Arctic Oscillation and Polar Vortex Analysis and Forecasts

November 9, 2020

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 positive and is predicted to remain positive over the next two weeks.
- The current positive AO is reflective of mostly negative pressure/geopotential height anomalies across the Arctic especially in the Central Arctic with mixed

pressure/geopotential height anomalies across the mid-latitudes. The North Atlantic Oscillation (NAO) is currently positive with negative pressure/geopotential height anomalies spread across Greenland and Iceland; and the NAO is predicted to also remain positive the next two weeks as pressure/geopotential height anomalies are predicted to be persistently negative the next two weeks.

- The next two weeks, ridging/positive geopotential height anomalies with normal to above normal temperatures are predicted to dominate Europe including the United Kingdom (UK). However during week two the ridging/positive geopotential height anomalies will push far enough west to allow some troughing/negative geopotential height anomalies with normal to below normal temperatures from Central and Western Asia to filter into Southeastern Europe.
- The predicted general pattern the next two weeks across Asia is ridging/positive geopotential height anomalies with normal to above normal temperatures in Eastern Asia with troughing/negative geopotential height anomalies with near seasonable to even below normal temperatures in Central/Western Asia.
- The predicted general pattern the next two weeks across North America is ridging/positive geopotential height anomalies with normal to above normal temperatures in the Eastern United States (US) and Eastern Canada with troughing/negative geopotential height anomalies coupled with normal to below normal temperatures for Alaska, Western Canada and the Western US. However next week some of the cooler temperatures will begin to filter into eastern North America.
- In the Impacts section I continue to discuss what to expect for the upcoming winter and the behavior of the polar vortex (PV) in the coming weeks.

Impacts

There are four main predictors that I follow for the upcoming winter: October Eurasian snow cover extent, high latitude blocking in the Eurasian sector, El Niño/Southern Oscillation (ENSO) and Arctic sea ice extent (SIE). The signal for the first two are so far underwhelming. Eurasian snow cover extent was slightly above normal but relative to the recent record may have even been slightly below normal. Blocking in the Eurasian sector looked impressive at the beginning of October but then quickly faded. And there are still no concrete signs of strong blocking in the Eurasian sector.

Though October Eurasian snow cover may not have a strong influence on the PV and winter weather I do believe that could change. There have been some recent studies that argue that November is the key month with the dipole pattern of above normal SCE in East Asia and below normal SCE in West Asia favoring a weak PV and a negative NAO (e.g. Wegmann et al. 2020). That is the current anomaly pattern across Asia and from the predicted atmospheric circulation pattern this SCE pattern could continue or even amplify. In addition, a recent paper showed that an increase in Siberian snow depth even into January can trigger an increase in upward energy transfer from the

troposphere to the stratosphere that weakens the PV (Lv et al. 2020). So, I do believe there is still the potential for Eurasian SCE to have more influence.

In contrast there are strong signals from the two latter predictors - ENSO and Arctic SIE. Currently La Niña is of moderate strength and this will likely continue through the winter months. I showed this plot in a recent blog, but I feel that it is worth repeating given the strength of La Niña, in **Figure i,** I show the correlation of winter La Niña with Northern Hemisphere (NH) winter temperatures. In general, La Niña favors relatively cold temperatures in the interior of the continents. The signal is stronger across North America and includes, Alaska, Western Canada and the Northwestern US with a hint of warmer temperatures in the Southeastern US. Elsewhere across the NH signals are fairly weak.

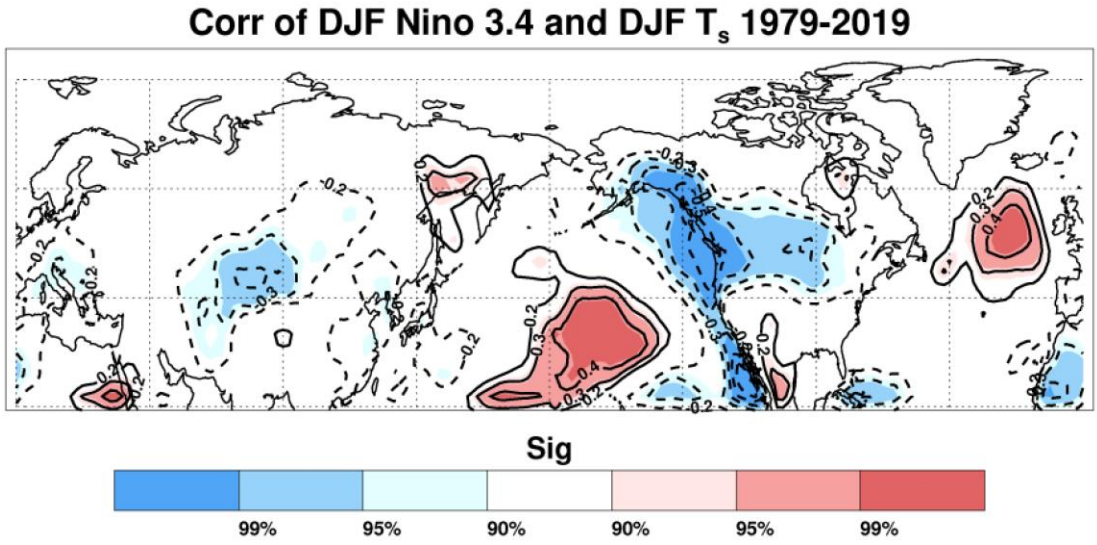

Figure i. Correlation of Niño 3.4 index with NH December, January and February surface temperatures 1979/90 through 2019/20 (contouring starting at value of 0.20). Statistically significance is shaded. Index is inverted to show temperature anomalies for La Niña.

As expected, negative Arctic SIE anomalies are becoming more and more focused in the Barents-Kara Seas (see below **Figure 16**). In **Figure ii**, I present an analysis of the relationship between low October Barents-Kara Seas SIE with NH winter temperatures. Interestingly the relationship can broadly be described as constructively interfering with or amplifying that of La Niña, favoring relatively cold temperatures in the interior of the continents. The signal is most robust across Asia. The cold temperatures in North America also includes the Pacific Northwest but the values are not statistically significant. On the flip side, relatively warm temperatures are widespread across the Arctic but focused in the Barents-Kara Seas with a second maximum near Greenland that extends southward across the Canadian Maritimes and

into New England. So, in general both La Niña and low Barents-Kara Seas SIE favor relatively cold temperatures in the interior of the continents with the signal stronger from La Niña across North America and from the Barents-Kara Seas SIE stronger across Asia. The combined effect of La Niña and low Barents-Kara Seas SIE favor relatively warm temperatures along the Southern US and up along the East Coast. I haven't mentioned Europe, but it seems neither La Niña nor low Barents-Kara Seas SIE seem to have a meaningful relationship with European temperatures.

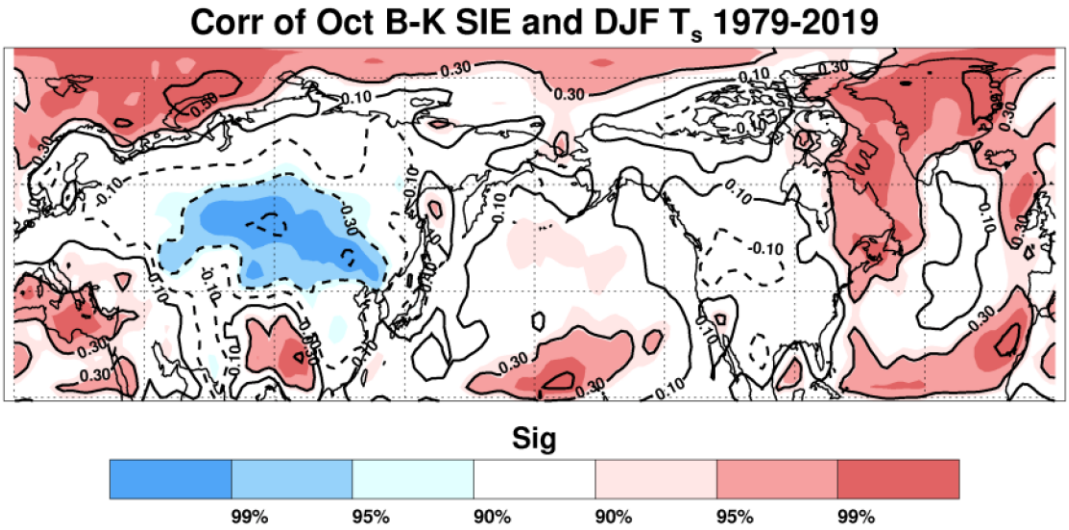

Figure ii. Correlation of October Barents-Kara sea ice extent with NH December, January and February surface temperatures 1979/90 through 2019/20 (contouring starting at value of 0.10). Statistically significance is shaded. Index is inverted to show temperature anomalies for low SIE.

