

Arctic Oscillation and Polar Vortex Analysis and Forecasts

December 23, 2022

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. With the start of 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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The AO/PV blog is partially supported by NSF grant AGS: 1657748.

Summary

- The Arctic Oscillation (AO) is currently negative and is predicted to remain negative to neutral the next two weeks as pressure/geopotential height anomalies across the Arctic are predicted to remain mostly positive except in the Central Arctic. The North Atlantic Oscillation (NAO) is currently neutral and is predicted to remain neutral to positive the next two weeks as pressure/geopotential height anomalies are predicted to be mostly negative across Greenland.
- Over the next two weeks troughing/negative geopotential height anomalies centered near Greenland will favor mostly ridging/positive geopotential height anomalies across troughing/negative geopotential height anomalies across Northern Europe with Europe with the exception of troughing/negative geopotential height anomalies across Northern Europe. This pattern will generally favor normal to above normal temperatures across Europe including the United Kingdom (UK) with normal to below normal temperatures across Scandinavia.

- Over the next two weeks, predicted ridging/positive geopotential height anomalies near Eastern Siberia will expand westward across Siberia with some residual troughing/negative geopotential height anomalies across far East Asia. This pattern favors expanding normal to above normal temperatures across Siberia and much of Asia with normal to below normal temperatures limited to far East Asia the next two weeks.
- Over the next two weeks, deepening troughing/negative geopotential height anomalies across Alaska and the Gulf of Alaska will force ridging/positive geopotential height anomalies across Eastern Canada and the Eastern United States (US). This pattern favors this week widespread normal to below normal temperatures across Alaska, Northern and Central Canada and the Central and Eastern US with normal to above normal temperatures across the Southwestern Canada and Northeastern Canada and the Western US. However, next week below normal temperatures will be confined to western North America while mild temperatures spread east of the Rockies in Canada and the US.
- I discuss what we can expect in the coming weeks with the polar vortex (PV) and hemispheric temperatures.

Plain Language Summary

The polar vortex (PV) is predicted to become stronger and more circular in shape heading into January. This pattern is supportive of mild temperatures east of the Rockies in North America, Europe and Asia and it does look like all three regions will be turning gradually milder. It is speculative on my part at this point, but I do think that the PV will not remain strong but another stretched PV or even the larger sudden stratospheric warming that supports colder temperatures across the Northern Hemisphere is probable later in January.

Impacts

Severe winter weather in North America east of the Rockies is predicted to continue into next week. But the cold weather is on borrowed time as a textbook strong polar vortex (PV), with an almost perfect circular circulation and with all the low geopotential heights centered in the polar stratosphere (see **Figure i**). In addition, the polar cap geopotential height anomalies (PCHs) forecast shows cold/negative PCHs in upper stratosphere coupling all the way to the surface (see **Figure ii**) and hence the mild forecast across the Northern Hemisphere from the weather models (see **Figure iii**).

GEFS 6-10 Day Forecast 10 mb GPH & T Anomaly
INIT: 00Z 12/23/2022 FCST: 12/29/2022 to 01/02/2023

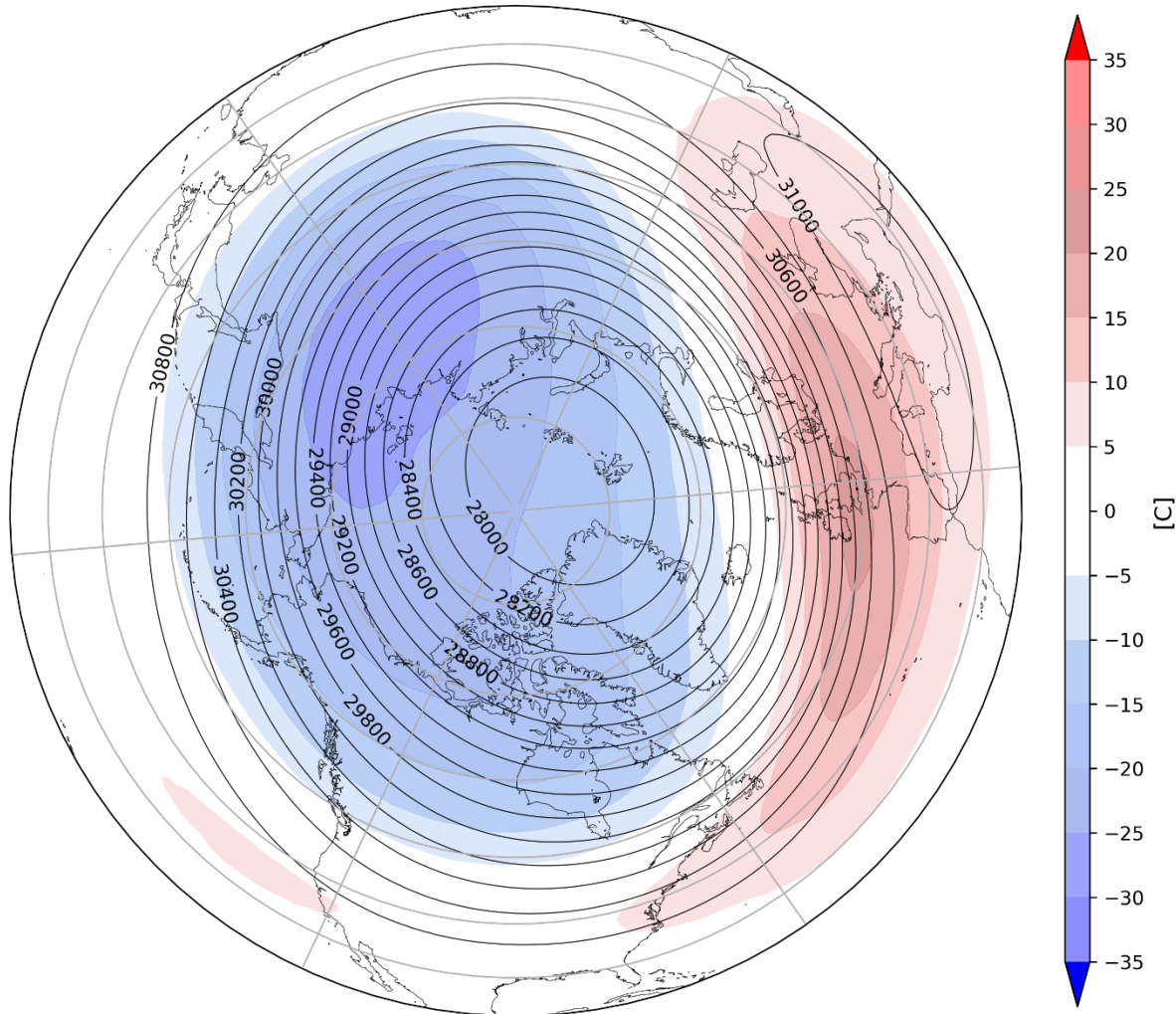


Figure i. Forecasted 10 mb geopotential heights (dam; contours) and temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere for 29 December 2022 – 2 January 2023. The forecasts are from the 00Z 23 December 2020 GFS model ensemble.

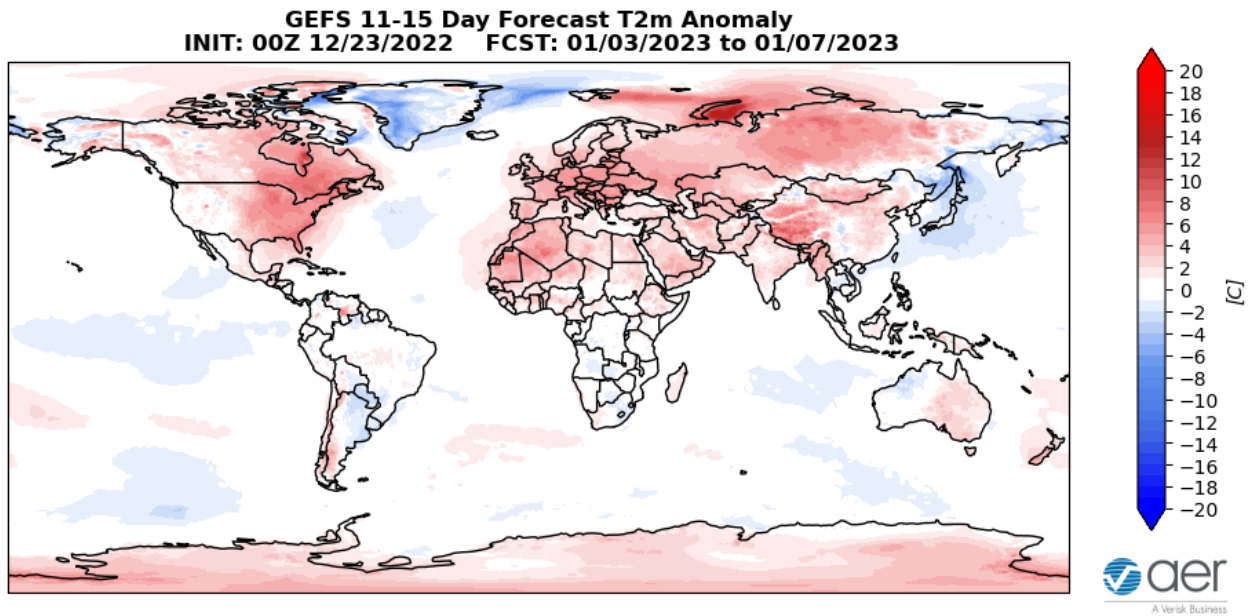
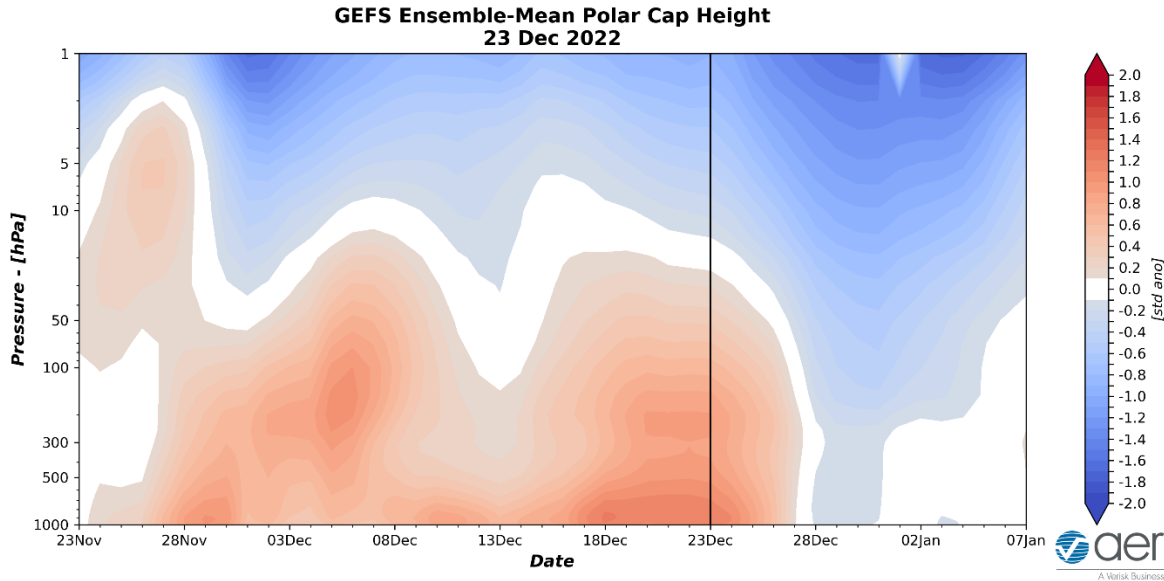


