Arctic Oscillation and Polar Vortex Analysis and Forecasts

November 29, 2019

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) recently 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.

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 neutral and is predicted to first trend negative this week and then turn positive next week.
- The current neutral AO is reflective of mixed pressure/geopotential height anomalies across the Arctic and mixed pressure/geopotential height anomalies across the mid-latitudes. The North Atlantic Oscillation (NAO) is negative with positive pressure/geopotential height anomalies spread across Greenland and Iceland; and the NAO trends are predicted to track the AO as positive heights transition to negative across Greenland over the next two weeks.

- This week, troughing/negative pressure/geopotential height anomalies over Northern Europe with ridging/positive geopotential height anomalies over Southern Europe will promote a mild westerly flow across most of Europe including the United Kingdom (UK) with normal to above normal temperatures. However, starting over the weekend amplifying ridging/positive geopotential height anomalies in the central North Atlantic will deepen troughing across Europe including the UK bringing northerly flow and colder temperatures in early December.
- Currently troughing/negative pressure/geopotential height anomalies and normal to below normal temperatures dominate Asia except ridging/positive geopotential height anomalies and normal to above normal temperatures across Southeastern Asia. However European troughing and amplifying ridging in Western Asia will favor a more southwesterly, mild flow across Western Asia with cold temperatures mostly confined to East Asia.
- This week and into next week ridging/positive geopotential height anomalies and normal to above normal temperatures across Alaska and Northern Canada will force troughing/negative geopotential height anomalies and normal to below normal temperatures across much of the United States (US). However, the forecast is for geopotential heights to fall across Alaska and Northern Canada with rising heights across the US. This will likely result in overall cooling of temperatures across Alaska and Northern Canada and milder temperatures across the US.
- In the Impacts section I continue to discuss the implications of the predicted stratospheric polar vortex (PV) disruption on winter weather.
- The AER Northern Hemisphere (NH) winter temperature anomaly is now posted on the blog.

Impacts

The AER winter forecast is shown below in **Figure i**. The region with the highest probability of observing below normal temperatures is Siberia and bleeding into East Asia consistent with the above normal snow cover extent observed in Siberia this past October. The other region that has a higher probability of experiencing below normal temperatures is central and eastern North America especially Central Canada and the Great Lakes region. In Europe the region with the best chance of experiencing below normal temperatures is Scandinavia. Most other regions have a better chance of experiencing normal to above normal temperatures this winter according to the model.

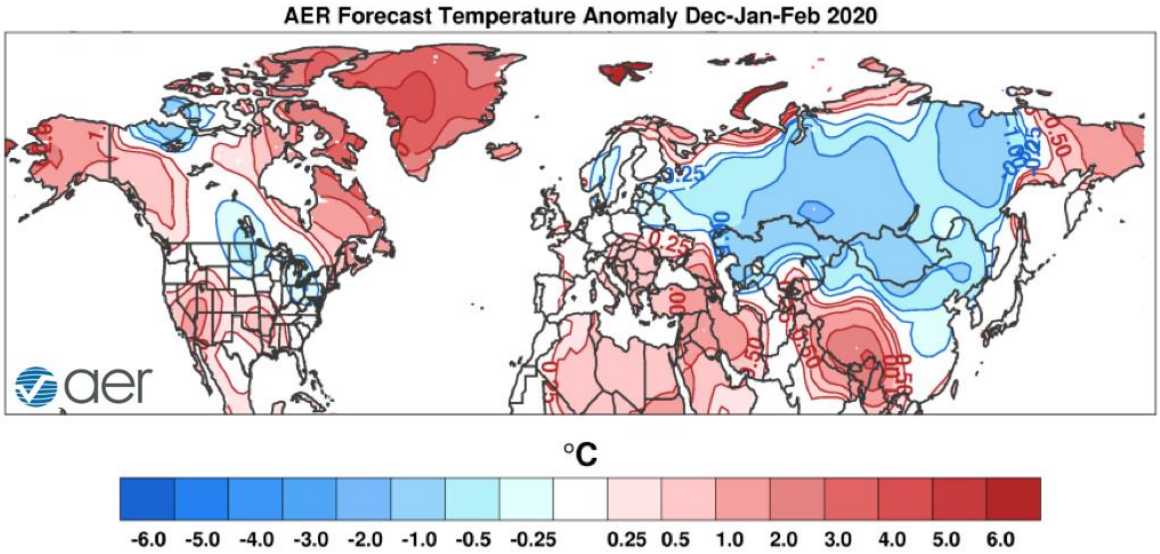

Figure i. The AER winter 2019/20 surface temperature anomalies forecast for the Northern Hemisphere.

I gave a webinar to the National Weather Service Bismarck office last Thursday on my forecast methodology so often discussed in the blog and included Arctic change influence on mid-latitude weather. They were kind enough to record and make public the webinar and a link is now included on the blog webpage for those that want to learn more.

I found it heartwarming that on Friday I was arguing with Twitter followers whether the upcoming stratospheric PV disruption was an "absorptive' or a "reflective" PV disruption. Shows me that there is a very sophisticated readership out there in the blogo- twitter-sphere.

To me it still looks like a significant PV disruption that could cross the threshold of a Major Midwinter Warming (MMW; reversal of the zonal mean zonal wind from westerly or positive to easterly or negative at 60°N and 10 hPa). Of course, if is does happen in December it is a bit of a misnomer since it is only early winter.

Our speculative PV forecast model (it tends to have quite a few false positives) shows the most likely time for an MMW would be from December 10th through December 24th with the highest probability on December 15th. A PV disruption of the magnitude predicted by most models seems to me to more strongly indicative of an absorptive event. Also, now most of the models are predicting a reversal of the AO from negative to positive, which again I believe is more consistent with an absorptive event.

However admittedly there is a brief period next week with western North America ridging (though the resultant downstream temperature anomalies are predicted to be

much weaker than is typical of reflective events). Also the ECWMF reanalysis does show a reflective layer (see **Figure ii**; defined as a negative zonal mean zonal wind gradient between 10 and 2 hPa). The problem is that it is very far north (most vertical energy transfer is between 40-80°N and Perlwitz and Harnik (2004) define a reflective layer between 58-74°N. The current reflective layer is centered at 75°N. Still I find the reflective events are easier to identify in hindsight and maybe the upcoming event is truly a mixture.

