Arctic Oscillation and Polar Vortex Analysis and Forecasts

January 11, 2021

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

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

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

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

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

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

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

Summary

- The Arctic Oscillation (AO) is currently negative and is predicted to remain negative the next two weeks as pressure/geopotential height anomalies are predicted to remain positive across the North Atlantic side of the Arctic the next two weeks.

- The current negative AO is reflective of positive pressure/geopotential height anomalies across the North Atlantic side of the Arctic with mixed pressure/geopotential height anomalies across the mid-latitudes. The North Atlantic Oscillation (NAO) is currently negative with positive pressure/geopotential height anomalies across Greenland and Iceland; and the NAO is predicted to remain negative the next two weeks as pressure/geopotential height anomalies are predicted to remain positive across Greenland.
- For the next two weeks ridging/positive geopotential height anomalies near Greenland will anchor troughing/negative geopotential height anomalies across Europe coupled with normal to below normal temperatures for much of Europe but especially Northern Europe including the United Kingdom (UK). In addition, the atmosphere is becoming stacked (the stratosphere and troposphere are aligned) so that the main center of the stratospheric polar vortex (PV) between the Urals and Scandinavia will help to anchor a strong negative height center in the mid-troposphere in the same region below.
- Over the next two weeks persistent troughing/negative geopotential height anomalies across Northern Asia in the stratosphere will help to maintain similar troughing/negative geopotential height anomalies in the mid-troposphere with ridging/positive geopotential height anomalies to the south. This pattern favors normal to below normal temperatures across Northern Asia, including much of Siberia, with normal to above normal temperatures across Southern Asia.
- Similarly, across North America the atmosphere is becoming increasingly stacked so that ridging/positive geopotential height anomalies across Alaska and Northern Canada with troughing/negative geopotential height anomalies across the United States (US) will nudge the mid-troposphere into a similar pattern favoring the building of Arctic high pressure at the surface. So though currently widespread normal to above normal temperatures exist across much of Canada and the US, temperatures are predicted to turn colder across both Canada and the US over the next two weeks.
- In the Impacts section I discuss the possible influence from the ongoing significant polar vortex (PV) disruption on the weather across the Northern Hemisphere (NH).

Impacts

We are just days away from completing the sixth step of the six steps I presented in the December 14, 2020 blog. The fifth step is the real or apparent downward circulation anomalies associated with a significant weakening of the PV and a major mid-winter warming (MMW where the zonal winds reverse from westerly to easterly at 60°N and 10 hPa) from the stratosphere to the troposphere as seen in the polar cap geopotential height anomalies (PCHs; see **Figure 11**). The PCHs are already positive/warm near the surface but this downward propagation, which is also referred to as “dripping,” will amplify or enhance the positive/warm tropospheric PCHs and force the AO to dip

deeper into negative territory completing step six. As I discussed in last week's blog when the tropospheric PCHs spike is when severe winter weather is most likely across the NH mid-latitudes. For this upcoming "drip" the severe winter weather associated with the increase in positive tropospheric PCHs is predicted to be a turn to much colder weather across Europe. Based on **Figure 11** this may already be the second drip with a previous drip the end of last week that is associated with the historic snowstorm across Spain including its capital of Madrid.

The sudden stratospheric warming itself is complex with multiple acts. First the stratospheric PV split into two as shown in last week's blog then it coalesced into one PV center and now it is predicted to split again this week (see **Figure 13**). And there could be more perturbation to the PV even after that but there seems to be lots of model uncertainty after this week's second split. This, I believe complicates the timing and nature of the coupling between the stratosphere and troposphere and confuses the forecaster and the numerical weather prediction models alike. For one thing, will the stratosphere couple to troposphere more akin to a PV displacement or a PV split? Though to first order, I showed in the December 28, 2020 blog, that based on recent research there are not big differences in the resultant temperature pattern on the timescale of a month or so (i.e., they both project onto the negative AO temperature pattern) though I have argued based on recent events there are some important regional differences.

I am sure all of you remember that leading up to the last MMW back in January 2019 that I argued possible differences between PV displacements and splits (unfortunately this was just before the AO/PV blog was archived). On December 24, 2018 I argued based on recent splits updated in **Figures I** and **ii,** which are all the PV splits since 2000 (including some not on other's lists of PV splits, e.g., https://csl.noaa.gov/groups/csl8/sswcompendium/) that PV splits favor cold across Northern Eurasia including Europe, especially if the daughter vortex in Eurasia is "land locked" as is occurring with the current event with easterly flow across Northern Eurasia (see **Figure 13**). In **Figure i,** I show 10 hPa geopotential heights for all the PV splits since 2000 close to the time when the winds turned easterly at 60°N and 10hPa (the exception being 2015 when the SSW did not achieve MMW status). In **Figure ii**, I show the temperature anomalies following the PV split. I have also argued that PV splits favor heavier snowfall than PV displacements simply based on what I remember from past events.

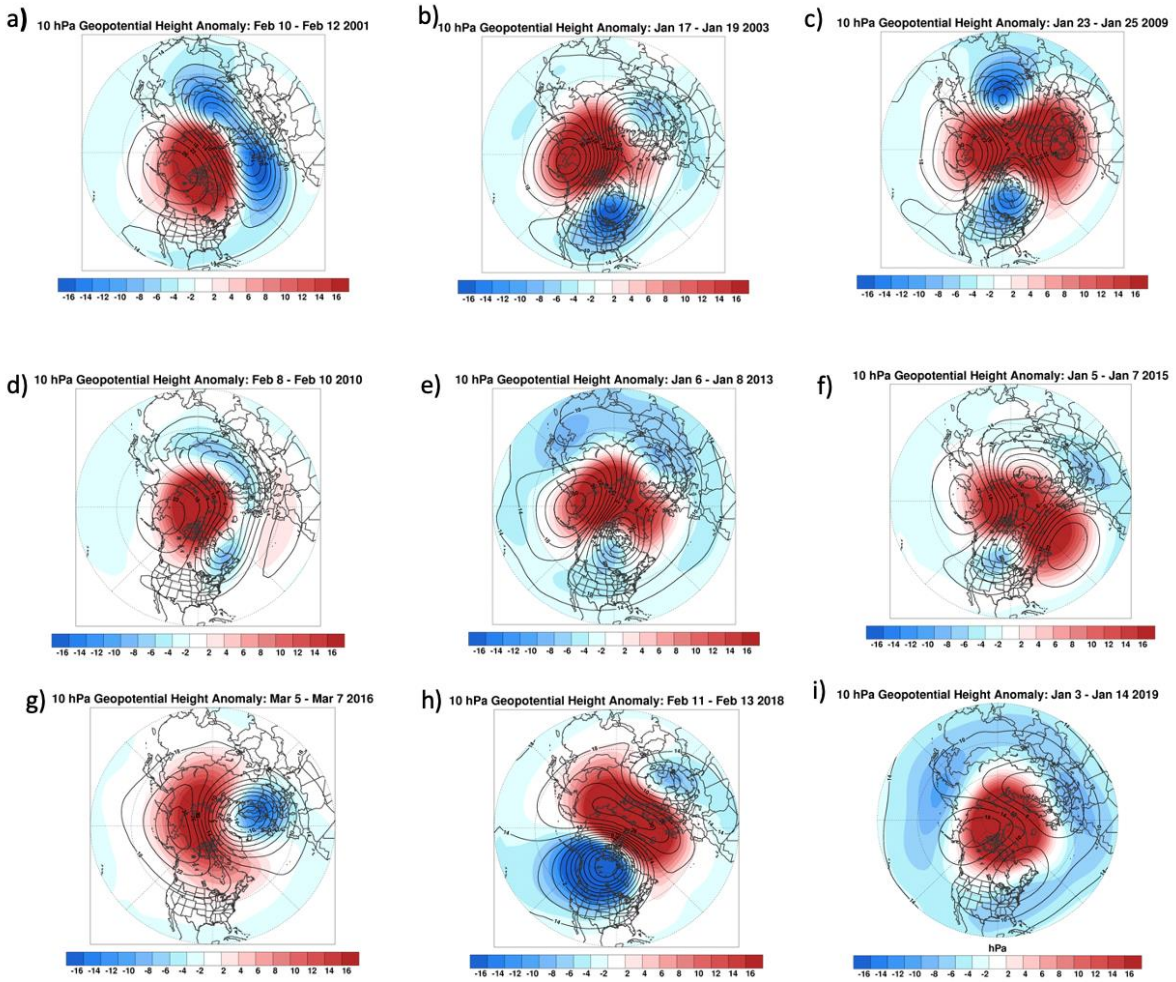


Figure i. Observed geopotential heights (contouring) and anomalies (shading) for a) February 10-12, 2001 b) January 17-19, 2003 c) January 23-25, 2009 d) February 8-10, 2010, e) January 6-8, 2013 f) January 5-7, 2015, g) March 5-7, 2016 and h) February 11-13, 2018 and i) January 3-14, 2019.

In contrast PV displacements favor colder temperatures across eastern North America and less so across Eurasia. So, for Europe there is a more robust cold signal for PV splits and for eastern North America there is a more robust signal for PV displacements. However even for PV splits there may be a delay, more often than not the cold seems to make it to eastern North America eventually. So, in summary PV splits bring cold and snow to Europe and snow but more moderate or modified cold weather to eastern North America. This formed the basis of my summary of PV disruptions in Table 1 of the December 7, 2020 blog (see middle row).

