Arctic Oscillation and Polar Vortex Analysis and Forecasts

February 20, 2023

Dear AO/PV blog readers:

We have shifted the public release of the Arctic Oscillation/Polar Vortex blog to Wednesday through the winter season.

For those who would like an early look on Mondays, we will be offering at a nominal price (US $50) a PDF version of the upcoming blog, and we will be rolling out access to the datasets used in the production of this blog. At present we plan to make available in comma-separated values the timeseries of the Polar Cap Height and the timeseries of the Wave Activity Flux (vertical component), though we would appreciate to hear your suggestions for additional data of interest to you all.

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 positive and is predicted to slowly trend negative over the next two weeks as pressure/geopotential height anomalies across the Arctic are currently negative and are predicted to transition to more positive, especially in the North Atlantic sector. The North Atlantic Oscillation (NAO) is currently slightly positive and is predicted to trend negative the next two weeks as pressure/geopotential height anomalies are currently weakly negative and are predicted to become increasingly positive across Greenland the next two weeks.
- This week predicted ridging/positive geopotential height anomalies near Iceland will favor troughing/negative geopotential height anomalies across Eastern Europe with ridging/positive geopotential height anomalies across Western Europe. However next week ridging/positive geopotential height anomalies previously centered near Iceland will slide west towards Greenland favoring with troughing/negative geopotential height anomalies across Western Europe with ridging/positive geopotential height anomalies across Eastern Europe. This pattern favors this week normal to above normal temperatures across Western and Southern Europe including the United Kingdom (UK) with normal to below normal temperatures across Northern and Eastern Europe. However next week normal to above normal temperatures will become more widespread across Eastern Europe with normal to below normal temperatures across Western Europe.
- The predicted general pattern across Asia this week is troughing/negative geopotential height anomalies across Northwestern and Eastern Siberia with ridging/positive geopotential height anomalies centered across Central Asia. However next week troughing/negative geopotential height anomalies will become widespread across Northern Asia with ridging/positive geopotential height anomalies across Southern Asia. This general pattern the next two weeks normal is above normal temperatures across much of Asia with normal to below normal temperatures limited across far Northwestern Asia and Eastern Siberia. However, during the first week of March below normal temperatures will become more widespread across Siberia.
- The general pattern predicted across North America the next two weeks is ridging/positive geopotential height anomalies centered south of the Aleutians forcing troughing/negative geopotential height anomalies across much of Canada and the Western United States (US) with more ridging/positive geopotential height anomalies across the Southeastern US. However, in early March ridging/positive geopotential height anomalies from Greenland will begin to spread into Northeastern Canada. This pattern generally favors the next two weeks normal to below normal across Alaska, much of Canada and the Western US with normal to above normal temperatures across the Eastern US. However, this week Alaska will be mostly above normal temperatures as the Aleutian ridging pushes north into Alaska and then next week above normal temperatures will push into Eastern Canada as Greenland ridging slides west.

- I discuss the predicted large polar vortex (PV) disruption and its potential impacts on Northern Hemisphere (NH) surface temperatures. It does appear that coupling between the stratosphere and troposphere is underway and the more important questions now are how long and widespread will be the coupling. Large uncertainties remain.
- I am on travel early next week and expect a disruption ot the blog schedule.

Plain Language Summary

A major disruption of the polar vortex (PV) is ongoing with no end in sight and is referred to as a major sudden stratospheric warming (SSW; see **Figure 13**). Often following SSWs, more severe wintry weather becomes more widespread across Northern Europe and Asia. But Europe and Asia are quite mild with colder temperatures widespread across North America (see **Figures 3** and **6**). However, I do think that in March the more classical negative NAO temperature pattern that includes colder temperatures across Northern Europe and/or Asia is likely. Meanwhile while cold temperatures are widespread in Canada and the Western US, atmospheric resistance to the cold air making it into the Eastern US, courtesy of a Southeastern US ridge, continues. Observing its tenacity is impressive even though I don't really understand it and is horribly frustrating as a snow lover. But could the SSW provide a small window of opportunity as Ol' Man Winter to make an appearance as he exits for his summer vacation.

Impacts

Happy President's Day! A US holiday celebrating George Washington and Abraham Lincoln but for me how holds a special place in my heart because, as far as I know, is the only day/holiday with two major Mid-Atlantic/Northeast snowstorms that produced two feet plus of snow in 1979 and 2003. And you can see snowfall maps and their relative rank among disruptive East Coast winter storms here: Northeast Snowfall Impact Scale table from NOAA.

I think the question of whether the stratosphere will couple to the troposphere has been answered in the affirmative and instead becomes the questions of when, duration and extent. A couple of mid-tropospheric features that I have been speculating about in the blog the past two weeks (see last week's blog and from and 6 February 2023) are now appearing in the numerical model forecasts. In general I do believe that the model forecasts are becoming more reliable. The first is a closed low over Western Asia and Northern Europe this week (see **Figure 2)** but even more impressively in early March (see **Figure 8**). This feature I have referred to in the blog for years as the tropospheric reflection of the polar vortex (PV) center in the stratosphere. The second feature is Greenland blocking/high pressure which now is predicted in all the weather models and looks quite impressive in early March (see **Figure 8**) and is the most iconic tropospheric feature associated with the tropospheric response to major SSWs. I do think that the

prospects of a classical negative NAO temperature pattern with relatively colder temperatures across Northern Europe and/or Northern Asia with relatively milder temperatures across Southern Europe and/or Southern Asia in March is looking increasingly likely but two important questions remain - the magnitude of the temperature anomalies and the spatial extent.

In **Figure 11**, I include the usual polar cap geopotential height anomalies (PCHs) for the pan-Arctic, which finally shows the first (and I think it is important to preface with "apparent") downward propagation or "drip" of warm/positive PCHs from the stratosphere to the troposphere that classically represents stratosphere-troposphere coupling. But as I did last week, I also include the PCHs plot limited to the North Atlantic sector in **Figure i**. This plot like last week shows stratosphere-troposphere coupling or a "drip" more advanced and more robust than in the pan-Arctic plot. This is why the high latitude blocking for now is more focused over the North Atlantic sector including Greenland and not closer to the North Pole.

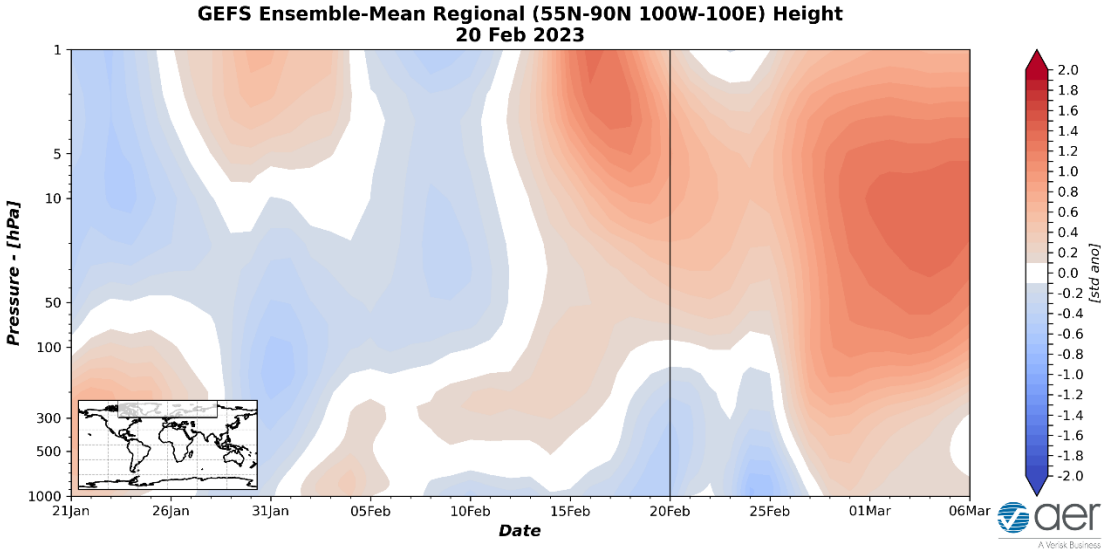


Figure i. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) but limited to the North Atlantic region (see insert) standardized anomalies. The forecast is from the 00Z 20 February 2023 GFS ensemble.

The "dripping paint" plot was first introduced in the influential paper of Baldwin and Dunkerton (2001), which I include in **Figure ii**. And based on their composite this first "drip" is likely only the first of multiple drips. And based on my own work, shown first for one winter in Cohen et al. (2013) and then more rigorously in Cohen et al. (2018), these "drips" are periods of increased probability or risk of severe winter weather across the Northern Hemisphere (NH) mid-latitudes. These drips can, but often do not, continue for weeks and even months, therefore given the lateness of this PV disruption, could coincide with impactful winter weather (cold but given the strengthening sun

most likely snow) at first and then transition to simply unpleasant spring weather. But again, it is worth cautioning that the PCHs plots are volatile and can vary widely from day to day.

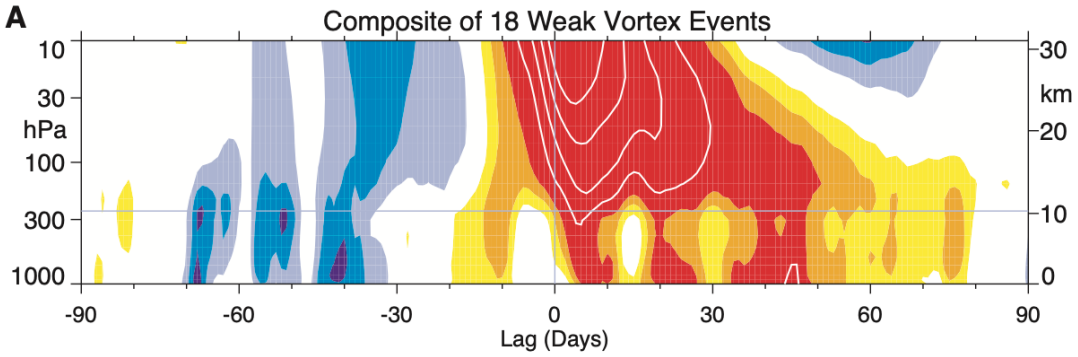


Figure ii. Composites of time-height development of the northern annular mode for 18 weak vortex events. The events are determined by the dates on which the 10-hPa annular mode values cross –3.0. The indices are nondimensional; the contour interval for the color shading is 0.25, and 0.5 for the white contours. The thin horizontal lines indicate the approximate boundary between the troposphere and the stratosphere.

