Arctic Oscillation and Polar Vortex Analysis and Forecasts

March 17, 2025

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. In late 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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Summary

- The Arctic Oscillation (AO) is currently positive and is predicted to trend towards neutral this week and remain near neutral next week as pressure/geopotential height anomalies across the Arctic are currently mostly negative and are predicted to become increasingly mixed over the next two weeks. The North Atlantic Oscillation (NAO) is currently negative with mostly positive pressure/geopotential height anomalies across Greenland and the NAO is predicted to trend towards neutral and then remain near neutral the next two weeks as pressure/geopotential height anomalies are predicted to become increasingly mixed across Greenland.
- Over the next two weeks Europe is predicted to be dominated by ridging/positive geopotential height anomalies with the exceptions of troughing/negative geopotential height anomalies across Southeastern Europe this week and then Western Europe next week. This pattern will support widespread normal to above normal temperatures across Europe including the United Kingdom (UK) with the exceptions of normal to below normal temperatures across Southeastern Europe this week and then far Western Europe next week.
- This week Asia all be dominated by ridging/positive geopotential height anomalies with the exception of troughing/negative geopotential height anomalies across Southeastern Asia. However next week Asia the influence from the sudden stratospheric warming will

deepen troughing/negative geopotential height anomalies across Siberia that will slide southeastward into Northeast Asia. This pattern favors this week widespread normal to above normal temperatures across Asia with normal to below normal temperatures limited to Southeast Asia and then next week normal to below normal temperatures will spread across Siberia and then push into Northeast Asia.

- The general pattern across North America this week is troughing/negative geopotential height anomalies across Alaska, Northern and Western Canada and the Western United States (US) with ridging/positive geopotential height anomalies across the East coast of North America. The next week the pattern will flip with ridging across western North America and troughing in eastern North America. This patten will favor widespread normal to below normal temperatures across Alaska, Western and Central Canada and the Western US with normal to above normal temperatures across Eastern Canada and the Eastern US. Then next week normal to above normal temperatures will spread across Alaska, Western Canada and the Western US with normal to below normal temperatures across Eastern Canada and the Eastern US.
- A long duration sudden stratospheric warming (SSW) will increasingly influence the weather across the Northern Hemisphere. What might we expect?
- Next week I am attending a workshop on the Arctic in Colorado. This is likely will result in an interruption to the blog schedule and I may even spring forward to the summer schedule.

Plain Language Summary

What do they say, March comes in like a lion and out like a lamb. From the Northern Hemisphere (NH) surface temperature anomalies for March so far, it has mostly come in like a lamb (see **Figure**). Maybe following the large polar vortex (PV) disruption of last week the script will be flipped and March will go out like a lion.

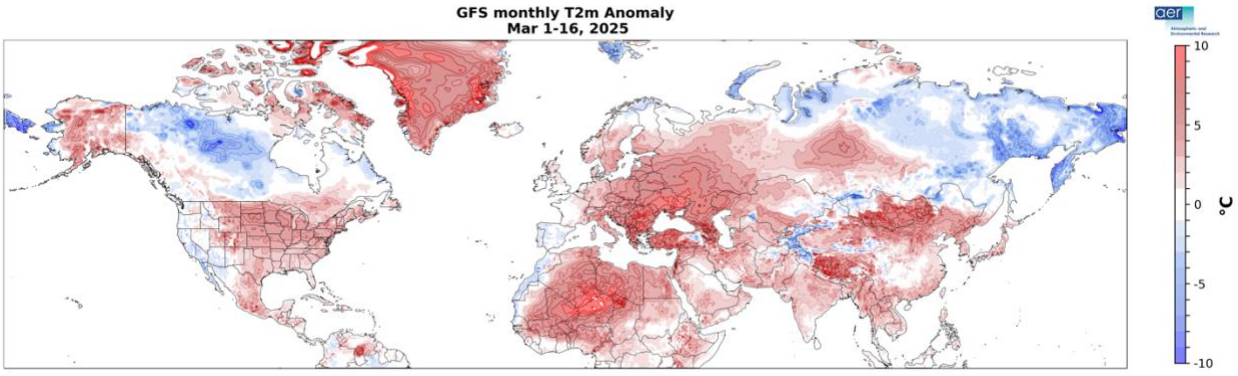

Figure. Estimate of the observed surface temperatures (°C; shading) from 01 Mar to 16 Mar 2025 based on GFS initializations and the GFS forecast from the 17 Mar 2025 run.

Impacts

I want to start this week's blog validation for the AER Northern Hemisphere (NH) winter surface temperature anomalies in **Figure ia**. The forecast was made public prior to the beginning of the winter and posted to the 25 November 2024 blog. This was a highly unusual winter from the behavior of the polar vortex (PV) and the tropospheric circulation with rapid variability (especially the PV), yet for a winter forecast, I think the AER forecast was excellent and I am proud of how the model performed. It was not perfect and obviously missed details (and if that missed occurred in your neighborhood that is not trivial) but the model accurately predicted the large-scale temperature pattern across the NH (**Figure ib**). The model correctly predicted relatively cold temperatures in western/central North America and parts of Central Asia, Siberia and China with widespread relatively mild temperatures elsewhere across the continents of the NH.

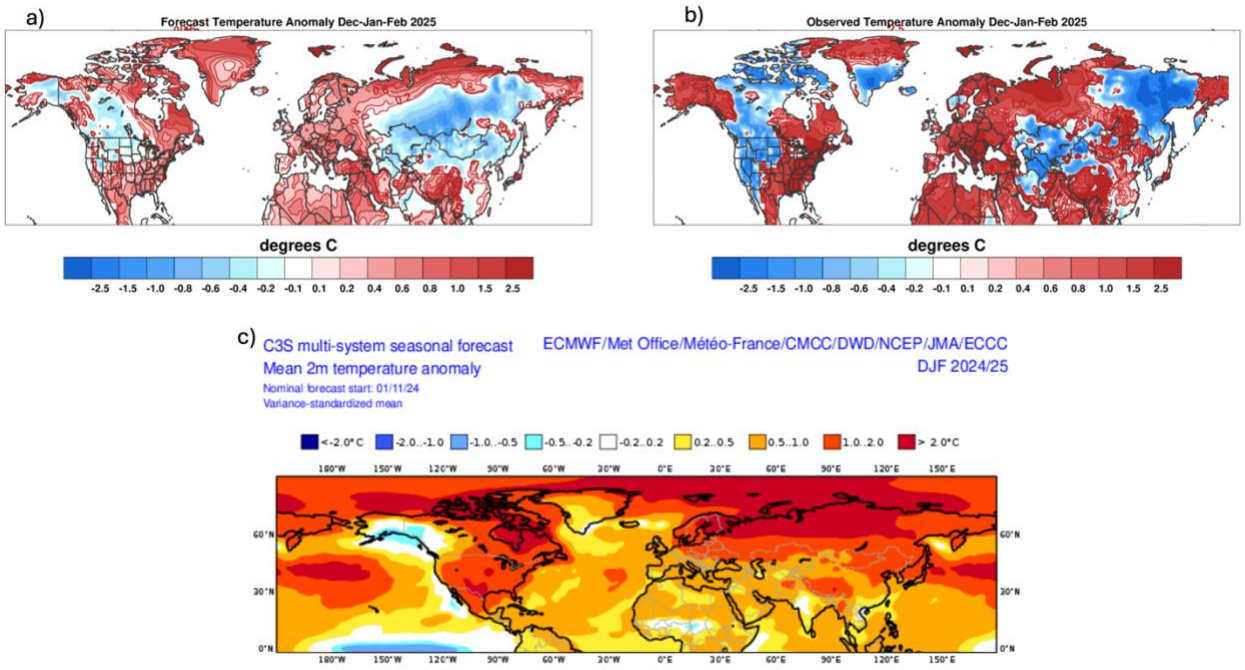

Figure i. a) The AER winter surface temperature anomaly forecast for December 2024, January and February 2025 using ERA5 reanalysis data, b) the observed winter surface temperature anomaly forecast for December 2024, January and February 2025 using ERA5 reanalysis data and c) the C3S winter temperature anomaly forecast for December 2024, January and February 2025 (plot taken from https://climate.copernicus.eu/).

If you are looking at your locale (like me!) and saying wait the observed temperature doesn't match my experience this winter, keep in mind grid size, some smoothing and I think a warm bias in ERA5 might mask the real temperature anomaly. Here in New England, it was a relatively cold winter (though not by much) and that is not showing up in my plot. I searched for other NH winter surface temperature anomaly plots and so far, could not find any. I will be curious to see the same plot from Copernicus.

As is often the case, regardless of how you rate the AER winter forecast, I doubt anyone would argue that it wasn't better than the dynamical model winter forecasts. When I posted the AER winter forecast, I only included the C3S winter forecast shown in **Figure 1c**. As is the case now every winter the dynamical models predict universal warmth, modified ever so slightly by the phase of ENSO in North America. Since it was anticipated to be a La Niña winter there is some token cold in Southern Alaska, which turned out to be wrong anyway.

