Arctic Oscillation and Polar Vortex Analysis and Forecasts

December 20, 2021

Dear AO/PV blog readers:

We have shifted the public release of the Arctic Oscillation/Polar Vortex blog to Wednesdays weekly through the winter season.

For those who would like an early look on Mondays, we will be offering at a nominal price (US $25) a PDF version of the upcoming blog, and we will be rolling out in the coming weeks access to the datasets used in the production of this blog. At present we plan to make available in comma-separated values the timeseries of the Polar Cap Height and the timeseries of the Wave Activity Flux (vertical component), though we would appreciate to hear your suggestions for additional data of interest to you all.

Special blog on winter 2018/2019 retrospective can be found here - http://www.aer.com/winter2019

Special blog on winter 2017/2018 retrospective can be found here - http://www.aer.com/winter2018

Special blog on winter 2016/2017 retrospective can be found here - http://www.aer.com/winter2017

Special blog on winter 2015/2016 retrospective can be found here - http://www.aer.com/winter2016

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.

Subscribe to our email list or follow me on Twitter (@judah47) for notification of updates.

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 positive pressure/geopotential height anomalies over Greenland are predicted to push into the Central Arctic with mixed pressure/geopotential height anomalies across the mid-latitudes. The North Atlantic Oscillation (NAO) is currently negative and is predicted to remain negative as positive pressure/geopotential height anomalies are predicted to persist across Greenland the next two weeks.
- The next two weeks, ridging/positive geopotential height anomalies across Greenland will favor troughing/negative geopotential height anomalies coupled with normal to below temperatures across much of Europe including the United Kingdom (UK). One except is for ridging/positive geopotential height anomalies coupled with normal to above normal temperatures moving from west to east across the Mediterranean countries.
- The predicted general pattern across Asia the next two weeks is an omega block pattern with troughing/negative geopotential height anomalies centered in the Barents-Kara Seas and Eastern Siberia bookending ridging/positive geopotential height anomalies in Central Asia. This will favor with normal to below normal temperatures across Northwestern and Eastern Asia with normal to above normal temperatures across much Central and Southern Asia.
- Persistent and nearly stationary ridging/positive geopotential height anomalies near the Aleutians will favor troughing/negative geopotential height anomalies in Western Canada and the Western US with ridging/positive geopotential height anomalies in Northeastern Canada and the Southeastern US. This pattern favors normal to below normal temperatures across Alaska, Western and Central Canada and the Western US with normal to above temperatures for much of the Eastern US and Eastern Canada. However, towards the end of the month cold air in western North America will slowly filter eastward.
- In the *Impacts* section I discuss the how I feel that the atmosphere has made a turn but not decisive, towards a weaker polar vortex (PV) in January and how it may impact the remainder of the winter for the Northern Hemisphere (NH).

Plain Language Summary

As I have been discussing, I feel that the atmosphere has approached a fork in the road for the winter. The first path includes a brief colder period as we close out the year and a resumption of relatively milder weather will return early in the new Year. The second path means the overall mild winter is mostly winding down and much of the remainder of the winter will feature colder weather. Based on my own diagnosis, I feel that the atmosphere has made a step towards the colder solution.

Impacts

In the past two blogs I have discussed how at least for me, how the winter evolves from here has reached a fork in the road and I can see two distinct paths with very different outcomes. The first path is a troposphere-stratosphere-troposphere (T-S-T) coupling event that in the short term is characterized by a relatively cold period across the Northern Hemisphere (NH) continents but transitions to an extended period of a strong polar vortex (PV), a positive AO/NAO and widespread relatively mild temperatures across the NH continents starting most likely in mid-January. This first path is supported by the polar cap geopotential height anomalies (PCHs) which shows cold/negative PCHs in the stratosphere and we are currently in the mid-point of this T-S-T coupling event where the mild tropospheric response to the strong PV is delayed but it is coming.

The second path is where the relatively cold period across the NH continents for the end of December and into early January disrupts the overall mild T-S-T coupling event. In its place, we are at the very beginning of a T-S-T coupling event that favors a more disrupted PV and the remainder of the winter is overall colder than the first path. In this second path or scenario the upcoming cold period would not be continuous but would also transition to a milder period in mid-January, but a significant weakened PV would couple to the surface leading to potentially and extended cold period in late winter. The best support of this scenario is recent and predicted ridging/high pressure in the Urals/Barents-Kara Seas region. It's not optimal to disrupt the PV but should at least force some weakening with potentially more significant weakening in January.

In recent winters, the lack of sea ice in the Barents-Kara Seas, in my opinion, has helped to anchor ridging/high pressure in the Urals/Barents-Kara Seas region giving it enough durability to disrupt the PV. However, this year sea ice is close to normal in this region and may not be much of a factor. Instead, Eurasian snow cover and depth (see **Figure i**), which is above normal across Siberia may be the boundary forcing that could be the difference in weakening the PV favoring a more negative AO/NAO resulting in a relatively cold pattern for the NH continents in late winter.

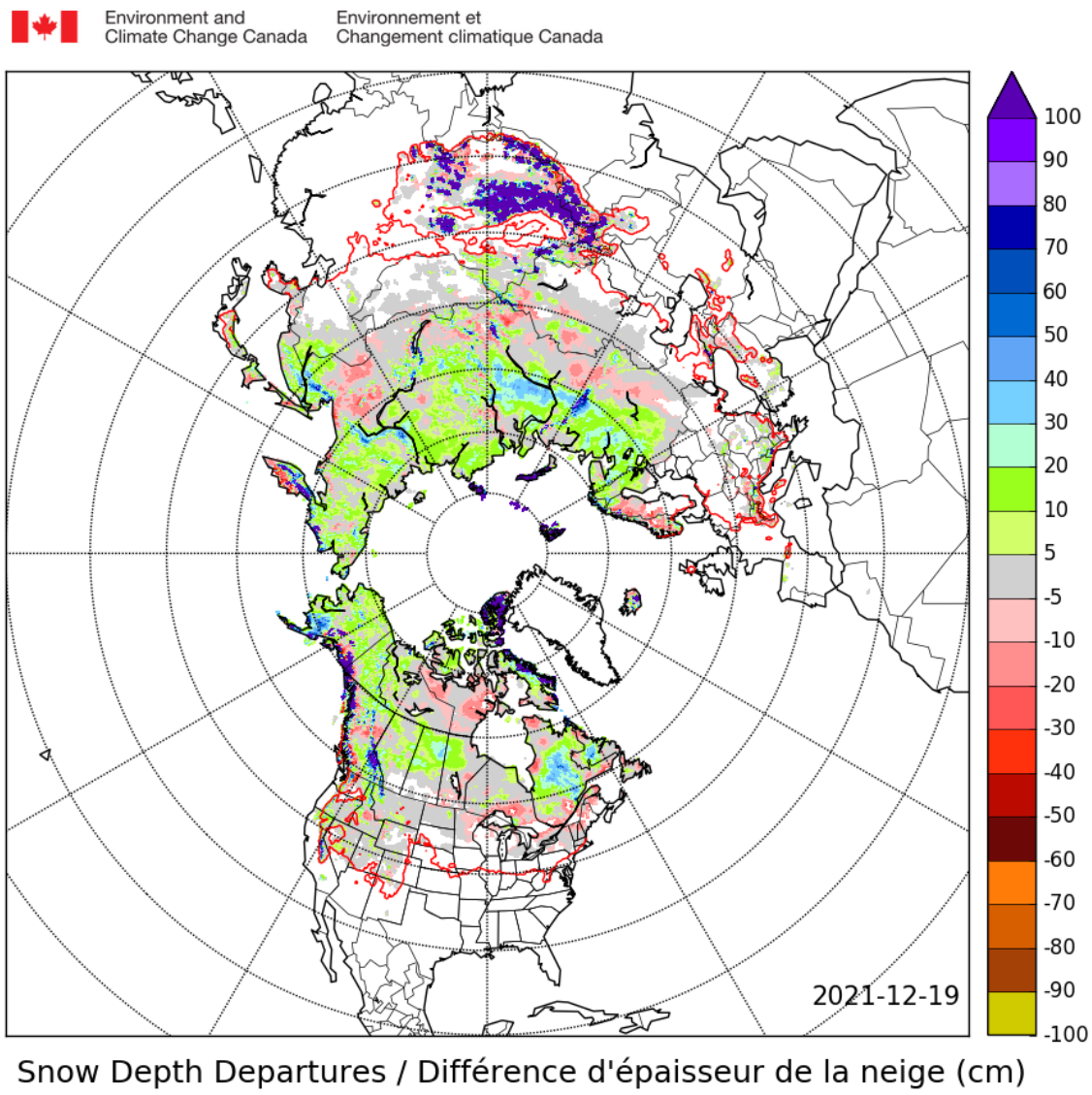

Figure i. Current snow depth anomalies across the Northern Hemisphere. Plot taken from: https://www.ccin.ca/ccw/snow/current.

