

Arctic Oscillation and Polar Vortex Analysis and Forecasts

December 9, 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 negative and is predicted to trend positive into positive territory and then settle back to neutral the next two weeks as pressure/geopotential height anomalies across the Arctic are currently mostly positive and are predicted to turn mixed to mostly negative to mixed over the next two weeks. The North Atlantic Oscillation (NAO) is currently negative with positive pressure/geopotential height anomalies across Greenland and the NAO is predicted to trend positive this week and remain positive next week as pressure/geopotential height anomalies are predicted to remain mostly mixed to negative across Greenland.
- This week ridging/positive geopotential height anomalies from the North Atlantic will extend across Northern Europe with troughing/negative geopotential height anomalies across Western Europe. Then next week will troughing/negative geopotential height anomalies across Greenland will extend across Northern Europe with ridging/positive geopotential height anomalies across Southern Europe. This pattern will support mostly normal to above normal temperatures across much of Europe with the exception of normal to below normal temperatures across Western Europe including the United Kingdom (UK) this week and then Scandinavia next week.
- This week ridging/positive geopotential height anomalies will dominate Eastern Asia with troughing/negative geopotential height anomalies across Western Asia and then

next week the pattern will reverse with troughing/negative geopotential height anomalies will dominate Eastern Asia with ridging/positive geopotential height anomalies across Western Asia. This pattern favors widespread normal to above normal temperatures across much of Asia, with regional normal to below normal temperatures first across Western and Central Asia this week and then Central and Eastern Asia next week.

- The general pattern across North America is ridging/positive geopotential height anomalies centered in Alaska, Western Canada and the Western United States (US) support troughing/negative geopotential height anomalies across Eastern Canada and the Eastern US but is predicted to relax next week and then possibly re-amplify heading into the holidays. 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 Canada and the Northeastern 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 that could slide southeast heading into the holidays.
- 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). But so far this winter it is all about the PV stretching and then relaxing over and over again in quick succession.

Plain Language Summary

Two stretched polar vortices are in the books and a third and fourth are looking increasingly likely this week and then again heading into the holidays. They are bringing cold weather to the Eastern US and Asia (see **Figures 3 & 9**) but nothing impressive. In between an interlude of a strong polar vortex favors a milder pattern next week. Western Europe isn't strongly influenced by stretched PVs, instead the weather is more dependent on Greenland high or low pressure. High pressure across Greenland this week will bring some cooler weather but overall looks like a mild pattern (see **Figure 3**). Longer term is it "rinse, lather, repeat" or more durable cold or mild weather? The jury is still out in my opinion.

Impacts

In last week's blog I discussed the next possible stretched PV occurring heading into the holiday season but was struggling to make what I was seeing consistent with the model forecasts. One issue that I was having was that I have been looking at the ensembles forecasts of the polar vortex (PV) to anticipate the weather in the Eastern US and the problem was that the ensembles kind of broad brush the short-term variability of the PV. The changes in the PV have been unusually rapid going from stretched PV to more circular and then repeating all over again and this is happening more rapidly than I can ever recall. I was struck by how unusually long duration the ensembles were predicting the pre-holiday stretched PV to last. This might be expected with a weak PV but not a strong PV. Anyway, the third stretched PV, will not be the week leading up to the holidays but rather the end of this week and over the weekend (see **Figure 12a**). And my rule of thumb is that the models are always playing catch up with the impacts or influence on our weather to stretched PVs. This explains the gradual cooling of the forecasts over the next week to ten days in the Eastern US and to a lesser extent some residual cold air in Central and East Asia.

But of course, while the PV remains strong any stretched PV is likely to be of short duration especially if the stretched PV is not particularly strong or amplified. Therefore, I would expect the same for any related cold air outbreaks. And this third stretched PV is looking more impressive than it did a week ago but overall looks fairly minor relative to historical stretched PVs so the associated cold air will not be terribly intense or of long duration. What is also important in these stretched PV events is the wave reflection that I have discussed previously in the blog with wave energy going 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 wave and the axis or position. I can see in my wave energy diagnostics the "wave reflection" but it is not overly impressive or robust (see **Figure i**). I think therefore the cold air associated with the event this week is run of the mill and shifted somewhat eastward based on the axis of the stretched PV. And what I mean by this based on where the axis of the stretched PV is in isolation, I would expect the cold air to be centered further to the west across North America, but the weak wave reflection is shunting the cold air further to the east. The reason for this is definitely esoteric so I will skip over the details. Readers already complain the blog is too technical!

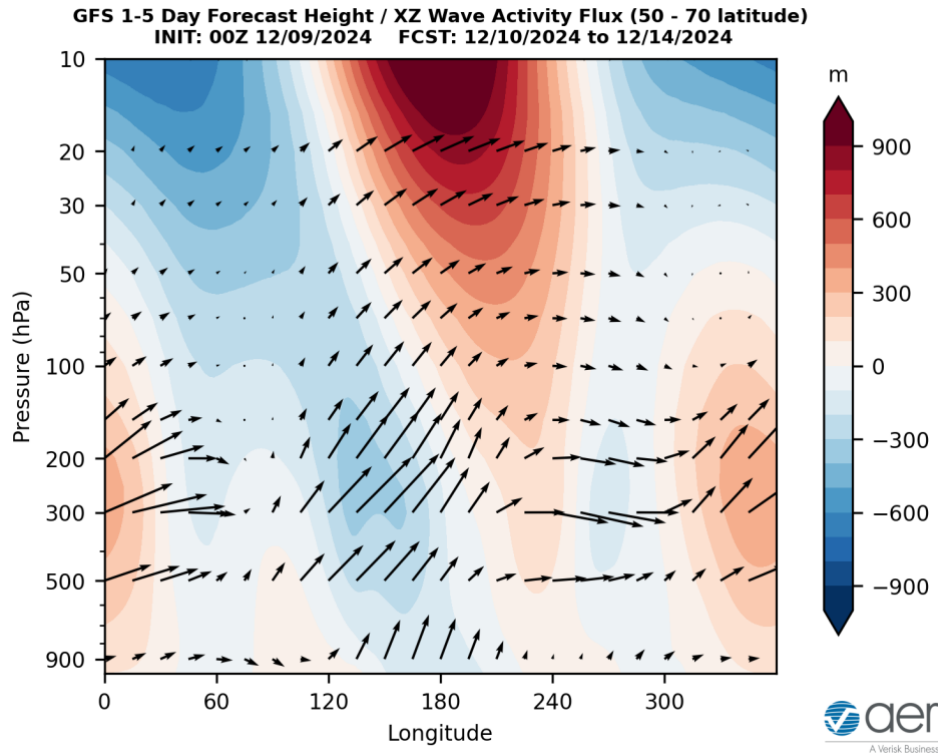
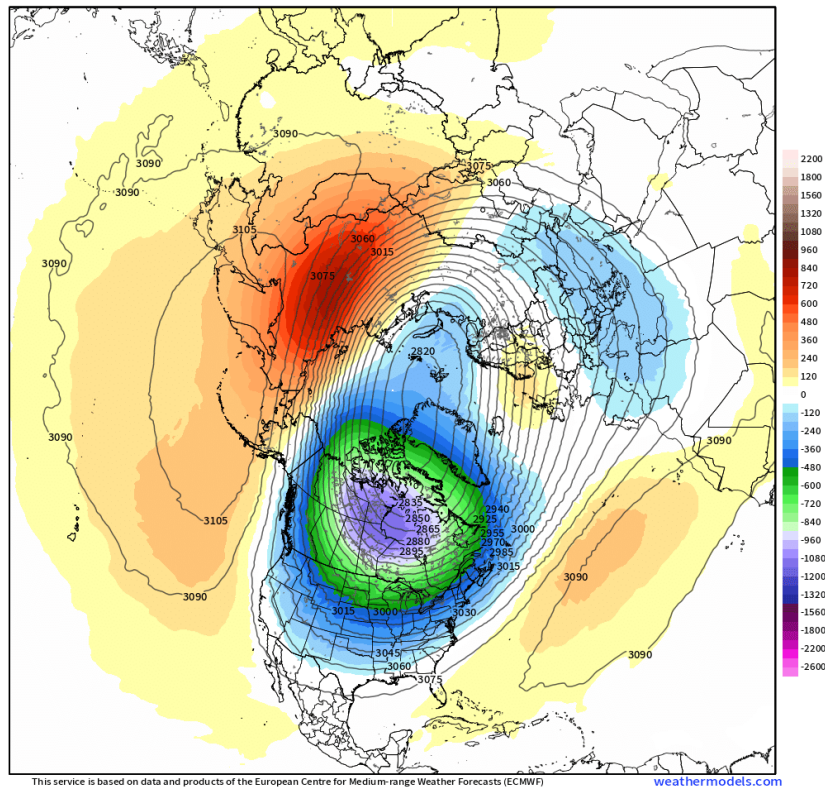