I argue the difference between the AER statistical model and the dynamical models is the influence of Arctic predictors through a polar vortex pathway to the mid-latitudes. Fall Arctic sea ice and Eurasian snow cover anomalies are key predictors in the model along with ENSO. But it never ceases to amaze me how little a correct forecast persuades many academics and those involved with operational forecast in the large government forecast centers. At this point probably the most often presented criticism of my ideas is all that I am arguing/presenting cannot be attributed to Arctic and/or PV forcing but rather natural or internal variability. It is really hard to get a winter forecast correct even once, something that can only be truly appreciated by someone who has actually tried it in real time. But the AER winter forecast outperforms the dynamical models consistently year after year. I refuse to believe that is possible only out of sheer luck. If I were that lucky, I wouldn't be spending the time writing the blog but rather playing the lottery or roulette. This is a subject I can discuss at great length but now back to the forecast discussion.

All the models are in consensus that the ongoing sudden stratospheric warming (SSW and is defined to occur when the zonal-mean zonal wind at 10 hPa and 60°N drops below zero m/s or easterly) will be of long duration and likely result in a Findal warming (PV will not return until next fall). The SSW briefly resulted in a PV split with one PV center over Northeastern Europe and the other over the Northeastern US. The minor PV center will be over the Northeastern US continues to quickly sail west and is currently over the Western US. But based on **Figure ii**, another PV split can occur with the minor PV center passing over the Northeastern US. The European operational model has been even more emphatic, predicting the major PV center over the Northeastern US for early April. That seems to me, to be highly unusual.

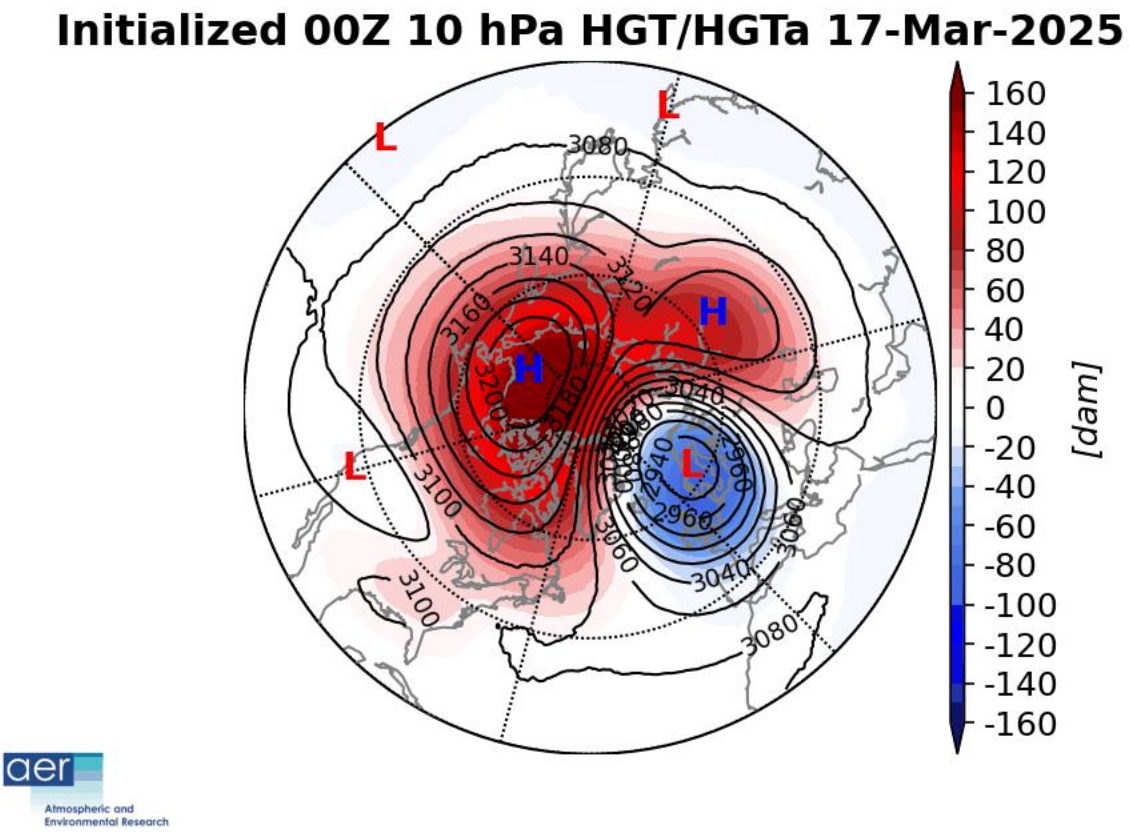

Figure ii. Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 17 Mar 2025 and forecasted from 18 Mar to 01 Apr 2025. The forecasts are from the 00Z 17 Mar 2025 GFS model ensemble.

The classical response to SSWs is Greenland high pressure or blocking that favors relative cold temperatures across Northern Europe and Northern Asia. Some Greenland blocking occurred right at the time of the SSW last week. This did result in colder for Western and Northern Europe coupled that is quickly coming to an end. But famously the influence from an SSW occurs episodically and appears to drip down from the stratosphere to the surface like paint dripping on a wall in vertical plots of the AO or polar cap geopotential height anomalies (PCHs) as show in **Figure 11**. And as can be seen in **Figure 11**, the first real drip of PCHs is predicted to occur the last week of March. This will almost certainly result in an increase in high-latitude blocking but where in my opinion remains uncertain. It could result in the classical SSW response, Greenland blocking (see **Figure iii**). This could bring with it cooler weather for Northern Europe and/or the Eastern US. With or without Greenland blocking, the forecast for the Eastern US is cooler weather to close out March due to strengthening ridging/positive geopotential height anomalies in western North America. The latest model forecasts are for the high-latitude blocking to be focused in the Eurasian Arctic at the end of March (see **Figure 9**) and that would favor cooler weather in Northeast Asia including China and not Europe and the Eastern US.

As I discussed last week, the main warm/positive PCHs are in the stratosphere the next two weeks (see **Figure 11**). For the SSW to have the biggest impact our weather the warm/positive PCHs need to make it to the lower troposphere and there is still no sign of that occurring in the two-week forecasts. The earliest that would occur is sometime in late April and possibly even May. So, in the meantime we get to enjoy the episodic or dripping influence of the SSW, or multiple appetizers while we await the main course.

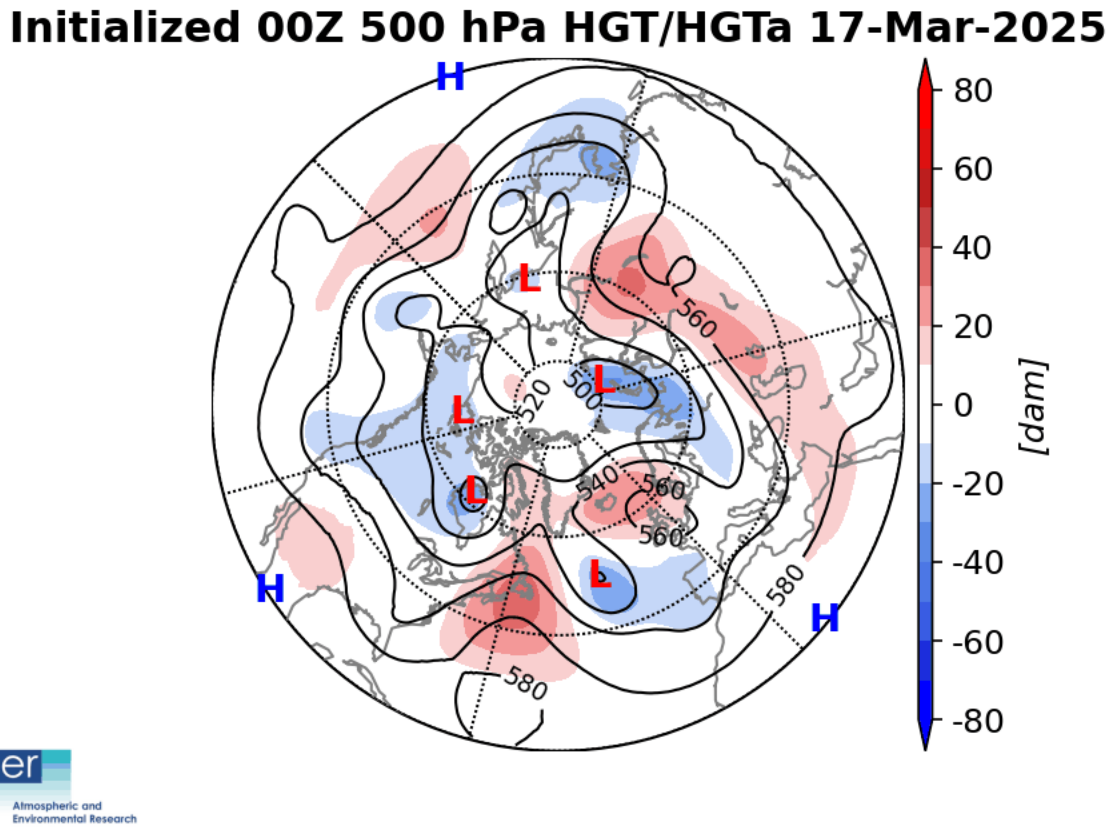

Figure iii. Initialized 500 mb geopotential heights (dam; contours) and decameter anomalies (dam; shading) across the Northern Hemisphere for 17 Mar 2025 and forecasted from 18 Mar to 01 March 2025. The forecasts are from the 00Z 17 Mar 2025 GFS model ensemble.

