Arctic Oscillation and Polar Vortex Analysis and Forecasts

December 2, 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.

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

Summary

- The Arctic Oscillation (AO) is currently positive and is predicted to slowly trend negative over the next two weeks towards neutral.
- The current positive AO is reflective of mostly negative pressure/geopotential height anomalies across the Arctic and mixed pressure/geopotential height anomalies across the mid-latitudes. The North Atlantic Oscillation (NAO) is positive with negative pressure/geopotential height anomalies spread across Greenland; and the NAO is predicted to remain positive as heights remain negative across Greenland over the next two weeks.

- The general pattern this week of troughing/negative pressure/geopotential height anomalies over Western Europe with ridging/positive geopotential height anomalies over Eastern Europe will result in normal to below normal temperatures in Western and Southern Europe including the United Kingdom (UK) with normal to above normal temperatures in Northern and Eastern Europe. However, next week troughing is predicted to strengthen across Northern Europe promoting a general westerly, mild flow of air across Europe including the UK. The GFS is predicting that the troughing amplifies over Europe mid-month bringing some colder air into Europe, however this is a low confidence forecast.
- Currently troughing/negative pressure/geopotential height anomalies and normal to below normal temperatures dominate East Asia with ridging/positive geopotential height anomalies and normal to above normal temperatures across Western and Central Asia except for the Urals. However, troughing is predicted to recede into Northern Siberia and continued cold temperatures with ridging dominating Asia favoring a general southwesterly, mild flow across much of Asia including the Middle East and East Asia.
- This GFS is predicting the general pattern of ridging/positive geopotential height anomalies and normal to above normal temperatures across Alaska and western North America with troughing/negative geopotential height anomalies and normal to below normal temperatures across much of Central and Eastern Canada and the United States (US). However, the ECMWF is predicting that the northern half of the riding north of Alaska will break away from the southern half of the ridging allowing a more zonal, milder flow of air across the US.
- In the Impacts section I present the AER Northern Hemisphere (NH) winter temperature anomaly forecast.

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 in 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.

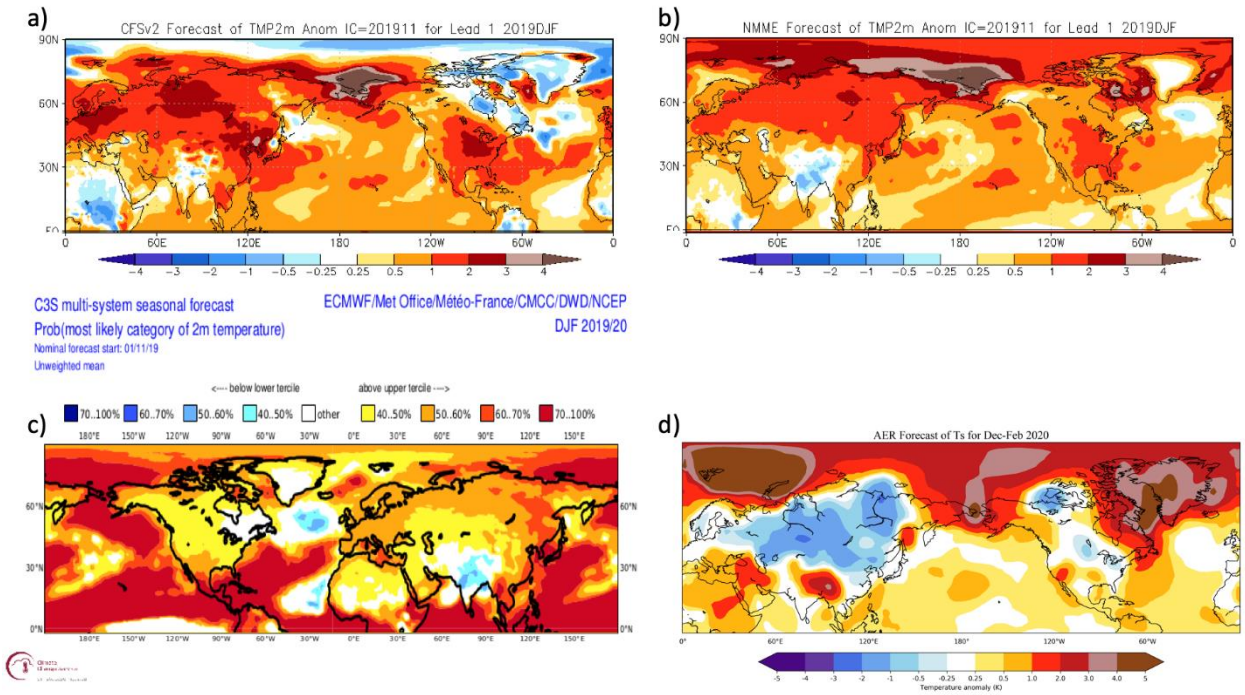

Figure i. The winter 2019/20 surface temperature anomalies forecast for the Northern Hemisphere from the a) NOAA CFSv2, b) the North American Multi-model Ensemble (NMME), c) the C3S model ensemble (ECMWF, UK Met and Meteo France models) and d) the AER statistical model.

I also included forecasts from the dynamical models in **Figure i**. The American and European models all show widespread warmth across, Europe, Asia and the US. This winter's forecast is consistent with other recent winter where the dynamical models have predicted nearly universal warmth across the NH.

I would attribute the colder AER winter forecast to the anticipation in the model of a significant stratospheric PV disruption with long lasting impacts on the tropospheric circulation/weather. The region most likely influenced colder is Siberia followed by central and eastern North America. The dynamical models either do not anticipate a significant PV disruption or that the disruption will not have a meaningful and/or short-lived impact on the weather.

Therefore, a critical question for the winter weather and which forecast will favorably verify this winter – will there be an impactful PV disruption this winter? The hemispheric pattern that set up in early to mid-November was highly favorable for disrupting the PV. With strong Ural/Scandinavian blocking and low heights near the Aleutians; and the PV has steadily but slowly weakened since the second week of November. But since late November the Ural/Scandinavian blocking has been replaced by much lower pressures/heights (probably in part to the migration of the PV center to that region), a pattern less favorable for disrupting the PV.

The models in general have been less aggressive in disrupting the PV and probably a major mid-winter warming (reversal of the zonal mean zonal wind from westerly or positive to easterly or negative at 60°N and 10 hPa) is less likely than I previously thought. All models predict a minor warming with ridging near Alaska and Northern Canada and the PV near and along the north slope of Eurasia. This does resemble what is referred to as a Canadian warming. This rarely results in a major warming, but I do believe can be a precursor to a more significant warming later on. In our paper on clustering of PV states (Kretschmer et al. 2018) the third cluster resembles a Canadian warming and the PV configuration for the first half of December with the PV displaced along the north slope of Eurasia and ridging warming near Alaska/Northern Canada. I include in **Figure ii** the first figure from the paper showing the five different clusters and the NH temperature anomalies for each cluster. The third cluster resembles both a Canadian warming and the near term forecast for the PV. Also, the associated temperature pattern resembles the predicted NH temperature pattern with cold temperatures across Northern Asia and Europe but milder elsewhere across Eurasia. The pattern across North America is reversed with relatively mild temperatures across Alaska and Northern Canada and seasonably cold across the US.