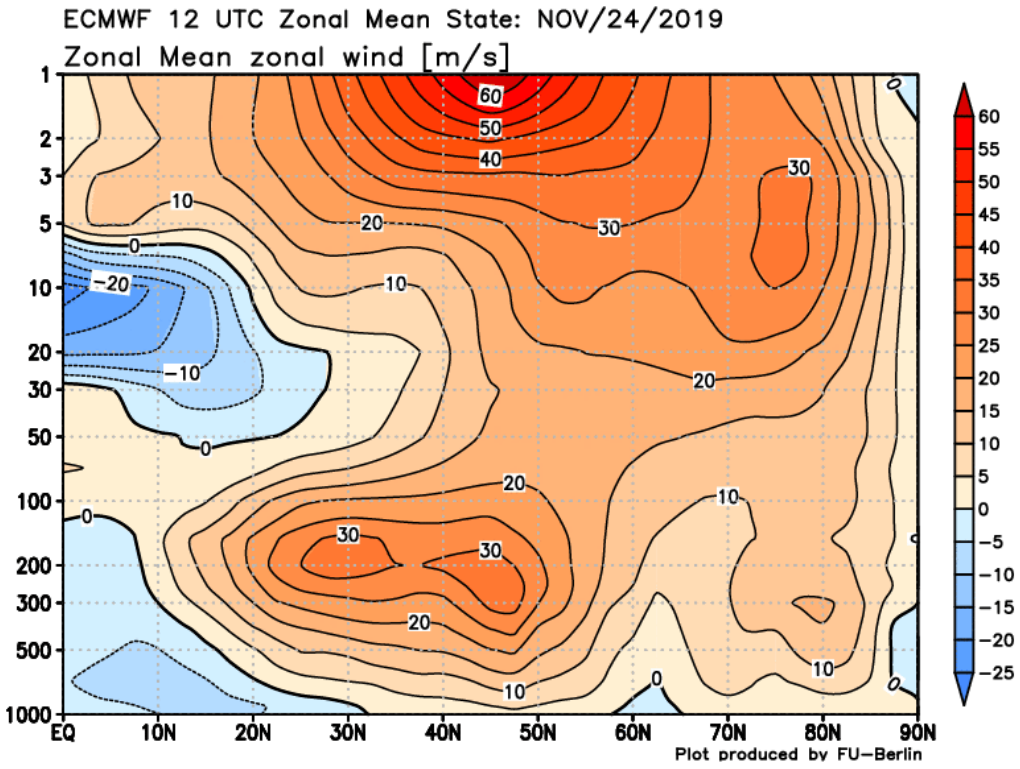

Figure i. Analyzed zonal-mean zonal wind from the European Centre for Medium Range Weather Forecasts (ECMWF) for 24 November 2019. ECMWF model plot from https://www.geo.fu-berlin.de/en/met/ag/strat/produkte/winterdiagnostics/index.html.

Still I am treating the upcoming PV disruption mostly as an absorptive event. This could be the most important weather event of the upcoming winter for the NH. As the energy transfer increases from the troposphere to the stratosphere, I expect an overall milder pattern across the NH with two possible regional exceptions – East Asia and western North America. It does seem to me that this scenario is consistent with the model forecasts heading into mid-December. Close to the peak of the PV disruption I would expect some immediate and short-lived tropospheric response with some regional severe winter weather. Then about two weeks later I would expect a more long-lasting and larger scale increase in severe winter weather across the NH but there will be places that will turn milder and it is difficult to know ahead of time. Based on past

events the most likely place to see colder temperatures is Siberia (I know what you are thinking - who cares, its cold no matter what). But I do think that warm sea surface temperatures in the Gulf of Alaska favor downstream troughing and cold and possibly snowy weather across the interior of North America.

If the PV disruption is significant and the coupling with the troposphere robust, this could potentially setup a cold January possibly persisting into February across large regions of the NH. On the other hand, if the PV disruption and/or the coupling with the troposphere are weaker than anticipated then we could be off to the races as far as NH temperatures.

Ironically, I was thinking, though I argue that PV disruptions lead to more severe winter weather across the NH mid-latitudes, the only guarantee with PV disruption seems to be a multi week period of milder weather for Europe and the Eastern US leading up to and including the PV disruption. Much more ephemeral is a multi-week and even multi-month period of severe winter weather for those regions. It is almost damned if you do and damned if you don't. If the PV is stable and strong that overwhelmingly favors mild weather and if the PV is significantly disrupted only milder weather is nearly for certain with much more uncertainty with the ensuing severe winter weather. The one possible exception seems to me are the reflected PV events where there seems to be a much stronger likelihood of North American cold weather east of the Rockies.

Near Term Conditions

1-5 day

The AO is currently neutral **(Figure 1**) with mixed geopotential height anomalies across the Arctic and mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 2**). And with positive geopotential height anomalies across Greenland (**Figure 2**), the NAO is negative.

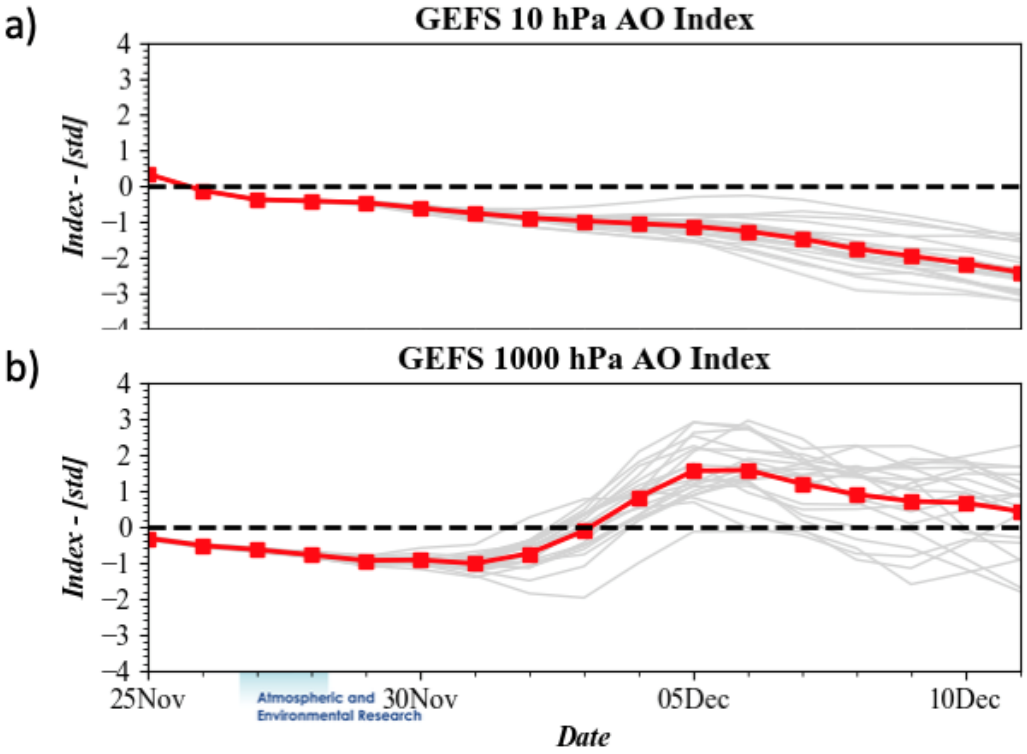

Figure 1. (**a**) The predicted daily-mean AO at 10 hPa from the 00Z 25 November 2019 GFS ensemble. (**b**)
The predicted daily-mean near-surface AO from the 00Z 25 November 2019 GFS ensemble. Gray lines
indicate the AO index from each individual ensemble member, with the ensemble-mean AO index
given by the red line with squares.

This week troughing/negative geopotential height anomalies across Northern Europe and ridging/positive geopotential height anomalies across Southern Europe (**Figure 2**) will result in normal to below temperatures across most of Europe including the UK under westerly flow with the possible exception of Scandinavia where more northerly flow favors normal to below normal temperatures (**Figure 3**). This week troughing/negative geopotential height anomalies across much of Asia (**Figure 2**) will favor normal to below normal temperatures **across much of Asia (Figure 3**). The one exception is Southeastern Asia where ridging/positive geopotential height anomalies (**Figure 2**) will result in normal to above normal temperatures **(Figure 3).**

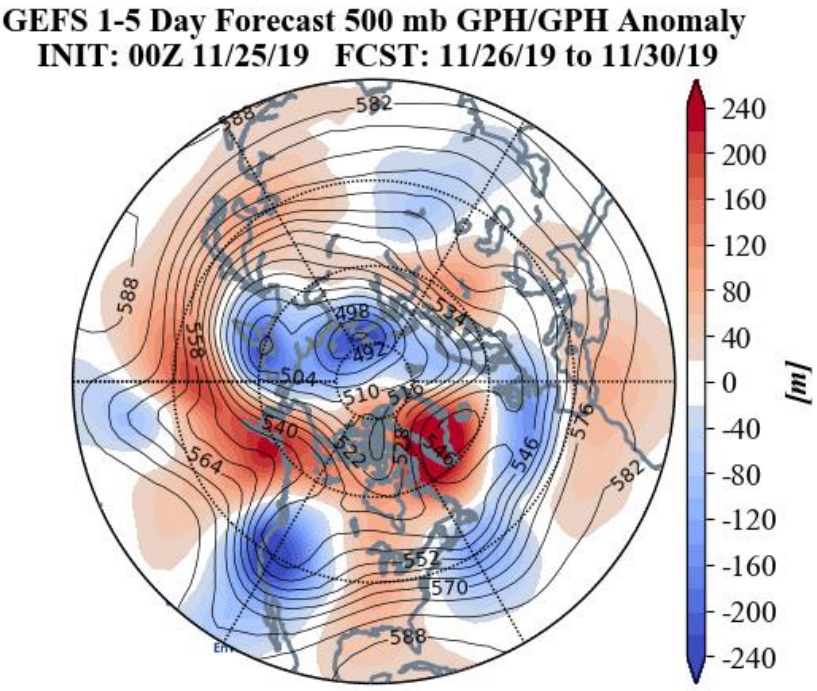

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 26 – 30 November 2019. The forecasts are from the 25 November 00z GFS ensemble.

