Arctic Oscillation and Polar Vortex Analysis and Forecasts

October 18, 2021

Dear AO/PV blog readers:

Starting next week, we will shift the public release of the Arctic Oscillation/Polar Vortex blog to Wednesdays weekly through the winter season.

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

Starting on Monday, 25 Oct 2021, we will announce the availability of the AO/PV report for the week with links to the report and attendant datasets. The content of the report will be publicly available on Wednesday, 27 Oct, on our web site.

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

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

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

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

Dr. Judah Cohen from Atmospheric and Environmental Research (AER) embarked on an experimental process of regular research, review, and analysis of the Arctic Oscillation (AO) and Polar Vortex (PV). This analysis is intended to provide researchers and practitioners real-time insights on one of North America's and Europe's leading drivers for extreme and persistent temperature patterns.

During the winter schedule the blog is updated once every week. Snow accumulation forecasts replace precipitation forecasts. Also, there is renewed emphasis on ice and snow boundary conditions and their influence on hemispheric weather. With the start of spring we transition to a spring/summer schedule, which is once every two weeks. Snow accumulation forecasts will be replaced by precipitation forecasts. Also, there will be less emphasis on ice and snow boundary conditions and their influence on hemispheric weather.

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

The AO/PV blog is partially supported by NSF grant AGS: 1657748.

Summary

- The Arctic Oscillation (AO) is currently negative and is predicted to straddle neutral over the next two weeks with mixed pressure/geopotential height anomalies across the Arctic and mixed pressure/geopotential height anomalies across the mid-latitudes. The North Atlantic Oscillation (NAO) is currently negative and is predicted to remain negative 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 Northern Europe including the United Kingdom (UK) and then next week will include Central Europe while ridging/positive geopotential height anomalies coupled with normal to above normal temperatures are predicted to dominate much of Southern Europe this week but limited to Southwestern Europe next week.
- Predicted for this week ridging/positive geopotential height anomalies coupled with normal to above normal temperatures in Western and Central Asia will force downstream troughing/negative geopotential height anomalies coupled with normal to below temperatures in Eastern Asia. However later next week troughing/negative geopotential height anomalies coupled with normal to below temperatures will be confined to Northern Siberia with widespread ridging/positive geopotential height anomalies coupled with normal to above normal temperatures widespread across Asia.
- This general pattern across North America the next two weeks is troughing/negative geopotential height anomalies coupled with normal to below normal temperatures in the Gulf of Alaska but extending into 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 in the Northeastern US where troughing/negative geopotential height anomalies coupled with normal to below temperatures are predicted for next week.
- In the *Impacts* section I once again discuss Siberian snow cover extent and the stratospheric polar vortex (PV), what the predicted weak PV this month could mean for the Northern Hemisphere (NH) winter.

Impacts

It is quite striking to me how persistent the ridging/high pressure has been over eastern North America over the past month which is helped being anchored by persistent troughing/low pressure in the Gulf of Alaska. This pattern has led to some record warm temperatures in September and October in eastern North America and is yet another fall that can best be described as feeling like endless summer. And based on the GFS forecasts below (see **Figures 2, 5 and 8**) those atmospheric features are here through the remainder of October, at the least. Typically, blocked or stuck patterns that are not coupled to the stratosphere (and this one, as far as I can tell is not) last up to three weeks or so. This blocked or stuck pattern looks to be at least double that in duration. I can't explain the tenacity of this pattern and not sure if it is being prolonged by coupling to the surface (water temperatures are well above normal in Hudson Bay, Baffin Bay and the Labrador Sea (see **Figure 17**)) but I do wonder if it can possibly persist long enough to ensure a mild start to winter in the Eastern US but especially Eastern Canada. Also, the persistent troughing/low pressure has cooled sea surface temperatures (SSTs) in the Gulf of Alaska and the multi-year "warm blob" in the eastern North Pacific has shifted west relative to recent years. The exact coupling of SSTs and the mid-troposphere is an unsettled topic but the westward shift in the warmest SST anomalies could be a factor later this winter.

I typically don't focus on the weather across North America in October but rather what is happening across Eurasia and especially Siberia. The weather pattern across Eurasia hasn't been as stagnant as North America but the predicted ridging/high pressure coupled with relatively warm temperatures across much of Asia is not conducive to the rapid expansion of snow cover across Eurasia including Siberia. Once again, this week I include a plot of Eurasian snow cover extent (SCE). in **Figure i,** I present my estimate of 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 lower end of the pack and the GFS forecast for the remainder of the month doesn't look favorable for a rapid advance in SCE in my opinion. A ridge centered over Central Asia is just not a conducive pattern for the rapid advance of snow cover but the opposite is. Therefore, I expect Eurasian snow cover extent to come in on the low end of recent years. The more extensive the snow cover the greater probability of an impactful PV disruption during winter and colder weather across the NH with a less extensive snow cover extent favoring a strong PV and milder weather across the NH.

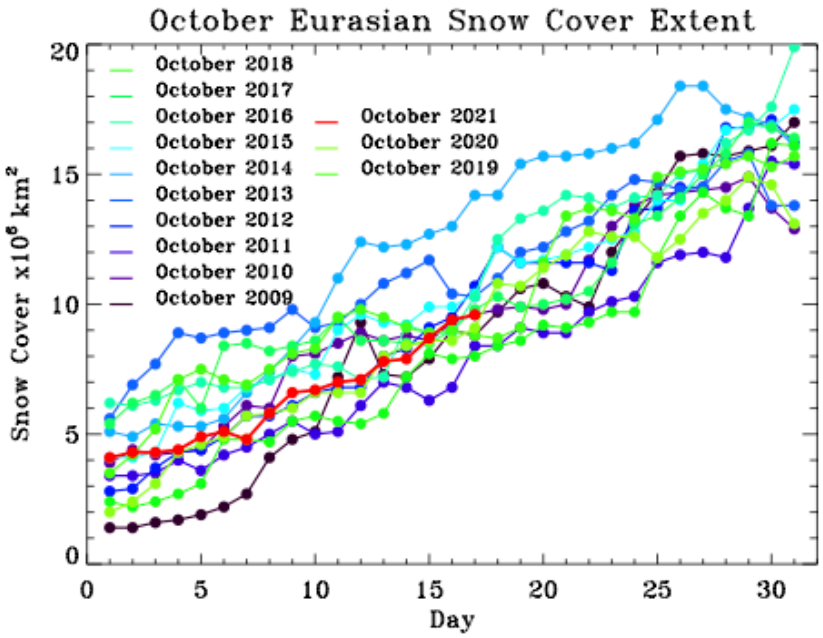

Figure i. Observed Eurasian daily snow cover extent in km^2 throughout the month of October from 2009 through 2020. Also show on red is the snow cover extent 1 – 16 October 2021.

Though I really haven't been discussing it, I have been computing the snow advance index (SAI; see Cohen and Jones 2011). For much of the month it has been negative suggestive of a strong PV and milder weather. If the SCE south of 60°N were to experience a jump in area towards the end of the month it could turn positive, but I don't see any signs of that just yet.