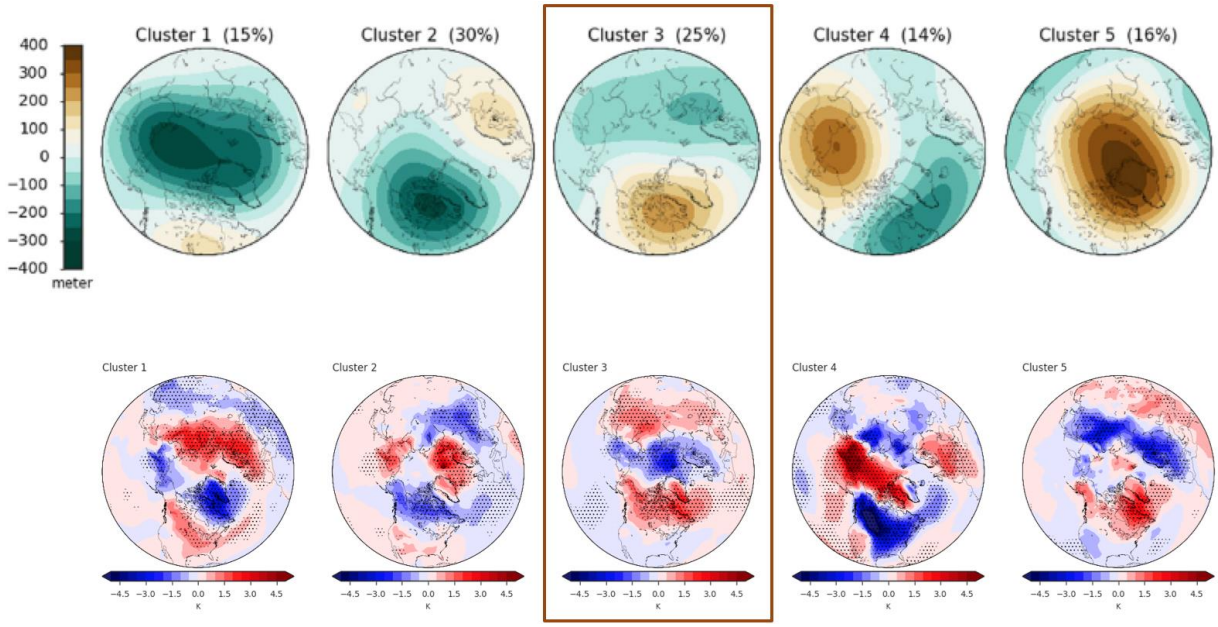

Figure ii. Composites of geopotential height anomalies at 100mb in winter (JF) from 1979-2018 for days assigned to the same cluster. The number in brackets gives the total occurrence (in percent) over all winter days. Below each cluster is the associated temperature anomaly pattern. Highlighted by the box is the third cluster, which resembles a Canadian warming.

The GFS is predicting a relatively cold pattern across eastern North America for the next two weeks while the ECMWF is appreciably milder especially after day 10. I hate to disagree with the superior ECMWF but it seems to me the GFS is more consistent with

the temperature pattern associated with a Canadian warming. Maybe like many model disagreements best to split the baby.

I believe that the extensive Siberian snow cover this October was a meaningful contributor to the PV weakening observed since mid-November and that is likely to continue. However Siberian snow cover has not received the level of support from Barents-Kara sea ice to disrupt the PV as it has the past two winters. Barents-Kara sea ice is close to normal and much higher than the two previous falls/early winters. As an aside the strong warming bullseye over the Barents Kara Seas in the AER winter forecast may not verify with near normal sea ice in the region.

Snow cover by itself might not be able to disrupt the PV sufficiently to force a major warming this year. Still based on the extensive snow cover, cold Siberia, generally low sea ice and warm Arctic I expect more perturbations to the PV in the coming months followed by periods of more severe winter weather.

Ironically though, low sea ice in the Barents-Kara Seas is favorable for disrupting the PV it does not seem to favor cold temperatures in the Eastern US. Instead I believe that low sea ice in the Chukchi-Beaufort Seas and west of Greenland are more favorable for cold temperatures in the Eastern US. Low sea ice in these regions support blocking near Alaska and Greenland respectively that often force troughing and cold temperatures in the Eastern US. This winter, so far, the negative sea ice extent anomalies are greater in these regions relative to the Barents-Kara Seas (see **Figure 16** below).

Near Term Conditions

1-5 day

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

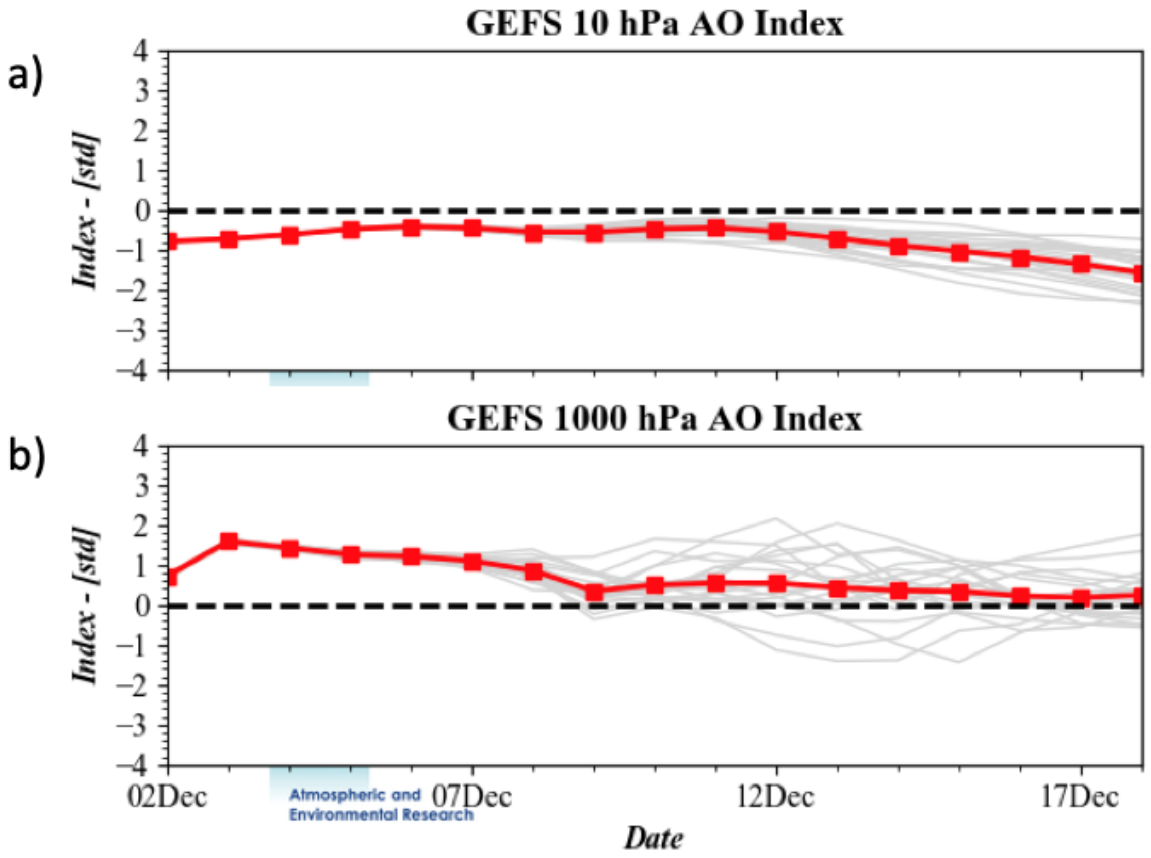

Figure 1. (**a**) The predicted daily-mean AO at 10 hPa from the 00Z 2 December 2019 GFS ensemble. (**b**) The predicted daily-mean near-surface AO from the 00Z 2 December 2019 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

This week predicted troughing/negative geopotential height anomalies across Southwestern Europe with ridging/positive geopotential height anomalies across the rest of Europe (**Figure 2**) will result in normal to below temperatures across Western and Southern Europe including the UK with normal to above normal temperatures across Northern and Eastern Europe (**Figure 3**). This week troughing/negative geopotential height anomalies across much of East Asia (**Figure 2**) will favor normal to below normal temperatures across much of East Asia **(Figure 3**). In contrast ridging/positive geopotential height anomalies are predicted to dominate Central Asia (**Figure 2**) resulting in normal to above normal temperatures for most of Western and Central Asia **(Figure 3).**

