Arctic Oscillation and Polar Vortex Analysis and Forecasts

January 4, 2021

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.

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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 the next two weeks as pressure/geopotential height anomalies are predicted to remain positive across the North Atlantic side of the Arctic the next two weeks.

- The current negative AO is reflective of positive pressure/geopotential height anomalies across the North Atlantic side of the Arctic with mixed pressure/geopotential height anomalies across the mid-latitudes. The North Atlantic Oscillation (NAO) is currently negative with positive pressure/geopotential height anomalies across Greenland and Iceland; and the NAO is predicted to remain negative the next two weeks as pressure/geopotential height anomalies are predicted to remain positive across Greenland.
- For the next two weeks ridging/positive geopotential height anomalies near Greenland will anchor troughing/negative geopotential height anomalies across Europe coupled with normal to below normal temperatures for much of Northern and Western Europe including the United Kingdom (UK). However, southwesterly flow will persist with widespread normal to above normal temperatures across Southern and Eastern Europe.
- Over the next two weeks persistent ridging/positive geopotential height anomalies with normal to above normal temperatures centered near the Urals and Barents-Kara Seas are predicted to force troughing/negative geopotential height anomalies coupled with normal to below normal temperatures downstream across Central Asia, much of Siberia and East Asia.
- This week troughing/negative geopotential height anomalies coupled with normal to below normal temperatures across Alaska and the Gulf of Alaska will force ridging/positive geopotential height anomalies with normal to above normal temperatures across Canada and the Western United States (US), with more troughing and seasonable temperatures in the Eastern US. However next week ridging/positive geopotential height anomalies with normal to above normal temperatures will build across all of western North America and much of Canada with troughing/negative geopotential height anomalies coupled with normal to below normal temperatures deepen across the Eastern US.
- In the Impacts section I discuss the possible influence from the ongoing significant polar vortex (PV) disruption on the weather across the Northern Hemisphere (NH).

Impacts

A significant weakening of the PV is underway and a major mid-winter warming (MMW where the zonal winds reverse from westerly to easterly at 60°N and 10 hPa) is likely in the next couple of days. Of the six steps I presented in the December 14, 2020 blog we are about to complete step four so just one more step to go before liftoff (or crash depending on your perspective).

Given the near certainty of an MMW, today's blog could be relatively short. All we really know is that the AO/NAO are predominantly in the negative phase for up to two months following an MMW. This includes both for PV displacements and splits. And though some early research tried to argue that there are tangible differences between PV

displacements and splits, more recent research has shown there are little substantive differences in the weather. Instead, the ensuing weather flowing both PV splits and displacements are nearly indistinguishable. I will just interject my own prejudices and biases with little scientific evidence, I do believe that PV splits favor European cold and Eastern US snow while displacements favor Eastern US cold.

Given that the most science supports a negative AO bias following an MMW, in **Figure i** I show the correlation of the negative AO with surface temperatures (panel a) and with snow cover days (panel b). A negative AO favors relatively cold temperatures for Northern Europe, Northern and East Asia and the Eastern US with relatively warm temperatures in the Mediterranean region (Southern Europe and North Africa) and the North American Arctic (this pattern is referred to as the quadrupole pattern). I don't think the fact that the North American Arctic is on average relatively warm during a negative AO, is appreciated enough. A negative AO also favors above normal snowfall (or at least snow on the ground) in the Eastern US but especially Europe (this figure is modified from Cohen and Jones 2011 and Cohen et al. 2015).

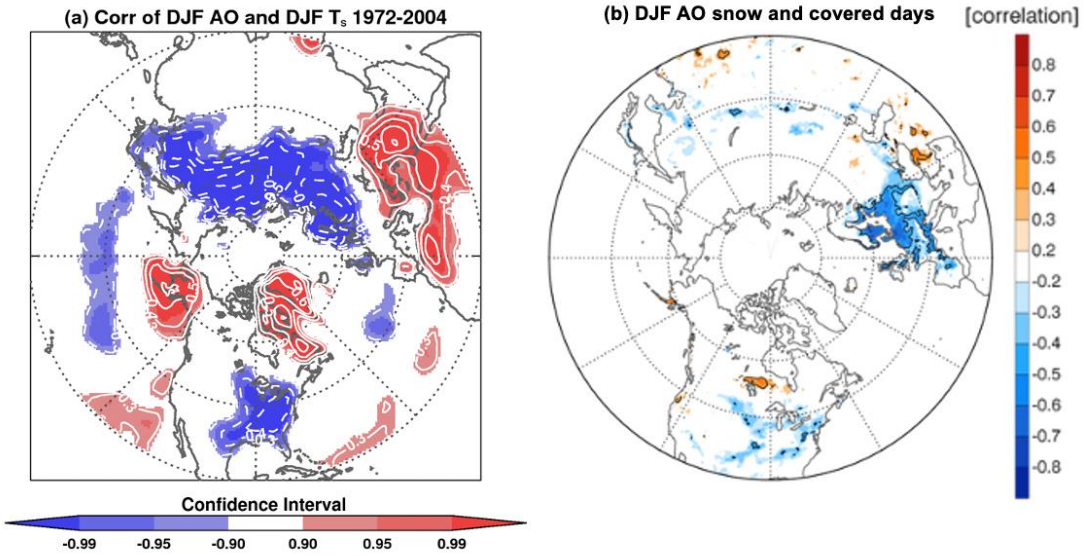

Figure i. **a)** Correlation between the DJF AO and DJF surface temperatures. Only statistically significant values are shown. **b)** Correlation between the DJF AO and days with snow cover on the ground. Black contour delineates those correlations that are significant at the 90% confidence level or higher.

Last week I presented surface temperature anomalies from an MMW perspective. This week I continue the theme from the AO perspective and admittedly they are consistent with some regional differences (e.g. Western US, Canada). And if we are going to discuss a negative AO pattern, I think the first winter that has to come to mind is 2009/10, the winter with the lowest observed winter AO on record. As I discussed last

week, I wrote a paper on that winter (Cohen et al. 2010) and in Figure 4e is shown the NH surface temperature anomalies plot for January-March 2010. That is a remarkable match to the correlation plot in **Figure i**, with the classic quadrupole pattern. Of course, what most people (at least in the US) remember are the historic snowstorms – snowmageddon and snowpocalypse. But look at Canada, despite a cold Eastern US, it was a very mild winter for all of Canada with a shallow snow cover.

And certainly, looking at the GFS forecast plots in today's blog, mid-January should feature some classical negative AO temperature and snow cover anomalies including predicted cold temperatures across Northern Asia, Northern Europe and the Eastern US and an increased probability of new snowfall first across Europe (**Figure 7**) and then the Eastern US (**Figure 10**).

Of course, the big news today is the ongoing sudden stratospheric warming (SSW) and imminent MMW. But we don't live in the stratosphere and other than an eclectic few, no one is going to remember winter 2020/21 based solely on an extreme and even entertaining SSW. Not only does the weather need to be anomalous, possibly extreme, it needs to occur in population centers (my biggest fear are epic "fish" storms). At least for the Northeastern US the risk of severe winter weather steadily increases as the Arctic warms and when the Arctic is at its warmest, the risk of severe winter weather is at its greatest. As an example, I show a modified version of Figure 2 from Cohen et al. (2018) for Boston in **Figure ii**. The PCT are polar cap temperature anomalies (at 500 hPa) and the AWSSI is the accumulated winter season severity index or AWSSI from Mayes-Boustead et al. 2015. First to me the linearity of the plot is striking. But most important for today's blog is the risk of severe winter weather is highest when polar-cap temperatures in the mid-troposphere are well above normal. Figure 2 from Cohen et al. 2018 shows the AWSSI with height. The AWSSI peaks with warm mid-tropospheric Arctic temperatures but not mid-stratospheric polar temperatures. However, if you look at the trend in mid-troposphere Arctic polar cap geopotential heights and Arctic tropospheric temperatures, the warming trend is greatest two weeks following a warming trend in mid-stratospheric Arctic in early to mid-January as shown in Figure 8.