This week ridging/positive geopotential height anomalies centered over Alaska and Greenland are predicted to force troughing/negative geopotential height anomalies in Western Canada, the Western US, New England and the Canadian Maritimes with more ridging in between the two troughs **(Figures 2).** This is predicted to result in widespread normal to above normal temperatures in Alaska, Northern and Eastern Canada and the Eastern US with normal to below normal temperatures across the Western Canada, the Western US and possibly in the Saint Lawrence River Valley **(Figures 3).**

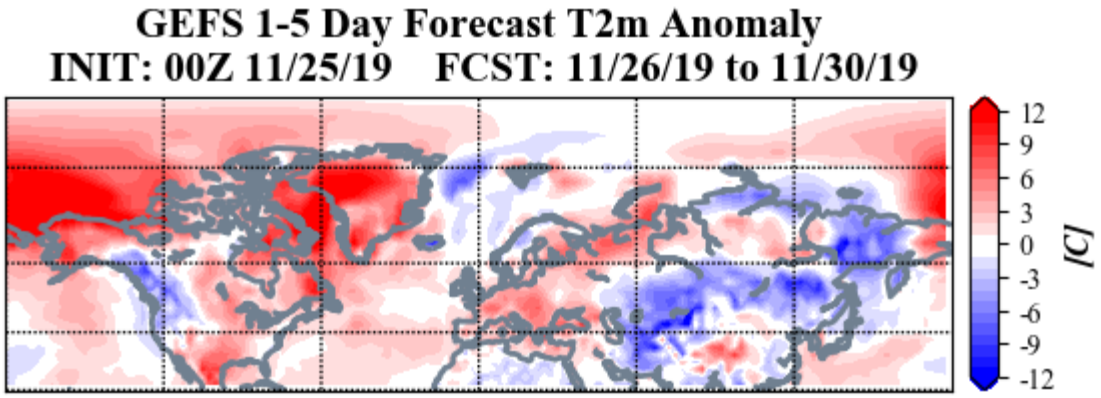

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 26 – 30 November 2019. The forecast is from the 00Z 25 November 2019 GFS ensemble.

Troughing and/or cold temperatures are predicted to bring new snowfall across Siberia, Northwestern Russia, Central Asia, and Scandinavia (**Figure 4**). However, intrusion of warm air on southerly winds will melt snow in Iran and Afghanistan (**Figure 4**). Troughing and cold temperatures are predicted to bring new snowfall to Alaska, Southwestern Canada, the Northwestern US, the Upper Midwest and the Canadian Maritimes (**Figure 4**).

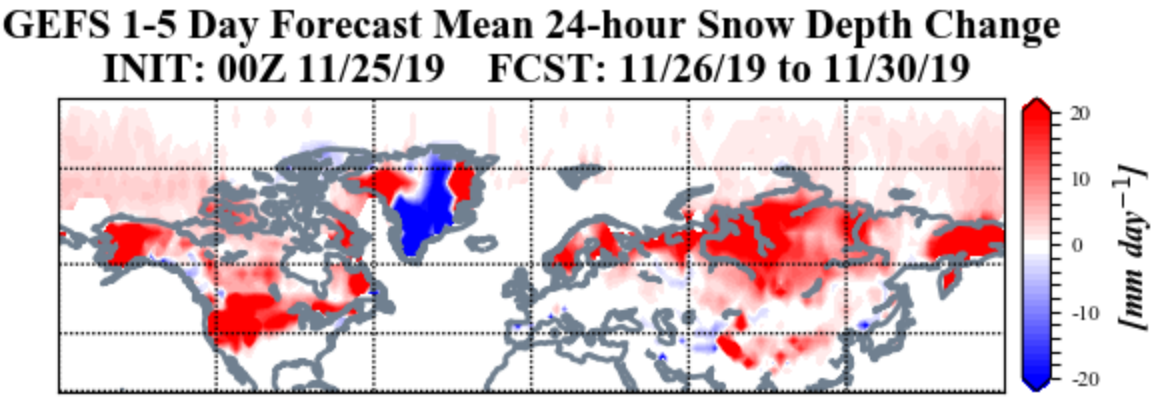

Figure 4. Forecasted snowdepth anomalies (mm/day; shading) from 26 – 30 November 2019. The forecast is from the 00Z 25 November 2019 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to trend positive into positive territory this period **(Figure 1**) as geopotential height anomalies turn more negative especially across the Eurasian Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 5**). And with weakening positive geopotential height anomalies predicted across Greenland (**Figure 2**), the NAO is predicted to trend positive as well.

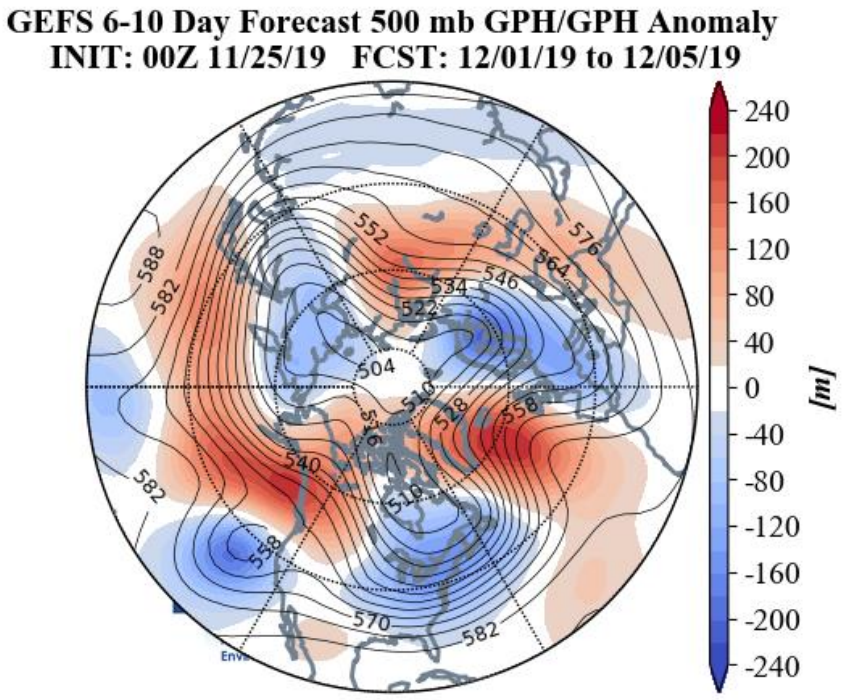

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 1 – 5 December 2019. The forecasts are from the 25 November 00z GFS ensemble.

Predicted ridging/positive geopotential height anomalies in the central North Atlantic will force downstream troughing/negative geopotential height anomalies and normal to below normal temperatures for much of Europe Including the UK with the exception of the Balkan states where southwesterly flow will transport milder temperatures to the region (**Figures 5 and 6**). Ridging/positive geopotential height anomalies will amplify in Western Asia downstream of the European trough with more troughing/negative geopotential height anomalies across East Asia (**Figure 5**). This is predicted to yield normal to above normal temperatures for Western Asia including the Middle East with normal to below temperatures for East Asia **(Figure 6**).