Comparing **Figures i** and **ii,** it shows to me at least that this PV disruption/SSW is unusual in that it has evolved so far in three stages and is of such long duration (be careful not to over-read what I am saying since you cannot directly compare the two plots). The same was true of the last SSW in January 2021. Two events don't make a trend (at least not one you want to stake your reputation on) but I still think that it is interesting to note.

To be honest, I don't know how this SSW will be labeled, displacement or split. (As a complete tangent, in fact, it could end up being labeled as the Final Warming [and from **Figure 13b** it really is looking more and more like a Final Warming and not an SSW with one or more distinct PV centers], which to my knowledge is not further categorized into spits or displacements. I thought that it was a mistake to not include the March 2016 in the SSW compendium and this would be even worse, though admittedly it is premature to start the whining given that achieving a Final Warming in mid-February remains a daunting challenge for the atmosphere, but now not impossible.). But in my own mind, I am thinking of it as a PV split with the second minor PV center lurking near the US Northeast coast (see **Figure 13a**). Why I point this out is just like there is tropospheric reflection of the PV center overhead of western Asia, could a mid-tropospheric reflection developing the region of the Northeastern US and/or Southeastern Canada? Nothing definite yet but such a feature flashes in and out in the weather model forecasts but of even more interest is - could this feature spawn a winter storm along the east coast of North America?

Every winter has its intangibles and one that has impressed me for this winter is the strength and stubbornness of the US Southeastern ridge. Sure this is a feature associated with La Niña but from what I can tell we are either leaving La Niña conditions or already in neutral ENSO conditions. I was surprised when during the negative NAO regime of early December there was no flattening the Southeastern ridge. But the model forecasts of the Southeastern ridge persisting even as the center of the high latitude blocking moves from just east of Greenland to west of Greenland and then into Northeastern Canada is even more dumbfounding. I certainly would expect some kind of Rex block (blocking high to the north with a cutoff low to the south) as predicted over Europe next week (see **Figure 5**). Maybe one will eventually be observed but this Southeast ridge has been impressive and a head scratcher for me.

I do think that this current PV disruption that started in late January and with no end in sight for the foreseeable future is a bit of a black swan event so for now I am cautious about making generalities or drawing conclusions. I haven't been following hemispheric wave propagation as closely as I have been doing this winter for very long, so there is more that I don't know than I know. I discussed last week how this event was unique (as far as I know, and I doubt truly unique) as the SSW began as a reflective event and then transitioned to an absorptive event or more classical SSW. But based on my wave energy diagnostics, the wave reflection never really quits, and it could be helping to anchor the ridge axis near the Aleutians and the trough axis over western North America that helps to prop up the Southeast ridge. Lots of speculation on my part and just wished I knew the reason for or understood the resiliency of the Southeast ridge and why it is not operating under the normal rules of synoptic variability this winter.

Wednesday Update

Seems to me the focus should be on the stratosphere-troposphere coupling post the major SSW but I can't claim to be objective or unbiased. The classical plot to identify stratosphere-troposphere coupling is the plotted Northern Annular Mode (same as the AO) or my preference - PCHs. Looking at the latest pan-Arctic PCHs in **Figure iii**, it may or may not show downward propagation from the mid-stratosphere to the surface. The warm/positive PCHs make it to the tropopause, disappear in the upper and mid-troposphere and then reappear in the lower troposphere to the surface. This forecast looks strange (certainly not classical and compare to **Figure ii**) and may or not show downward propagation. This plot can be quite volatile and will be interesting to follow the downward progress of warm/positive PCHs changes in the coming days and weeks.

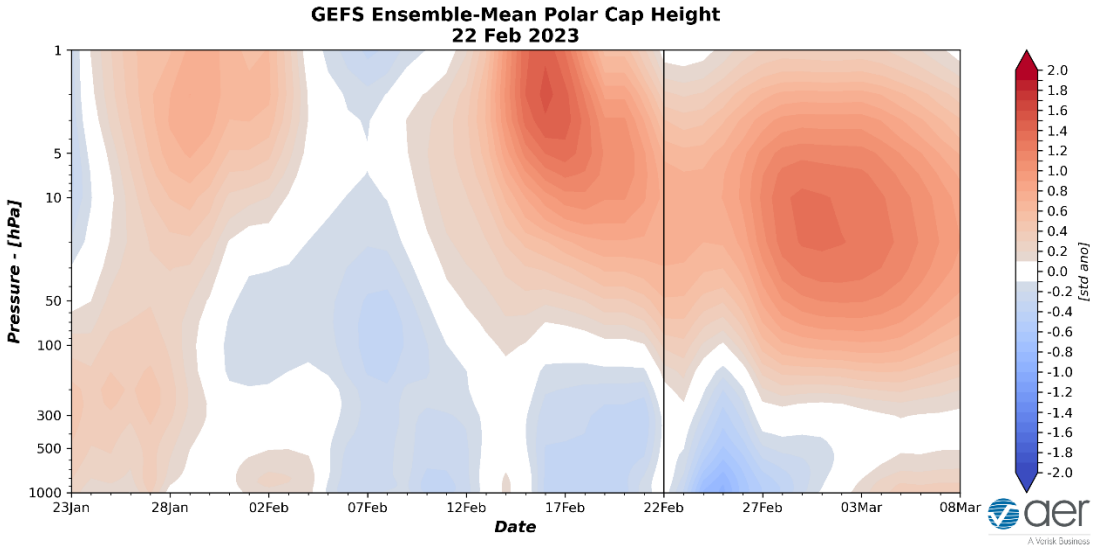


Figure iii. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 22 February 2023 GFS ensemble.

But based on less conventional metrics, I would argue that the downward propagation or influence of the major SSW is fairly obvious in the model forecasts. In **Figure iv**, I show on the left-hand side the predicted 10 hPa geopotential heights for 28 February through 4 March. The main PV center is located solidly in Western Asia centered on the Urals, there is a high-pressure center over the Arctic and centered near the North Pole and then there is either a tail extending from the main PV center across the mid-latitudes of the North Atlantic and across the US or a second minor PV center over the US. In the anomaly space this creates alternating stripes of low and high heights starting with relatively low heights across northern Eurasia, relatively high heights across the Arctic and then relatively low heights across the US or a tripole. I would then argue that this general anomaly pattern is similarly predicted in the mid-troposphere for the following five-day period from 5 March through 9 March on the right-hand side. The forecast can also be characterized as consisting of a main low center across Northern Eurasia, high latitude blocking or high heights from the Aleutians across the Arctic to Greenland and a second region of lower heights across the US or once again three strips or striations of alternating relatively high and low heights or tripole.

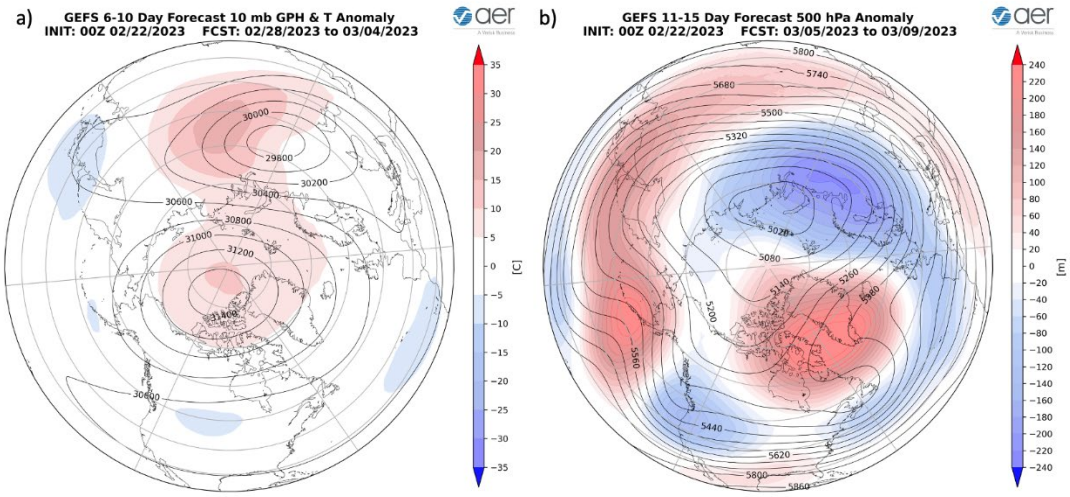


Figure iv. (a) Forecasted 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere from 28 February – 4 March 2023. (b) Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 5 – 9 March 2023. The forecasts are from the 00Z 22 February 2023 GFS model ensemble.

The main mid-tropospheric low center is predicted to be on the North Slope or along the Arctic coast of Eurasia. The impact on the weather is to induce a mostly westerly flow of air across Northern Eurasia, which is a mild wind direction across Eurasia. The largest exception is across Northern Europe where the wind direction is more northerly and should result in relatively cold temperatures across Northern Europe and milder temperatures across Southern Europe or the classical temperature pattern associated with Greenland blocking or a negative NAO. And it does seem to me that the potential does exists for early March to be unseasonably cold across Northern Europe, especially Scandinavia but also including the UK. The models are predicting that the Eurasian PV center to slowly sink south in early March promoting more easterly flow across Northern Eurasia in the stratosphere. No signs of this from the weather models of a similar sinking south of the mid-tropospheric low center, however I think this scenario is worth watching for. If the mid-tropospheric low center can drift south across Eurasia, then this would also promote a more easterly flow across northern Eurasia in the troposphere and would expand the relatively cold temperatures across Northern Asia and could possibly deepen the cold across Europe. But for now, this is speculative until it appears in the weather model forecasts.

I would argue whether you consider the major SSW as a PV displacement or PV split is not just academic but could have material impacts on the sensible weather especially across North America. I can't provide support, but it is my impression that PV splits are more favorable for a closed low center in the Northern US and/or Southern Canada (as I discussed on Monday) and a Northeastern US/Southeastern Canada winter storm

compared to a PV displacement. This assertion or argument needs to be considered as speculative but something to monitor.