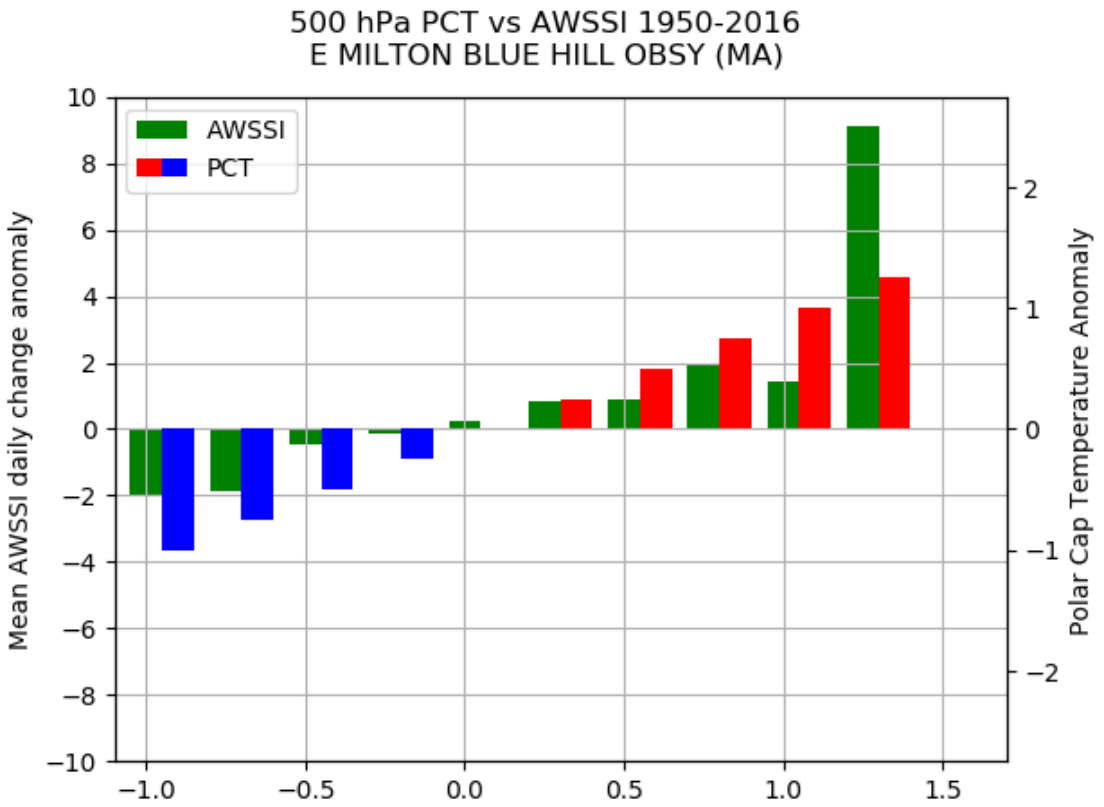

Figure ii. Composite values of Arctic polar cap temperature anomalies at 500 hPa (averaged 65-90°N) and the composited accumulated winter season severity index (AWSSI from Mayes-Boustead et al. 2015) for Boston (taken at Blue Hill) for the given Arctic temperatures.

So, I think of an SSW as a facilitator for amplified tropospheric Arctic warming. The Arctic tends to be relatively warm these days all the time but an SSW amplifies the ambient Arctic warming to a threshold where severe winter weather is much more likely. An SSW in isolation does not force severe winter weather in the mid-latitudes but it does “prime the pump” of tropospheric amplified Arctic warming at a later time. So to that end the maximum or peak polar cap geopotential height anomalies (PCHs) that originate in the stratosphere with the advent of the SSW, must successfully make their way down into the troposphere to initiate severe winter weather. If you look at the current PCH forecast (**Figure 11**) the largest anomalies are currently in the upper stratosphere. The greatest risk of severe winter weather should coincide if and when the maximum positive PCHs descend to the mid to lower troposphere. As an aside the latest PCH forecast is showing something that I have never seen before - descending of the maximum PCHs through the stratosphere that bounces off the tropopause and starts to ascend forming a "U" shape! That is truly bizarre, and it will be interesting to see if this verifies.

There is much more that I was hoping to discuss but as usual just not enough time (and I am experiencing computer issues). But I will end with the complication of anticipating the weather in the coming weeks based on the two most recent MMWs from February 2018 and January 2019. Both events looked similar in the stratosphere with two daughter vortices, one minor daughter vortex Eurasia and one major daughter vortex in North America (though admittedly it may not be obvious from the figure). Despite the similarities in the stratosphere, the tropospheric circulation was quite different (**Figure iii**) and so was the resultant weather (**Figure iv**). Following the MMW in mid-February 2018 the tropospheric pattern resembled a negative AO with plenty of high latitude blocking, in particular near Greenland, coupled with cold in Europe, the Eastern US and Siberia. Following the MMW in early-January 2019 the tropospheric pattern resembled a positive AO with a lack of high latitude blocking coupled with mild temperatures in Europe, the Eastern US and Siberia.

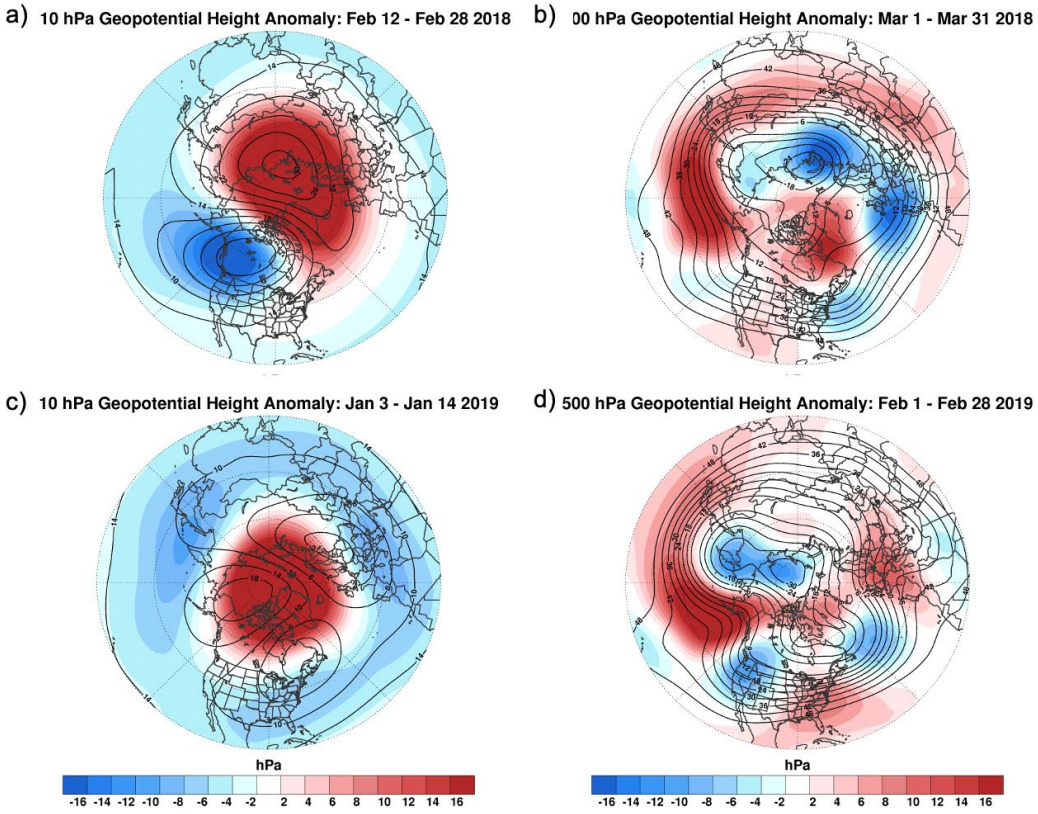

Figure iii. **a)** Observed 10 hPa geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the NH from February 12-28, 2018. **b)** Observed average 500 hPa geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the NH from March 1-31, 2018. **c)** Same as a) but from January 3-14, 2019. **d)** Same as b) but from February 1-28, 2019. Data from NCEP/NCAR reanalysis.

In conclusion, I do expect the weather in the weeks post the MMW of January 2021 to be more similar to 2018 than 2019 but a discussion for another week.