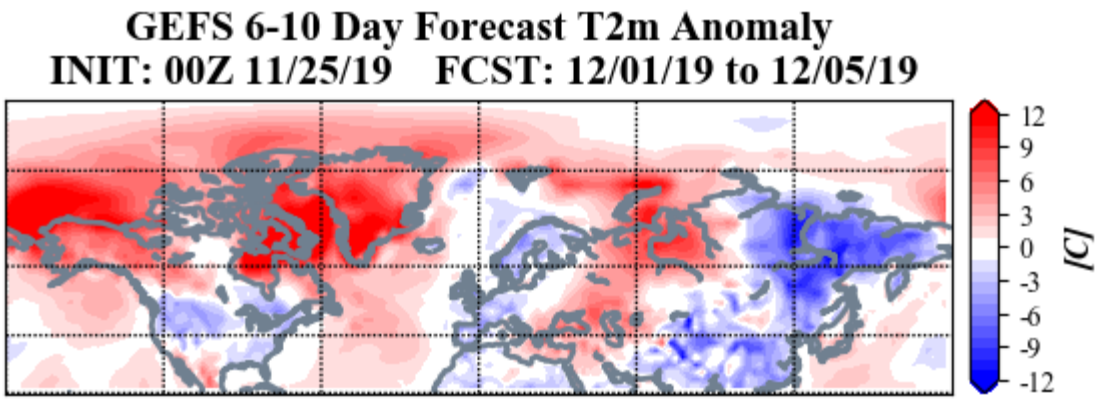

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 1 – 5 December 2019. The forecasts are from the 00Z 25 November 2019 GFS ensemble.

The pattern is predicted to continue from the previous period across North America with ridging/positive geopotential height anomalies across the north with troughing/negative geopotential height anomalies to the south **(Figure 5).** This pattern is predicted to bring normal to above normal temperatures across Alaska and much of Northern Canada with normal to below normal temperatures in much of Southern Canada and the US **(Figure 6).**

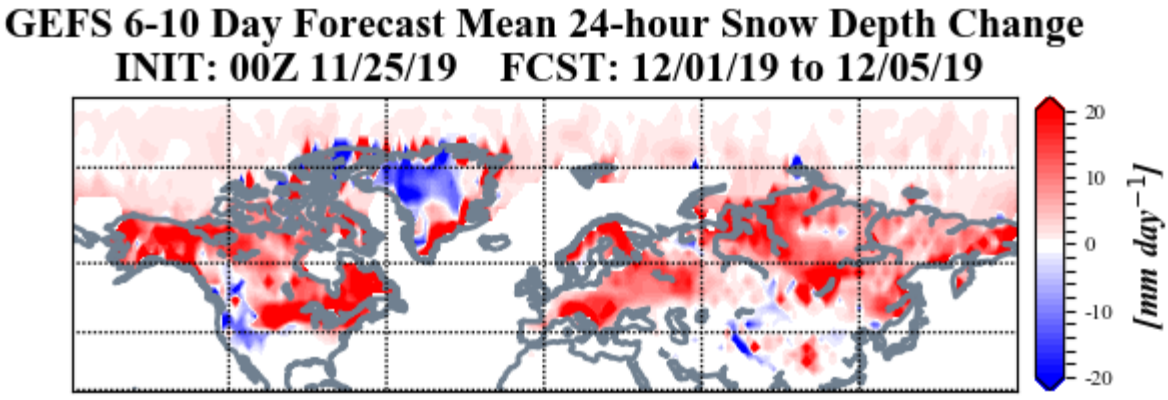

Figure 7. Forecasted snowdepth changes (mm/day; shading) from 1 – 5 December 2019. The forecasts are from the 00Z 25 November 2019 GFS ensemble.

Troughing and/or cold temperatures will support the potential for new snowfall across much of Siberia, Scandinavia, Eastern and Central Europe, Northwest Russia, the Tibetan Plateau, Northeast Asia, Alaska, Canada and the Northern and Eastern US (**Figure 7**). Some snowmelt is predicted in the Western US (**Figure 7**).

11-15 day

With mostly negative geopotential height anomalies predicted for the Arctic (**Figure 8**), the AO is predicted to remain positive this period (**Figure 1**). With predicted weak negative pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO is likely to turn positive this period as well.

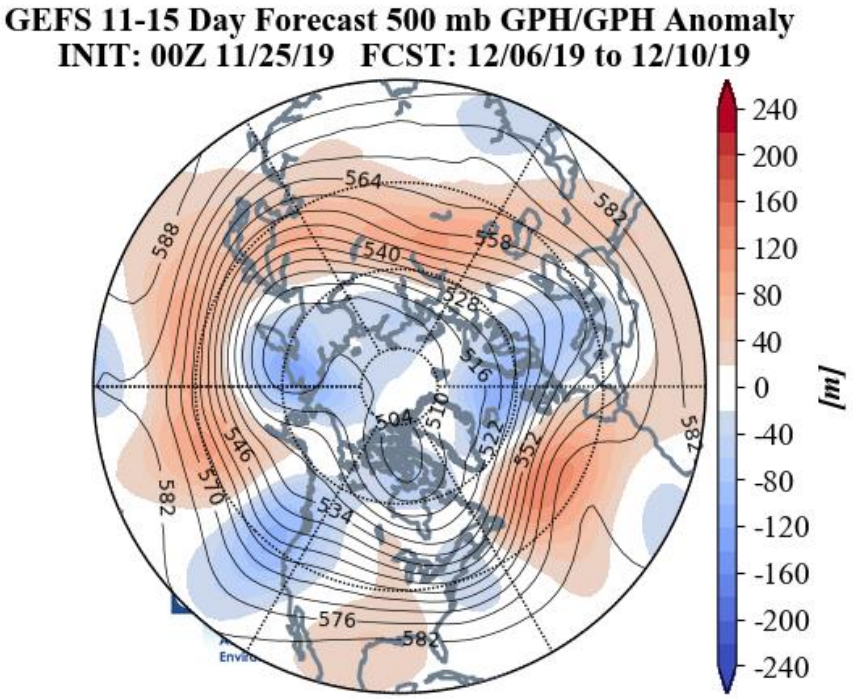

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 6 – 10 December 2019. The forecasts are from the 25 November 00z GFS ensemble.

Troughing/negative geopotential height anomalies across Europe are predicted to still dominate Europe (**Figures 8**) persisting a northerly flow with relatively cool temperatures across much of Europe including the UK this period with the possible exception of far Southeastern Europe due to a mild southwesterly flow (**Figures 9**). Ridging/positive geopotential height anomalies are previously over Western Asia are predicted to spread eastward with troughing/negative geopotential height anomalies confined to Far East Asia (**Figure 8**). This pattern favors normal to above normal temperatures across Western and Central Asia including the Middle East and the Indian subcontinent with normal to below normal temperatures in Eastern Siberia, Northeastern and Southeastern Asia (**Figure 9**).