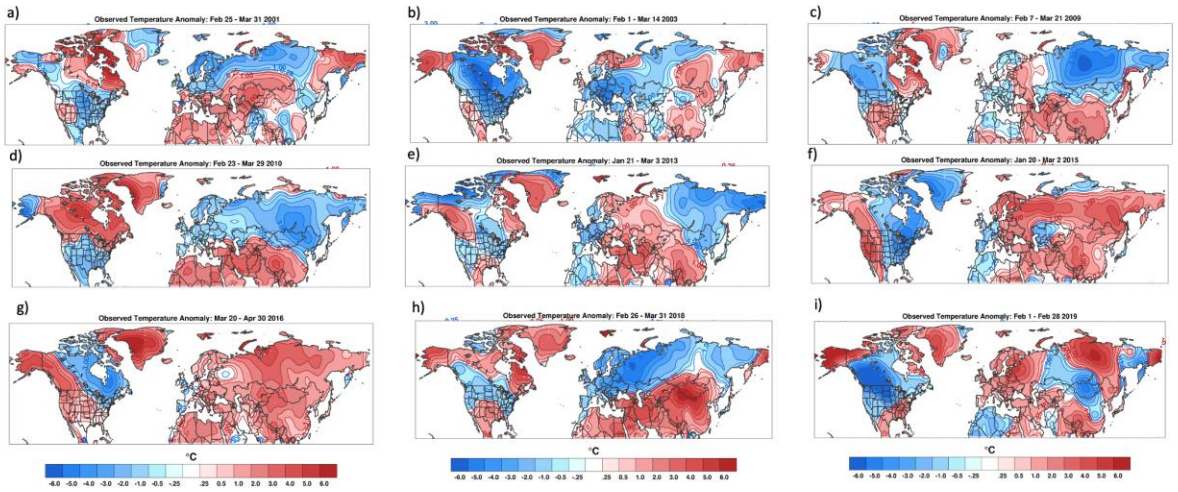


Figure ii. Observed surface temperature anomalies (shading) for a) February 25-March 31, 2001 b) February 1-March 14, 2003 c) February 7-March 21, 2009 d) February 23-March 29, 2010, e) January 21-March 3, 2013 f) January 20-March 2, 2015, g) March 20-April 30, 2016, h) February 26-March 31, 2018 and i) February 1- 28, 2009.

What I argued back in December 2018 and just a month ago was not based on research but my own analysis of recent events. However, a paper was just published that supports at least one idea – PV splits favor cold for Europe relative to PV displacements. In **Figure iii,** I present part of Figure 10 from Hall et al. 2020. This analysis does not support my other idea that PV displacements favor cold in eastern North America. The publication of this paper is very timely.

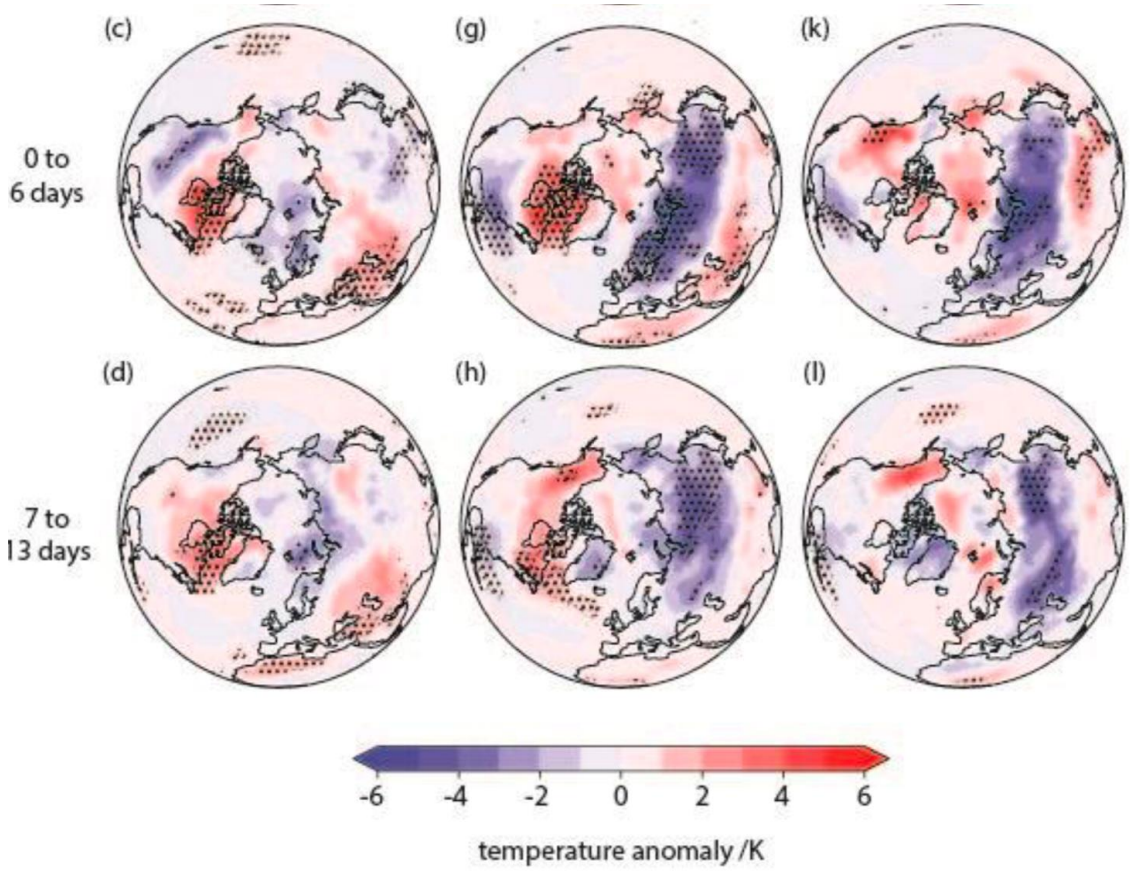


Figure iii.

Figure iii. Surface temperature anomalies over the northern hemisphere for displacement, split and split minus displacement events, for 7-day averaged periods after the surface impact date. Stippling shows area of significance (P<0.05). Figure copied from Hall et al. (2020).

Yet despite the complexity of the ongoing troposphere-stratosphere-troposphere coupling event, in a lot of ways it is nearly textbook and is following what I described in **Table 1** from December 7, 2020. Since the Table is so nicely summarizing what we have observed so far, I decided to include it here again. Leading up to the PV disruption, it has been mild in the Eastern US and Europe with severe winter weather focused in East Asia (e.g., record cold Beijing). Now during the disruption, the cold is shifting towards Northern Eurasia and will be entrenched across Europe within two weeks of the beginning of the event. The only impact missing is cold weather for the US. But if you believe the GFS forecast (see **Figure 9**) the cold will arrive in the US soon thereafter.

Table 1. Expected weather during and after three different vertical energy transfer scenarios described in the December 7, 2020 blog. But for today's blog the middle row is most relevant.

Vertical atmospheric energy transfer type	Weather during energy transfer	Duration of induced weather	Main impact on weather during PV disruption	Weather 2-4 weeks after PV disruption
reflective	N/A	days	Cold eastern North America/Central Asia	N/A
Absorptive polar region	Mild Eastern US/Europe & cold East Asia/western North America	2-4 weeks	Cold northern Eurasia can also cause cold in western North America	Consistent with negative AO, displacement favors cold eastern North America while split favors cold in Europe and/or US
Absorptive equatorial region then transitioning to absorptive polar region	Mild for entire Northern Hemisphere transitioning to Mild Eastern US/Europe & cold East Asia/western North America	4-6 weeks (or possibly more if it does not culminate in large PV disruption)	Cold northern Eurasia can also cause cold in western North America	Consistent with negative AO, displacement favors cold eastern North America while split favors cold in Europe and/or US

Baldwin and Dunkerton 1999 were the first to show the "dripping" effect of the circulation anomalies from the stratosphere to the troposphere, episodically up to 80 days using the AO index. I have shown the same thing with the PCHs, I prefer using the PCHs since it both captures the Ural blocking that is the tropospheric precursor to the PV disruption and the Greenland blocking that follows the PV disruption. Of the recent PV splits I am expecting this current PV disruption to follow a script closest to 2002/03, 2012/13 and 2017/18. I did bring up 2009/10 to be provocative and I still there could be some similarities to that event. Of those four events the most recent two were during neutral to cold ENSO winters. As I discussed in last week's blog with each drip of PCHs from the stratosphere to the troposphere enhances the risk of severe winter weather across the NH mid-latitudes. In **Figure iv**, I show the PCHs for the entire cold season of 2012/13 and the notable severe winter weather events associated with each spike in troposphere PCHs (figure shown in Cohen et al. 2013).

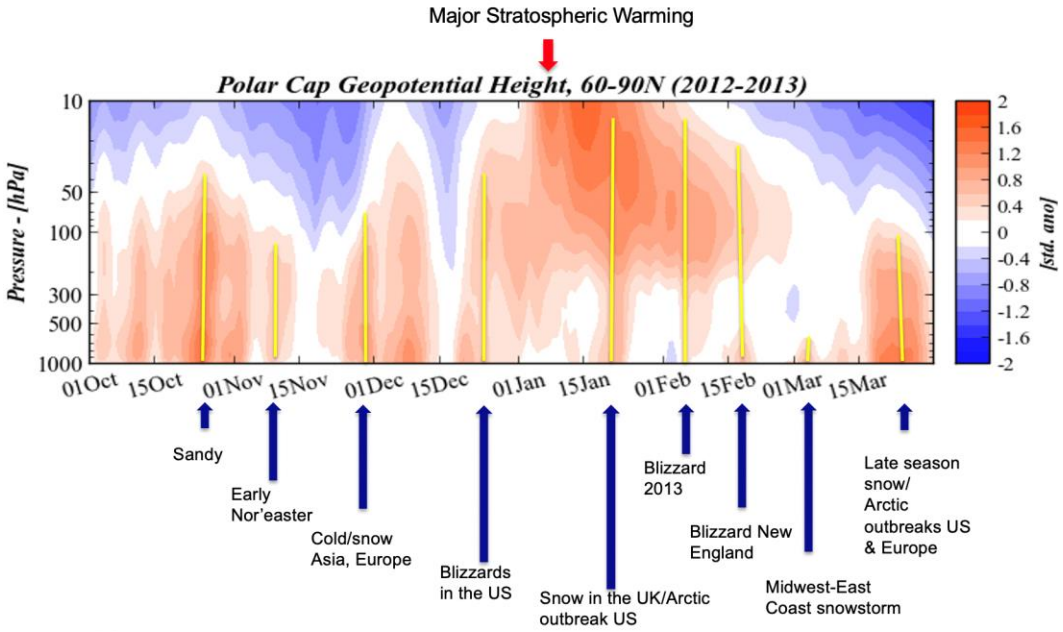


Figure iv. Observed daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies from October 1, 2012 - March 31, 2013. Blue arrows indicate severe winter weather events across the NH. Red arrow indicates major stratospheric warming.

In **Figure v**, I show a similar plot for winter 2017/18. The timing of the MMW is closer to 2012/13 than 2017/18 but in both the severe winter weather arrived in Europe and the Western US first, but eventually made its way to the Eastern US, but it can take time. In **Figure vi**, I show the PCHs from November 1, through January to provide some context of where we are in the cycle if these events provide applicable information for this winter.

