Arctic Oscillation and Polar Vortex Analysis and Forecasts

October 11, 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 neutral and is predicted to remain negative to neutral over the next two weeks with mostly positive pressure/geopotential height anomalies across the North Atlantic side of the Arctic and mixed pressure/geopotential height anomalies across the mid-latitudes. The North Atlantic Oscillation (NAO) is currently neutral and is

predicted to remain negative to neutral as pressure/geopotential height anomalies are predicted to remain mostly positive 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 this week in Eastern Europe and then next week in Northern Europe including the United Kingdom (UK) while ridging/positive geopotential height anomalies coupled with normal to above normal temperatures are predicted to dominate much of Western Europe including the UK this week and then Southern Europe next week.
- Predicted for this week and into early next week ridging/positive geopotential height anomalies coupled with normal to above normal temperatures in Western Asia will force downstream troughing/negative geopotential height anomalies coupled with normal to below temperatures in Eastern Asia. However later next week predicted zonal flow will bring widespread above normal temperatures with the exception of Eastern Siberia.
- This general pattern across North America the next two weeks is troughing/negative geopotential height anomalies coupled with normal to below normal temperatures across the west coast of North America including Alaska forcing downstream ridging/positive geopotential height anomalies coupled with normal to above temperatures in much of Canada and the United States (US) from the Rockies eastward. However, one exception is along the US East Coast where troughing/negative geopotential height anomalies coupled with normal to below temperatures are predicted starting next week as the center of the ridging drifts westward.
- In the *Impacts* section I discuss the stratospheric polar vortex (PV), what the predicted weak PV this month could mean for the Northern Hemisphere (NH) winter. I also briefly discuss Siberian snow cover extent.

Impacts

Typically, it is not until December when a large disruption of the polar vortex (PV) is expected that are of the variety of sudden stratospheric warmings (SSWs) that result in splits and displacements of the PV with the largest events resulting in the reversal of the zonal wind at 60°N and 10 hPa referred to as major (mid-winter) warmings. These events peak in January and February. However, the models are predicting a fairly large disruption of the PV that could reach record weak values for the date and at least some ensemble members of the ECMWF model are predicting a possible major warming. The earliest major warmings that I am aware of have occurred the last few days of November back in 1958 and 1968, so I think the possibility of a major warming in October is highly unlikely but not impossible.

It does look to me from the recent polar cap geopotential height anomalies (PCHs) plots (**Figure 11**) that we are likely looking at a full troposphere-stratosphere-

troposphere coupling event. The tropospheric precursor can be observed in late September into early October with a re-emergence this week. The tropospheric precursor has generated anomalous vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere that began in early October and is predicted to continue for much of the next two weeks (**Figure 12**). This is predicted to lead to a weakening of the stratospheric PV and a warming of the polar stratosphere, which according to the latest GFS PCH forecast, will peak around October 25th. Following the peak in the disruption of the stratospheric PV, I do believe that there is a good possibility of those warm/positive PCHs to descend from the stratosphere to the troposphere resulting in higher pressures across the Arctic likely centered near Greenland and a negative AO/NAO. This will likely favor more widespread relatively cold temperatures across Northern Europe and/or Asia and probably eventually in the Eastern US; my guess would be starting in early November. This new pattern of a negative AO/NAO and colder temperatures could last a few weeks.

There is then plenty of speculation what might follow next. I think @SimonLeeWx thread on his reasoning why we should expect a stronger PV the first half of winter received a lot of attention. He brings the PV of 2016/17 as a good analog to support his reasoning and I agree. If you are a winter weather enthusiast or someone bullish on cold weather, I will throw in an even scarier analog – 2019/2020. The PV was weakest that winter right at the beginning of December, it was not impressive, but the models were initially predicting a much more significant weakening, even possibly a major warming. But as the event drew closer the models backed off the more extreme predictions and there was short lived minor warming, and this was followed by the PV off to the races and record strong PV that winter coupled with a very mild winter across the NH.

While I certainly agree this scenario is plausible, I don't think we have enough data points to know what will happen next. What I am going to write next is highly speculative. There has been an observed cooling trend in the polar stratosphere in the fall months through December with a reversal to a warming trend in January and February (I believe that I most recently showed this in Figure 8 from Cohen et al. (2018) but I believe more recent trend analysis exists out there but should be consistent with the older analysis). My explanation of the diverging trends in the stratospheric PCHs in fall and winter is that in the fall increasing atmospheric CO_2 is resulting in a radiatively forced cooling trend in the polar stratosphere. Based on radiative arguments this cooling trend should continue into winter as well, however it is being completely offset by a dynamically forced warming trend due to Arctic change (my opinion supported by my analysis) and an increasing trend in WAFz. Therefore, I do think that we need to separate the weakening trend of the PV that we observe in winter from fall PV trends. Though it is very complicated and there is dynamic weakening of the PV and some associated warming with those events taking place in the fall as well but not enough to cancel out the radiative cooling trends.

I don't like to look too far back for possible analogs, because I do believe that the climate system is different enough today even compared to thirty or forty years ago to make me reluctant to compare, but at least based on PCHs in the 1980's and 1960's there are more examples of early weakenings of the stratospheric PV and positive PCHs of the magnitude predicted by the GFS. Those years include 1960/61 (yes please!), 1984/85 and 1987/88. Many of the winters that followed an anomalously weak PV in October featured major warmings and/or relatively cold temperatures. The weakest November PV of recent years was in 2009 and that winter the PV was relatively strong for a brief period in January and it coupled to the surface for an even shorter period just prior to a major warming in February 2010.

The predicted stratospheric PV weakening looks to me to be one where the WAFz converges in the polar stratosphere rather than one where the WAFz is reflected. I have not done a thorough analysis, but I am guessing that the two fall weakenings of the stratospheric PV in 2016 and 2019 concluded with a WAFz reflection. If something similar happens in October or early November, then I do believe the likelihood of a strong and persistent PV in the coming months increases. I will just conclude that I think the strength of Ural blocking in the months November through January will be more influential on the strength of the winter PV more so than the relative strength of the PV in October.

Now that it is October, my attention of course turns to Siberian snow cover extent (SCE). The more extensive the snow cover the greater probability of an impactful PV disruption during winter with a less extensive snow cover extent favoring a strong PV. I show in **Figure i** the observed daily snow cover extent for October 2021 compared with other Octobers dating back to 2009. The vast majority of those Octobers, the SCE was above normal so the graph is a bit skewed, but so far the SCE in October 2021 is in the middle of the pack but it's early and at least the GFS forecast next week doesn't look favorable for a rapid advance in SCE. A ridge centered over Siberia is not a conducive pattern for the rapid advance of snow cover.