The next necessary link in this chain reaction is ridging/high pressure in the Urals/Barents-Kara Seas region. And based on our estimate of December 2021 sea level pressure anomalies, the most prominent anomaly feature in the eastern hemisphere is high pressure (SLP) in the Barents-Kara Seas (see **Figure ii**). Again, the pattern is not optimal for disrupting the PV but it is a start especially after the November SLP pattern that was optimal for strengthening the PV. Furthermore there are signs that Urals/Barents-Kara Seas blocking will continue into January (see **Figure 14**). Still the

elephant in the room are the large positive anomalies south of the Aleutians and are consistent with La Niña and a negative Pacific Decadal Oscillation (PDO).

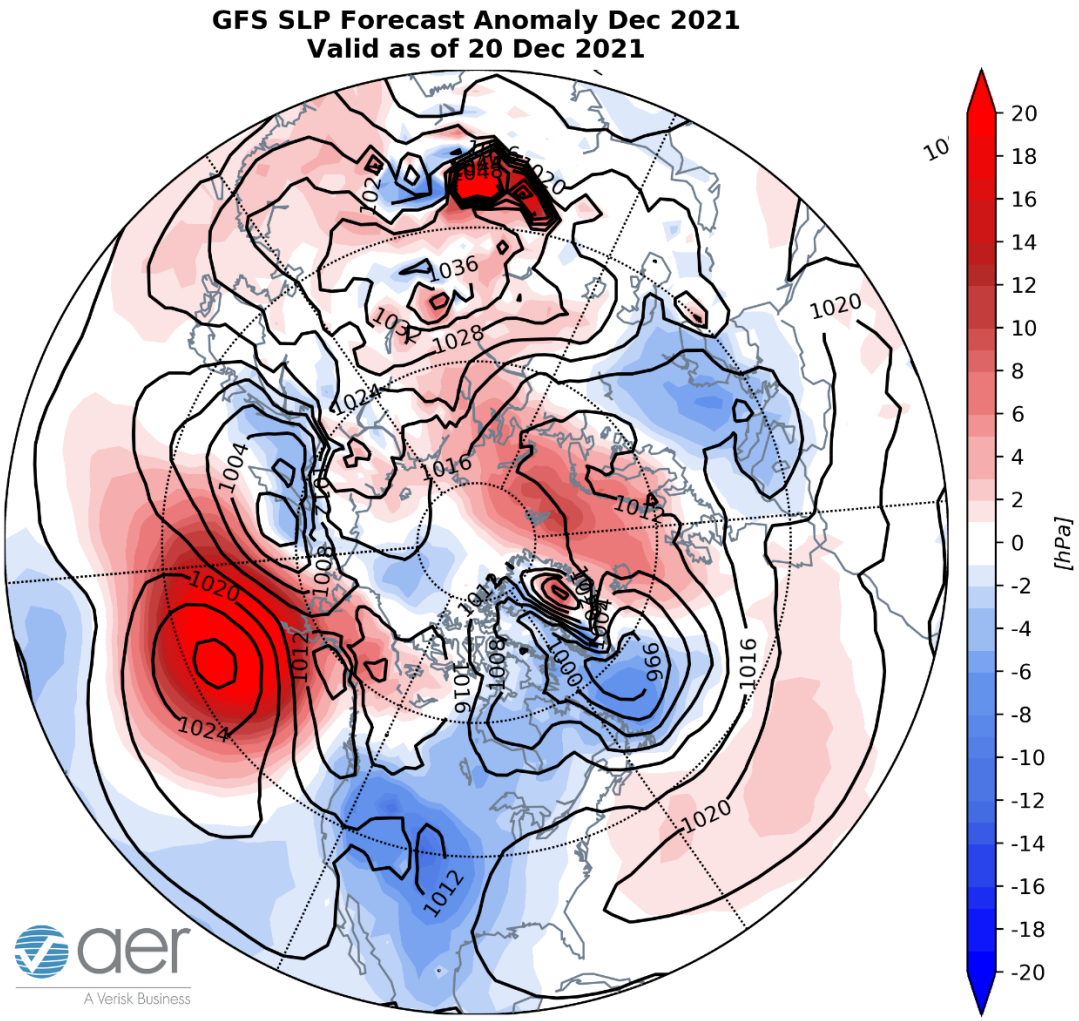

Figure ii. Estimated sea level pressure (contours) and anomalies (shaded) for December 2021 from GFS analysis and forecasts from 20 December 2021.

A recent paper by Wegmann et al. 2021 argues that a Eurasian, west to east snow cover/depth dipole in November with below normal snow cover in West Asia and above normal snow cover in East Asia favors the T-S-T coupling that begins with Ural/Barents-Kara Seas ridging/high pressure is followed by a weakened PV and culminate with a negative AO/NAO. The snow cover extent anomalies from November 2021 certainly resemble the west to east dipole in Wegmann et al. (compare **Figure iii** with their Figure 3), so it will be interesting to follow.

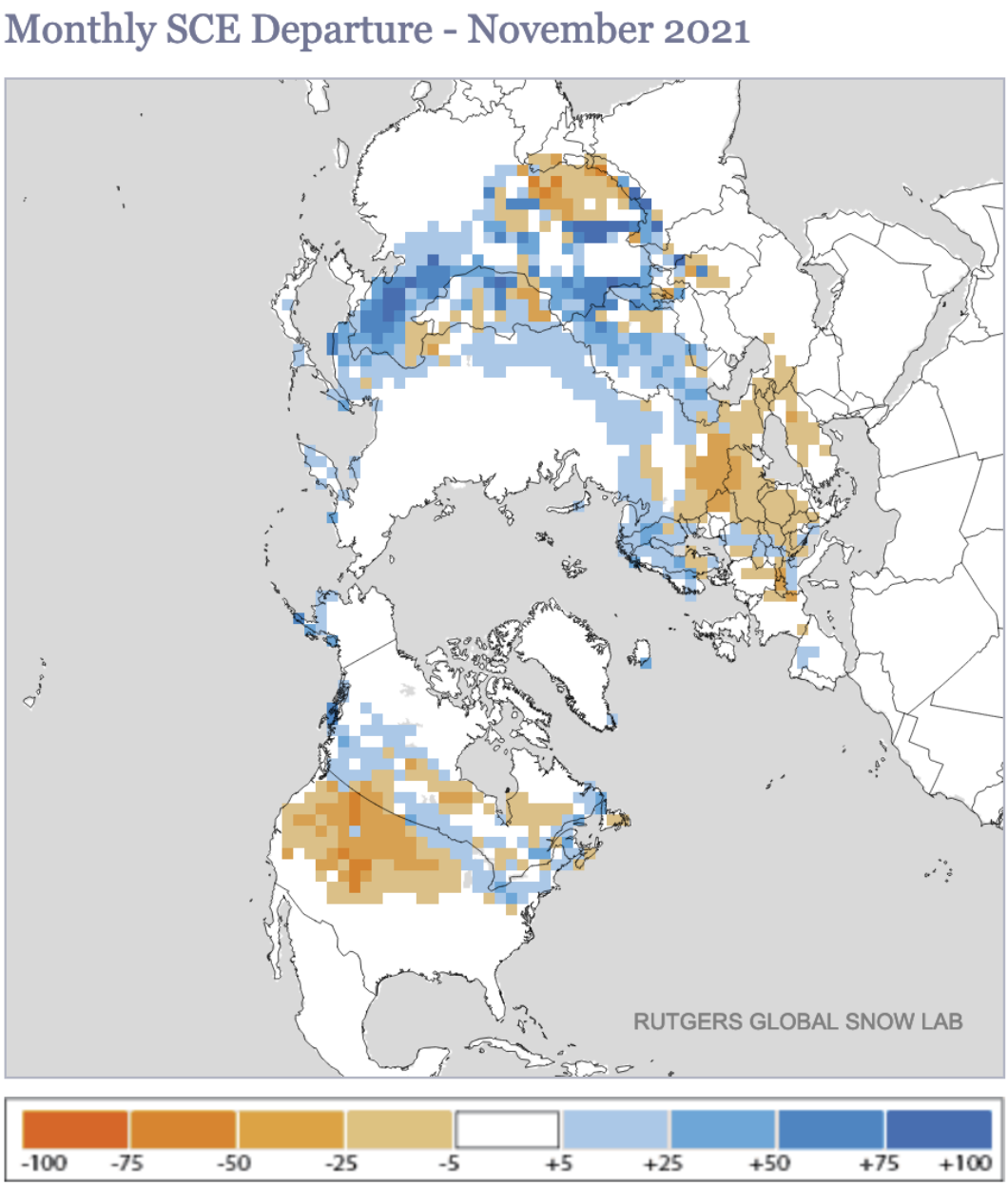

Figure **iii**. November 2021 snow cover extent anomalies across the Northern Hemisphere from http://climate.rutgers.edu/snowcover/index.php

In my opinion, the atmosphere has not fully committed to one path over the other, but I do think that the atmosphere has taken a recognizable step towards the colder scenario. First the GFS is predicting that the cold stratospheric PCHs will warm and are getting close to normal rather than deepening (see **Figure 11**). Also coloring my expectations is the predicted return of Ural ridging/high pressure with downstream troughing/low pressure in East Asia (see **Figure 8**). I think that this will be enough to continue disrupting the stratospheric PV. And as I tweeted, our highly experimental PV

model is predicting a significant/meaningful disruption of the PV in January but most likely in late January. And if I were to choose a recent year to illustrate this type of scenario it would be winter 2015/16 where the overwhelming cold PCHs especially in the stratosphere in December eventually transitioned to warm PCHs throughout the atmospheric column beginning in the troposphere (see **Figure iv**). And no one should interpret what I just wrote that I am predicting a repeat of 2015/16 but seems to me the best possible example of observed and possible future evolution of PCHs.