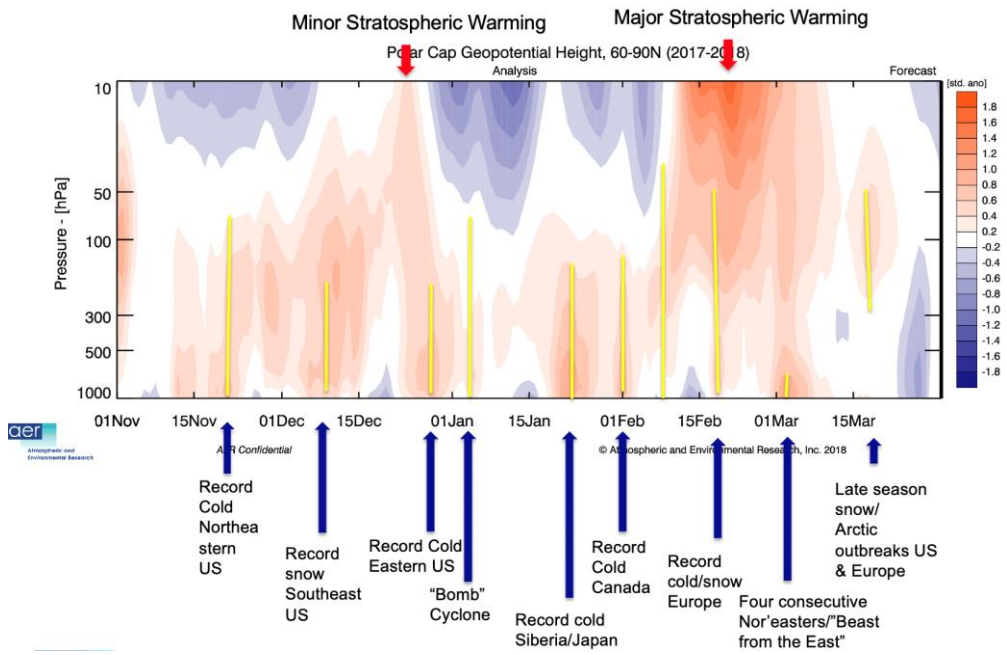


Figure v. Observed daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies from October 1, 2017 - March 31, 2018. Blue arrows indicate severe winter weather events across the NH.Red arrows indicate minor and major stratospheric warmings.

I think winter 2002/03 as an analog is on the cold extreme of the possible distribution for this winter and I believe 2012/13 is probably a better analog. As you can see from **Figure ii**, it was cold In the Eastern US eventually, the overall winter months December 2012 -February 2013 still averaged above normal in the Eastern US (**Figure vii**).

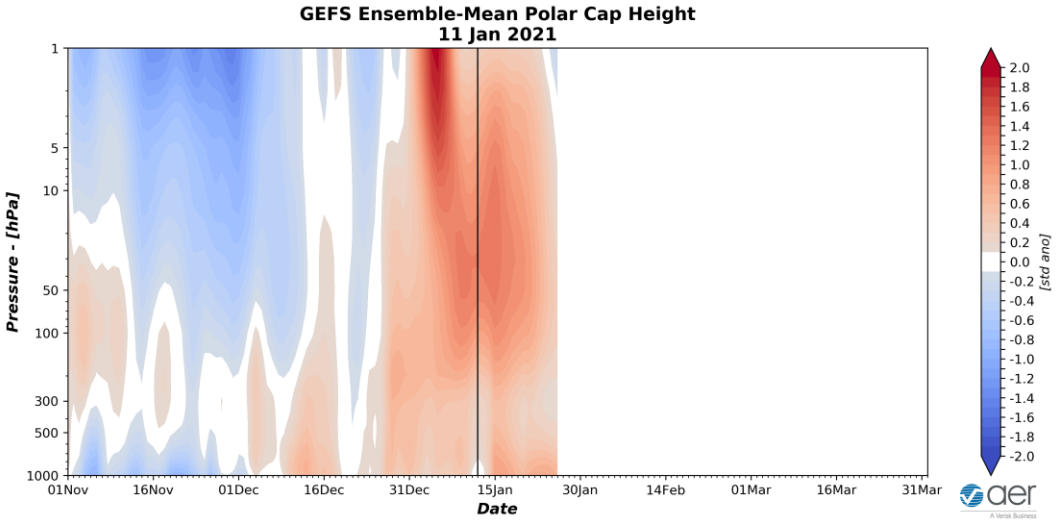
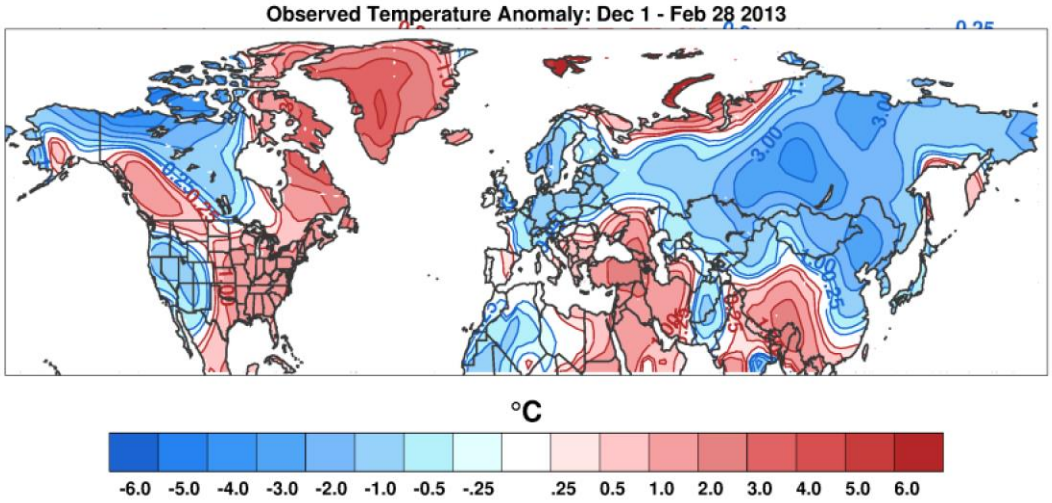


Figure vi. Observed from November 1, 2020 and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 4 January 2021 GFS ensemble. Please note that this PCH plot extends to 1 hPa and not 10hPa.

The models are suggesting the cold starts east of the Rockies in the US forced by strong ridging in the Gulf of Alaska but then the weather models predict that the pattern starts to retrograde/drift west and the ridging by the end of the month is near the Aleutians, which would clearly keep the core of the cold air in western North America in a canonical La Niña type pattern. This pattern is also consistent with the current Madden-Julian Oscillation (MJO) phase three (though it is predicted to be very weak; see **Figure 18**). PV splits seem to favor a barotropic atmosphere where systems are stacked vertically. Across Eurasia the lowest geopotential heights in the troposphere are predicted to lie directly underneath the lowest geopotential heights in the stratosphere. I would expect something similar across North America. The lowest heights in the stratosphere are in eastern North America coupled with northerly flow. Translate that to the troposphere and that should favor the coldest weather in eastern North America. Using the stratosphere to predict the temperature pattern across North America, suggests to me the coldest temperatures will be in eastern North America. So, I am skeptical of the model forecasts, which seems to contradict what I see in the stratosphere. However, low heights stretch across much of the US by week two and I can see this favoring the lowest heights in the Western US as predicted by the models. Still the troughing would extend eastward into the Eastern US suppressed by Greenland blocking a la winter 2010/11 – a La Niña winter but not one with an MMW.



.**Figure vii**. Observed surface temperature anomalies °C; shading) December 1. 2012 through February 28, 2013.

In conclusion, first I am skeptical of models forecasts beyond a week, I expect the models to struggle. Second even if the cold air settles in western North America for a period, as winter progresses, I expect the cold air to come east with time not unlike 2012/13 and 2017/18. Most of the time you expect the cavalry to show up and it does but not always. And two winters in **Figures i** and **ii** when I waited, and waited for the cavalry to show up (aka the cold air) but it never did are winters 2005/06 and to a lesser extent 2018/19 (see winter-2019-recap). I am not expecting a repeat of those winters, but it is certainly possible. On the upside, it would improve the AER winter forecast for North America.

1-5 day

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

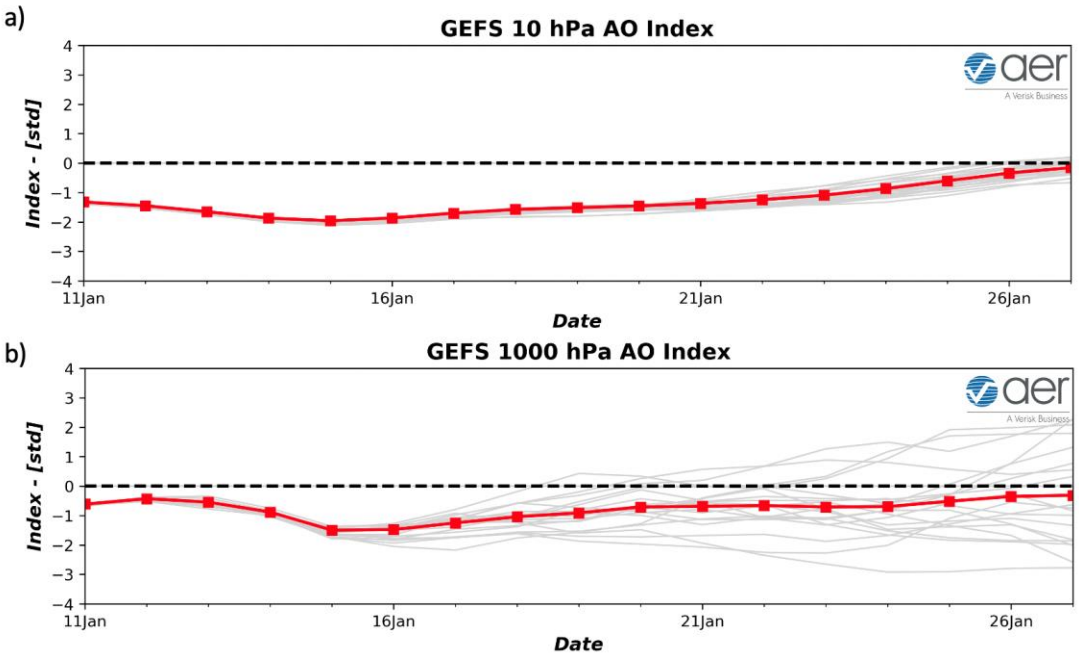


Figure 1. (**a**) The predicted daily-mean AO at 10 hPa from the 00Z 11 January 2021 GFS ensemble. (**b**)The predicted daily-mean near-surface AO from the 00Z 11 January 2021 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

This week, ridging/positive geopotential height anomalies centered south of Greenland are predicted to force downstream troughing/negative geopotential height anomalies

across Europe (**Figure 2**). In addition, the atmosphere is becoming increasingly barotropic (the atmosphere is becoming stacked or vertically aligned) so that the location of the main center of the stratospheric PV between the Urals and Scandinavia is contributing to a mid-tropospheric troughing/negative geopotential height anomaly center in the same location. This pattern favors normal to below normal temperatures across much of Europe including the UK while a mild southwesterly flow will favor normal to above normal temperatures across Southeastern Europe (**Figure 3**). This week, troughing/negative geopotential height anomalies across much of Northern Asia in the stratosphere will help to develop troughing/negative geopotential height anomalies across much of Northern Asia in the mid-troposphere with ridging/positive geopotential height anomalies across Southern Asia (**Figure 2**). This pattern favors normal to below normal temperatures for much of Northern Asia with normal to above normal temperatures for Southern Asia **(Figure 3**).

