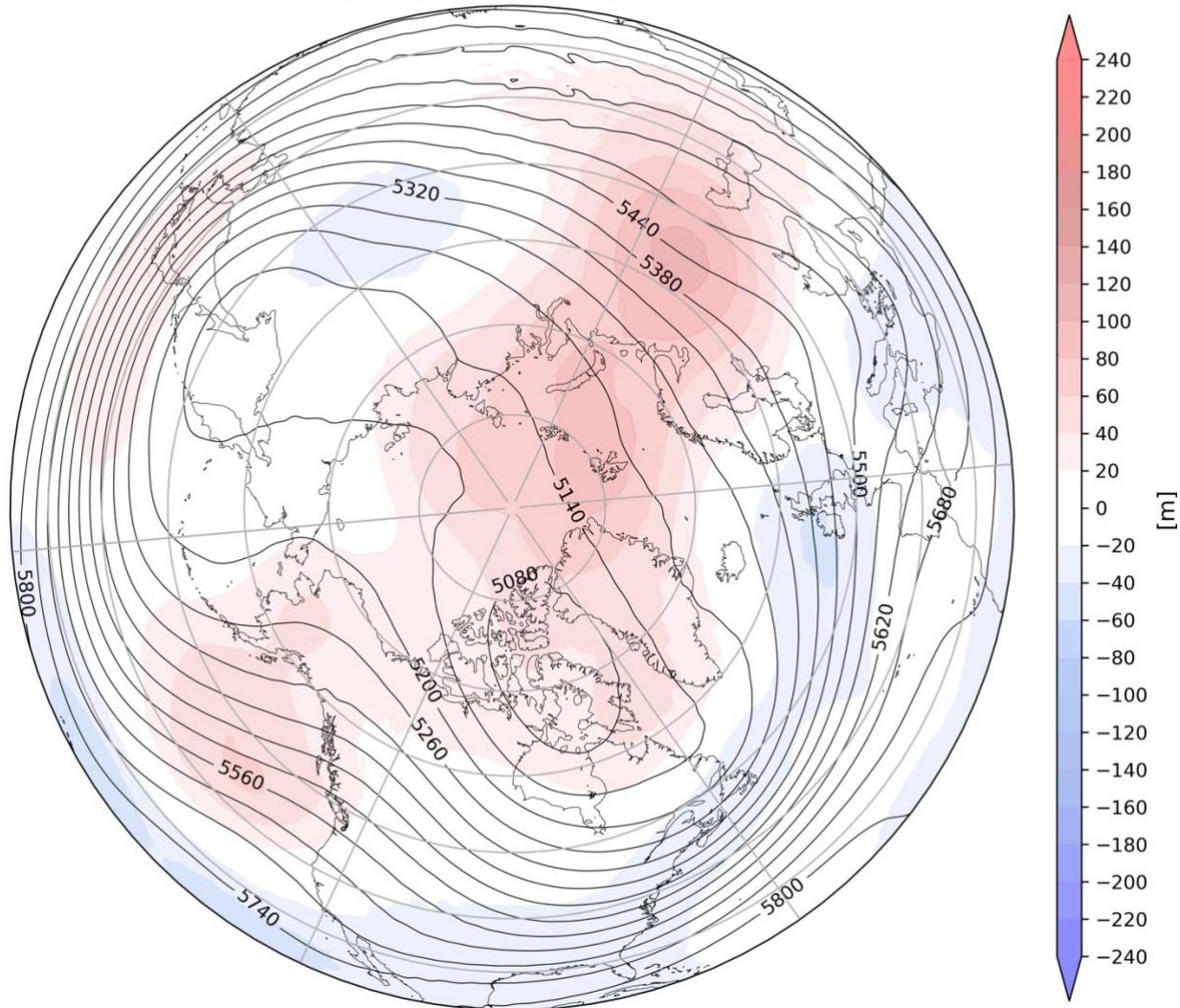


Figure 13. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for January 2024. The forecasts are from the 00Z 02 December 2024 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 13**) and surface temperatures for January (**Figure 14**) from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging across the Urals and the Barents-Kara Seas, the Gulf of Alaska extending into Alaska, Western Canada and the Western US with troughing across Northwestern Europe and extending into Southeastern Europe and the eastern Mediterranean, Northeast Asia extending to the Dateline, Eastern Canada and the Eastern US (**Figure 13**). This pattern favors seasonable to relatively warm temperatures across much of Europe, Western and Southern Asia, Alaska, Western Canada and the Western US with seasonable to relatively cold temperatures across Western Siberia and Northeast Asia, Central and Southeastern Canada and the Eastern US (**Figure 14**).

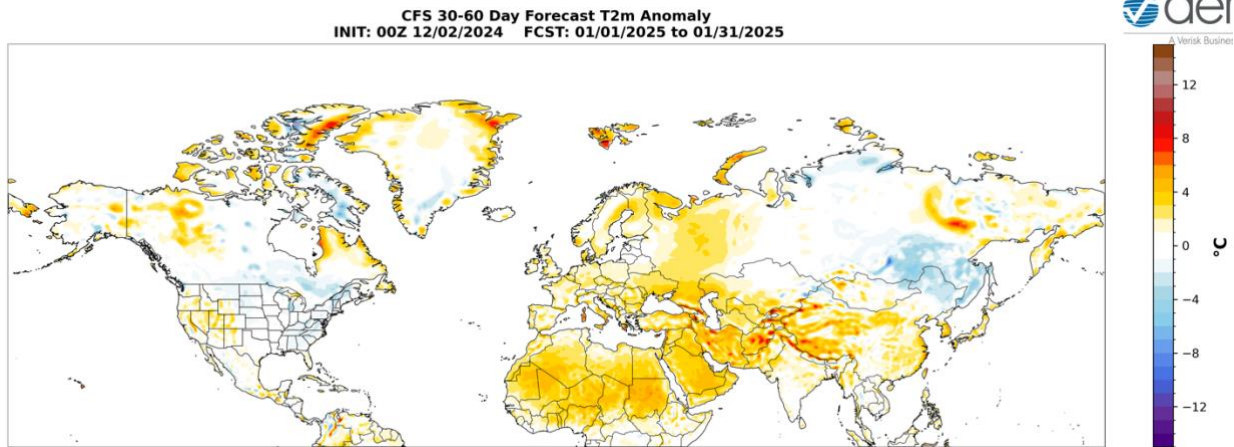


Figure 14. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for January 2024. The forecasts are from the 00Z 02 December 2024.