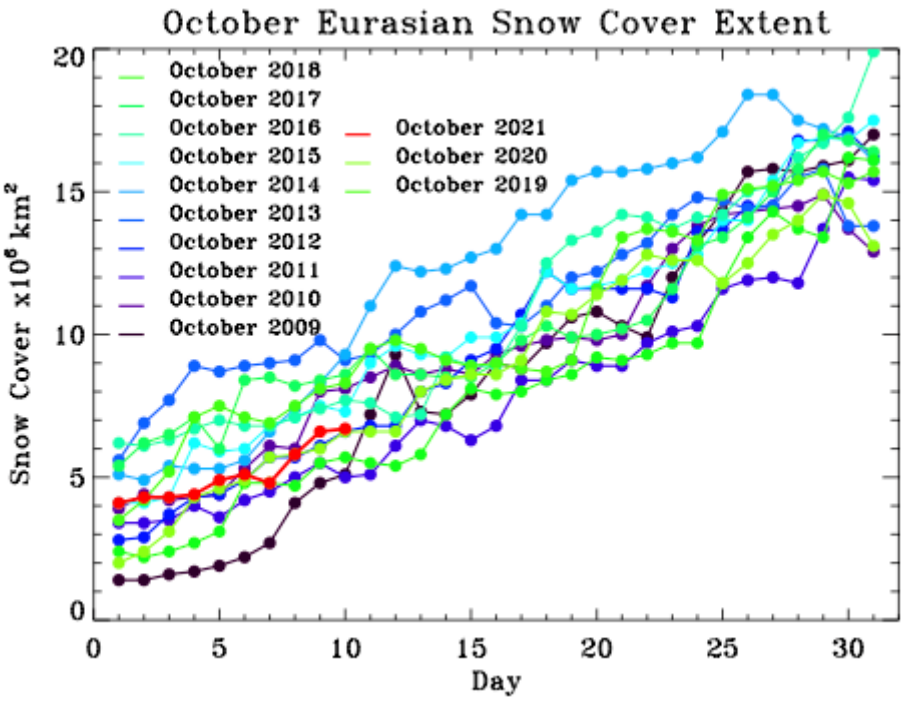

Figure i. Observed Eurasian daily snow cover extent in km^2 throughout the month of October from 2009 through 2020. Also show on red is the snow cover extent 1 – 9 October 2021.

1-5 day

The AO and NAO are predicted to be negative this week **(Figure 1**) as geopotential height anomalies are predicted to be positive across the North Atlantic side of the Arctic including Greenland with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 2**).

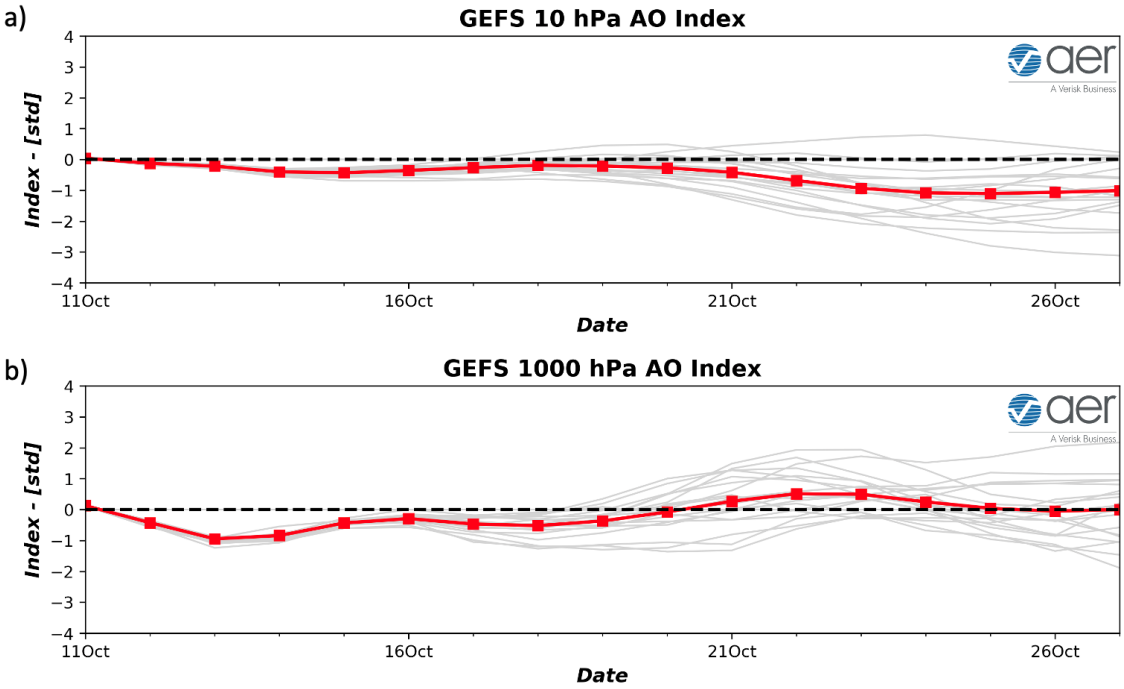

Figure 1. (a) The predicted daily-mean AO at 1000 hPa from the 00Z 11 October 2021 GFS ensemble. (b)The predicted daily-mean near-surface AO from the 00Z 11 October 2021 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

Ridging/positive geopotential height anomalies across Greenland will promote troughing/negative geopotential height anomalies across Eastern Europe with ridging/positive geopotential height anomalies in Western Europe (**Figures 2).** This will favor widespread normal to below normal temperatures across much of Central and Eastern Europe with normal to above normal temperatures across Western Europe including the UK (**Figure 3**). The general pattern across Asia this period is ridging/positive geopotential height anomalies across Western Asia that will force downstream troughing/negative geopotential height anomalies in Eastern Asia (**Figure 2**). This pattern favors normal to above normal temperatures across much of Western and Central Asia with normal to below normal temperatures in Eastern Asia **(Figure 3**).