Though everything I have discussed so far seems to favor a widespread, relatively mild winter across the NH, I do think any winter forecast remains of low confidence. And this is mostly attributable to the currently anomalously weak stratospheric PV for October that is predicted to be near record weak for the date later this week. I have been anticipating for a while the weak stratospheric PV could couple with the mid-troposphere, leading to "reshuffling of the deck" in the troposphere. If the stratosphere couples to the troposphere as is now predicted by the GFS (see **Figure 11**) the most likely outcome is an increase in high latitude blocking with high pressure centered over the Arctic. The GFS is further predicting that maximum warming in the polar stratosphere will eventually migrate to near Greenland. This could promote Greenland blocking pulling the center of the positive geopotential height anomalies from Eastern Canada to near Greenland, resulting in a colder pattern not just for Northern Europe but the Eastern US as well. Just as an aside, I do think that if the PV were relatively strong currently, I would be more confident in a mild winter. This can very much still happen but if the PV were currently strong, I think a mutually reenforcing strong PV-mild NH temperatures death grip could already be gaining momentum for an extended period.

But higher geopotential heights either over the North Pole or even Greenland are unlikely to persist long enough to have a material impact on the weather during the winter months. As of yet, I have not seen much evidence that high pressure/blocking in the Central Arctic or near Greenland perturbs the PV. Though in our recent paper Cohen et al. 2021, some of the analysis suggested that Greenland blocking was a long lead precursor to a stretched PV (see Figure 2). And in what I consider to be pure coincidence, the latest CFS forecast for November does resemble the pattern for a stretched stratospheric PV both in the stratosphere (**Figure ii**) and troposphere (**Figure 14**). But please keep in mind what Abraham Maslow said, "If the only tool you have is a hammer, you tend to see every problem as a nail."

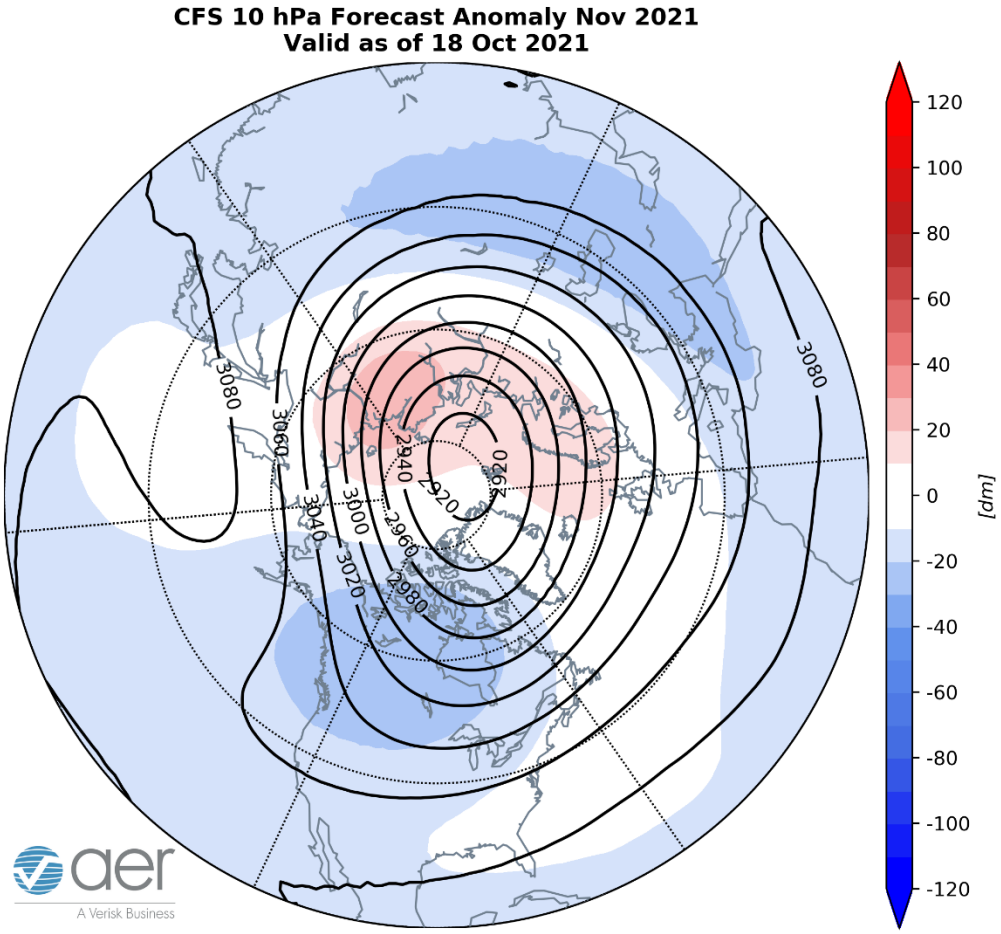

Figure ii. Forecasted average 10 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for November 2021. The forecasts are from the 00Z 18 October 2021 CFS.

This should not come as a surprise to anyone, but I do believe the character of the winter will be strongly dependent on the behavior of the PV this winter. It has been a bit of a soap opera ("As the PV Turns") seeing on Twitter armchair prognostications of the

PV in the coming weeks ranging from a record early sudden stratospheric warming (SSW that results 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) to a raging PV that bottles up the cold over the Arctic to start the winter. In my opinion we just don't know. I include the PV animation from this morning in **Figure iii**, it is suggestive that there could be a subsequent PV disruption after the one later this week. So for now, the guessing continues.

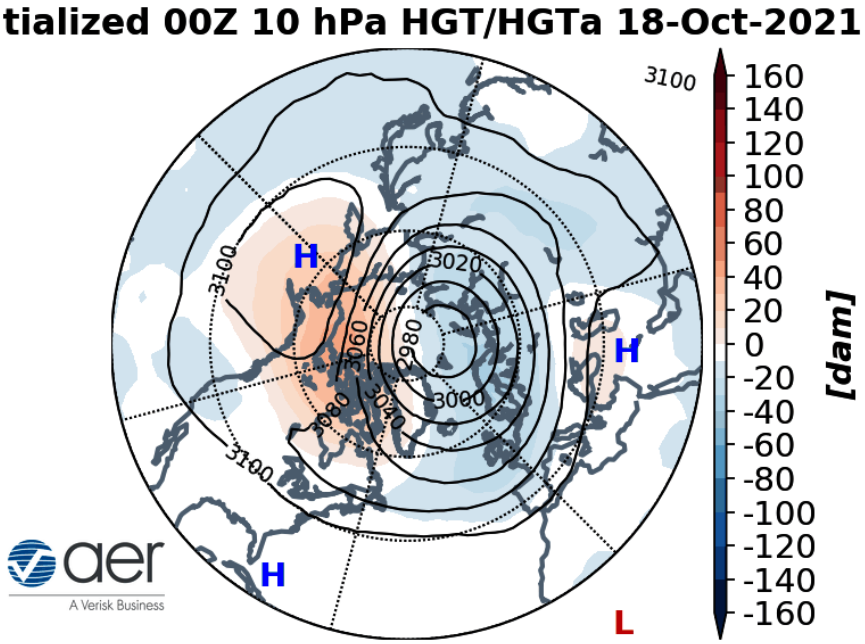

Figure iii. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 18 October 2021 and forecasted averaged from 19 October – 3 November 2021. The forecasts are from the 00Z 18 October 2021 GFS model ensemble.