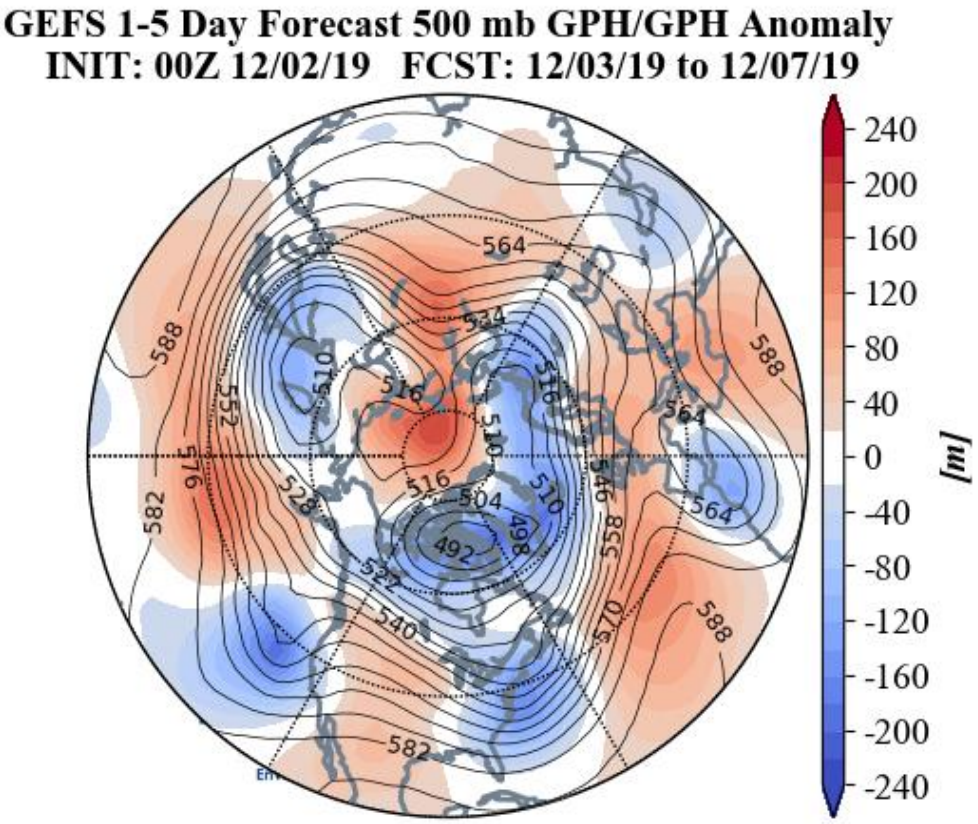

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 3 – 7 December 2019. The forecasts are from the 2 December 00z GFS ensemble.

This week troughing/negative geopotential height anomalies are predicted across Alaska and Northern Canada extending southeastward into Eastern Canada and the Eastern US with ridging/positive geopotential height anomalies centered over the Western US and Southwestern Canada (**Figures 2**). This is predicted to result in normal to above normal temperatures in Southwestern Canada and the Western US with normal to below normal temperatures across Alaska, Northern and Eastern Canada and the Eastern US **(Figures 3).**

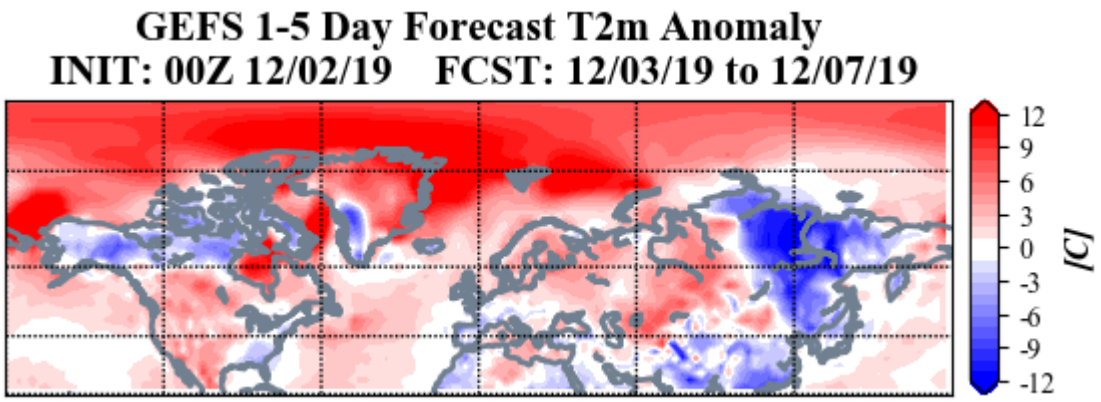

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 3 – 7 December 2019. The forecast is from the 00Z 2 December2019 GFS ensemble.

Troughing and/or cold temperatures are predicted to bring new snowfall across Siberia, Northwestern Russia, Eastern Europe and even the higher terrain of Southern Europe (**Figure 4**). However, intrusion of warm air on southerly winds will melt snow in Scandinavia (**Figure 4**). Troughing and cold temperatures are predicted to bring new snowfall to Alaska, much of Canada, the Northwestern US, and the Northeastern US (**Figure 4**).

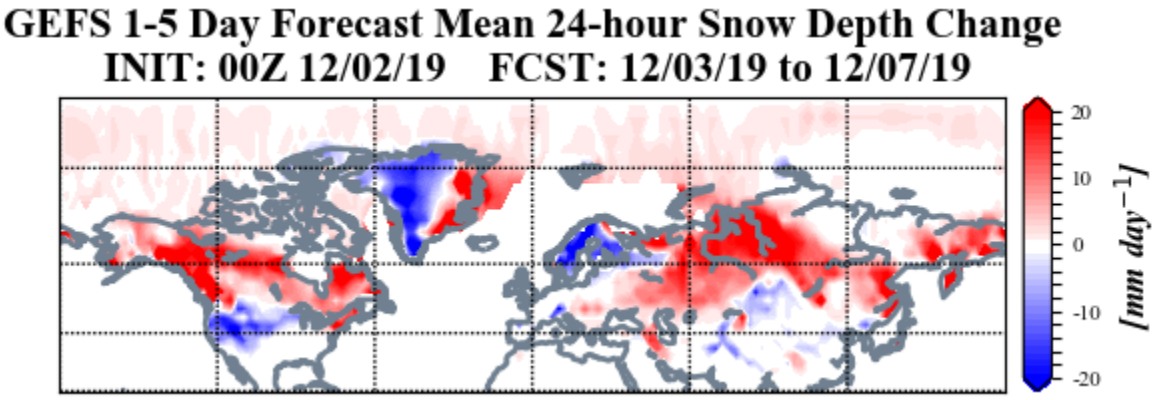

Figure 4. Forecasted snowdepth anomalies (mm/day; shading) from 3 – 7 December 2019. The forecast is from the 00Z 2 December2019 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to trend negative towards neutral this period **(Figure 1**) as geopotential height anomalies turn more positive across the North Pacific side of the

Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 5**). And with negative geopotential height anomalies predicted across Greenland (**Figure 2**), the NAO is predicted to remain positive.