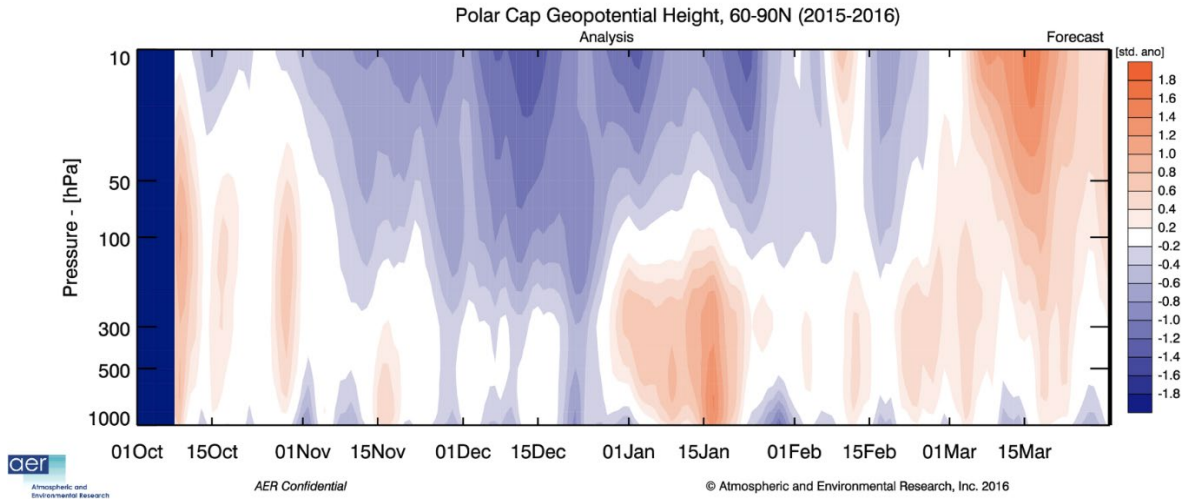

Figure iv. Observed daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies from 1 October 2015 – 31 March 2016.

I still expect the first stratospheric PV disruption to be a stretched PV and not a full on sudden stratospheric warming (SSW). In our recent Cohen et al. 2021 paper we showed that Greenland blocking/high pressure can be a precursor to a stretched PV about two weeks before the event. This would help bring the very cold temperatures in Western Canada south and east across Canada and the US most likely in early January. The impacts from a stretched PV can be highly anomalous but typically of shorter duration so a turn to colder weather would unlikely be more than a week or two. However, based on our PV mole the probability of an SSW would increase in late January and possibly into February. With SSWs the strongest response, i.e., widespread cold temperatures, tends to be across northern Eurasia including Europe. This scenario of a stretched PV eventually transitioning to an SSW occurred in winter 2017/18 for example.

One last thing to keep in mind is that following a stretched PV event, the PV can quickly strengthen and temperatures across the NH can turn much milder. This scenario happened in winter 2019/20 and seems plausible to me as well, especially if forecasts of Urals/Barents-Kara Seas ridging/high pressure are wrong and instead the region is dominated by troughing/low pressure.

1-5 day

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

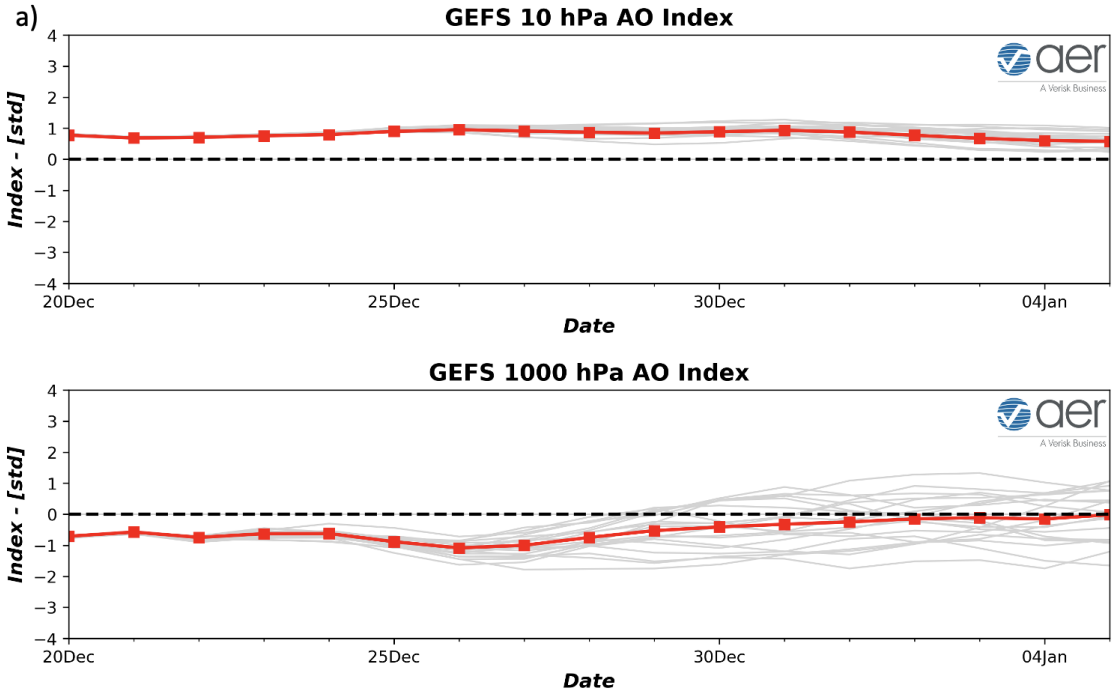

Figure 1. (a) The predicted daily-mean AO at 1000 hPa from the 00Z 20 December 2021 GFS ensemble. (b)The predicted daily-mean near-surface AO from the 00Z 20 December 2021 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

This week, ridging/positive geopotential height anomalies centered across Greenland will favor troughing/negative geopotential height anomalies across much of Europe including the UK this period except for ridging/positive geopotential height anomalies across the western Mediterranean (**Figures 2). This will result in normal to below normal temperatures across much of Europe** including the UK **with the exception of** normal to above normal temperatures across southwestern Europe (**Figure 3**). This week, an omega pattern is predicted across Asia with ridging/positive geopotential height anomalies centered in Western Siberia sandwiched by troughing/negative geopotential height anomalies across Northwestern Asia and Eastern Siberia (**Figure 2**). This pattern favors normal to below normal temperatures across much of Western and Eastern Asia with normal to above normal temperatures across Central and Southern Asia **(Figure 3**).

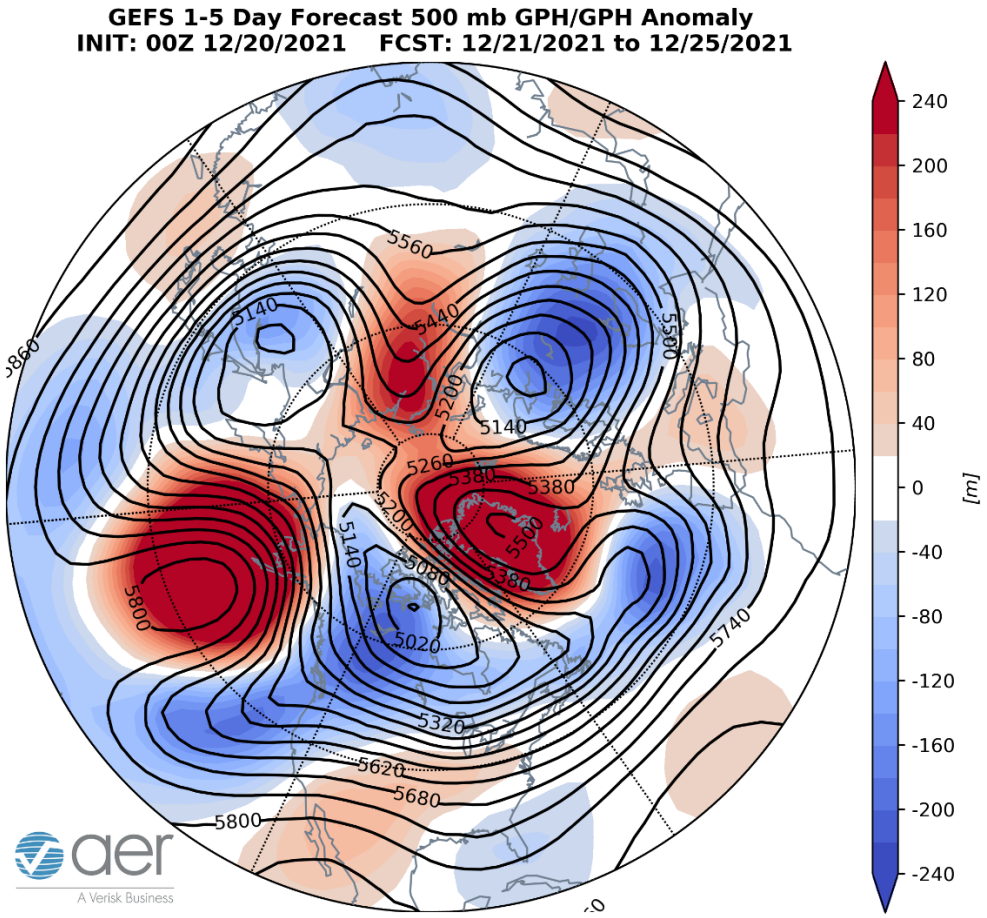

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 21 – 25 December 2021. The forecasts are from the 00z 20 December 2021 GFS ensemble.

