Arctic Oscillation and Polar Vortex Analysis and Forecasts

March 10, 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 negative and is predicted to trend positive this week and remain positive next week as pressure/geopotential height anomalies across the Arctic are currently mostly positive and are predicted to become increasingly negative over the next two weeks. The North Atlantic Oscillation (NAO) is currently negative with positive pressure/geopotential height anomalies across Greenland and the NAO is predicted to trend towards neutral and then positive the next two weeks as pressure/geopotential height anomalies are predicted to become increasingly negative across Greenland.
- This week ridging/positive geopotential height anomalies across Greenland will generally support troughing/negative geopotential height anomalies across Northern and Western Europe with more ridging across Southern and Eastern Europe. Then next week the return of troughing/negative geopotential height anomalies across will generally support more widespread ridging/positive geopotential height anomalies across most of Europe. This pattern will support normal to below normal temperatures across Northern and Western Europe including the United Kingdom (UK) with normal to above normal temperatures across Southern and Eastern Europe. The next week normal to above normal temperatures will become more widespread across much of Europe.
- This week Asia all be dominated by ridging/positive geopotential height anomalies with

the exception of troughing/negative geopotential height anomalies across Northeastern Asia. However next week Asia will be dominated by ridging/positive geopotential height anomalies and zonal flow. This pattern favors widespread normal to above normal temperatures across Asia with normal to below normal temperatures across Northeastern Asia including Eastern Siberia and then next week normal to above normal temperatures will become even more widespread across Asia.

- The general pattern across North America the next two weeks 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 Souteastern Canada and the Eastern US. 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.
- After a winter season of rapid transitions in the polar vortex (PV) we are finally settling into a long duration sudden stratospheric warming (SSW). Could the SSW result in a classical tropospheric response of Greenland blocking?

Plain Language Summary

March is starting off differently than the general surface temperature anomalies of the winter. Warm temperatures still dominate the Northern Hemisphere (NH) but now include Western Canada and much of the US. Also, an important difference is that relatively cold temperatures dominate Siberia. The days of rapid transitions in the polar vortex (PV) are over for this winter with a predicted large and long-lasting disruption of the PV. Following such large PV disruptions, Greenland blocking is more frequent with cold weather across Northern Europe and eventually the Eastern US. Some of that is occurring this week but that is not likely the main impact of the large PV disruption. I am anticipating that a return of colder weather is possible at the very end of March and/or early April.

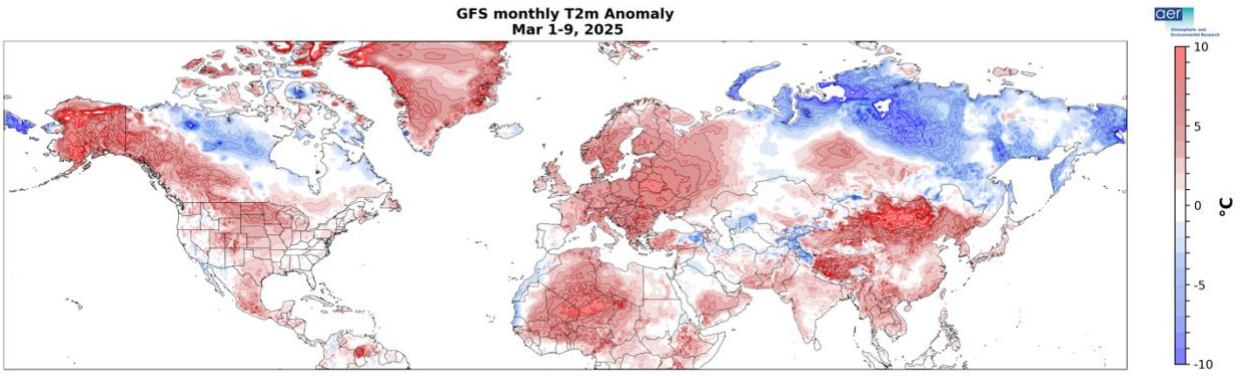

Figure. Estimate of the observed surface temperatures (°C; shading) from 01 Mar to 9 Mar 2025 based on GFS initializations and the GFS forecast from the 10 Mar 2025 run.

Impacts

All winter long the polar vortex (PV) was changing at a frenetic pace. That is clearly over this PV season. All the models are in consensus that an impressive sudden stratospheric warming (SSW) is ongoing and will be of long duration (maybe even until next fall and then it will be characterized as a Final warming). An SSW is defined to occur when the zonal-mean zonal wind at 10 hPa and 60°N drops below zero m/s (or easterly) on average for a twenty four-hour period; that should occur in the next day or two. And the GFS solution of a PV split is correct in the end. The major PV center will be over Northwest Asia and Northern Europe while the minor PV center will be over the Eastern US but quickly sailing west in the induced rather strong easterly flow.