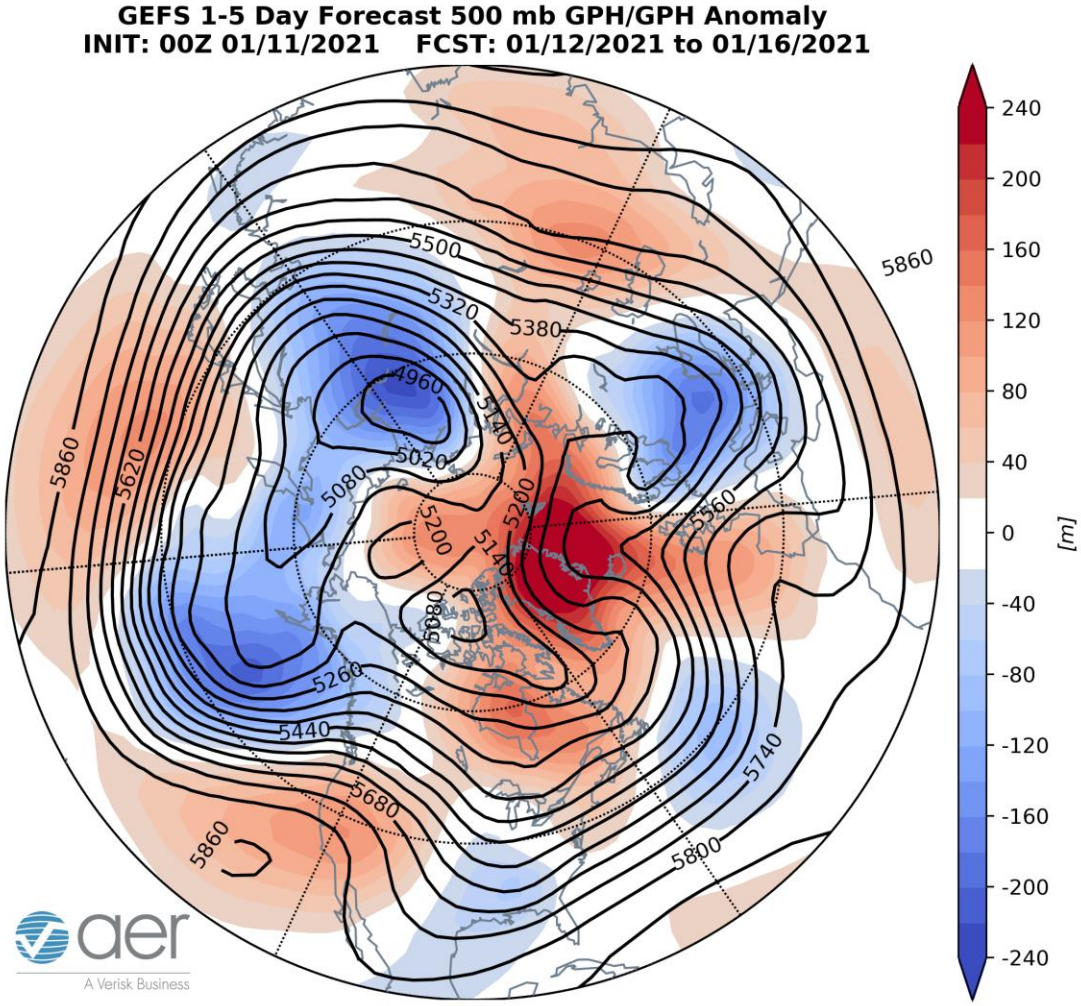


Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 12 – 16 January 2021. The forecasts are from the 00z 11 January 2021 GFS ensemble.

This week troughing/negative geopotential height anomalies across Alaska and the Gulf of Alaska will force downstream ridging/positive geopotential height anomalies across most of Canada with more troughing/negative geopotential height anomalies in the Southeastern US **(Figure 2).** This pattern is predicted to bring widespread normal to above normal temperatures across much of Canada and the Northern and Western US with normal to below normal temperatures for Northern Alaska and the Southeastern US **(Figure 3).**

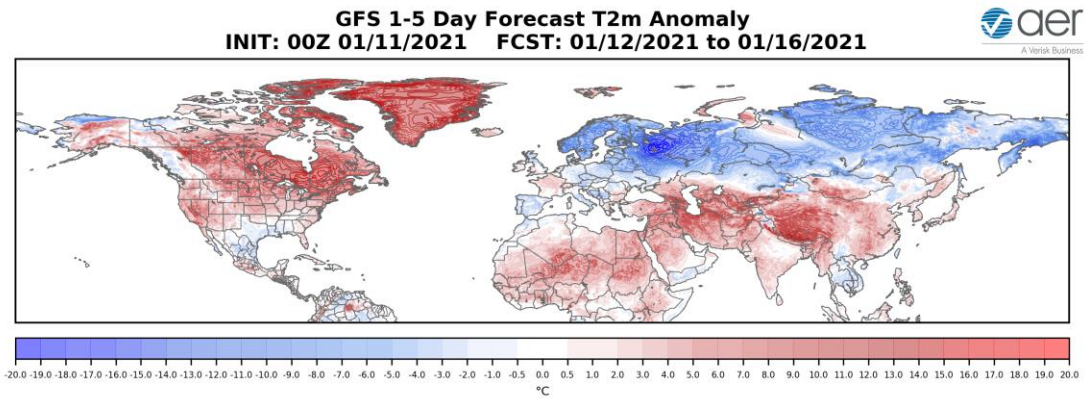


Figure 3. Forecasted surface temperature anomalies (°C; shading) from 12 – 16 January 2021. The forecast is from the 00Z 11 January 2021 GFS ensemble.

Troughing and/or colder temperatures are predicted to support new snowfall across the Alps, Central, Eastern and Northern Europe, Turkey and Northern and East Asia while warmer temperatures will cause regional snow melt in Spain, Southern Asia and Japan (**Figure 4**). Troughing and/or colder temperatures are predicted to support new snowfall across parts of Alaska, and Canada while warmer temperatures will cause snow melt in parts of Southern Canada and the US (**Figure 4**).

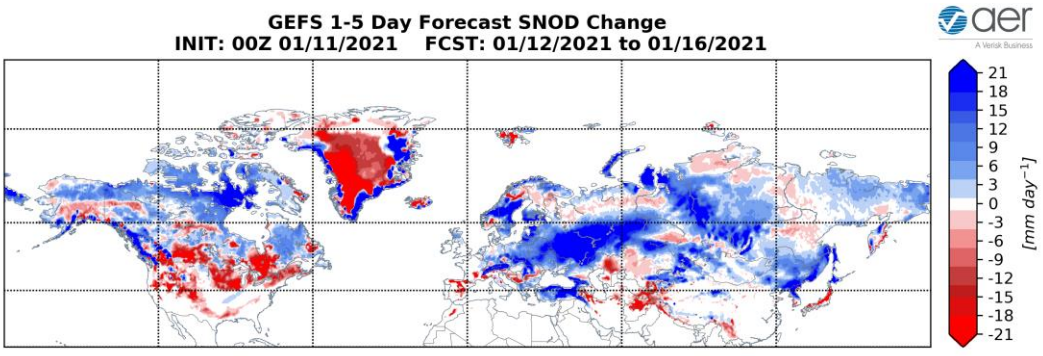


Figure 4. Forecasted snow depth changes (mm/day; shading) from 12 – 16 January 2021. The forecast is from the 00Z 11 January 2021 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to remain negative next week **(Figure 1**) as positive geopotential height anomalies persist across the North Atlantic side of the Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 5**). And with positive geopotential height anomalies predicted across Greenland (**Figure 5**), the NAO is predicted to also remain negative.