As can be seen from **Figure 11**, polar cap geopotential height anomalies (PCHs) are cold/negative in the stratosphere. This follows the interannual trend. However the cold/negative PCHs extend into the troposphere, do not follow recent interannual trends (for example see Figure 8 from Cohen et al. 2018). The last time tropospheric cold/negative PCHs dominated the month of November was 2013. Winter 2013/14 was an unusual winter and a repeat should not be expected. Before that it was 2011, once again a fall that comparisons with 2020 keep popping up, not least of which is that it preceded a La Niña winter. But again, the winter 2011/12 was highly unusual and a repeat should not be expected.

But what the cold/negative PCHs not only in the stratosphere but also in the troposphere for much of November do signal is that we are on the cusp or teetering towards a troposphere-stratosphere-troposphere (T-S-T) coupling event that includes both a strong stratospheric PV and a positive AO that in combination contribute to widespread relatively mild temperatures across the NH. Increasing the probability of such an event is if the GFS forecast of any high pressure/blocking currently near

Scandinavia (see **Figure 2**) drifts we into the North Atlantic leaving behind a vacuum to be filled by low pressure (see **Figure 8**) verifies. The predicted pattern of ridging/positive geopotential height anomalies in the North Atlantic and East Asia extending into the North Pacific coupled with troughing/negative geopotential height anomalies centered near the Urals is hostile to the vertical transfer of energy from the troposphere to the stratosphere. This will allow the current strong stratospheric PV to persist and increases the likelihood that it couples to the surface with a positive AO. This would likely result in an extended period of mild weather across the NH including the Eastern US, Northern Europe and East Asia. Relatively cold weather might be expected in western North America and Western Asia.

There are no givens in weather forecasting, but the possibility of strong PV/positive AO seem increasingly likely and it would likely last through much of December and possibly even into January. Of course, last year it lasted all winter but that was highly unusual and should not be expected to repeat this winter as well, but certainly not impossible.

One curious thing for me is that though we have seen impressive snow and cold in North America so far this fall it has been pretty much absent from Eurasia. Sure, it has been a really warm year for Eurasia, but I don't understand why all forecasts for cold temperatures in Eurasia fail to verify. It is hard for me to see any meaningful disruption of the PV without it first getting cold in Asia.

I do believe that the best hope for the short circuit of a T-S-T coupling event with a strong PV/positive AO, is for the GFS forecasts in the 11-15 day period to be wrong and it seems to me that the forecasts in that time period, at least for the high latitudes, have not been very good. Also, the GFS is predicting that the stratospheric PV center is drifting to the Siberian slope (see **Figure iii**). In that position the PV is vulnerable to increasing disruptions. But for now, that remains speculative.

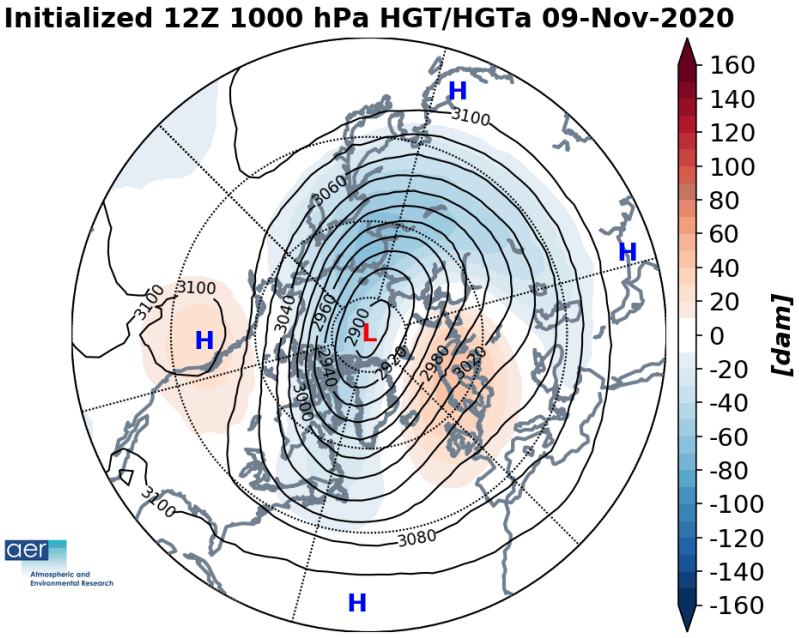

Figure iii. Forecasted 10 mb geopotential heights (dam; contours) and anomalies (°C; shading) across the Northern Hemisphere for 9 –25 November 2020.

1-5 day

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

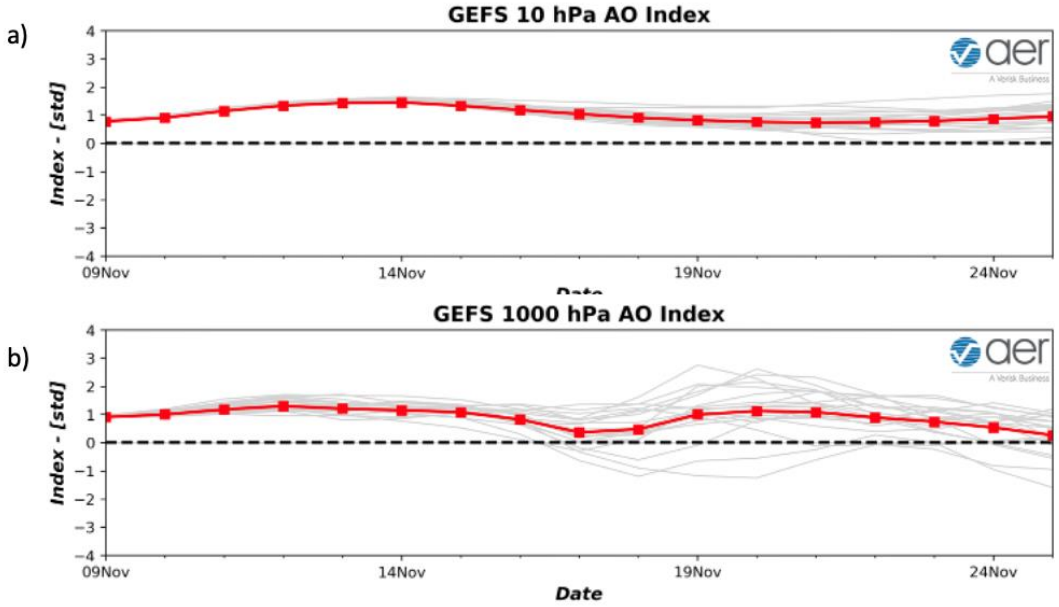

Figure 1. (**a**) The predicted daily-mean AO at 10 hPa from the 00Z 9 November 2020 GFS ensemble. (**b**)The predicted daily-mean near-surface AO from the 00Z 9 November 2020 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

This week, ridging/positive geopotential height anomalies are predicted to dominate much of Europe (**Figure 2**). This pattern favors normal to above normal temperatures for much of Europe including the UK (**Figure 3**). This week, ridging/positive geopotential height anomalies in Europe are predicted to support troughing/negative geopotential height anomalies in Western Asia with more ridging/positive geopotential height anomalies in Eastern Asia (**Figure 2**). This pattern favors widespread normal to above normal temperatures for Central and Eastern Asia with near normal to slightly below normal temperature in Western Asia **(Figure 3**).