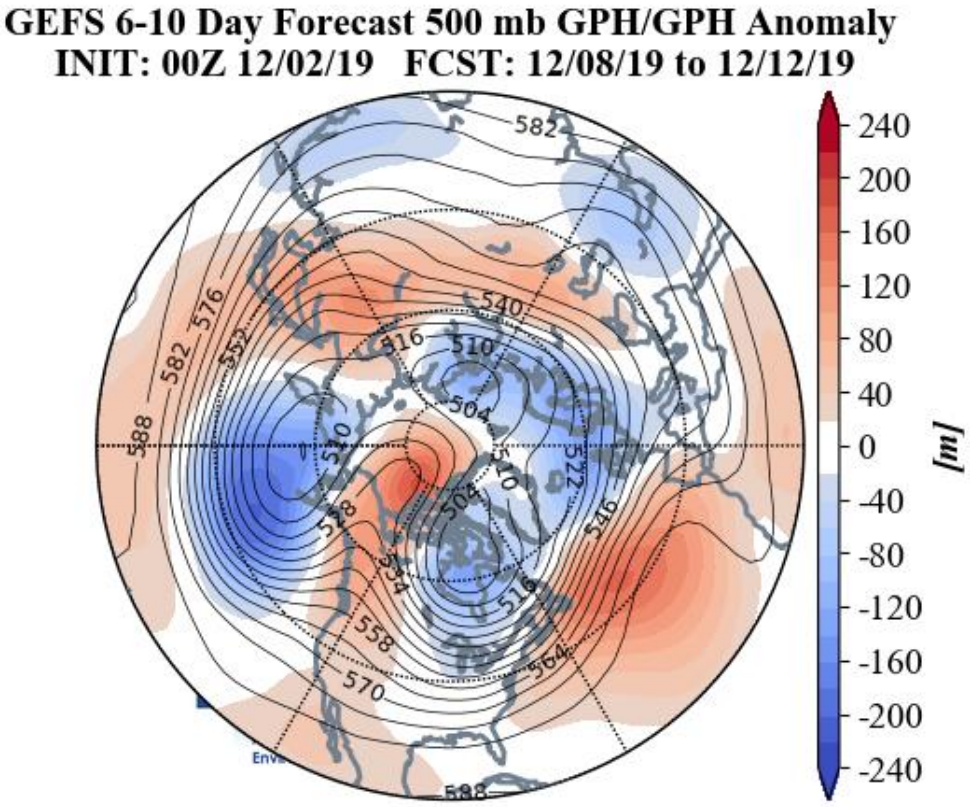

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 8 – 12 December 2019. The forecasts are from the 2 December 00z GFS ensemble.

Predicted troughing/negative geopotential height anomalies across Northern Europe with higher heights to the south will promote a westerly, mild flow of air across the continent with normal to above normal temperatures for much of Europe Including the UK with the exception of Scandinavia where below normal heights will support cold temperatures (**Figures 5 and 6**). Ridging/positive geopotential height anomalies will dominate the interior of Asia with troughing/negative geopotential height anomalies confined to extreme Northern and Southern Asia (**Figure 5**). This is predicted to yield normal to above normal temperatures for most of Asia **with** normal to below temperatures confined to Northern Siberia and parts of Southeast Asia and the Middle East (**Figure 6**).

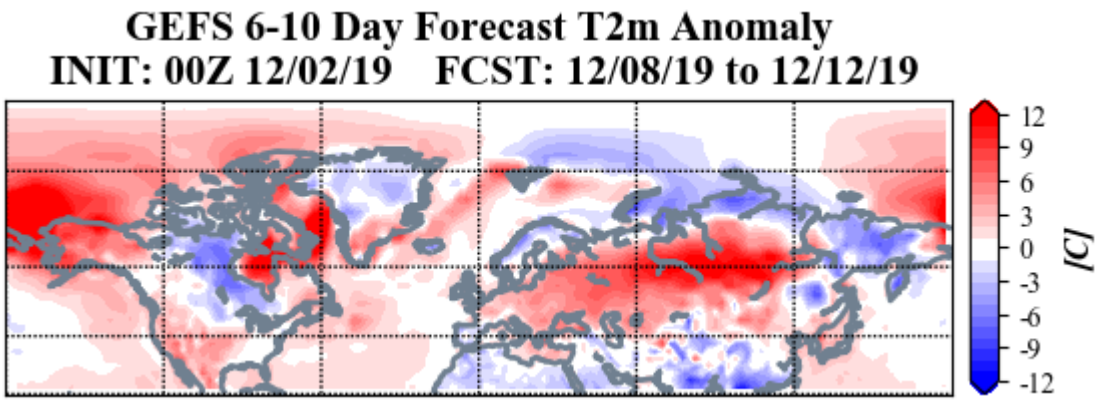

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 8 – 12 December 2019. The forecasts are from the 00Z 2 December 2019 GFS ensemble.

The predicted pattern across North America this period is ridging/positive geopotential height anomalies across western North America with troughing/negative geopotential height anomalies in eastern North America (Figure 5). This pattern is predicted to bring normal to above normal temperatures across Alaska, Western Canada and the Western US with normal to below normal temperatures in Eastern Canada and the Eastern US **(Figure 6).**

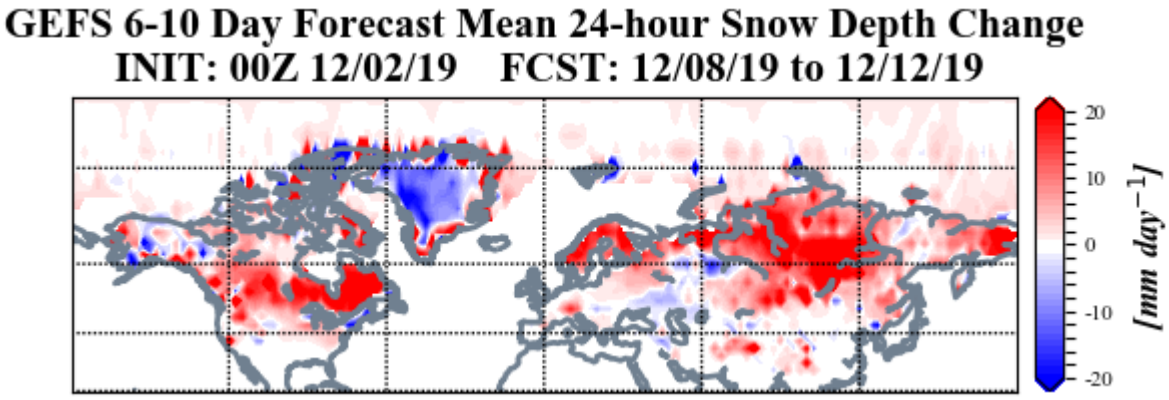

Figure 7. Forecasted snowdepth changes (mm/day; shading) from 8 – 12 December 2019. The forecasts are from the 00Z 2 December 2019 GFS ensemble.

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

11-15 day

With mostly negative geopotential height anomalies predicted for the North Atlantic side of the Arctic but positive geopotential height anomalies predicted for the North Pacific side of the Arctic (**Figure 8**), the AO is predicted to remain near neutral this period (**Figure 1**). With predicted weak negative pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO is likely to remain positive this period.