Figure i. Longitude-height cross section of geopotential eddy height anomalies (shading) and wave activity flux (vectors) forecasted for 10 December through 14 December 2024. The forecasts are from the 00Z 09 December 2024 GFS ensemble.

Then next week (of Monday December 16) looks mild again in the Eastern US as the PV snaps back to a more circular shape. But this is quickly followed by yet another or a fourth stretched PV for the pre-holiday week (see **Figure 12b**). This is the one that I have been most focused on based on focusing my analysis on the ensembles. I was looking at the operational models as well but maybe I lost sight of the trees for the forest as the operational runs are very noisy and exhibit large volatility compared to the more stable ensembles. And I don't think that this will surprise you, this is a difficult event to predict and for extrapolating the impact on our weather the challenge is compounded.

First, from looking at the operational runs in particular this could be the strongest stretched PV of the season. Again, it is important to keep in mind that this is relative to this year only and not historically. This statement is based on the expectation that the PV overall will remain relatively strong. If the models are wrong and the PV does weaken relative to historical averages, then the cold air outbreak associated with it could become deeper and of longer duration. Not there yet but does need to be monitored. And I do want to highlight the ECMWF operational model that has been predicting a larger stretched PV event that could potentially result in a cold air outbreak of greater magnitude than currently being predicted by the models (see **Figure ii**). The new operational ECMWF seems to me prone to extreme solutions, so I think healthy skepticism of this more extreme solution is warranted, especially for a two week plus forecast.



I do wonder if low sea ice inhibits troughing over Hudson Bay and instead pulls the western North America ridge further east than usual. This in turn pushes the eastern North America trough to the east with the core of cold air outbreaks passing over the Canadian Maritimes and then out into the North Atlantic.

Longer term, how the PV behaves, and its associated influence on our weather, will strongly depend on high latitude blocking. The models still playing hide and seek with Ural blocking (in the GFS see **Figure 8** but not the ECMWF). The stronger the Ural blocking, the larger the stretched PVs and even possibly a transition to a sudden stratospheric warming (SSW). But given the difficulty or challenge of forecasts of less than two weeks and even in the case for the upcoming week, the one week forecasts, I think best to keep an open mind for now on what could transpire post the holiday period and even during the holiday period.

So, in summary, highly unusual pattern with lots of volatility/variability in the forecasts and in the observed weather. Another two stretched PVs and their related cold air outbreaks into the Eastern US in the next two weeks separated by a strong PV and milder weather. The first cold air outbreak is the end of the week and over the weekend. Then it turns mild for the weekdays of next week and based on the latest ECMWF ensembles, it turns cold again in the Eastern US appropriately so right around the first official day of meteorological winter. Hard to anticipate for how long this rapid cycle of cold, mild, cold, mild lasts but as long as the PV remains. But for now it seems the atmosphere is still on the “rinse, lather, repeat” merry go-round and can seem to get off the ride.