Ridging/positive geopotential height anomalies near the Aleutians will contribute to deepening troughing/negative geopotential height anomalies in western North America with strengthening ridging/positive geopotential height anomalies across Northeastern Canada and the Southern US this period **(Figure 2). T**his will favor normal to below normal temperatures across Alaska, much of Canada and the US West Coast with normal to above normal temperatures in Northeastern Canada and much of the US from the Rockies eastward **(Figure 3).**

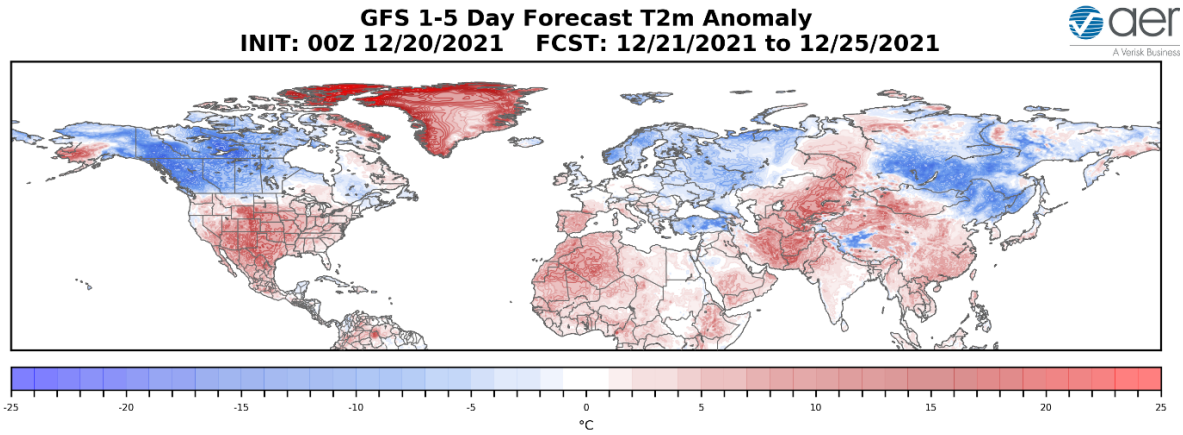

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 21 – 25 December 2021. The forecast is from the 00Z 20 December 2021 GFS ensemble.

Troughing and/or cold temperatures are predicted to support new snowfall across Northeastern Europe, Western and Eastern Asia while mild temperatures promote snowmelt in Southern Europe and Central Asia (**Figure 4**). Troughing and/or cold temperatures are predicted to support new snowfall across Alaska, much of Canada and the Western US while mild temperatures promote snowmelt in the US Northern Plains and New England (**Figure 4**).

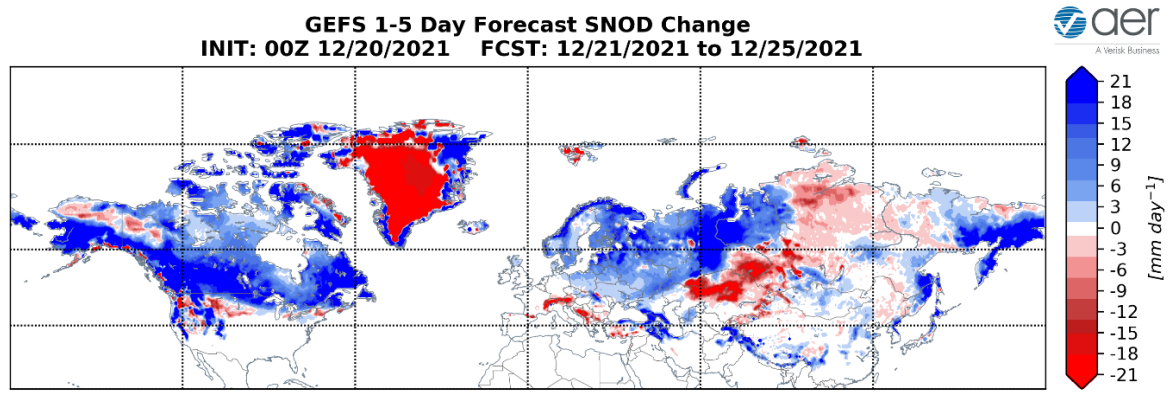

Figure 4. Forecasted snow depth changes (mm/day; shading) from 21 – 25 December 2021. The forecast is from the 00Z 20 December 2021 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to remain negative this period **(Figure 1**) as positive geopotential height anomalies dominate the Arctic but especially Greenland with mixed geopotential

height anomalies across the mid-latitudes of the NH (**Figure 5**). And with persistent positive geopotential height anomalies across Greenland (**Figure 5**), the NAO is predicted to remain negative this period.

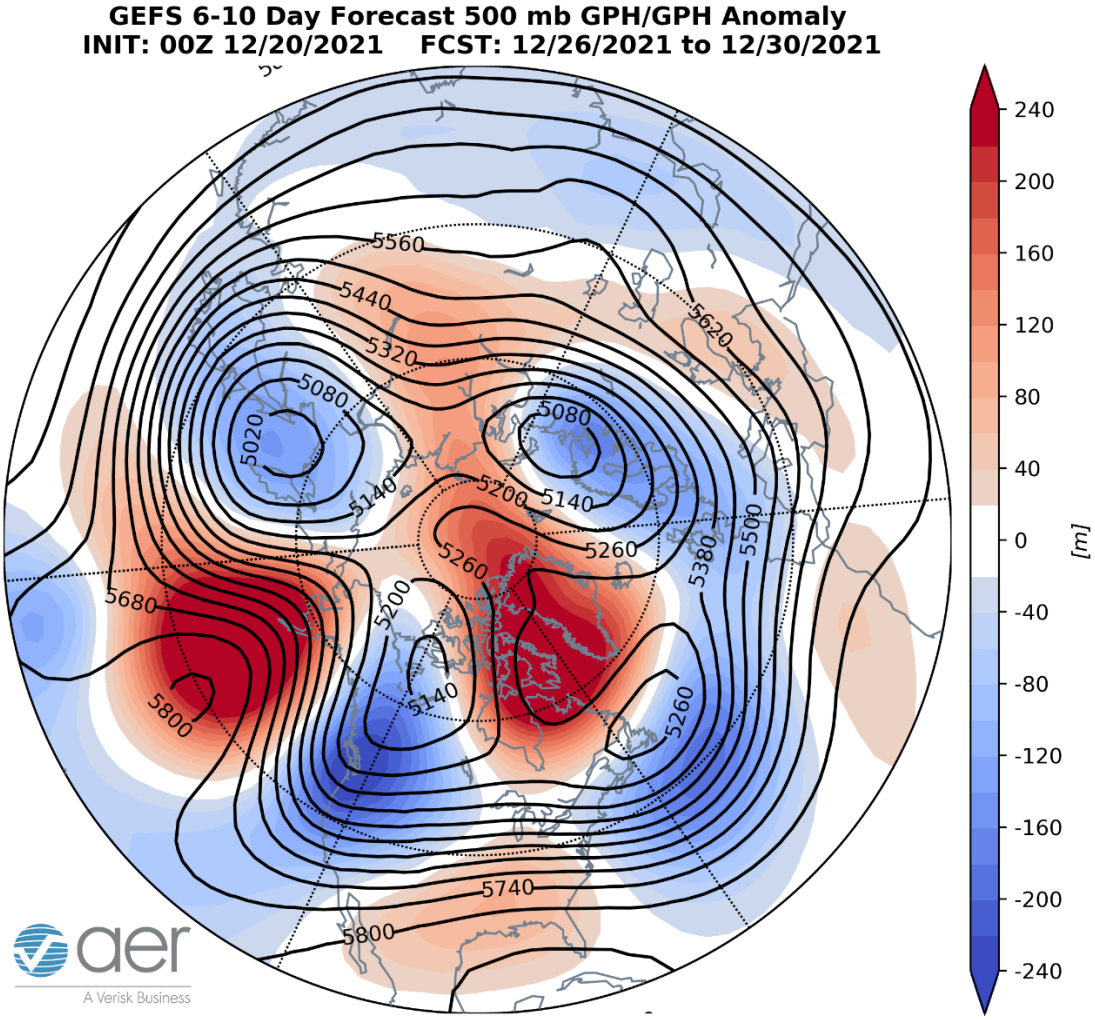

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 26 – 30 December 2021. The forecasts are from the 00z 20 December 2021 GFS ensemble.