Figure ii. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 3 – 7 January 2023. The forecast is from the 00Z 23 December 2022 GFS ensemble.

Of course, one possibility is what happened in winter 2019/20 where the strong PV coupled to a strong positive AO at the surface mutually reinforcing a mild pattern across the NH. I still do not consider this outcome as most likely. Ridging/positive geopotential height anomalies are predicted in and around the Urals but not actually over the Urals. This pattern is not optimal but coupled with deep troughing/negative geopotential height anomalies across the northern North Pacific sector I think that it is sufficient to initiate more active vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere. This will likely lead to

perturbing the stratospheric PV. The models are starting to show elongation of the PV as might be expected with a stretched PV/wave reflection. However, I am unsure of the nature of the PV disruption. I think you could argue that the wavelength of the dominate wave in the Northern Hemisphere (NH) is quite large, sufficient to lead to a larger disruption of the PV.

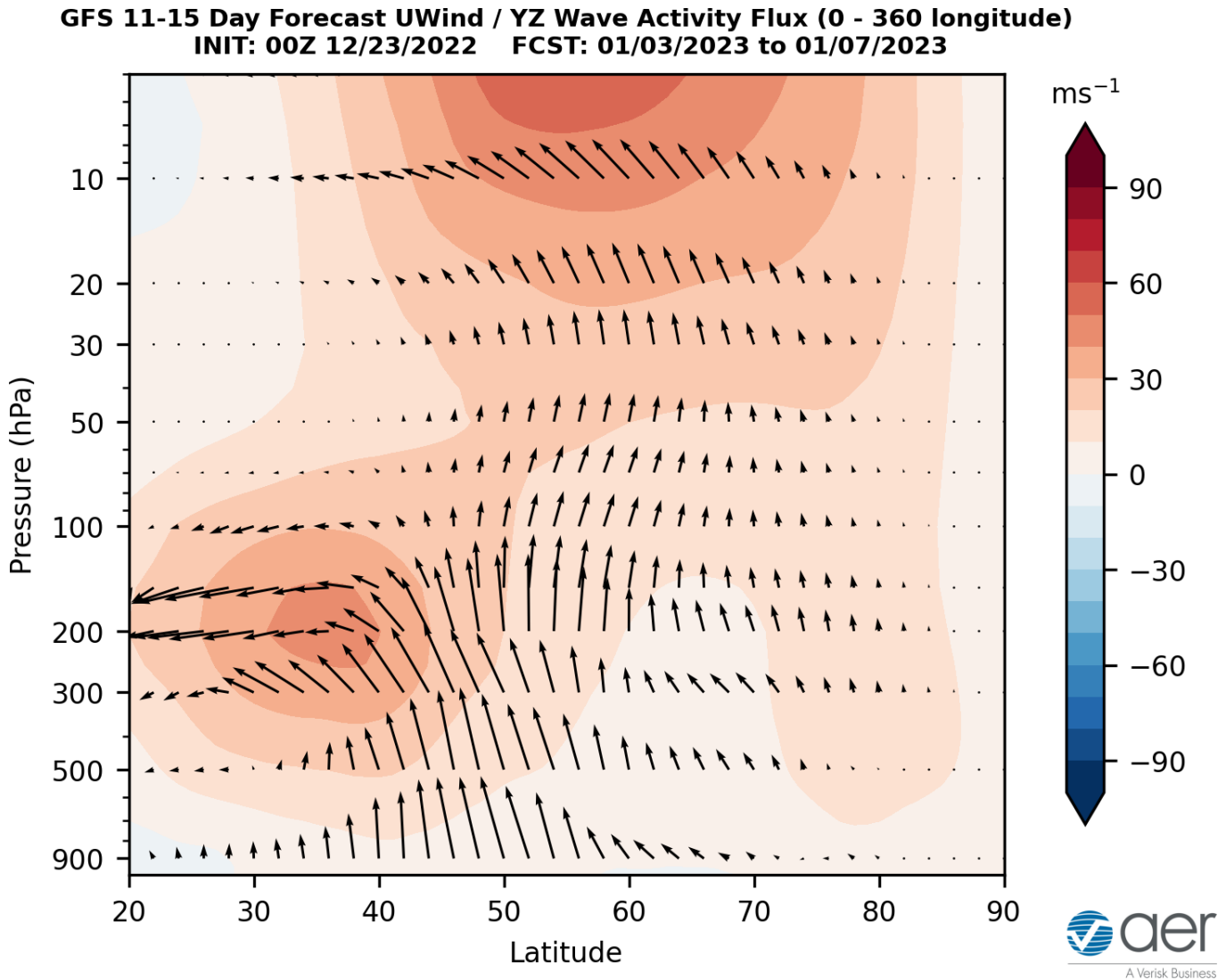


Figure iv. Latitude-height cross section of xonal mean zonal wind (shading) and wave activity flux (vectors) forecasted for 3 – 7 January 2023. The forecast is from the 00Z 23 December 2022 GFS ensemble.

Looking at WAF forecasts from the GFS, WAF in the vertical and longitudinal direction for early January show the WAF vectors all pointed upward into the upper stratosphere (see **Figure iv**) with no signs of reflection. This supports a larger PV disruption associated with a sudden stratospheric warming (SSW).

I would consider this a low confidence forecast. I am more certain that the probability of a PV disruption is increasing for early January but less certain if it will be more minor (stretching) or major (a sudden stratospheric warming). For what it's worth the latest ECMWF weeklies show a classical stretched PV and tropospheric response with ridging in western North America and troughing in eastern North America (see **Figure v**) right through the first week of February, which would be impressive! I actually believe that the weather models struggle with correctly predicting PV stretching and its coupling with the weather so really not sure what to make of this unusual ECWMF forecast. Could this be a case of the broken clock being correct twice a day? I am very much interested in this ECMWF forecast and how it will verify.

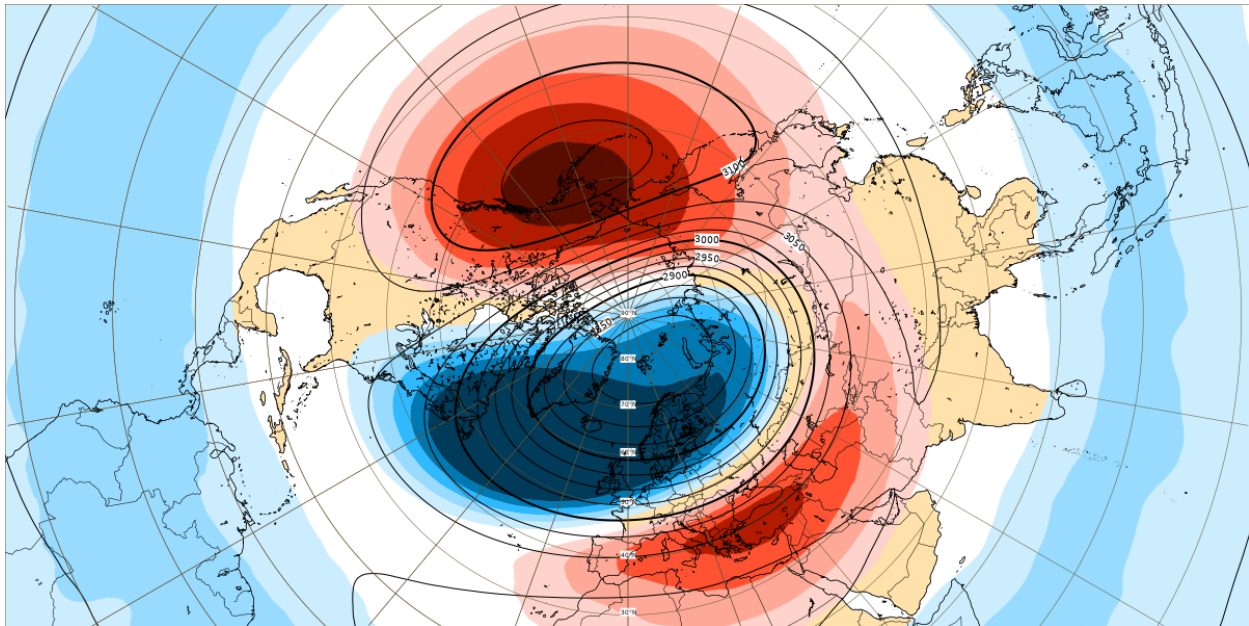


Figure v. Forecasted 10 mb geopotential heights (dam; contours) and temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere for 9 – 16 January 2023. The forecasts are from the 00Z 22 December 2020 ECMWF ensemble. Charts courtesy of <https://charts.ecmwf.int/>.