It is my impression that the models really struggle predicting the behavior of the stratospheric PV once vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere becomes active as the case is currently. The models tend to both over- and under-predict the magnitude of a PV disruption. Therefore, we don't have a long lead accurate forecast of the behavior of the behavior more than a week or two at most. Based on the model deficiencies and lack of data points, I don't believe we can accurately anticipate the behavior of the PV in November and whether the PV is strong or weak in November the opposite can be true in December. And as I discussed last week the tropospheric circulation will be more

determinative of the future behavior of the PV, than the state of the PV today or even this week.

As I mentioned last week, I believe Scandinavian-Ural blocking/high pressure in the troposphere is the atmospheric feature most important in modulating the strength of the PV. There are no signs of its return in the two-week forecast. I do believe that sea ice anomalies in the Barents-Kara seas can influence Ural blocking. During September and for the first half of October a large area of negative anomalies in the Laptev and East Siberian Seas. From **Figure 16** that area is filling in quickly and based on predicted negative geopotential height anomalies in the region, I expect it to continue filling in rapidly. It is possible that once the Barents-Kara Seas is the only remaining region with negative sea ice anomalies in the Eurasian sector, it could contribute to focus the ridging less in Siberia and closer to the Urals and Scandinavian regions. But admittedly this is mostly speculation on my part.

1-5 day

The AO and NAO begin this week negative **(Figure 1**) as geopotential height anomalies are predicted to be positive across Greenland with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 2**). However later this week as negative geopotential height anomalies deepen on the North Pacific and Eurasian sides of the Arctic (**Figure 2**), the AO will turn neutral to even slightly positive (**Figure 1**).

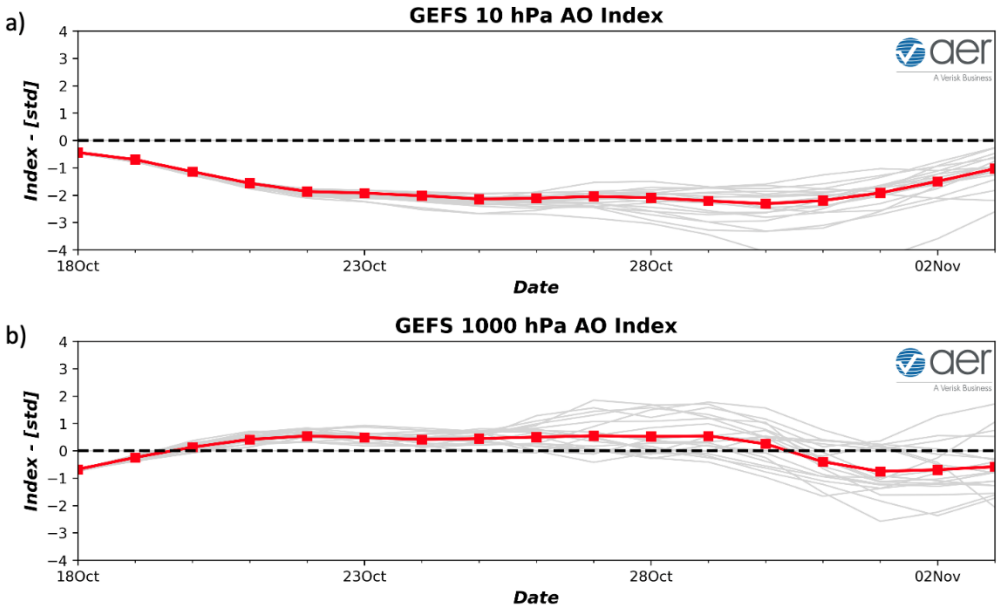

Figure 1. (a) The predicted daily-mean AO at 1000 hPa from the 00Z 18 October 2021 GFS ensemble. (b)The predicted daily-mean near-surface AO from the 00Z 18 October 2021 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

Ridging/positive geopotential height anomalies across Greenland will promote troughing/negative geopotential height anomalies across Northern Europe with ridging/positive geopotential height anomalies cross Southern Europe (**Figures 2). This will favor widespread** normal to below normal temperatures across Northern Europe including the UK with normal to above normal temperatures across Central and Southern Europe (**Figure 3**). The general pattern across Asia this period is ridging/positive geopotential height anomalies centered in Central 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**).

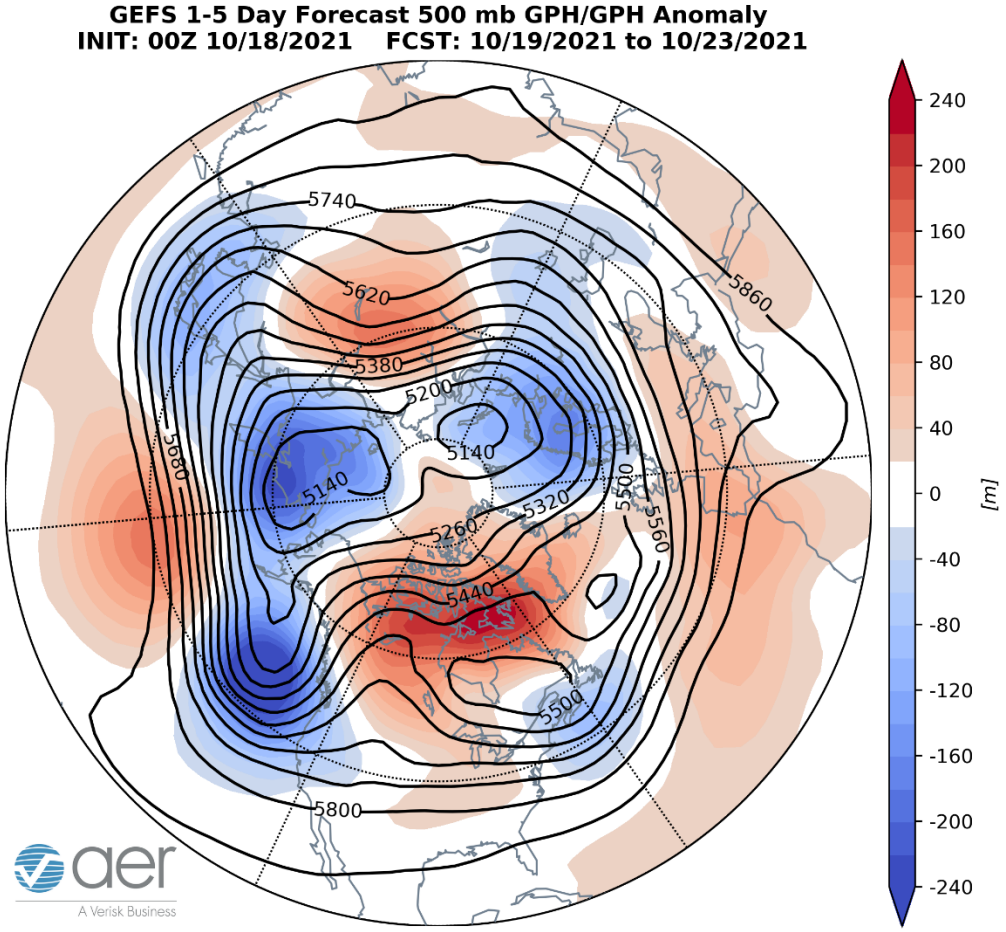

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 19 – 23 October 2021. The forecasts are from the 00z 18 October 2021 GFS ensemble.