Near-Term

This week

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

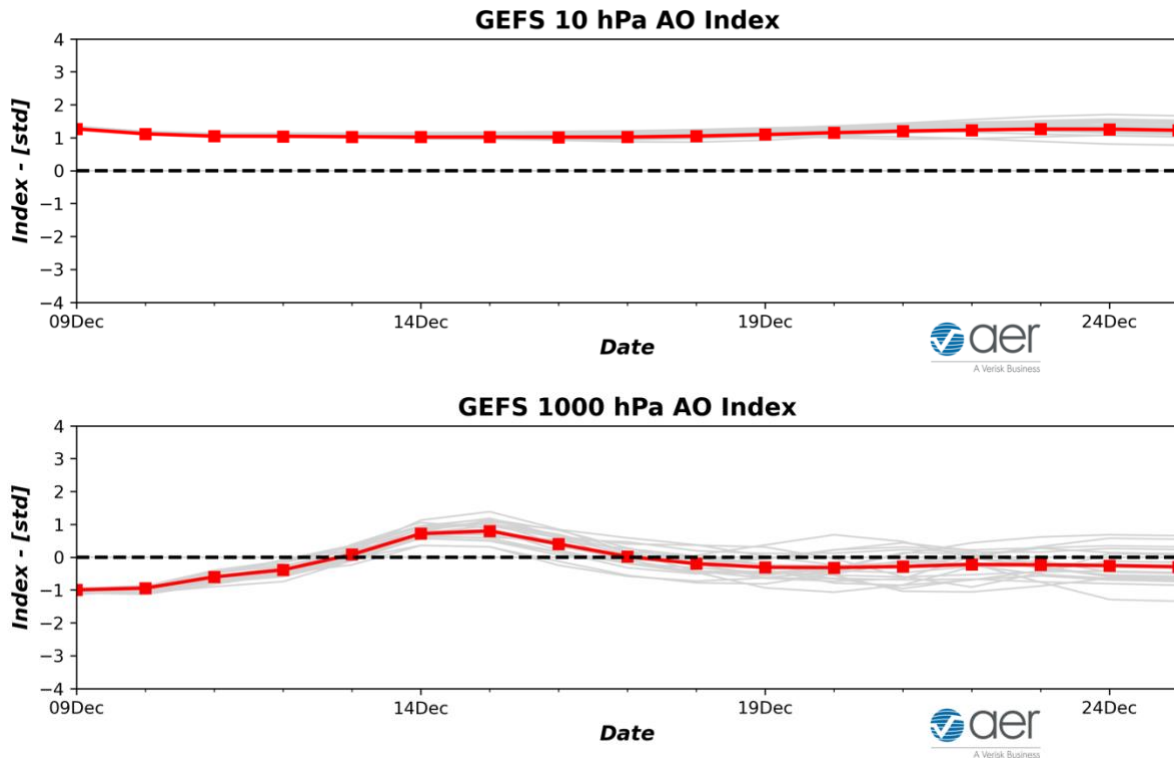


Figure 1. a) The predicted daily-mean AO at 10 hPa from the 00Z 09 December 2024 GFS ensemble. b) The predicted daily-mean AO at 1000 hPa from the 00Z 09 December 2024 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble mean AO index given by the red line with squares.

This week, ridging/positive geopotential height anomalies in the North Atlantic will extend across Northern Europe with toughing/negative geopotential height anomalies across Western Europe (**Figures 2**). This pattern will favor normal to below normal temperatures across Western Europe including the UK with normal to above normal temperatures across the remainder of Europe (**Figure 3**). This week the predicted pattern across Asia is toughing/negative geopotential height anomalies across Western and Central Asia with ridging/positive geopotential height anomalies across Eastern Asia (**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 Western Russia and Central Asia (**Figure 3**).

GEFS 1-5 Day Forecast 500 hPa Anomaly
INIT: 00Z 12/09/2024 FCST: 12/10/2024 to 12/14/2024

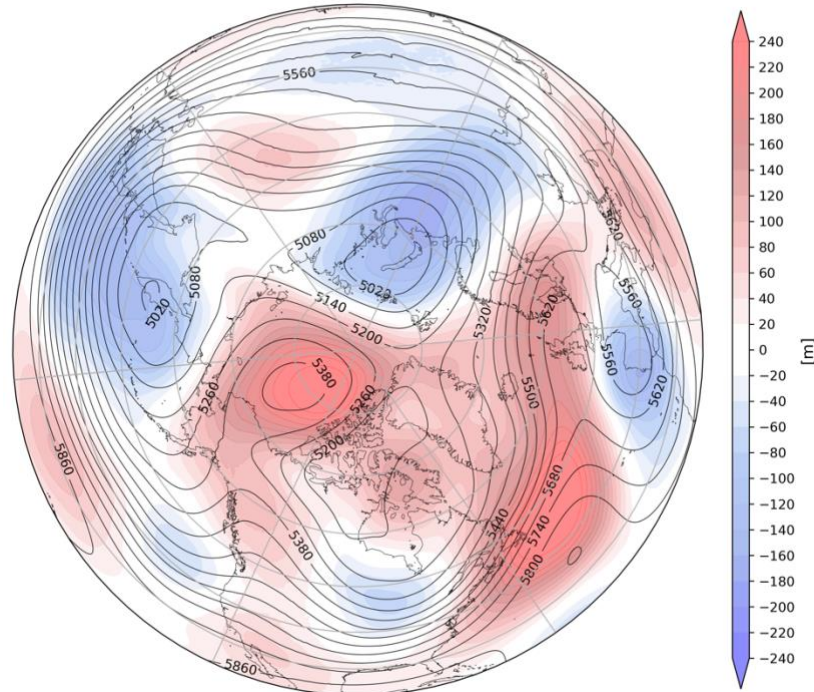


Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 10 Dec to 14 Dec 2024. The forecasts are from the 00Z 09 December 2024 GFS ensemble.

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, the Canadian Maritimes and the Western and Southern US with normal to below normal temperatures across Central Canada and the Northeastern US (**Figure 3**).

GEFS 1-5 Day Forecast T2m Anomaly
INIT: 00Z 12/09/2024 FCST: 12/10/2024 to 12/14/2024

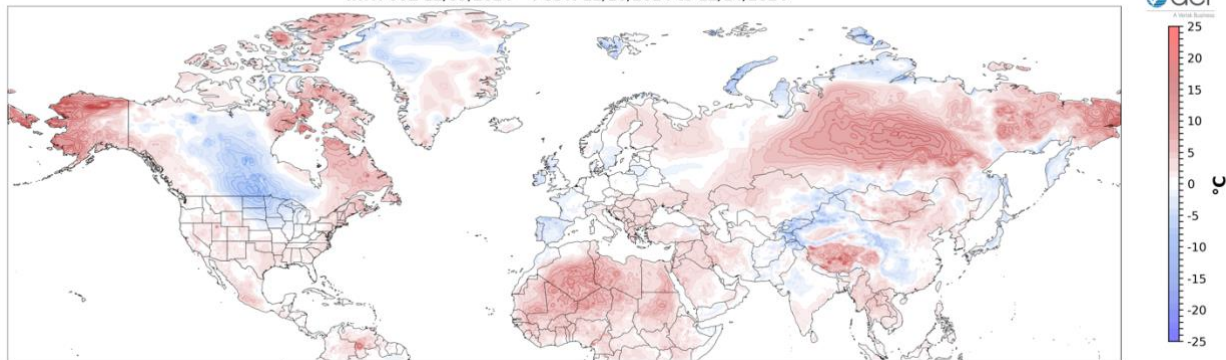


Figure 3. Forecasted surface temperature anomalies (°C; shading) from 10 Dec to 14 Dec 2024. The forecast is from the 00Z 09 December 2024 GFS ensemble.

Trouching and/or cold temperatures will support new snowfall across Norway, the Urals, parts of Siberia and the Tibetan Plateau while warm temperatures will support snowmelt in Scandinavia this week (**Figure 4**). Trouching and/or cold temperatures will support new snowfall across Alaska, much of Canada and the US Great Lakes while warm temperatures will support snowmelt in Western Alaska, Western and Southeastern Canada and New England this week (**Figure 4**).