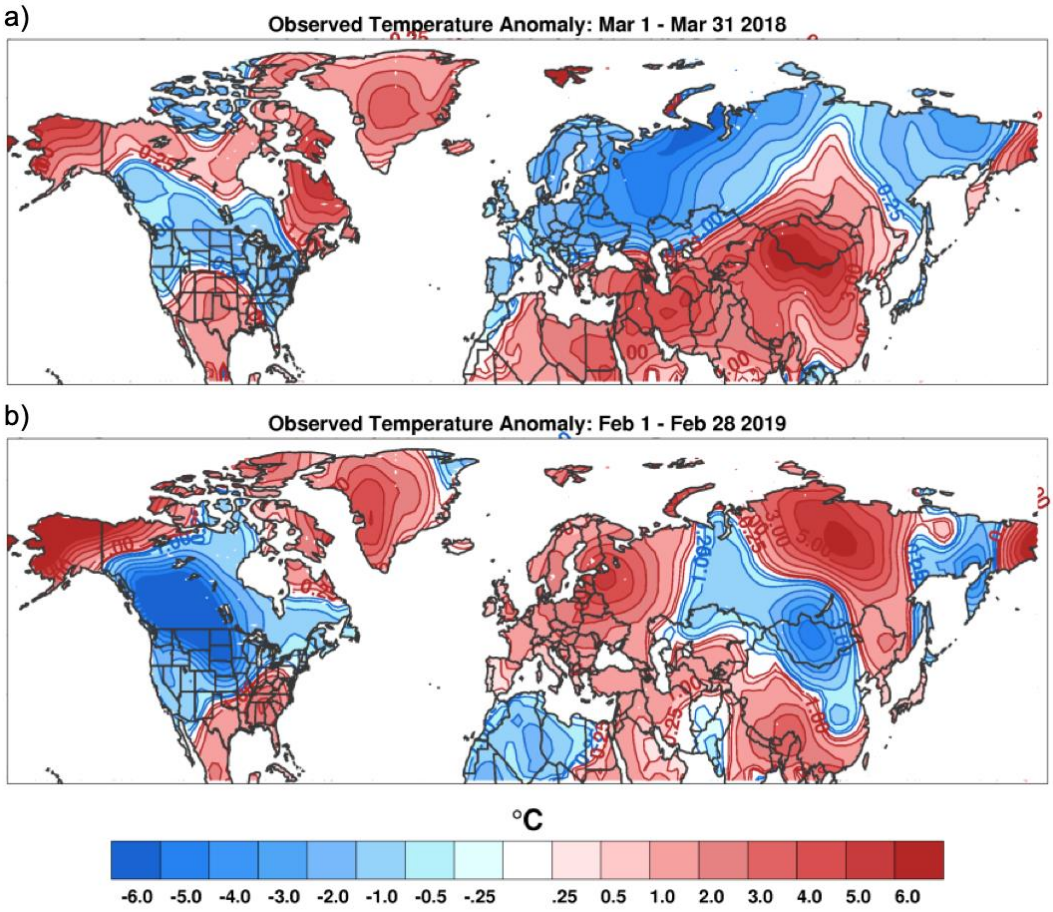

Figure iv. **a)** Observed surface temperature anomalies (°C; shading) from March 1-31, 2018. **b)** Same as a) except from February 1-28, 2019. Data from NCEP/NCAR reanalysis.

1-5 day

The AO is currently negative **(Figure 1**) with positive pressure/geopotential height anomalies across the North Atlantic side of the Arctic and mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 2**). And with predicted positive geopotential height anomalies across Greenland (**Figure 2**), the NAO is predicted to also be negative this week.

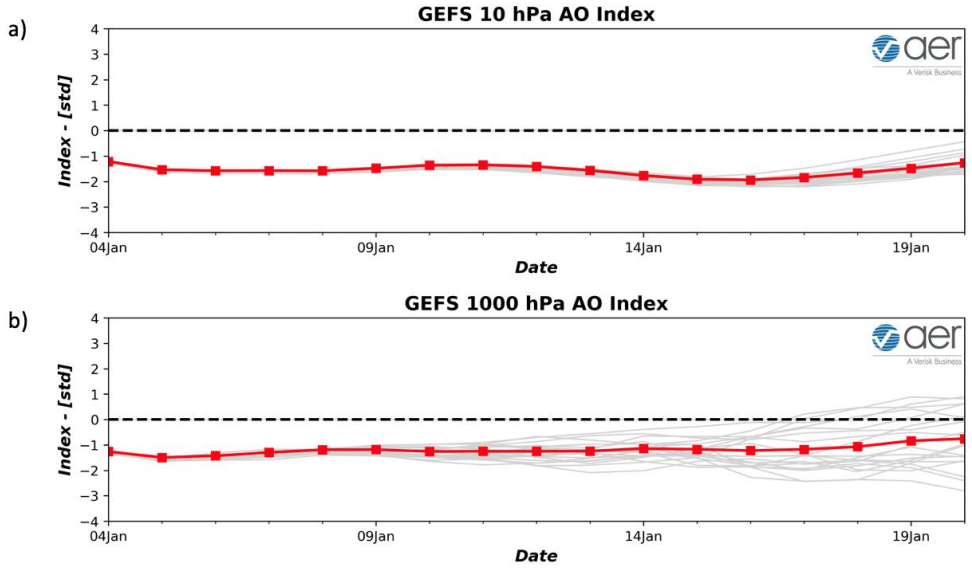

Figure 1. (**a**) The predicted daily-mean AO at 10 hPa from the 00Z 4 January 2021 GFS ensemble. (**b**)The predicted daily-mean near-surface AO from the 00Z 4 January 2021 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

This week, ridging/positive geopotential height anomalies centered south of Greenland are predicted to force downstream troughing/negative geopotential height anomalies across Europe (**Figure 2**). This pattern favors normal to below normal temperatures across Northern and Western Europe including the UK while a mild southwesterly flow will favor widespread normal to above normal temperatures across Eastern Europe (**Figure 3**). This week, ridging/positive geopotential height anomalies centered near the Urals are predicted to force downstream troughing/negative geopotential height anomalies across much of Siberia, Eastern and Central Asia (**Figure 2**). This pattern favors normal to below normal temperatures for much of Southern Siberia, Central and Eastern Asia with normal to above normal temperatures for Northern Siberia, Western and Southern Asia **(Figure 3**).

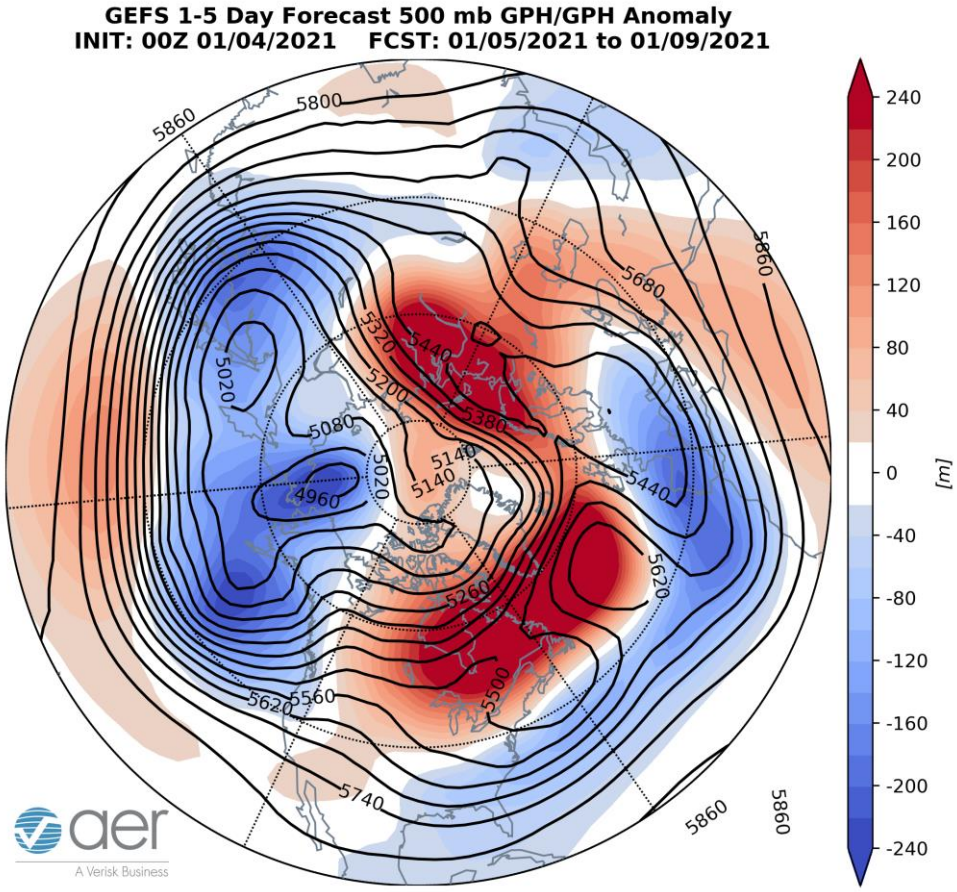

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 5 – 9 January 2021. The forecasts are from the 00z 4 January 2021 GFS ensemble.