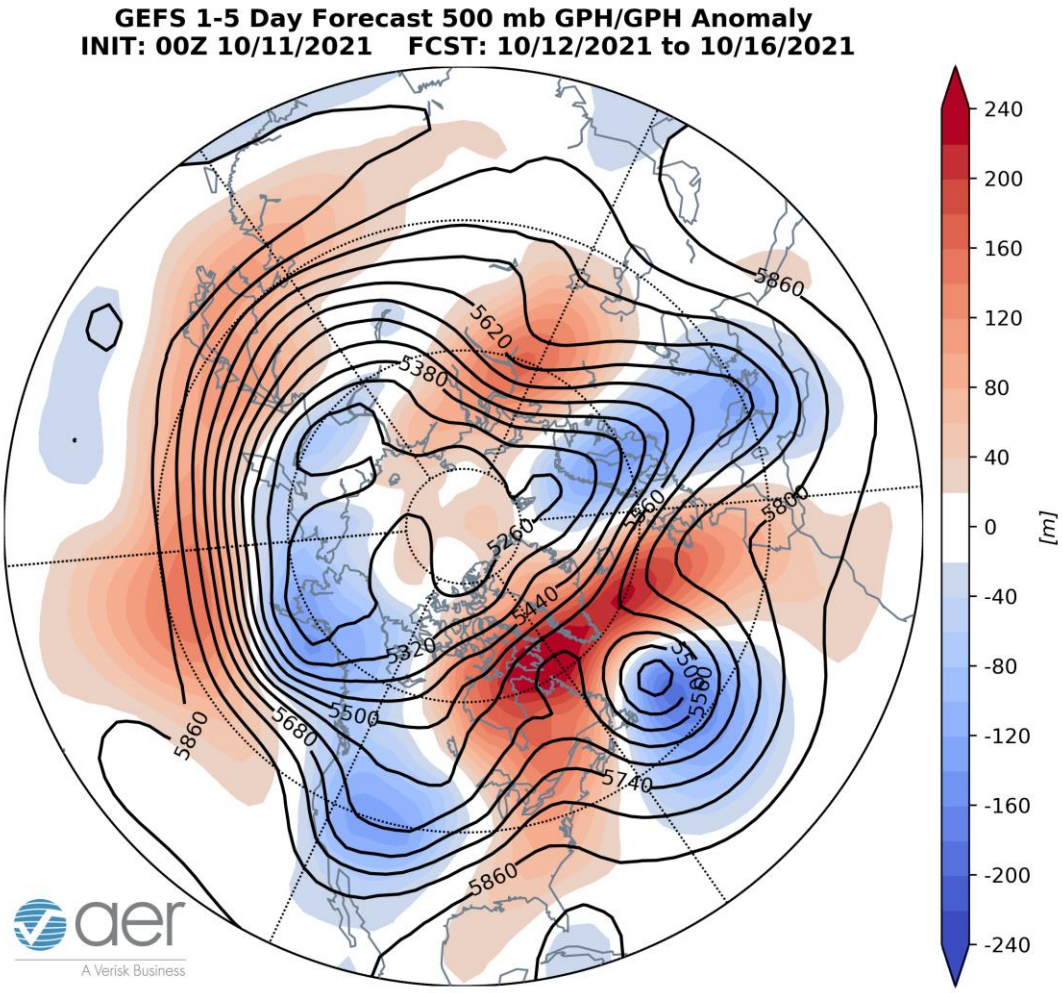

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 12 – 16 October 2021. The forecasts are from the 00z 11 October 2021 GFS ensemble.

The general pattern this week is troughing/negative geopotential height anomalies across western North America including Alaska forcing downstream ridging/positive geopotential height anomalies across much of North America east of the Rockies **(Figure 2).** This pattern is predicted to bring normal to below normal temperatures across much of Alaska, Western Canada, and especially the Western US with normal to above normal temperatures across much of Canada and the US east of the Rockies **(Figure 3).**

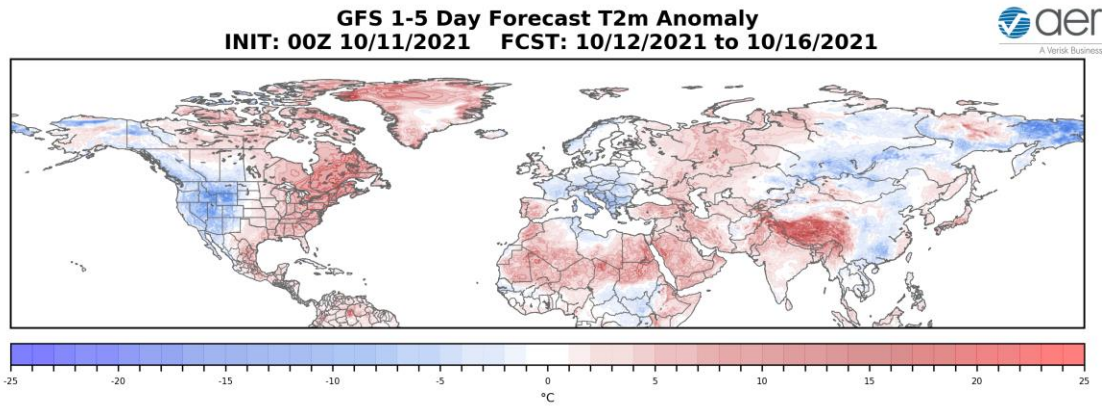

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 12 – 16 October 2021. The forecast is from the 00Z 11 October 2021 GFS ensemble.

Troughing and/or cold temperatures are predicted to support new snowfall across Scandinavia, Siberia into Northern Mongolia and China (**Figure 4**). Troughing and/or cold temperatures are predicted to support new snowfall across Alaska, Northern Canada and the higher elevations of Western Canada and the US (**Figure 4**).

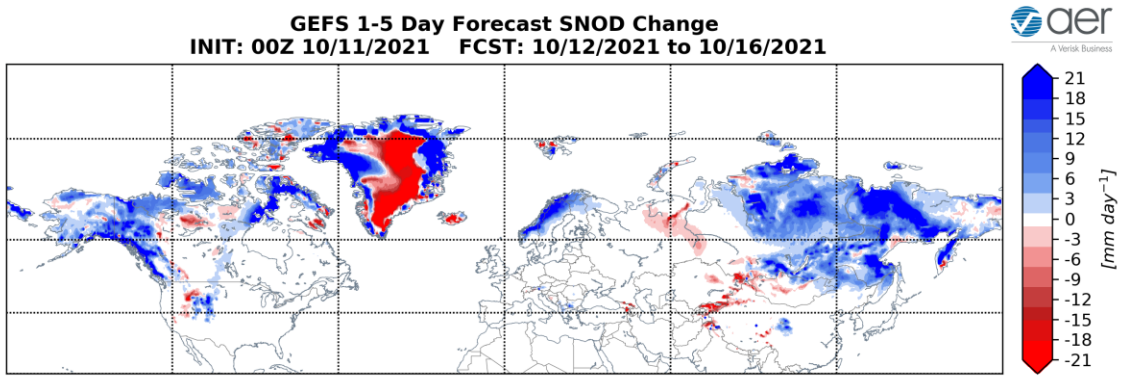

Figure 4. Forecasted snow depth changes (mm/day; shading) from 12 – 16 October 2021. The forecast is from the 00Z 11 October 2021 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to continue to remain negative to neutral this period **(Figure 1**) as geopotential height anomalies remain positive across the North Atlantic side of the Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 5**). And with mostly positive geopotential height anomalies continuing across Greenland (**Figure 5**), the NAO is predicted to be negative this period.