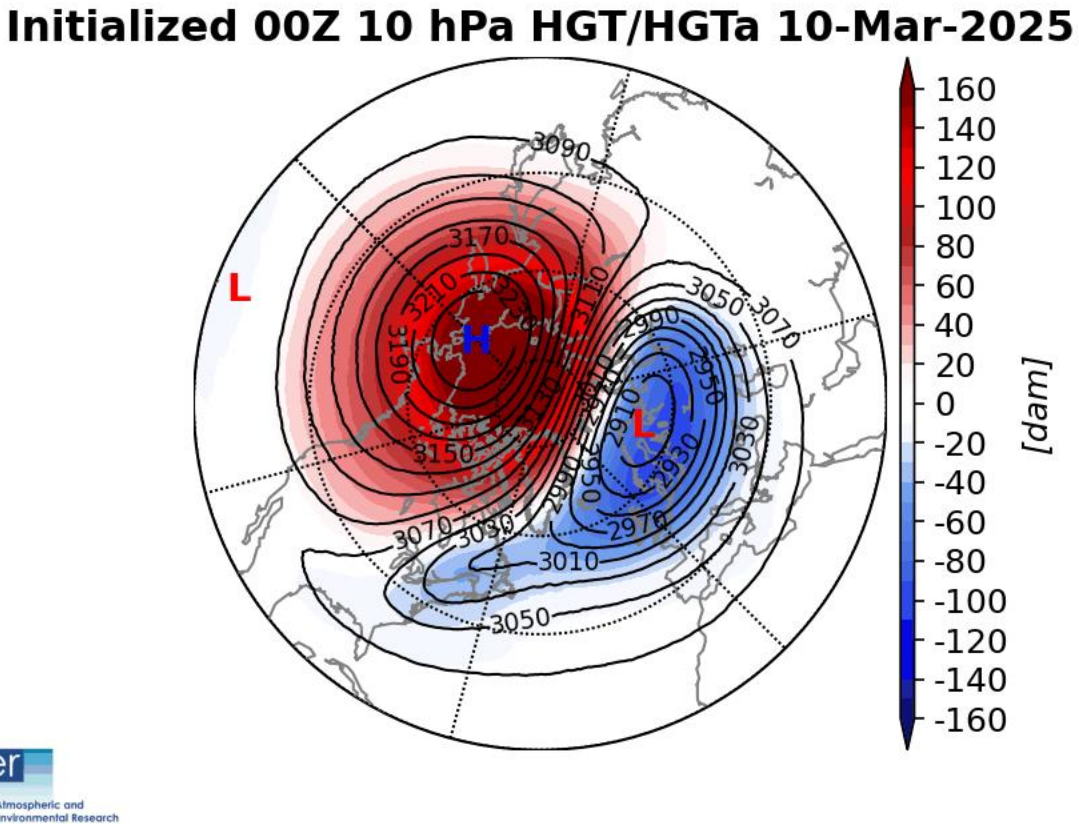

Figure i. Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 10 Mar 2025 and forecasted from 11 Mar to 25 Mar 2025. The forecasts are from the 00Z 10 Mar 2025 GFS model ensemble.

The classical response to SSWs is Greenland high pressure or blocking that favors relative cold temperatures across Northern Europe and Northern Asia. There is some Greenland blocking predicted this week. As I discussed last week, it is my impression that there is an immediate and a delayed tropospheric response to SSWs. I mentioned in last week's blog to look for the forecast to get colder with time across Northern Europe and the forecasts are now colder for both Western and Northern Europe coupled with Greenland blocking (see **Figure ii**). Some

colder weather is also predicted for Southeastern Canada and the Northeastern US but the cold in both regions is not overly impressive, especially the Northeastern US as the Greenland blocking is predicted to be transient (see **Figure ii**). I think the cooler weather (and based on **Figure 11** the Greenland blocking) is related to the immediate impact from the SSW, which is not as impactful as the delayed response.

So, if any cold this week and next week are the appetizers when is the main meal, i.e., more impressive/longer duration Greenland blocking coupled with colder weather for Northern Europe and/or the Eastern US? Looking at the polar cap geopotential height anomalies (PCHs) in **Figure 11**, the main warm/positive PCHs are in the stratosphere the next two weeks. For the SSW to impact our weather the warm/positive PCHs need to make it to the lower troposphere. Assuming that the GFS forecast in **Figure 11** is correct (always standing on thin ice), the earliest that could happen is the very last week of March. But for the biggest impact, the largest warm/positive PCHs would be in the troposphere and not the stratosphere and there is no sign of that occurring in the two-week forecasts. The earliest that would occur is sometime in April and possibly even May.