So in conclusion, a mild pattern for the NH will be all but inevitable. This isn't a short term (on the order of days or a week) pattern flip, it will take time to generate more widespread colder weather. But I do think that it is coming just not sure if it will come in the form of a stretched PV or an SSW. Happy holidays.

Everything below is unchanged from earlier in the week!

Recent and Very Near Term Conditions

The AO is predicted to be negative this week (**Figure 1**) with positive geopotential height anomalies predicted across the North Pacific and North Atlantic sectors of the

Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 2**). And with positive geopotential height anomalies this week across Greenland (**Figure 2**), the NAO is predicted to be neutral to negative this week as well (**Figure 1**).

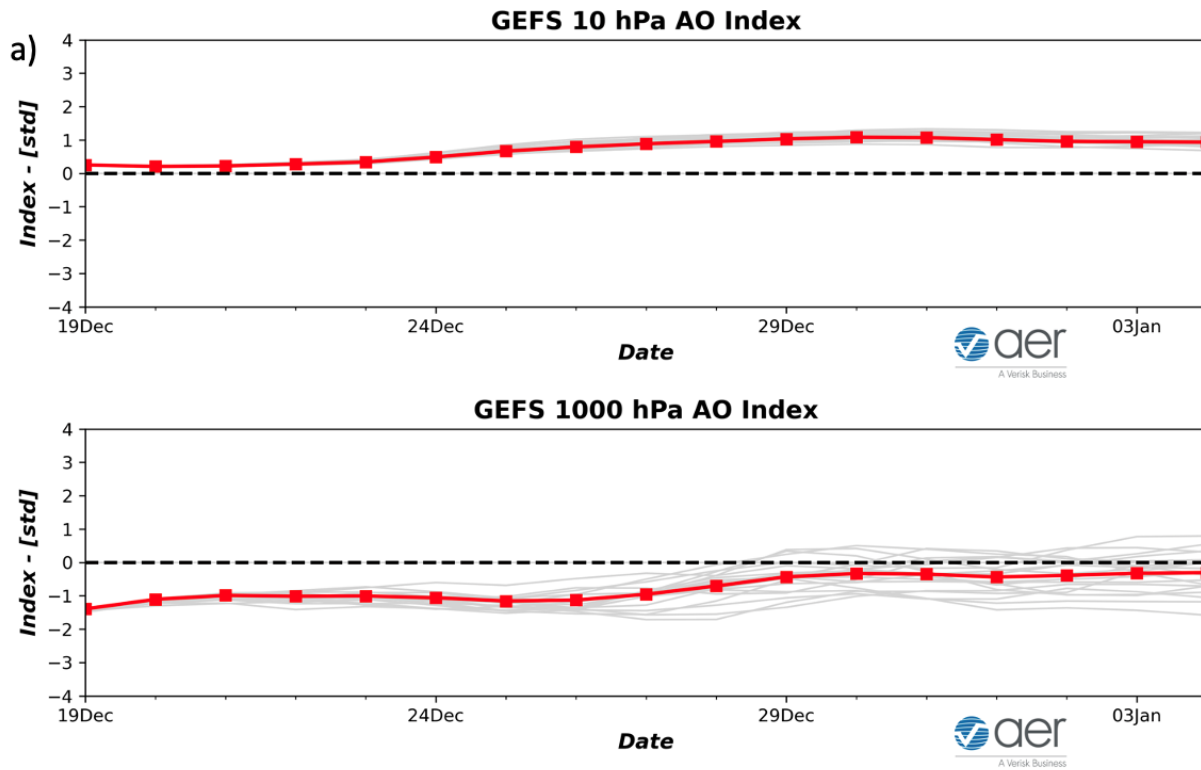


Figure 1. (a) The predicted daily-mean AO at 1000 hPa from the 00Z 19 December 2022 GFS ensemble. (b) The predicted daily-mean near-surface AO from the 00Z 19 December 2022 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

Ridging/positive geopotential height anomalies across Greenland and Baffin Bay will favor troughing/negative geopotential height anomalies across Northern Europe with ridging/positive geopotential height anomalies across Southern Europe (**Figure 2**). **This will favor** normal to below normal temperatures across Northern Europe with normal to above normal temperatures across much of Southern and Central Europe including the UK (**Figure 3**). Ridging/positive geopotential height anomalies in the Beaufort and Chukchi Seas will spread into Eastern Siberia with troughing/negative geopotential height anomalies across Western Siberia that extend southeastward into East Asia (**Figure 2**). This pattern favors normal to above normal temperatures across Eastern Siberia and Southern and Western Asia with normal to below normal temperatures across Western Siberia and East Asia (**Figure 3**).

GEFS 1-5 Day Forecast 500 hPa Anomaly
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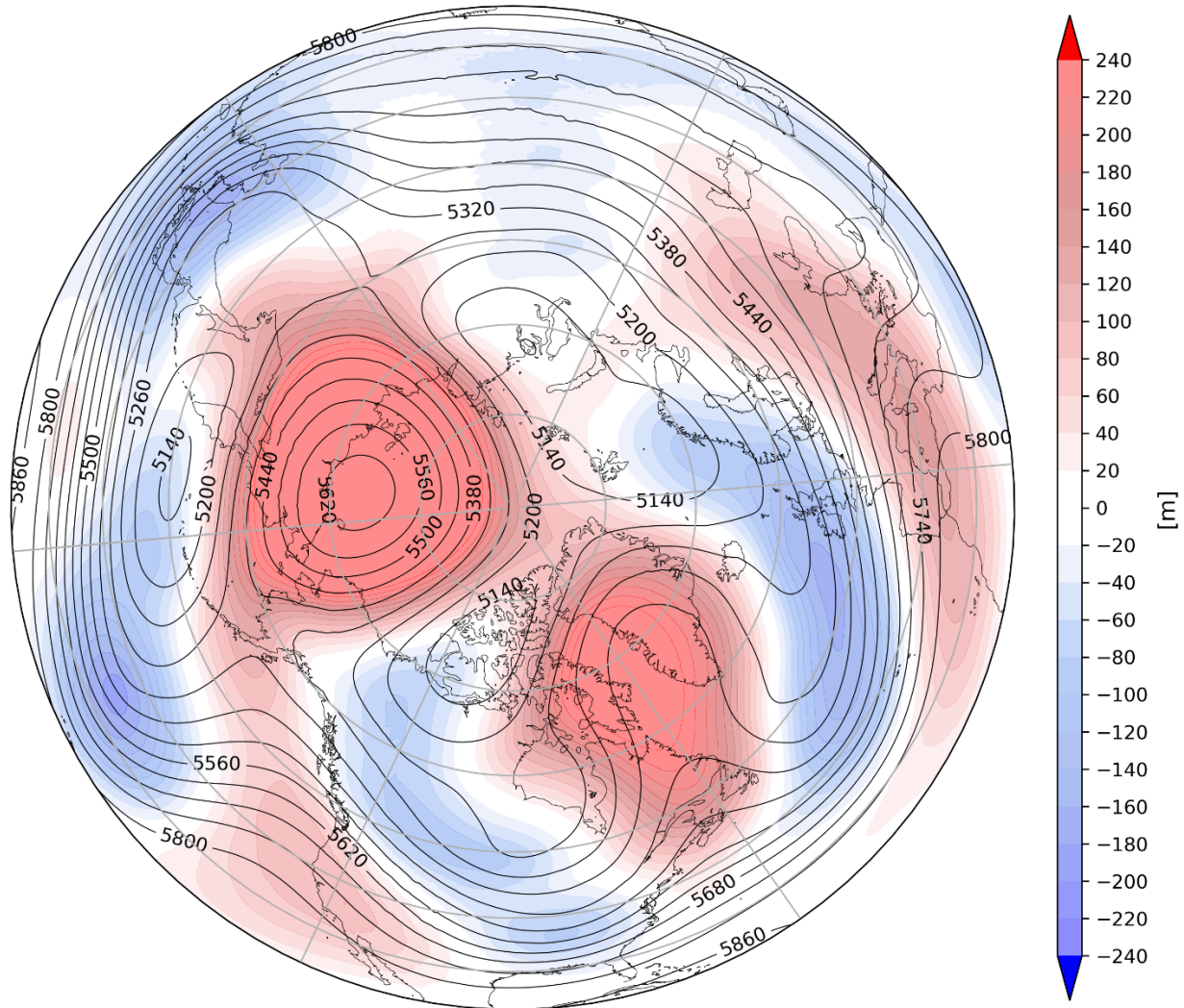


Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 20 – 24 December 2022. The forecasts are from the 00z 19 December 2022 GFS ensemble.

Ridging/positive geopotential height anomalies predicted to be centered in the Beaufort Sea will extend southward into the Gulf of Alaska will force troughing/negative geopotential height anomalies from Western Canada southeastward into the Eastern US (**Figure 2**). The pattern will favor normal to below normal temperatures across Alaska, Western Canada and the Eastern and Central US with normal to above normal temperatures across Eastern Canada and the Southwestern US (**Figure 3**).