Finally, I tweeted out yesterday an accumulative snowfall anomaly plot across the NH for winter 2022/23. In **Figure v**, I show the same plot with revised color shading to alleviate most of the color saturation in the tweeted image. Snowfall is derived from the ERA5 gridded analysis and uses a 1991-2020 climatology. Since it is gridded data and at relatively low resolution, the anomalies are smoothed and may not match what you experienced in your own neighborhood, but the macro anomaly pattern looks reasonable to me. For winter 2022/23 seems to me the big winner in the snowfall lottery is the Sierra Nevada mountains of California. The snowfall riches extend east across the Central Rockies, a bonanza for Western US water managers and skiers. Other notable winners are Western and Eastern Canada, Southern Alaska, Scandinavia, Iran, Northwest Russia, Southern Siberia, parts of the Tibetan Plateau and especially Kamchatka, the Japanese Alps and Hokkaido. Big losers are the Eastern US and Western Europe but especially in the megalopolis I95 corridor in the Northeastern US and in the Alps. Also looks like low snowfall totals in the Balkans over to Turkey. More generally the winter of 2022/23 snowfall can be largely summarized as favoring the North Pacific Rim at the expense of both coasts of the North Atlantic including Southeastern Greenland. The plot also seems to suggest above normal snowfall in the higher latitudes, which would be consistent with a mild winter in the Eastern US and Europe but could also be an artifact of the dataset and/or plotting.

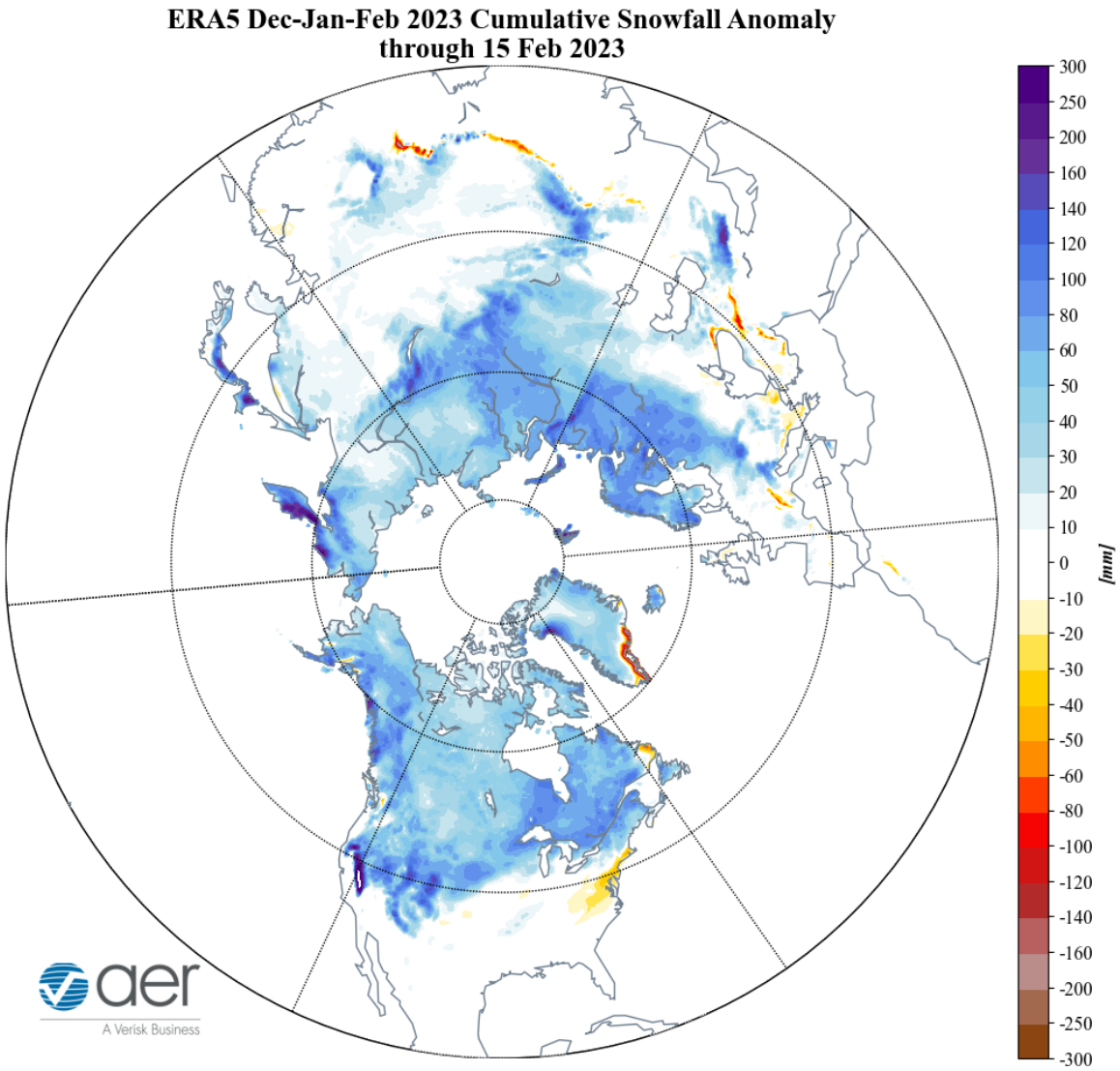


Figure v. Observed winter (1 December 2022 through 15 February 2023) snowfall anomaly in millimeters across the Northern Hemisphere using ERA5 data. The climatology is the 30-year average from 1991-2020.

Recent and Very Near Term Conditions

The AO is predicted to be positive this week **(Figure 1**) with mostly negative geopotential height anomalies predicted across the Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 2**). And with weak negative geopotential height anomalies this week across Greenland (**Figure 2**), the NAO is predicted to be positive to neutral this week (**Figure 1**).

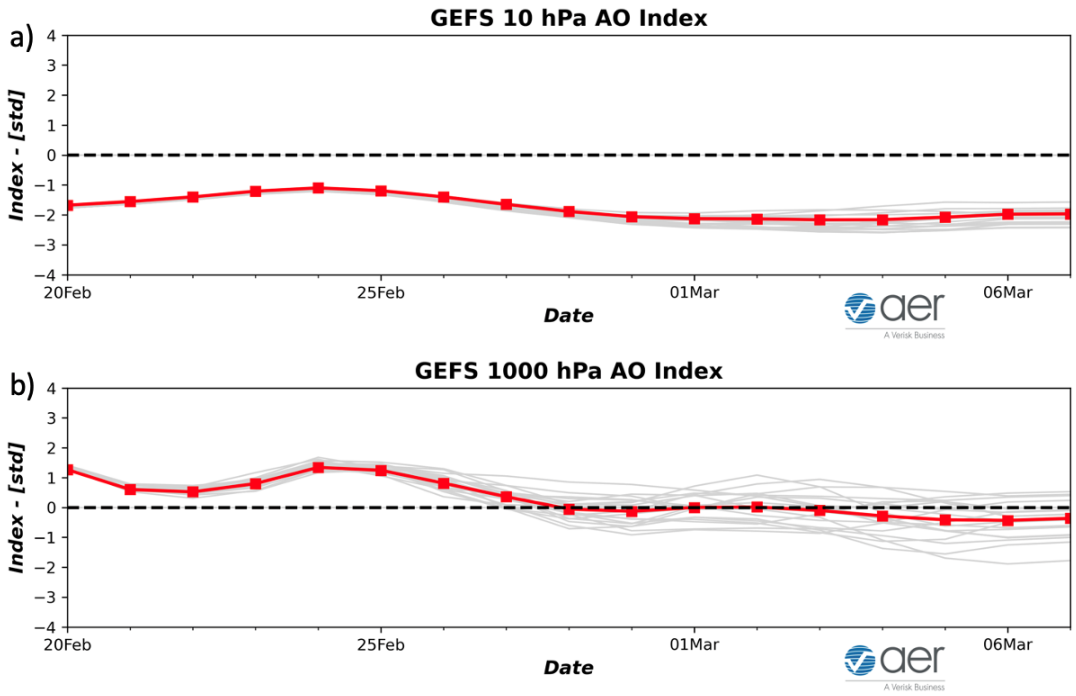


Figure 1. (a) The predicted daily-mean AO at 1000 hPa from the 00Z 20 February 2023 GFS ensemble. (b)The predicted daily-mean near-surface AO from the 00Z 20 February 2023 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

Predicted ridging/positive geopotential height anomalies centered near Iceland will extend into Western Europe and favor troughing/negative geopotential height anomalies across Eastern Europe this period (**Figure 2).** This pattern will favor normal to above normal temperatures across Western and Southern Europe including the UK with normal to below normal temperatures across Northern and Eastern European (**Figure 3**). Troughing/negative geopotential height anomalies across Northwestern Asia and Eastern Siberia are predicted to bookend ridging/positive geopotential height anomalies centered in Central Asia (**Figure 2**). This pattern favors normal to below normal temperatures limited to Northwestern Asia and Eastern Siberia with normal to above normal temperatures widespread across much of Asia **(Figure 3**).