This week troughing/negative geopotential height anomalies across Alaska and the Gulf of Alaska will force downstream ridging/positive geopotential height anomalies across most of Canada with more troughing/negative geopotential height anomalies in the Eastern US **(Figure 2).** This pattern is predicted to bring widespread normal to above normal temperatures across much of Canada and the Western US with normal to below normal temperatures for Alaska and the Eastern US **(Figure 3).**

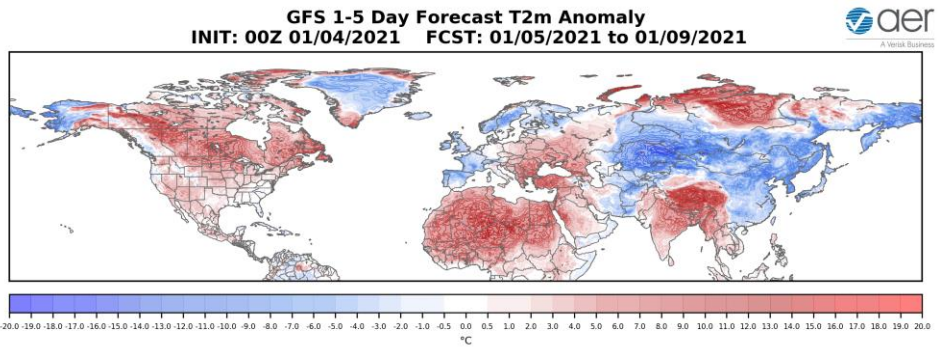

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 5 – 9 January 2021. The forecast is from the 00Z 4 January 2021 GFS ensemble.

Troughing and/or colder temperatures are predicted to support new snowfall across the Alps, the Pyrenees, continental Europe and East Asia while warmer temperatures will cause regional snow melt in the Baltic States, Scandinavia and Western Asia (**Figure 4**). Troughing and/or colder temperatures are predicted to support new snowfall across parts of Alaska, Northeastern Canada and the Northwestern US while warmer temperatures will cause snow melt in parts of Western Canada and the Northeastern US (**Figure 4**).

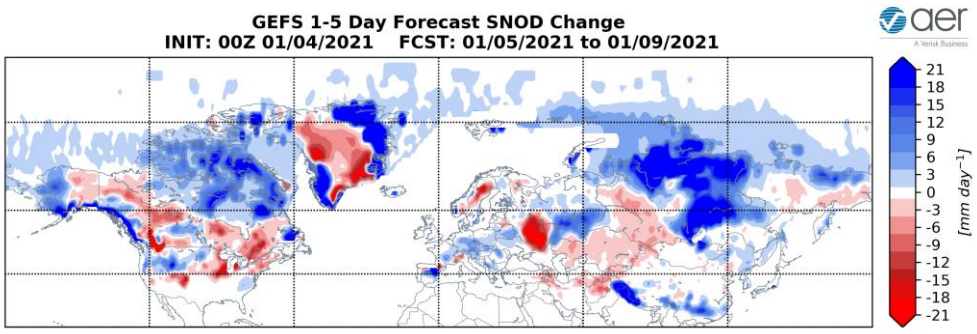

Figure 4. Forecasted snow depth changes (mm/day; shading) from 5 – 9 January 2021. The forecast is from the 00Z 4 January 2021 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to remain negative next week **(Figure 1**) as positive geopotential height anomalies persist across the North Atlantic side of the Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 5**). And with positive geopotential height anomalies predicted across Greenland (**Figure 5**), the NAO is predicted to also remain negative.

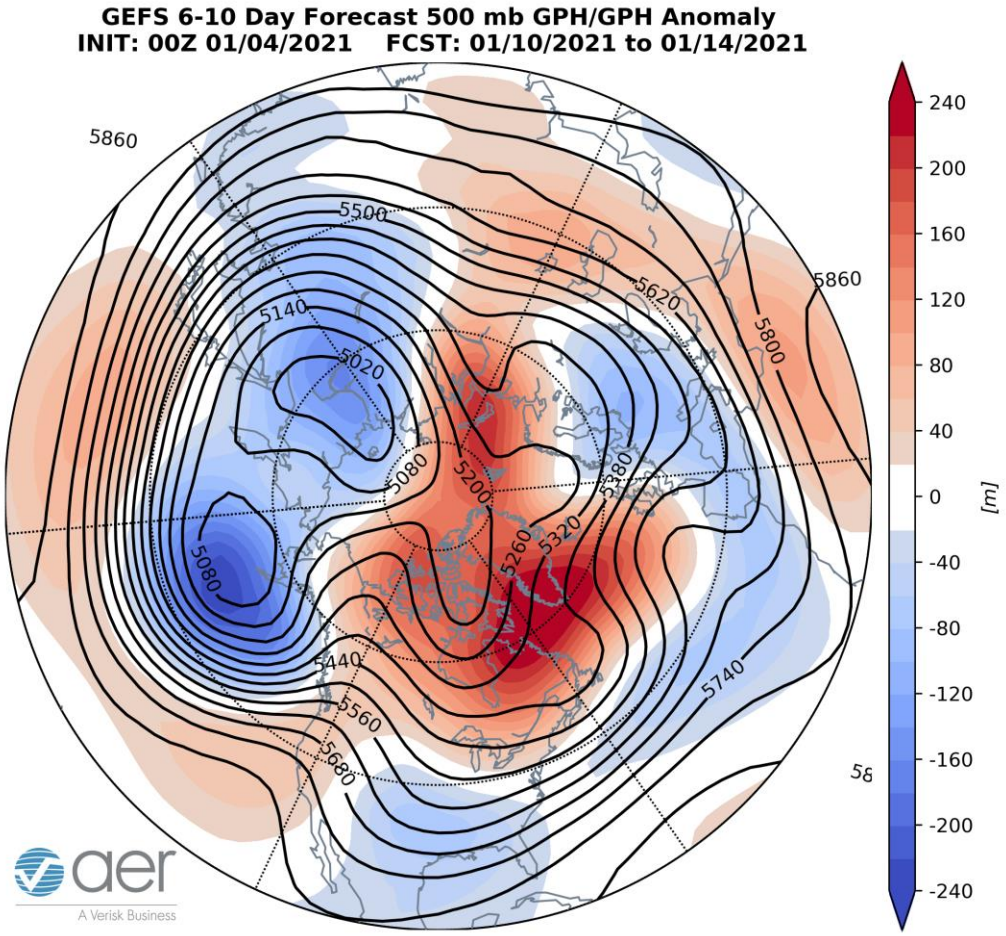

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 10 – 14 January 2021. The forecasts are from the 00z 4 January 2021 GFS ensemble.

Ridging/positive geopotential height anomalies centered across Southern Greenland are predicted to anchor downstream troughing/negative geopotential height anomalies across Western Europe this period (**Figures 5).** This pattern favors normal to below normal temperatures across Northern and Western Europe including the UK while southwesterly flow of mild air will persist normal to above normal temperatures across Southeastern Europe (**Figure 6**). Persistent ridging/positive geopotential height anomalies centered near the Urals and Barents-Kara Seas will continue to force downstream troughing/negative geopotential height anomalies across Siberia and Central and East Asia this period (**Figure 5**). This is predicted to favor widespread normal to below normal temperatures across much of Northern and East Asia with normal to above normal temperatures in Northwestern Siberia, Western and Southern Asia **(Figure 6**).

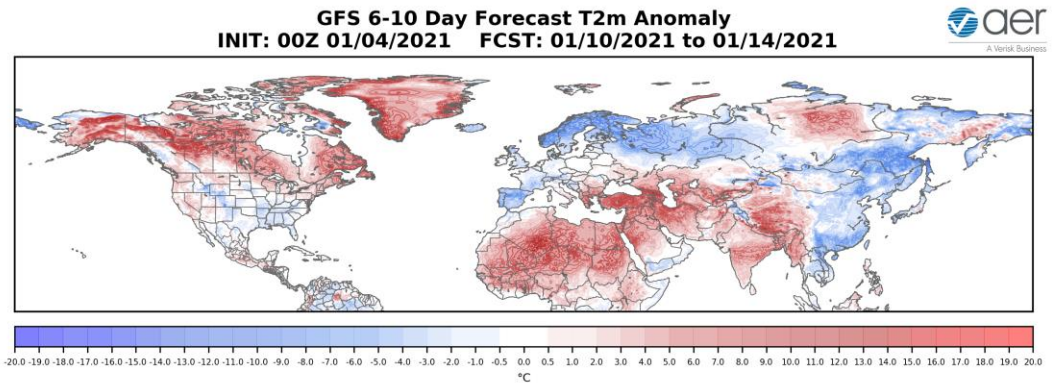

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 10 – 14 January. The forecasts are from the 00Z 4 January 2021 GFS ensemble.