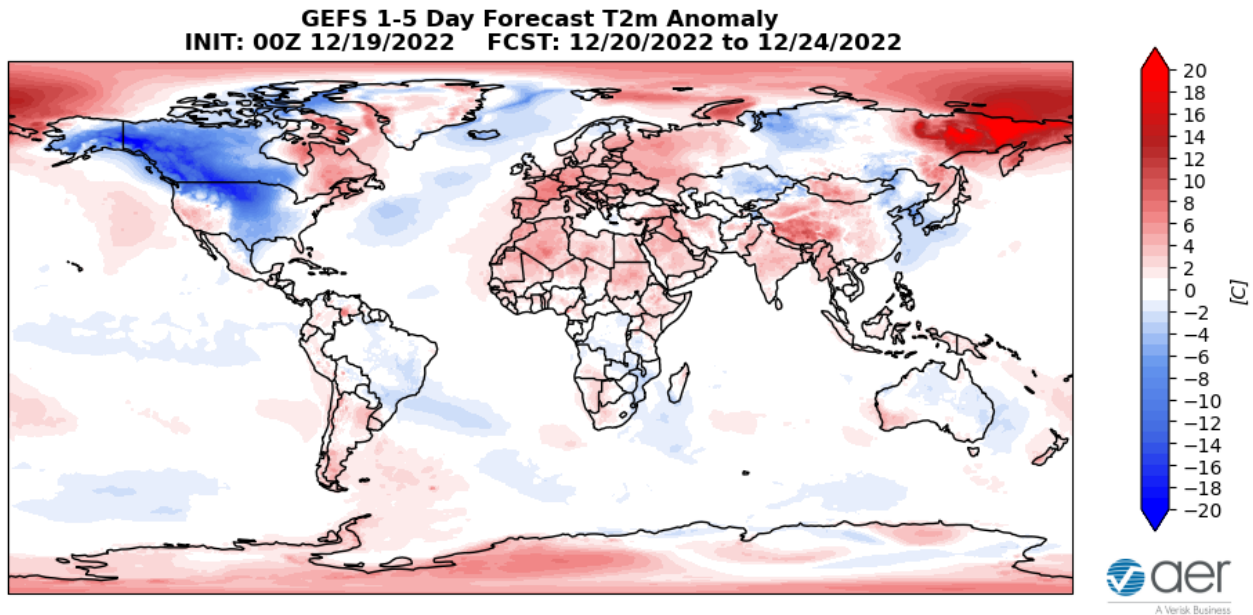


Figure 3. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 20 – 24 December 2022. The forecast is from the 00Z 19 December 2022 GFS ensemble.

Trouging and/or cold temperatures will support new snowfall across Scandinavia, Western Siberia and East Asia while mild temperatures will support snowmelt in Central and Eastern Europe (**Figure 4**). Trouging and/or cold temperatures will support new snowfall across southern Alaska, Western Canada and the Northwestern and Central US while mild temperatures will support snowmelt across the Southwestern Canada and New England (**Figure 4**).

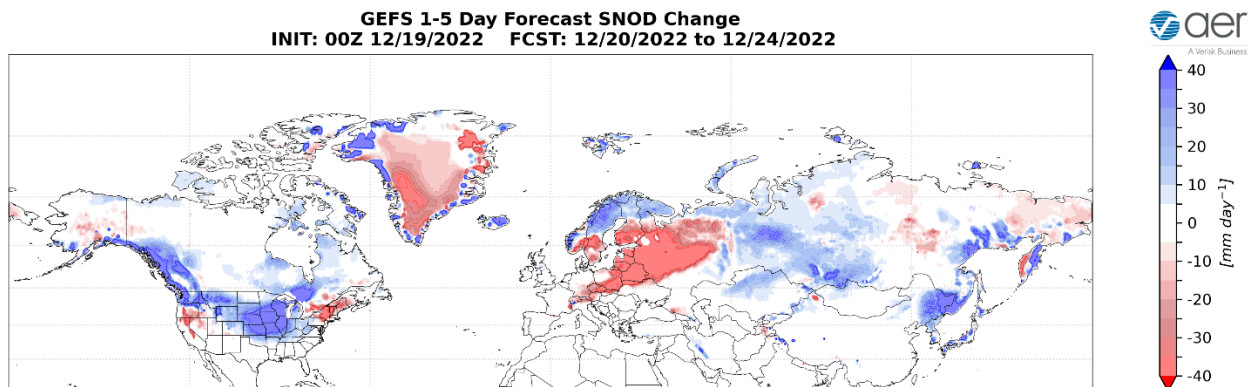


Figure 4. Forecasted snow depth changes (mm/day ; shading) from 20 – 24 December 2022. The forecast is from the 00Z 19 December 2022 GFS ensemble.

Near-Term

1-2 week

The AO is predicted to remain negative this period (**Figure 1**) as geopotential height anomalies remain mostly positive across the North Pacific and North Atlantic sectors of the Arctic and mixed across the mid-latitudes (**Figure 5**). With mostly positive geopotential height anomalies across Greenland (**Figure 5**), the NAO is predicted to remain neutral to negative this period as well.

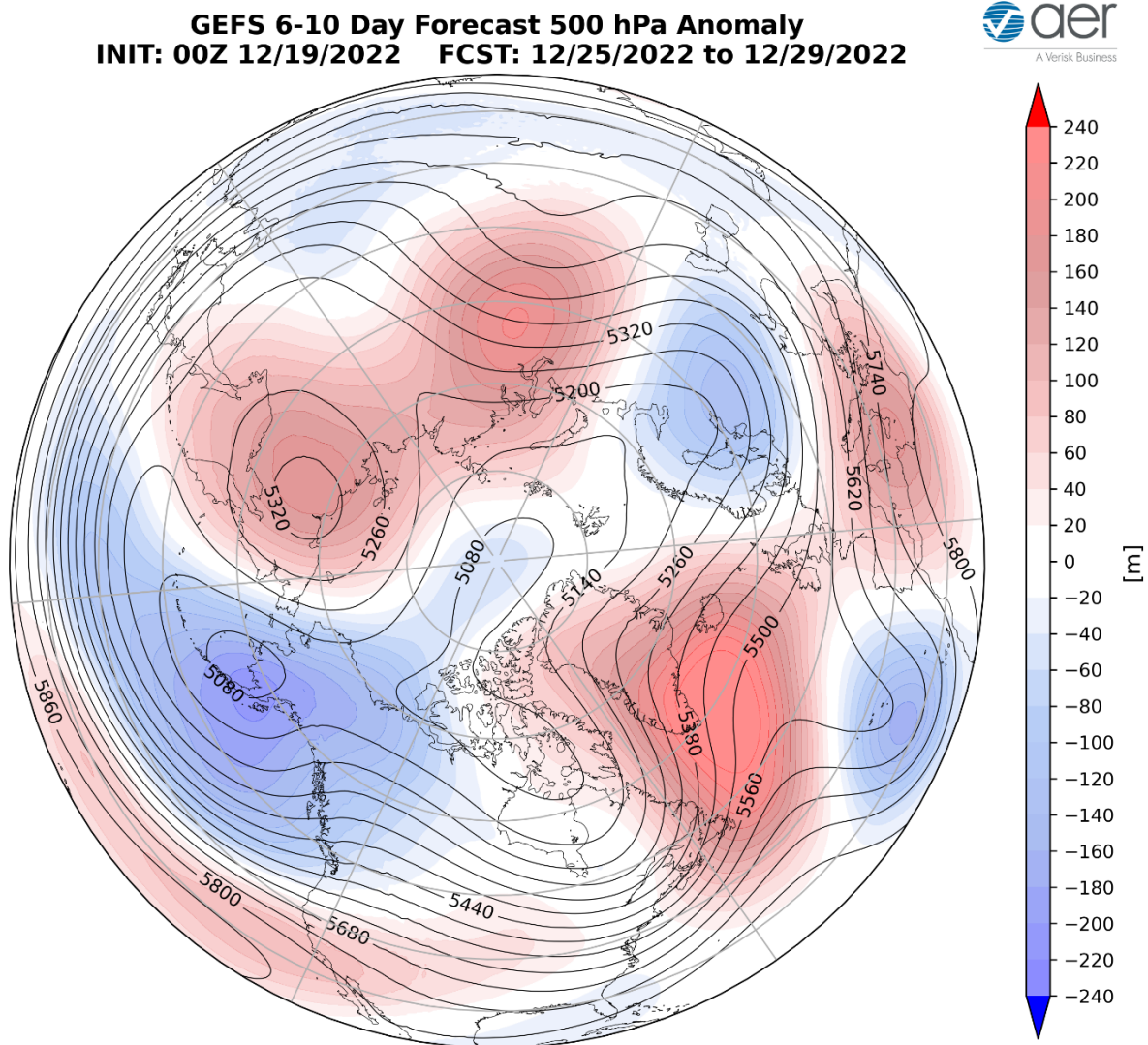


Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 25 – 29 December 2022. The forecasts are from the 00z 19 December 2022 GFS ensemble.

With ridging/positive geopotential height anomalies predicted to persist across Greenland troughing/negative geopotential height anomalies are favored across Northern Europe with ridging/positive geopotential height anomalies across Southern

Europe (**Figure 5**). Normal to below normal temperatures are predicted to persist across Northern Europe this time including the UK with normal to above normal temperatures across Southern and Central Europe (**Figure 6**). Persistent ridging/positive geopotential height anomalies in Eastern Siberia are predicted to spread across all of Siberia forcing troughing/negative geopotential height anomalies to the south across Eastern Asia this period (**Figure 5**). This pattern favors widespread normal to above normal temperatures across Northern, Western and Southern Asia with normal to below normal temperatures predicted in pockets in Central and Eastern Asia (**Figure 6**).

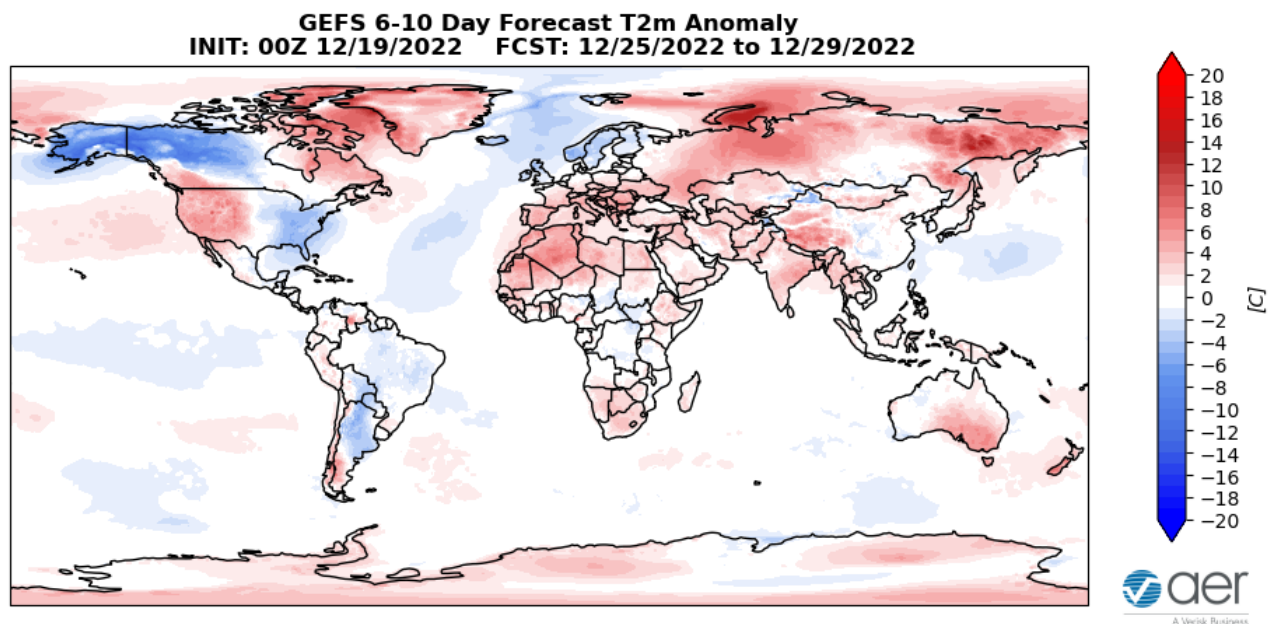


Figure 6. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 25 – 29 December 2022. The forecast is from the 00Z 19 December 2022 GFS ensemble.