The general pattern this week is troughing/negative geopotential height anomalies centered in the Gulf of Alaska extending into 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 Western Canada, and especially the Western US with normal to above normal temperatures across much of Alaska, Canada and the US east of the Rockies **(Figure 3).**

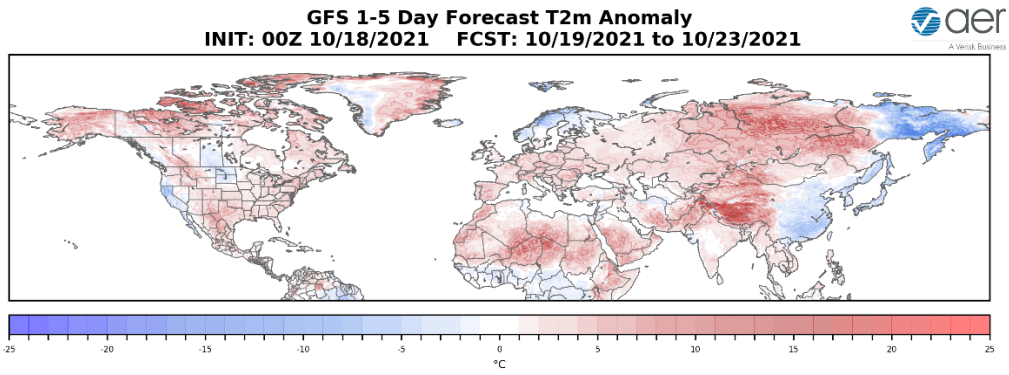

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 19 – 23 October 2021. The forecast is from the 00Z 18 October 2021 GFS ensemble.

Troughing and/or cold temperatures are predicted to support new snowfall across Scandinavia, Northern Siberia and the Tibetan Plateau while mild temperatures promote snowmelt in Southern Siberia and Northern China (**Figure 4**). Troughing and/or cold temperatures are predicted to support new snowfall across Western Alaska and far Northern Canada while mild temperatures promote snowmelt in Western Canada and the US (**Figure 4**).

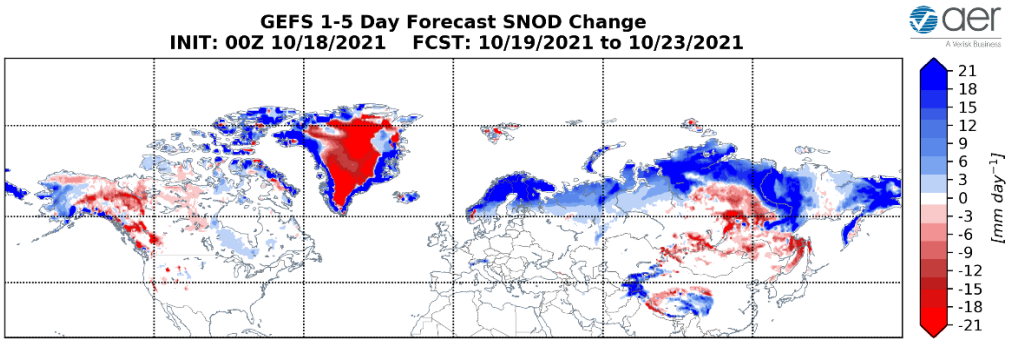

Figure 4. Forecasted snow depth changes (mm/day; shading) from 19 – 23 October 2021. The forecast is from the 00Z 18 October 2021 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to continue to remain near neutral this period **(Figure 1**) as geopotential height anomalies remain mixed across 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 the North Atlantic side of the Arctic (**Figure 5**), the NAO is predicted to be negative this period.

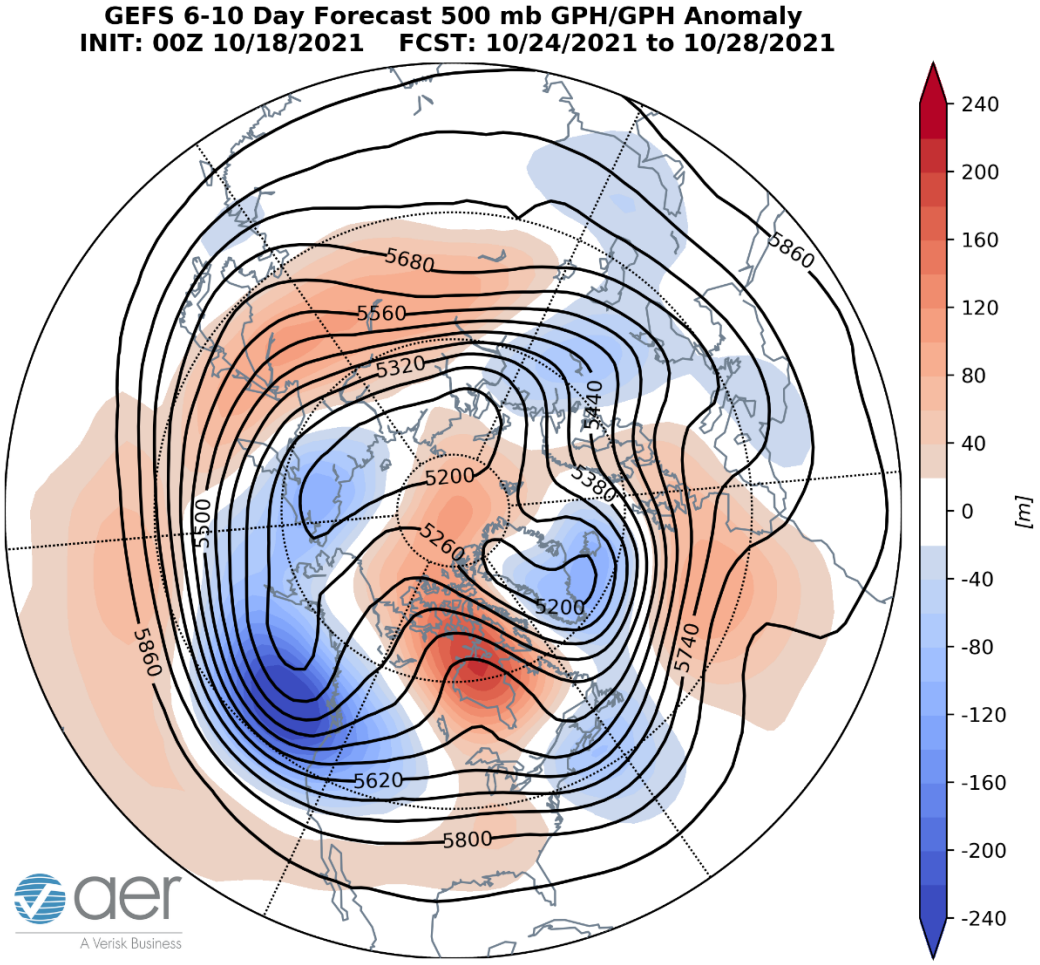

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 24 – 28 October 2021. The forecasts are from the 00z 18 October 2021 GFS ensemble.