The quickest way to maximize the impact in the US from the SSW, is for wave reflection to occur. SSWs themselves create a favorable environment for wave reflection and stretched PVs in the weeks following the SSW. Once again, I present the energy diagnostics that are used to display the presence or absence of wave reflection. No wave reflection is predicted this week or next week (see **Figure iva**). The energy diagnostics for the last few days of March are suggestive of wave reflection (see **Figure ivb**). Again, not sure how much I believe this particular forecast, but something to monitor in the coming weeks.

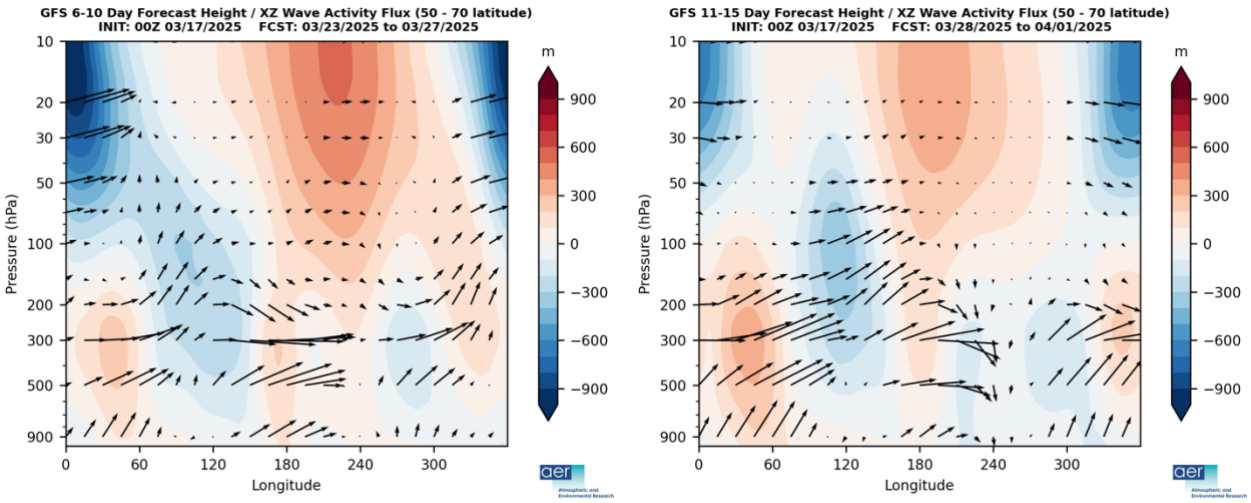

Figure iv. Longitude-height cross section of geopotential eddy height anomalies (shading) and wave activity flux (vectors) a) predicted for 23 Mar through 27 Mar 2025 and b) forecasted for 28 Mar through 01 Apr 2025. The forecasts are from the 00Z 17 Mar 2025 GFS ensemble.

I created the blog for these types of situations but really hard for me to get excited about this SSW. As I shared last week, the SSW is two months too late. If the SSW occurred on 10 January instead of 10 March, this could likely be the single most important weather event of the winter, having a large and lasting impact on our weather. But given that the spring equinox is imminent, the SSW is more likely to result in chilly and wet weather rather than cold and snowy weather, outside of higher elevations and higher latitudes. As they say hoping for a better year next year and seasonally appropriate – hope springs eternal.

Near-Term

This week

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

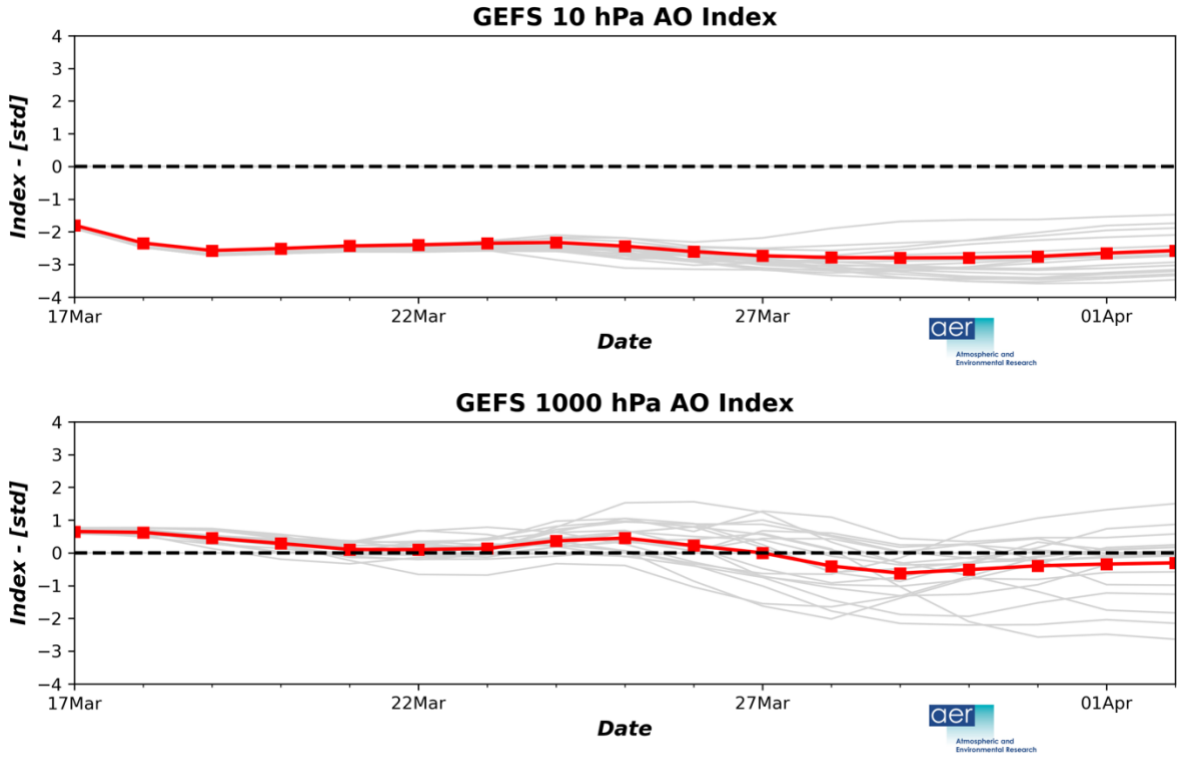

Figure 1. a) The predicted daily-mean AO at 10 hPa from the 00Z 17 Mar 2025 GFS ensemble. b) The predicted daily-mean AO at 1000 hPa from the 00Z 17 Mar 2025 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble mean AO index given by the red line with squares.

This week ridging/positive geopotential height anomalies will dominate Europe with the exception of troughing/negative geopotential height anomalies across Southern and Eastern Europe (**Figures 2).** This pattern will favor widespread normal to above normal temperatures across much of Europe including the UK with normal to below normal temperatures limited to Southern and Eastern Europe this period (**Figure 3**). This week ridging/positive geopotential height anomalies will dominate much of Asia with troughing/negative geopotential height anomalies mostly limited to Southeastern Asia (**Figure 2**). This pattern favors normal to above normal temperatures widespread across much of Asia with normal to below normal temperatures limited to Southeast Asia **(Figure 3**).

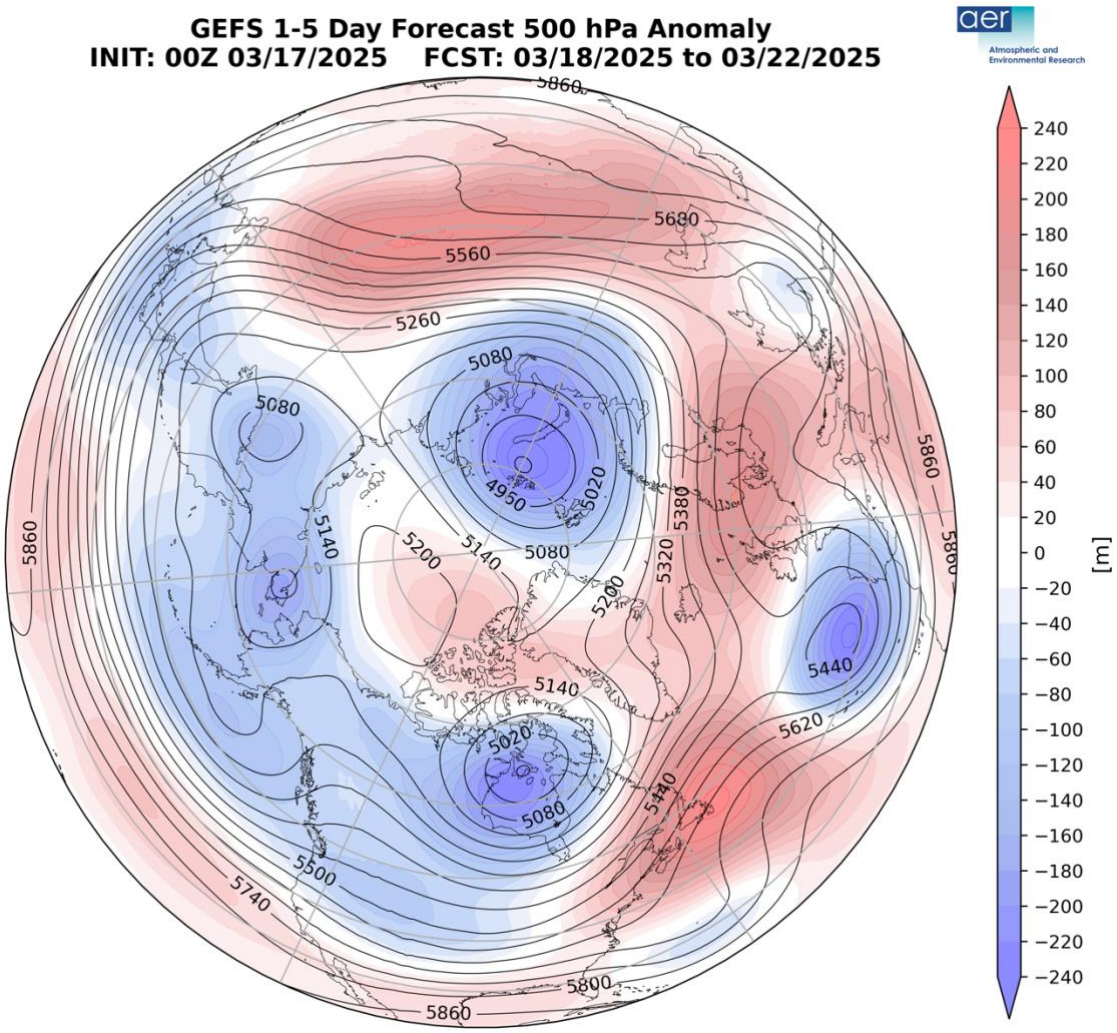

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 18 Mar to 22 Mar 2025. The forecasts are from the 00Z 17 Mar 2025 GFS ensemble.