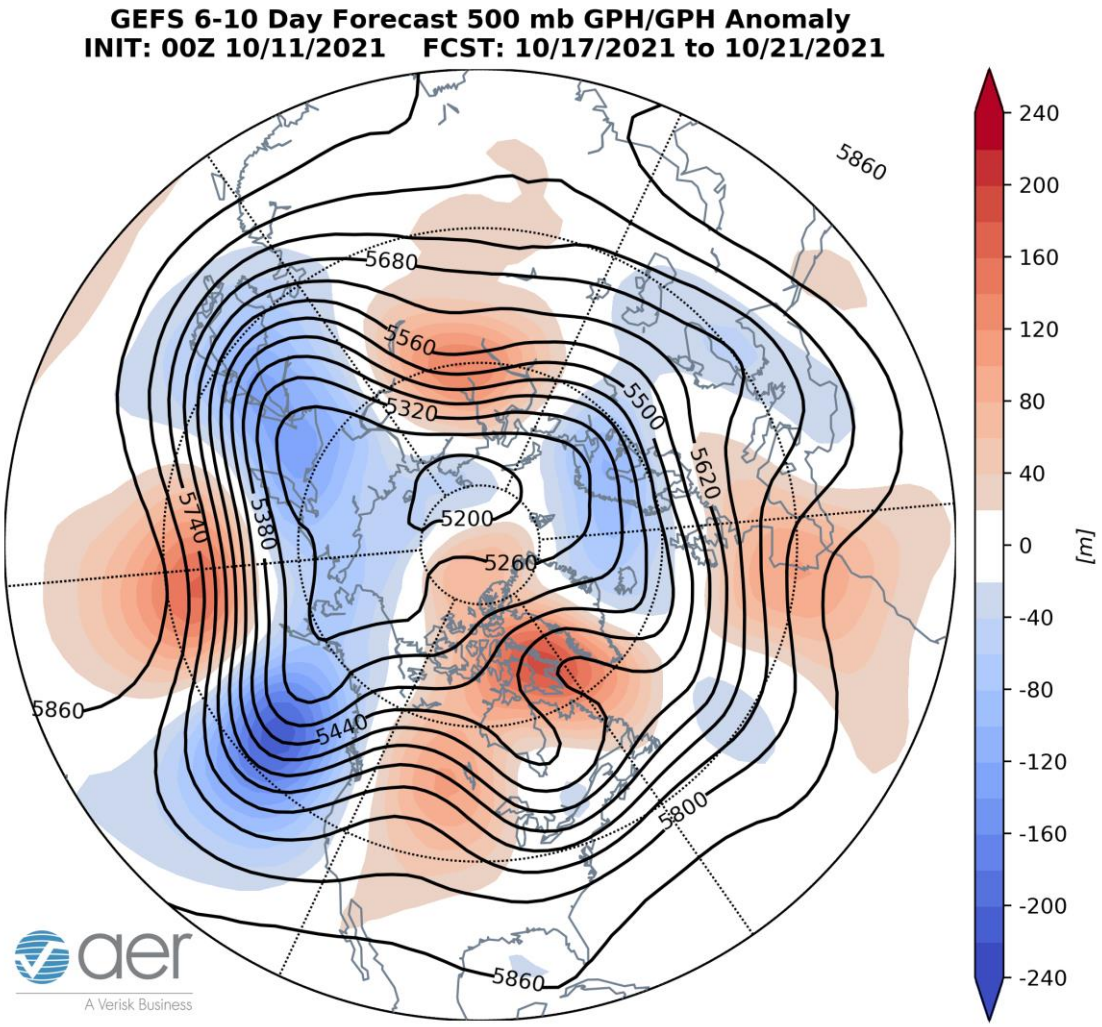

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 17 – 21 October 2021. The forecasts are from the 00z 11 October 2021 GFS ensemble.

Persistent ridging/positive geopotential height anomalies are predicted across Greenland favoring troughing/negative geopotential height anomalies across Northern Europe including the UK with ridging/positive geopotential height anomalies across Southwestern Europe this period (**Figures 5).** This will result in widespread normal to above normal temperatures across Europe including the UK with normal to below normal temperatures across Scandinavia (**Figure 6**). Ridging/positive geopotential height anomalies are predicted to persist across Western and Central Asia that will continue to favor troughing/negative geopotential height anomalies across Eastern Asia this period (**Figure 5**). This pattern favors normal to above normal temperatures widespread across Western and Central Asia with normal to below normal temperatures in East Asia **(Figure 6**).

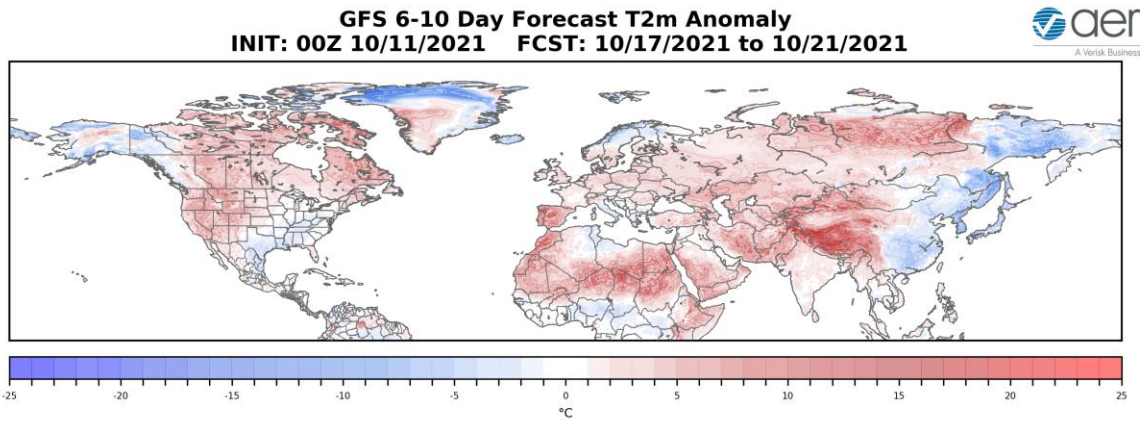

Figure 6. Forecasted surface temperature anomalies (°C; shading) from17 – 21 October 2021. The forecasts are from the 00Z 11 October 2021 GFS ensemble.

Troughing/negative geopotential height anomalies are predicted across Alaska and the Gulf of Alaska contributing to ridging/positive geopotential height anomalies widespread across much of North America except for weak troughing/negative geopotential height along the US East Coast **(Figure 5).** The widespread ridging is predicted to bring normal to above normal temperatures across much of Canada and the US with the exception of normal to below normal temperatures in Alaska, the West Coasts of Canada and the US and the US East Coast **(Figure 6).**

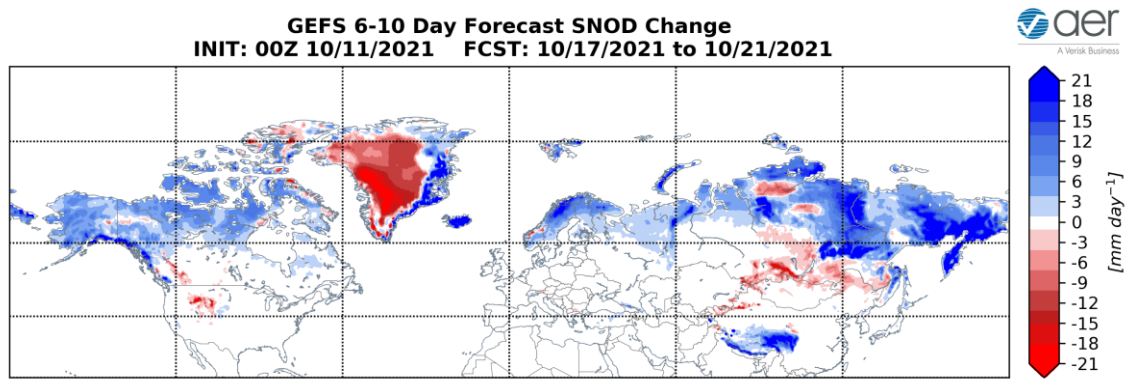

Figure 7. Forecasted snow depth changes (mm/day; shading) from 17 – 21 October 2021. The forecast is from the 00Z 11 October 2021 GFS ensemble.

Troughing and/or cold temperatures are predicted to support new snowfall across Scandinavia, Northern Asia and the Tibetan Plateau (**Figure 7**). Troughing and/or cold temperatures are predicted to support new snowfall across Alaska, Northern Canada and the West Coast of Canada (**Figure 7**).