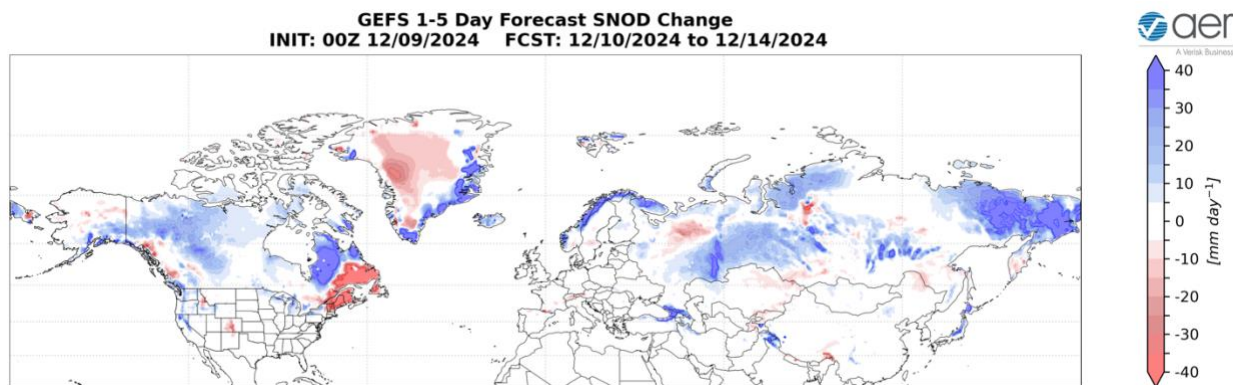


Figure 4. Forecasted snow depth changes (mm/day; shading) from 10 Dec to 14 Dec 2024. The forecast is from the 00Z 09 December 2024 GFS ensemble.

Near-Mid Term

Next week

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

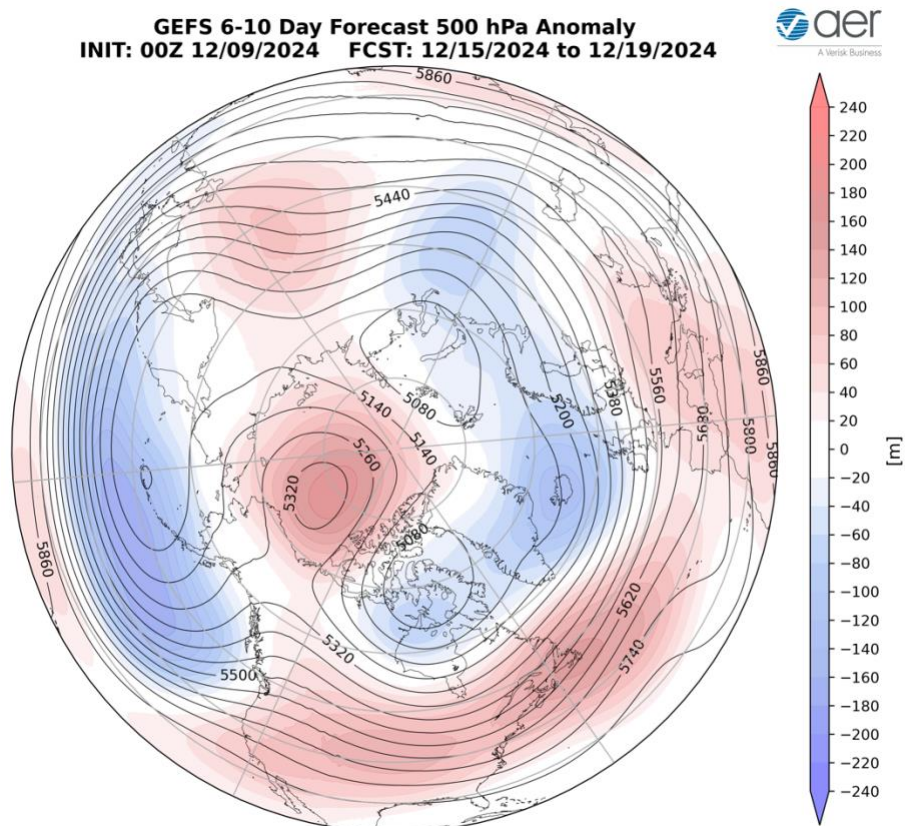


Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 15 Dec to 19 Dec 2024. The forecasts are from the 00Z 09 December 2024 GFS ensemble.

Predicted troughing/negative geopotential height anomalies across Greenland will extend across Northern Europe with ridging/positive geopotential height anomalies across Southern Europe this period (**Figure 5**). This zonal pattern will favor normal to above normal temperatures across much of Europe including the UK with normal to below normal temperatures across Northern Scandinavia this period (**Figure 6**). The predicted pattern across Asia is This week the predicted pattern across Asia is toughing/negative geopotential height anomalies across Western Asia with ridging/positive geopotential height anomalies across Eastern Asia (**Figure 5**). This pattern favors widespread normal to above normal

temperatures across Eastern Asia with normal to below normal temperatures limited to parts of Central and Western Asia (**Figure 6**).

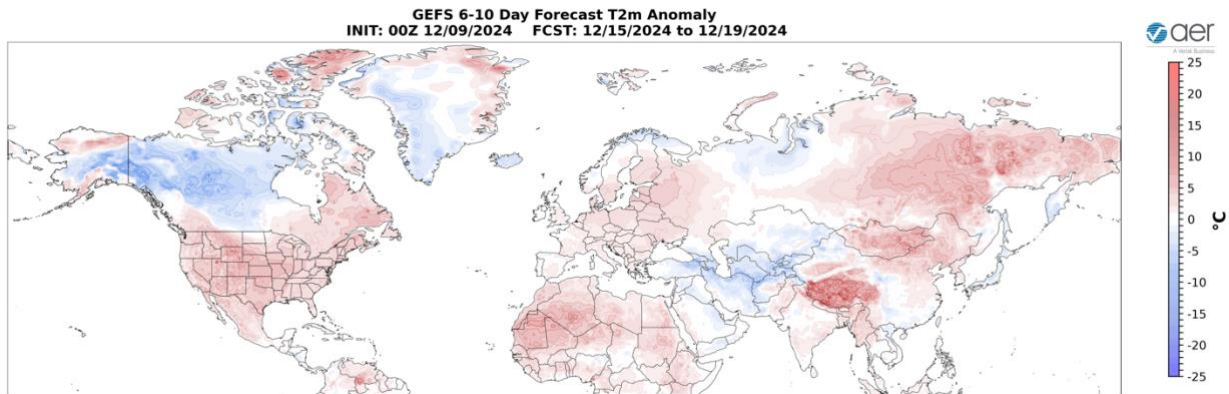


Figure 6. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 15 Dec to 19 Dec 2024. The forecast is from the 00Z 09 December 2024 GFS ensemble.

Persistent ridging/positive geopotential height anomalies across Alaska, Western Canada and the Western US will continue to support troughing/negative geopotential height anomalies albeit across Central Canada and the Eastern US with more ridging/positive geopotential height anomalies across the Canadian Maritimes this period (**Figure 5**). This pattern will favor widespread normal to above normal temperatures across much of North America with normal to below normal temperatures limited to parts Alaska, Western and Central Canada under northerly flow (**Figure 6**).