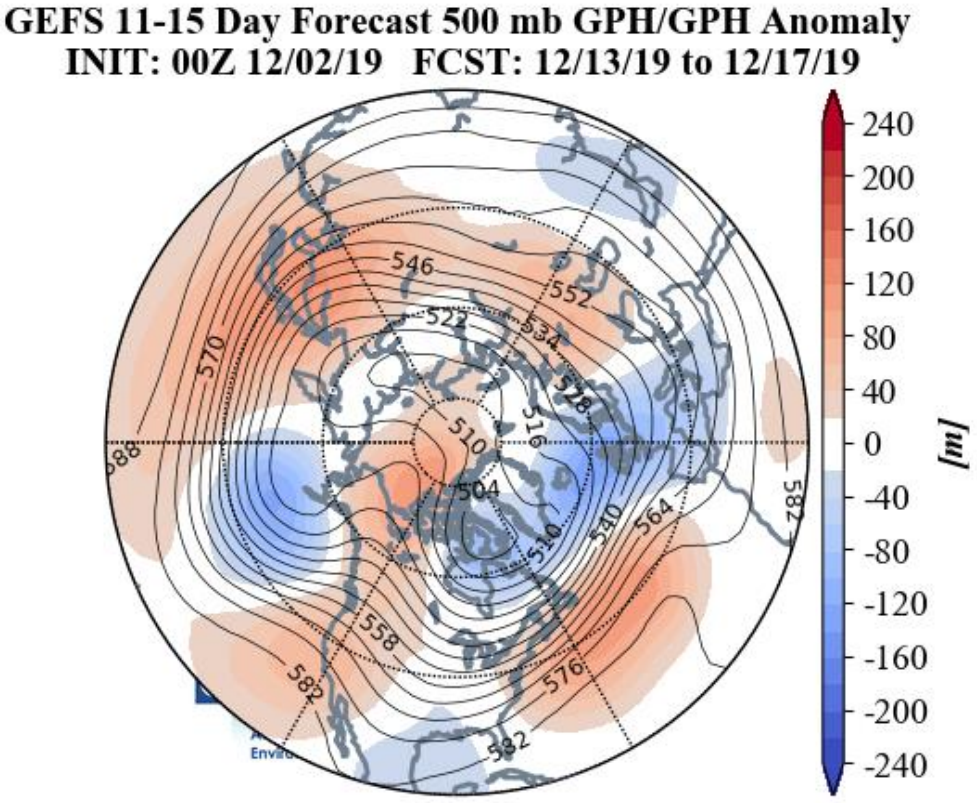

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 13 – 17 December 2019. The forecasts are from the 2 December 00z GFS ensemble.

Predicted deepening troughing/negative geopotential height anomalies across Western Europe (**Figures 8**) will introduce a more northerly flow this period with relatively cold temperatures across much of Europe including the UK this period with the exception of Eastern Europe due to a persistent mild southwesterly flow (**Figures 9**). Ridging/positive geopotential height anomalies are predicted to dominate Asia with troughing/negative geopotential height anomalies confined to Northern Siberia and the Persian Gulf region (**Figure 8**). This pattern favors normal to above normal temperatures across much of Asia including the Middle East and East Asia with the exception of normal to below normal temperatures in Northern Siberia and the Indian subcontinent (**Figure 9**).

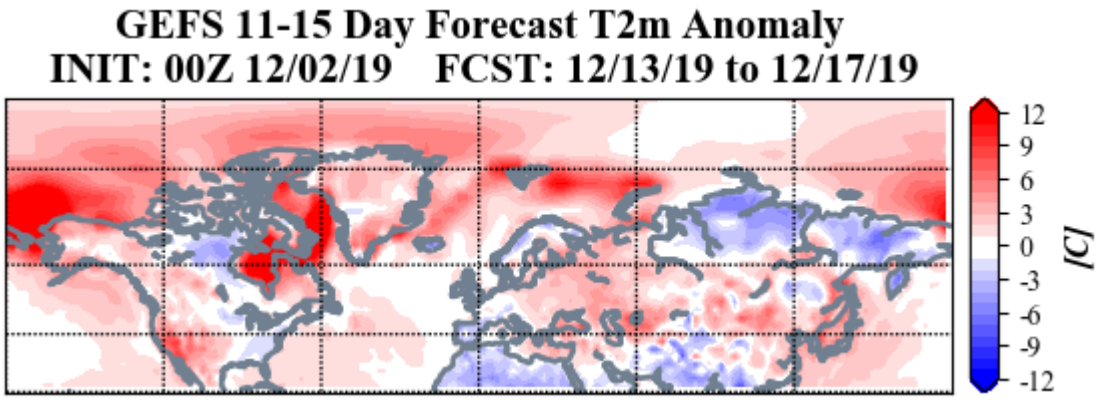

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 13 – 17 December 2019. The forecasts are from the 2 December 00z GFS ensemble.

The GFS is predicting a continuation of the western ridge/eastern trough pattern with ridging/positive geopotential height anomalies from Alaska, through Western Canada and the Western US with downstream roughing/negative geopotential height anomalies in Eastern Canada and the Eastern US (**Figure 8**). This is predicted to favor normal to above normal temperatures across Alaska, Western Northern Canada and the Western US with normal to above normal temperatures in Eastern Canada and the Eastern US (**Figure 9**). It is worth noting that the ECMWF is predicting a significantly milder pattern.

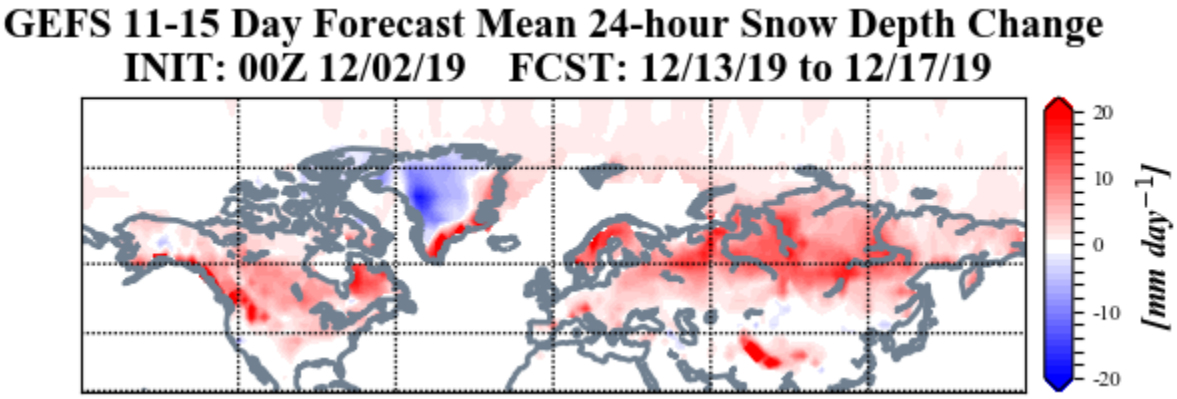

Figure 10. Forecasted snow depth changes (mm/day; shading) from 13 – 17 December 2019. The forecasts are from the 00z 2 December GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across much of Siberia, Northwestern Russia, Central Asia, Scandinavia and possibly parts of Eastern and Central Europe, Southern Alaska, much of Canada and possibly the Northern and Central US (**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, while tropospheric PCHS are predicted to turn slightly below normal (**Figure 11**). The models have been predicting a sudden stratospheric warming (SSW) for a while now and the latest GFS ensembles still predicts at least a minor but there is some disagreement among the models.

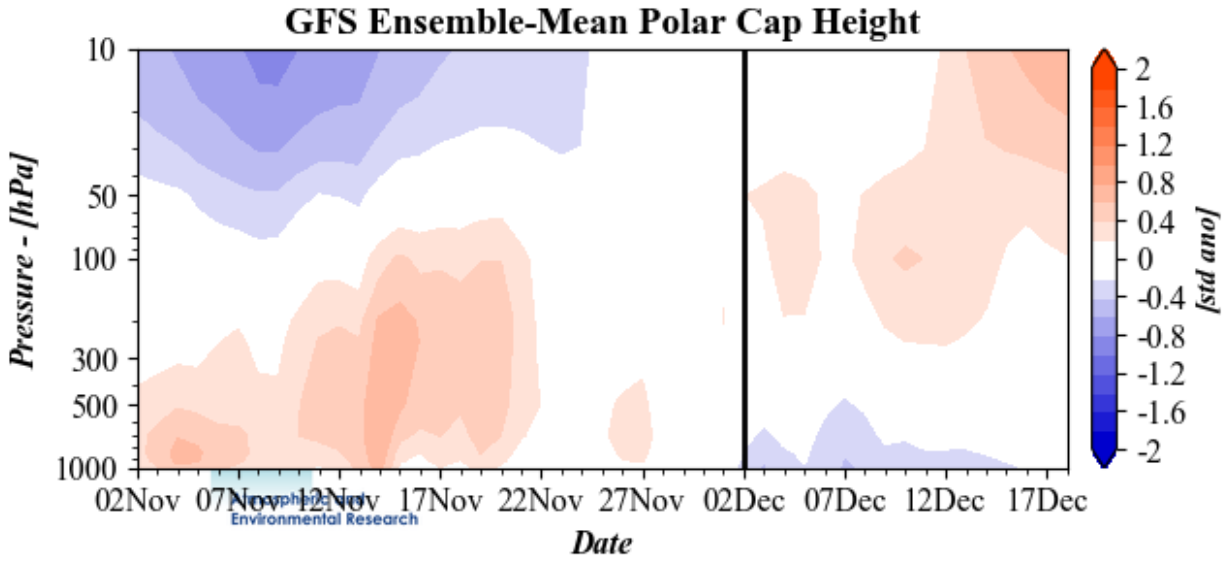

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecasts are from the 00Z 2 December 2019 GFS ensemble.