With ridging/positive geopotential height anomalies previously in the Beaufort Sea will drift into Eastern Siberia allowing troughing/negative geopotential height anomalies in Alaska and Western Canada and the Eastern US with more ridging/positive geopotential height anomalies in the Southwestern US and persisting near Baffin Bay this period (**Figure 5**). This pattern will favor normal to below normal temperatures widespread across Alaska, Western Canada and the Eastern US with normal to above normal temperatures in Eastern Canada and the Western US (**Figure 6**).

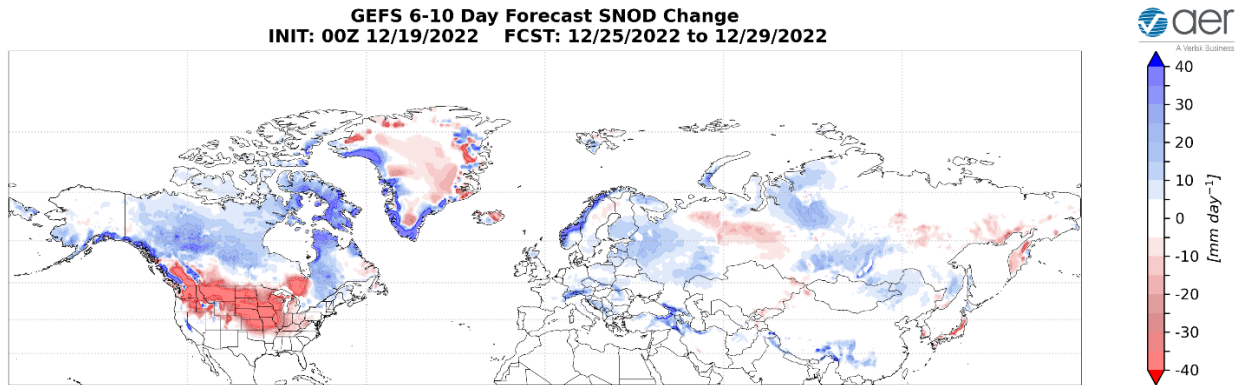


Figure 7. Forecasted snow depth changes (mm/day; shading) from 25 – 29 December 2022. The forecast is from the 00Z 19 December 2022 GFS ensemble.

Trouging and/or cold temperatures will support new snowfall across Scandinavia, Eastern Europe, Western, Central and Eastern Asia while mild temperatures will support snowmelt in the Urals and Eastern Siberia (**Figure 7**). Trouging and/or cold temperatures will support new snowfall across western and southern Alaska and much of Canada while mild temperatures will support snowmelt in the Western and Central US (**Figure 7**).

3-4 week

Positive geopotential height anomalies are predicted to continue to dominate the North Atlantic sector of the Arctic with mixed geopotential height anomalies across the mid-latitudes this period (**Figure 8**), therefore the AO should remain neutral to negative this period (**Figure 1**). With weak but positive pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO will also remain neutral to negative this period.

GEFS 11-15 Day Forecast 500 hPa Anomaly
INIT: 00Z 12/19/2022 FCST: 12/30/2022 to 01/03/2023

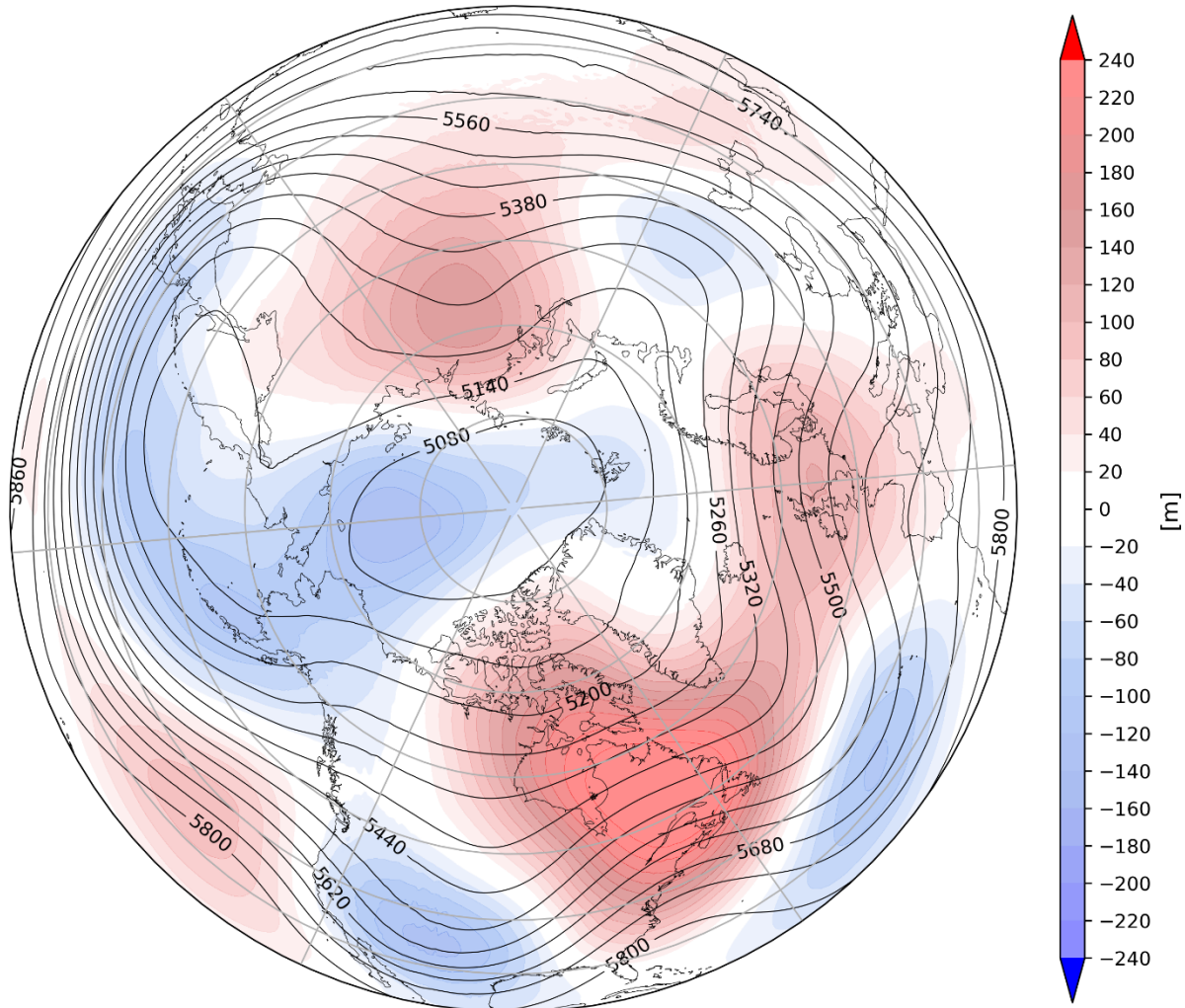


Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 30 December 2022 – 3 January 2023. The forecasts are from the 00z 19 December 2022 GFS ensemble.

With only weak ridging/positive geopotential height anomalies predicted across Greenland ridging/positive geopotential height anomalies are predicted to dominate Europe this period (**Figure 8**). This pattern favors normal to above normal temperatures across Europe however induced northerly flow will allow for normal to below normal temperatures in pockets across Northern and Eastern Europe including the UK (**Figures 9**). Predicted ridging/positive geopotential height anomalies centered Western Siberia will help to anchor troughing/negative geopotential height anomalies across far Eastern Siberia that extend southward into East Asia and across Western Asia (**Figure 8**). This pattern favors widespread normal to above normal temperatures

across much of Siberia, Southern and Central Asia with normal to below normal temperatures across Eastern and Western Asia and far Eastern Siberia (**Figure 9**).

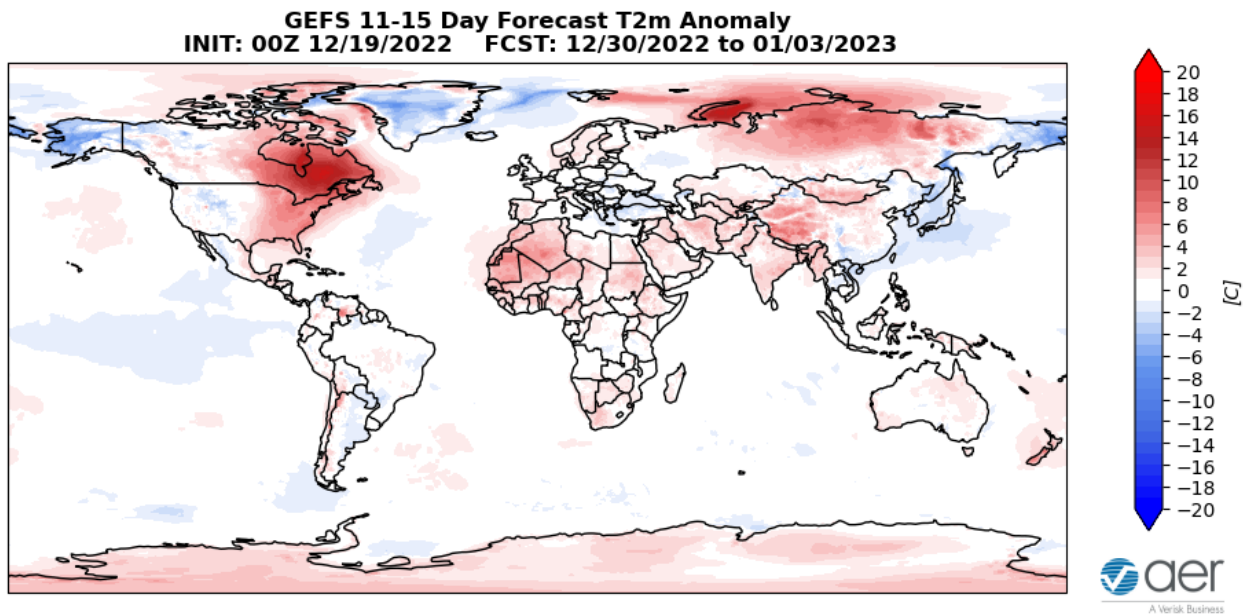


Figure 9. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 30 December 2022 – 3 January 2023. The forecast is from the 00Z 19 December 2022 GFS ensemble.