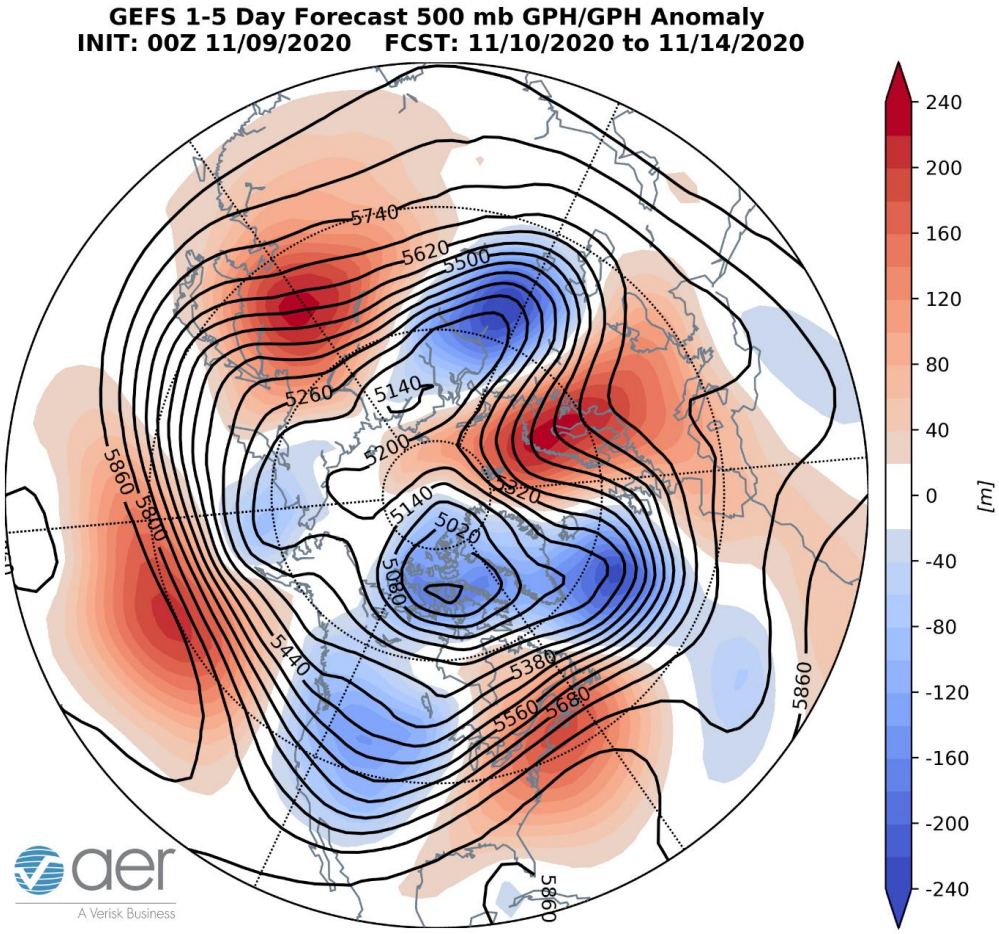

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 10 – 14 November 2020. The forecasts are from the 00z 9 November 2020 GFS ensemble.

This week ridging/positive geopotential height anomalies are predicted to stretch across Alaska, the Eastern US and Eastern Canada with troughing/negative geopotential height anomalies across Western Canada and the Western US **(Figure 2).** This pattern is predicted to bring normal to above normal temperatures across Alaska, the Eastern US and Eastern Canada with normal to below normal temperatures for Western Canada and the Western US **(Figure 3).**

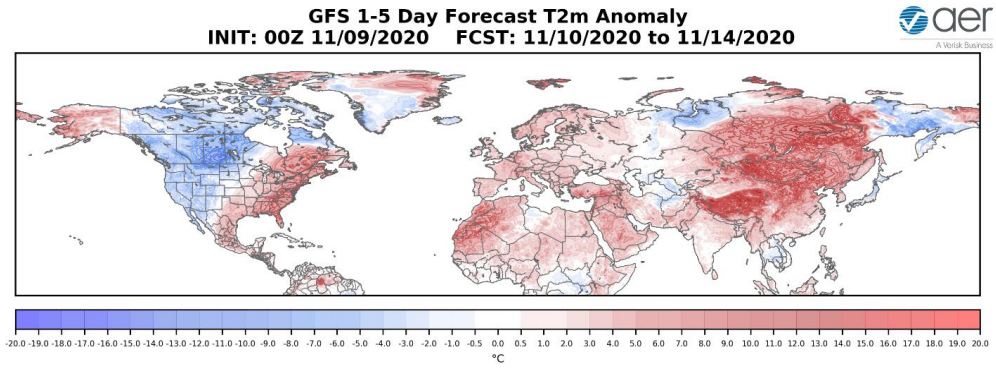

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 10 – 14 November 2020. The forecast is from the 00Z 9 November 2020 GFS ensemble.

Troughing and/or colder temperatures are predicted to support new snowfall across Northern Asia but mostly Siberia and the Himalayas while warmer temperatures will cause snow melt in Scandinavia and Eastern Asia (**Figure 4**). Troughing and/or colder temperatures are predicted to support new snowfall across Alaska, Western Canada and the Northwestern US while warmer temperatures will cause snow melt in Southeastern Canada and the US Southern Rockies (**Figure 4**).

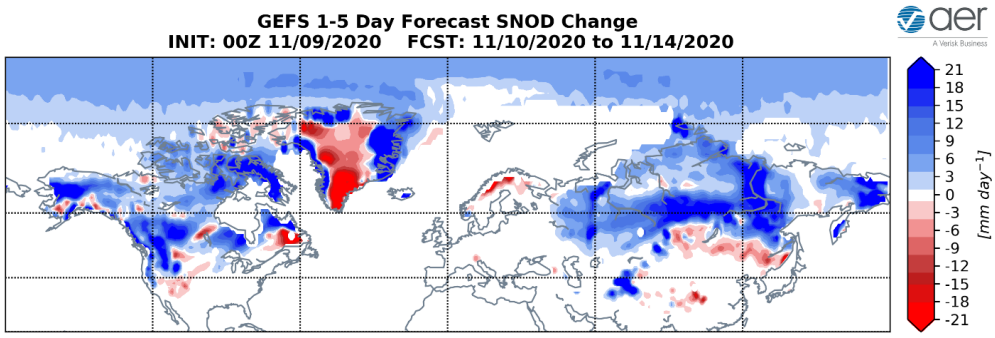

Figure 4. Forecasted snow depth changes (mm/day; shading) from 10 – 14 November 2020. The forecast is from the 00Z 9 November 2020 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to remain positive next week **(Figure 1**) as negative geopotential height anomalies are predicted to dominate the Central Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 5**). And with the persistent negative geopotential height anomalies predicted across Greenland (**Figure 5**), the NAO is predicted to remain positive.