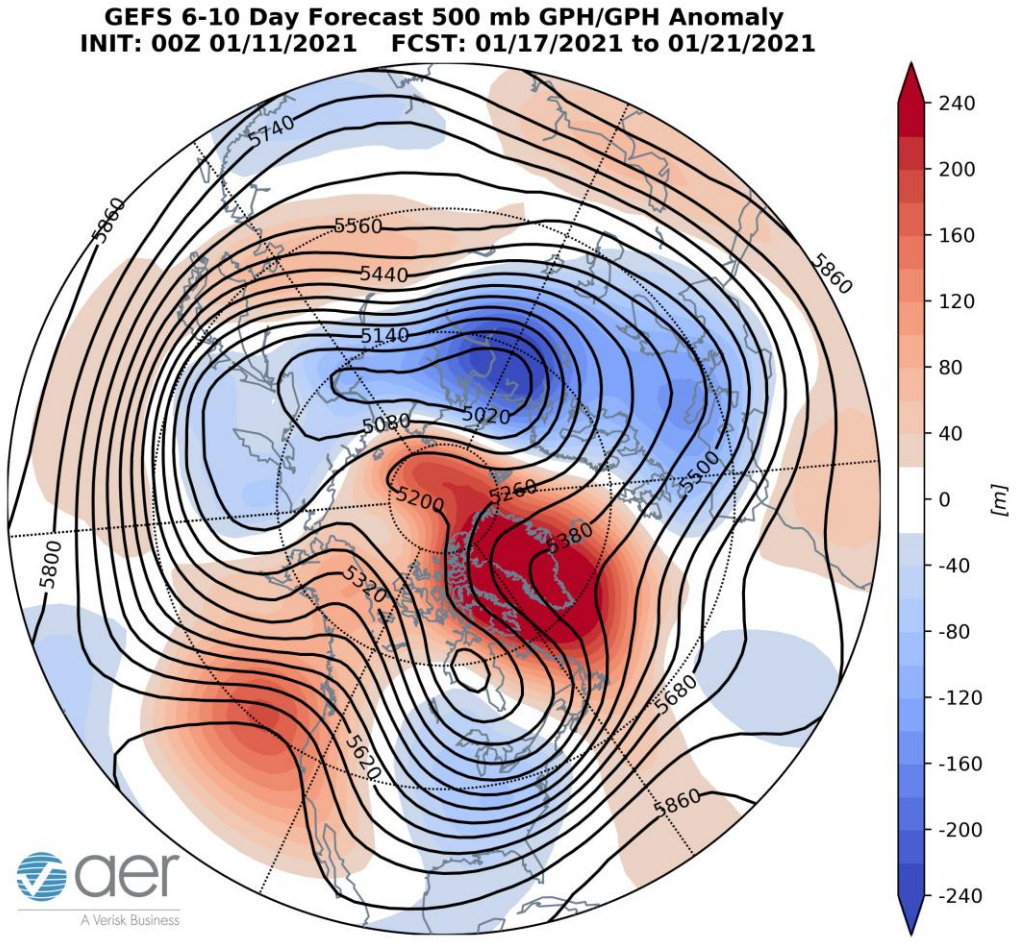


Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 17 – 21 January 2021. The forecasts are from the 00z 11 January 2021 GFS ensemble.

Ridging/positive geopotential height anomalies centered across Greenland with a stratospheric PV center in between the Urals and Scandinavia are predicted to anchor troughing/negative geopotential height anomalies across Europe this period (**Figures 5). This pattern favors** normal to below normal temperatures across most of Europe including the UK (**Figure 6**). Persistent troughing/negative geopotential height anomalies across Northern Asia in the stratosphere will help persist troughing/negative

geopotential height anomalies in the mid-troposphere across Northern Asia with ridging/positive geopotential height anomalies across the Southern Asia this period (**Figure 5**). This is predicted to favor widespread normal to below normal temperatures across much of Northern Asia with normal to above normal temperatures Central and Southern Asia **(Figure 6**).

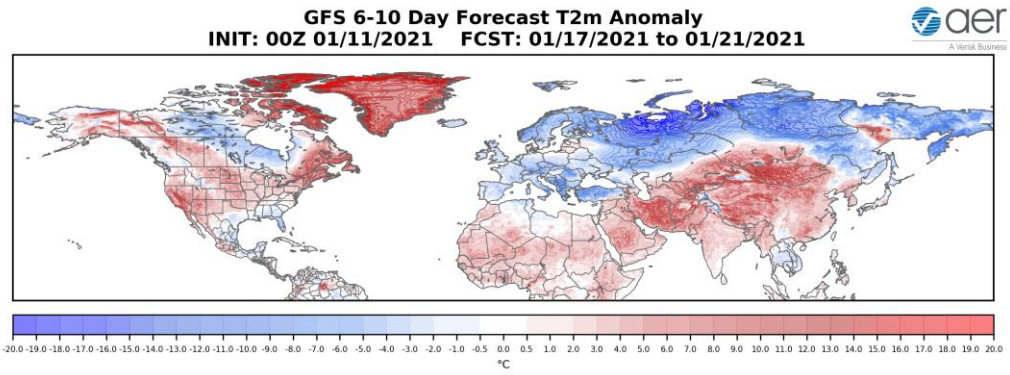


Figure 6. Forecasted surface temperature anomalies (°C; shading) from 17 – 21 January. The forecasts are from the 00Z 11 January 2021 GFS ensemble.

Ridging/positive geopotential height anomalies across Alaska and Northern Canada with deepening troughing/negative geopotential height anomalies across the US in the stratosphere will contribute to developing a similar pattern in the mid-troposphere this period **(Figure 5).** This pattern is predicted to bring normal to above normal temperatures across Alaska, much of Canada and the US with normal to below normal temperatures across Southeastern US and increasingly in developing northerly flow in Central Canada **(Figure 6).**

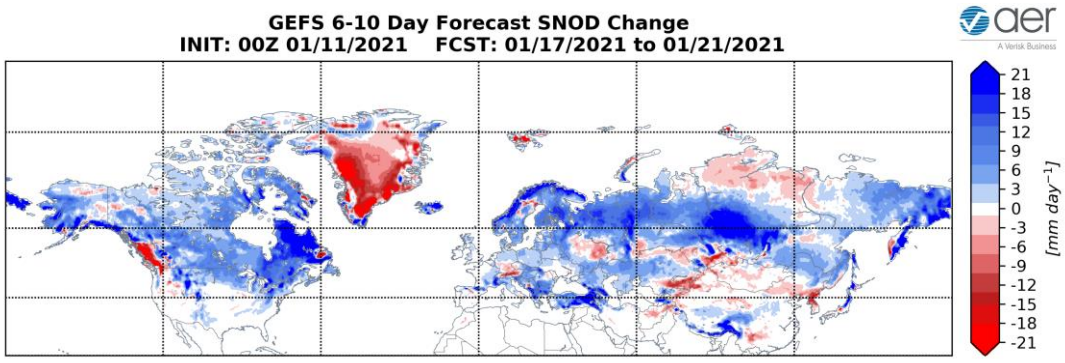


Figure 7. Forecasted snow depth changes (mm/day; shading) from 17 – 21 January. The forecasts are from the 00Z 11 January 2021 GFS ensemble.

Troughing and/or colder temperatures are predicted to potentially support new snowfall across the Pyrenees, the Alps, Turkey, large areas of Central and Eastern Europe,

Northern and Central Asia including Japan while warmer temperatures will cause regionalized snow melt in Central Asia (**Figure 7**). Troughing and/or colder temperatures are predicted to support new snowfall across much of Alaska, Canada and the Northern and Eastern US while warmer temperatures will cause possible snow melt in the Pacific Northwest (**Figure 7**).

11-15 day

As geopotential height anomalies are predicted to remain positive on the North Atlantic side of the Arctic and into the Central Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 8**), the AO should remain negative this period (**Figure 1**). With continued positive pressure/geopotential height anomalies spread across Greenland (**Figure 8**), the NAO is predicted to remain negative this period as well.

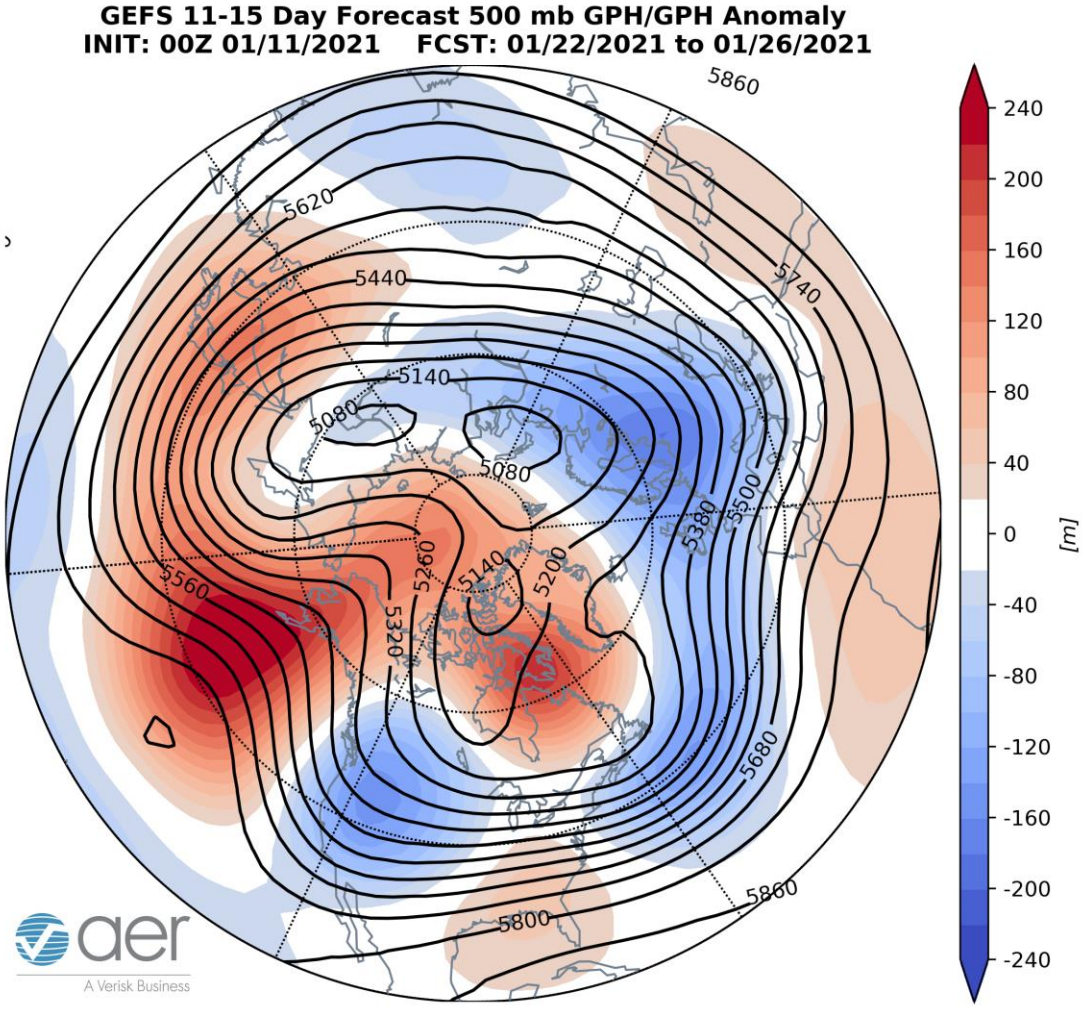


Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 22 – 26 January 2021. The forecasts are from the 00z 11 January 2021 GFS ensemble.