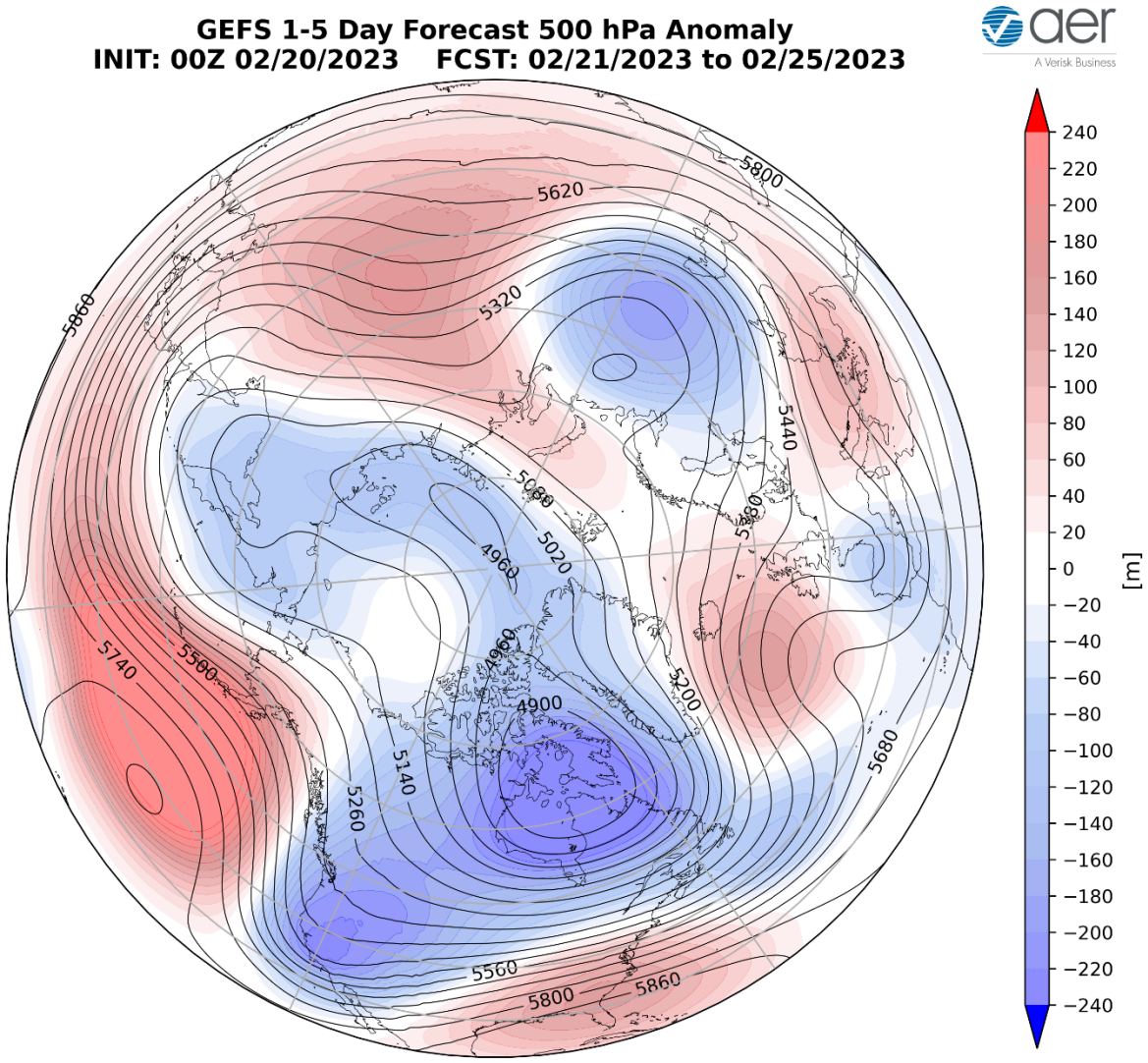


Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 21 – 25 February 2023. The forecasts are from the 00z 20 February 2023 GFS ensemble.

Predicted ridging/positive geopotential height anomalies centered south of the Aleutians pushing into Alaska will favor troughing/negative geopotential height anomalies across Canada and the Western US with more ridging/positive geopotential height anomalies across the Eastern US **(Figure 2).** The pattern will favor normal to below normal temperatures across much of Canada and the Western US with normal to above normal temperatures across Alaska and the Eastern US **(Figure 3).**

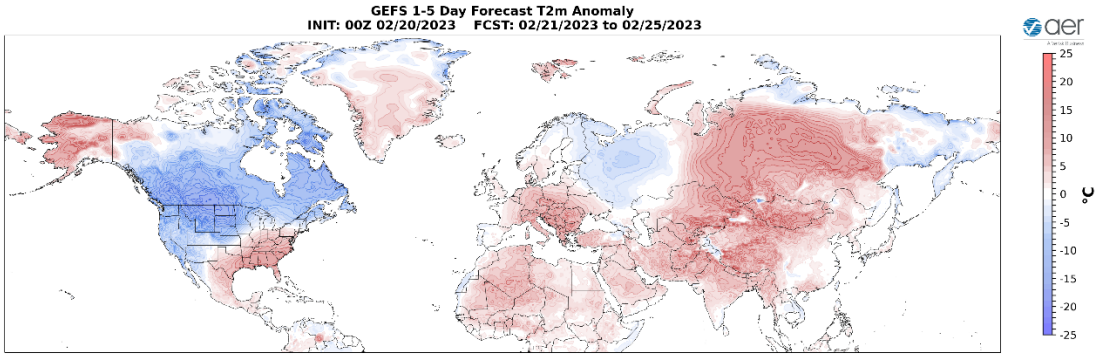


Figure 3. Forecasted surface temperature anomalies (°C; shading) from 21 – 25 February 2023. The forecast is from the 00Z 20 February 2023 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall to Norway, the Alps, the Pyrenes, Northern Siberia and the Tibetan Plateau while mild temperatures will support snowmelt across Eastern Europe, Western Russia, Central Asia and Southern Siberia (**Figure 4**). Troughing and/or cold temperatures will support new snowfall across northern Alaska, the Western Canada, the Western and Northern US while mild temperatures will support snowmelt across Southwest Alaska, Central Canada and the Canadian Maritimes (**Figure 4**).

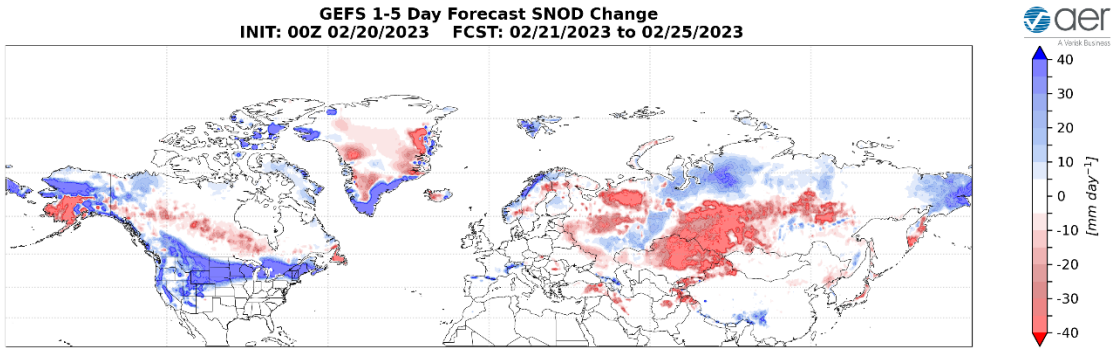


Figure 4. Forecasted snow depth changes (mm/day; shading) from 21 – 25 February 2023. The forecast is from the 00Z 20 February 2023 GFS ensemble.

Near-Term

1-2 week

The AO is predicted to trend towards neutral this period **(Figure 1**) as geopotential height anomalies become increasingly positive across the North Atlantic sector of the Arctic and mixed across the mid-latitudes (**Figure 5**). With mostly positive geopotential height anomalies across Greenland (**Figure 5**), the NAO is predicted to flip negative this period.

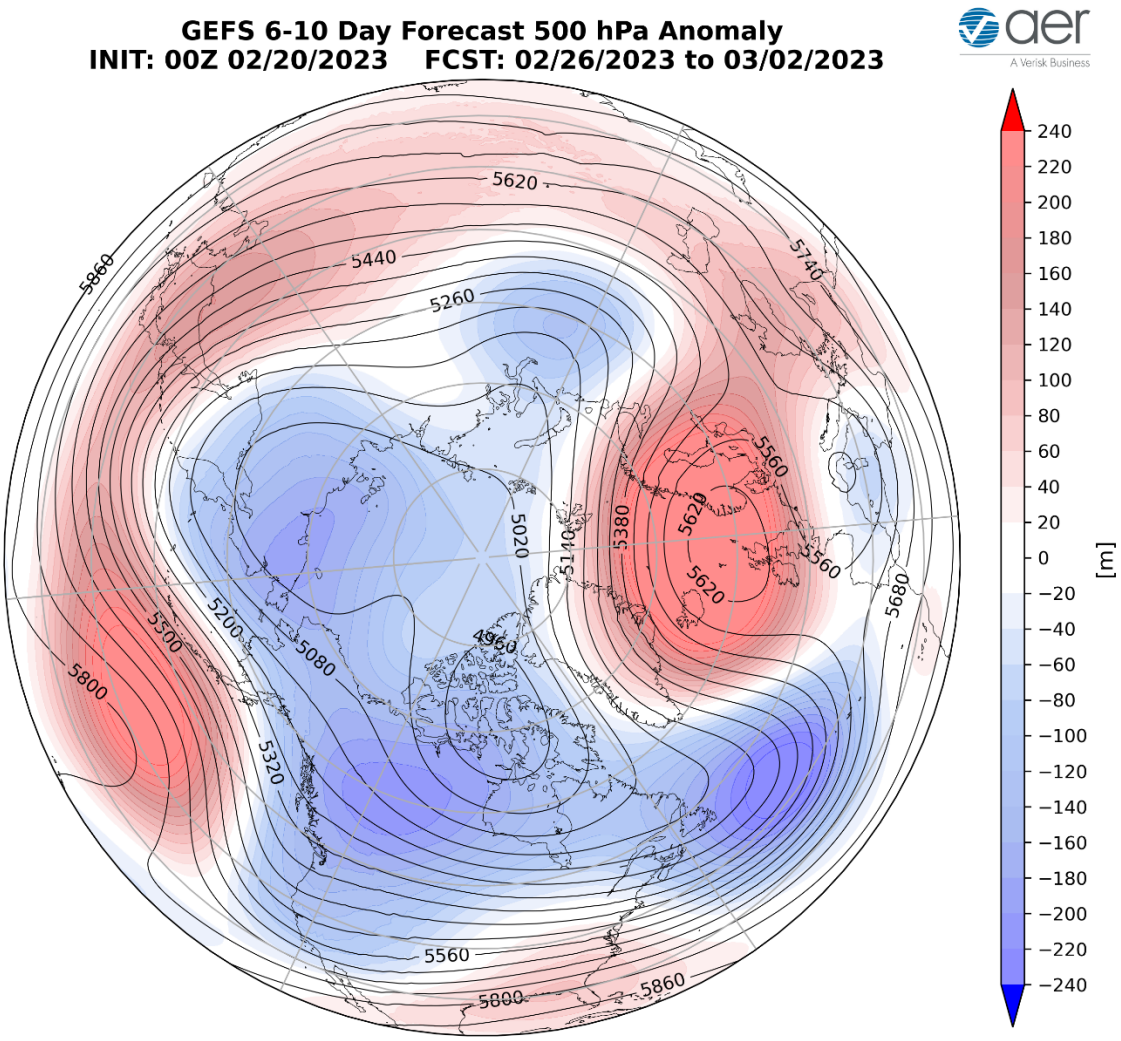


Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 26 February – 2 March 2023. The forecasts are from the 00z 20 February 2023 GFS ensemble.