Temporary relaxation of ridging/positive geopotential height anomalies across Greenland will allow a brief return of ridging/positive geopotential height anomalies across Western Europe including the UK favoring with downstream troughing/negative geopotential height anomalies across Eastern Europe with this period (**Figures 5).** This will result in widespread normal to above normal temperatures across Western Europe including the UK with normal to below normal temperatures across Eastern Europe (**Figure 6**). Ridging/positive geopotential height anomalies in Central Asia that will expand eastward with troughing/negative geopotential height anomalies strung across

Northern Asia this period (**Figure 5**). This pattern favors normal to above normal temperatures widespread across Asia with normal to below normal temperatures limited to far Northern and Eastern Siberia **(Figure 6**).

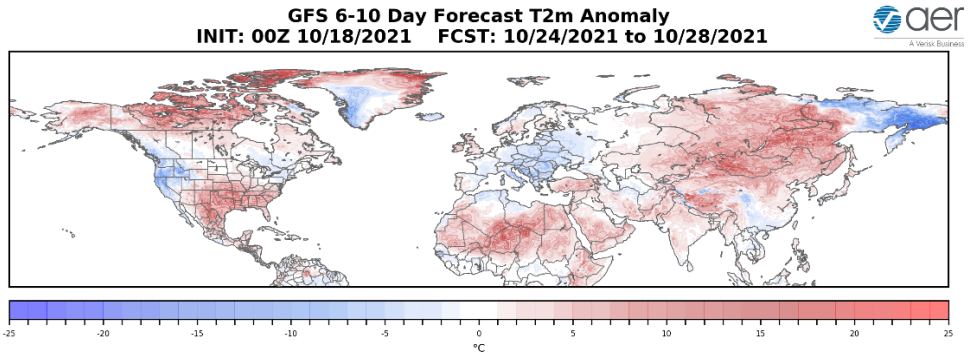

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 24 – 28 October 2021. The forecasts are from the 00Z 18 October 2021 GFS ensemble.

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

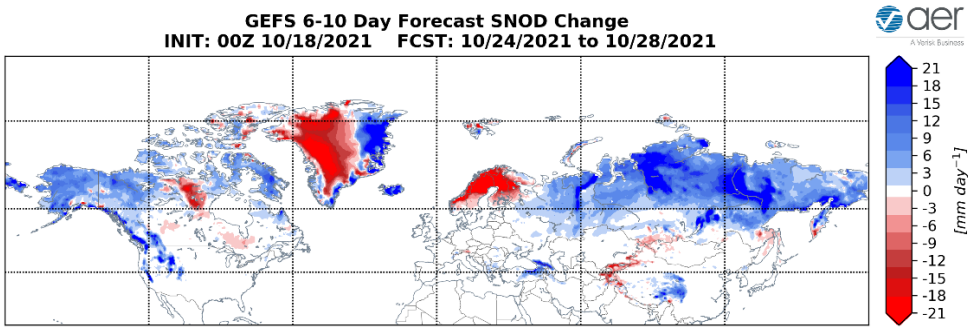

Figure 7. Forecasted snow depth changes (mm/day; shading) from 24 – 28 October 2021. The forecast is from the 00Z 18 October 2021 GFS ensemble.

Troughing and/or cold temperatures are predicted to support new snowfall across Northern Asia while milder temperatures promote snowmelt across Scandinavia and the Tibetan Plateau (**Figure 7**). Troughing and/or cold temperatures are predicted to support new snowfall across Alaska, Northern and Western Canada and the US Rockies (**Figure 7**).

11-15 day

With mostly positive geopotential height anomalies predicted across the Central Arctic and Greenland but negative on the North Pacific side of the Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 8**), the AO should remain near neutral before dipping into negative territory this period (**Figure 1**). With predicted weak positive pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO is forecasted to remain neutral to negative this period.

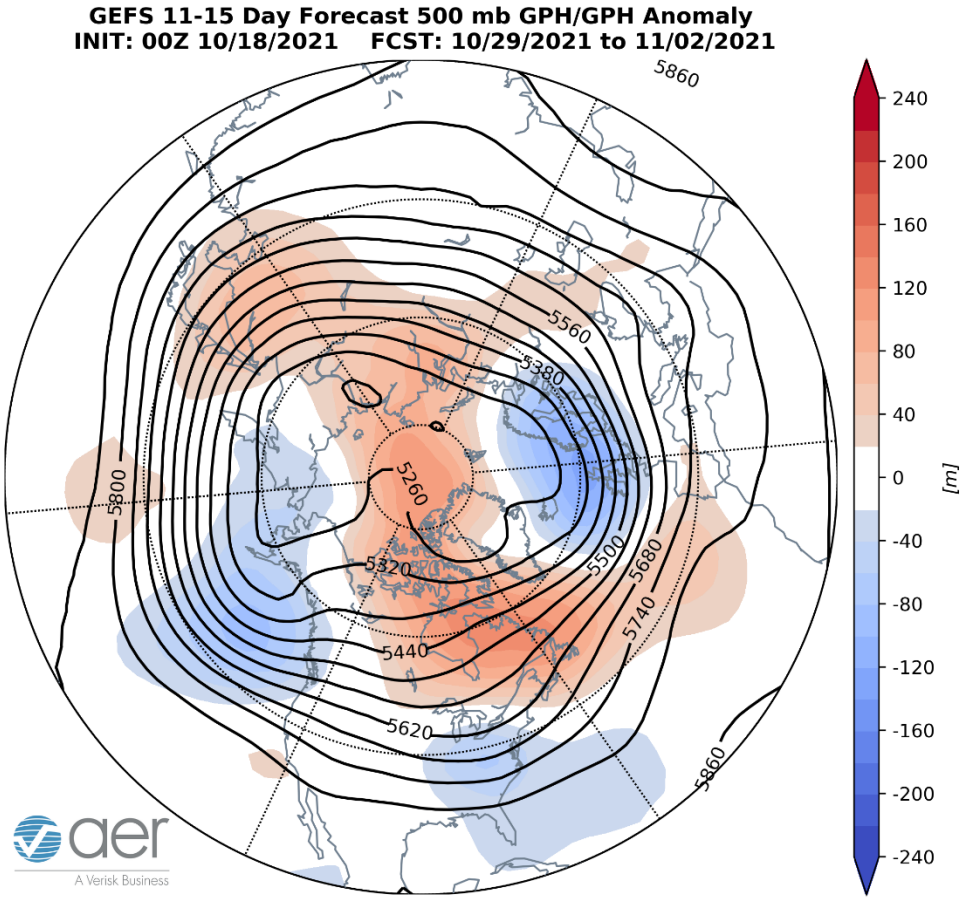

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 29 October – 2 November 2021. The forecasts are from the 00z 18 October 2021 GFS ensemble.

The return of ridging/positive geopotential height anomalies across Greenland will once again favor troughing/negative geopotential height anomalies across Northern Europe with ridging/positive geopotential height anomalies confined across Southwestern Europe this period (**Figure 8**). This pattern favors widespread normal to below normal temperatures across much of Central and Eastern Europe with normal to above normal

temperatures across far Western Europe including the UK this period (**Figures 9**). Ridging/positive geopotential height anomalies are predicted across much of Asia with troughing/negative geopotential height anomalies limited to Eastern Siberia this period (**Figure 8**). This pattern favors widespread normal to above normal temperatures across much of Asia with normal to below normal temperatures mostly confined to Eastern Siberia this period (**Figure 9**).