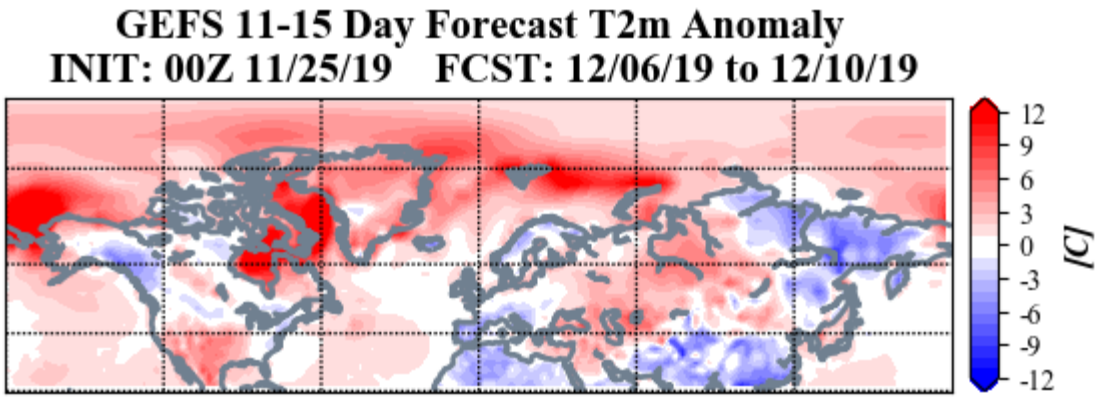

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 6 – 10 December 2019. The forecasts are from the 25 November 00z GFS ensemble.

Troughing/negative geopotential height anomalies are predicted to become more widespread across Alaska Northern Canada with ridging/positive geopotential height anomalies now across the Central US (**Figure 8**). This is predicted to favor a cooling trend across Alaska and Northern Canada with a milder trend across Southern Canada and the US (**Figure 9**). However residual cold temperatures are still likely across Southern Canada and the Northern US (**Figure 9**).

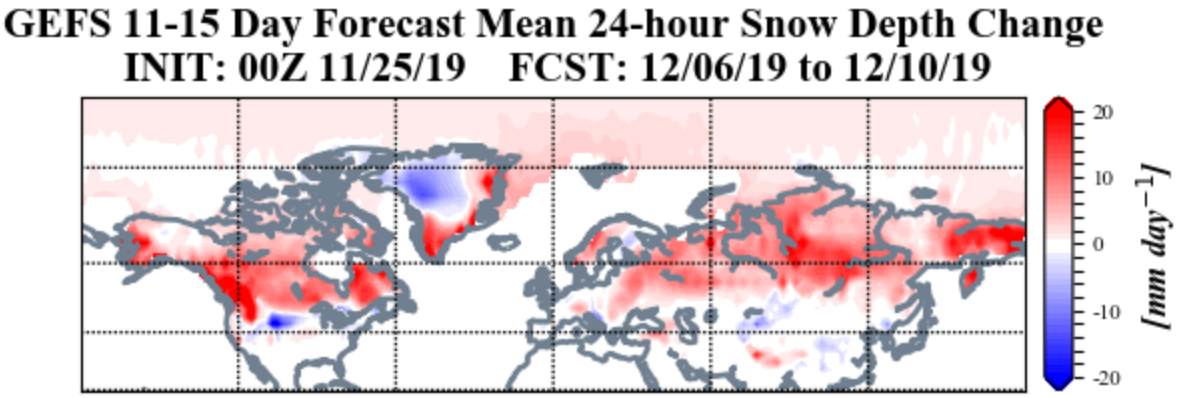

Figure 10. Forecasted snow depth changes (mm/day; shading) from 6 – 10 December 2019. The forecasts are from the 00z 25 November GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across much of Siberia, Northwestern Russia, Central Asia, Scandinavia and possibly parts of Eastern Europe, western Alaska, much of Canada and the Northwestern US (**Figure 10**). Snowmelt is possible in China and the US Plains (**Figure 10**).

Longer Term

30–day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows near normal PCHs in both the stratosphere and the troposphere (**Figure 11**). However, the trends in both are in opposite directions with stratospheric PCHs predicted to turn above normal next week, a sign of a sudden stratospheric warming (SSW) while tropospheric PCHS are predicted to turn below normal (**Figure 11**).

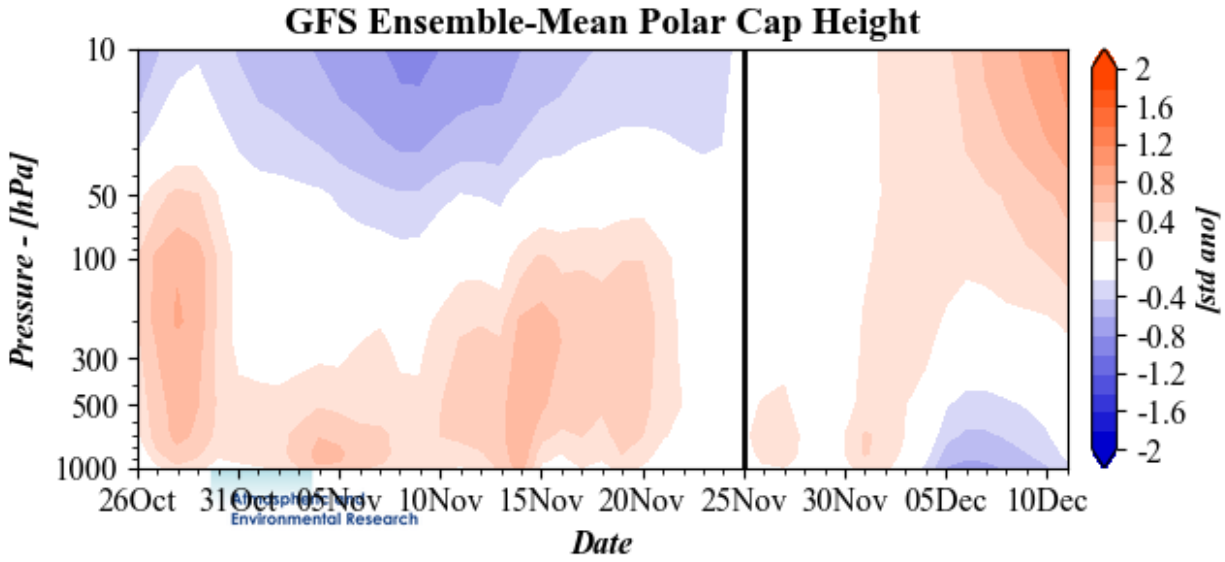

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecasts are from the 00Z 25 November 2019 GFS ensemble.

The plot of Wave Activity Flux (WAFz) or poleward heat transport shows a relatively active upcoming two-week period (**Figure 12**). One major WAFz pulse is for this week and another one for the second week of December (**Figure 12**). In the mid-stratosphere some negative/cold PCHS are predicted possibly a sign of a reflective event but it is confined to the mid-stratosphere which seems unusual to me.

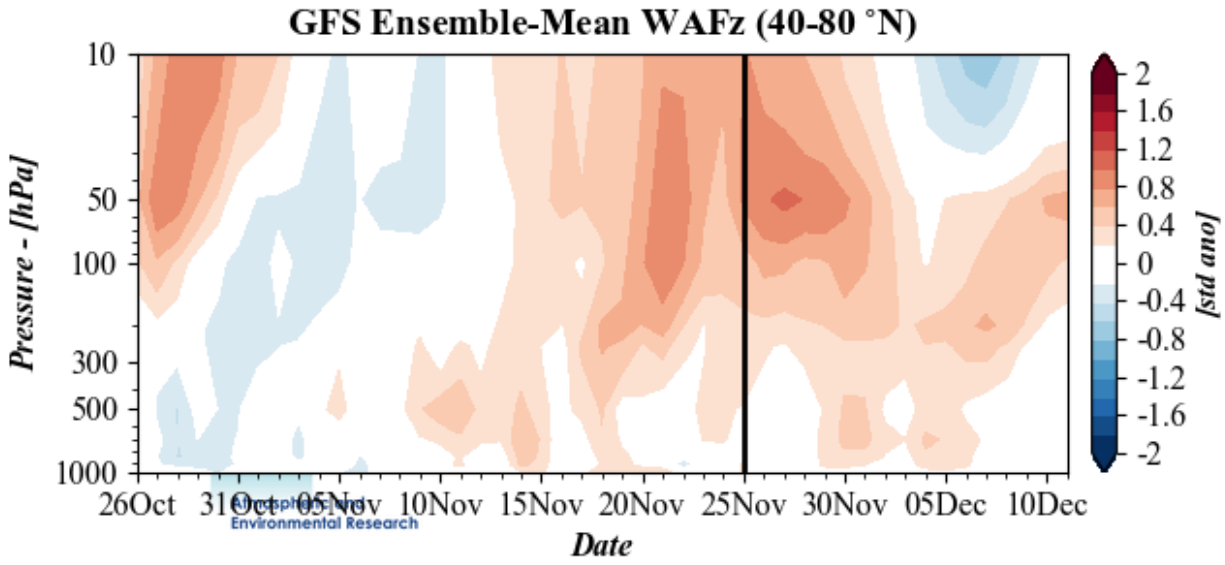

Figure 12. Observed and predicted daily vertical component of the wave activity Wux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 25 November 2019 GFS ensemble.