Predicted persistent ridging/positive geopotential height anomalies in Siberia will continue to favor troughing/negative geopotential height anomalies across Alaska, Western Canada and the Western US with ridging/positive geopotential height anomalies will persist in Eastern Canada and now extends into the Eastern US this period (**Figure 8**). This pattern favors widespread normal to below normal temperatures across Alaska, Western Canada and the Western US with normal to above normal temperatures across Eastern Canada and the Eastern US (**Figure 9**).

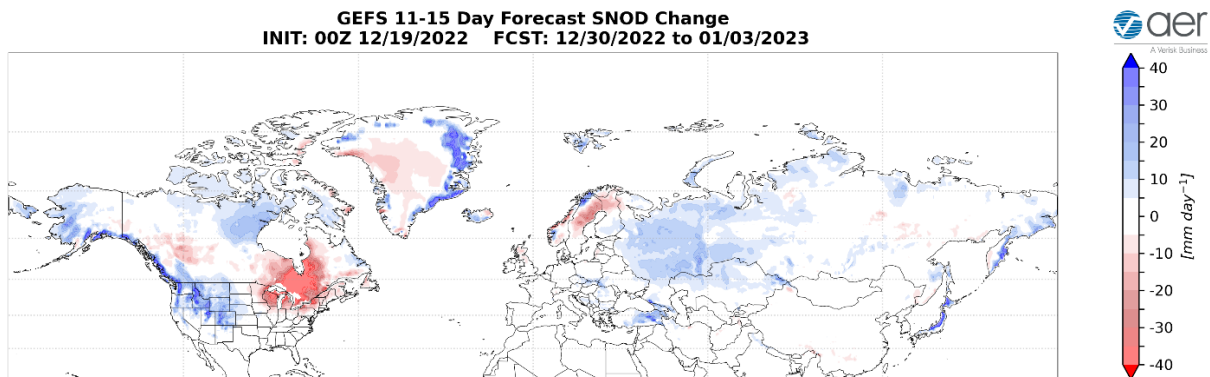


Figure 10. Forecasted snow depth changes (mm/day; shading) from 30 December 2022 – 3 January 2023. The forecast is from the 00Z 19 December 2021 GFS ensemble.

Trouthing and/or cold temperatures will support new snowfall across Norway, Turkey, Western and Eastern Asia while mild temperatures will support snowmelt in Sweden (**Figure 10**). Trouthing and/or cold temperatures will support new snowfall across western Alaska, Northern Canada and the Western US while mild temperatures will support snowmelt in Western Canada, the Great Lakes and southern Hudson Bay (**Figure 10**).

Longer Term

30-day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows cold/negative PCHs in the upper stratosphere with warm/positive PCHs in the lower and mid stratosphere and the troposphere (**Figure 11**). Cold/negative PCHs in the upper stratosphere are predicted to strengthen and descend into the lower stratosphere starting this week (**Figure 11**).

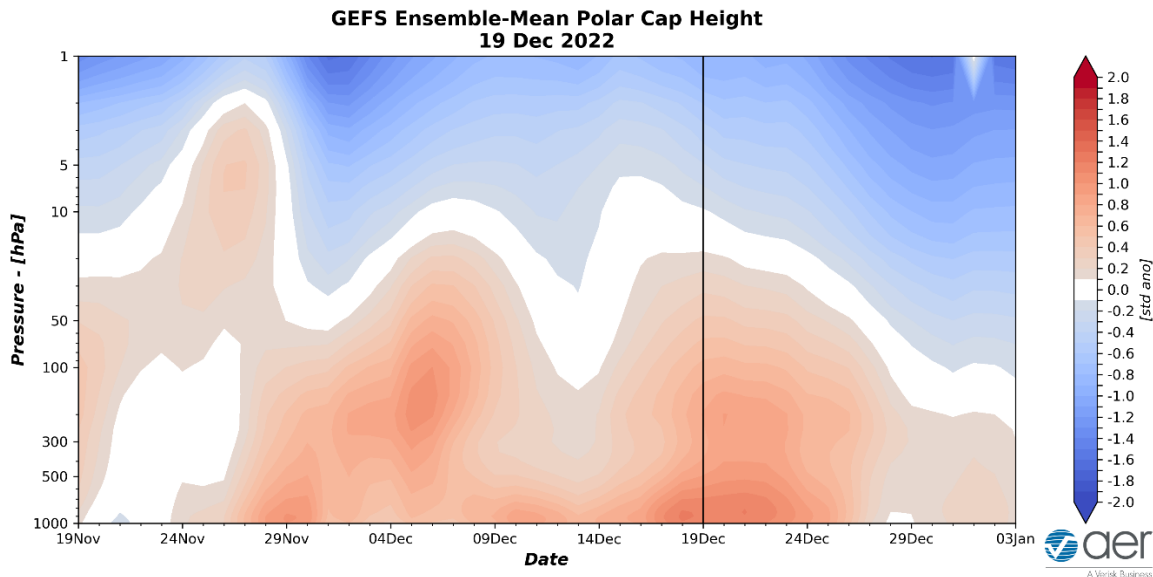


Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 19 December 2022 GFS ensemble.

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

weaken (**Figure 11**), in concert with the strengthening cold/negative PCHs in the stratosphere (**Figure 1**).

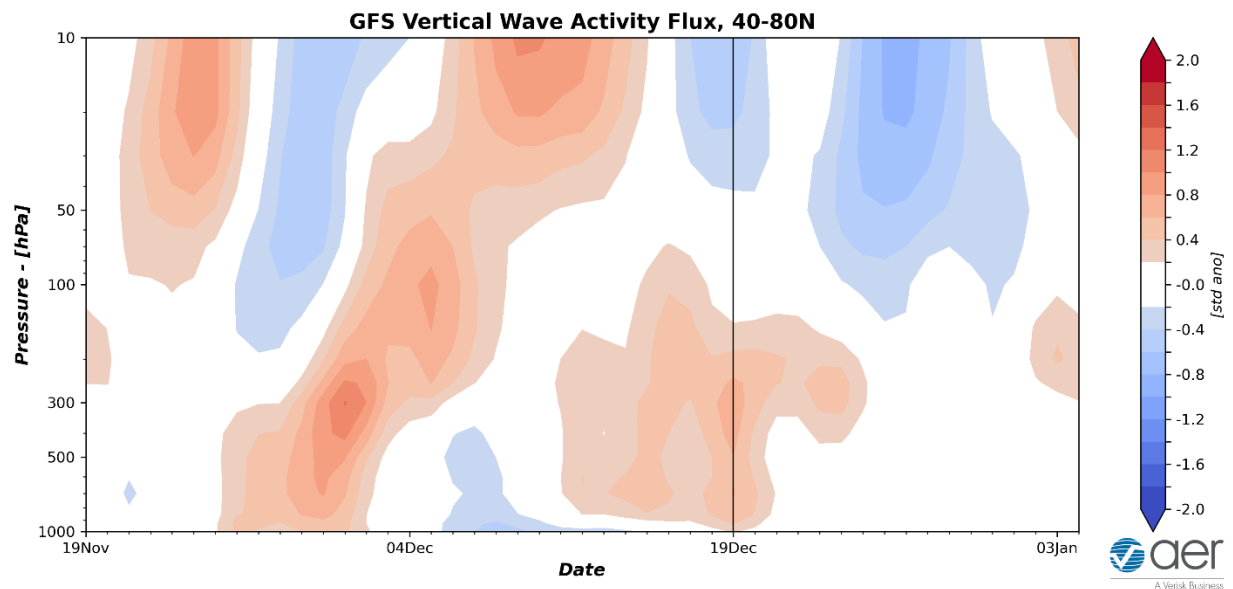


Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 19 December 2022 GFS ensemble.

Above normal vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere the past week (**Figure 12**) has resulted in mixed stratospheric PCHs with warm in the lower stratosphere and cold in the upper stratosphere (**Figure 11**). The GFS is predicting a mostly below normal period of WAFz in the next two weeks (**Figure 12**), resulting in overall cooling in the stratosphere heading into the holiday season (**Figure 11**).