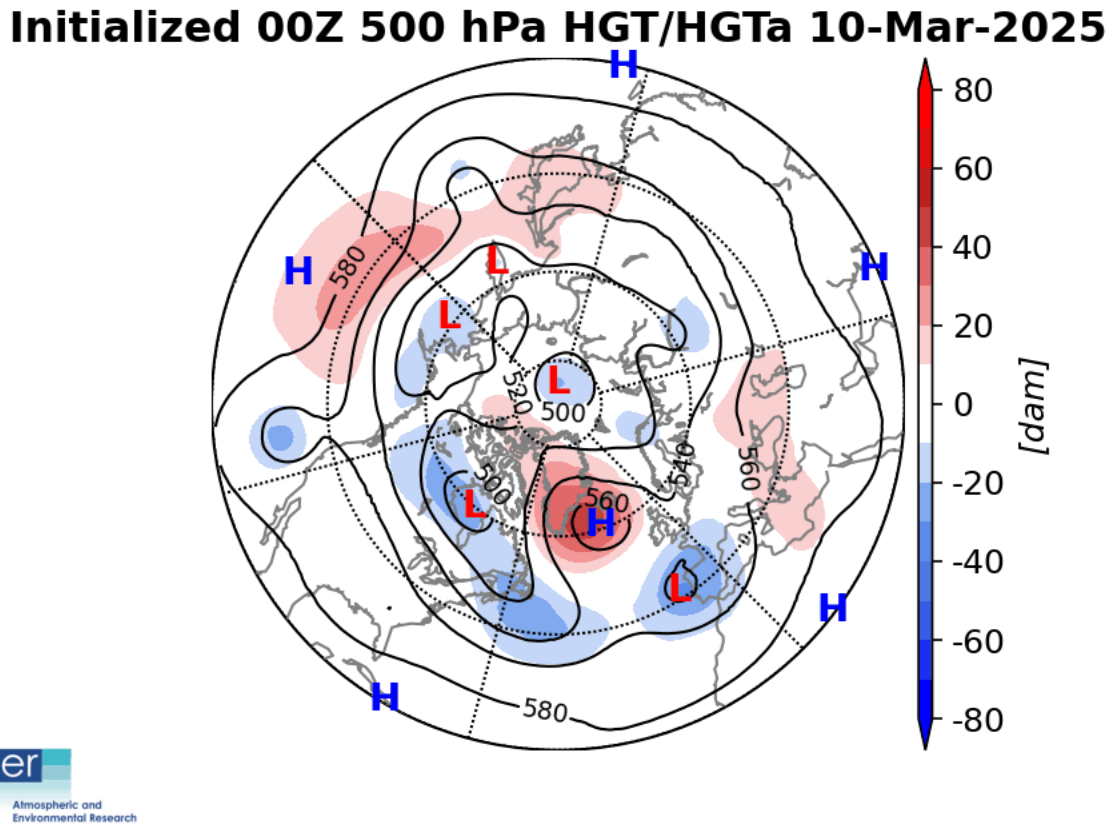

Figure iii. Initialized 500 mb geopotential heights (dam; contours) and decameter anomalies (dam; shading) across the Northern Hemisphere for 10 Mar 2025 and forecasted from 11 Mar to 25 March 2025. The forecasts are from the 00Z 10 Mar 2025 GFS model ensemble.

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 iiia**). Instead, the wave energy is directed upward and absorbed in the polar stratosphere resulting in the SSW. However, SSWs themselves create a favorable environment for wave reflection and stretched PVs in the weeks following the SSW. Wave reflection following an SSW can contribute to some of the most severe winter weather in the Eastern US. The energy diagnostics for the fourth week of March are suggestive of wave reflection (see **Figure iiib**). Not sure how much I believe this particular forecast, but something to monitor in the coming weeks.