Persistent ridging/positive geopotential height anomalies previously across Greenland will continue to support troughing/negative geopotential height anomalies widespread across Europe including the UK with the exception of ridging/positive geopotential height anomalies in the eastern Mediterranean (**Figures 5).** This will result in normal to below normal temperatures widespread across Europe including the UK with normal to above normal temperatures across Southeastern Europe (**Figure 6**). The omega pattern is predicted to persist across Asia with ridging/positive geopotential height anomalies centered in Western Siberia sandwiched by troughing/negative geopotential height

anomalies across Northwestern Asia and Eastern Siberia this period (**Figure 5**). This pattern favors normal to below normal temperatures across much of Northwestern and Eastern Asia with normal to above normal temperatures across Central and Southern Asia **(Figure 6**).

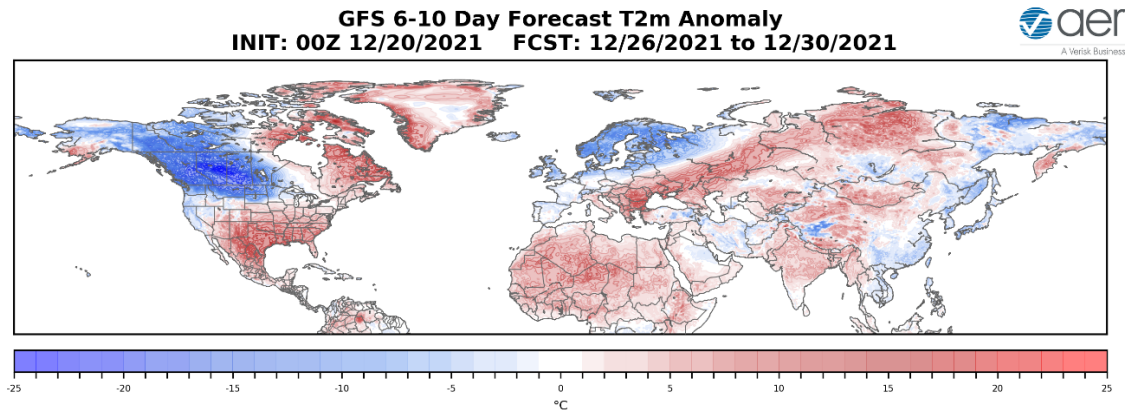

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 26 – 30 December 2021. The forecasts are from the 00Z 20 December 2021 GFS ensemble.

Persistent ridging/positive geopotential height anomalies near the Aleutians will anchor troughing/negative geopotential height anomalies across Western Canada and the Western US with ridging/positive geopotential height anomalies across Northeastern Canada and the Southeastern US this period **(Figure 5).** This will favor normal to below normal temperatures across Alaska, much of Western and Central Canada and the Northwestern US with normal to above normal temperatures in Eastern Canada and the Southern and Eastern US **(Figure 6).**

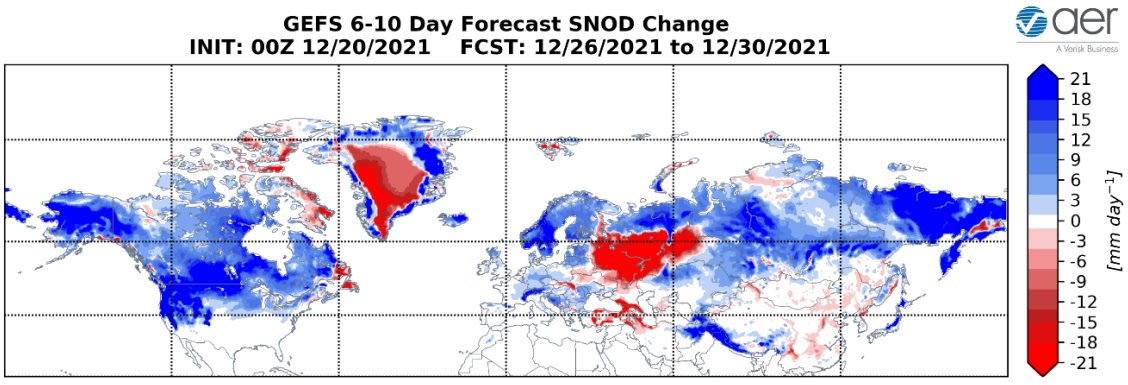

Figure 7. Forecasted snow depth changes (mm/day; shading) from 26 – 30 December 2021. The forecast is from the 00Z 20 December 2021 GFS ensemble.

Troughing and/or cold temperatures are predicted to support new snowfall across Northern Europe, the Alps, Northern Asia and the Tibetan Plateau while milder temperatures promote snowmelt across Western Asia (**Figure 7**). Troughing and/or cold temperatures are predicted to support new snowfall across Alaska, much of Canada and the Northwestern US while milder temperatures promote snowmelt across far Eastern Canada (**Figure 7**).

11-15 day

With geopotential height anomalies predicted to remain mostly positive across the Arctic and mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 8**), the AO should remain negative to neutral this period (**Figure 1**). With predicted positive pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO is forecasted to remain negative this period.

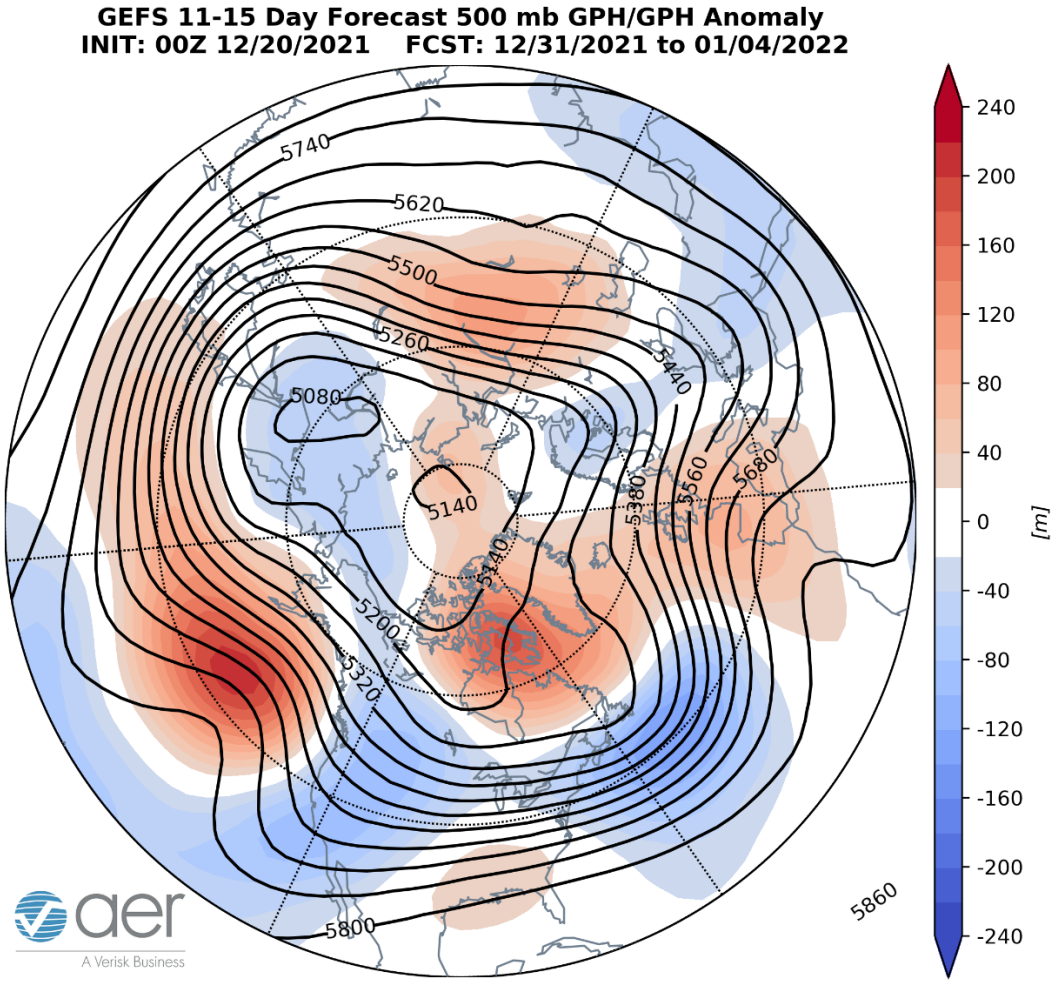

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 31

December 2021 – 4 January 2022. The forecasts are from the 00z 20 December 2021 GFS ensemble.