11-15 day

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

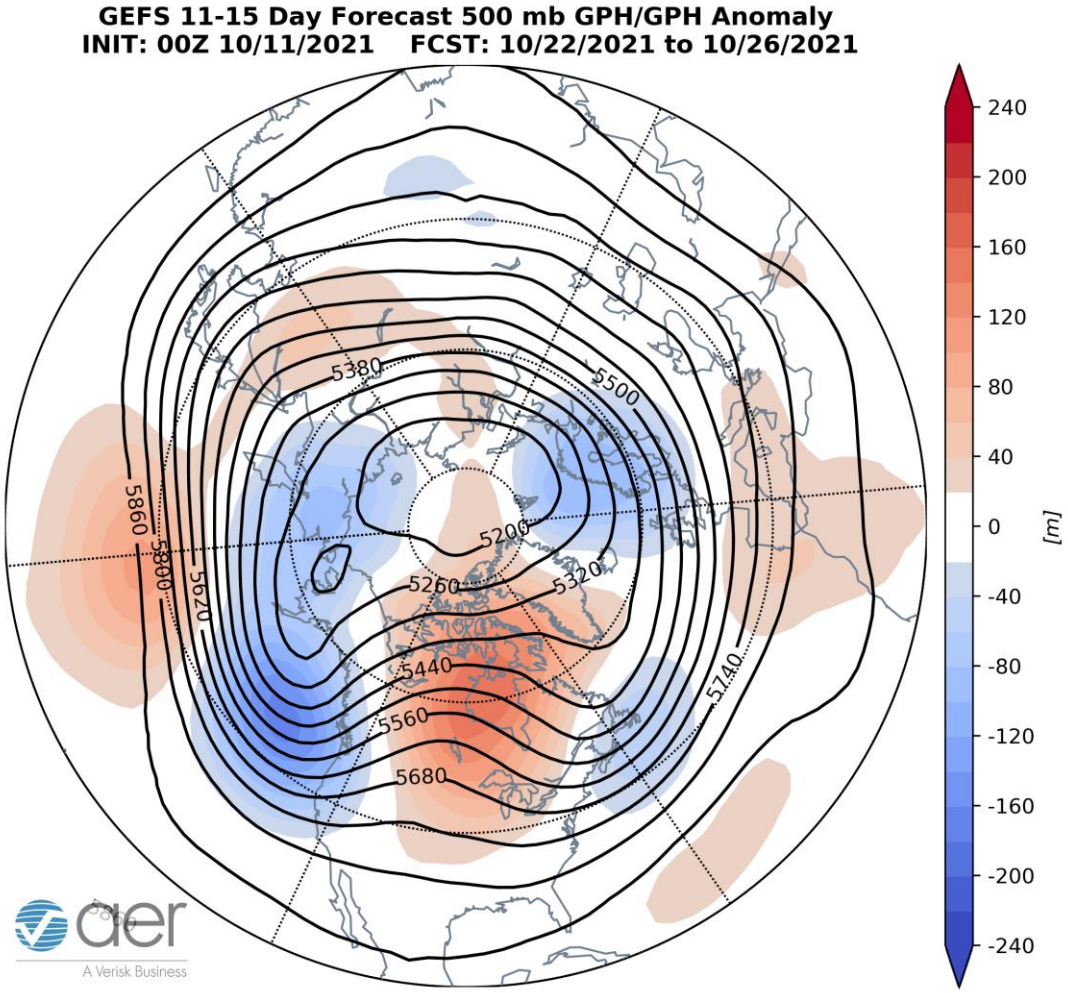

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 22 – 26 October 2021. The forecasts are from the 00z 11 October 2021 GFS ensemble.

Ridging/positive geopotential height anomalies across Greenland will continue to favor troughing/negative geopotential height anomalies across Northern Europe with ridging/positive geopotential height anomalies across Southern Europe this period (**Figure 8**). This pattern favors widespread normal to below normal temperatures across much of Northern Europe including the UK with normal to above normal temperatures across the countries along the Mediterranean this period (**Figures**

9). Ridging/positive geopotential height anomalies are predicted across Southern Asia with troughing/negative geopotential height anomalies across far Northern Asia favoring zonal flow this period (**Figure 8**). A zonal flow pattern favors widespread normal to above normal temperatures across much of Asia with normal to below normal temperatures mostly confined to the North Slope of Asia (**Figure 9**).

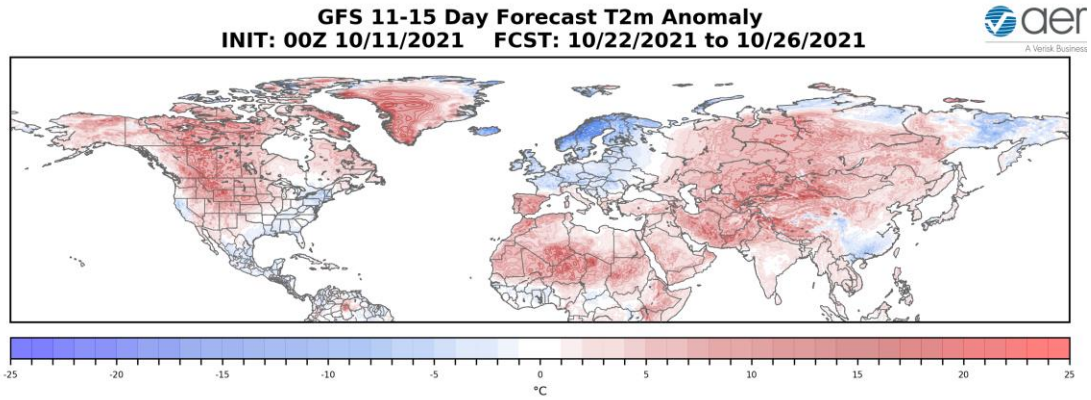

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 22 – 26 October 2021. The forecasts are from the 00z 11 October 2021 GFS ensemble.

The general pattern of troughing/negative geopotential height anomalies along the west coast of North America with downstream ridging/positive geopotential height anomalies across the US and Canada east of the Rockies is predicted to persist this period (**Figure 8**). This pattern favors normal to above normal temperatures widespread across much of the US and Canada with normal to below normal temperatures limited to the West and East Coasts of the US (**Figure 9**).

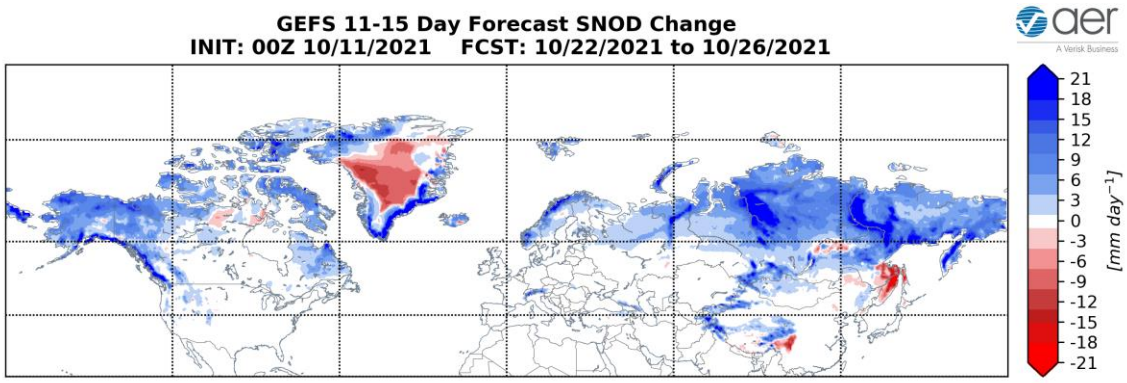

Figure 10. Forecasted snow depth changes (mm/day; shading) from 22 – 26 October 2021. The forecast is from the 00Z 11 October 2021 GFS ensemble.