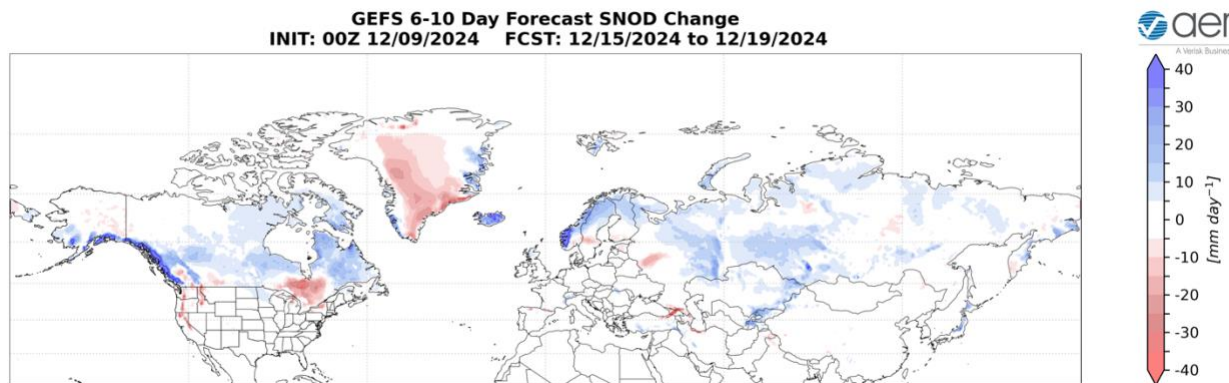


Figure 7. Forecasted snow depth changes (mm/day ; shading) from 15 Dec to 19 Dec 2024. The forecast is from the 00Z 09 December 2024 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across Scandinavia, the Alps, Western Russia, Western and Eastern Siberia, the Tibetan Plateau and Japan while warm temperatures will support snowmelt in Eastern Europe and southeastern Siberia this period (**Figure 7**). Troughing and/or cold temperatures will support new snowfall across southern Alaska, the West coast mountains of Canada, Central and Eastern Canada and the Northwestern US while warm temperatures will support snowmelt in Southeastern Canada and 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 remain near neutral (**Figure 1**). With predicted weak and negative pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO will likely remain positive to relatively close to neutral this period.

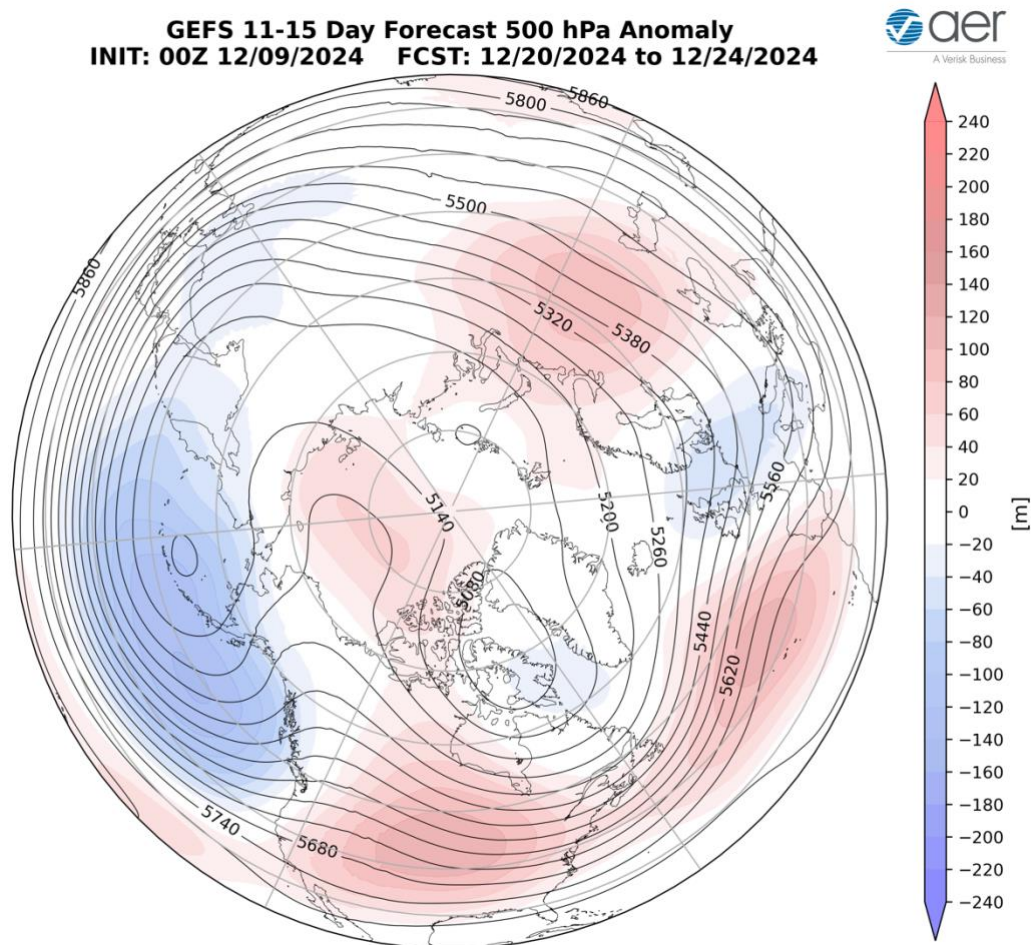


Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 20 Dec to 24 Dec 2024. The forecasts are from the 00Z 09 December 2024 GFS ensemble.

Persistent troughing/negative geopotential height anomalies across Greenland is predicted to continue to extend across Northern and even Western Europe with ridging/positive geopotential height anomalies persisting across Southern Europe (**Figure 8**). This pattern should favor widespread normal to above normal temperatures across much of Europe with more reasonable temperatures in Western Europe including the UK and maybe even below normal

temperatures in parts of Scandinavia this period (**Figures 9**). The pattern across Asia is predicted to flip this period with 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 parts of Central and East Asia this period (**Figure 9**).