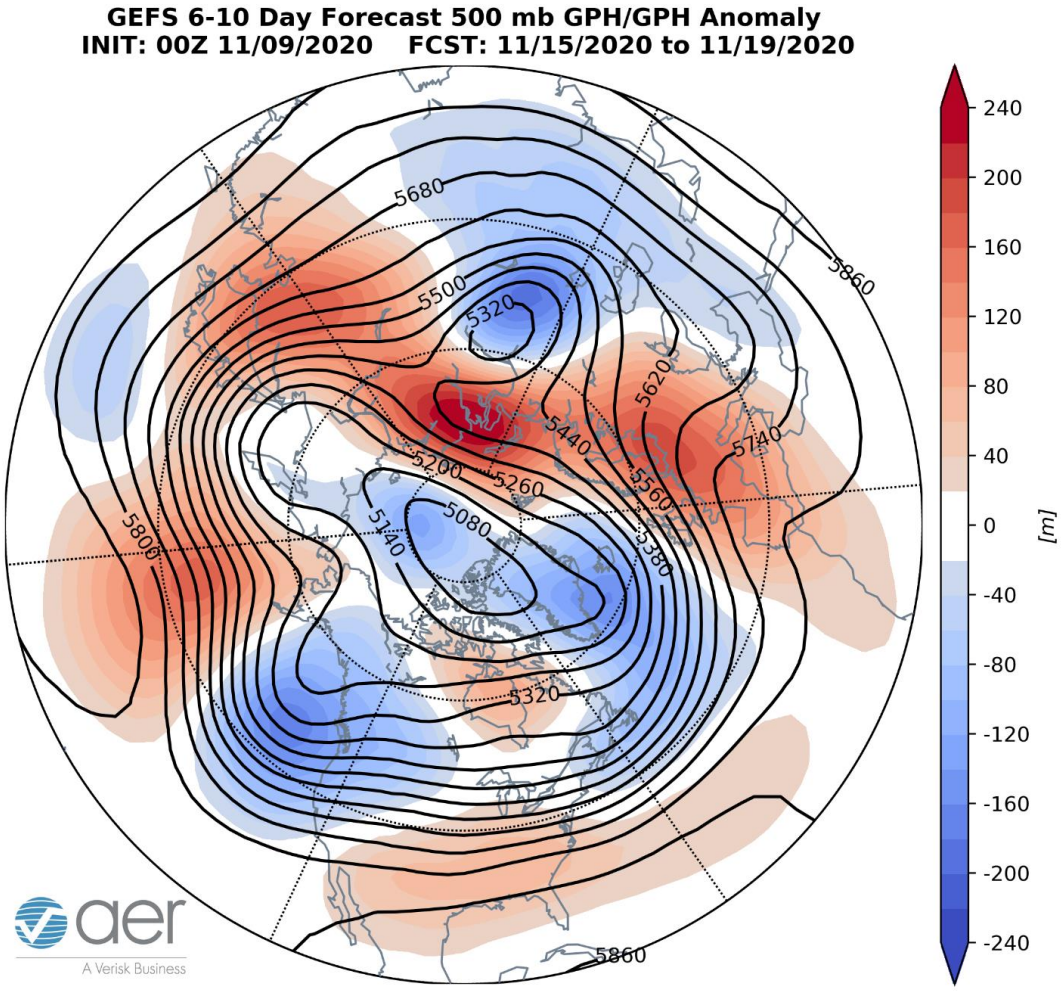

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 15 – 19 November 2020. The forecasts are from the 00z 9 November 2020 GFS ensemble.

Persistent ridging/positive geopotential height anomalies are predicted to dominate all of Europe (**Figures 5).** This pattern favors normal to above normal temperatures across all of Europe including the UK (**Figure 6**). Persistent European ridging/positive geopotential height anomalies are predicted to anchor troughing/negative geopotential height anomalies in Western and into Central Asia with more ridging/positive geopotential height anomalies in Eastern Asia this period (**Figure 5**). This is predicted to favor widespread normal to above normal temperatures across far Western and Eastern Asia with normal to below normal temperatures in Central Asia **(Figure 6**).

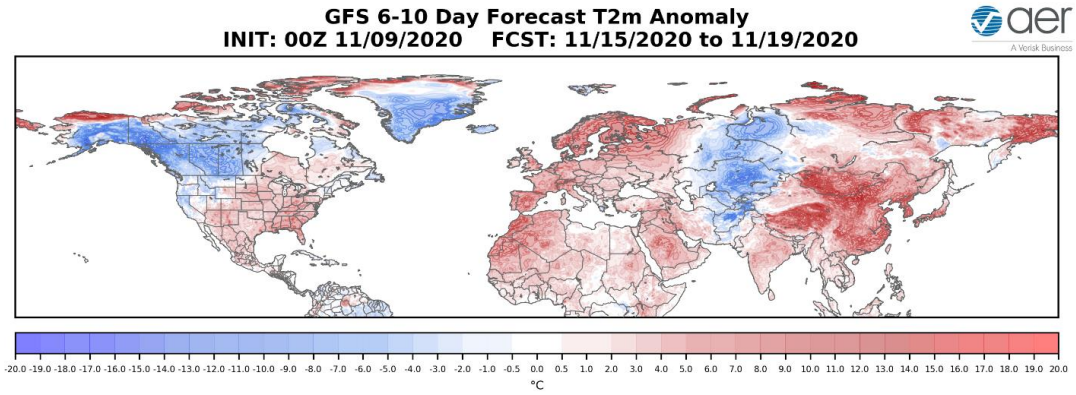

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 15 – 19 November 2020. The forecasts are from the 00Z 9 November 2020 GFS ensemble.

Ridging/positive geopotential height anomalies previously near the Aleutians are predicted to anchor troughing/negative geopotential height anomalies in western North America with more ridging/positive geopotential height anomalies in eastern North America this period **(Figure 5).** This pattern is predicted to bring 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 6).**

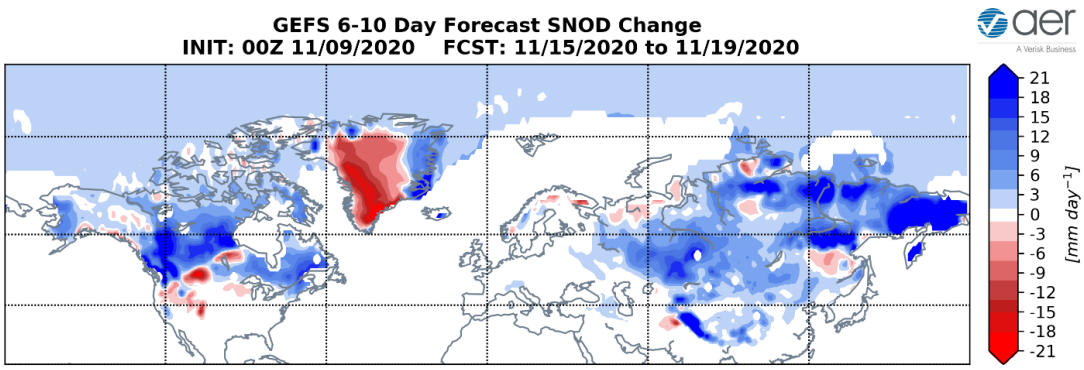

Figure 7. Forecasted snow depth changes (mm/day; shading) from 15 – 19 November 2020. The forecasts are from the 00Z 9 November 2020 GFS ensemble.

Troughing and/or colder temperatures are predicted to support new snowfall across Northern and Central Asia while warmer temperatures will cause regionalized snow melt (**Figure 7**). Troughing and/or colder temperatures are predicted to support new snowfall across Alaska, much of Canada, the Northwestern and possibly New England while warmer temperatures will cause snow melt in the Central Rockies and into the Canadian Plains (**Figure 7**).

11-15 day

Predicted persistent negative geopotential height anomalies in the Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 8**), will keep the AO tethered to positive values this period (**Figure 1**). With persistent negative pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO is predicted to also levitate in positive territory.