Persistent ridging/positive geopotential height anomalies centered across Greenland with a stratospheric PV center in between the Urals and Scandinavia are predicted to continue to anchor troughing/negative geopotential height anomalies across Europe this period (**Figures 8**). The forecast is for a more widespread normal to below normal temperatures across Europe including the UK with only regional normal to above normal temperatures in Southeastern Europe (**Figures 9**). Similarly, persistent troughing/negative geopotential height anomalies across Northern Asia in the stratosphere will help persist troughing/negative geopotential height anomalies in the mid-troposphere across Northern Asia with ridging/positive geopotential height anomalies across Southern Asia this period (**Figure 8**). This pattern favors normal to below normal temperatures across the northern third of Asia with normal to above normal temperatures across much of the southern two thirds of Asia (**Figure 9**).

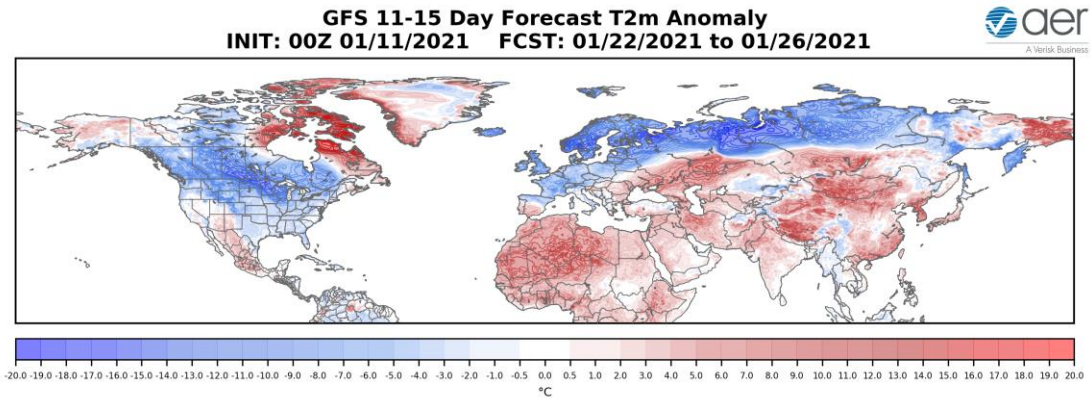


Figure 9. Forecasted surface temperature anomalies (°C; shading) from 22 – 26 January 2021. The forecasts are from the 00z 11 January 2021 GFS ensemble.

Ridging/positive geopotential height anomalies across Alaska and Northern Canada with deepening troughing/negative geopotential height anomalies across the US in the stratosphere will continue to nudge a similar pattern in the mid-troposphere across North America this period (**Figure 8**). This pattern favors widespread normal to below normal temperatures for much of Canada and the US with normal to above normal temperatures for Alaska, Northwest Canada and the Southwestern US (**Figure 9**).

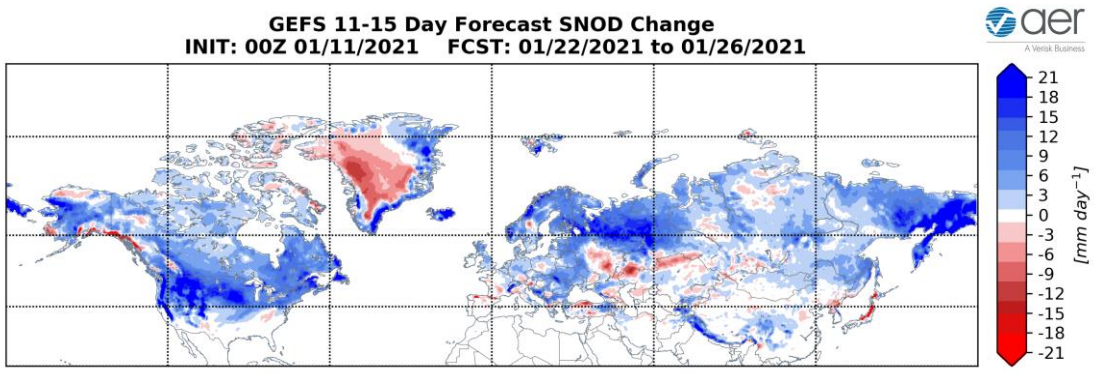


Figure 10. Forecasted snow depth changes (mm/day; shading) from 22 – 26 January 2021. The forecasts are from the 00z 11 January 2021 GFS ensemble.

Troughing and/or colder temperatures are predicted to support new snowfall across much of Europe and Northern Asia while warmer temperatures will cause snowmelt in Southwestern Europe, Japan and Central Asia (**Figure 10**). Troughing and/or colder temperatures are predicted to support new snowfall across Alaska, much of Canada and possibly the Northern US from coast-to-coast (**Figure 10**).

Longer Term

30–day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows warm/positive normal PCHs throughout the troposphere and stratosphere for much of the next two weeks (**Figure 11**).

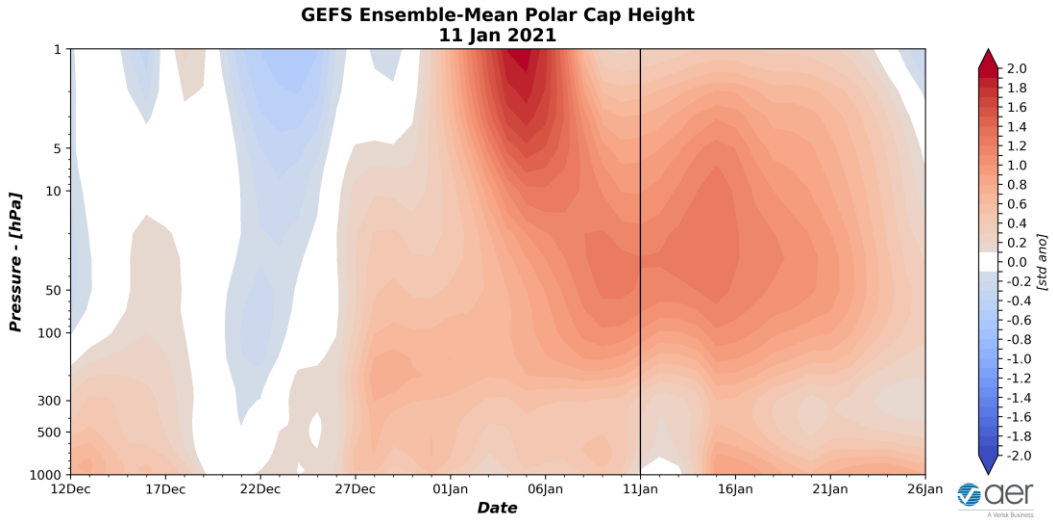


Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 11 January 2021 GFS ensemble. Please note that the PCH plot now extends to 1 hPa.

Normal to warm/positive PCHs in the lower troposphere are consistent with the predicted negative surface AO the next two weeks (**Figure 1**). Warm/positive PCHs in the stratosphere are consistent with the negative stratospheric AO the next two weeks (**Figure 1**).

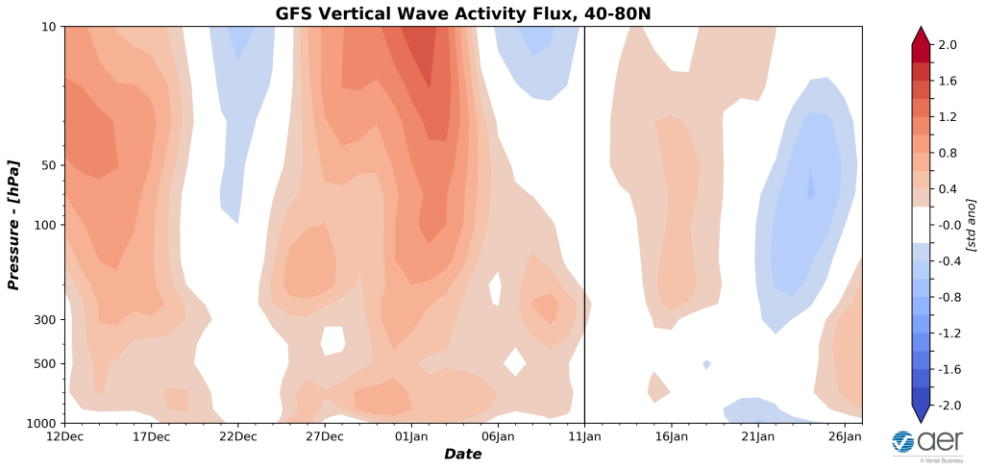


Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 11 January 2021 GFS ensemble.

The plot of Wave Activity Flux (WAFz and is proportional to poleward heat transport) forecasts is showing currently near normal WAFz throughout the atmospheric column (**Figure 12**). Though a major mid-winter warming (MMW where the zonal winds reverse from westerly to easterly at 60°N and 10 hPa) has already occurred, at least one more pulse of WAFz is predicted for this week and into the weekend. This will continue to perturb the PV and delay its recovery.

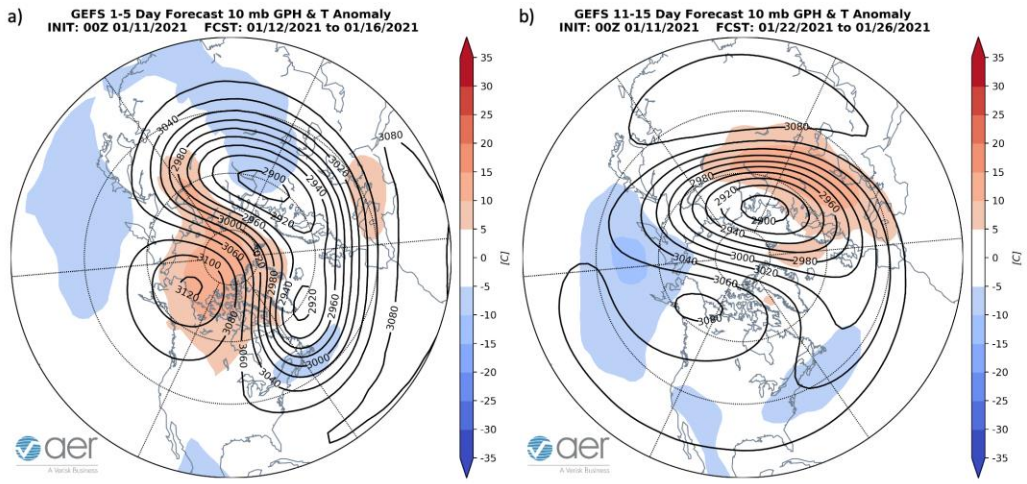


Figure 13. (**a**) Forecasted 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 12 - 16 January 2021. (**b**) Same as (a) except forecasted averaged from 22 – 26 January 2021. The forecasts are from the 00Z 11 January 2021 GFS model ensemble.