Amplifying ridging/positive geopotential height anomalies near Iceland will expand across Northern Europe and support troughing/negative geopotential height anomalies in Western Europe with more ridging/positive geopotential height anomalies across Eastern Europe (**Figures 5).** This pattern favors normal to below normal temperatures across Western Europe including the UK with normal to above normal temperatures across Central and Eastern Europe (**Figure 6**). Troughing/negative geopotential height anomalies in Northwestern Asia and Eastern Siberia are predicted to merge this period with ridging/positive geopotential height anomalies being suppressed into Southern Asia this period (**Figure 5**). This pattern still favors widespread normal to above normal temperatures widespread across Asia but focused in Central Siberia and East Asia with

normal to below normal temperatures mostly limited to Eastern Siberia **(Figure 6**). I still think the extent of warm temperatures could be overdone.

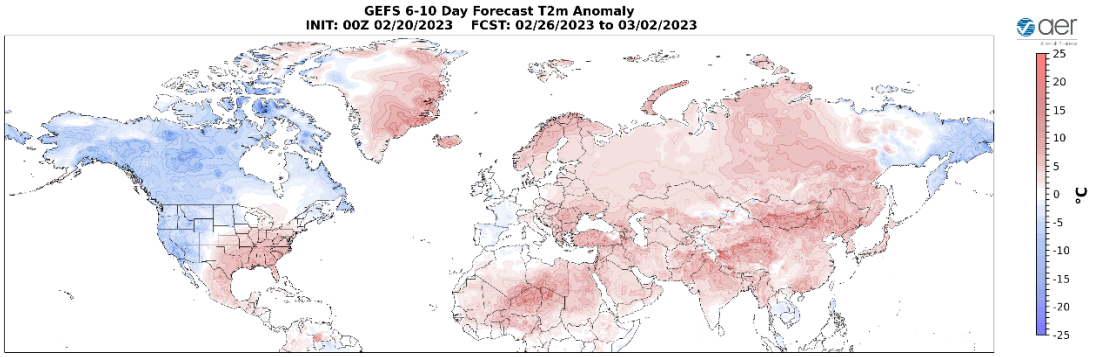


Figure 6. Forecasted surface temperature anomalies (°C; shading) from 26 February – 2 March 2023. The forecast is from the 00Z 20 February 2023 GFS ensemble.

Persistent ridging/positive geopotential height anomalies south of the Aleutians will anchor troughing/negative geopotential height anomalies across Canada and the Western US with more ridging/positive geopotential height anomalies centered in the Southeastern US this period **(Figure 5).** This pattern will favor normal to below normal temperatures across Alaska, much of Canada and the Western US with normal to above normal temperatures across the Eastern US **(Figure 6).**

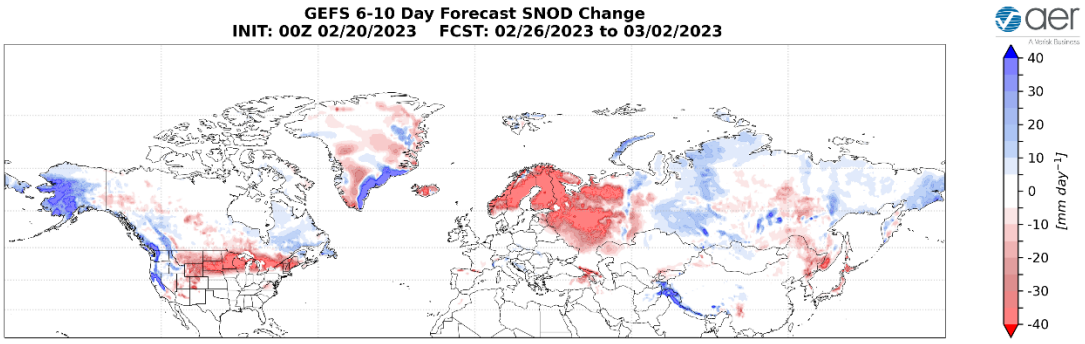


Figure 7. Forecasted snow depth changes (mm/day; shading) from 26 February – 2 March 2023. The forecast is from the 00Z 20 February 2023 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across Siberia and the Tibetan Plateau while mild temperatures will support snowmelt in Scandinavia, the Baltics and Northwestern Russia and Northeast Asia (**Figure 7**). Troughing and/or cold temperatures will support new snowfall across Alaska, Western and Eastern Canada and the higher elevations of the Western US while mild temperatures will support snowmelt in the Western and Northern Plains, the Great Lakes and Northern New England (**Figure 7**).

3-4 week

With positive geopotential height anomalies dominating the North Atlantic sector of the Arctic and with mixed geopotential height anomalies across the mid-latitudes this period (**Figure 8**), the AO should finally dip into negative territory this period (**Figure 1**). With positive pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO will push deep into negative territory this period as well.

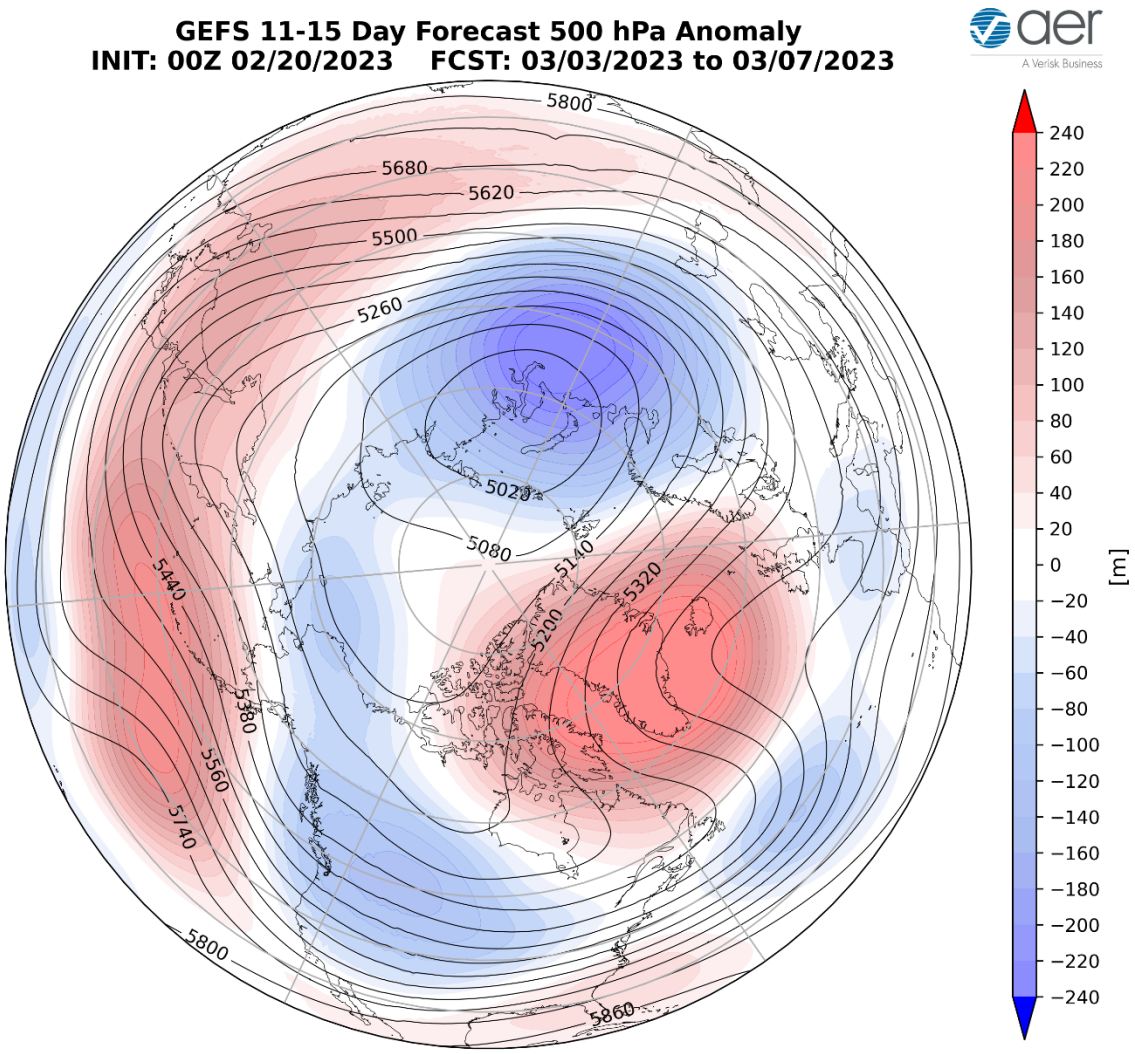


Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 3 – 7 March 2023. The forecasts are from the 00z 20 February 2023 GFS ensemble.

Ridging/positive geopotential height anomalies centered across Greenland will favor deepening troughing/negative geopotential height anomalies across Europe this period (**Figure 8**). This pattern should increasingly favor a classic negative NAO pattern with

normal to below normal temperatures across Northern Europe including the UK with normal to above normal temperatures across Southern Europe (**Figures 9**). A deep trough/negative geopotential height anomalies center is predicted to develop centered near the Urals but extending across Siberia with ridging/positive geopotential height anomalies spread across Southern Asia this period (**Figure 8**). This pattern favors widespread normal to above normal temperatures across much of Asia with normal to below normal temperatures mostly limited to Northwestern Asia and Eastern Siberia (**Figure 9**) but could expand across Siberia this period.