Greenland ridging/positive geopotential height anomalies are predicted to drift west into Baffin Bay allowing geopotential heights to rise across Western Europe with troughing/negative geopotential height anomalies across Eastern Europe this period (**Figure 8**). This pattern favors more normal to below normal temperatures across much of Europe including the UK with normal to above normal temperatures across Scandinavia this period (**Figures 9**). Previous troughing/negative geopotential height anomalies in Western Asia are predicted to dampen, allowing ridging/positive geopotential height anomalies across Central Asia to strengthen with persistent troughing/negative geopotential height anomalies in East Asia this period (**Figure 8**). This pattern favors more widespread normal to above normal temperatures across much of Asia with normal to below normal temperatures across Eastern Asia this period (**Figure 9**).

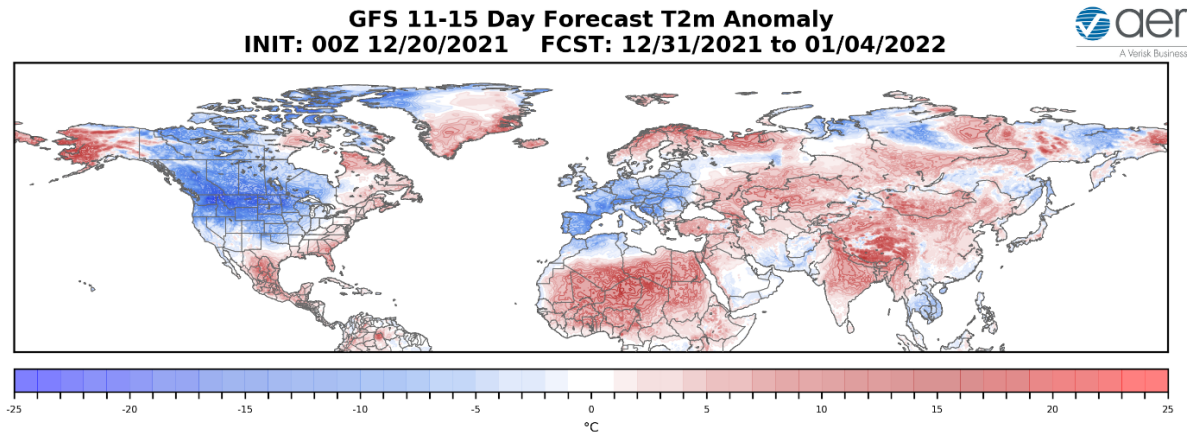

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 31 December 2021 – 4 January 2022. The forecasts are from the 00z 20 December 2021 GFS ensemble.

Persistent ridging/positive geopotential height anomalies near the Aleutians are predicted to slide into the Gulf of Alaska forcing troughing/negative geopotential height anomalies in western North America further to the east with ridging/positive geopotential height anomalies across Northeastern Canada and the Southeastern US this period (**Figure 8**). This pattern favors normal to below normal temperatures across Eastern Alaska, Western and Central Canada and the Northwestern US with normal to above normal temperatures in Eastern Canada and the Southern US and US East Coast (**Figure 9**).

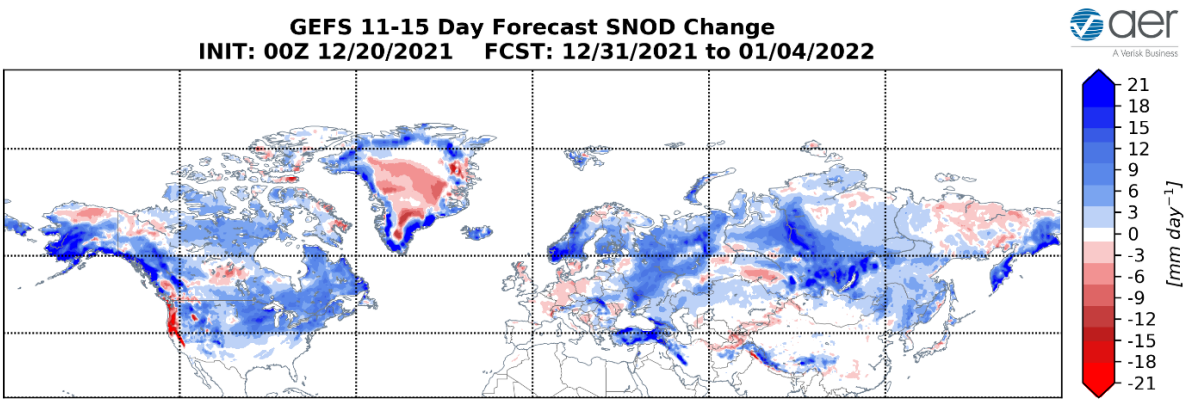

Figure 10. Forecasted snow depth changes (mm/day; shading) from 31 December 2021 – 4 January 2022. The forecast is from the 00Z 20 December 2021 GFS ensemble.

Troughing and/or cold temperatures are predicted to support possible new snowfall across Eastern Europe including Turkey and much of Northern and Eastern Asia while milder temperatures promote snowmelt across Central Asia (**Figure 10**). Troughing and/or cold temperatures are predicted to support possible new snowfall across Southern Alaska, much of Canada and the Northern US while milder temperatures promote snowmelt for the US West Coast (**Figure 10**).

Longer Term

30–day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows cold/negative PCHs throughout the stratosphere and warm/positive PCHs in the troposphere (**Figure 11**). The largest negative departures are currently and are predicted to remain in the upper stratosphere (**Figure 11**), which could propagate down to the troposphere sometime in January. Currently the stratosphere and troposphere are decoupled and waiting for coupling to resume, though exactly how remains an open question to me.

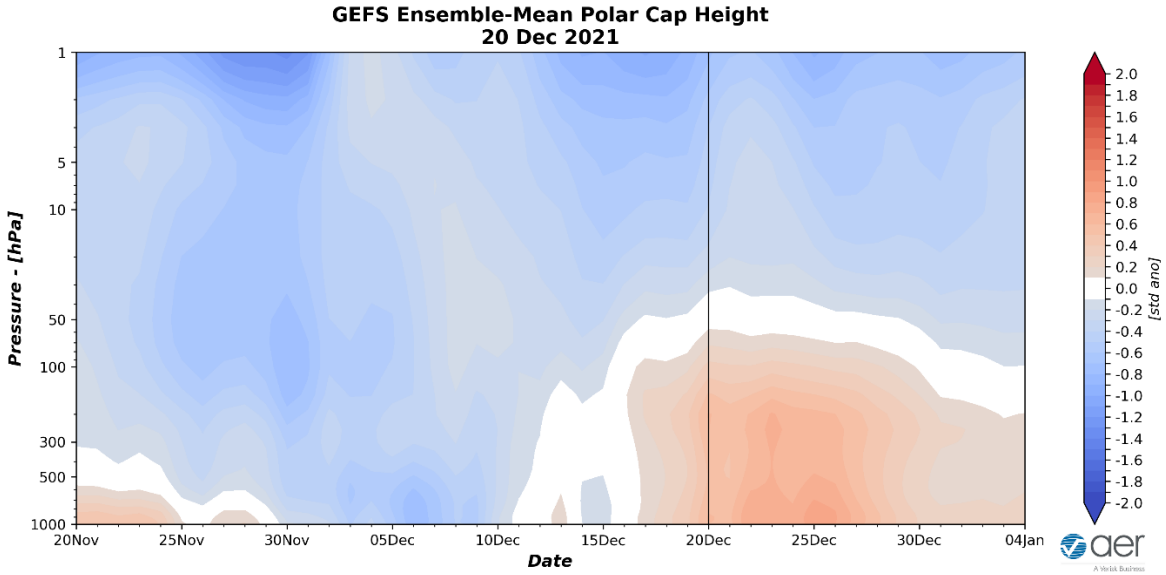

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 20 December 2021 GFS ensemble.

The normal to above normal PCHs predicted this week in the lower troposphere are consistent with the predicted negative surface AO this week and negative to neutral AO next week (**Figure 1**).

The vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere is predicted to remain somewhat more active for the remainder of December (**Figure 12**). The uptick in WAFz is consistent with recent and predicted Urals and to the east of the Urals ridging this week and next week (**Figure 12**). However, the positive WAFz anomalies are relatively weak, and the strong polar vortex should remain strong for the remainder of the month as suggested by the relatively cold stratospheric PCHs. Though the GFS looks suggestive of a stretched polar vortex, so something to watch.