This week troughing/negative geopotential height anomalies across Alaska, Northern and Western Canada and the Western US will support ridging/positive geopotential height anomalies across the East Coast of Canda and the East Coast of US. (**Figure 2**). This pattern favors widespread normal to below normal temperatures across Alaska, Northern and Western Canada and the Western US with normal to above normal temperatures across Eastern Canada and the Eastern US. (**Figure 3**).

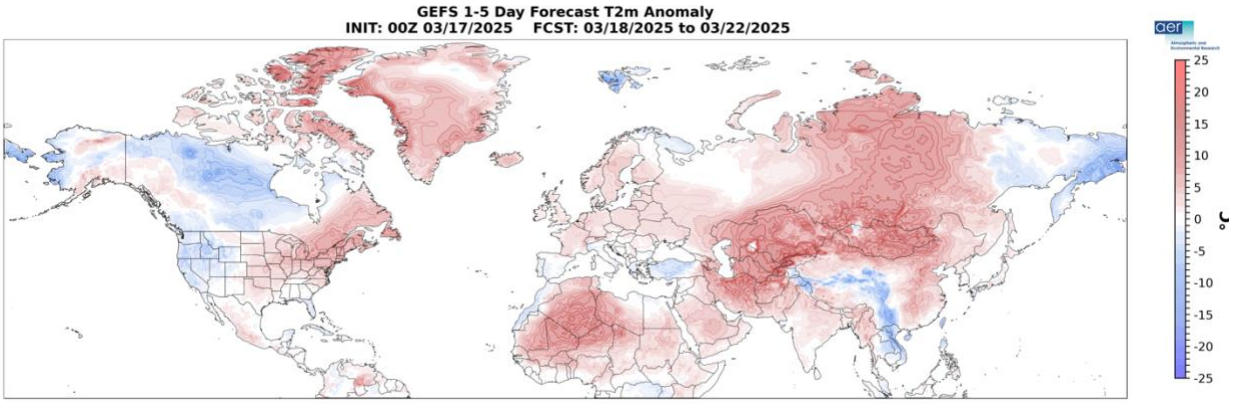

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 18 Mar to 22 Mar 2025. The forecasts are from the 00Z 17 Mar 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across parts of Siberia and the Caucuses while warm temperatures will support widespread snowmelt across Scandinavia, Northern Asia and the Tibetan Plateau this week (**Figure 4**). Troughing and/or cold temperatures will support new snowfall across Northern Canada and parts of the Western US while warm temperatures will support snowmelt in central Alaska, Western and Southern Canada and California this week (**Figure 4**).

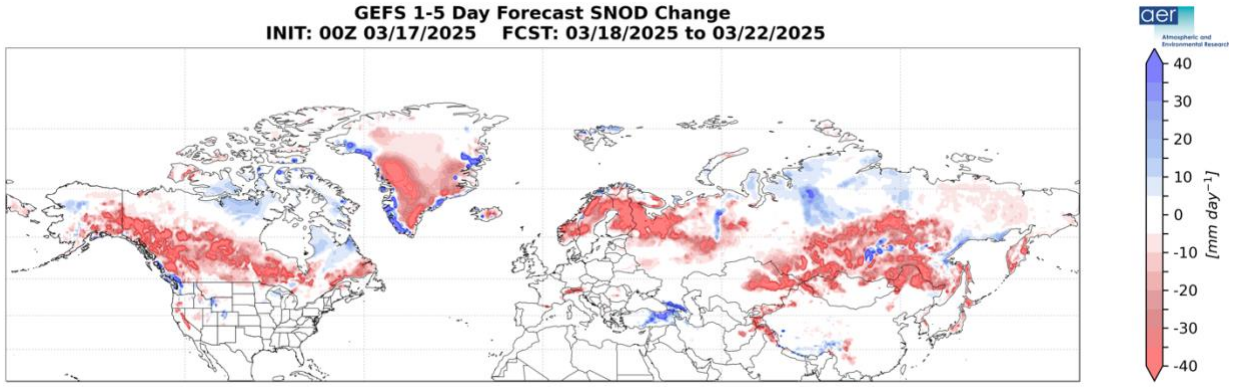

Figure 4. Forecasted snow depth changes (mm/day; shading) from 18 Mar to 22 Mar 2025. The forecasts are from the 00Z 17 Mar 2025 GFS ensemble.

Near-Mid Term

Next week

With geopotential height anomalies becoming mostly mixed across the Arctic and with mixed geopotential height anomalies across the mid-latitudes this period (**Figure 5**), the AO will likely be near neutral this period (**Figure 1**). With predicted mixed pressure/geopotential height anomalies across Greenland (**Figure 5**), the NAO will likely be near neutral this period.

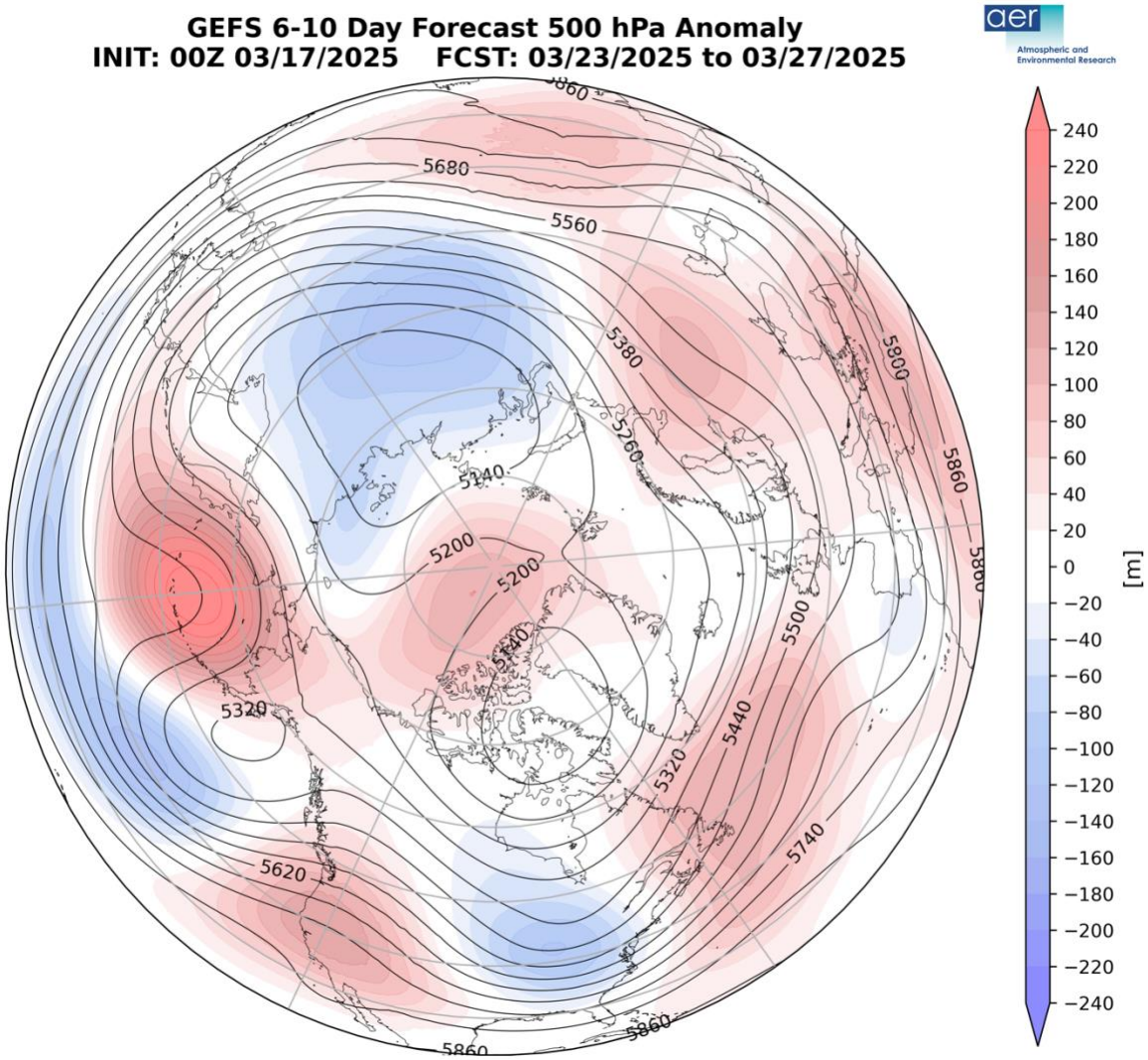

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 23 Mar to 27 Mar 2025. The forecasts are from the 00Z 17 Mar 2025 GFS ensemble.