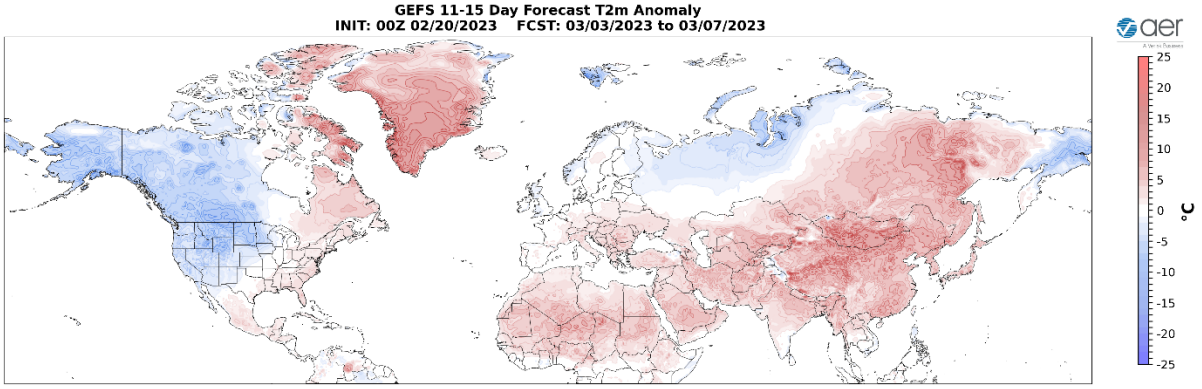


Figure 9. Forecasted surface temperature anomalies (°C; shading) from 3 – 7 March 2023. The forecast is from the 00Z 20 February 2023 GFS ensemble.

Persistent ridging/positive geopotential height anomalies south of the Aleutians will continue to anchor troughing/negative geopotential height anomalies across Alaska, Western Canada and the Western US with more ridging/positive geopotential height anomalies centered in the Southeastern US and spreading west across Northeastern Canada from Greenland this period (**Figure 8**). This pattern favors widespread normal to below normal temperatures across Alaska, Western Canada and the Western US with normal to above normal temperatures in Eastern Canada and the Eastern US (**Figure 9**).

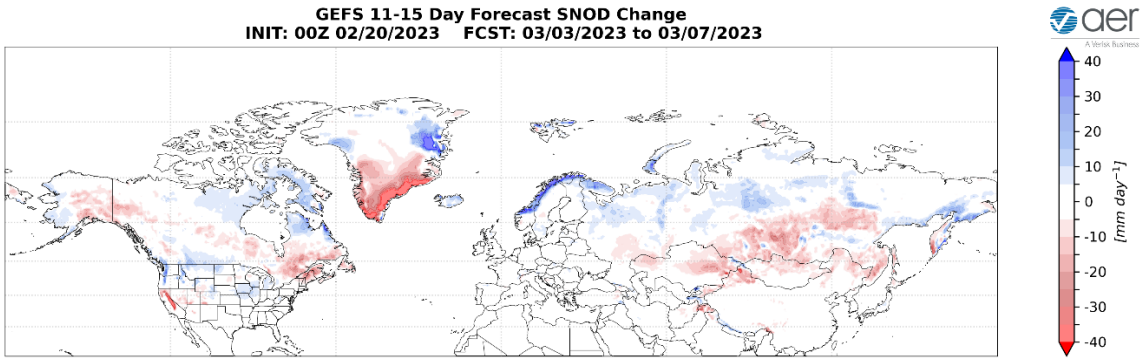


Figure 10. Forecasted snow depth changes (mm/day; shading) from 3 – 7 March 2023. The forecast is from the 00Z 20 February 2023 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across Norway and Northern Asia while mild temperatures will support snowmelt in Central Asia and Southern Siberia (**Figure 10**). Troughing and/or cold temperatures will support new snowfall across western Alaska, Hudson Bay, the Cascades, and the Canadian and the Northern US Plains while mild temperatures will support snowmelt in the Sierras, the Central Rockies, Southeastern Canada and Northern New England (**Figure 10**).

Longer Term

30–day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows normal to warm/positive PCHs throughout the stratosphere with cold/negative PCHs in the troposphere (**Figure 11**). However, the warm/positive PCHs in the mid stratosphere are predicted to strengthen this week and peak next week (**Figure 11**). Meanwhile the cold/negative PCHs in the troposphere are predicted to turn mostly warm/positive next week as warm/positive PCHs "drip" downs from the stratosphere into the troposphere commonly observed following a major sudden stratospheric warming (SSW; **Figure 11**). As long as warm/positive PCHs persist in the lower stratosphere more "drips" into the troposphere are likely in the coming weeks.

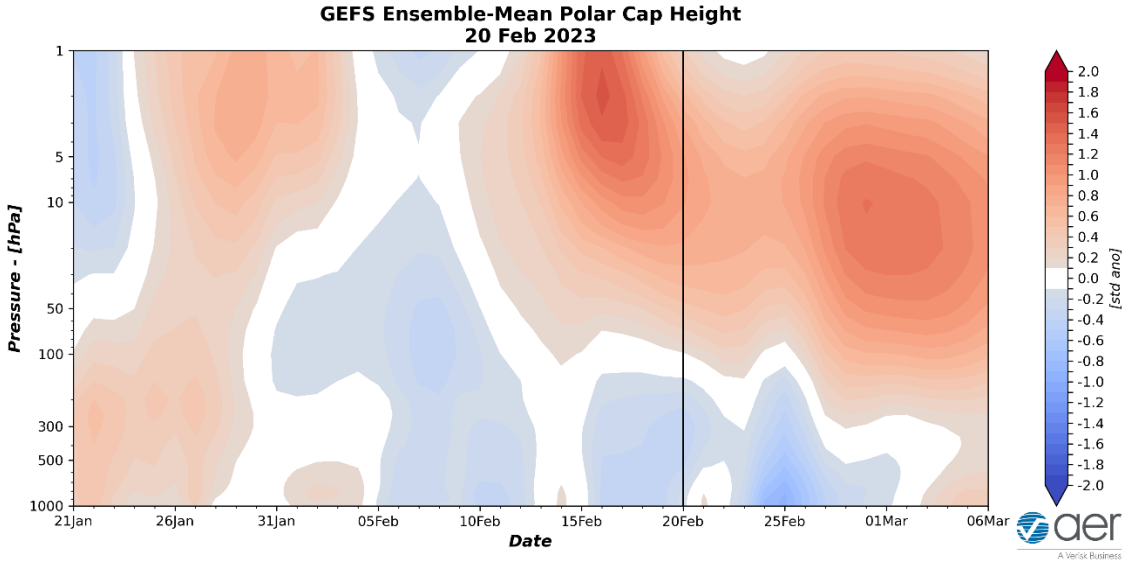


Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 20 February 2023 GFS ensemble.

The mostly cold/negative PCHs in the lower troposphere this week (**Figure 11**) are consistent with the predicted positive surface AO (**Figure 1**). However, the AO is predicted to finally turn negative in early March (**Figure 1**) coinciding when

warm/positive PCHs in the lower stratosphere are predicted to “drip” into the troposphere (**Figure 11**.

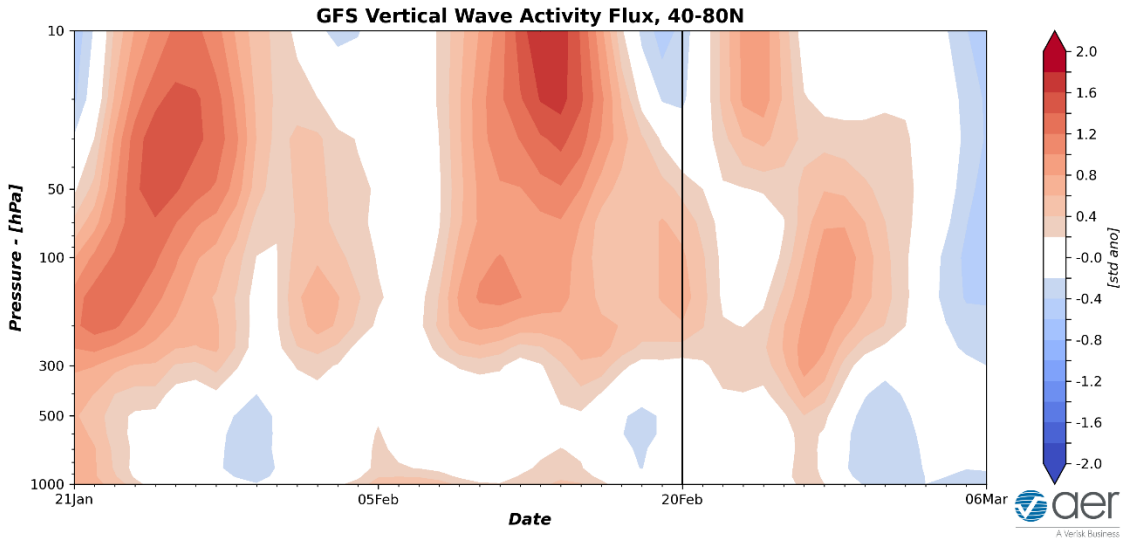


Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 20 February 2023 GFS ensemble.

Vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere has been active since the beginning of the year with one peak the last week of January and another peak last week (**Figure 12**) which has resulted in warming of the polar stratosphere since the end of January and now a major SSW the last two weeks of February (**Figure 11**). The GFS is predicting that the WAFz will remain mostly active this week (**Figure 12**), resulting in a second peak of the major SSW in the mid- stratosphere next week (**Figure 11**).

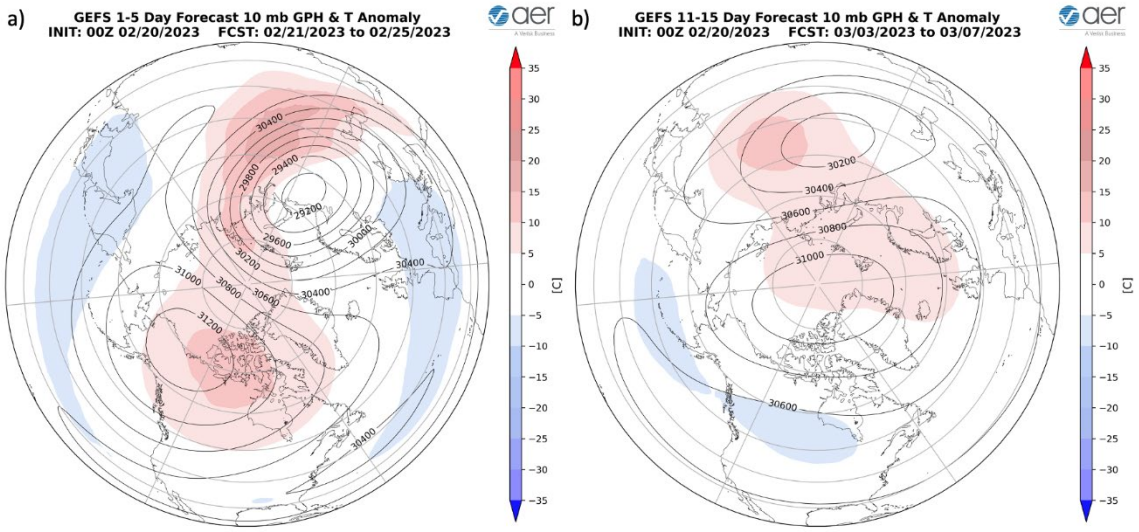


Figure 13. (a) Forecasted 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere from 21 – 25 February 2023. (b) Same as (a) except forecasted averaged from 3 – 7 March 2023. The forecasts are from the 00Z 20 February 2023 GFS model ensemble.