The stratospheric AO is currently slightly positive (**Figure 1**) reflective of a near normal PV. However, in response to the positive WAFz predicted over the next two weeks, the stratospheric AO is predicted to continuously trend negative and could be in strong negative territory by the second week of December (**Figure 1**).

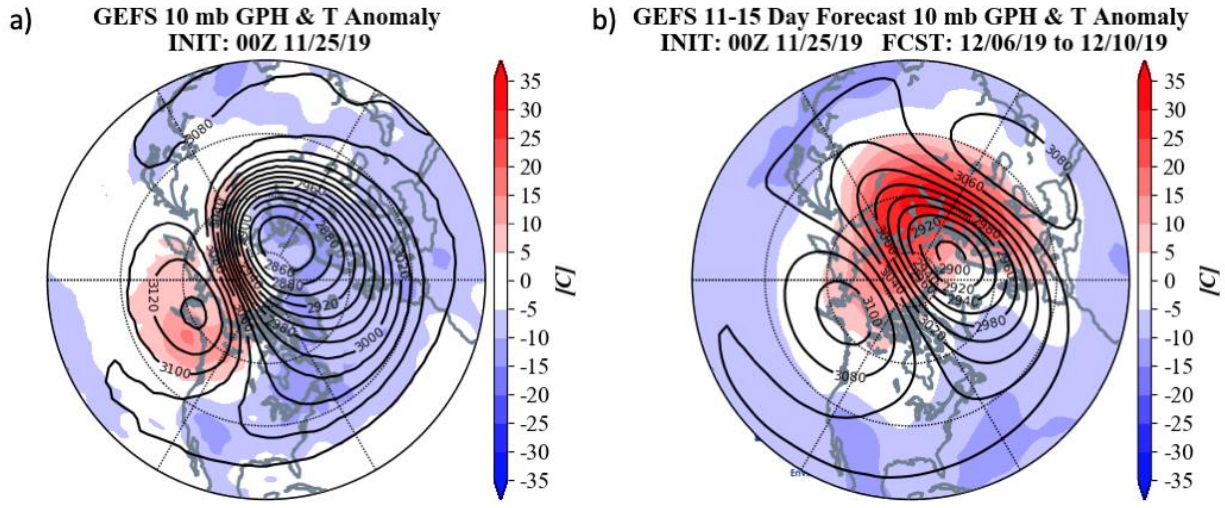

Figure 13. (**a**) Analyzed 10 mb geopotential heights (dam; contours) and temperature anomalies (°C;

shading) across the Northern Hemisphere for 25 November 2019. (**b**) Same as (a) except forecasted averaged from 6 – 10 December 2019. The forecasts are from the 00Z 25 November 2019 GFS operational model.

Despite the strong circulation around the PV center and relatively low heights, the PV is not circular in shape but rather elongated and displaced towards Eurasia, signs of some disruption already (**Figure 13**). The counterclockwise flow around the PV center is bringing northerly flow to North America rather than westerly flow more common with a strong PV with a more circular configuration (**Figure 13)**. The northerly flow is supportive of the predicted cold temperatures in eastern North America in Southern Canada and the US.

Currently there is warming, and a ridge centered near Alaska in the stratosphere (**Figure 13).** But over time the new WAFz pulses are predicted to cause warming over much of Northern Eurasia and reinforce the ridging centered over Alaska with relatively warm temperatures widespread across the Arctic (**Figure 13)**. Also, the PV center is predicted to remain displaced towards northwest Eurasia over the next wo weeks. The displacement of the PV center towards Scandinavia is likely contributing to a tropospheric reflection helping to deepen the troughing across Europe next week (e.g., **Figure 5**). The displacement of the stratospheric PV towards Eurasia is usually the first sign of a more significant PV disruption that is now being predicted by most models.

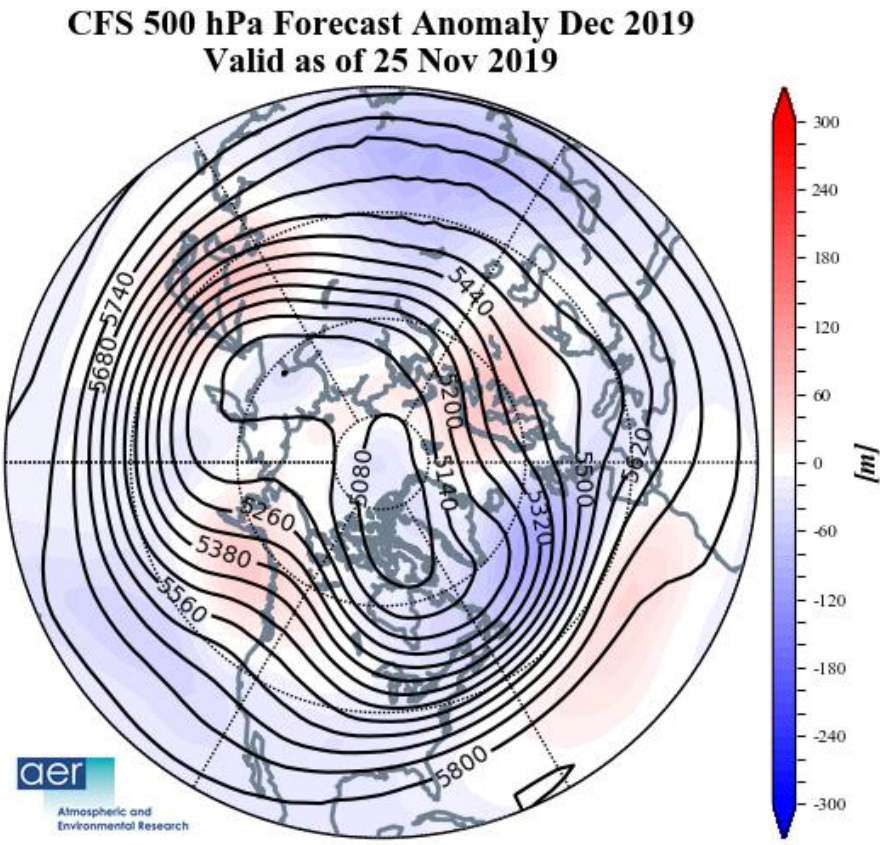

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for December 2019. The forecasts are from the 25 November 2019 CFS.

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 Northern Europe, East Asia, Alaska and Western Canada with troughs over Greenland and Iceland, Southern Europe, Central Asia, Eastern Siberia, the Dateline, and Eastern North America (**Figure 14).** This pattern favors relatively mild temperatures for much of Europe, Western Asia, Southeast Asia and Western North America with seasonable to relatively cold temperatures for Siberia, Northeast Asia, Eastern Canada and the Eastern US (**Figure 15**). The CFS has also shown little consistency from run to run.