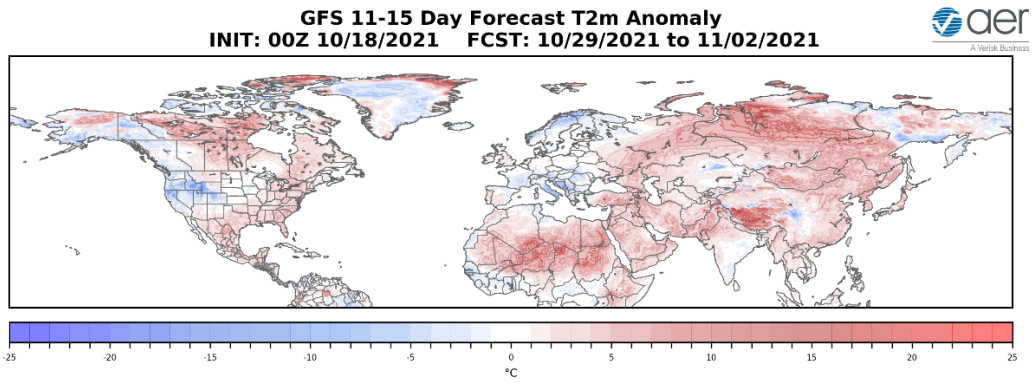

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 29 October – 2 November 2021. The forecasts are from the 00z 18 October 2021 GFS ensemble.

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 Alaska and the West Coasts of Canada and the US (**Figure 9**).

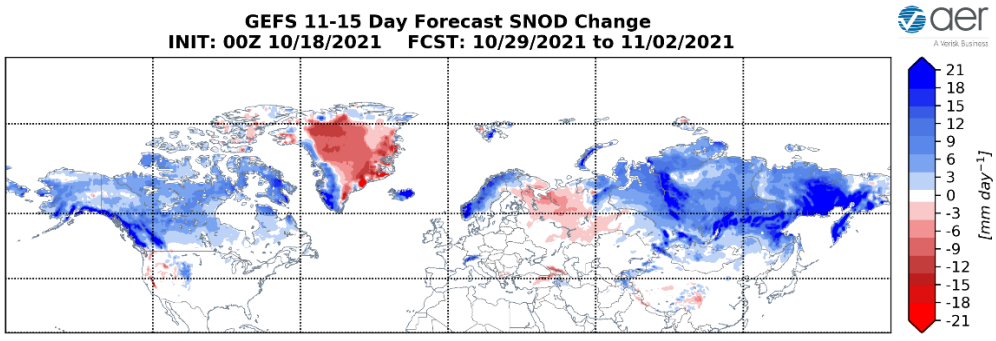

Figure 10. Forecasted snow depth changes (mm/day; shading) from 29 October – 2 November 2021. The forecast is from the 00Z 18 October 2021 GFS ensemble.

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 Western Canada and the US Rockies (**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 and especially the stratosphere (**Figure 11**). The PCHs in the lower troposphere are predicted to transition to cold/negative while the maximum of warm/positive PCHs in the stratosphere are predicted to strengthen this week and began descending into the troposphere next week (**Figure 11**).

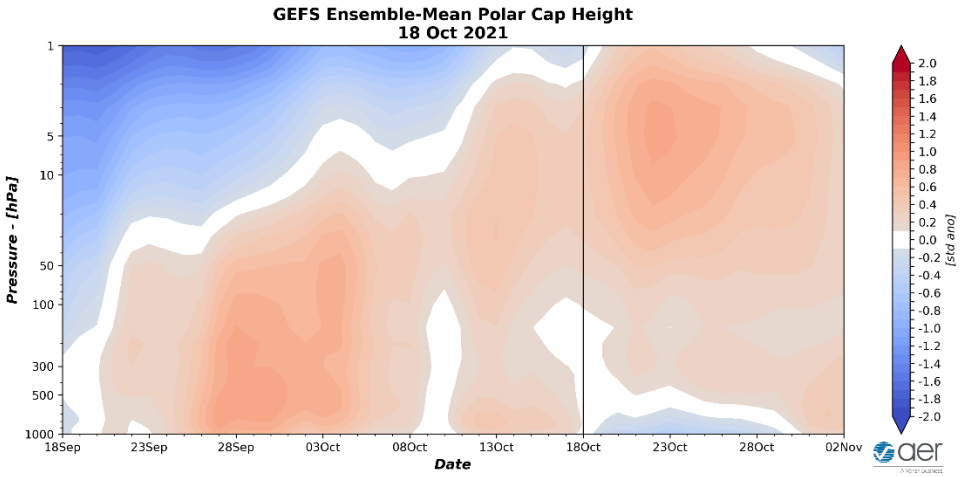

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 18 October 2021 GFS ensemble.

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

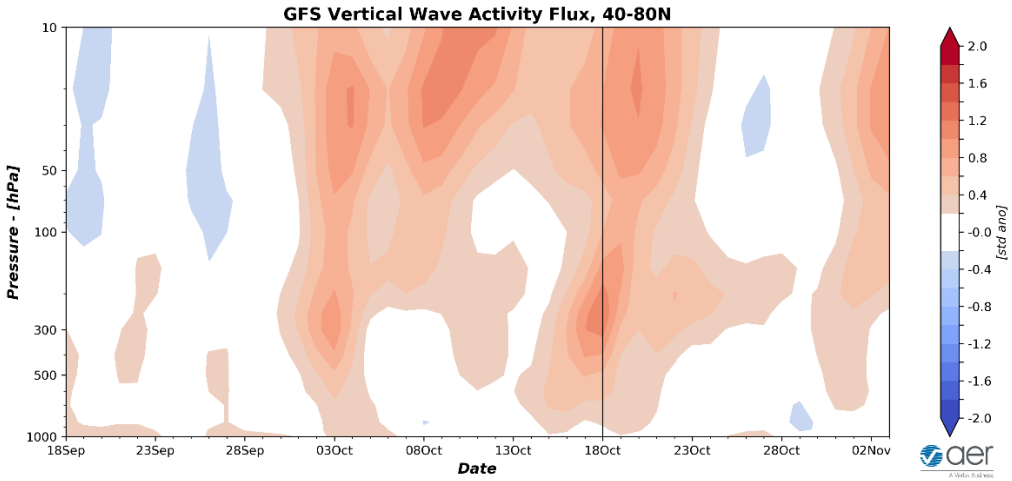

Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 18 October 2020 GFS ensemble.

The cooling of PCHs in the lower 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 intermittently continue over the next two weeks (**Figure 12**).