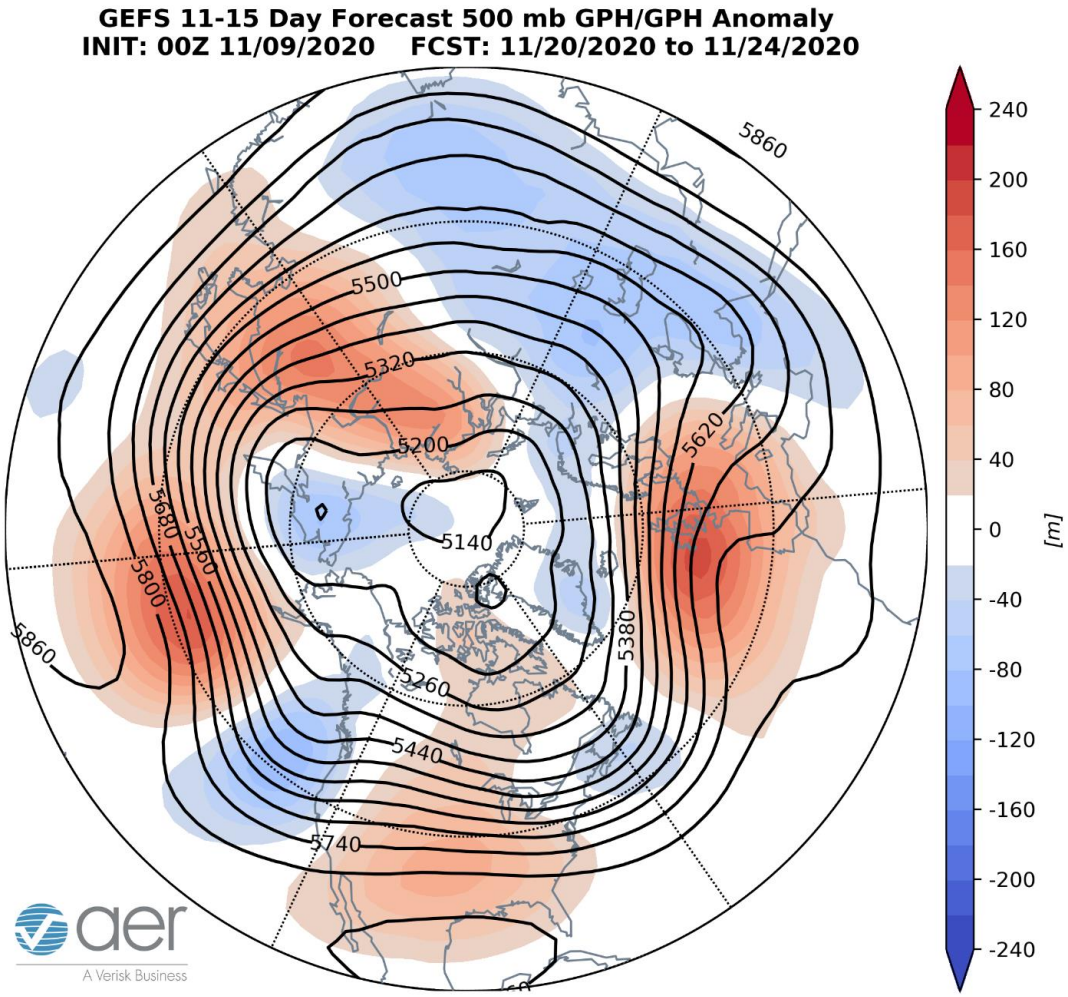

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 20 – 24 November 2020. The forecasts are from the 00z 9 November 2020 GFS ensemble.

European ridging/positive geopotential height anomalies are predicted to drift westwards towards the eastern North Atlantic allowing some backdoor troughing/negative geopotential height anomalies from Western Asia to trail southwestward towards Southeastern Europe this period (**Figures 8**). The forecast is for normal to above normal temperatures across most of Europe including the UK with

normal to below normal temperatures bleeding into Southeastern Europe from Western Asia this period (**Figures 9**). Predicted ridging/positive geopotential height anomalies focused over Europe will support troughing/negative geopotential height anomalies across Western Asia and into Southcentral Asia with more ridging/positive geopotential height anomalies in East Asia this period (**Figure 8**). This pattern favors widespread normal to above normal temperatures across most of Asia with normal to below normal temperatures in Southcentral Asia and into Southwestern Asia (**Figure 9**).

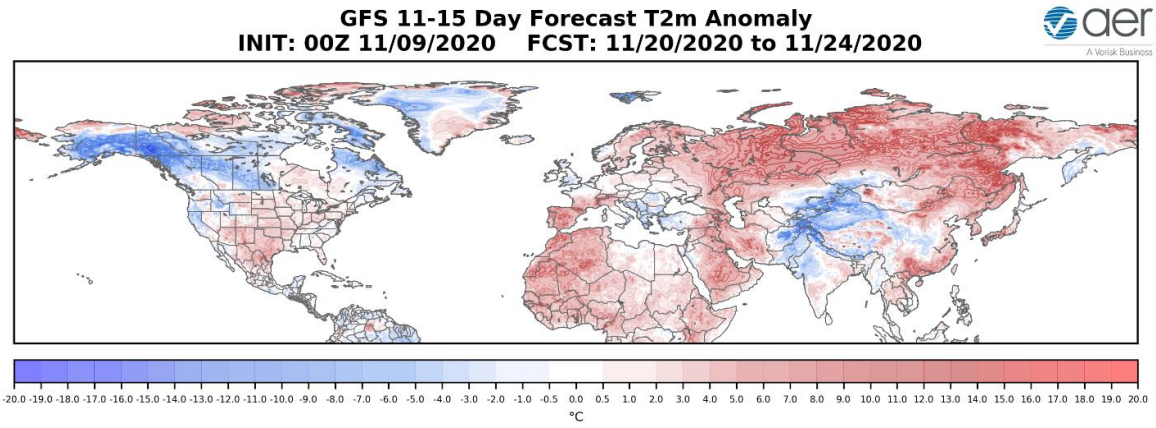

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 20 – 24 November 2020. The forecasts are from the 00z 9 November 2020 GFS ensemble.

Ridging/positive geopotential height anomalies previously near the Aleutians are predicted to drift towards the Dateline allowing troughing/negative geopotential height anomalies across western North America to drift into the Gulf of Alaska with ridging/positive geopotential height anomalies previously in eastern North America sliding into central North America this period (**Figure 8**). This pattern favors widespread normal to below normal temperatures for Alaska, Western Canada and Western US with some of the colder temperatures filtering into Eastern Canada and even into the Northeastern US this period with normal to above normal temperatures in the Central US and Southcentral Canada (**Figure 9**).

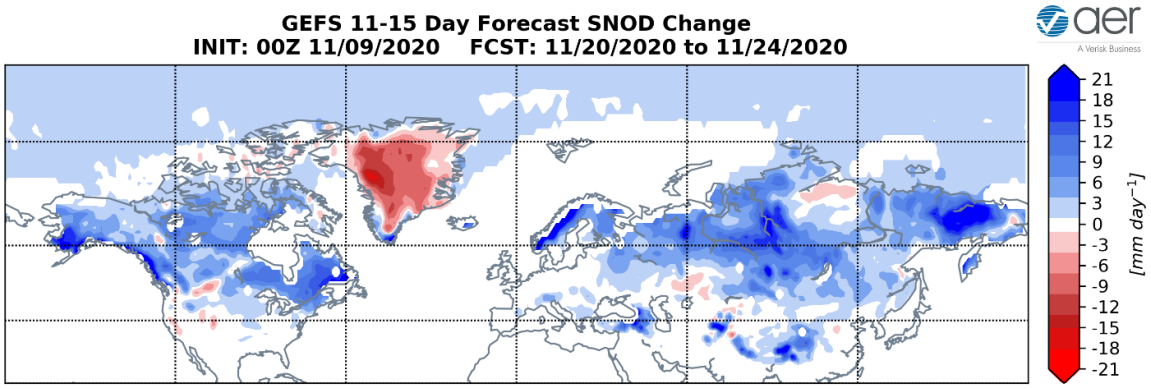

Figure 10. Forecasted snow depth changes (mm/day; shading) from 20 – 24 November 2020. The forecasts are from the 00z 9 November 2020 GFS ensemble.

Troughing and/or colder temperatures are predicted to support new snowfall across much of Northern Eurasia, Central Asia and even possibly Eastern Europe (**Figure 10**). Troughing and/or colder temperatures are predicted to support new snowfall across Alaska, Canada, Quebec and possibly New England (**Figure 10**).

Longer Term

30–day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows normal PCHs in the mid to upper troposphere but cold/negative PCHs in the stratosphere and lower stratosphere (**Figure 11**). The cold/negative PCHs are predicted to continually strengthen in the stratosphere through mid- to late-November (**Figure 11**).

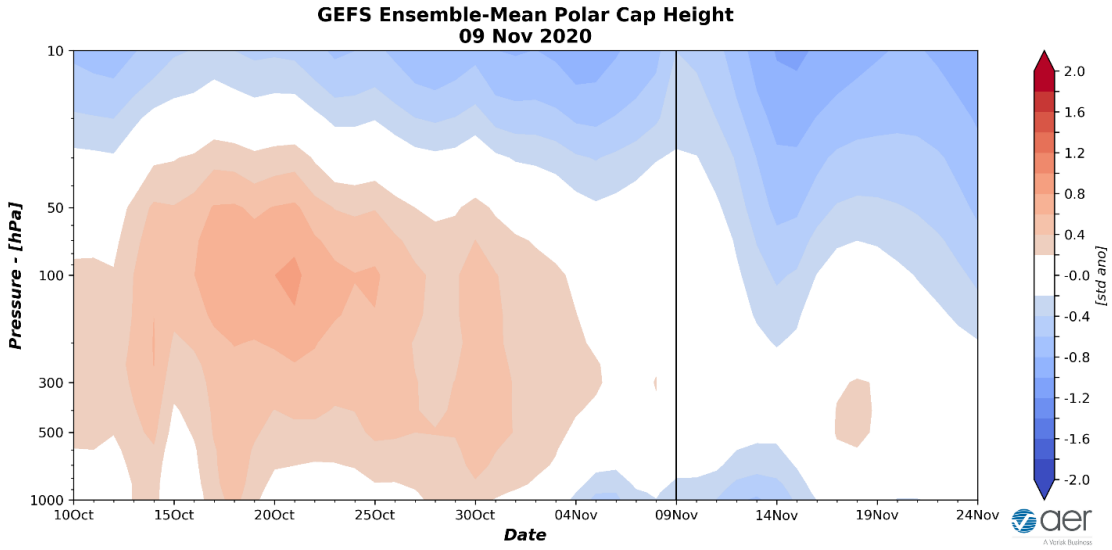

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 9 November 2020 GFS ensemble.