The more active WAFz has shifted the already weakened stratospheric major PV center over towards the Urals **(Figure 13a**) with the relatively coldest temperature anomalies across mid latitudes of the two major ocean basins. Coupled with the shifted PV is ridging centered across Alaska and Northwestern Canada and with warming extending from Central Asia across the North Pole and into Northern Canada with the relatively warmest temperatures across Central Asia in the polar stratosphere this week (see **Figure 13a**). There is also a predicted minor PV center off the US East Coast (see **Figure 13a**). The persistent active WAFz predicted for next week will continue to weaken the PV, with the major PV center shifted further south to a position over Central Asia with the coldest relative temperatures across the Aleutians and Western Canada in the polar stratosphere (see **Figure 13b**). Meanwhile ridging and warming will strengthen with the ridge now centered over the North Pole and the peak warming centered across Central Asia and extending towards the North Pole (see **Figure 13b**). With the ongoing weakening of the PV, the stratospheric AO is predicted to remain negative the next two weeks **(Figure 13**).

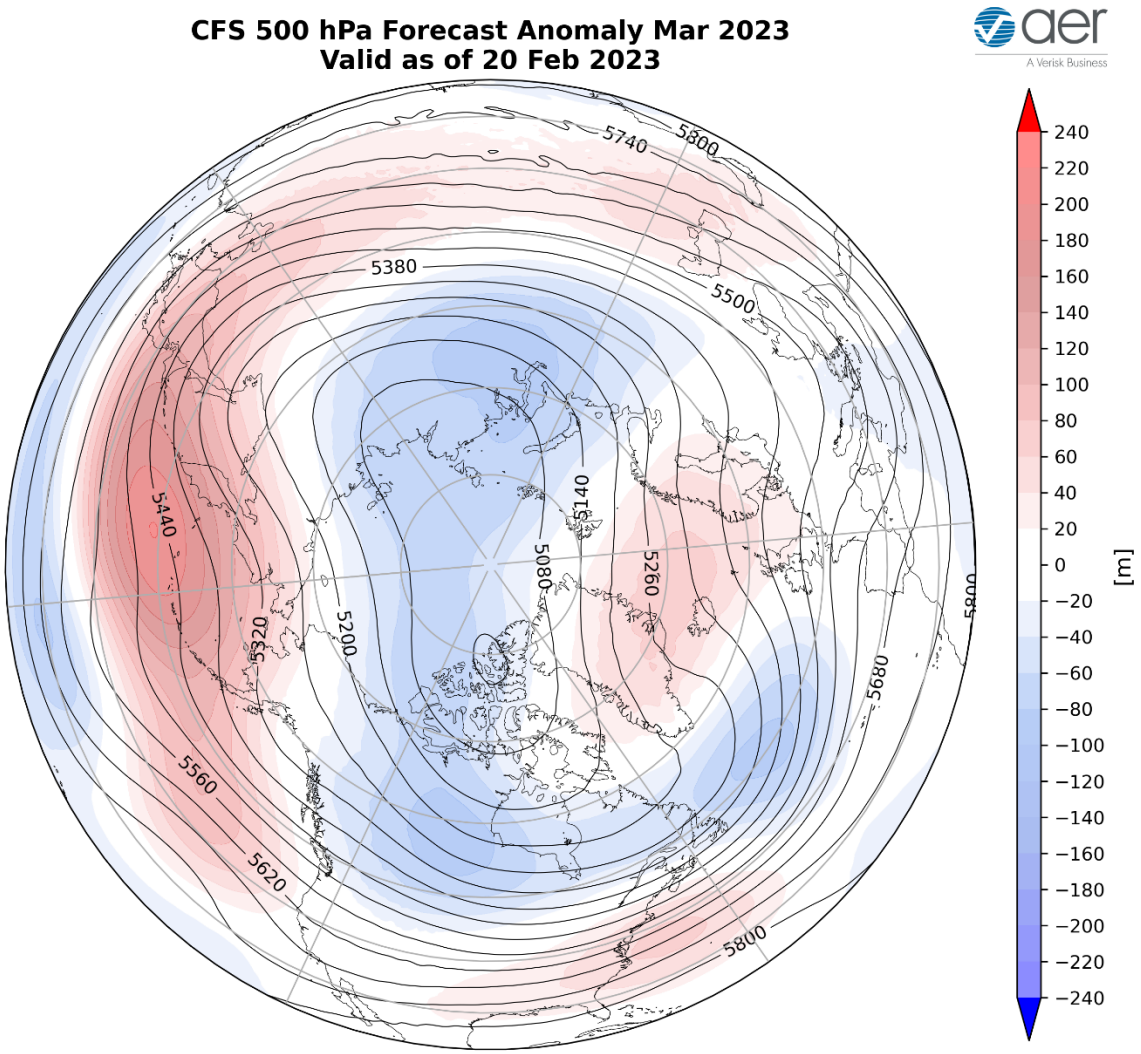


Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for March 2023. The forecasts are from the 00Z 20 February 2023 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and surface temperatures for March (**Figure 15**) from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging across Greenland to Iceland and Northern Europe, from Eastern Siberia over to western Alaska and centered near the Dateline and along the US East Coast with troughing across Eastern Europe, Northern and Eastern Asia, much of Canada and the Western US (**Figure 14).** This pattern favors seasonable to relatively warm temperatures across much of Western and Southern Europe, Southern and Eastern Asia, Eastern Siberia, and the Southern and Eastern US with seasonable to relatively cold temperatures across Eastern Europe, Northern Asia, Alaska, much of Canada and the Western and Northern US (**Figure 15**).For what it's worth the CFS

continues to predict a mid-tropospheric circulation and surface temperature pattern which is mostly consistent with a pattern forced by a major SSW, though modified by a negative Pacific-North America pattern and an overall warmer pattern across Europe than shown in historical composites of the temperature response to major SSWs. This forecast may or may not be correct.

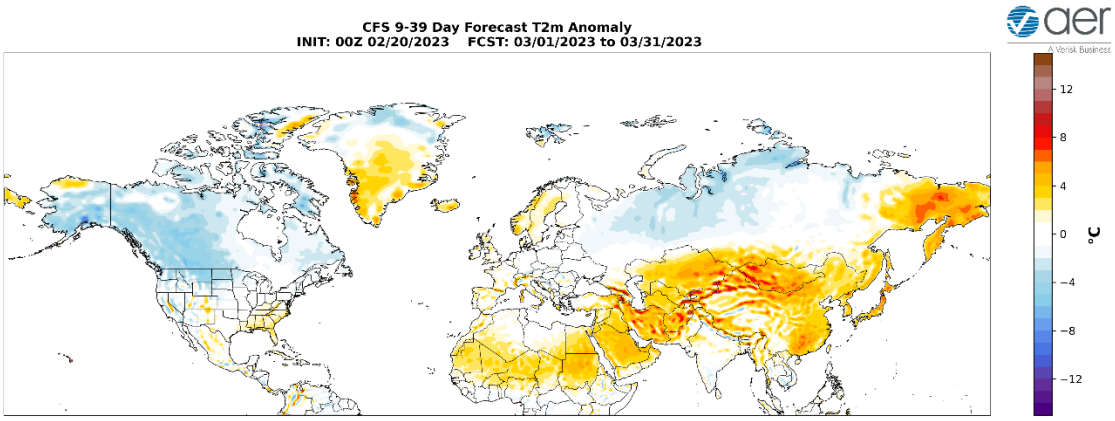


Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for March 2023. The forecasts are from the 00Z 20 February 2023 CFS.

Boundary Forcings

Arctic Sea Ice

Arctic sea ice, which as expected is below normal (see **Figure 16**) but the regional anomalies have been more extensive than in recent years. The greatest concentration of below normal remains in the Barents-Kara Seas, which I believe favors high latitude blocking. So it could be Arctic sea ice is increasingly favoring high latitude blocking in the Barents-Kara Seas region and PV disruptions. Certainly, the PV has been unusually disrupted in January and February.

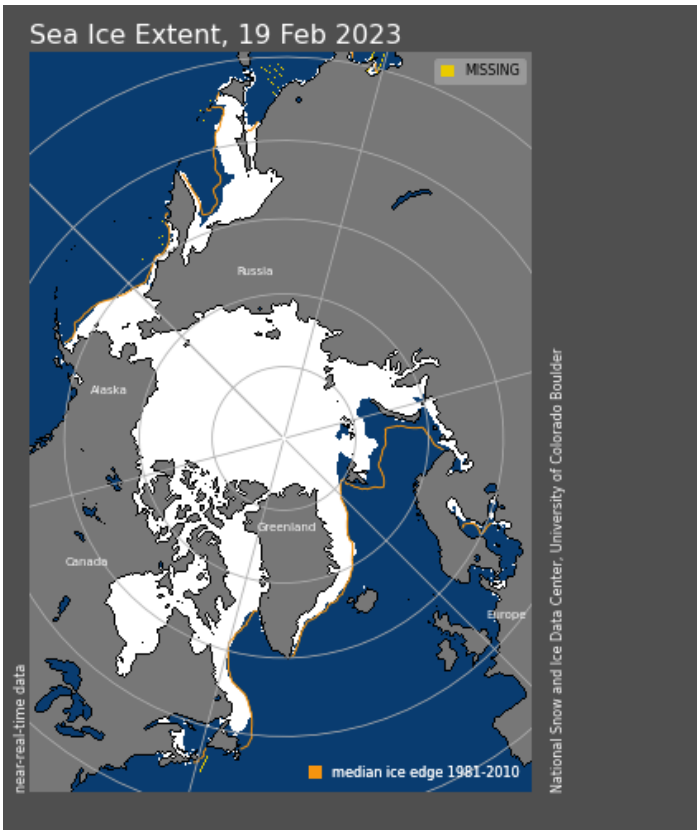


Figure 16. Observed Arctic sea ice extent on 19 February 2023 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image from the National Snow and Ice Data Center (NSIDC).