Troughing and/or cold temperatures are predicted to support new snowfall across Scandinavia, Northern Asia and the Tibetan Plateau (**Figure 10**). Troughing and/or cold

temperatures are predicted to support new snowfall across Alaska, Northern and Eastern Canada and the higher elevations of Western Canada and the US (**Figure 10**).

Longer Term

30–day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows normal to warm/positive PCHs in the troposphere through the mid-stratosphere with cold/negative PCHs limited to the upper stratosphere (**Figure 11**). The PCHs in the troposphere are predicted to transition to cold/negative while the warm/positive PCHs in the stratosphere are predicted to strengthen next week (**Figure 11**).

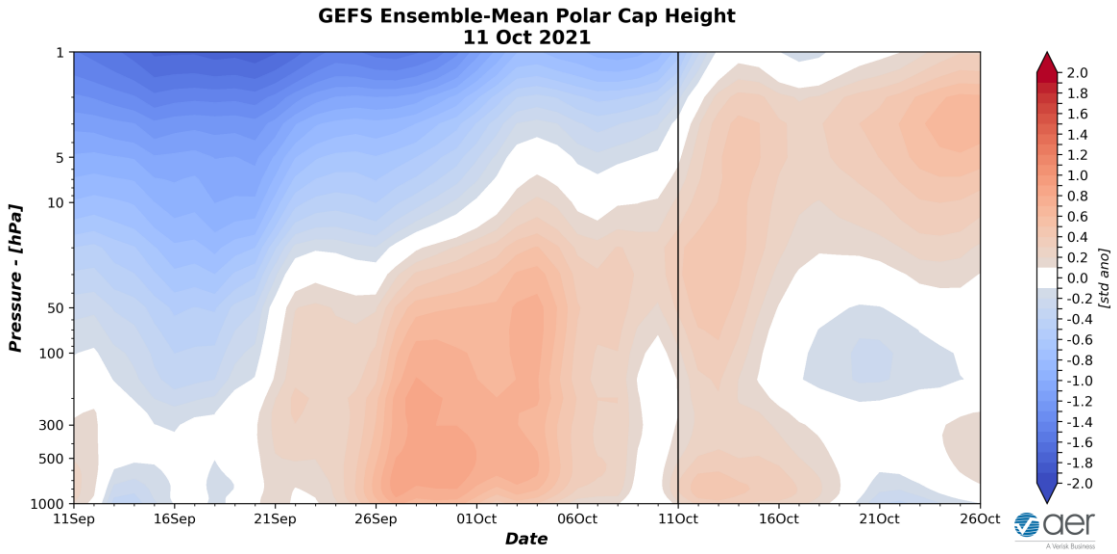

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 11 October 2021 GFS ensemble.

The warm/positive tropospheric PCHs this week are consistent with the predicted negative surface AO this week (**Figure 1**). However, as PCHs transition to neutral to cold in the lower troposphere next week, the surface AO will slowly climb to neutral and even possibly positive (**Figure 1**).

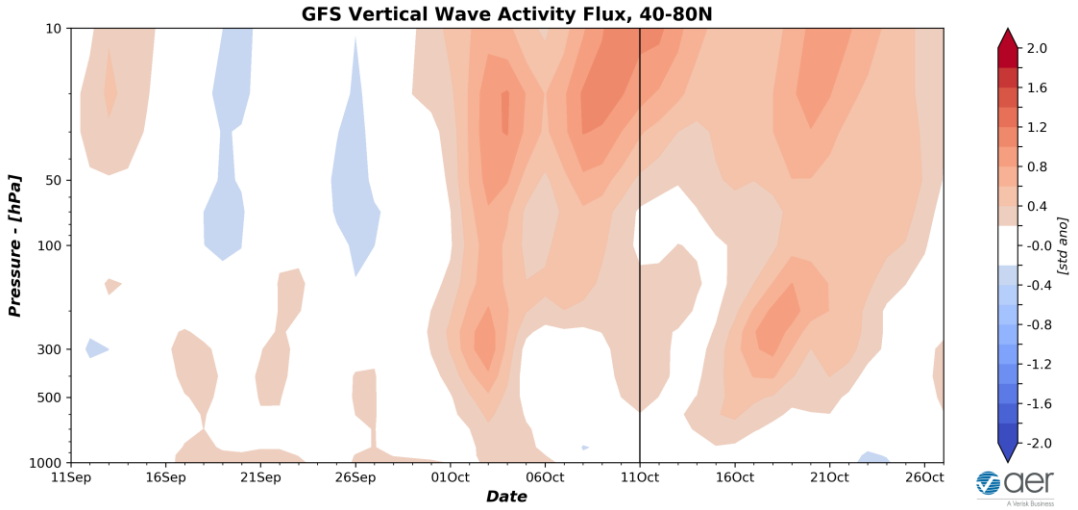

Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 11 October 2020 GFS ensemble.

The cooling of PCHs in the troposphere and warming of PCHs in the stratosphere are a result of strong vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere that has been observed this month and is predicted to continue over the next two weeks (**Figure 12**).

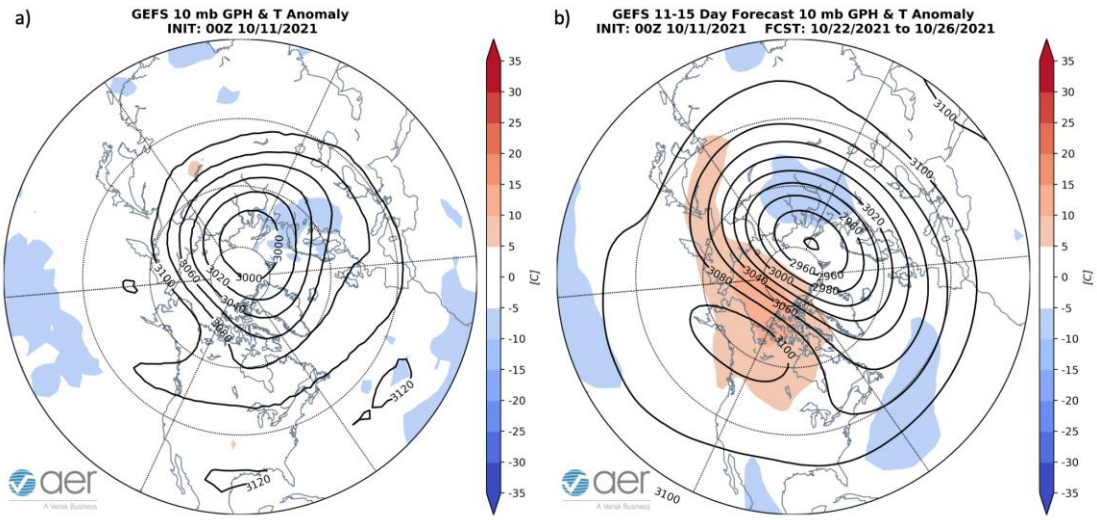

Figure 13. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 11 October 2020. (b) Same as (a) except forecasted averaged from 22 – 26 October 2020. The forecasts are from the 00Z 11 October 2020 GFS model ensemble.