Cold/negative PCHs in the lower troposphere are predicted to spike this week consistent with the predicted positive AO this week (**Figure 1**). However, the forecast for next week is neutral to possibly weakly positive PCHs in the troposphere and could signal a return to neutral AO next week. I still believe there could be volatility in the PCH forecast that have important long-term implications for troposphere-stratosphere coupling.

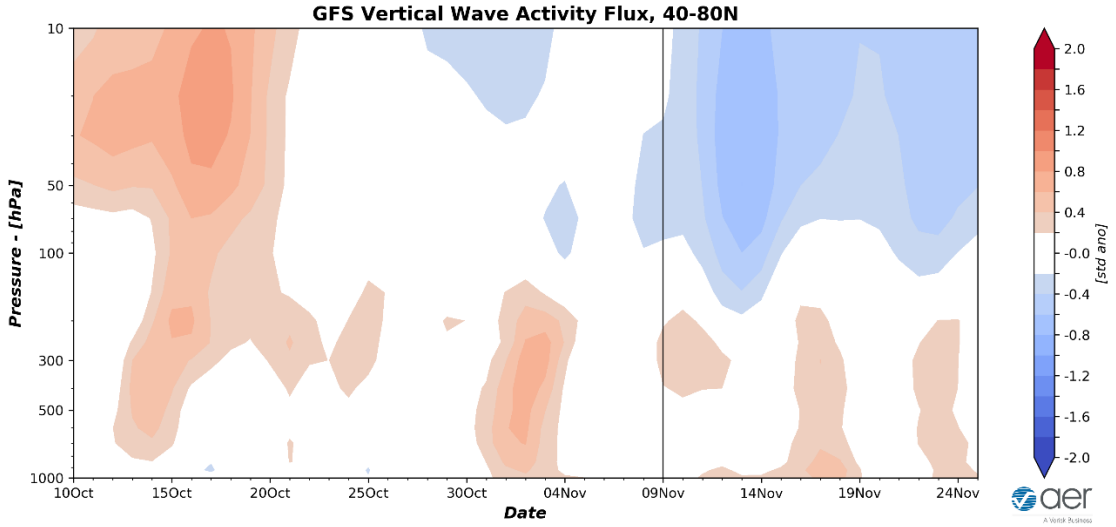

Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 9 November 2020 GFS ensemble.

The plot of Wave Activity Flux (WAFz) or poleward heat transport shows forecasts of some active WAFz in the troposphere over the next two weeks that is not predicted to enter the stratosphere (**Figure 12**). Other than the troposphere-only pulses, the GFS is predicting a relatively quiet period of WAFz especially in the stratosphere (**Figure 12**).

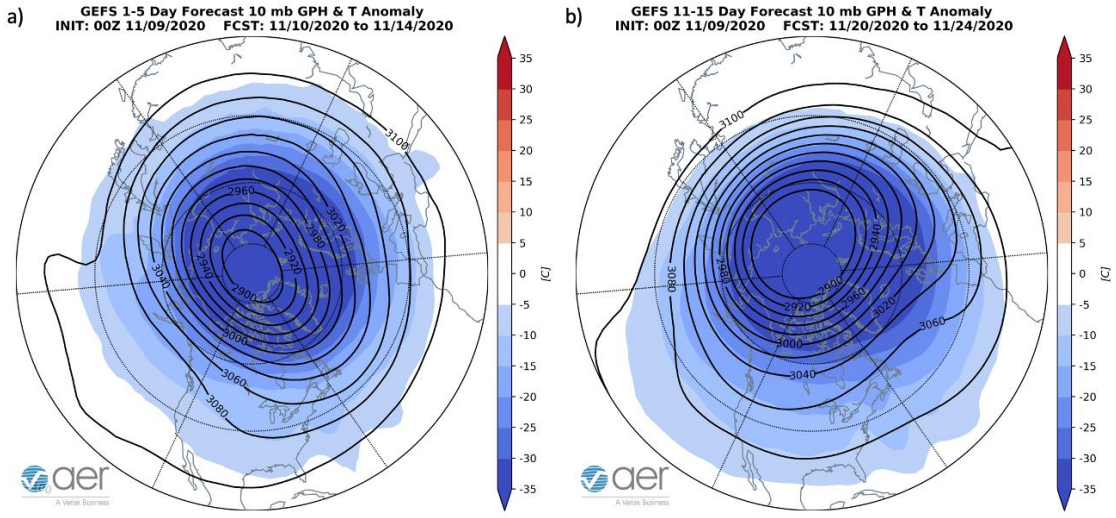

Figure 13. (**a**) Forecasted 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 10 –14 November 2020. (**b**) Same as (a) except forecasted averaged from 20 – 24 November 2020. The forecasts are from the 00Z 9 November 2020 GFS model ensemble.

The upcoming quieter period of WAFz (**Figure 12**) will support a strengthening PV. The PV is predicted to take up a position near the North Pole and deepen this week (**Figure 13**). Currently there are no signs of any weakening of the PV, however, the GFS for next week is predicting a drift of the PV center towards Eurasia. This could be an initial sign of eventual PV weakening.

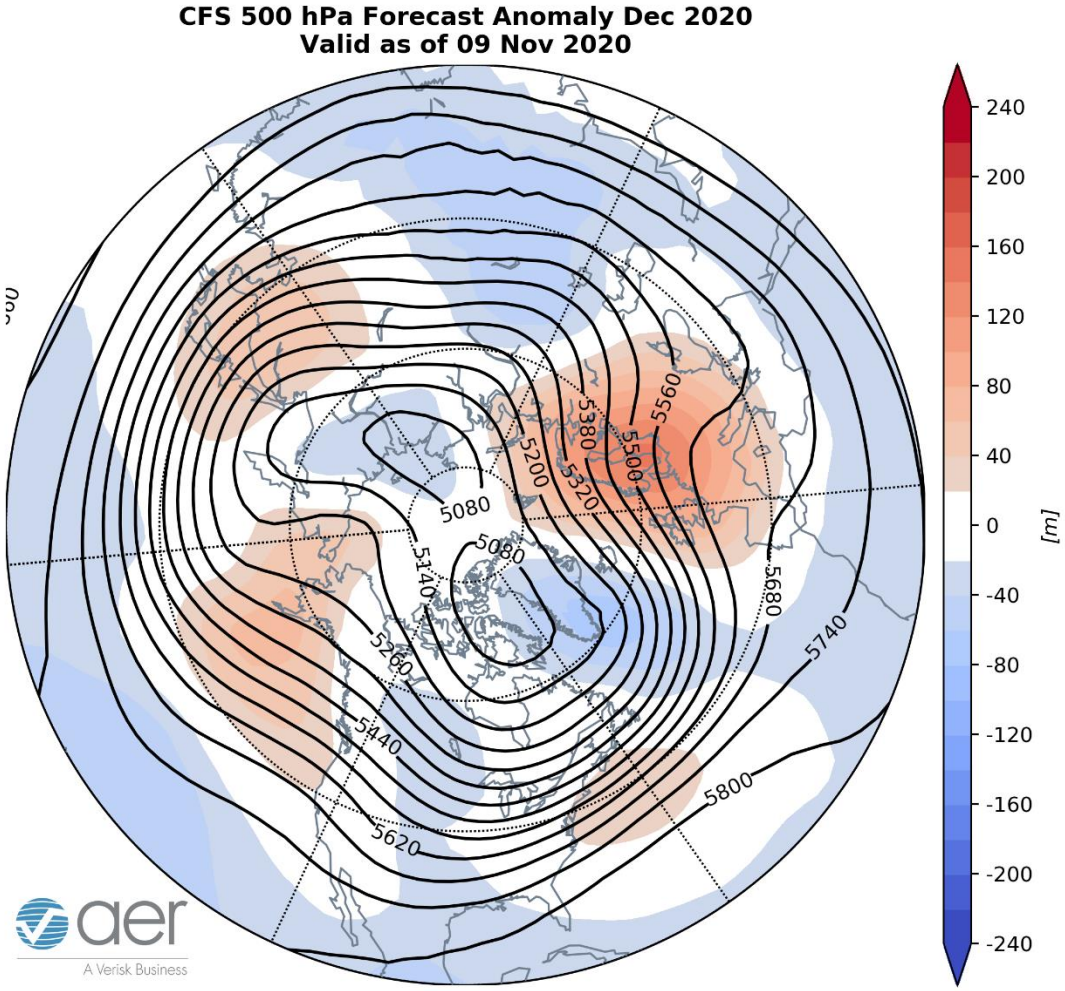

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for December 2020. The forecasts are from the 00Z 9 November 2020 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and the surface temperatures (**Figure 15**) forecast for December from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging across Europe, East Asia, Alaska and the Gulf of Alaska with troughing in the eastern Mediterranean, Central Asia, Siberia, Central **Canada** and the Central US (**Figure 14).** **T**his pattern favors relatively warm temperatures for much of Europe centered on Scandinavia, East Asia and much of the US with seasonable to

relatively cold temperatures for Southeastern Europe, Siberia, Southern Asia, Alaska, Western Canada and the Canadian Maritimes (**Figure 15**).