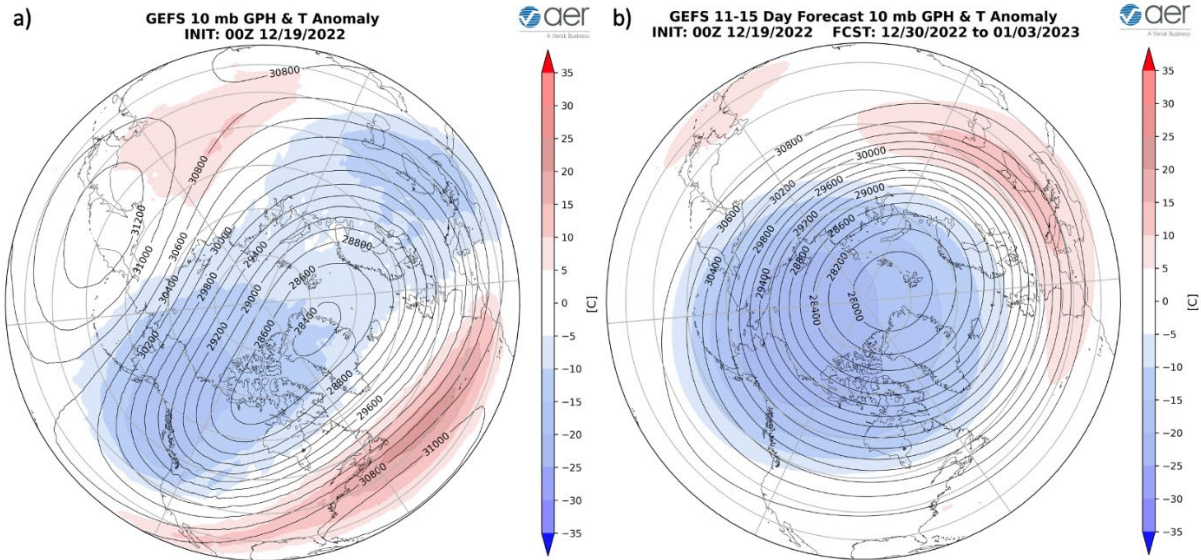


Figure 13. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere for 19 December 2022. (b) Same as (a) except forecasted averaged from 30 December 2022 – 3 January 2023. The forecasts are from the 00Z 19 December 2020 GFS model ensemble.

Still the recent more active WAFz has caused a minor perturbation of the stratospheric PV with the PV center shifted over to Greenland with a ridge center near Kamchatka (**Figure 13**). This configuration of the PV is it consistent with a stretched PV though the orientation of the trough axis from Scandinavia to the Gulf of Alaska is unusual (**Figure 13**). The below normal WAFz predicted for the next two weeks will allow the PV to strengthen, become circular in shape and for the polar stratosphere to cool (**Figure 13**). These are all signs of a strong PV. Therefore, the stratospheric AO is predicted to remain positive to possibly strongly positive over the next two weeks (**Figure 1**). A strong, circular PV favors an overall mild pattern.

CFS 500 hPa Forecast Anomaly Jan 2023
Valid as of 19 Dec 2022

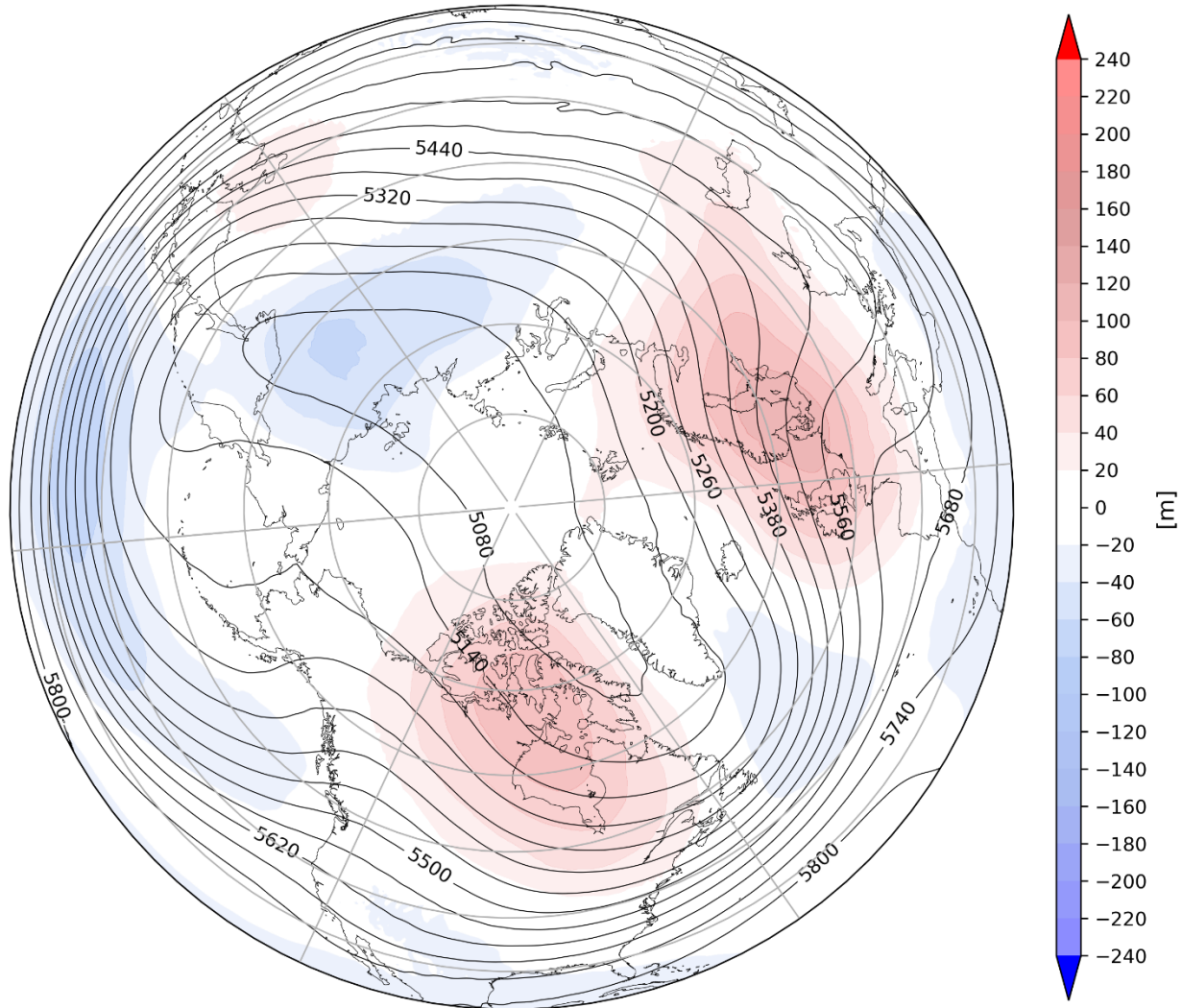


Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for January 2022. The forecasts are from the 00Z 19 December 2022 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and surface temperatures for January (**Figure 15**) from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging stretching across Northern Europe and the Canadian Arctic archipelagos with troughing across the eastern Mediterranean, Siberia, East Asia, near the Aleutians and eastern North America (**Figure 14**). This pattern favors seasonable to relatively warm temperatures across Europe, Western and Central Asia, Eastern Siberia, Western and Central Canada and the Western and Central US with seasonable to relatively cold temperatures across Western and Central Siberia, East Asia, Alaska, Eastern Canada and the Northeastern US (**Figure**

15).

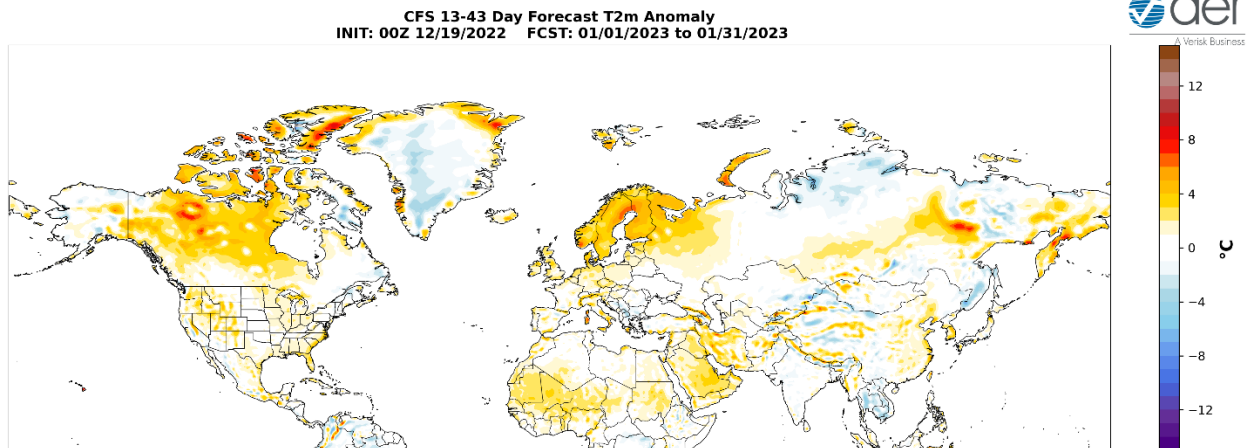


Figure 15. Forecasted average surface temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere for January 2022. The forecasts are from the 00Z 19 December 2022 CFS.

Boundary Forcings

Arctic Sea Ice

Arctic sea ice, which as expected is below normal (see **Figure 16**) but the regional anomalies have been more extensive in recent years. I believe that the realization of a cold NH winter is most dependent on high latitude blocking in the North Atlantic sector, and that is where I am focused. Sea ice extent is below normal in the Barents-Kara Seas, which I believe favors high latitude blocking. Sea ice is below normal in the Chukchi and Bering Seas but I do think that the predicted pattern is conducive for the sea ice extent to grow. So it could be Arctic sea ice is increasingly favoring high latitude blocking in the Barents-Kara Seas region and PV disruptions.