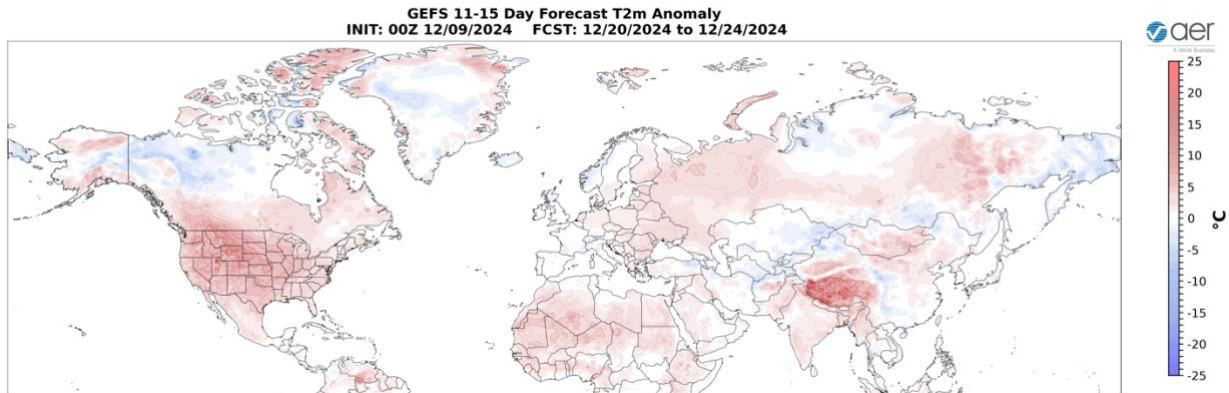


Figure 9. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 20 Dec to 24 Dec 2024. The forecast is from the 00Z 09 December 2024 GFS ensemble.

Ridging/positive geopotential height anomalies are predicted to persist across Alaska, Western Canada and the Western US supporting troughing/negative geopotential height anomalies across Eastern Canada and the Eastern US this period (**Figure 8**). This pattern will favor widespread normal to above normal temperatures across much of Alaska, Western Canada and the Western US with normal to below normal temperatures mostly limited to Eastern Canada and the Eastern US this period (**Figure 9**). I am following the ECMWF that has more robust cooling in eastern North America albeit still underwhelming.

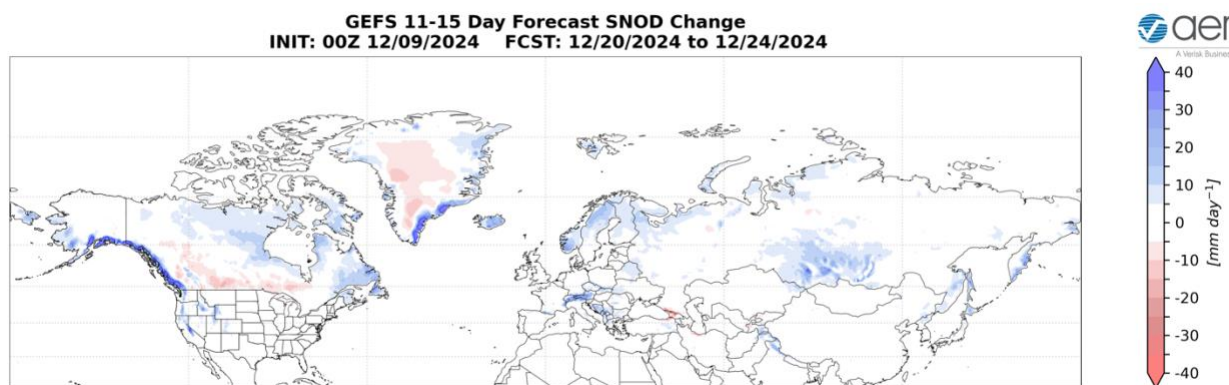


Figure 10. Forecasted snow depth changes (mm/day ; shading) from 20 Dec to 24 Dec 2024. The forecast is from the 00Z 09 December 2024 GFS ensemble.

Trouching and/or cold temperatures will support new snowfall across Scandinavia, the Alps, the Balkans, Western Russia, parts of Siberia and parts of Northeast Asia this period (**Figure 10**). Trouching and/or cold temperatures will support new snowfall across western Alaska, the west coast mountains of Canada, Northern and Eastern Canada and New England while warm temperatures will support snowmelt in Western Canada 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**). The cold/negative PCHs from the stratosphere are predicted to descend all the way to the surface but only briefly. Then the contrast between cold/negative PCHs in the stratosphere and warm/positive PCHs are predicted in the troposphere is predicted to return for the pre-holiday period (**Figure 11**). For now, this suggests that the stratosphere and troposphere are mostly uncoupled but that could change with time.

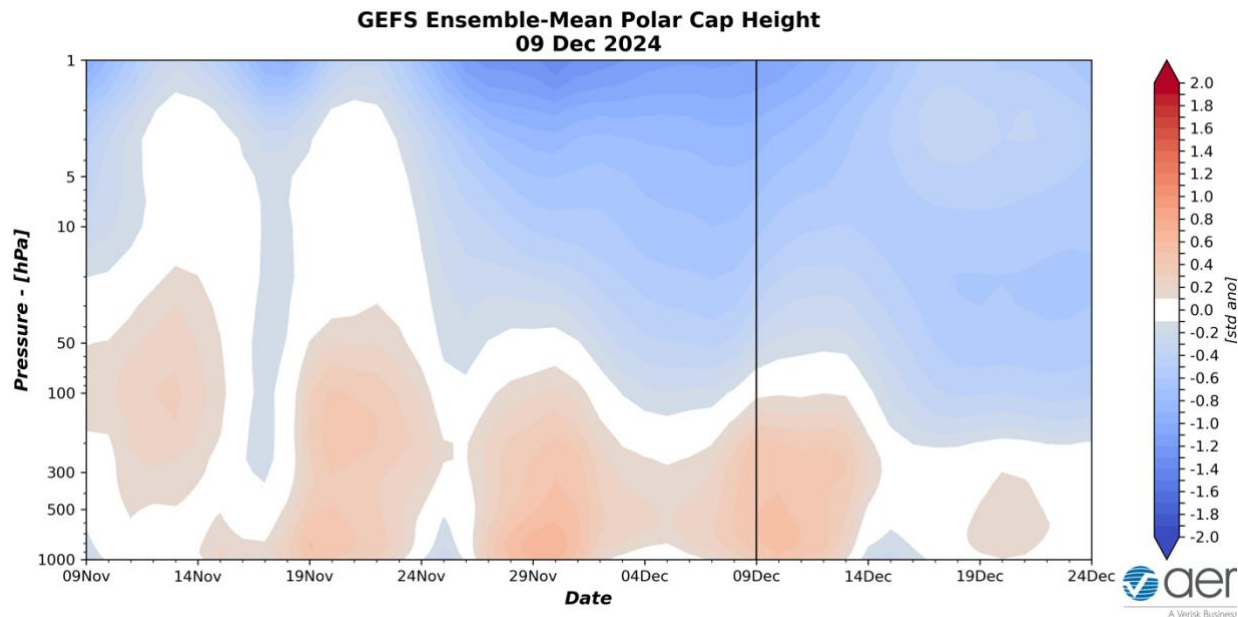


Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 09 December 2024 GFS ensemble.

The predicted alternating warm/positive followed by cold/negative PCHs in the lower troposphere the next two weeks (**Figure 11**) are consistent with the predicted negative then positive surface AO the next two weeks (**Figure 1**). Still waiting to see if the cold/negative PCHs in the stratosphere could couple to the surface for a longer duration or whether the warm/positive PCHs in the troposphere could force a larger polar vortex disruption.