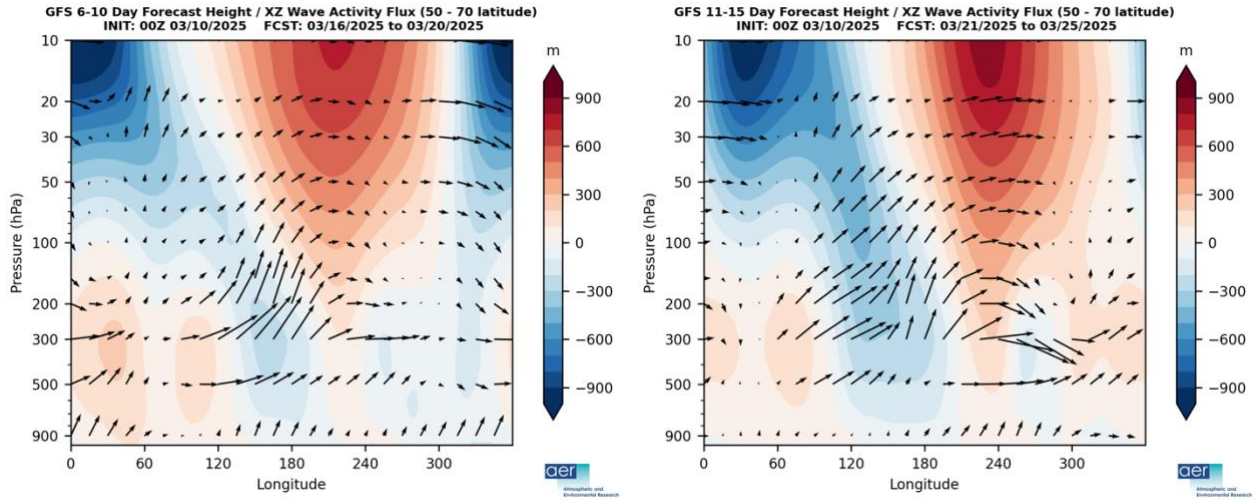

Figure iii. Longitude-height cross section of geopotential eddy height anomalies (shading) and wave activity flux (vectors) a) predicted for 16 Mar through 20 Mar 2025 and b) forecasted for 21 Mar through 25 Mar 2025. The forecasts are from the 00Z 10 Mar 2025 GFS ensemble.

In conclusion to reiterate something that I discussed last week. For me the SSW is two months too late. If the SSW was predicted for 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 it is already the second week of March, 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. With another lackluster winter for snow here in the Northeastern US (outside of lack effect), I am left wondering what could have been, if only.

Near-Term

This week

The AO is predicted to be mostly negative this week **(Figure 1**) with mostly positive geopotential height anomalies across the Arctic, centered on Greenland, and 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.