The positive WAFz is predicted to perturb a relatively strong PV (**Figure 13**). The PV is predicted to become displaced towards the Barents-Kara Seas coupled with ridging centered near Alaska (**Figure 13**). In addition, the relatively cool polar stratosphere is predicted to warm due to active WAFz, especially over the North Pacific side of the Arctic (**Figure 13**). The weakening of the PV over the next two weeks is consistent with the stratospheric AO starting near neutral this week and then turning strongly negative next week (**Figure 1**).

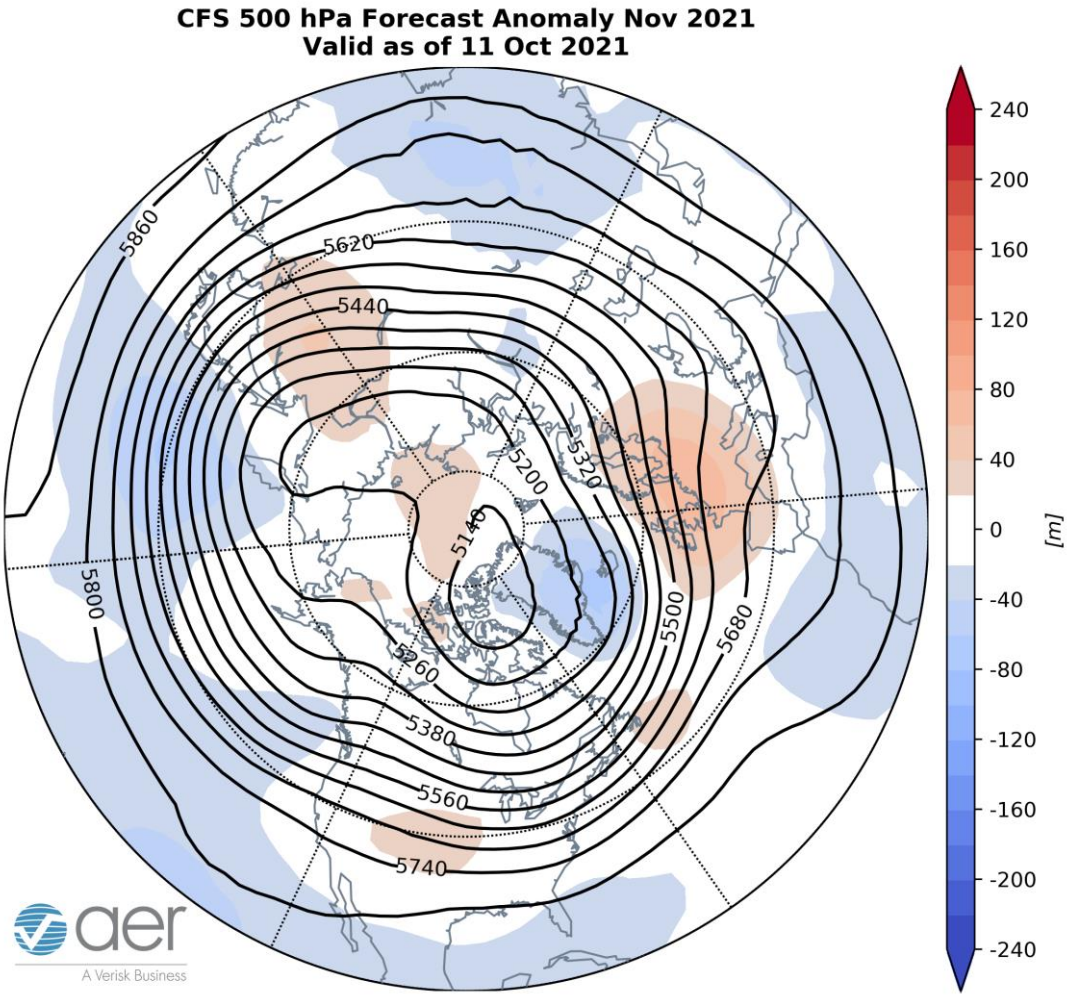

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for November 2021. The forecasts are from the 00Z 11 October 2021 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and surface temperatures for October (**Figure 15**) from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging over Europe, East Asia and the Central US with troughing in Western Asia, Central Asia, Eastern Siberia, the Western North Pacific, Alaska, the Gulf

of Alaska and Greenland (**Figure 14).** This overall zonal and positive AO pattern favors seasonable to relatively warm temperatures widespread across Europe, Asia, Canada and the US except for Eastern Siberia, Alaska and the West Coasts of Canada and the US (**Figure 15**). I have low confidence in this forecast, especially of the troposphere-stratosphere-coupling event completes as I anticipate.

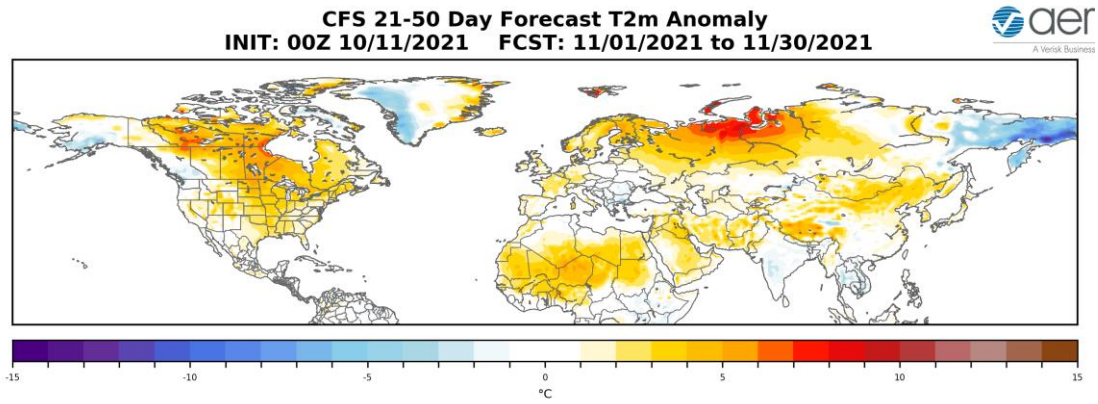

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for November 2021. The forecasts are from the 00Z 11 October 2021 CFS.

Surface Boundary Conditions

Arctic Sea ice

Arctic sea ice is growing but remains well below normal east of Greenland, along the Eurasian coast and in the Barents-Kara Seas. Sea ice is close to normal in the Canadian Archipelagos and in the Chukchi Sea. 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.