SSTs/El Niño/Southern Oscillation

Equatorial Pacific sea surface temperatures (SSTs) anomalies are below normal and we continue to observe weak La Niña conditions (**Figure 17)** and La Niña conditions are expected through the spring. Observed SSTs across the NH remain well above normal especially in the central North Pacific (west of recent years), the western North Pacific and offshore of eastern North America though below normal SSTs exist regionally especially in the South Pacific.

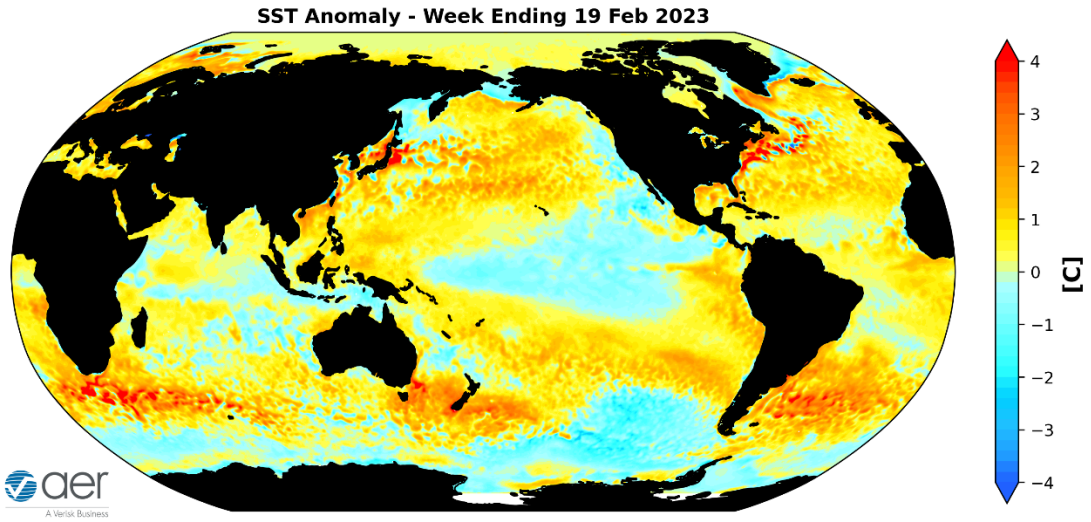


Figure 17. The latest weekly-mean global SST anomalies (ending 19 February 2023). Data from NOAA OI High-Resolution dataset.

Madden Julian Oscillation

Currently the Madden Julian Oscillation (MJO) is in phase eight (**Figure 18**). The forecasts are for the MJO to quickly weaken to where no phase is favored and then move to phases 7 and 8. Phases 7 and 8 favor high latitude blocking with troughing over the US. Seems that the MJO is having some influence on the weather across North America in the short term. So far the weather models are not predicting widespread high latitude blocking but that could change. But admittedly this is outside of my expertise.

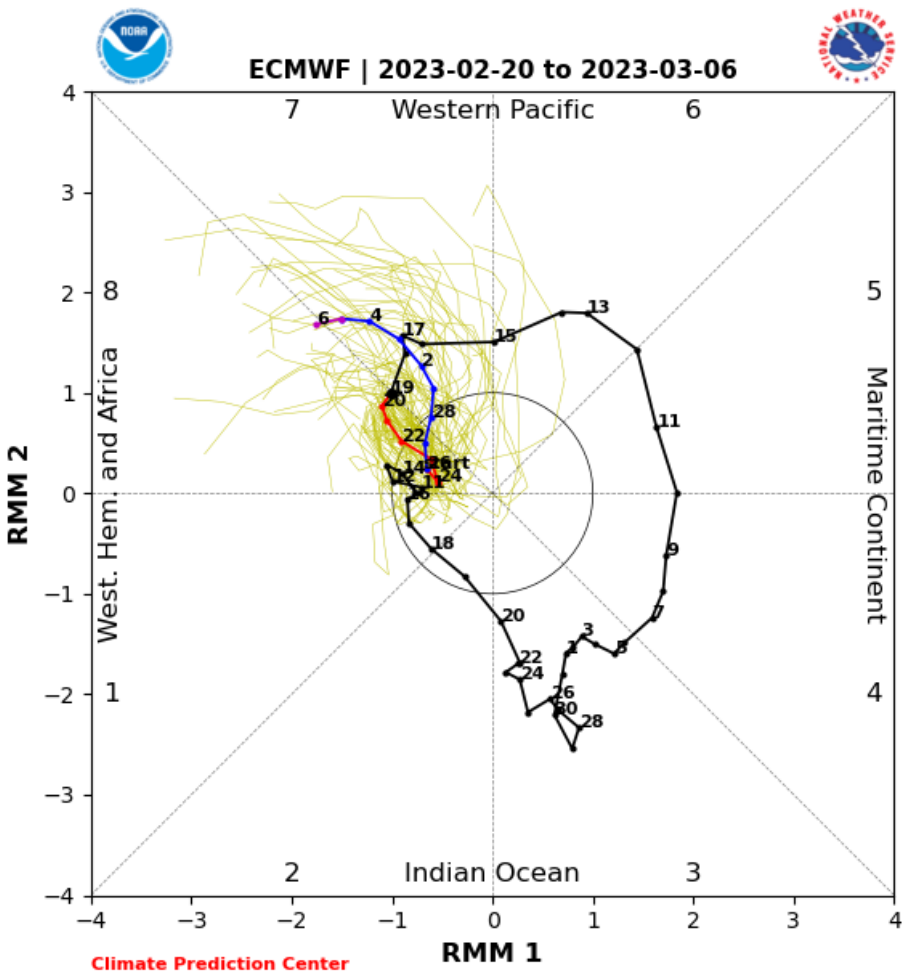
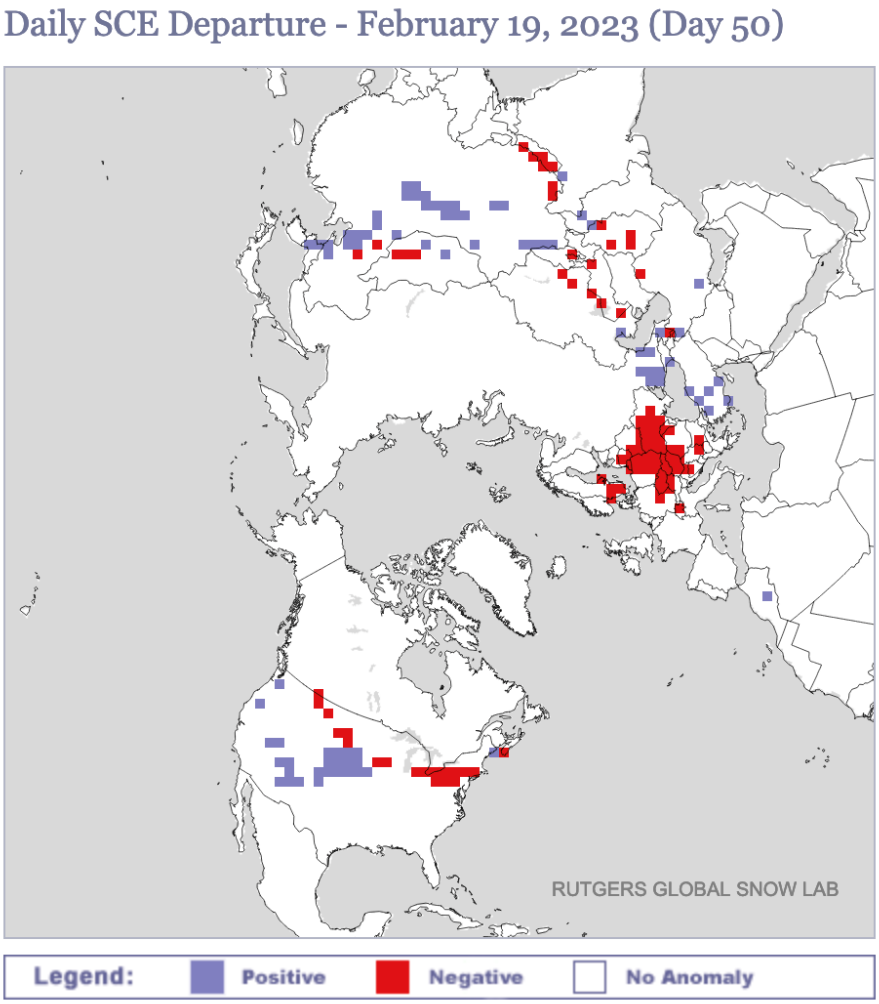


Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 13 February 2023 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model "spread" is denoted by the gray shading. Sector numbers indicate the phase of the MJO, with geographical labels indicating where anomalous convection occurs during that phase. Image source: https://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/CLIVAR/clivar_wh.shtml

Snow Cover

Snow cover extent (SCE) anomalies across the NH has increased this past week mostly across North America with above normal snow cover focused in the Western US. Meanwhile Eurasian snow cover is now below normal (see **Figure 19**). Snow cover is above normal across East Asia but snow cover extent is below normal in Central Europe and below normal the Eastern US. I expect snow cover to remain stable in the coming weeks but could pick up across the US with predicted colder weather.



\Figure 19. Observed North Hemisphere snow cover anomalies on 19 February 2023. Plot from http://climate.rutgers.edu/snowcover/index.php

Get Detailed Seasonal Weather Intelligence with sCast

We appreciate your taking the time to read the public Arctic Oscillation blog from Dr. Judah Cohen and the AER Seasonal Forecasting team.

Dr. Cohen's detailed monthly seasonal forecast, sCast, is also available for purchase. sCast provides a monthly 30-60-90-180-day outlook into temperature and precipitation, solar flux and wind anomalies across the globe, and regional population weighted cooling and heating degree forecasts for the US.

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