Troughing/negative geopotential height anomalies will migrate to a position near the Aleutians that will begin to build ridging/positive geopotential height anomalies across western North America and much of Canada with deepening troughing/negative geopotential height anomalies across the Eastern US **(Figure 5).** This pattern is predicted to bring normal to above normal temperatures across Alaska, much of Canada and the Western US with normal to below normal temperatures across Southern and Eastern US **(Figure 6).**

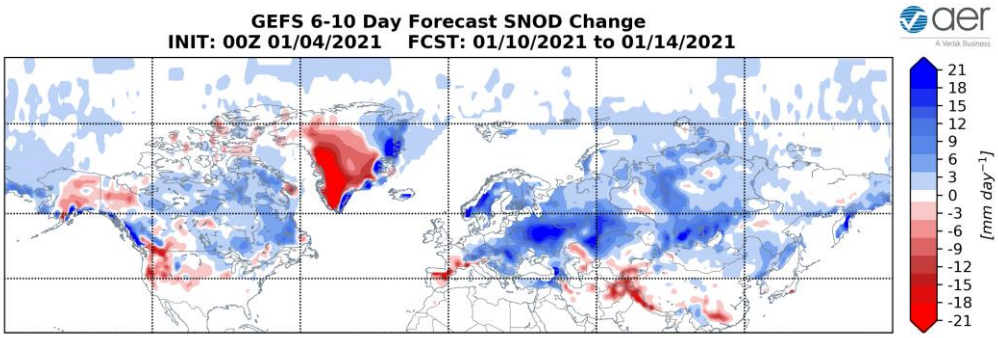

Figure 7. Forecasted snow depth changes (mm/day; shading) from 10 – 14 January. The forecasts are from the 00Z 4 January 2021 GFS ensemble.

Troughing and/or colder temperatures are predicted to potentially support new snowfall across large areas of Central and Eastern Europe, Northern and Central Asia while warmer temperatures will cause regionalized snow melt in Afghanistan and Pakistan (**Figure 7**). Troughing and/or colder temperatures are predicted to support new snowfall across much of Canada US while warmer temperatures will cause possible snow melt in the Western US Plains (**Figure 7**).

11-15 day

As geopotential height anomalies are predicted to remain positive on the North Atlantic side of the Arctic and into the Central Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 8**), the AO should remain negative this period (**Figure 1**). With continued positive pressure/geopotential height anomalies spread across Greenland (**Figure 8**), the NAO is predicted to remain negative this period as well.

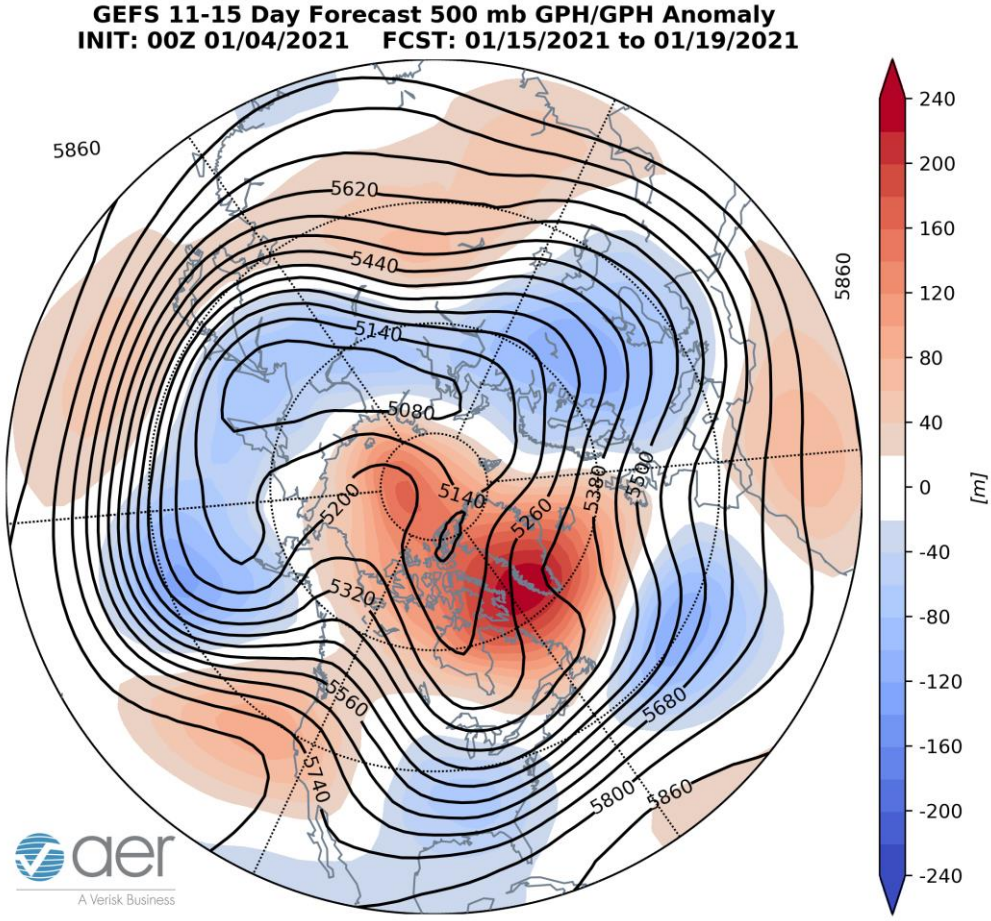

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 15 – 19 January 2021. The forecasts are from the 00z 4 January 2021 GFS ensemble.

Persistent ridging/positive geopotential height anomalies centered near Greenland coupled with ridging centered near the Urals are predicted to lock in troughing/negative geopotential height anomalies across Europe this period (**Figures 8**). The forecast is for a more widespread normal to below normal temperatures across Europe including the UK with only regional normal to above normal temperatures this period (**Figures 9**). Persistent ridging/positive geopotential height anomalies focused near the Urals are predicted to finally wane this period with troughing/negative geopotential height anomalies across all of Northern Eurasia and ridging/positive geopotential height anomalies in Central Asia this period (**Figure 8**). This pattern favors normal to below

normal temperatures across Northern Asia with normal to above normal temperatures across much of Central and Southern Asia (**Figure 9**).

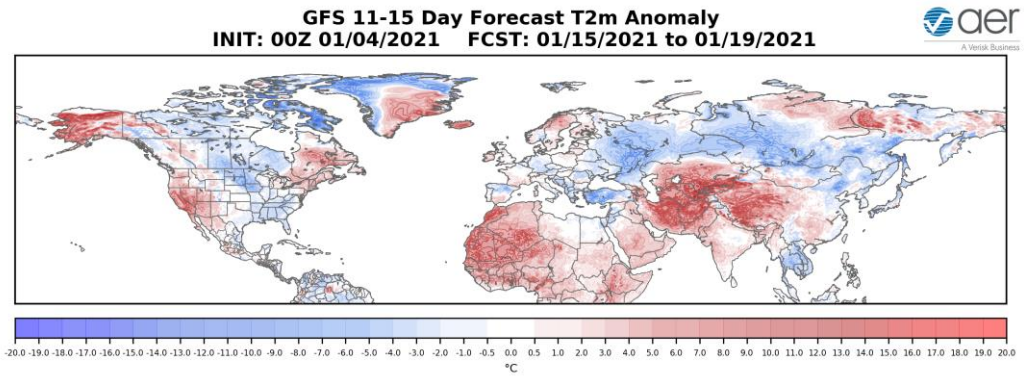

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 15 – 19 January 2021. The forecasts are from the 00z 4 January 2021 GFS ensemble.

The general predicted pattern this period is ridging/positive geopotential height anomalies across western North America with developing troughing/negative geopotential height anomalies across the eastern North America (**Figure 8**). This pattern favors normal to above normal temperatures for Alaska, western Canada, the Canadian Maritimes and the Western US with normal to below normal temperatures for Central Canada and the Eastern US (**Figure 9**).