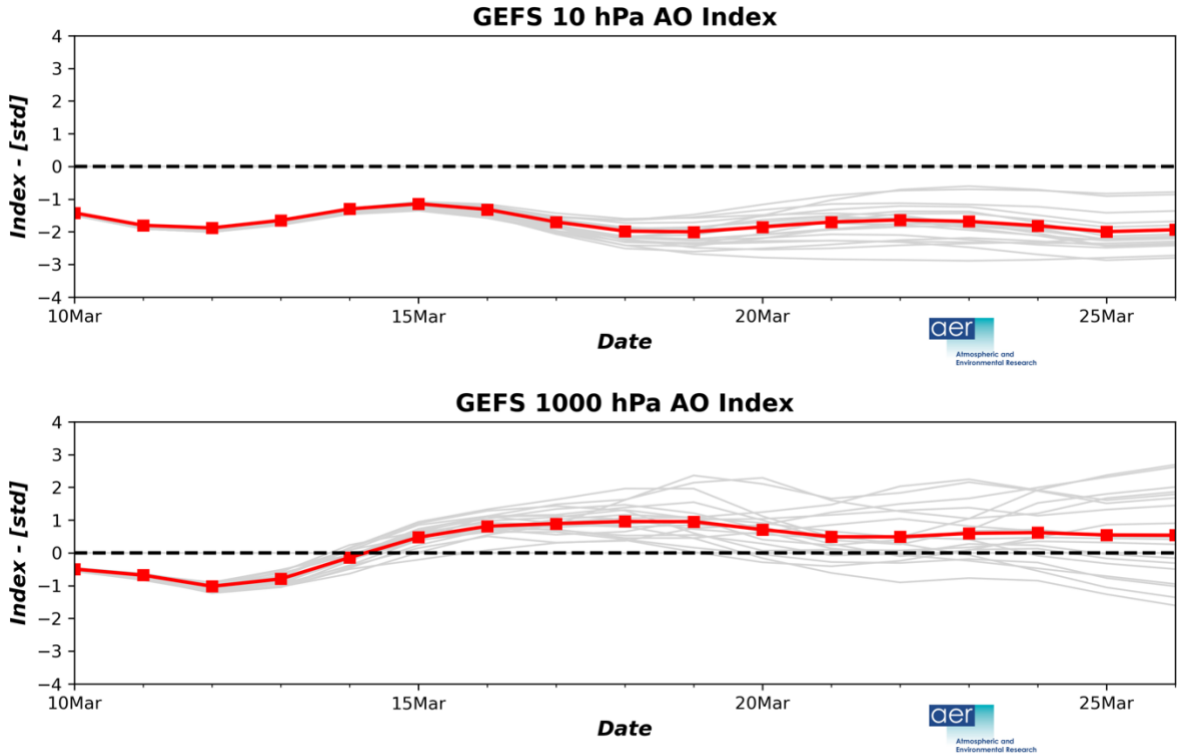

Figure 1. a) The predicted daily-mean AO at 10 hPa from the 00Z 10 Mar 2025 GFS ensemble. b) The predicted daily-mean AO at 1000 hPa from the 00Z 10 Mar 2025 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble mean AO index given by the red line with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

This week ridging/positive geopotential height anomalies across Greenland will support troughing/negative geopotential height anomalies across Western and Northern Europe with ridging/positive geopotential height anomalies across Southern and Eastern Europe (**Figures 2).** This pattern will favor normal to below normal temperatures across Western and Northern Europe including the UK with normal to above normal temperatures across 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 across Northeastern Asia (**Figure 2**). This pattern favors normal to above normal temperatures widespread across much of Asia with normal to below normal temperatures across parts of Northeast Asia including Eastern Siberia **(Figure 3**).