The plot of Wave Activity Flux (WAFz) or poleward heat transport shows strong negative anomalies this week followed by strong positive anomalies for the upcoming week (**Figure 12**). The predicted negative WAFz in mid-stratosphere possibly a sign of a reflective event. In the weeks leading up to the major warmings in 2018 and 2019 there was no similar strong negative WAFz anomalies. Still it is confined to the mid-stratosphere which seems unusual to me.

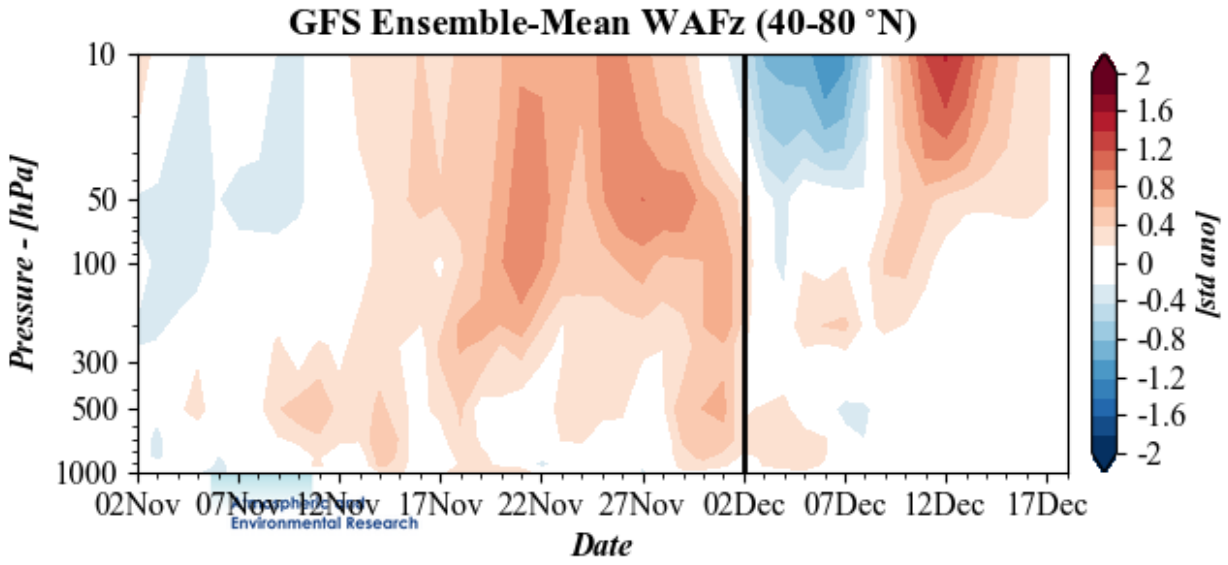

Figure 12. Observed and predicted daily vertical component of the wave activity Wux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 2 December 2019 GFS ensemble.

The stratospheric AO is currently slightly negative (**Figure 1**) reflective of a slightly perturbed PV. However, in response to the positive WAFz predicted for next week, the stratospheric AO is predicted to turn more strongly negative (**Figure 1**) but likely not enough to qualify as a major warming (reversal of the zonal mean zonal wind from westerly or positive to easterly or negative at 60°N and 10 hPa).

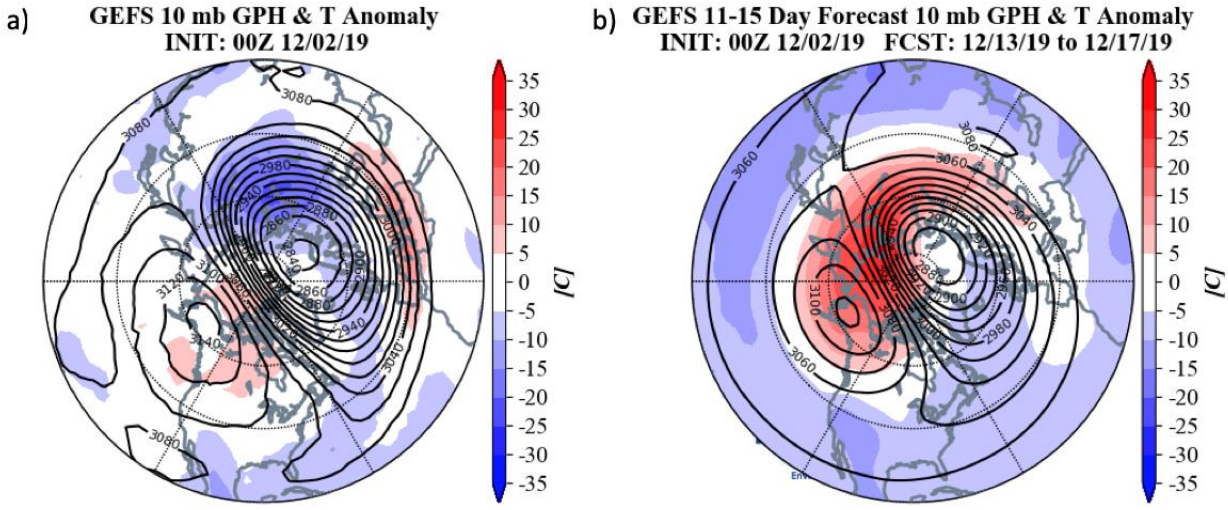

Figure 13. (**a**) Analyzed 10 mb geopotential heights (dam; contours) and temperature anomalies (°C;shading) across the Northern Hemisphere for 2 December 2019. (**b**)

Same as (a) except forecasted averaged from 6 – 10 December 2019. The forecasts are from the 00Z 2 December 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, with the flow around the PV heavily skewed towards the Eurasian sector, signs of some disruption (**Figure 13**). The counterclockwise flow around the PV center is bringing northerly flow to North Europe, supportive of the low geopotential heights and cold forecast for Scandinavia.

Currently there is warming, and a ridge centered over Alaska and Northwest Canada in the stratosphere (**Figure 13).** Over time the new WAFz pulse is predicted to amplify the warming over the North Pacific side of the Arctic and reinforce the ridging centered over Alaska (**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 Northern 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 debated by most models.