The PV has coalesced into one center, between Scandinavia and Iceland. However, the increased WAFz activity this week is predicted to create two daughter vortices one major vortex between the Urals and Scandinavia and a minor vortex along Southern Greenland (**Figure 13**). The PV is weakening as high pressure centered over Alaska strengthens. The high pressure over Alaska and northwestern Canada is predicted to weaken with time while the PV is predicted to consolidate once again and strengthen centered near the Urals (**Figure 13**). The second PV split looks more robust that the one last week and I believe will cross the threshold definition of a stratospheric PV split Charlton and Perez (2007).

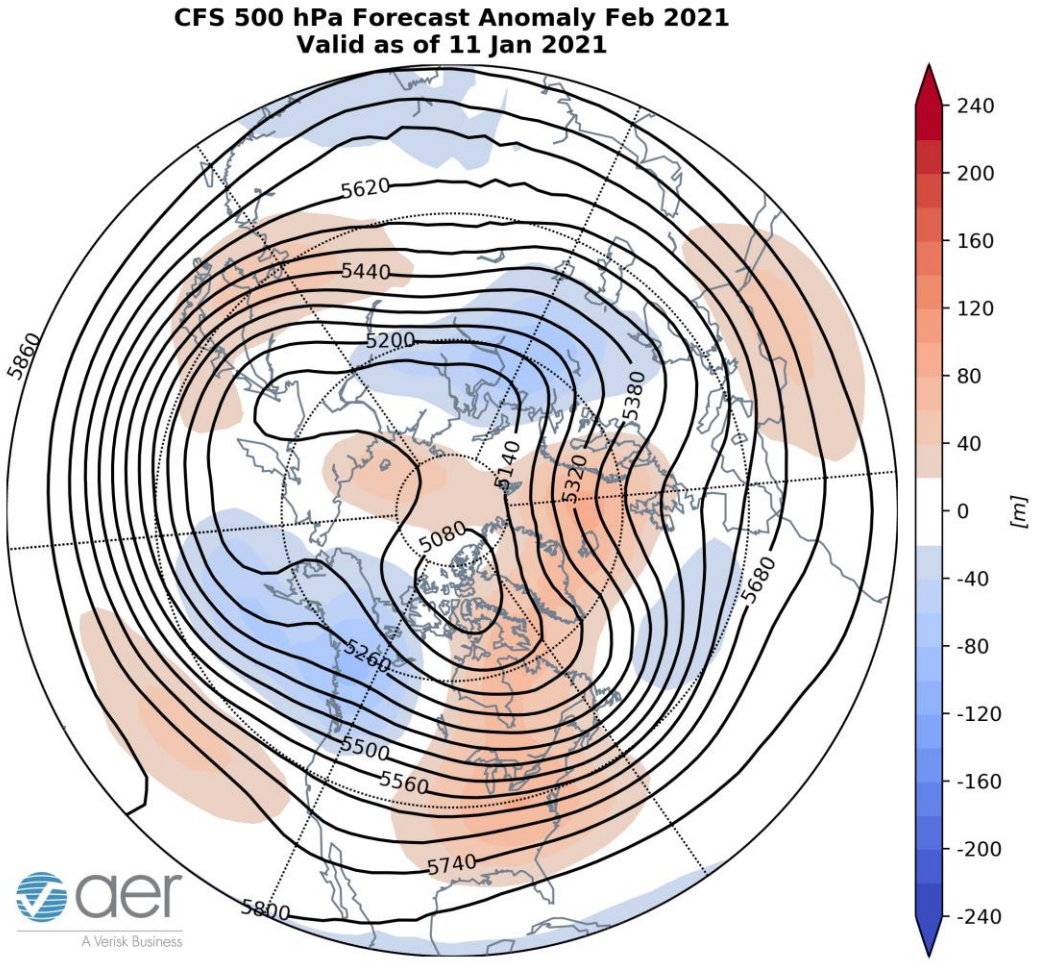


Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for February 2021. The forecasts are from the 00Z 11 January 2021 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and the surface temperatures (**Figure 15**) forecast for February from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging between Iceland and Scandinavia, Central Asia and eastern North America with troughing in Eastern Europe into Western Asia Eastern Siberia and western North America (**Figure 14).** This pattern favors relatively cold temperatures for Europe, Northern Asia, Alaska and Western and Northern Canada with seasonable to relatively warm temperatures for Scandinavia, Central and Eastern Asia, Southern Canada and much of the US (**Figure 15**). I consider the forecast to be of low confidence.

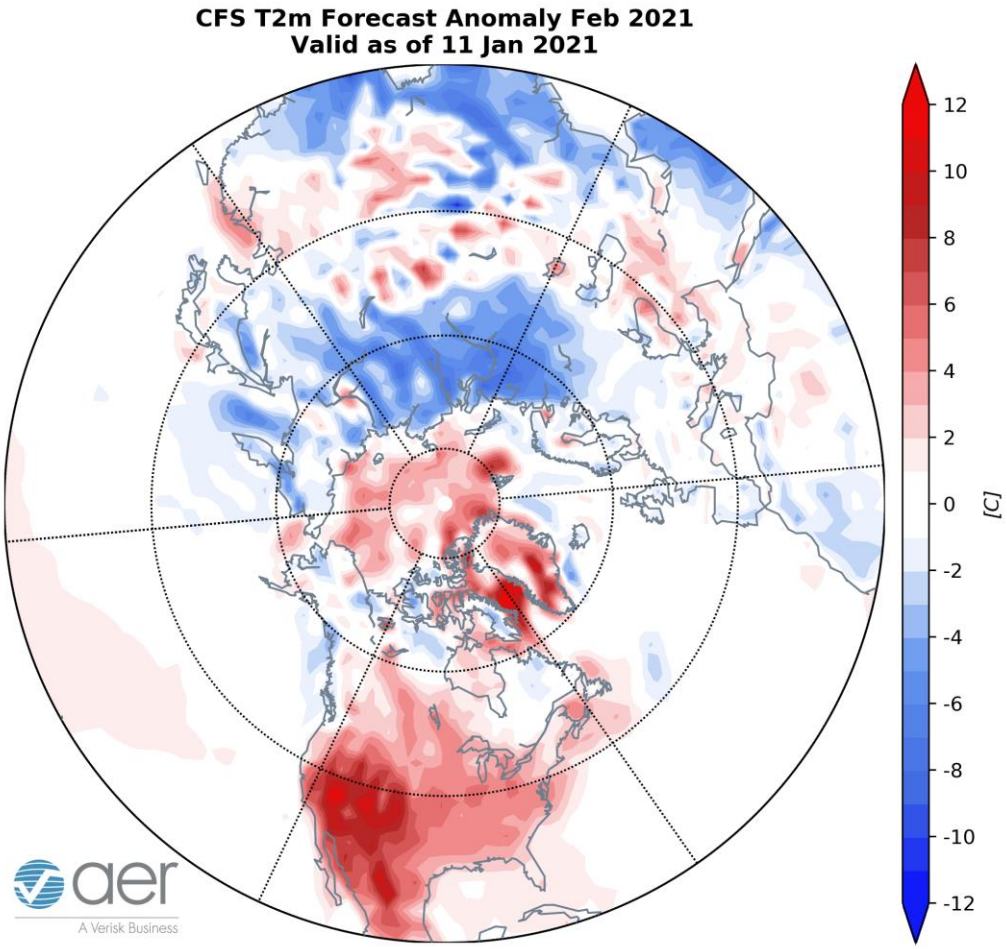


Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for February 2021. The forecasts are from the 00Z 11 January 2021 CFS.

Surface Boundary Conditions

Arctic sea ice extent

Arctic sea ice continues to grow but currently remains below normal. Negative sea ice anomalies exist in the Bering Sea but especially in the Barents-Kara Seas (**Figure 16**). Below normal sea ice in the Barents-Kara seas favor Ural blocking and 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 and Bering seas may favor colder temperatures across North America but have not been shown to weaken the PV. Sea ice should continue to grow in this region based on the forecast.

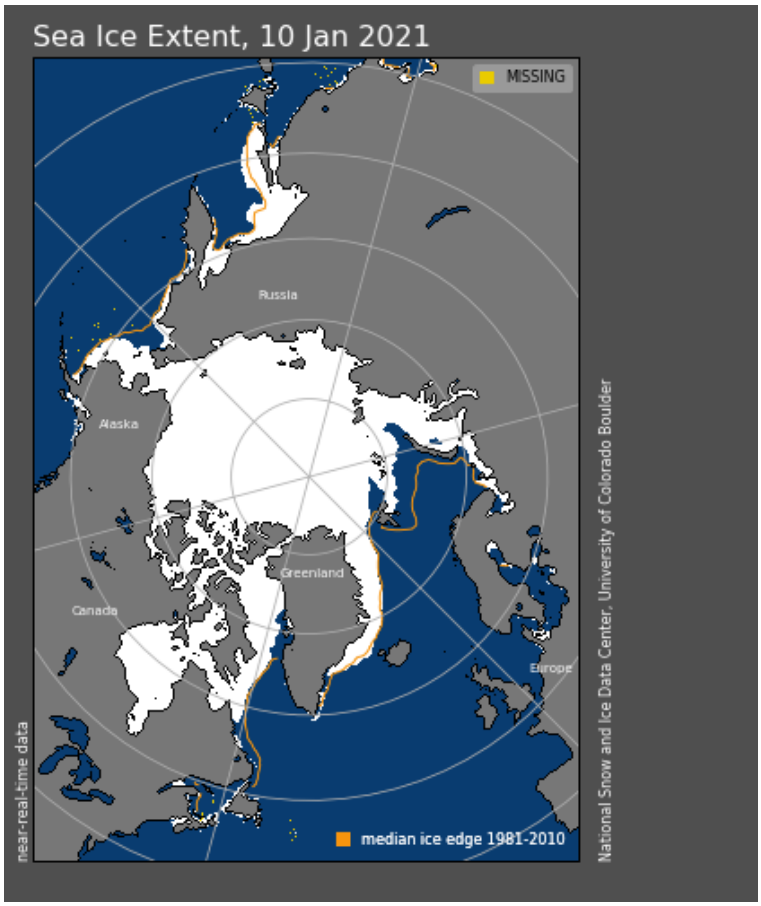


Figure 16. Observed Arctic sea ice extent on 10 January 2021 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image courtesy of National Snow and Ice Data Center (NSIDC).