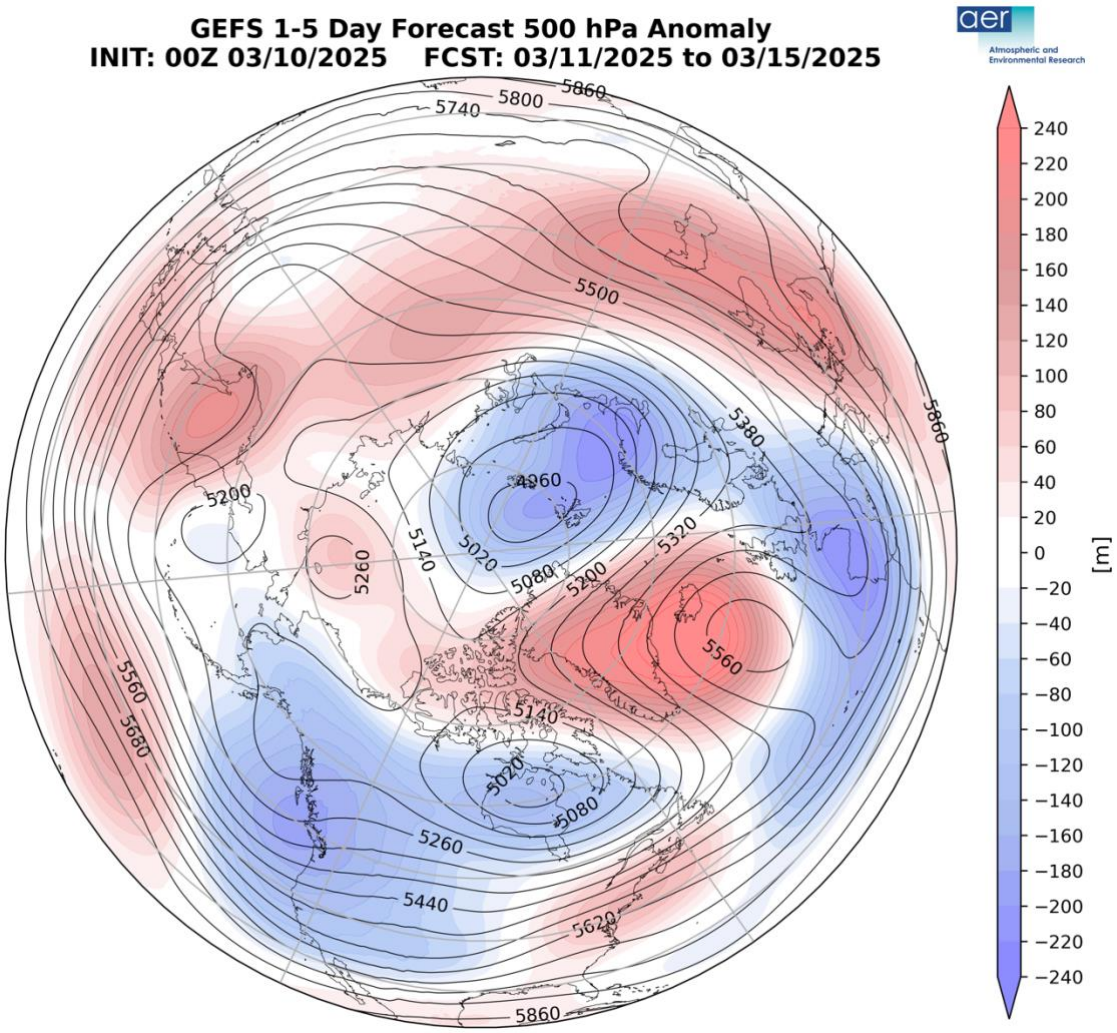

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 11 Mar to 15 Mar 2025. The forecasts are from the 00Z 10 Mar 2025 GFS ensemble.

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 Eastern Canda and the Eastern 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 Southeastern Canada and the Eastern US. (**Figure 3**).

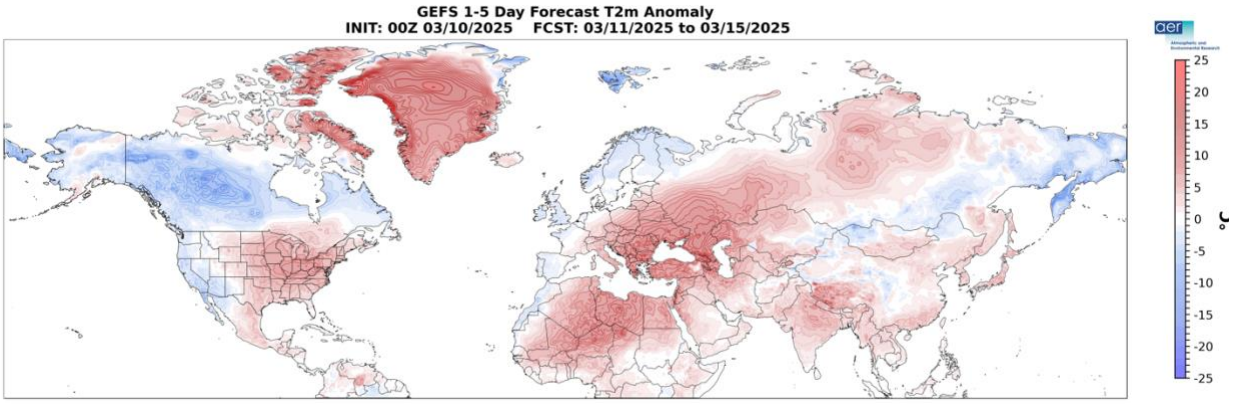

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 11 Mar to 15 Mar 2025. The forecasts are from the 00Z 10 Mar 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across Norway, parts of Siberia, Northeast Asia and the Tibetan Plateau while warm temperatures will support widespread snowmelt across Scandinavia and Northern Asia this week (**Figure 4**). Troughing and/or cold temperatures will support new snowfall across Southwestern and Eastern Canada and the Western US while warm temperatures will support snowmelt in central Alaska, Northwestern and Southeastern Canada and the Northeastern US this week (**Figure 4**).

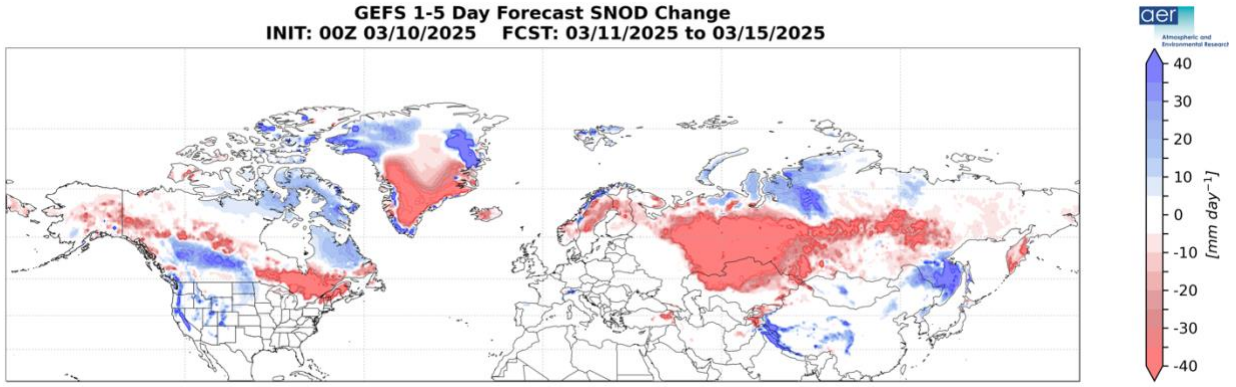

Figure 4. Forecasted snow depth changes (mm/day; shading) from 11 Mar to 15 Mar 2025. The forecasts are from the 00Z 10 Mar 2025 GFS ensemble.