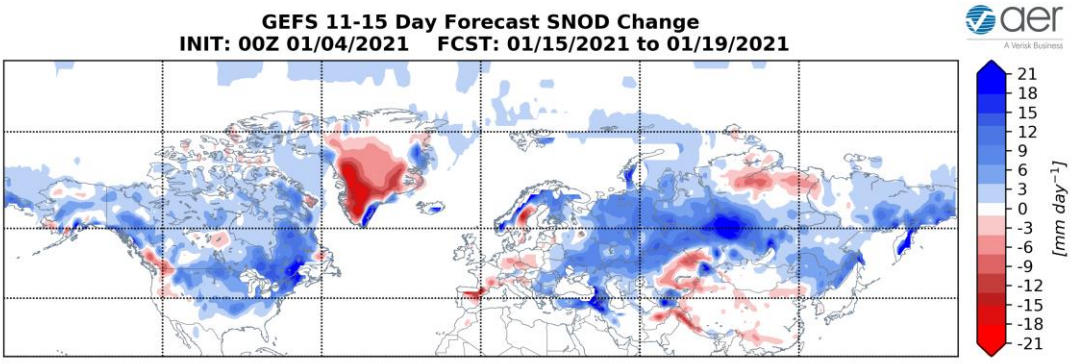

Figure 10. Forecasted snow depth changes (mm/day; shading) from 15 – 19 January 2021. The forecasts are from the 00z 4 January 2021 GFS ensemble.

Troughing and/or colder temperatures are predicted to support new snowfall across much of Northern and Eastern Europe and Northern Asia while warmer temperatures will cause snowmelt in Western Europe and Central Asia (**Figure 10**). Troughing and/or colder temperatures are predicted to support new snowfall across Alaska, much of Canada and possibly the Northern two thirds of the US east of the Rockies (**Figure 10**).

Longer Term

30–day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows warm/positive normal PCHs throughout the troposphere and stratosphere for the next two weeks (**Figure 11**).

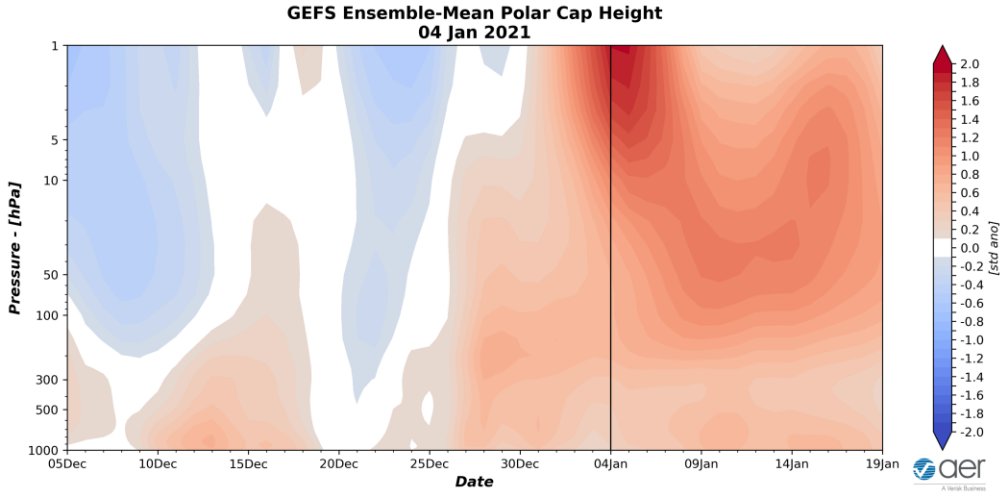

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 4 January 2021 GFS ensemble. Please note that the PCH plot now extends to 1 hPa.

Normal to warm/positive PCHs in the lower troposphere are consistent with the predicted negative surface AO the next two weeks (**Figure 1**). Warm/positive PCHs in the stratosphere are consistent with the negative stratospheric AO the next two weeks (**Figure 1**).

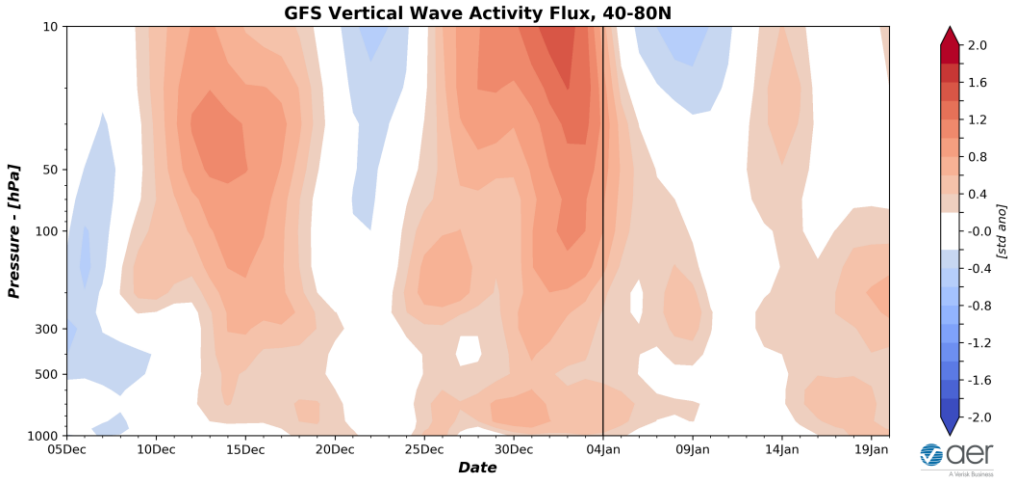

Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 4 January 2021 GFS ensemble.

The plot of Wave Activity Flux (WAFz and is proportional to poleward heat transport) forecasts is showing currently a strong WAFz pulse throughout the atmospheric column that will end this week (**Figure 12**). The first pulse of WAFz in mid-December did weaken the stratospheric PV just enough to precondition the PV for a more significant PV weakening the end of December. One more weak pulse is predicted mid-January that could weaken the PV further. Based on all weather model forecasts, the ongoing PV weakening should meet the threshold of a major mid-winter warming (MMW where the zonal winds reverse from westerly to easterly at 60°N and 10 hPa) in the next couple of days.

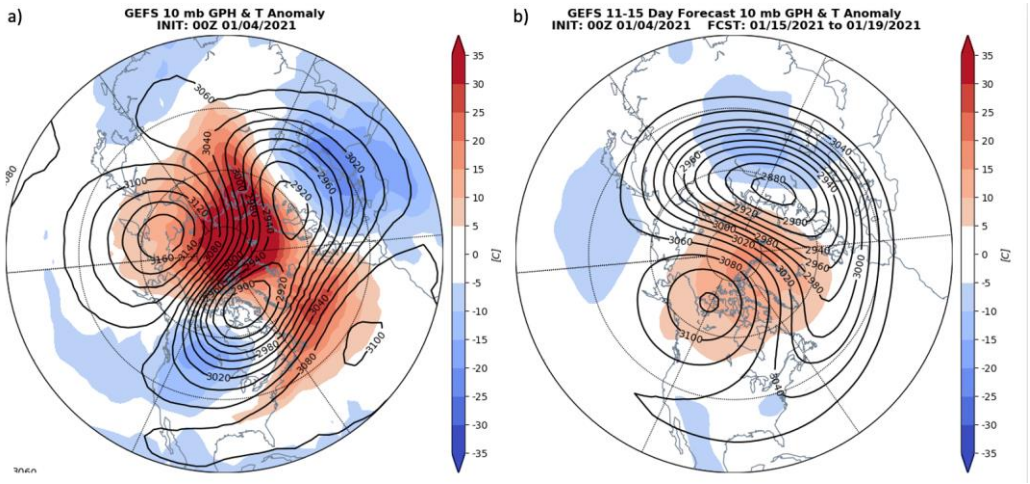

Figure 13. (**a**) Analyzed 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 4 January 2021. (**b**) Same

as (a) except forecasted averaged from 15 – 19 January 2021. The forecasts are from the 00Z 4 January 2021 GFS model ensemble.

The PV is currently split into two centers, one near Scandinavia and the other over Baffin Bay (**Figure 13**). The PV is weakening as high pressure centered over Eastern Siberia strengthens. The high pressure over Eastern Siberia is predicted to strengthen and drift towards Canada while the PV is predicted to consolidate and drift towards the Urals (**Figure 13**). The PV weakening is an absorptive event, which is most closely associated with cold temperatures in Northern Eurasia.