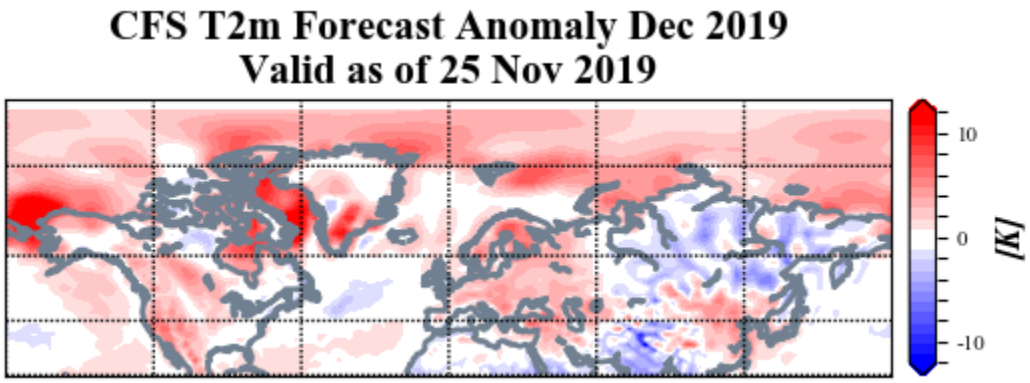

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for December 2019. The forecasts are from the 25 November 2019 CFS.

Surface Boundary Conditions

Arctic sea ice extent

In this week's plot I included a plot of Arctic Seas sent to me by David Birch; seems like a good idea. Arctic sea ice growth rate has accelerated but remains well below normal. Large negative sea ice anomalies exist in three regions: the Chukchi-Beaufort, west of Greenland-Canadian Archipelagos and Barents-Kara Seas. The anomalies in the North Pacific sector have emerged as the most well below normal (**Figure 16**), however, based on model forecasts sea ice in the Chukchi-Beaufort Seas may grow more quickly in the next two weeks. Below normal sea ice in and around Greenland and the Canadian Archipelagos may favor a negative winter NAO. Based on recent research low sea ice anomalies in the Chukchi and Bering seas favors cold temperatures in central and eastern North America while low 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 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.

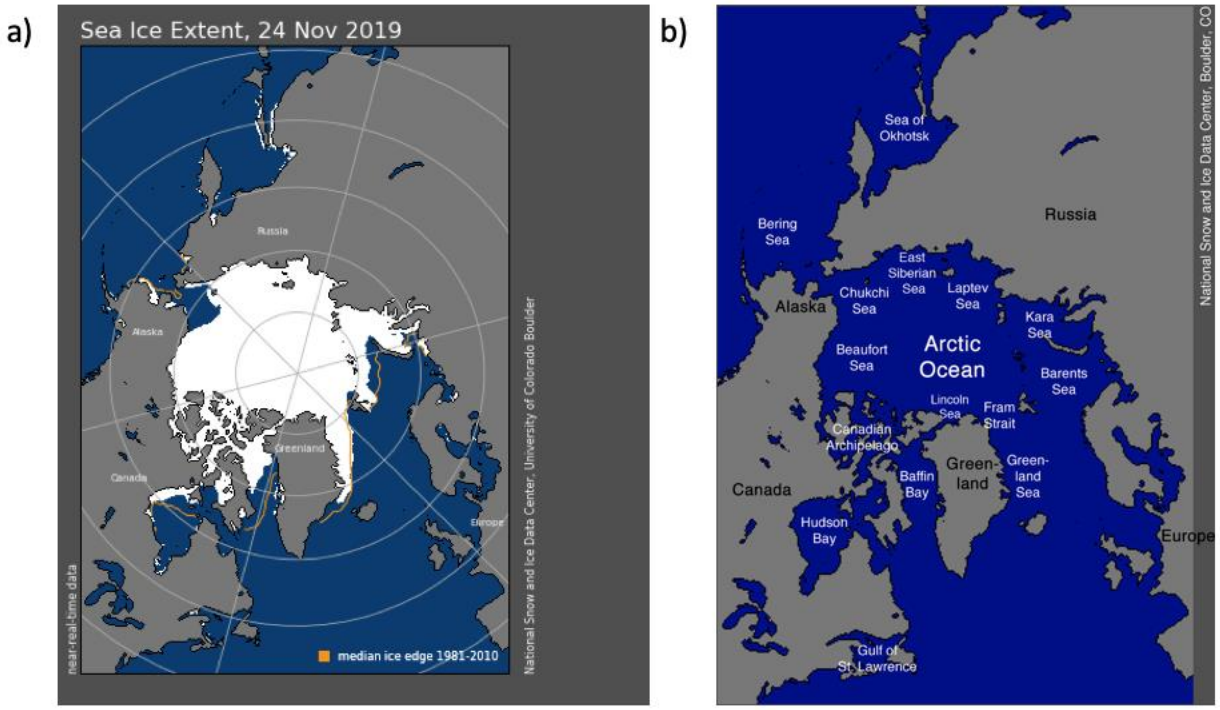

Figure 16. a) Observed Arctic sea ice extent on 24 November 2019 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. b) Map of Arctic Seas. Images courtesy of National Snow and Ice Data Center (NSIDC). Snow and Ice Data Center (NSIDC).

SSTs/El Niño/Southern Oscillation

Equatorial Pacific sea surface temperatures (SSTs) anomalies have cooled and Neutral El Niño/Southern Oscillation (ENSO) conditions seem most likely (**Figure 17**). Observed SSTs across the NH remain well above normal especially near Alaska and along the north slope of Asia though below normal SSTs exist regionally especially west of South America. Warm SSTs around Alaska may favor mid-tropospheric ridging in the region this upcoming winter.

This is outside of my expertise but the relatively warm SSTs east of Africa and relative cold SSTs west of Indonesia in the Indian Ocean are known as the positive phase of the Indian Ocean Dipole (+IOD). This has been shown to suppress convection over the Maritime continent. These correspond to some of the Madden Julian Oscillation (MJO) phases associated with warmer weather patterns in the Eastern US during the winter months (Benedict et al. 2015).

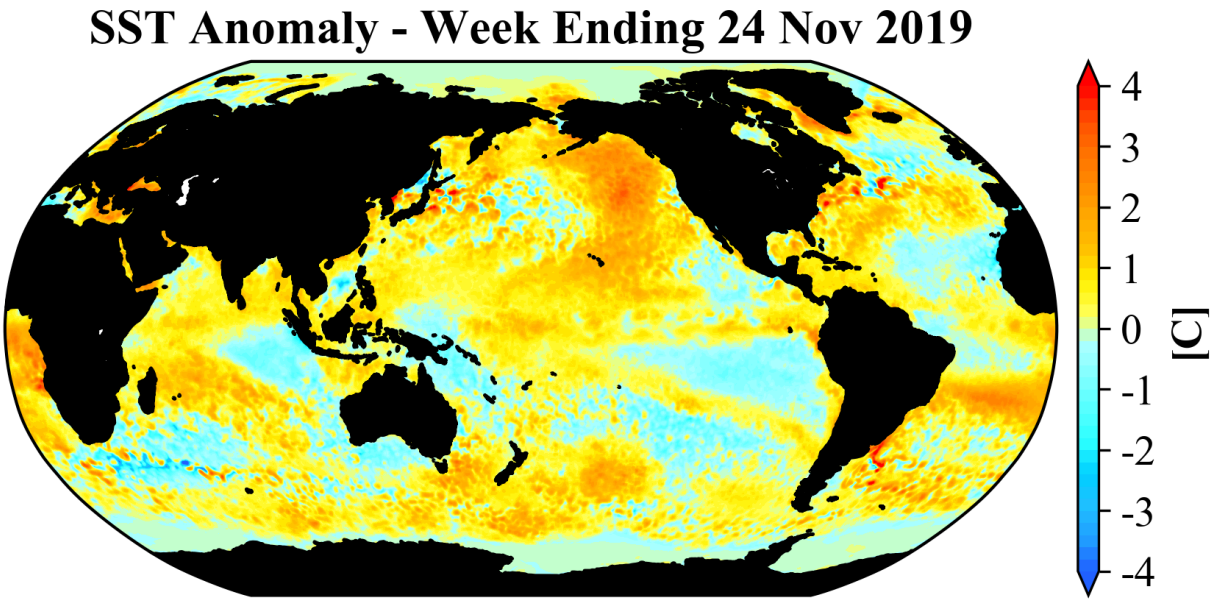

Figure 17. The latest weekly-mean global SST anomalies (ending 17 November 2019). Data from NOAA OI High-Resolution dataset.