Boundary Forcings

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 is emerging (**Figure 15**) 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 eastern North America 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.

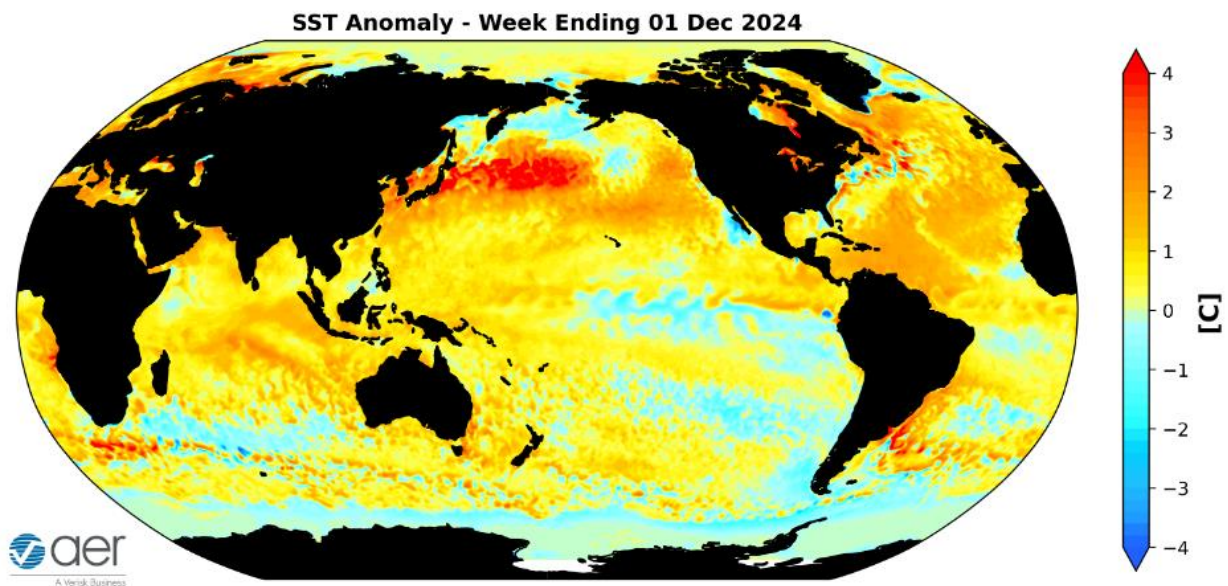


Figure 15. The latest daily-mean global SST anomalies (ending 01 Dec 2024). Data from NOAA OI High-Resolution dataset. Source <https://psl.noaa.gov/map/clim/sst.shtml>

Madden Julian Oscillation

Currently the Madden Julian Oscillation (MJO) is currently in in phase five (**Figure 16**). The forecasts are for the MJO to slowly make its way into phase six and then stall. Phases five and six favor ridging in the eastern North America and troughing in western North America, especially Alaska. Therefore, it seems that the MJO is having little influence on North American weather next week but maybe a little more next week. But admittedly this is outside of my expertise.

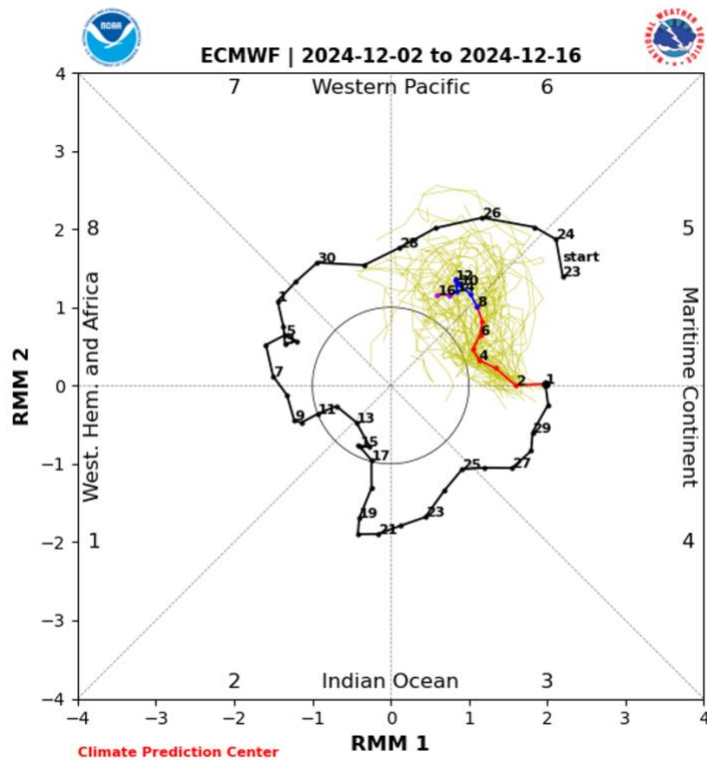


Figure 16. Past and forecast values of the MJO index. Forecast values from the 00Z 02 December 2024 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model 'spread' is denoted by the gray shading. Sector numbers indicate 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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