SSTs/El Niño/Southern Oscillation

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

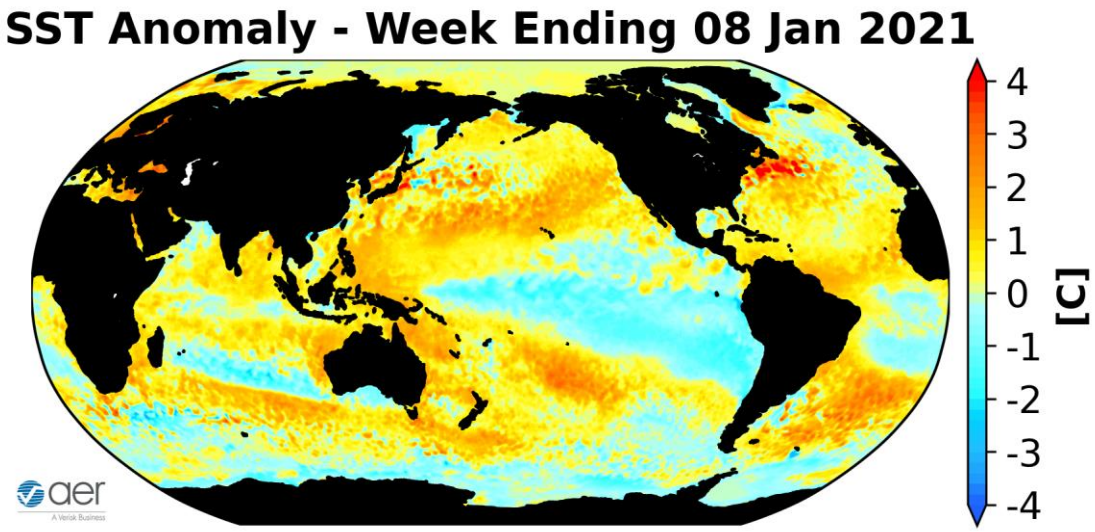


Figure 17. The latest weekly-mean global SST anomalies (ending 8 January 2021). Data from NOAA OI High-Resolution dataset.

Currently the Madden Julian Oscillation (MJO) is in phase three (**Figure 18**). The forecasts are for the MJO to quickly weaken where no phase is favored for the next two weeks. Phase three favors ridging south of the Aleutians, troughing in western North America and ridging in eastern North America. This pattern is predicted in two weeks so not sure of the connection to a weak phase three today. Therefore it doesn't appear to me that the MJO is contributing to the pattern across North America but admittedly this is outside of my expertise.

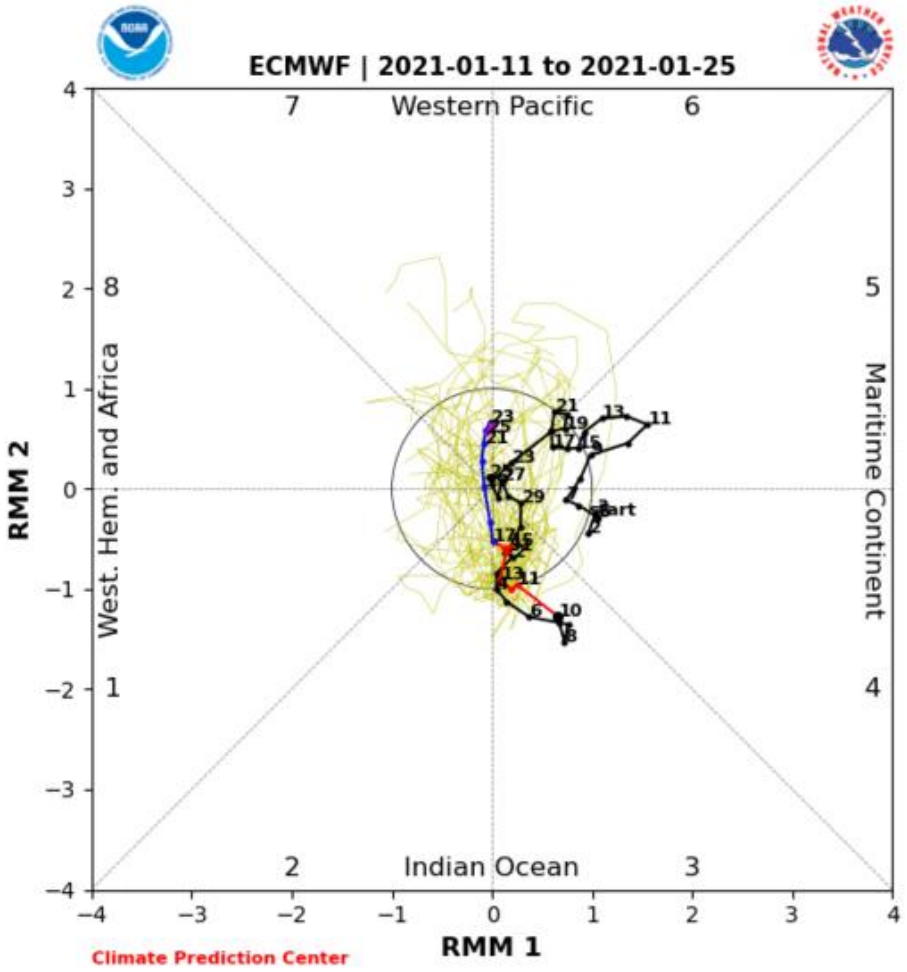


Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 11 January 2021 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model "spread" is denoted by the gray shading. Sector numbers indicate 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

Northern Hemisphere Snow Cover

Snow cover remained steady over the past week across Eurasia and is now near the low end of decadal means. Snow cover advance will likely continue to increase especially across East Asia and more likely into Europe the next two weeks. Above normal snow cover extent in October, favors a strengthened Siberian high, cold temperatures across northern Eurasia and a weakened polar vortex/negative AO this upcoming winter followed by cold temperatures across the continents of the NH.

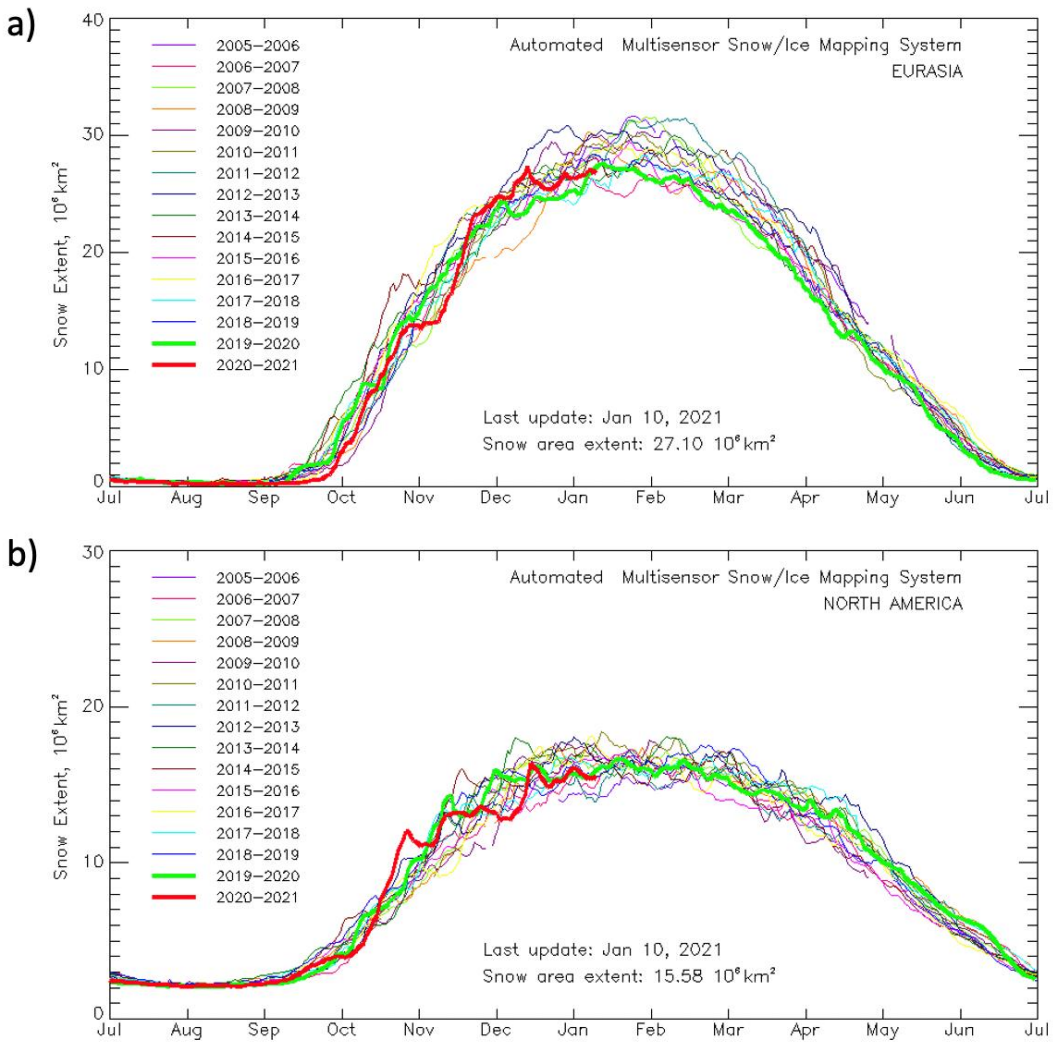


Figure 19. Observed Eurasian (top) and North American (bottom) snow cover extent through 3 January 2021. Image source: https://www.star.nesdis.noaa.gov/smcd/emb/snow/HTML/snow_extent_plots.html

North American snow cover remained steady over the past week and is near decadal means. The early advance of snow cover across Canada this fall, has likely contributed to an early start of cold temperatures across the Central and Eastern US but the lack of snow cover is now likely contributing to milder temperatures.