Near-Mid Term

Next week

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

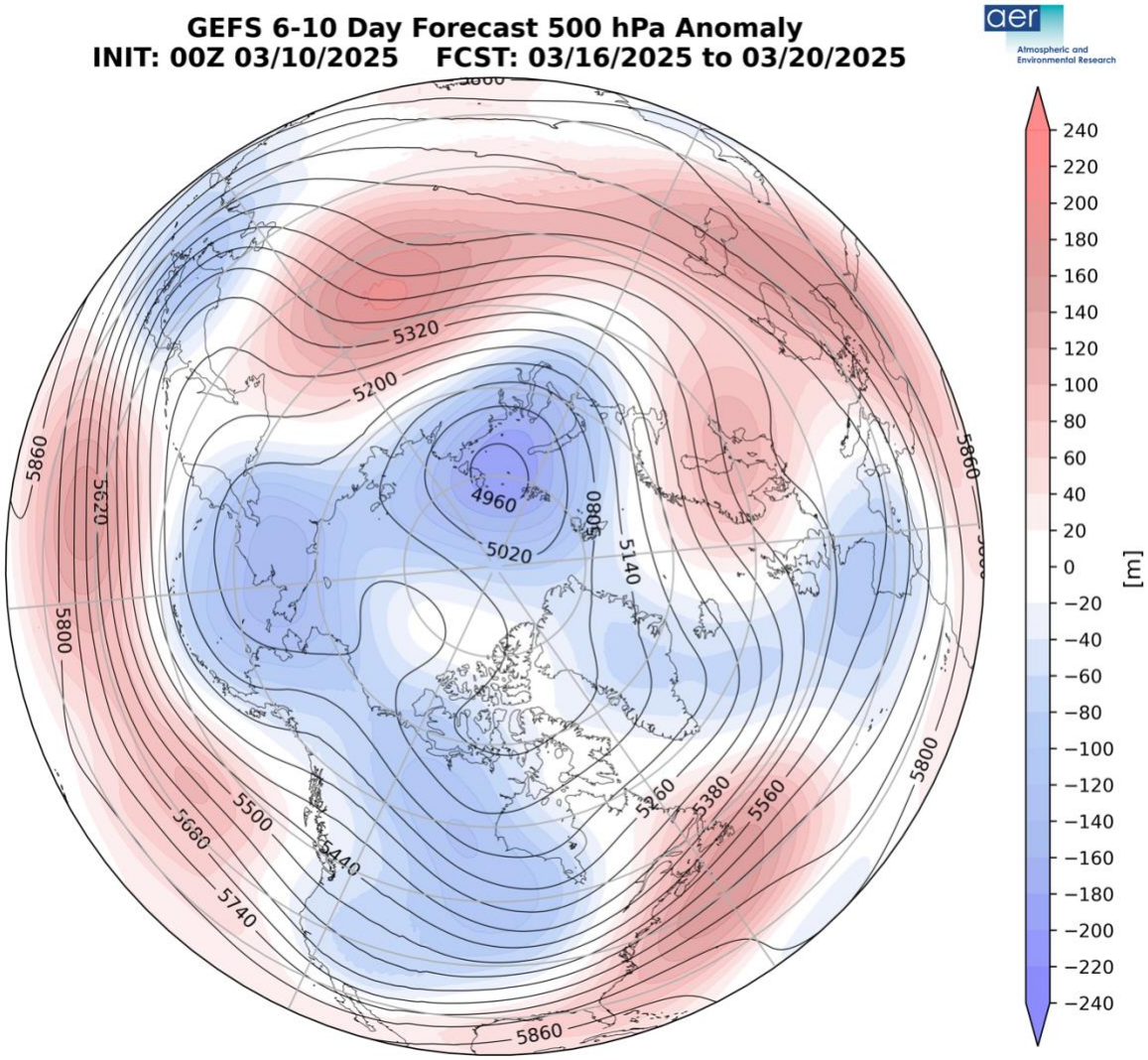

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 16 Mar to 20 Mar 2025. The forecasts are from the 00Z 10 Mar 2025 GFS ensemble.