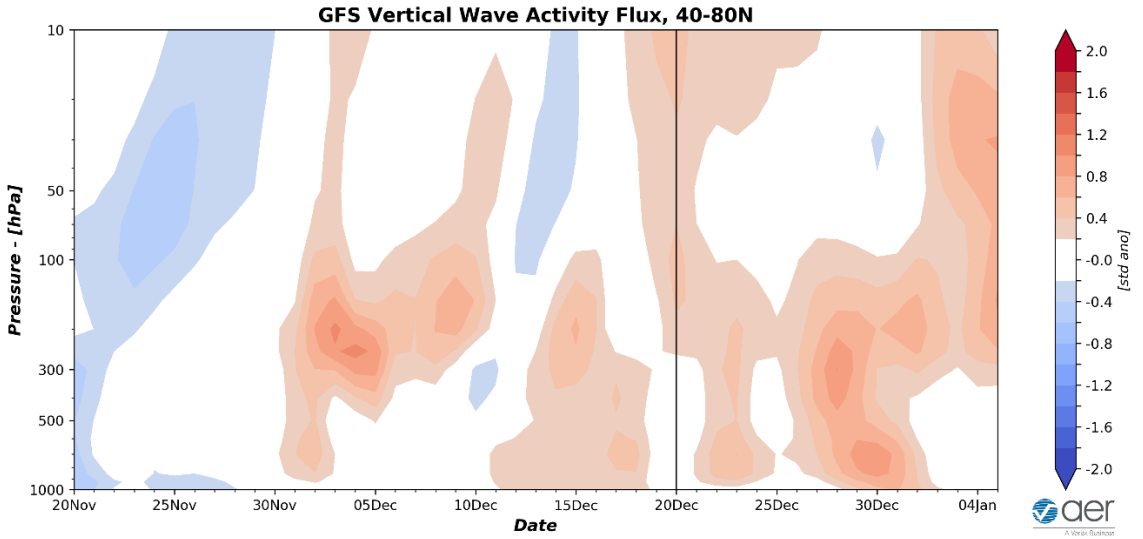

Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 20 December2021 GFS ensemble.

The recent uptick in WAFz has perturbed the stratospheric PV with the PV center displaced towards Eurasia and centered in the Barents-Kara Seas with ridging near the Dateline and polar stratospheric warming across Eastern Siberia (**Figure 13**). However, the perturbation is relatively minor, and the PV is relatively strong resulting in a current positive stratospheric AO (**Figure 11**).

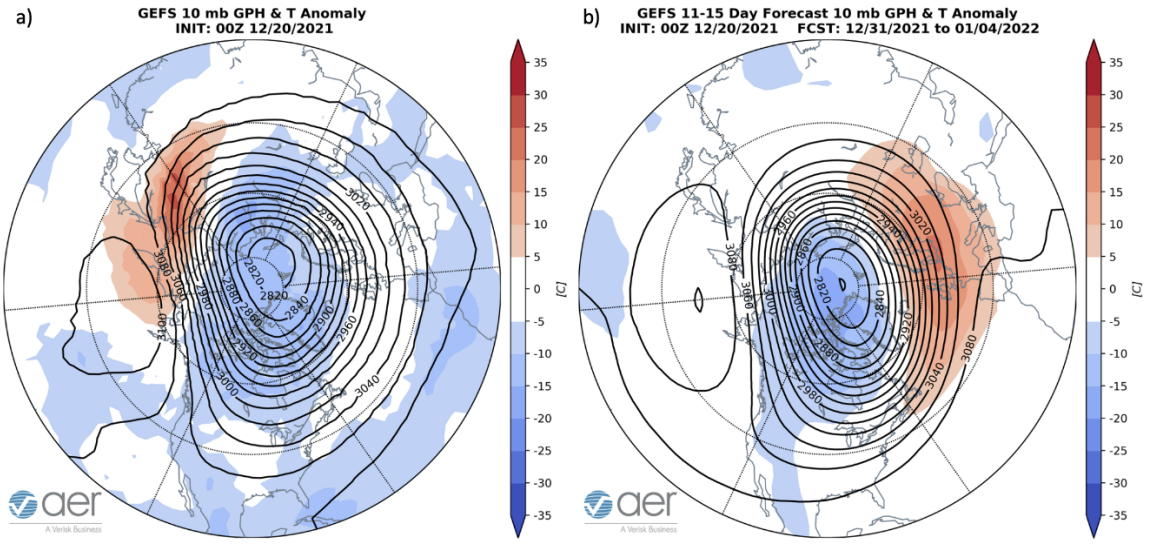

Figure 13. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 20 December 2021. (b)

Same as (a) except forecasted averaged from 30 December 2021 – 4 January 2022. The forecasts are from the 00Z 20 December 2021 GFS model ensemble.

In the near term the active WAFz is predicted to be minor allowing for the PV to remain relatively strong with the PV centered near the North Pole during the week of New Year (**Figure 13**) with a persistent positive stratospheric AO the next two weeks (**Figure 11**). However, strengthening polar stratospheric ridging near the Dateline with additional warming swinging to the east out of Europe could be suggestive of a stretched PV (**Figure 13**).

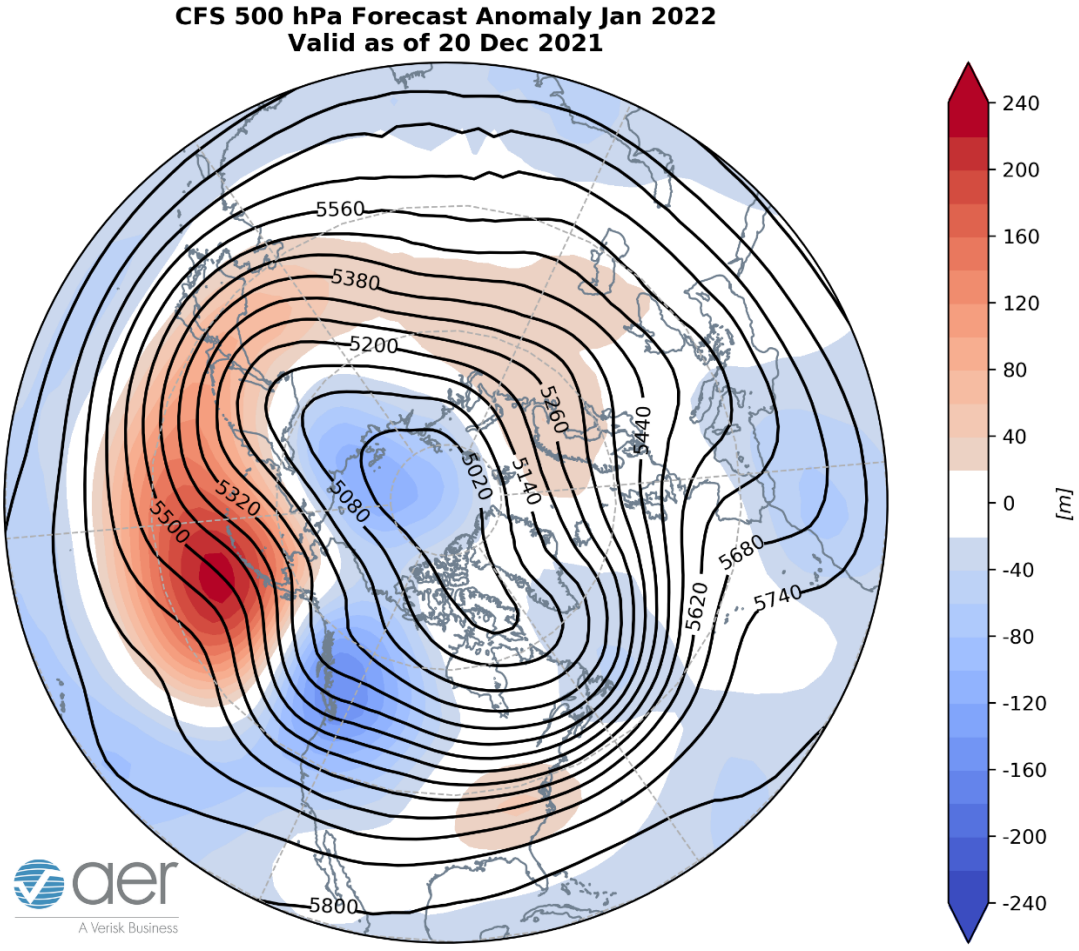

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for January 2022. The forecasts are from the 00Z 20 December 2021 CFS.

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 centered in the Barents-Kara Seas and Scandinavia region,

centered south of the Aleutians and in the Southeastern US with troughing across Western Europe, East Asia and western North America (**Figure 14).** This pattern favors seasonable to relatively warm temperatures widespread across Eastern Europe, Western and Southern Asia and the Southeastern US with seasonable to relatively cold temperatures across Western Europe, Siberia, Alaska, much of Canada and the Northeastern US (**Figure 15**). The cold in Western Canada could be extreme based on the CFS.