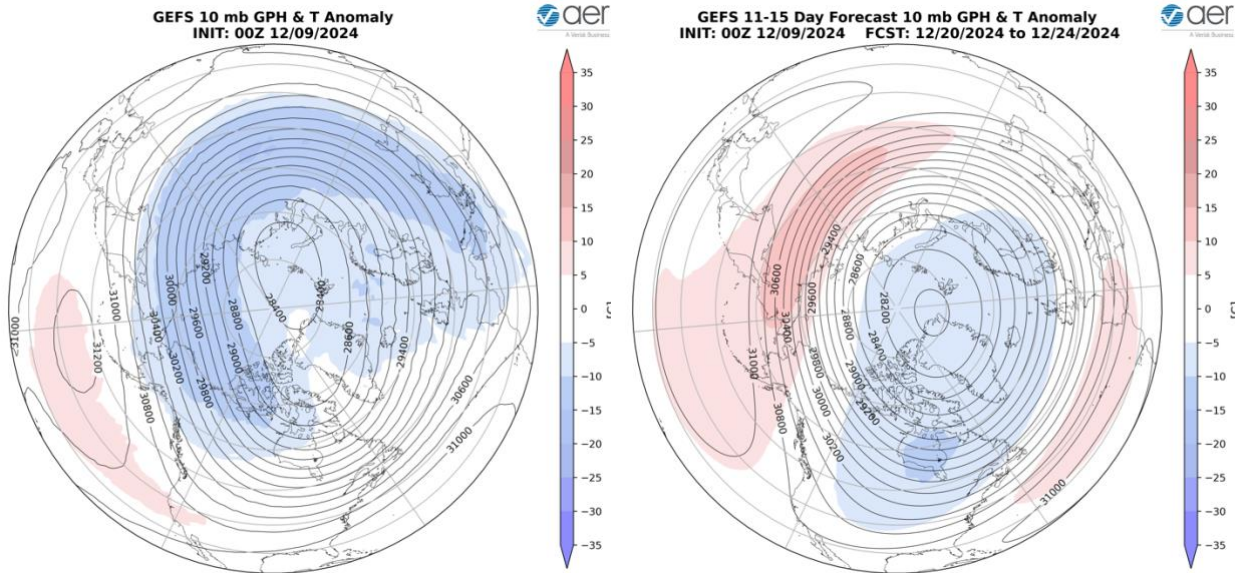


Figure 12. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere for 09 December 2024. (b) Same as (a) except forecasted averaged from 20 Dec to 24 Dec 2024. The forecasts are from the 00Z 09 December 2024 GFS 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 extending from Asia to Western Canada with warm temperatures centered near the Dateline (**Figure 12a**). This is consistent with a stretched PV configuration. This is related to the cold air outbreak even if relatively weak flow of cold air out of Canada to the US later this week. This is the third stretched PV in rapid succession. Then, in late December the PV center is predicted to remain near the North Pole 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 fourth 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 any cold air outbreaks should remain brief with each individual stretched PV event.

CFS 500 hPa Forecast Anomaly Jan 2025
Valid as of 09 Dec 2024

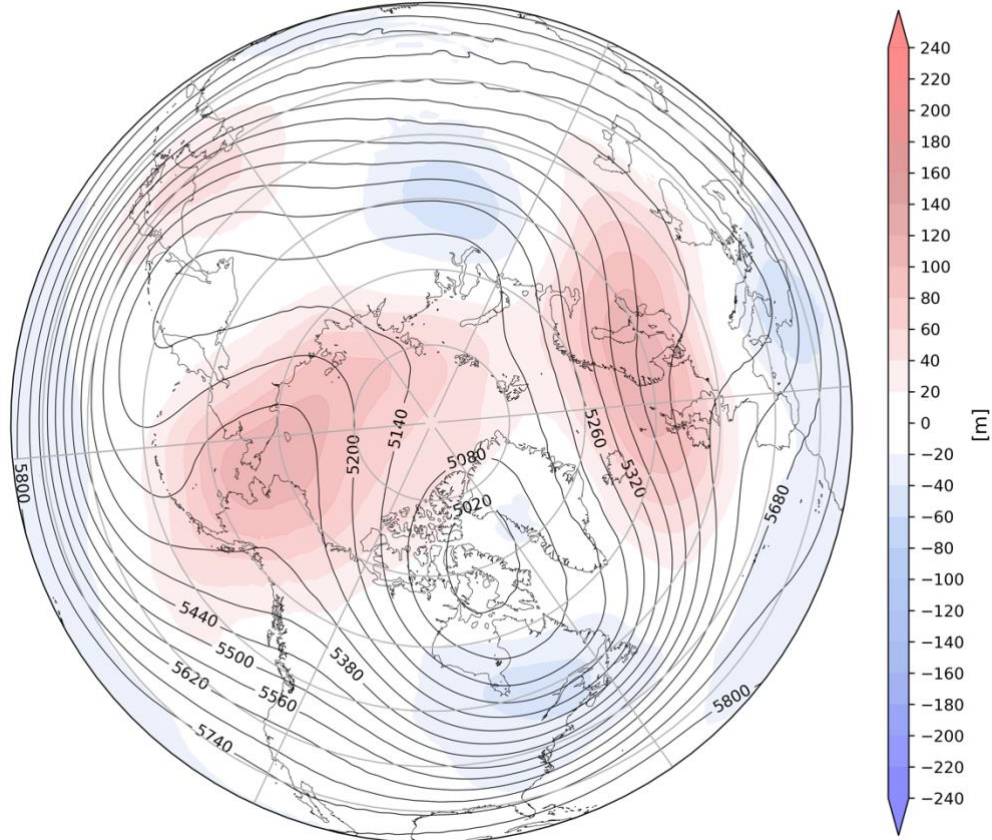


Figure 13. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for January 2025. The forecasts are from the 00Z 09 December 2024 CFS.

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 Beaufort Sea, Gulf of Alaska extending into Alaska, Western Canada and the Western US with troughing across Southwestern Europe and extending into Southeastern Europe and the eastern Mediterranean, East 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, Southern Asia, Eastern Siberia, Alaska, Western Canada and the Western US with seasonable to relatively cold temperatures across Northern and Northeast Asia, Central and Southeastern Canada and the Eastern US (**Figure 14**).