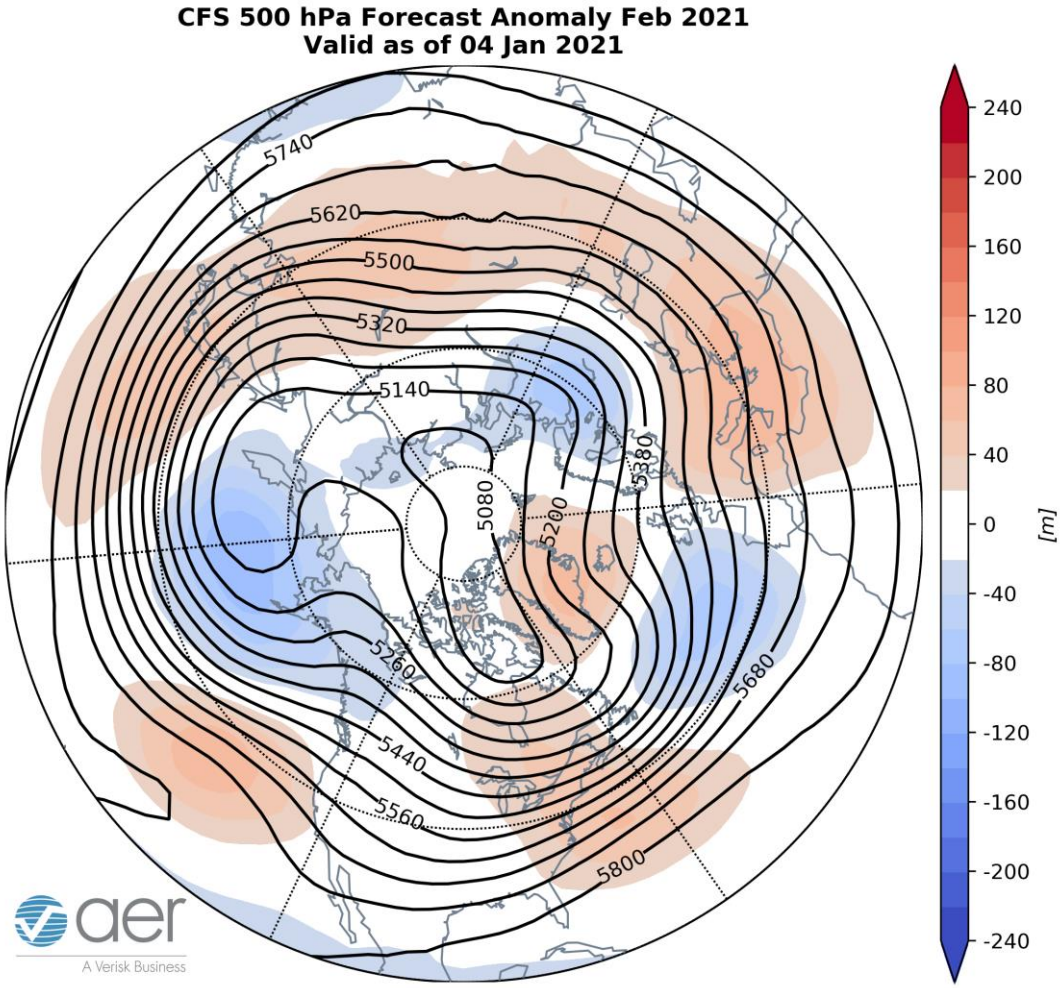

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for February 2021. The forecasts are from the 00Z 4 January 2021 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and the surface temperatures (**Figure 15**) forecast for February from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast

for the troposphere is ridging near Greenland, Southern Eurasia and western North America with troughing in Northern Europe, Northern Asia but especially Siberia, the Dateline, Eastern Canada and the Central US (**Figure 14).** This pattern favors relatively warm temperatures for Southern Europe, Central Asia and western North America with seasonable to relatively cold temperatures for Northern Europe, Northern and Eastern Asia, Eastern Canada and the Central US (**Figure 15**). The CFS forecast for February is consistent with expectations for the month following an MMW but still seems to me to be of low confidence.

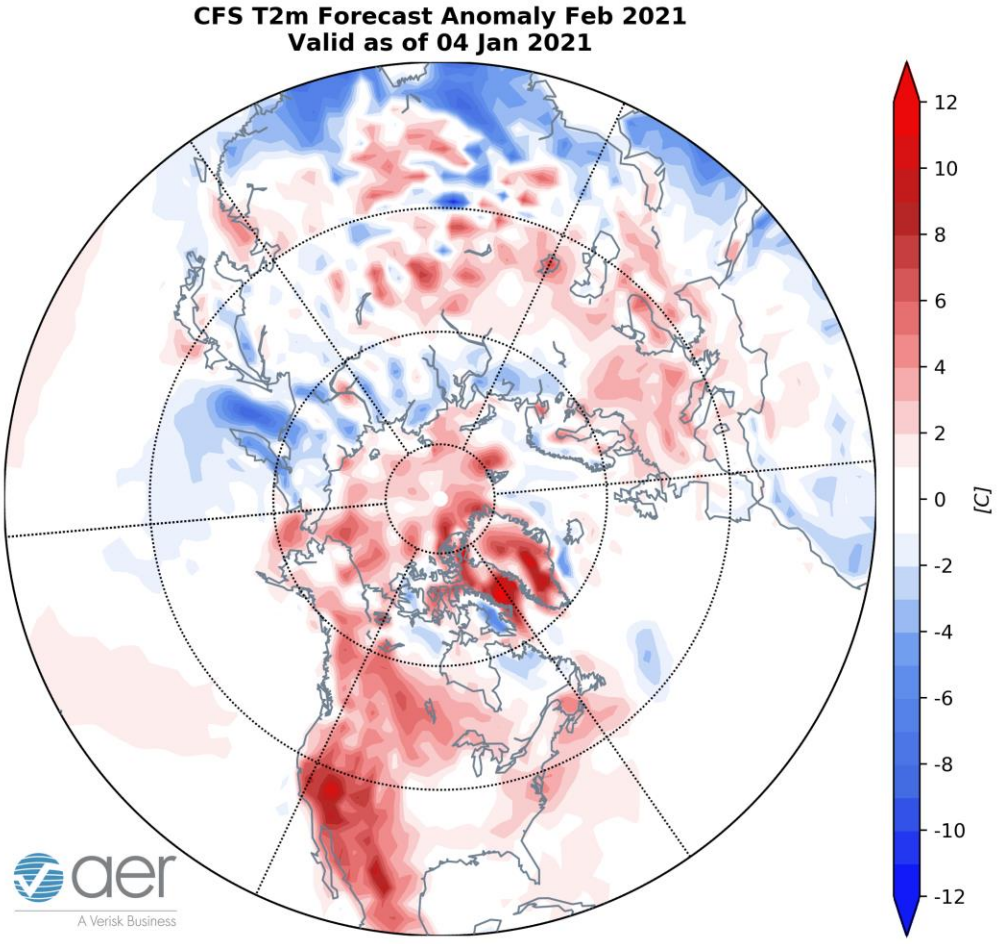

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for February 2021. The forecasts are from the 00Z 4 January 2021 CFS.

Surface Boundary Conditions

Arctic sea ice extent

Arctic sea ice continues to grow but currently remains below normal. Negative sea ice anomalies exist in the Bering Sea but especially in the Barents-Kara Seas (**Figure 16**). Below normal sea ice in the Barents-Kara seas favor Ural blocking and cold temperatures in Central and East Asia, 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 and Bering seas may favor colder temperatures across North America but have not been shown to weaken the PV. Sea ice should continue to grow in this region based on the forecast.

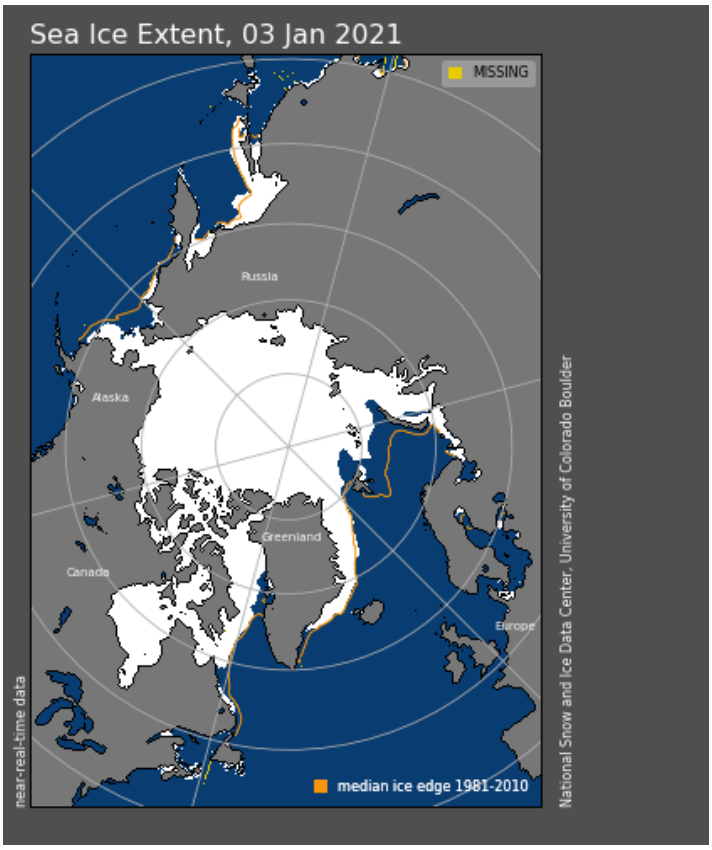

Figure 16. Observed Arctic sea ice extent on 3 January 2021 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image courtesy of National Snow and Ice Data Center (NSIDC).