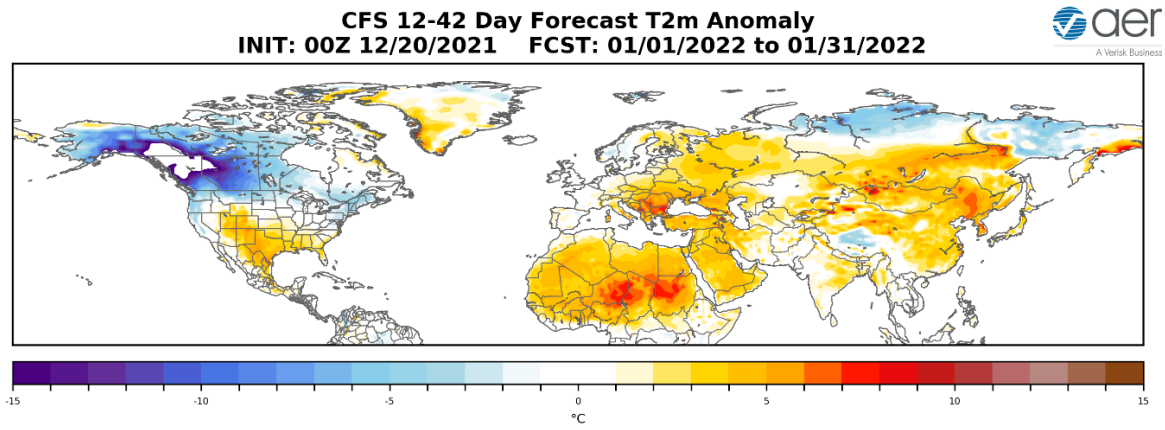

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for January 2022. The forecasts are from the 00Z 20 December 2021 CFS.

Surface Boundary Conditions

Arctic Sea ice

Arctic sea ice is growing but remains below normal mostly in Baffin Bay and Hudson Bay. In the Barents-Kara Seas extent is getting closer to normal. Sea ice is above normal in the Bering Sea. Below normal sea ice in the Barents-Kara seas favors cold temperatures in Central and East Asia, while below normal sea ice in Baffin Bay favors cold temperatures in the Eastern Europe and Northern Europe however this topic remains controversial. Recent research has shown that the regional anomalies that are most highly correlated with the strength of the stratospheric PV are across the Barents-Kara seas region where low Arctic sea ice favors a weaker winter PV. Low sea ice in the Chukchi, Beaufort and Bering seas may favor colder temperatures across North America but has not been shown to weaken the PV.

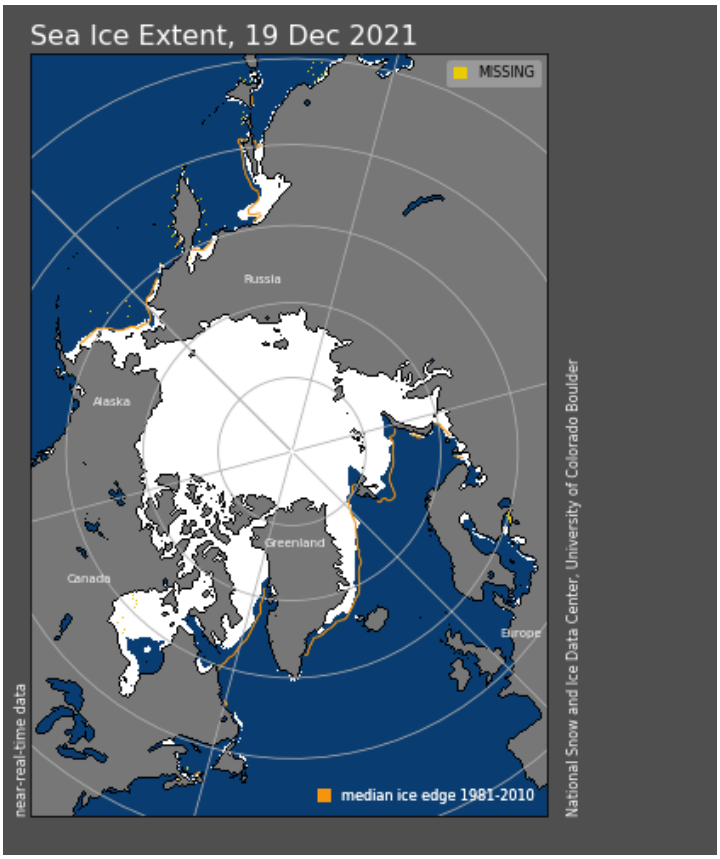

Figure 16. Observed Arctic sea ice extent on 19 December 2021 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image from the National Snow and Ice Data Center (NSIDC).

SSTs/El Niño/Southern Oscillation

Equatorial Pacific sea surface temperatures (SSTs) anomalies are below normal and we continue to observe weak to possibly moderate La Niña conditions (**Figure 17**) and La Niña conditions are expected through the winter. 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 North Pacific. Not my expertise but the SST pattern in the North Pacific are strongly resembling a negative Pacific Decadal Oscillation (PDO) pattern that favors colder temperatures across northwestern North America and milder temperatures across southeastern North America.

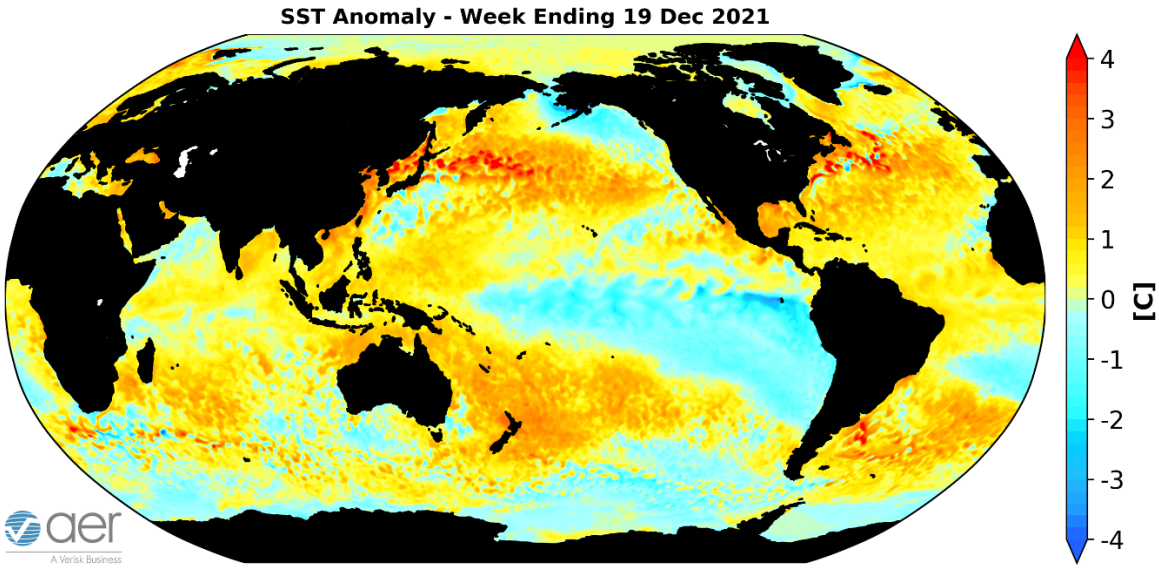

Figure 17. The latest weekly-mean global SST anomalies (ending 19 December 2021). Data from NOAA OI High-Resolution dataset.

Currently the Madden Julian Oscillation (MJO) is in phase seven (**Figure 18**). The forecasts are for the MJO to linger in phase seven through early January. MJO phase seven favors high latitude blocking including Alaska. Initially phase seven favors troughing and cold temperatures in the Western US and ridging and mild temperatures in the Eastern US but then reverses. The warm forecasts in the East are consistent with MJO forcing this week but admittedly this is outside of my expertise.

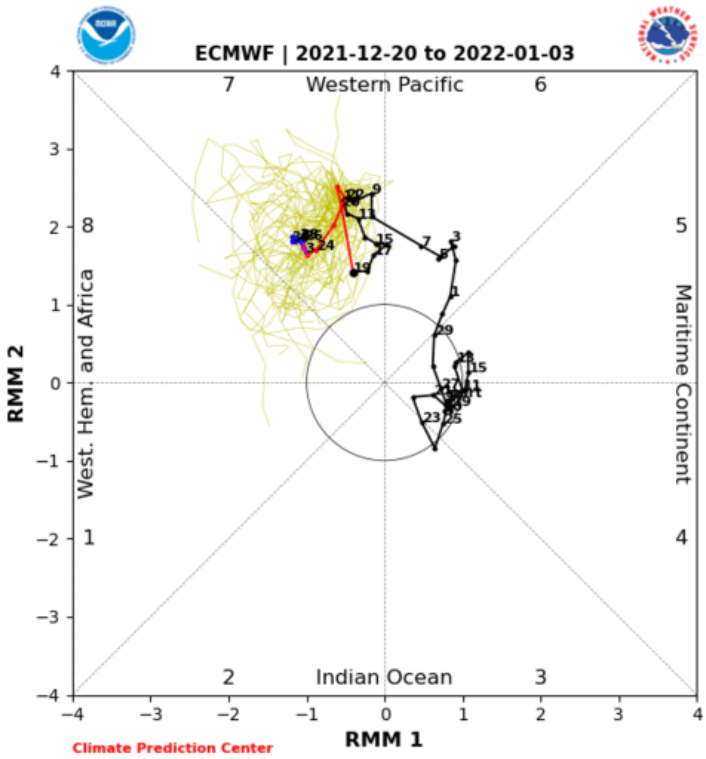

Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 20 December 2021 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model "spread" is denoted by the gray shading. Sector numbers indicate 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

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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.

Our sCast principal engineer, Karl Pfeiffer, can help you use sCast and other AER seasonal forecast products to deliver important, long-lead time weather intelligence to your business. Please reach out to Karl today!