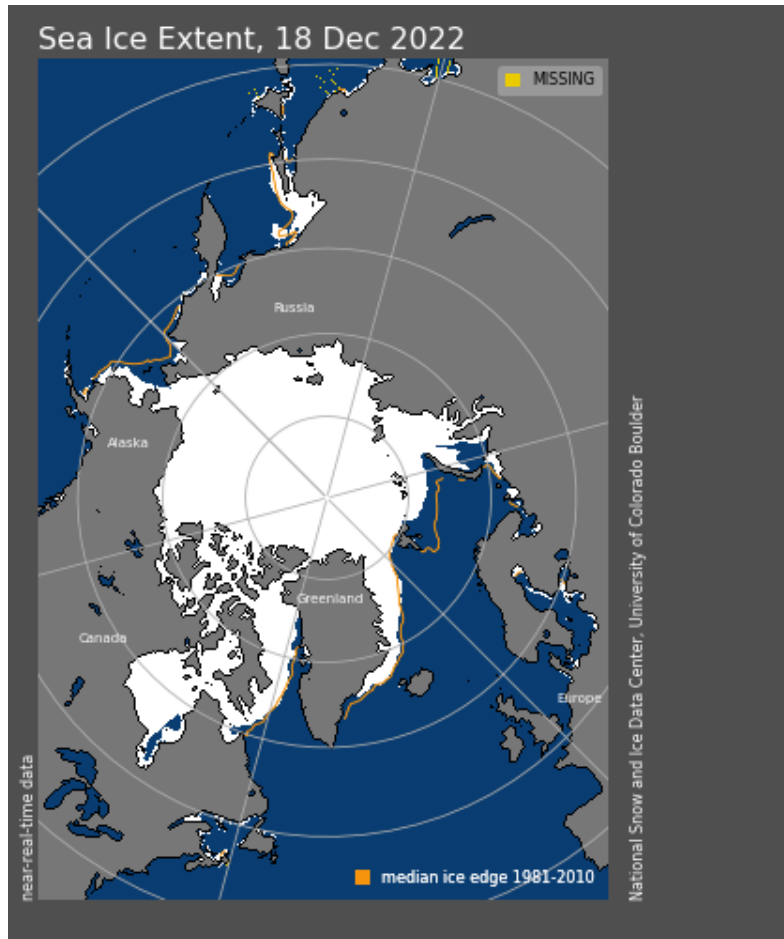


Figure 16. Observed Arctic sea ice extent on 18 December 2022 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image from the National Snow and Ice Data Center (NSIDC).

SSTs/El Niño/Southern Oscillation

Equatorial Pacific sea surface temperatures (SSTs) anomalies are below normal and we continue to observe weak La Niña conditions (**Figure 17**) and La Niña conditions are expected through the fall. Observed SSTs across the NH remain well above normal especially in the central North Pacific (west of recent years), the western North Pacific and offshore of eastern North America though below normal SSTs exist regionally especially in the South Pacific.

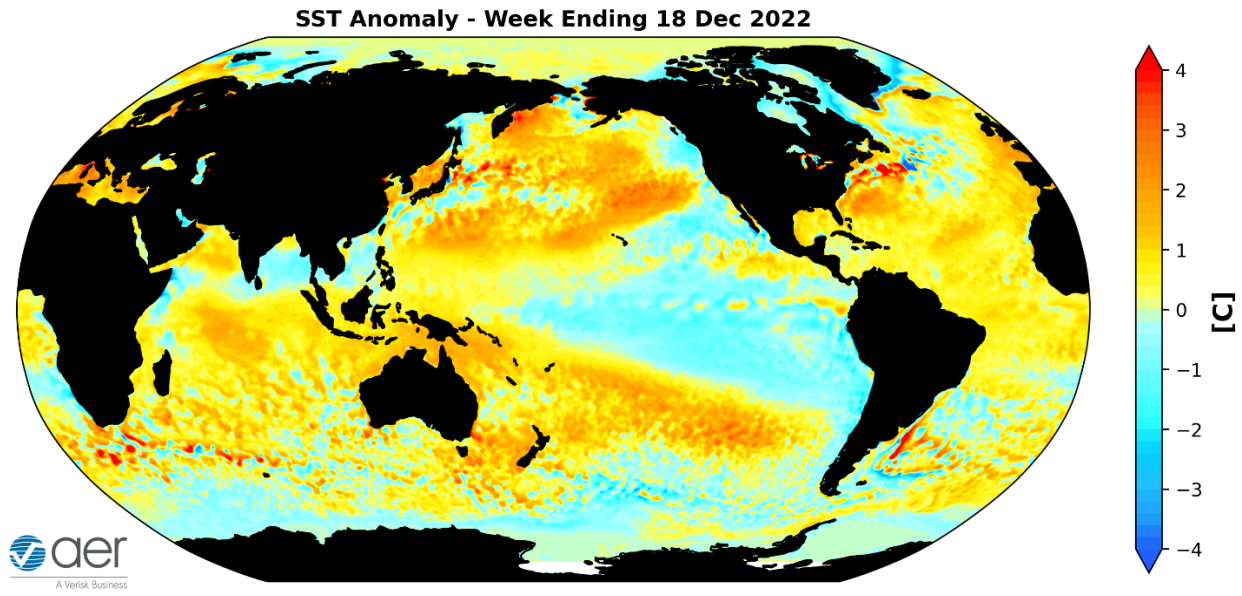


Figure 17. The latest weekly-mean global SST anomalies (ending 18 December 2022). Data from NOAA OI High-Resolution dataset.

Madden Julian Oscillation

Currently no phase of the Madden Julian Oscillation (MJO) is favored (**Figure 18**). The forecasts are for the MJO to remain weak where no phase is favored and then emerge into phase five and then six and seven next week. Phases five through seven favor first troughing over Alaska and western North America with ridging across eastern North America and then evolving into ridging over western North America with increasing troughing in eastern North America. Seems that the MJO could be having an influence on the weather across North America in the coming weeks. But admittedly this is outside of my expertise.

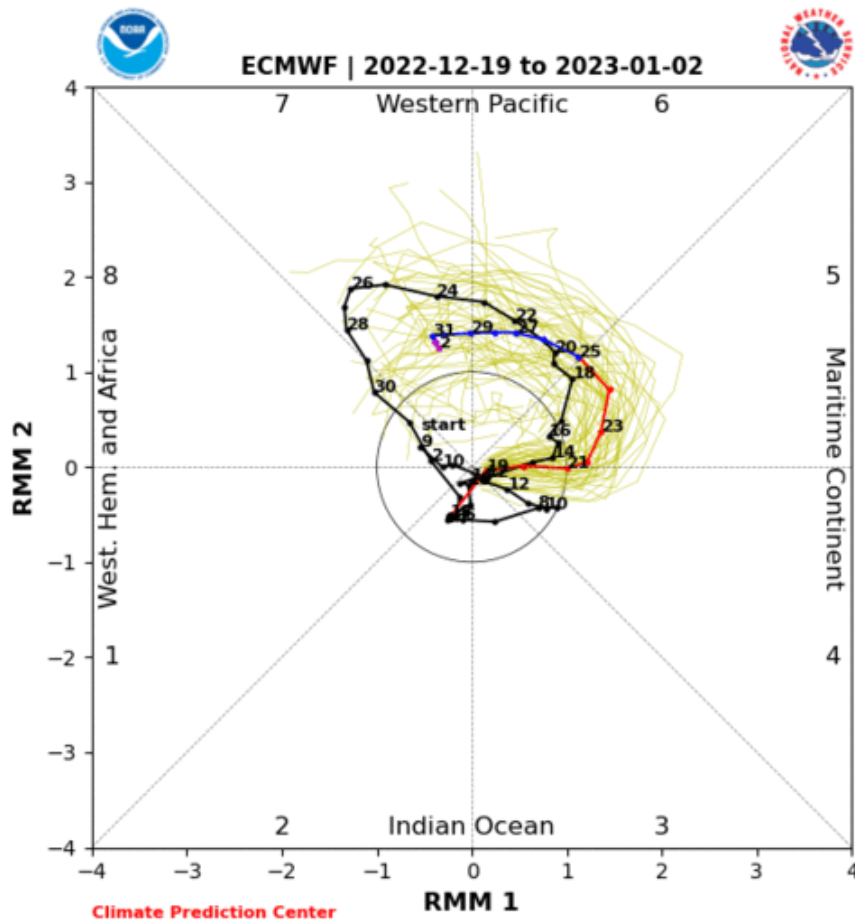


Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 19 December 2022 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model “spread” is denoted by the gray shading. Sector numbers indicate the phase of the MJO, with geographical labels indicating where anomalous convection occurs during that phase. Image source:

<http://www.atmos.albany.edu/facstaff/roundy/waves/phasediags.html>

Snow Cover

Snow cover extent (SCE) across the NH has advanced again this week (see **Figure 19**). Snow cover has advanced both across North America and Eurasia this week and therefore SCE remains near decadal means. With the predicted widespread cold across North America, I expect snow cover to advance more rapidly across North America than Eurasia this week.

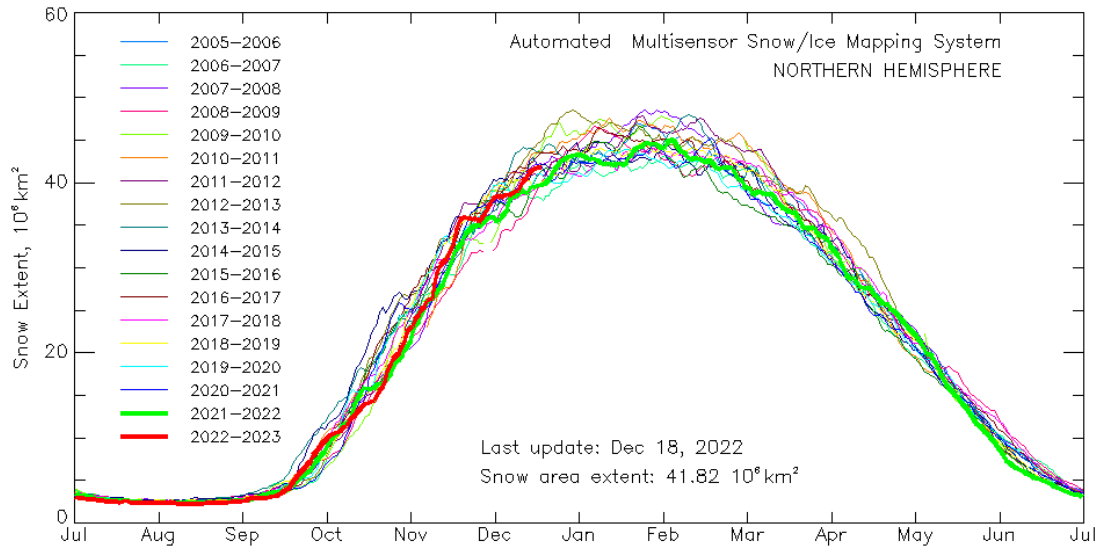


Figure 19. Observed North American snow cover extent through 18 December 2022. Plot from https://www.star.nesdis.noaa.gov/smcd/emb/snow/HTML/snow_extent_monitor.html