Once again ridging/positive geopotential height anomalies are predicted to dominate Europe with the exception of troughing/negative geopotential height anomalies across the Iberian Peninsula (**Figure 5**). This pattern favors widespread normal to above normal

temperatures across much of Europe including the UK with normal to below normal temperatures limited to Spain and Portugal this period (**Figure 6**). Ridging/positive geopotential height anomalies will continue to dominate Asia with deepening troughing/negative geopotential height anomalies across Siberia (**Figure 5**). This pattern favors widespread normal to above normal temperatures across most of Asia with normal to below normal temperatures limited to Northern Siberia this period (**Figure 6**).

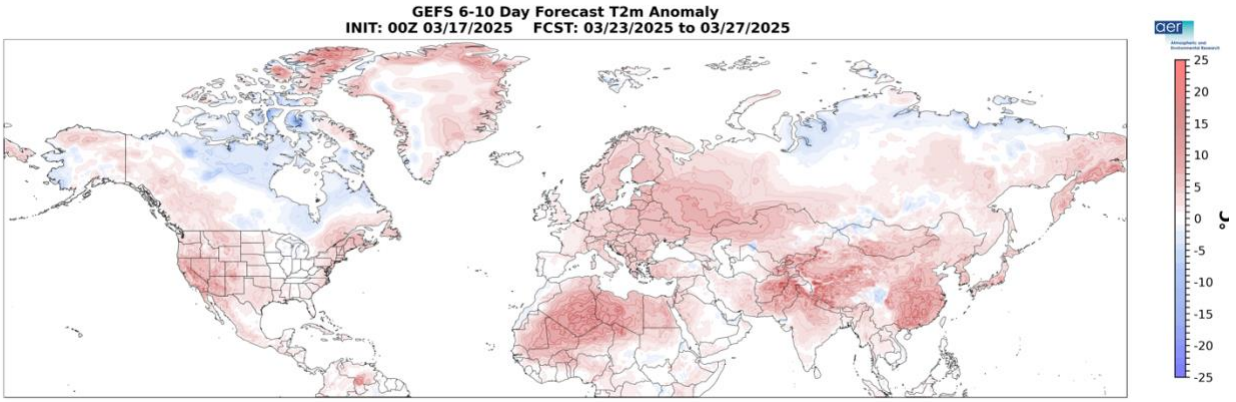

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 23 Mar to 27 Mar 2025. The forecasts are from the 00Z 10 Mar 2025 GFS ensemble.

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

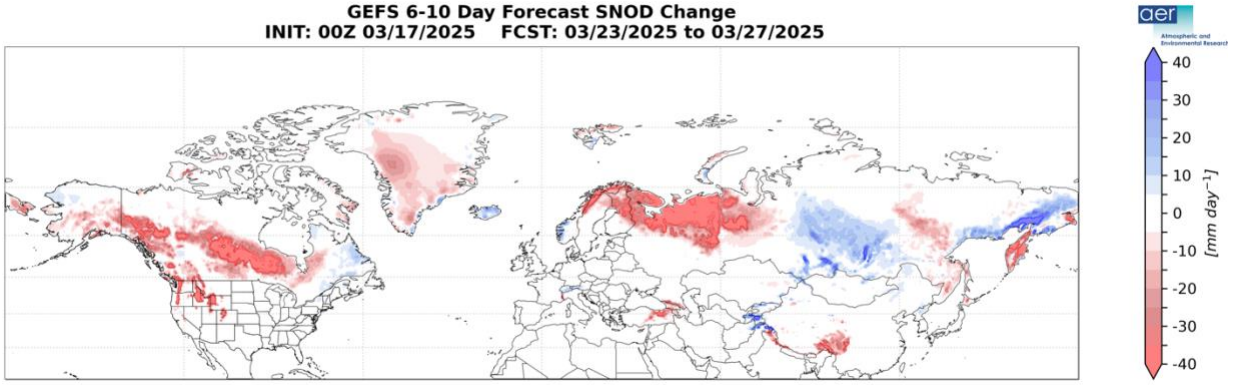

Figure 7. Forecasted snow depth changes (mm/day; shading) from 23 Mar to 27 Mar 2025. The forecasts are from the 00Z 17 Mar 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across the Alps, parts of Siberia and the Tibetan Plateau while warm temperatures will support snowmelt in Scandinavia, Northwest Russia, Southeastern Siberia and Northeast Asia this period (**Figure**

7). Troughing and/or cold temperatures will support new snowfall across western Alaska, the Eastern Canada and new England while warm temperatures will support snowmelt across southern Alaska, Western and Southern Canada and the Western US this period (**Figure 7**).

Mid Term

Week Two

With predicted persistent mostly mixed geopotential height anomalies across the Arctic and mixed geopotential height anomalies across the mid-latitudes this period (**Figure 8**), the AO will likely remain close to neutral this period (**Figure 1**). With predicted slightly positive pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO will likely be neutral to negative this period.

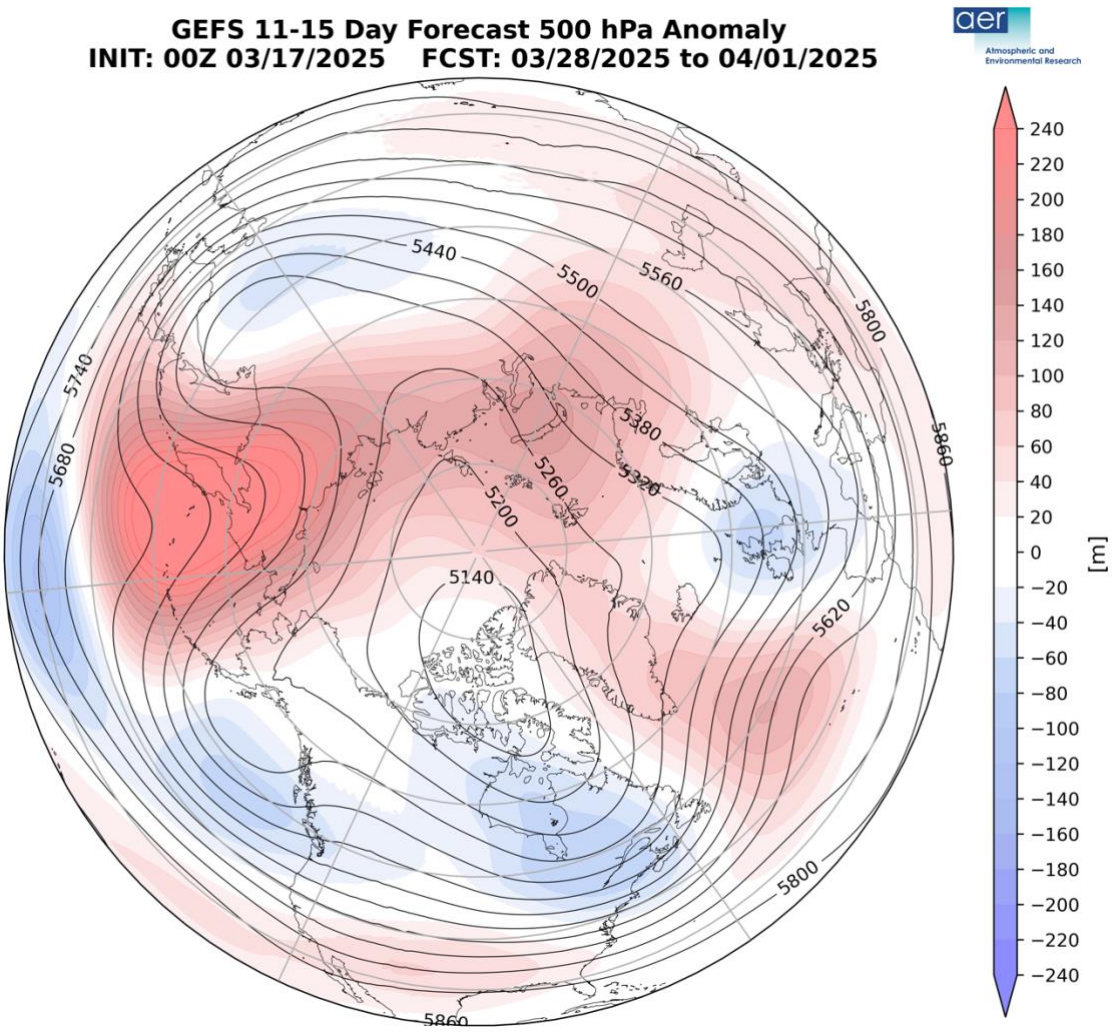

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 28 Mar to 01 Apr 2025. The forecasts are from the 00Z 17 Mar 2025 GFS ensemble.