SSTs/El Niño/Southern Oscillation

Equatorial Pacific sea surface temperatures (SSTs) anomalies remain negative and we continue to observe moderate La Niña conditions (**Figure 17**) and La Niña is expected to persist through the winter and remain moderate to weak. Observed SSTs across the NH remain well above normal especially near Alaska and in the Gulf of Alaska, the western North Pacific and offshore of eastern North America though below normal

SSTs exist regionally especially in the Southern Hemisphere and south of Iceland. Warm SSTs in the Gulf of Alaska may favor mid-tropospheric ridging in the region.

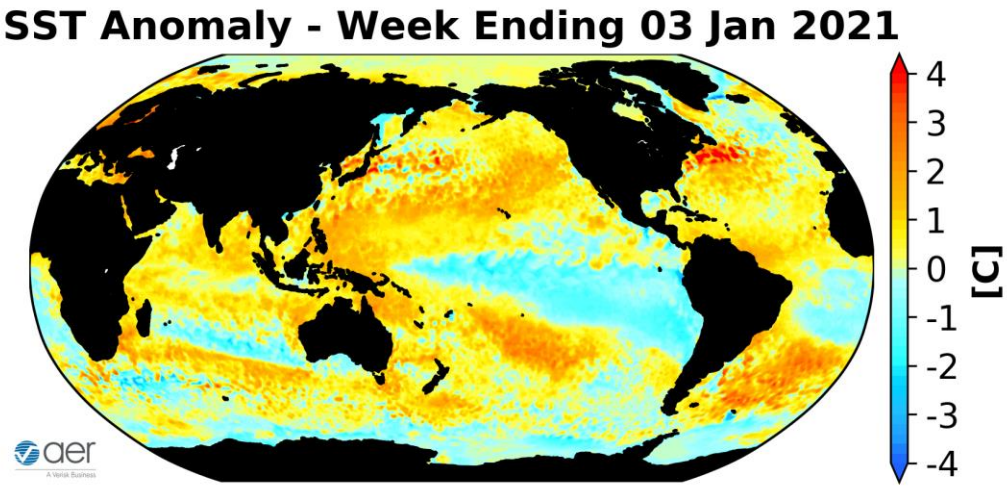

Figure 17. The latest weekly-mean global SST anomalies (ending 3 January 2021). Data from NOAA OI High-Resolution dataset.

Currently no phase of the Madden Julian Oscillation (MJO) is favored (**Figure 18**). The forecasts are for the MJO to remain where no phase is favored for the next two weeks. Therefore it doesn't appear to me that the MJO is contributing to the pattern across North America but admittedly this is outside of my expertise.

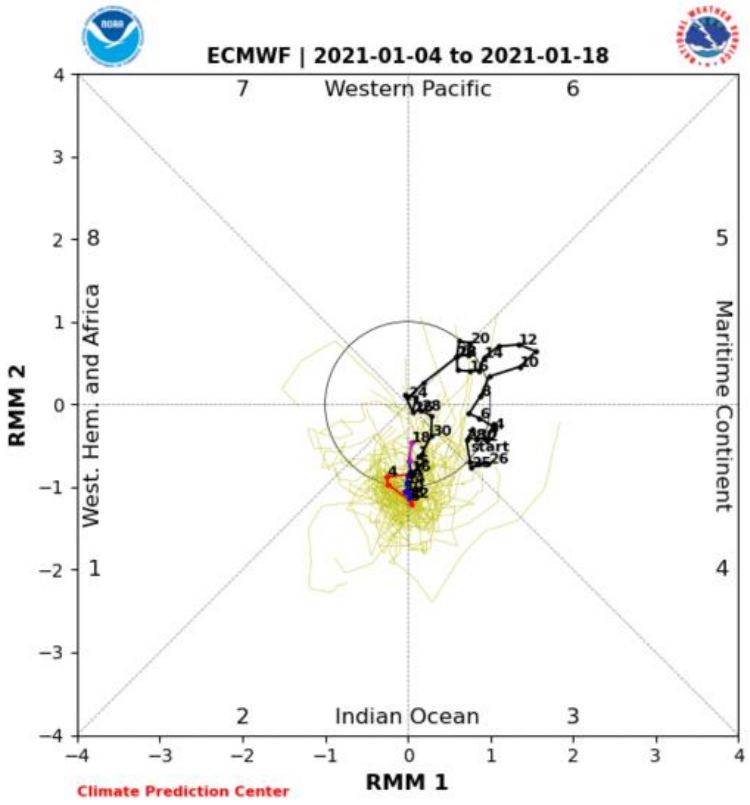

Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 4 January 2021 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model "spread" is denoted by the gray shading. Sector numbers indicate 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

Northern Hemisphere Snow Cover

Snow cover advanced slowly over the past week across Eurasia but remains near decadal means. Snow cover advance will likely continue to increase especially across East Asia and more likely into Europe the next two weeks. Above normal snow cover extent in October, favors a strengthened Siberian high, cold temperatures across northern Eurasia and a weakened polar vortex/negative AO this upcoming winter followed by cold temperatures across the continents of the NH.

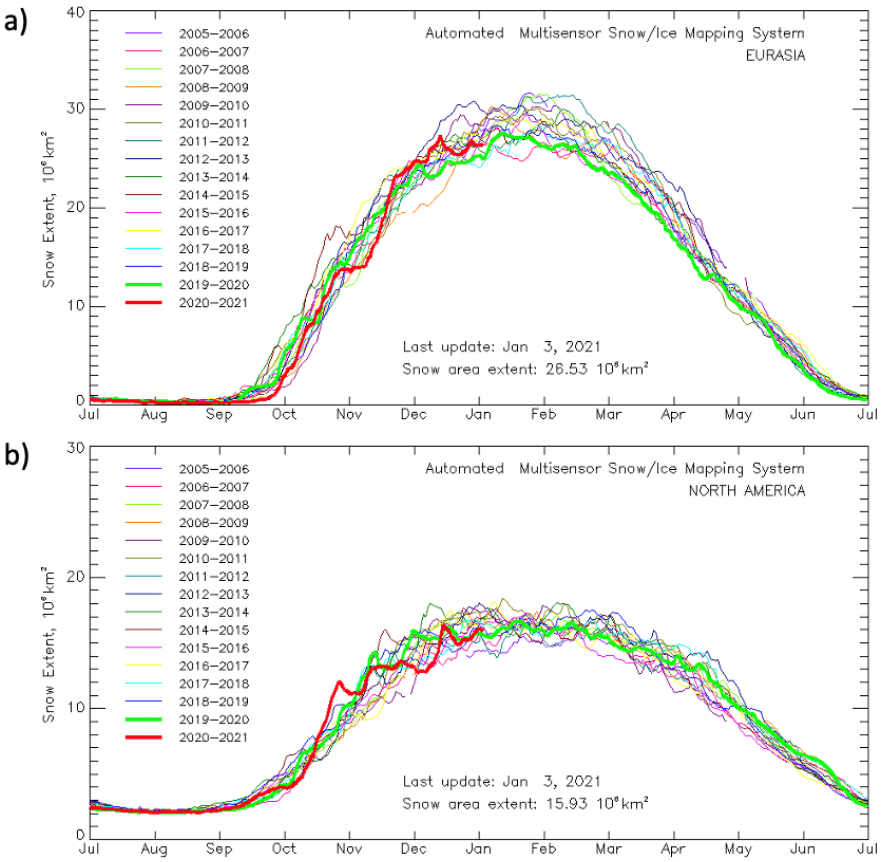

Figure 19. Observed Eurasian (top) and North American (bottom) snow cover extent through 3 January 2021. Image source: https://www.star.nesdis.noaa.gov/smcd/emb/snow/HTML/snow_extent_plots.html

North American snow cover advanced slowly over the past week and is near decadal means. The early advance of snow cover across Canada this fall, has likely contributed to an early start of cold temperatures across the Central and Eastern US but the lack of snow cover is now likely contributing to milder temperatures.