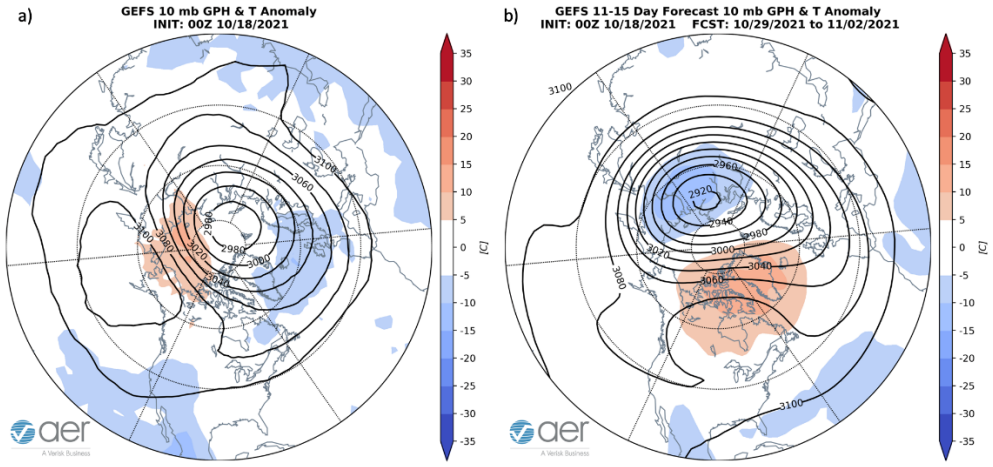

Figure 13. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 18 October 2021. (b) Same as (a) except forecasted averaged from 29 October – 2 November 2021. The forecasts are from the 00Z 18 October 2021 GFS model ensemble.

The positive WAFz is starting to perturb the stratospheric PV, with the PV displaced towards the Barents-Kara Seas and with weak warming on the North Pacific side of the polar stratosphere (**Figure 13**). With further positive WAFz The PV is predicted to

become displaced towards Siberia coupled with ridging centered near Greenland (**Figure 13**). In addition, the core of the warm polar stratosphere is predicted to migrate towards the North American 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 this week into next week (**Figure 1**).

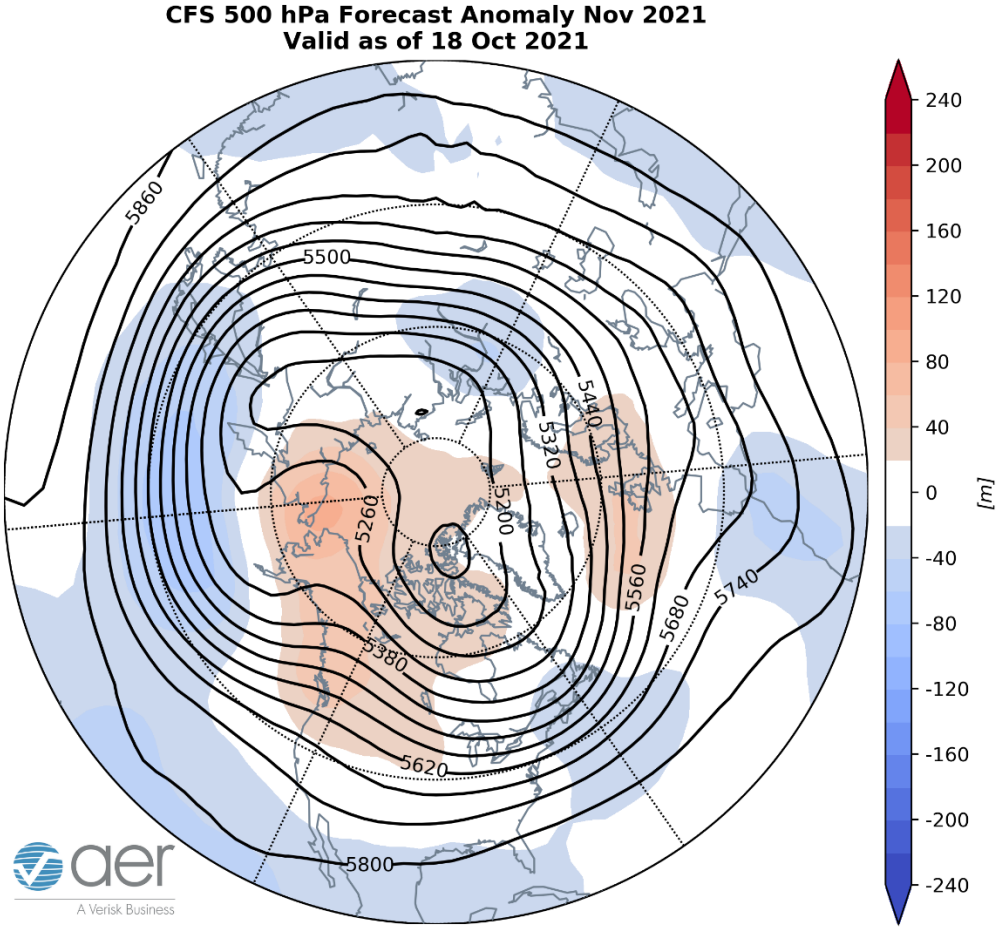

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for November 2021. The forecasts are from the 00Z 18 October 2021 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and surface temperatures for November (**Figure 15**) from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging over Northern Europe, Eastern Siberia, Alaska and Western Canada with troughing in Southwestern Europe, Western Asia, Central Asia, Eastern Siberia, the Dateline and Eastern Canada (**Figure 14).** **T**his pattern favors seasonable to relatively warm temperatures widespread across Central Europe, Central Asia, much of Alaska and Canada and the Western US with seasonable to relatively cold across

Northern Scandinavia, Western Asia, Northeastern Asia and the Eastern US (**Figure 15**). The tropospheric pattern does resemble to me the pattern associated with a stretched stratospheric PV. Though while this forecast does intrigue me, I have low confidence in this forecast until I see more evidence of a stretched PV in the shorter-range models.

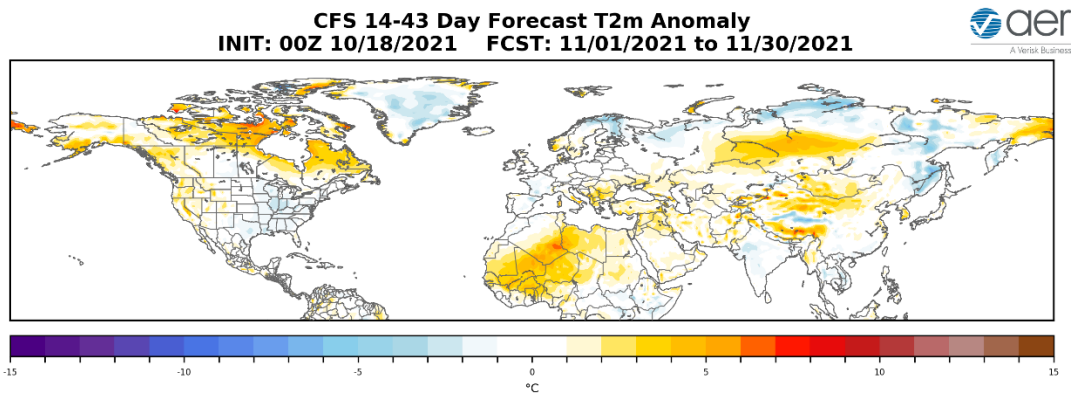

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for November 2021. The forecasts are from the 00Z 18 October 2021 CFS.

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. Sea ice is advancing in the Laptev and East Siberian seas and soon the largest negative anomalies should be focused in the Barents-Kara seas. 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.