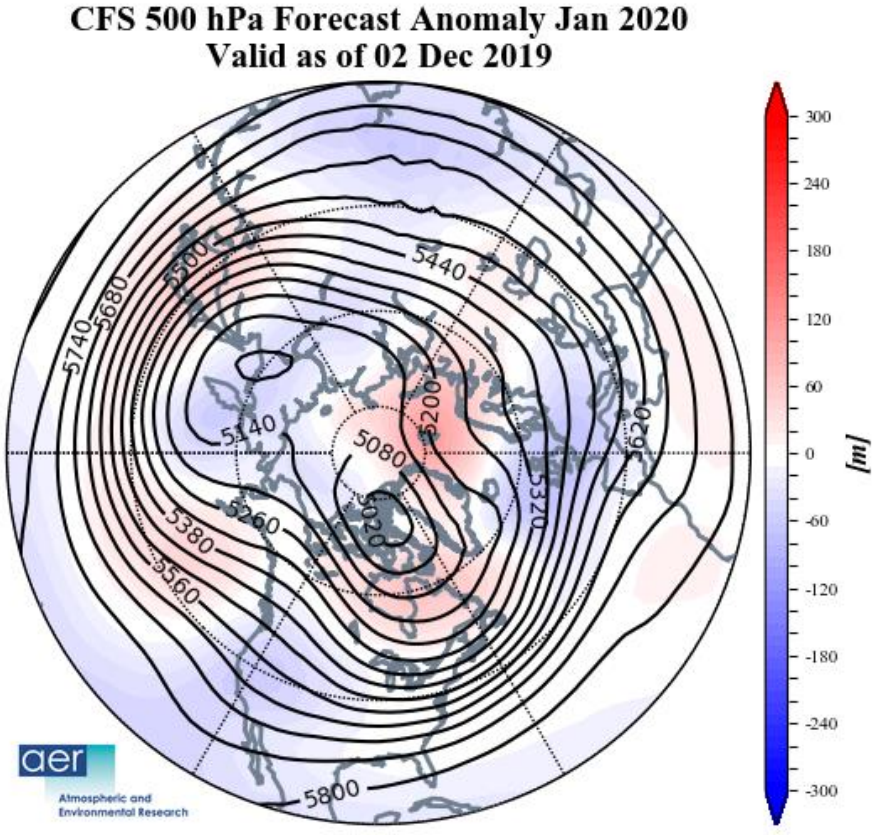

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for January 2020. The forecasts are from the 2 December 2019 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and the surface temperatures (**Figure 15**) forecast for January from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging across the Barents-Kara Seas, East Asia, the Gulf of Alaska and Western Canada with troughs over Greenland and Iceland, Western 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 forecast for January has consistently shown a circulation pattern that projects on the pattern of variability associated with a negative AO.

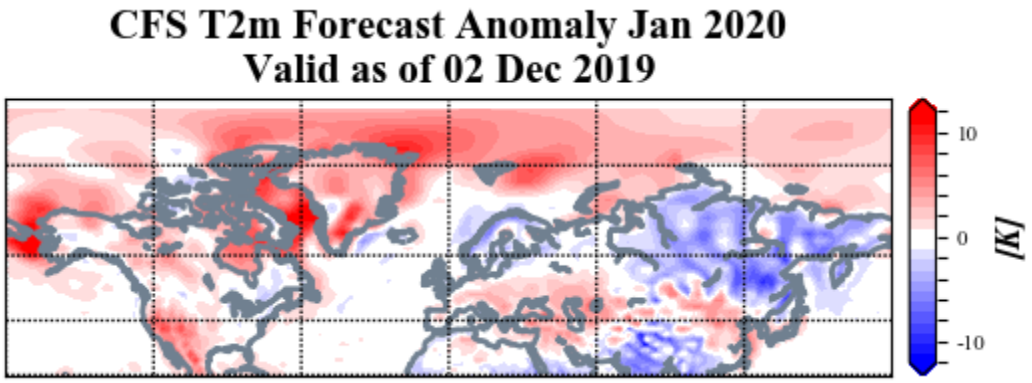

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for January 2020. The forecasts are from the 2 December 2019 CFS.

Surface Boundary Conditions

Arctic sea ice extent

Arctic sea ice growth rate continues to grow slowly and remains well below normal. Large negative sea ice anomalies exist in three regions: the Chukchi-Beaufort, west of Greenland-Candian 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.

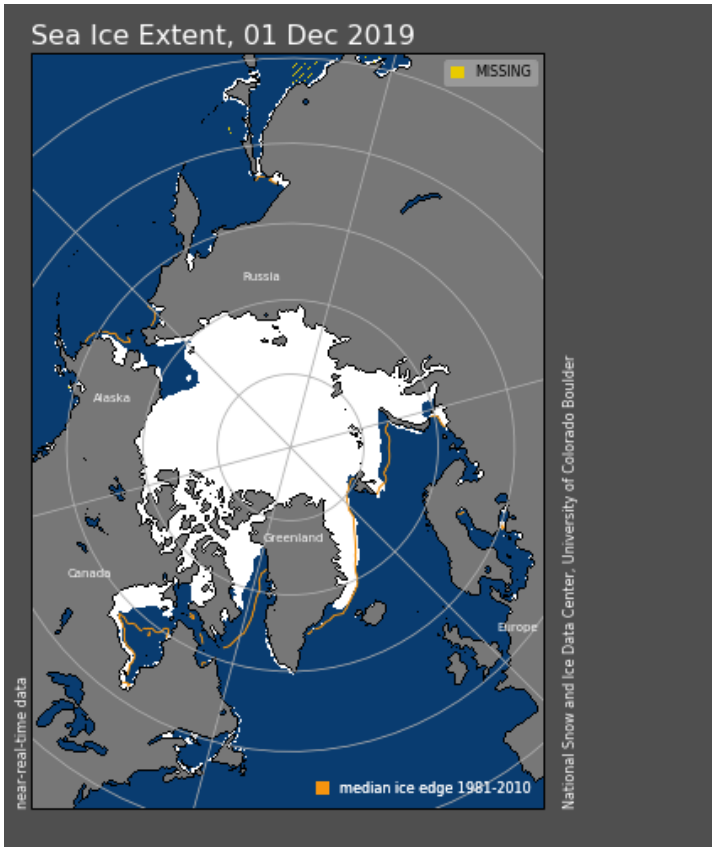

Figure 16. a) Observed Arctic sea ice extent on 1 December 2019 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010.

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 really 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).

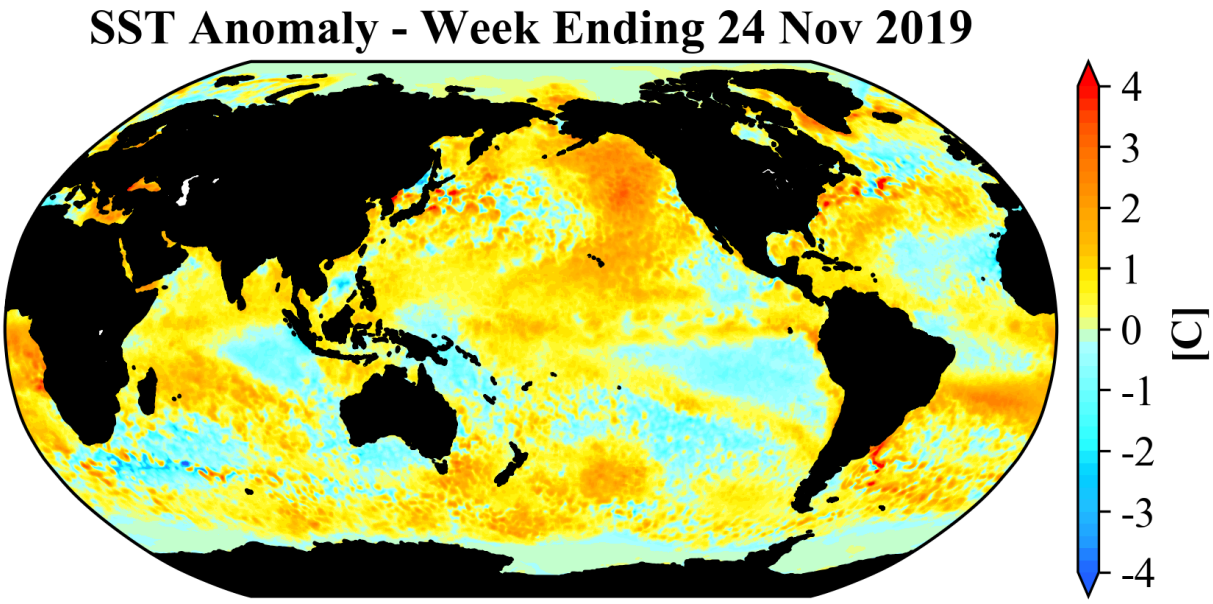

Figure 17. The latest weekly-mean global SST anomalies (ending 24 November 2019). Data from NOAA OI High-Resolution dataset. This plot has not been updated from last week.