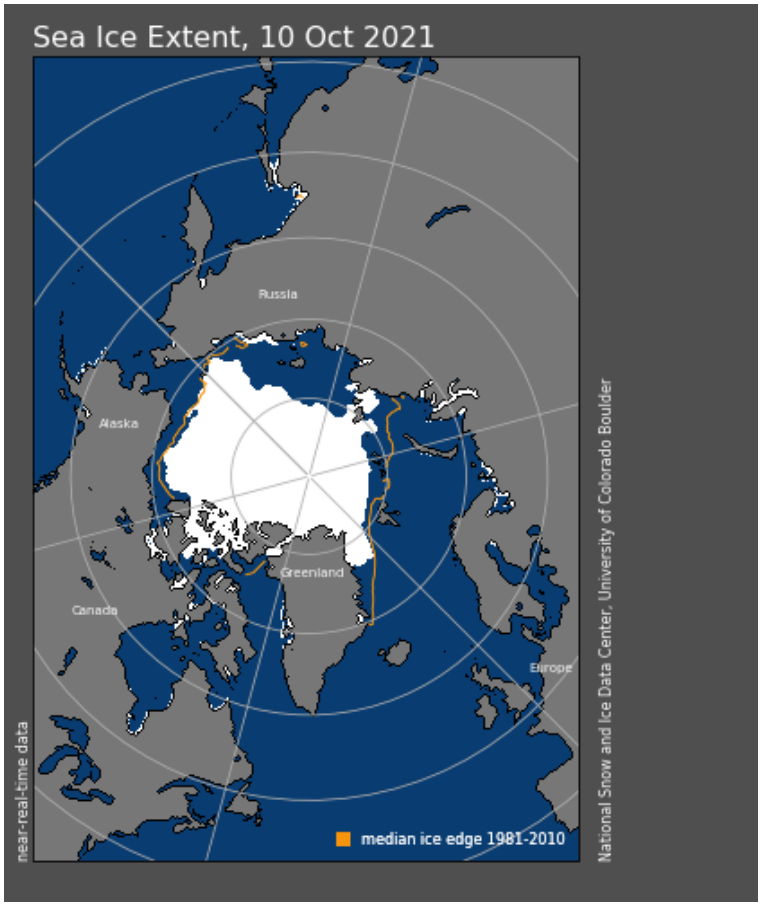

Figure 16. Observed Arctic sea ice extent on 10 October 2021 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image courtesy of National Snow and Ice Data Center (NSIDC). Snow and Ice Data Center (NSIDC).

SSTs/El Niño/Southern Oscillation

Equatorial Pacific sea surface temperatures (SSTs) anomalies are below normal, and we continue to observe neutral to weak La Niña conditions (**Figure 17**) and La Niña conditions are expected through the fall. Observed SSTs across the NH remain well above normal especially in the Baltic Sea, Gulf of Alaska, the western North Pacific and offshore of eastern North America though below normal SSTs exist regionally especially in the Southern Hemisphere. Warm SSTs in the Gulf of Alaska may favor mid-tropospheric ridging in the region.

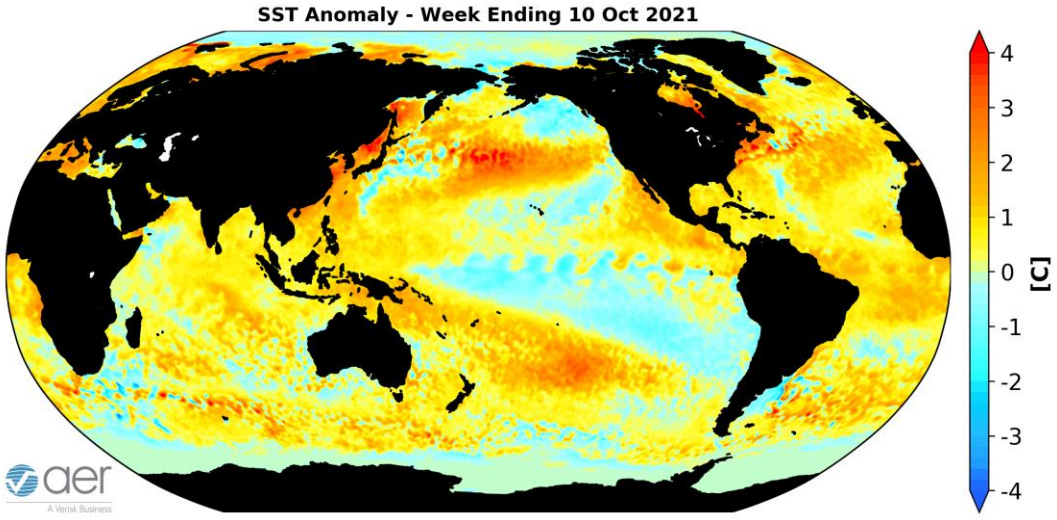

Figure 17. The latest weekly-mean global SST anomalies (ending 10 October 2021). Data from NOAA OI High-Resolution dataset.

Currently the Madden Julian Oscillation (MJO) is in phase five (**Figure 15**). The forecasts are for the MJO to quickly move into phase six and then quickly weaken where no phase is favored the remainder of the next two weeks. Phases five and six favor ridging over the Eastern US with troughing over Northern and Western Canada. Therefore it seems likely that the MJO is contributing significantly to the predicted weather pattern across North America over the next two weeks but admittedly this is outside of my expertise.

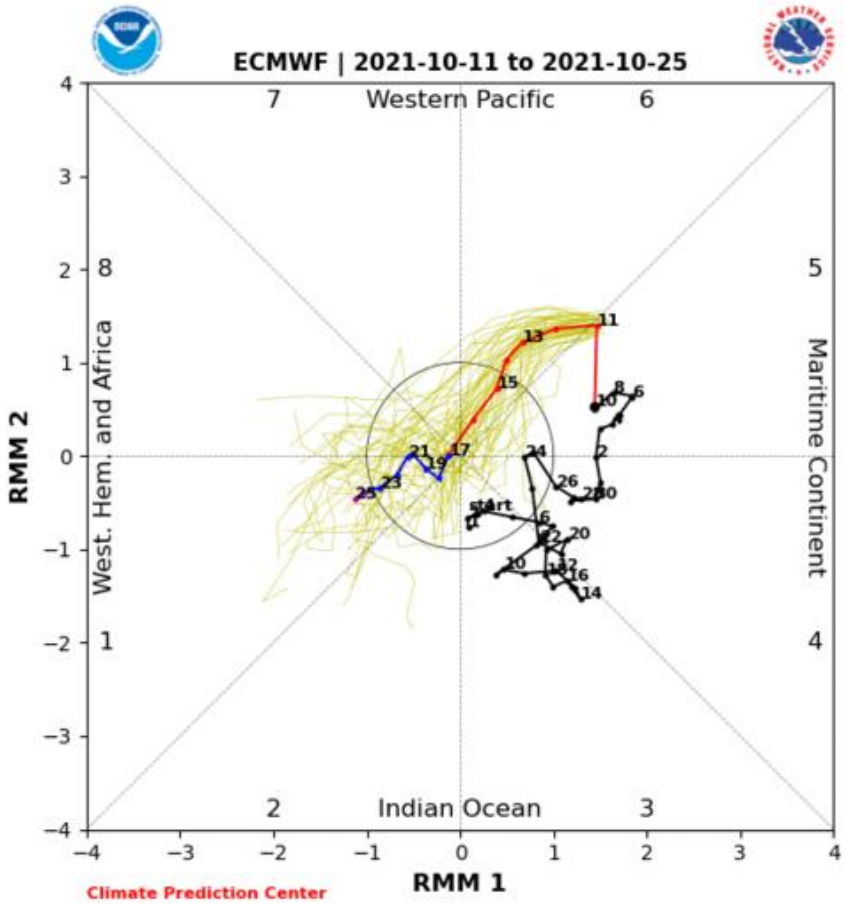

Figure 15. Past and forecast values of the MJO index. Forecast values from the 00Z 11 October 2021 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model "spread" is denoted by the gray shading. Sector numbers indicate 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