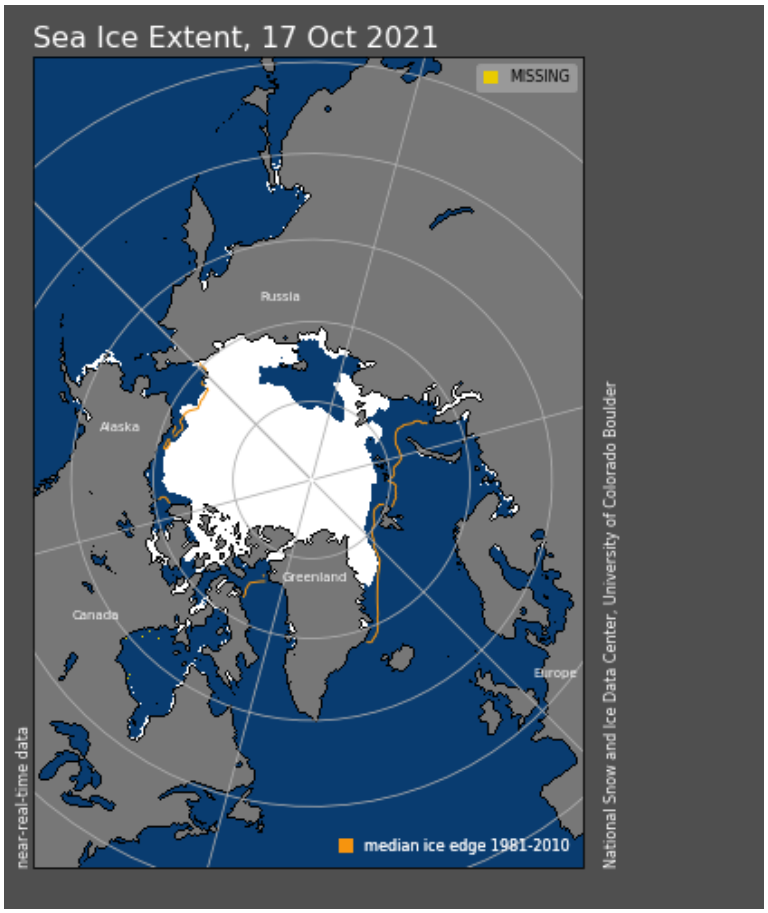

Figure 16. Observed Arctic sea ice extent on 17 October 2021 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image courtesy of National Snow and Ice Data Center (NSIDC). Snow and Ice Data Center (NSIDC).

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, central North Pacific (west of recent years), the western North Pacific and offshore of eastern North America though below normal SSTs exist regionally especially in the Southern Hemisphere. Not my expertise but the SST pattern in the North Pacific is starting to resemble a negative Pacific Decadal Oscillation (PDO) pattern that favors colder temperatures across northwestern North America and milder temperatures across southeastern North America.

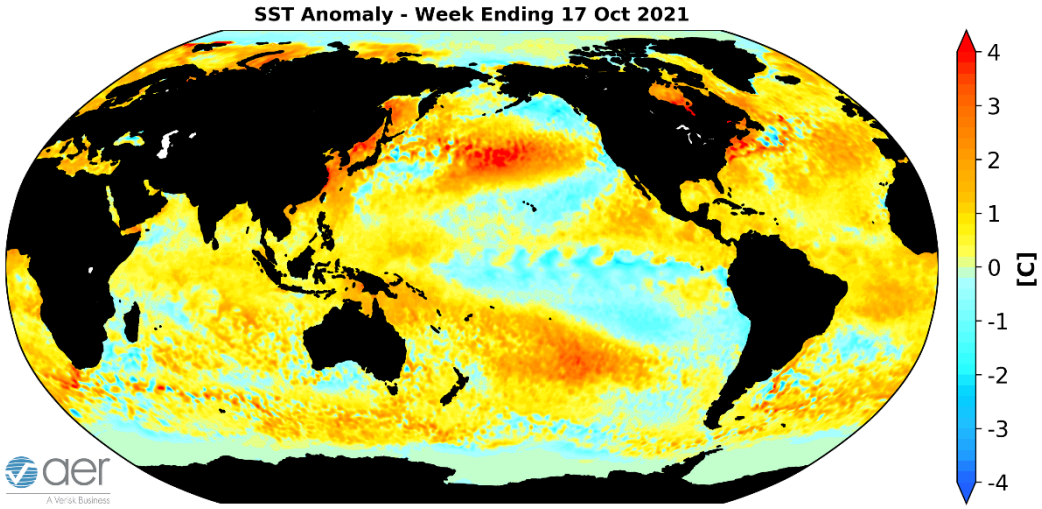

Figure 17. The latest weekly-mean global SST anomalies (ending 17 October 2021). Data from NOAA OI High-Resolution dataset.

Currently no phase of the Madden Julian Oscillation (MJO) is favored (**Figure 15**). The forecasts are for the MJO to remain weak where no phase is favored the remainder of the next two weeks. Therefore, it seems unlikely 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.

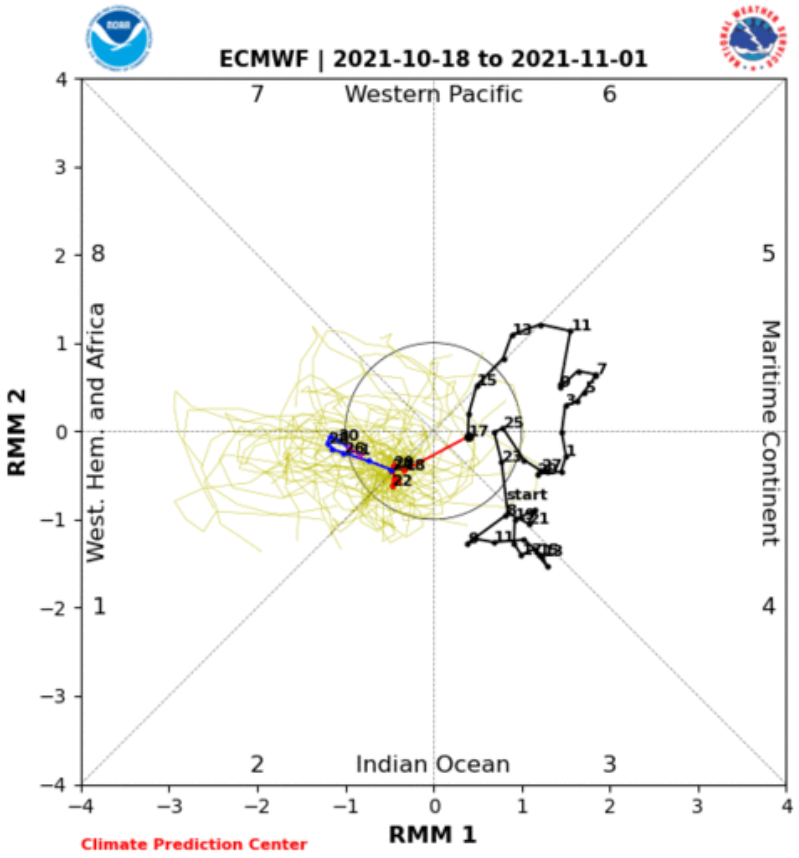

Figure 15. Past and forecast values of the MJO index. Forecast values from the 00Z 18 October 2021 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model "spread" is denoted by the gray shading. Sector numbers indicate 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