Strengthening ridging/positive geopotential height anomalies across Greenland will support troughing/negative widespread geopotential height anomalies across Western Europe with ridging/positive geopotential height anomalies across Eastern Europe this period (**Figure 8**). This pattern should favor normal to above normal temperatures widespread across much of Europe with normal to below normal temperatures across Western Europe including the UK this period (**Figures 9**). Ridging/positive geopotential height anomalies will become focused across Western Asia and the Eurasian Arctic with troughing/negative geopotential height anomalies digging into Northeast Asia this period (**Figure 8**). The predicted pattern favors widespread normal to above normal temperatures across most of Asia with normal to below normal temperatures mostly limited to parts of Northeastern Asia this period (**Figure 9**).

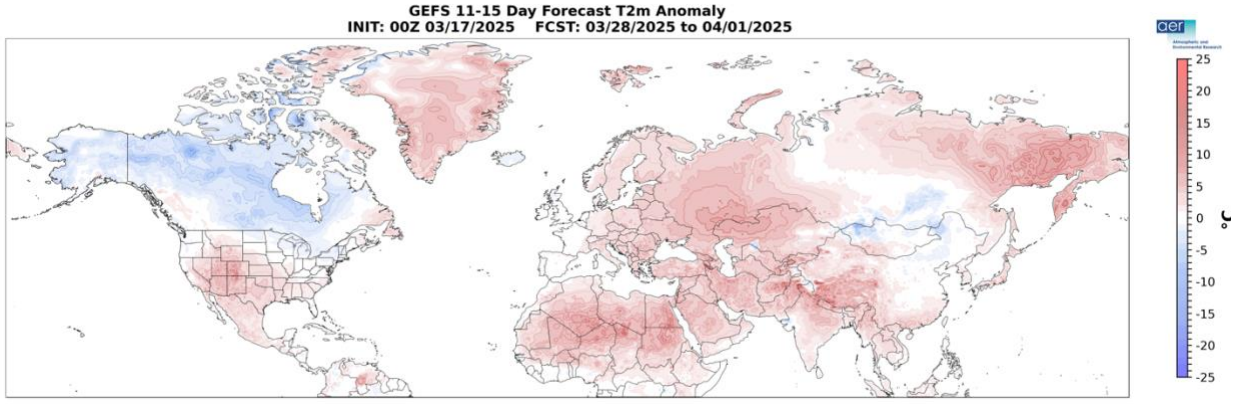

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 28 Mar to 01 Apr 2025. The forecasts are from the 00Z 17 Mar 2025 GFS ensemble.

Strengthening ridging/positive geopotential height anomalies just west of the Dateline will support troughing/negative geopotential height anomalies across Alaska and much of Canada with ridging/positive geopotential height anomalies across the Southern US will also favor mostly zonal flow across the US this period (**Figure 8**). This pattern supports normal to below normal temperatures across Alaska, much Canada and the far Northern US with normal to above normal temperatures across most of the US this period (**Figure 9**).

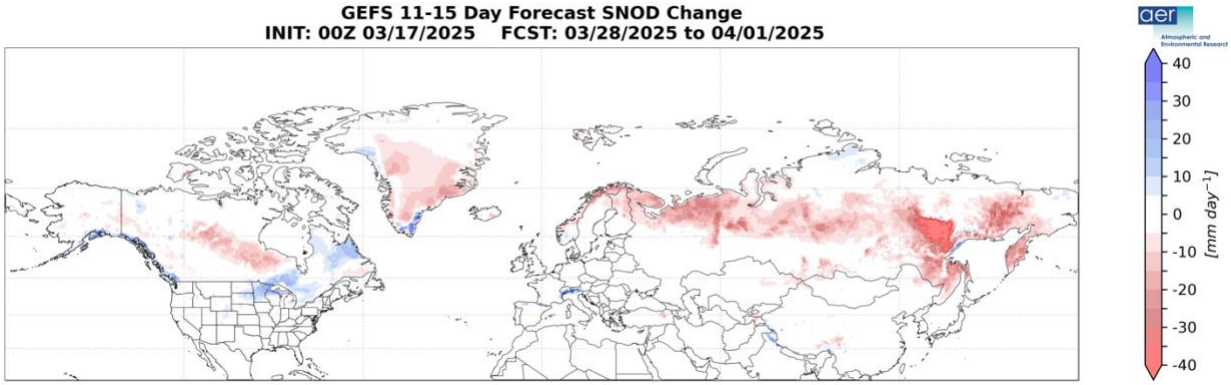

Figure 10. Forecasted snow depth changes (mm/day; shading) from 28 Mar to 01 Apr 2025. The forecasts are from the 00Z 17 Mar 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across the Alps and the Tibetan Plateau while warm temperatures will support snowmelt in Scandinavia, and widespread across Siberia and Northeast Asia and this period (**Figure 10**). Troughing and/or cold temperatures will support new snowfall across parts of Eastern Canada and the US Upper Midwest while warm temperatures will support snowmelt in Central Canada this period (**Figure 10**).

Longer Term

30–day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows warm/positive PCHs in the throughout the stratosphere and upper troposphere with cold/negative PCHs in the mid to lower troposphere (**Figure 11**). The strong warm/positive PCHs in the upper stratosphere are predicted to descend all the way to the surface next week. The warm/positive PCHs in the stratosphere represent a sudden stratospheric warming (SSW) or even possibly a final warming.

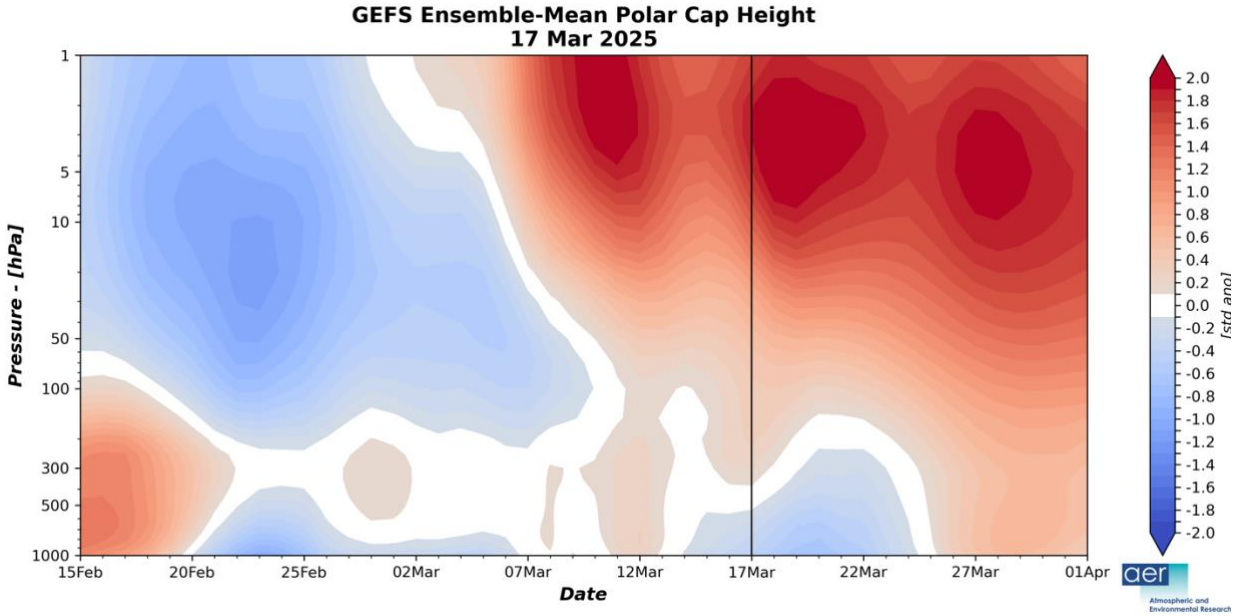

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 17 Mar 2025 GFS ensemble.

The predicted cold/negative PCHs in the lower troposphere this week (**Figure 11**) are consistent with the predicted positive surface AO this week (**Figure 1**). Then as the warm/positive PCHs descend to the lower troposphere next week, the surface AO is predicted to turn more negative. I feel that the AO could eventually become more negative than currently predicted.

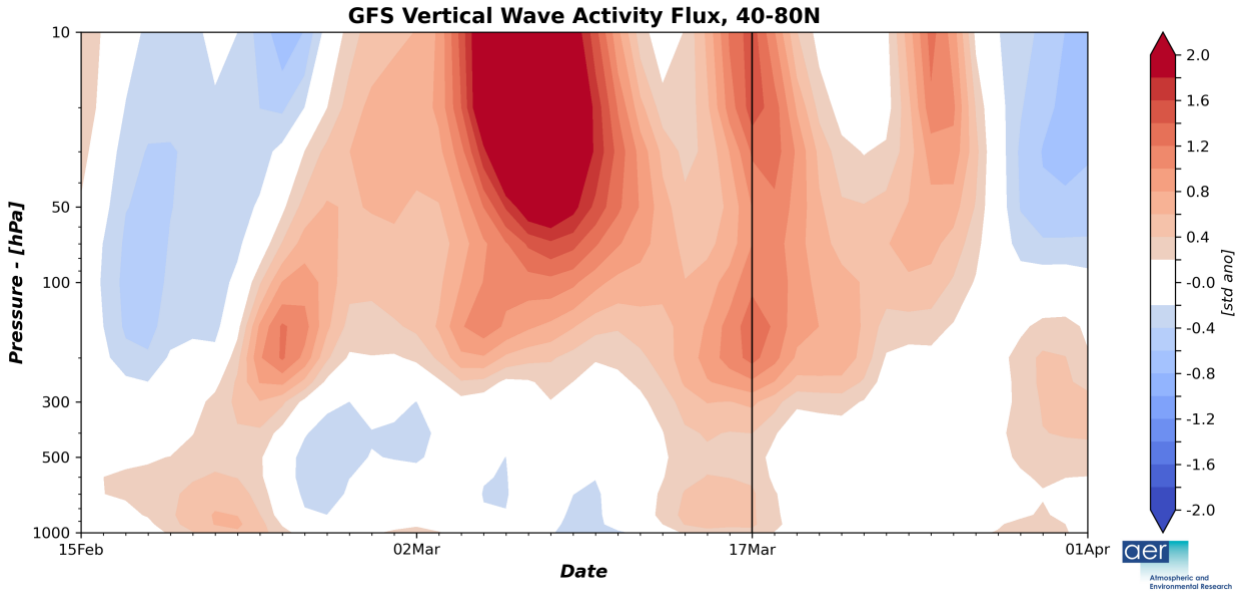

Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 17 Mar 2025 GFS ensemble.

Vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere has been very active since early February (**Figure 12**). The strongest WAFz pulse of the season peaked two weeks ago (**Figure 12**). This large pulse trigger the ongoing SSW this week. Now that we have a mature SSW, WAFz should turn quitter.

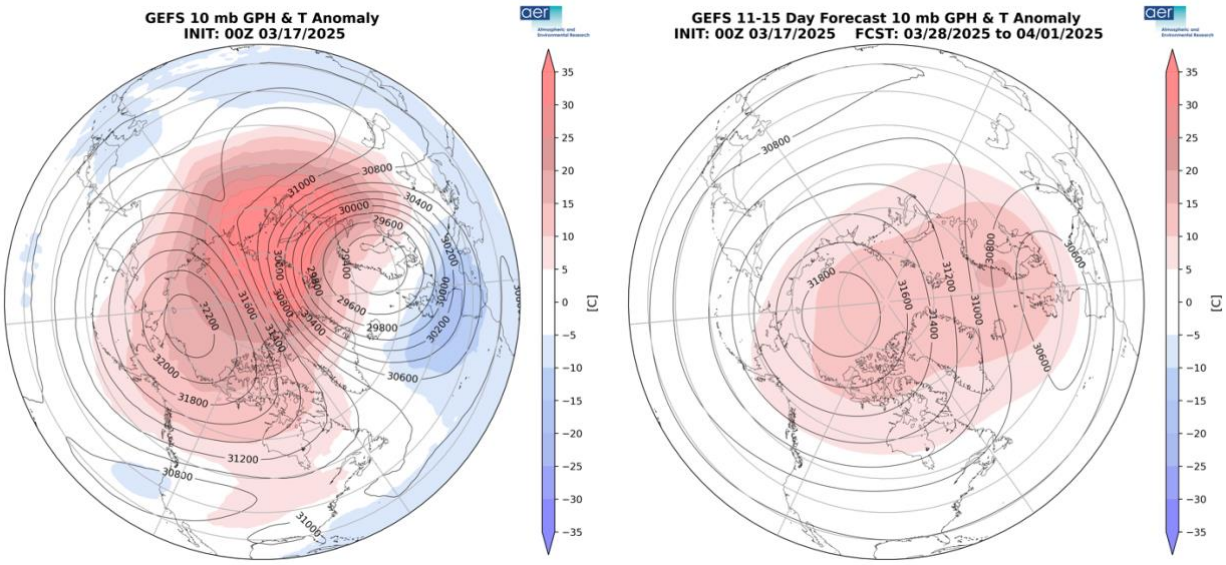

Figure 13. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 17 Mar 2025. (b) Same as (a) except forecasted averaged from 28 Mar to 01 Apr 2025. The forecasts are from the 00Z 17 Mar 2025 GFS model ensemble.

Currently the polar vortex (PV) is split with the major center over Scandinavia and the minor center over the Western US with relatively coldest temperatures across Europe with high-pressure ridging centered over the Beaufort Sea but extending into Canada and the relatively warmest temperatures across Siberia into the Central Arctic in the polar stratosphere (**Figure 13a**). This is consistent with a PV split type of SSW. Then in late-March the PV is predicted to be centered over the UK with ridging still centered over the Beaufort Sea in the polar stratosphere. The relatively coldest temperatures are predicted across mid-latitudes and the warmest temperatures spread across the Arctic and Northern Europe in the stratosphere (**Figure 13b**). This is consistent with an SSW. The stratospheric AO in **Figure 1** this week and next week will be persistently deeply negative, consistent with an SSW.

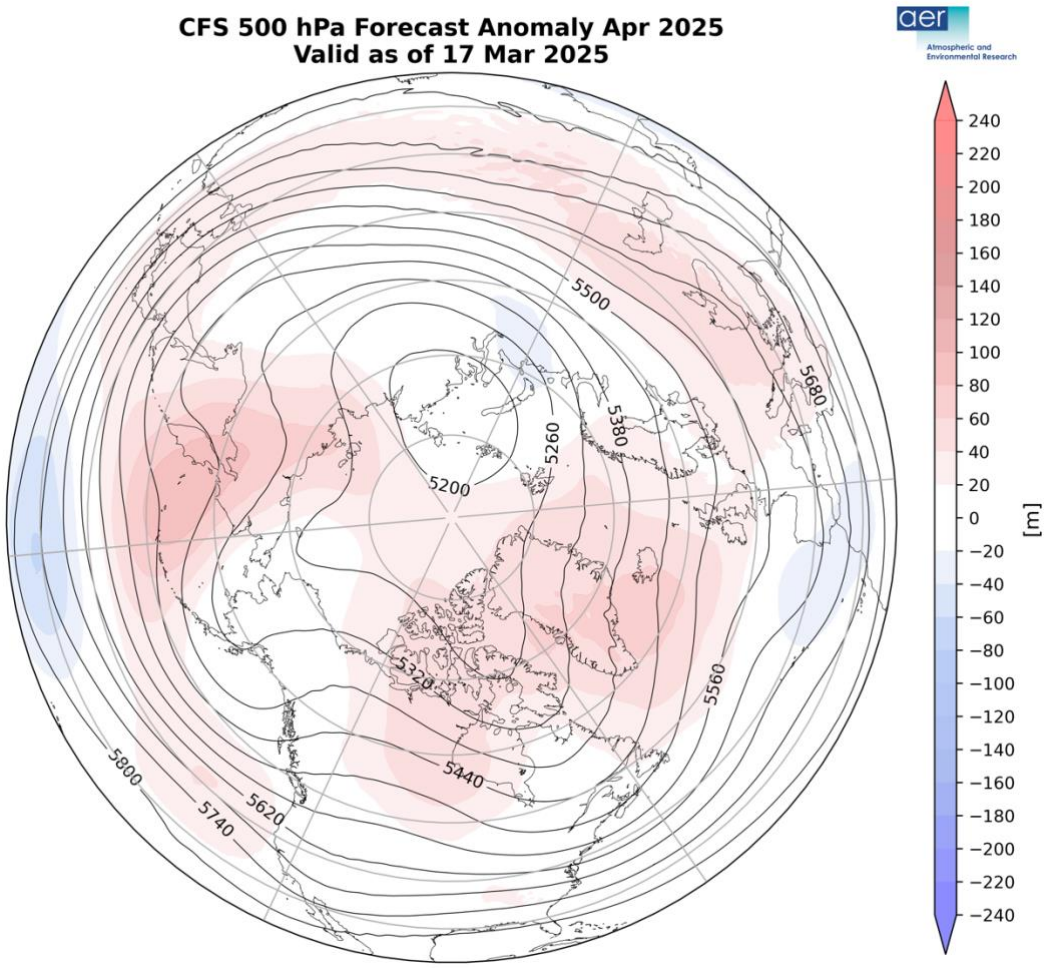

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for April 2025. The forecasts are from the 00Z 17 Mar 2025 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and surface temperatures for April (**Figure 15**) from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging centered across Greenland and the northern North Atlantic, Southeastern Europe, Southwest Asia, Eastern Siberia and the Dateline and the Western Canada with troughing across Western Europe, Northern and Eastern Asia, Alaska, Eastern Canada and the Northeastern US (**Figure 14**). This pattern favors seasonable to relatively warm temperatures across Eastern Europe, much of Asia, especially Southern Asia, Eastern Siberia, Alaska, Western and Northern Canada and the Western US with seasonable to relatively cold temperatures across Western Europe, Southern Siberia, Northeast Asia, Southeastern Canada and the Eastern US (**Figure 15**).