CFS 23-53 Day Forecast T2m Anomaly
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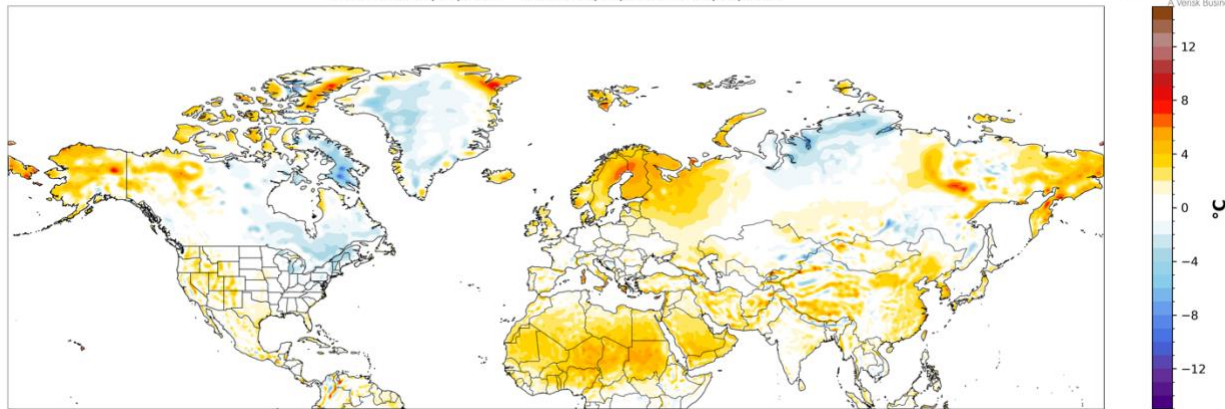


Figure 14. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for January 2025. The forecasts are from the 00Z 09 December 2024.

Boundary Forcings

Arctic Sea Ice

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 15**). 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. I do wonder if low sea ice extent in Hudson Bay is contributing to atmospheric ridging and warming over eastern North America.

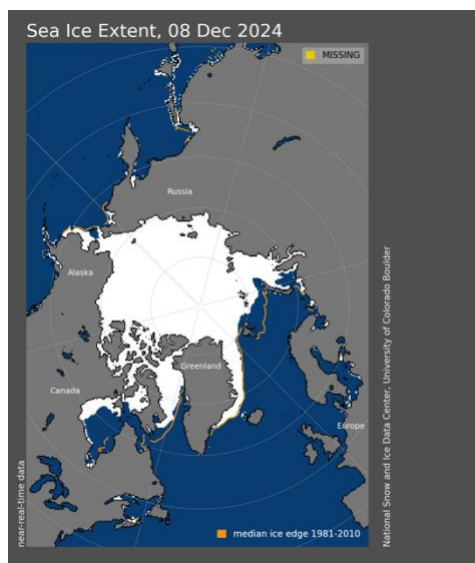


Figure 15. Observed Arctic sea ice extent on 08 December 2024 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image from the National Snow and Ice Data Center (NSIDC). URL <https://nsidc.org/sea-ice-today>.

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 is emerging (**Figure 16**) 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.

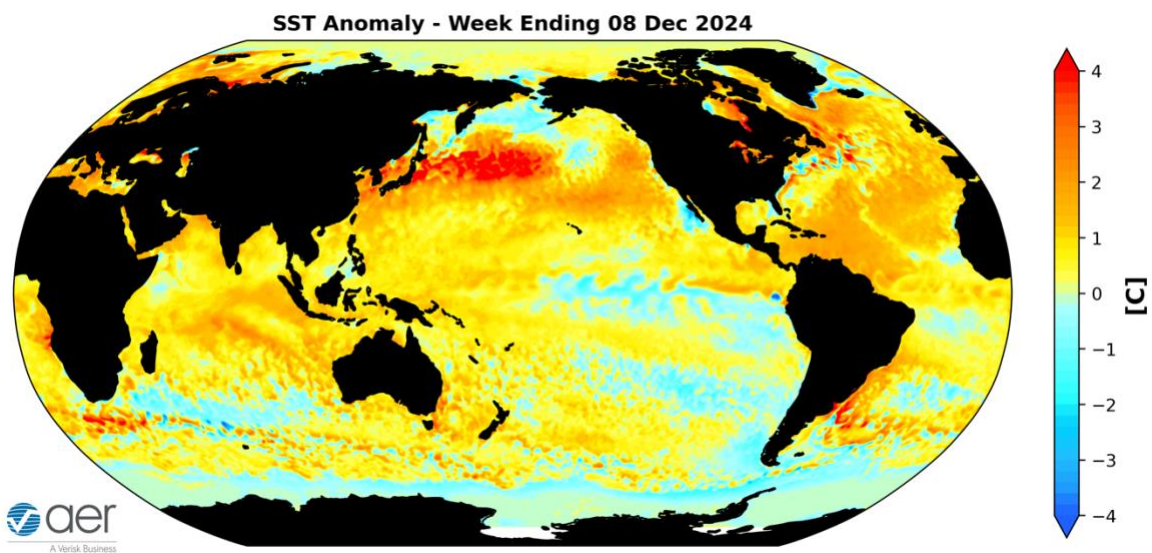


Figure 16. The latest daily-mean global SST anomalies (ending 07 Dec 2024). Data from NOAA OI High-Resolution dataset. Source <https://psl.noaa.gov/map/clim/sst.shtml>

Madden Julian Oscillation

Currently the Madden Julian Oscillation (MJO) is currently in in phase five (**Figure 17**). The forecasts are for the MJO to slowly make its way into phase six and then weaken to where no phase is favored. 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.

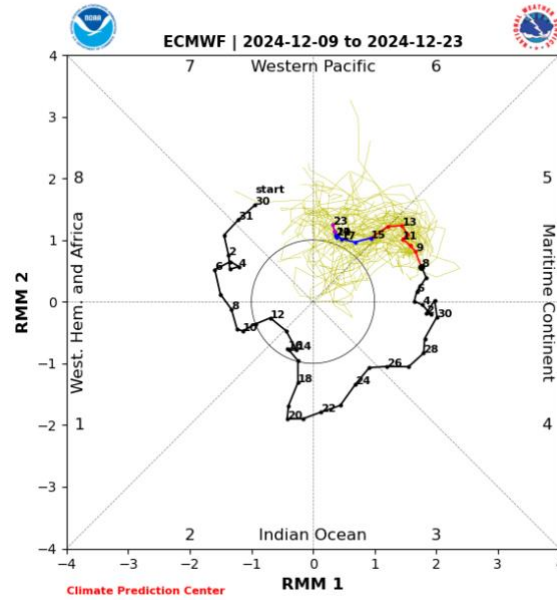


Figure 17. Past and forecast values of the MJO index. Forecast values from the 00Z 09 December 2024 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model 'spread' is denoted by the gray shading. Sector numbers indicate 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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We appreciate your taking the time to read the public Arctic Oscillation blog from Dr. Judah Cohen and the AER Seasonal Forecasting team.

Dr. Cohen's detailed monthly seasonal forecast, [sCast](#), is also available for purchase. [sCast](#) provides a monthly 30-60-90-180-day outlook into temperature and precipitation, solar flux and wind anomalies across the globe, and regional population weighted cooling and heating degree forecasts for the US.

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