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 and then weaken again to where no phase is favored over the next two weeks. Some MJO influence is possible across North American weather in the forecast period as phase one favors high latitude blocking and troughing in the US transitioning to ridging in the Eastern US and troughing in the Western US, which is not currently predicted.

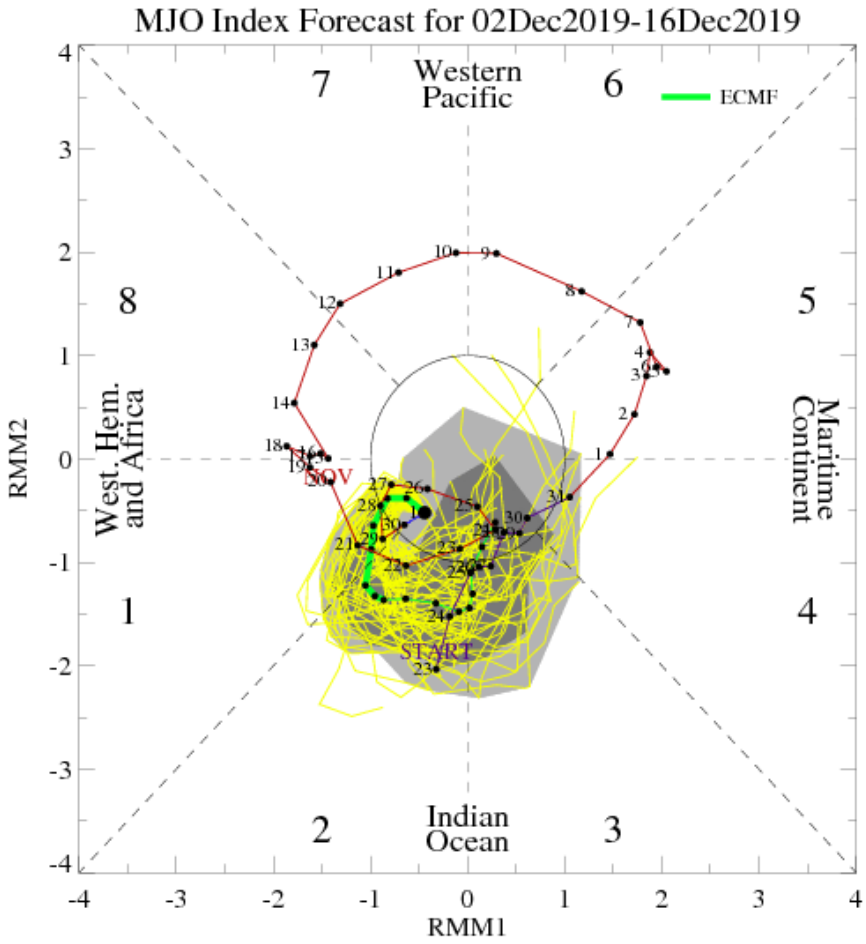

Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 2 December 2019 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model "spread" is denoted by the gray shading. Sector numbers indicate 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 Western 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.

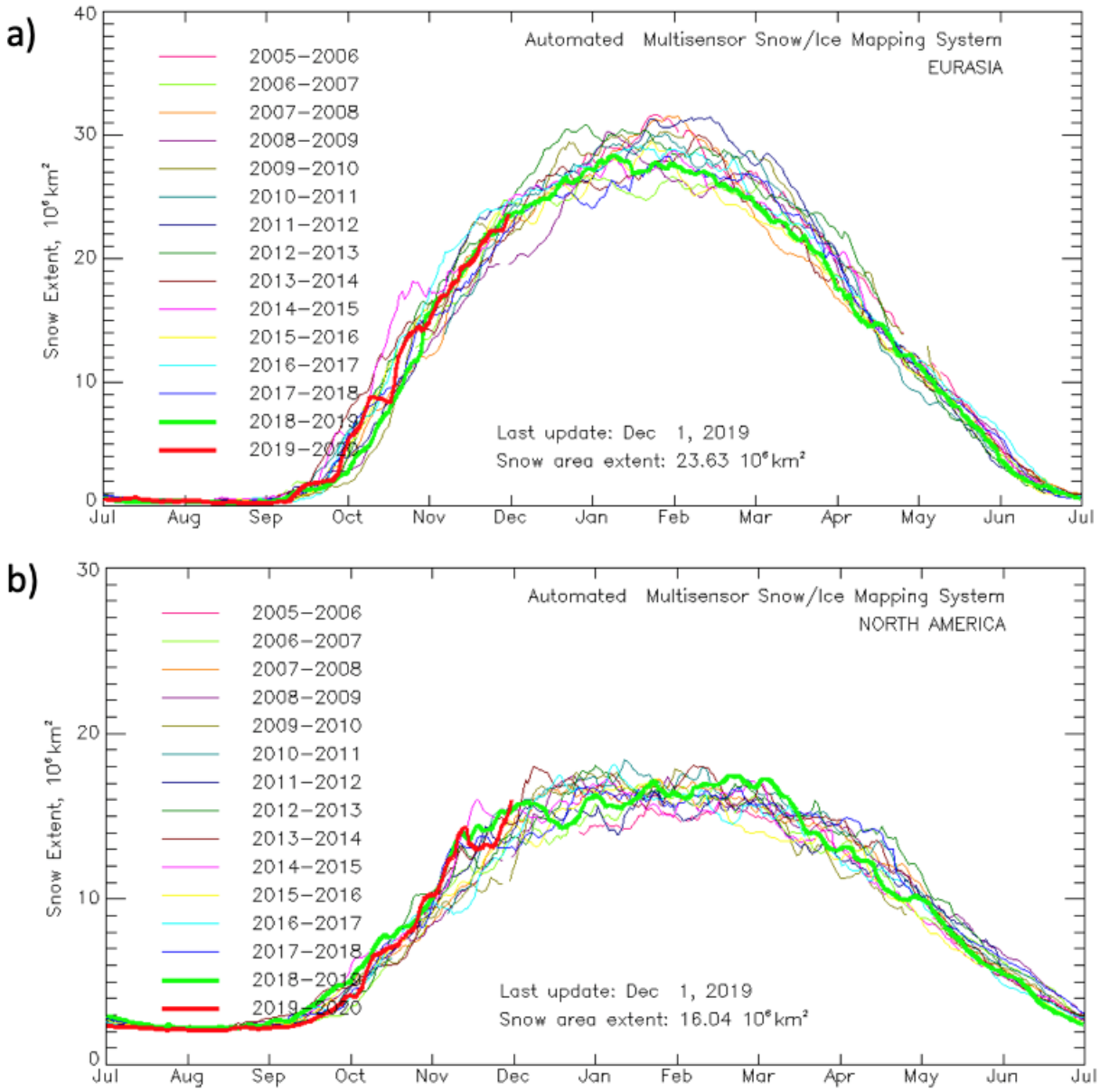

Figure 19. Observed Eurasian (top) and North American (bottom) snow cover extent through 1December 2019. Image source: https://www.star.nesdis.noaa.gov/smcd/emb/snow/HTML/snow_extent_plots.html

North American snow cover rapidy advanced this week, with the cold, coast to coast snowstorm, and extent is now at a decadal high. 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.