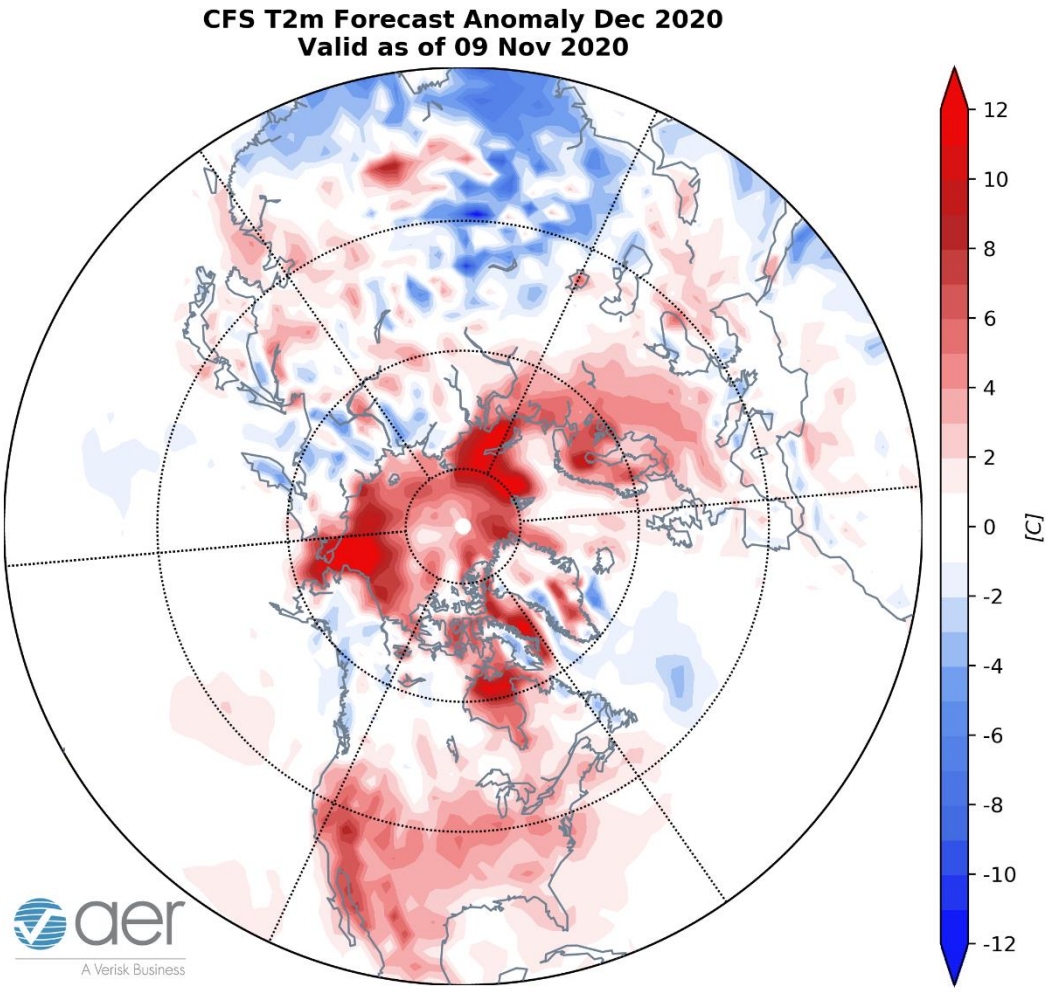

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for December 2020. The forecasts are from the 00Z 9 November 2020 CFS.

Surface Boundary Conditions

Arctic sea ice extent

Arctic sea ice continues to grow but currently remains well below normal. Negative sea ice anomalies exist continuously from Alaska to the Barents-Kara Seas (**Figure 16**). However the largest negative sea anomalies are now focused in the Barents Kara Seas. Below normal sea ice in the Barents-Kara seas favor 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, Beaufort and Bering seas may favor colder temperatures across North America but has not been shown to weaken the PV.

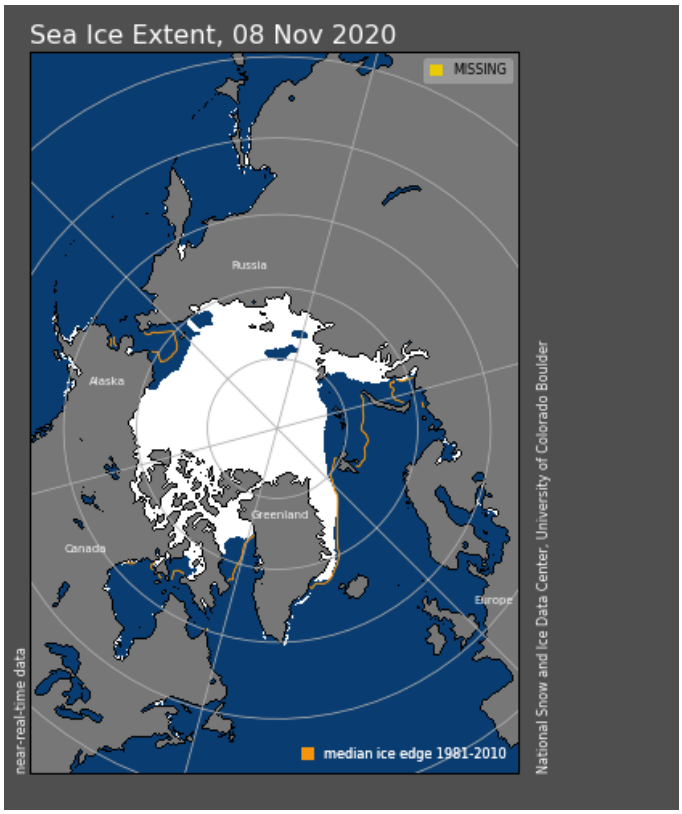

Figure 16. Observed Arctic sea ice extent on 8 November 2020 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image courtesy of National Snow and Ice Data Center (NSIDC). Snow and Ice Data Center (NSIDC).

SSTs/El Niño/Southern Oscillation

Equatorial Pacific sea surface temperatures (SSTs) anomalies continue to cool slowly and we have now entered moderate La Niña conditions (**Figure 14**) and La Niña is expected to persist through the fall and could even be moderate to strong this winter. 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.