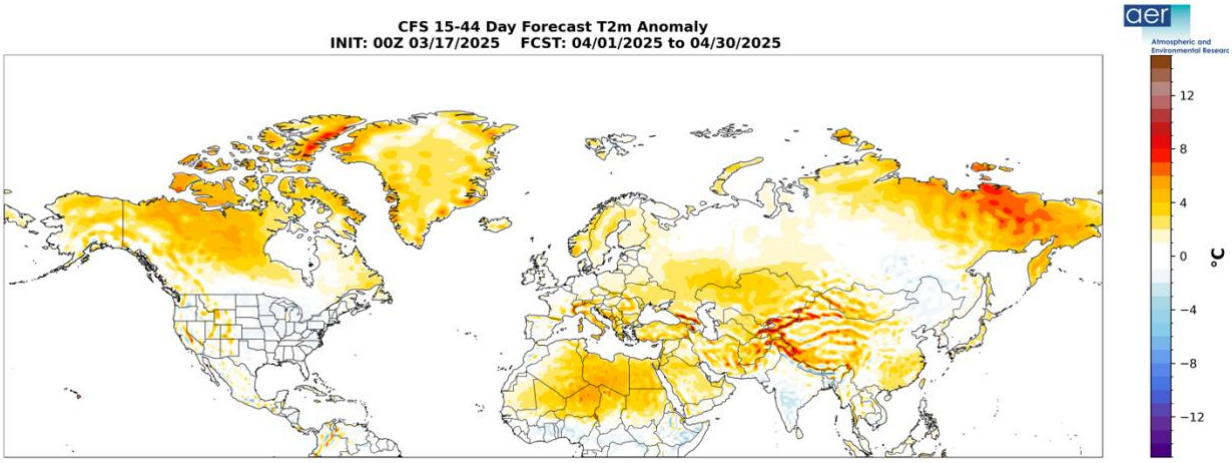

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for April 2025. The forecasts are from the CFS 00Z 17 Mar 2025.

Boundary Forcings

Arctic Sea Ice

Sea ice growth continues relatively slowly and is near or at record low extent for this time of year with negative anomalies in the Barents-Kara Seas, the Sea of Okhotsk, the Bering Sea and the Labrador Sea (see **Figure 16**). The influence of sea ice on remote weather is likely waning and we will soon hit the March sea ice extent maximum for the year.

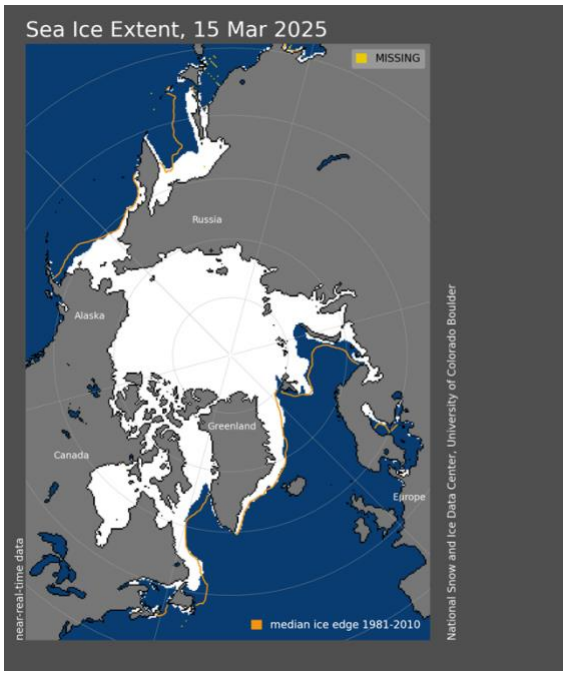

Figure 16. Observed Arctic sea ice extent on 15 Mar 2025 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image from the National Snow and Ice Data Center (NSIDC). URL: https://nsidc.org/sea-ice-today

SSTs/El Niño/Southern Oscillation

Equatorial Pacific sea surface temperatures (SSTs) anomalies are below normal, between the Dateline and Indonesia, indicating that the winter La Niña event is waning (**Figure 17**) and neutral conditions are expected through the spring. Observed SSTs across the NH remain well above normal especially in the central North Pacific centered on the Dateline and the western North Pacific, much of the North Atlantic and offshore of the Canadian Maritimes though below normal SSTs exist regionally especially in the South Pacific. I have wondered if the warmer SSTs this year relative to recent years along the west coast of North America is favoring the cold air further to the east this winter compared to the past decade and this was certainly true in January and February.

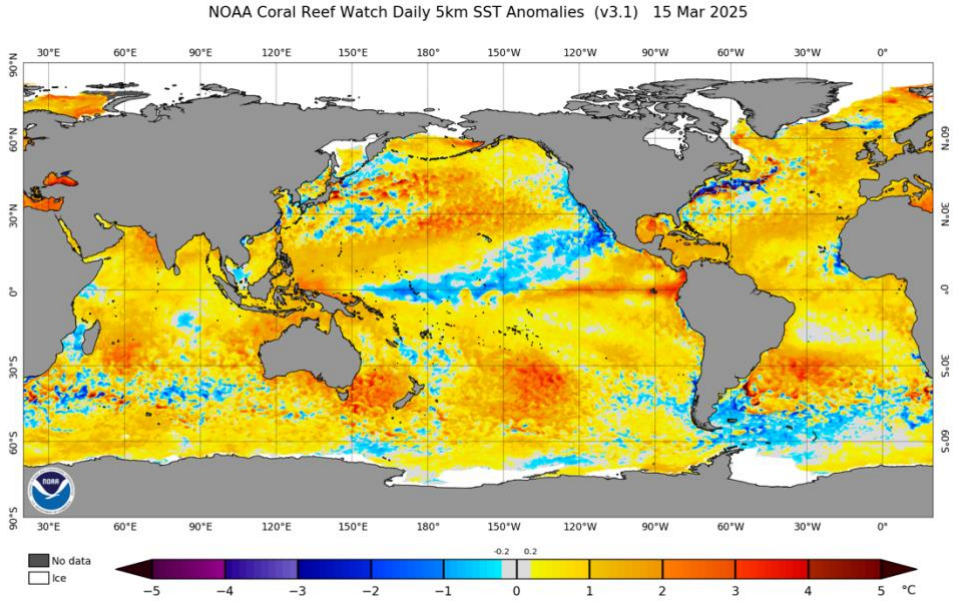

Figure 17. The latest daily-mean global SST anomalies (ending 15 Mar 2025). Data from NOAA OI High-Resolution dataset.

Madden Julian Oscillation

Currently the Madden Julian Oscillation (MJO) is in phase thee but very weak (**Figure 18**). The forecasts are for the MJO to immediately weaken to where no phase is favored and eventually emerge into phases six and seven. Phase six and into phase seven favors troughing in western North America with strong ridging in the Eastern US. Therefore, it seems to me that the MJO will have little influence on North American weather for the next two weeks. But admittedly this is outside of my expertise.

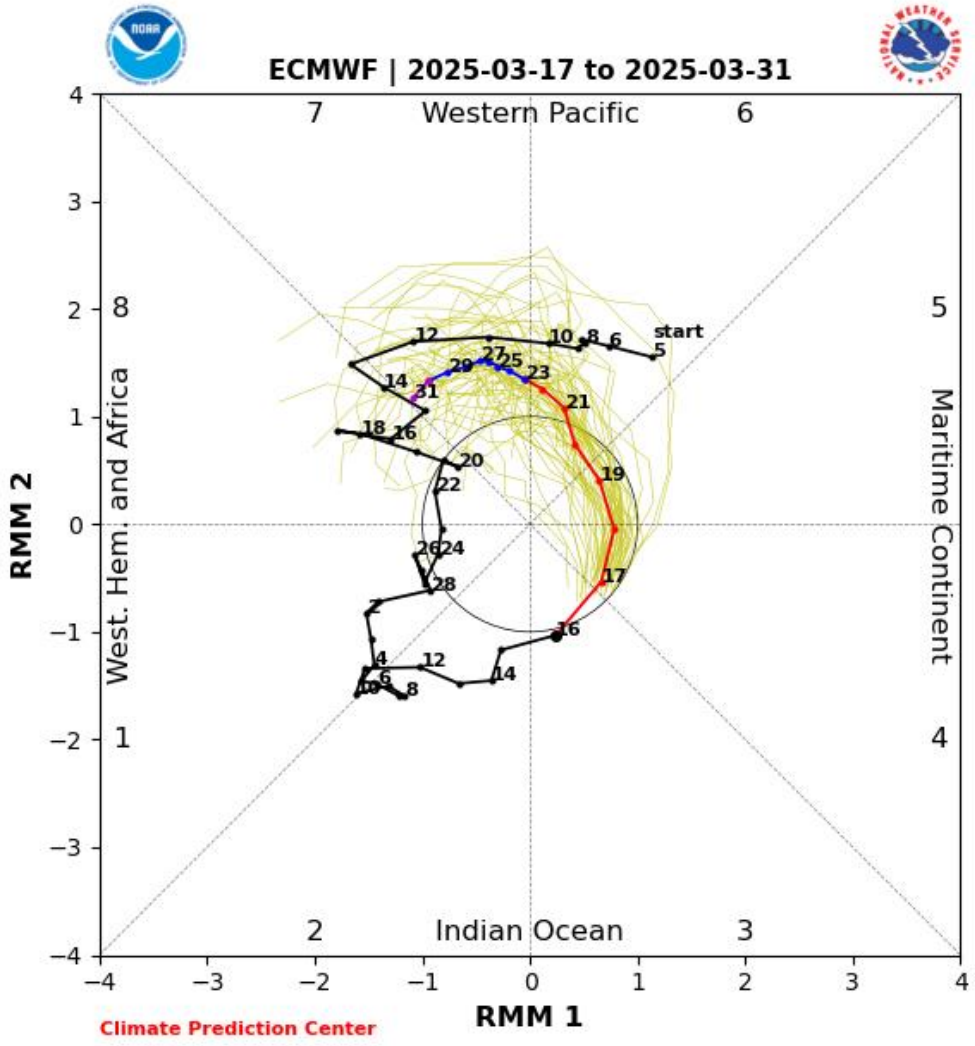

Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 17 Mar 2025 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model 'spread' is denoted by the gray shading. Sector numbers indicate 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/ecmf.shtml

Atmospheric and Environmental Research

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