Currently no phase of the Madden Julian Oscillation (MJO) is favored (**Figure 18**). The forecasts are for the MJO to emerge into phase 1 and then to phase 2 over the next two weeks. Some MJO influence is possible across North American weather in the forecast period as theses phases favor high latitude blocking and troughing in the US transitioning to ridging in the Eastern US and troughing in the Western US.

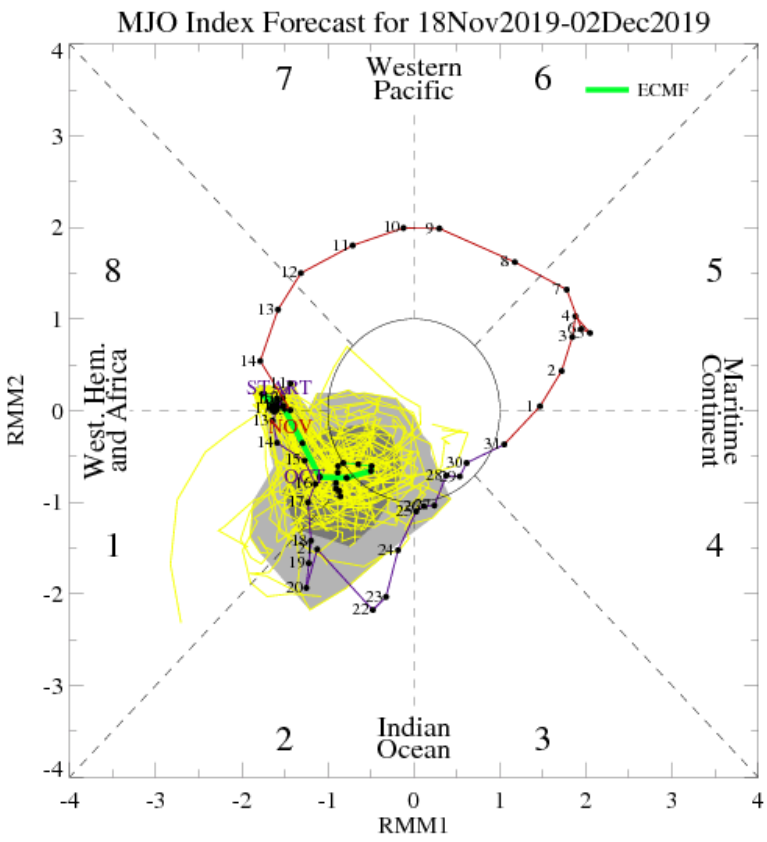

Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 18 November 2019 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model "spread" is denoted by the gray shading. Sector numbers indicate 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 continues its climb across Eurasia and is currently near decadal averages. Snow cover will likely continue to advance especially across East Asia this week and Europe the following week as troughing and cold temperatures spread across the region. 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.

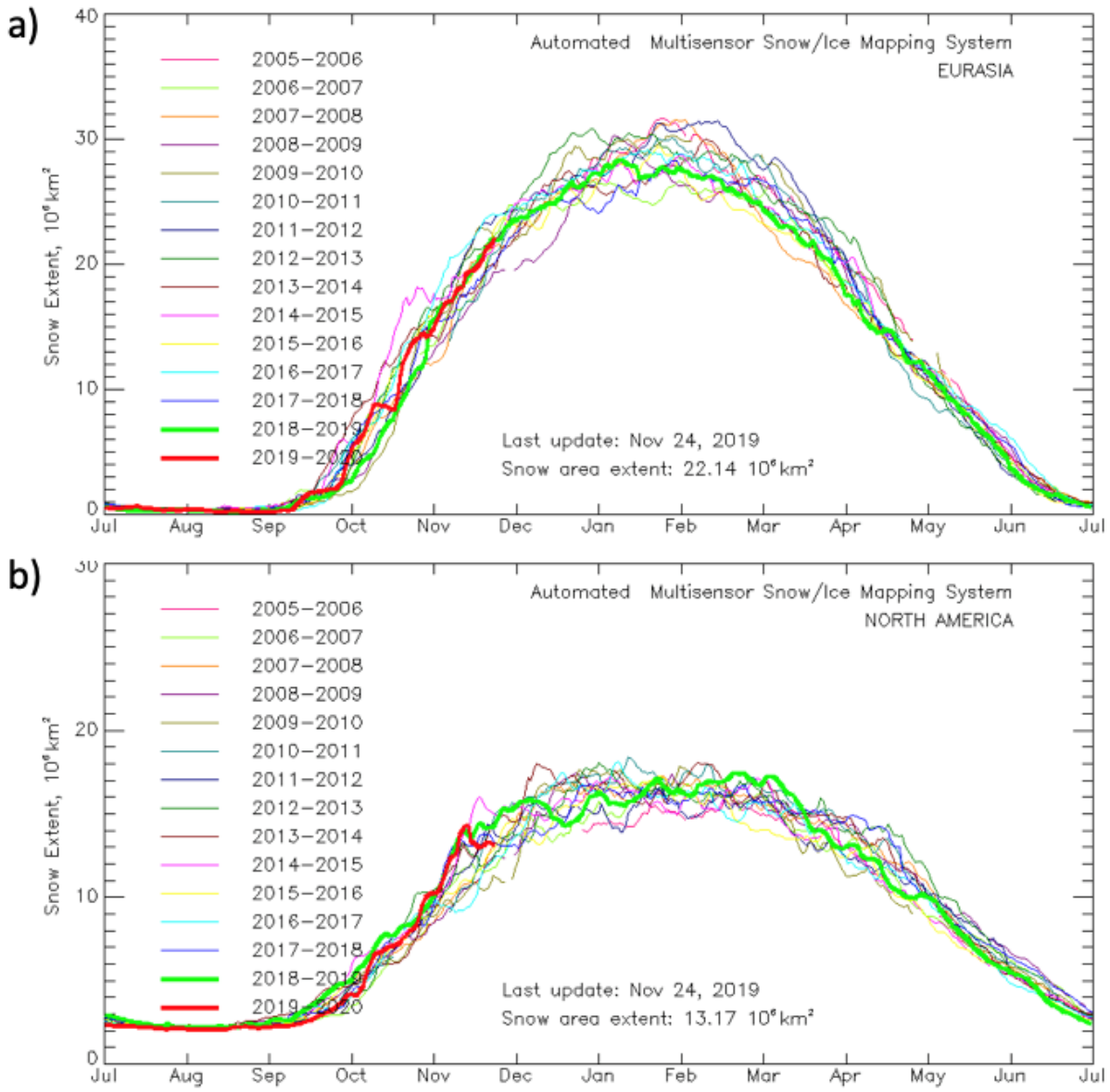

Figure 19. Observed Eurasian (top) and North American (bottom) snow cover extent through 24 November 2019. Image source: https://www.star.nesdis.noaa.gov/smcd/emb/snow/HTML/snow_extent_plots.html

North American snow cover melted back from decadal highs and is below last year at this time closer to decadal means. However snow cover advance should pick up with predicted colder temperatures. The early advance of snow cover across Canada this fall, has likely contributed to an early start of cold temperatures across the Western US and now Eastern US.