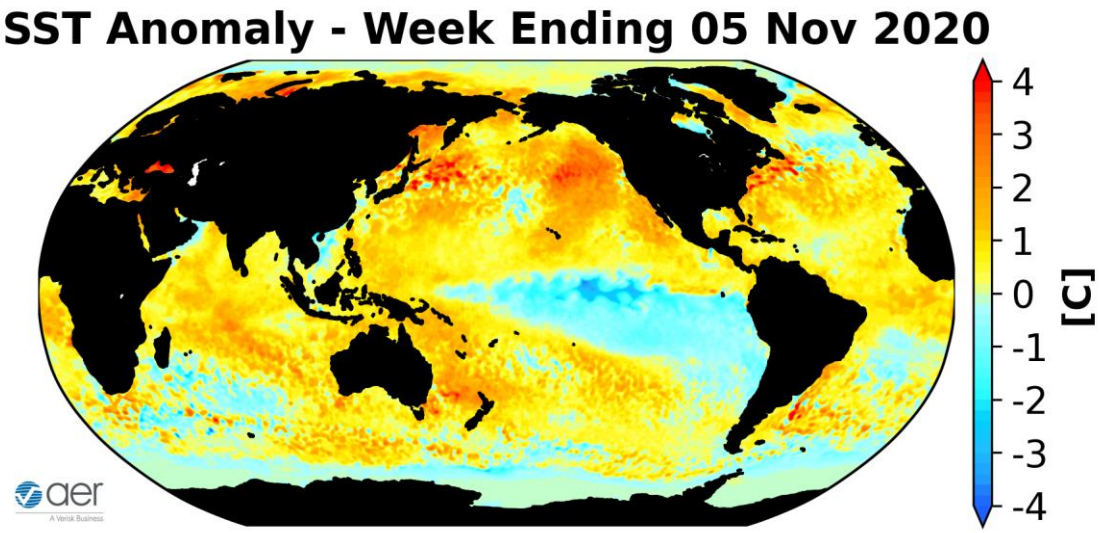

Figure 17. The latest weekly-mean global SST anomalies (ending 5 November 2020). Data from NOAA OI High-Resolution dataset.

Currently no phase of the Madden Julian Oscillation (MJO) is favored (**Figure 15**). The forecasts are for the MJO to emerge into phases eight and one and then once again weaken where no phase is favored. MJO phases eight and one favor troughing across western North America with ridging in Eastern Canada. The MJO could be contributing to the short-term pattern across North America.

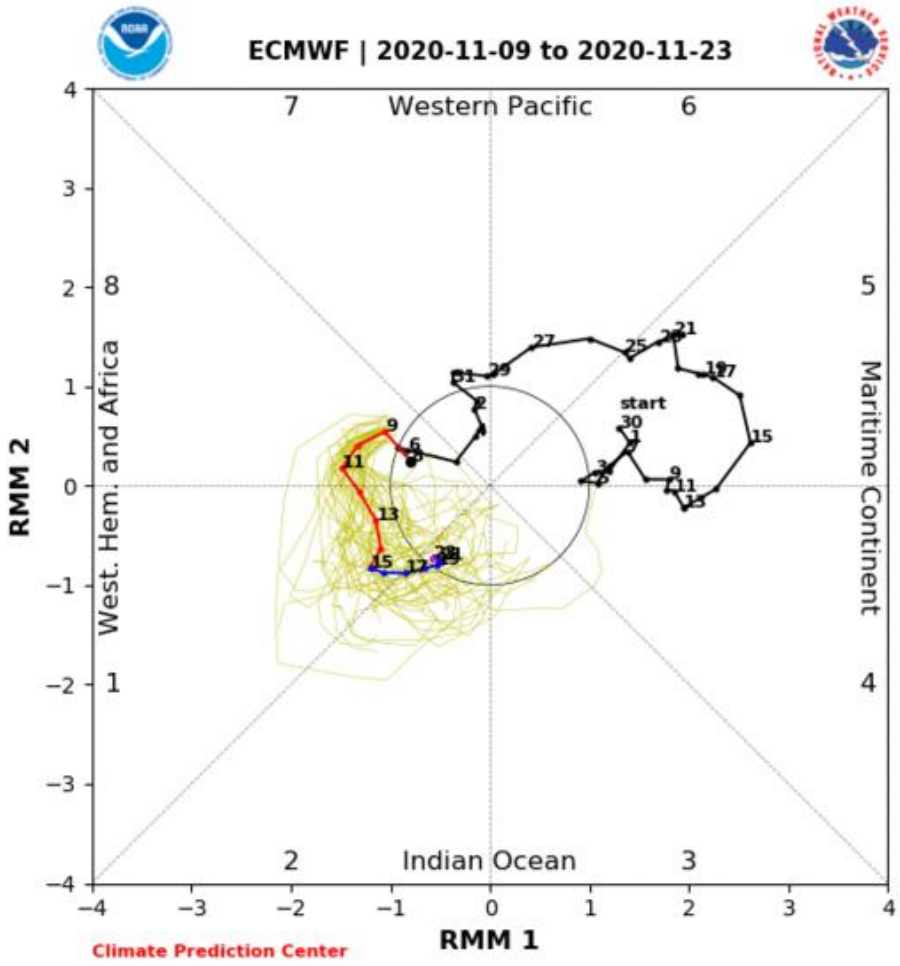

Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 9 November 2020 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model "spread" is denoted by the gray shading. Sector numbers indicate 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 advance stalled the past week across Eurasia and is the lowest value of any recent year. Snow cover advance will likely increase especially across East Asia 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.

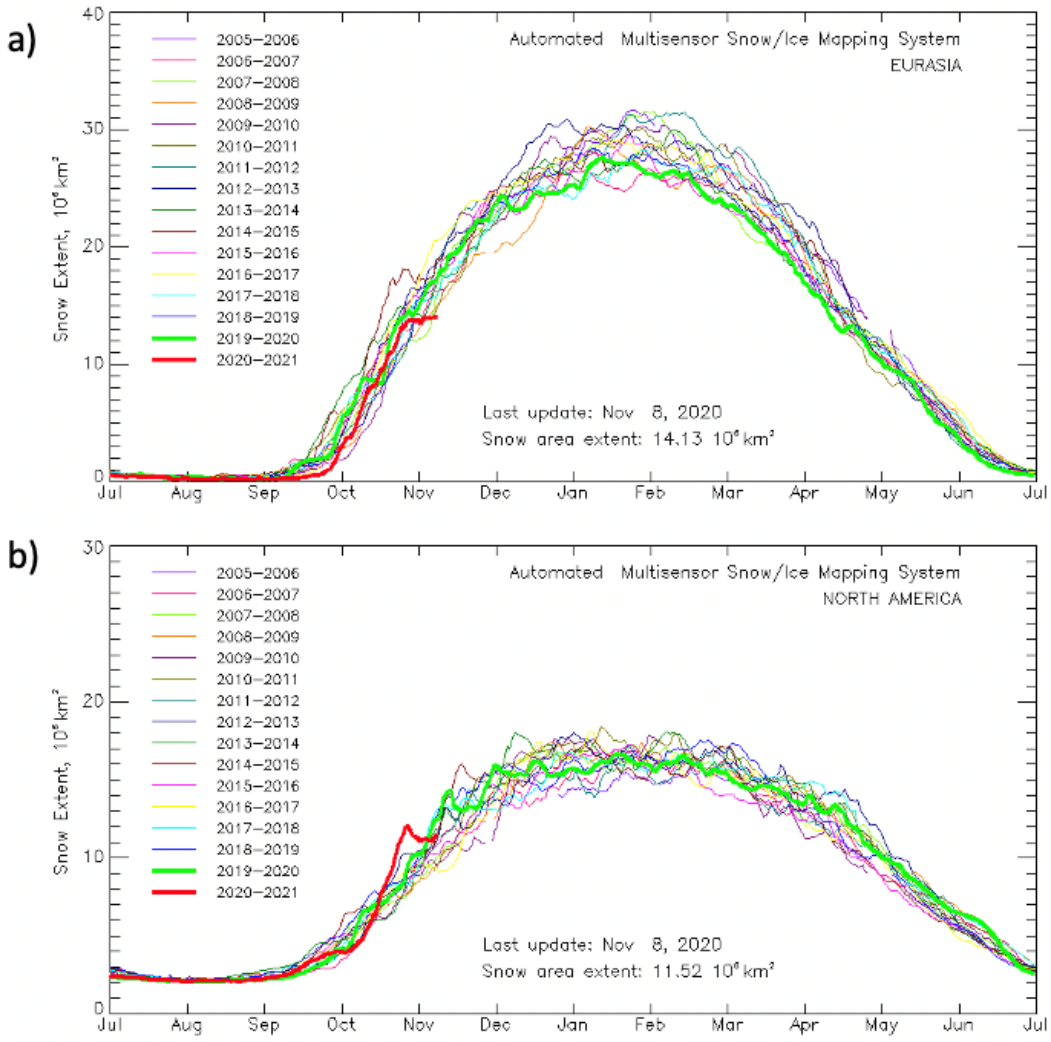

Figure 19. Observed Eurasian (top) and North American (bottom) snow cover extent through 8 November 2020. Image source: https://www.star.nesdis.noaa.gov/smcd/emb/snow/HTML/snow_extent_plots.html

North American snow cover retreated but remains near decadal highs. 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.