The return of troughing/negative geopotential height anomalies to Greenland will support mostly ridging/positive geopotential height anomalies across Europe centered over Northern and Eastern Europe with troughing/negative geopotential height anomalies limited

to Western Europe (**Figure 5**). This pattern favors widespread normal to above normal temperatures across much of Europe with normal to below normal temperatures limited to Western Europe including the UK this period (**Figure 6**). Ridging/positive geopotential height anomalies will become more widespread across Asia with troughing/negative geopotential height anomalies limited to far East Asia (**Figure 5**). This pattern favors normal to above normal temperatures across most of Asia with normal to below normal temperatures limited to Southeastern Asia and Eastern Siberia this period (**Figure 6**).

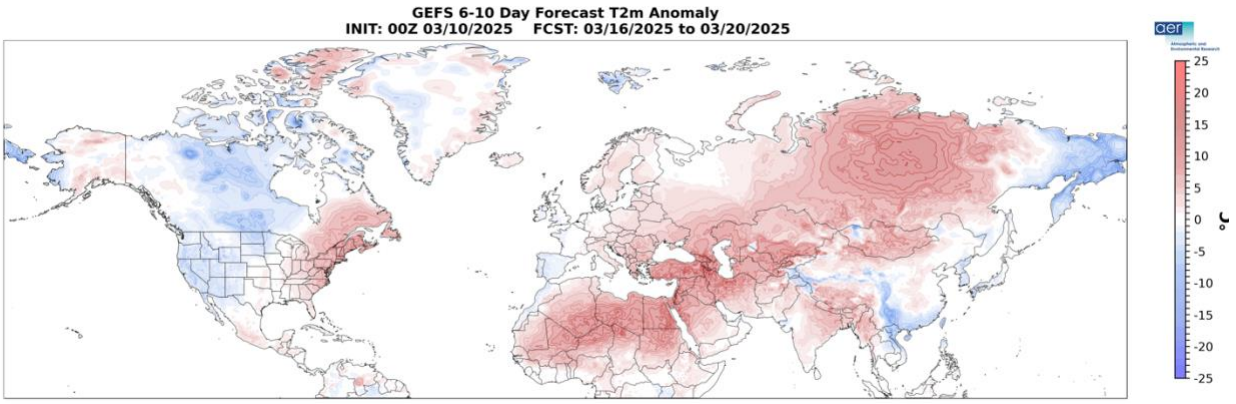

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 16 Mar to 20 Mar 2025. The forecasts are from the 00Z 10 Mar 2025 GFS ensemble.

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

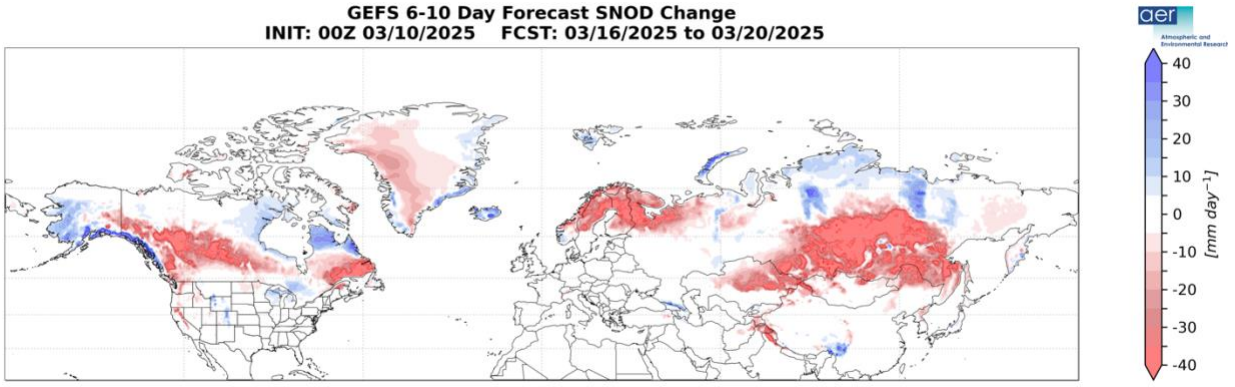

Figure 7. Forecasted snow depth changes (mm/day; shading) from 16 Mar to 20 Mar 2025. The forecasts are from the 00Z 10 Mar 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across Northern Siberia and the Tibetan Plateau while warm temperatures will support snowmelt in Scandinavia, Siberia

and Northeast Asia this period (**Figure 7**). Troughing and/or cold temperatures will support new snowfall across western Alaska, the West Coast mountains of Canada, Northeastern Canada and the Great Lakes while warm temperatures will support snowmelt across Southern Canada this period (**Figure 7**).

Mid Term

Week Two

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

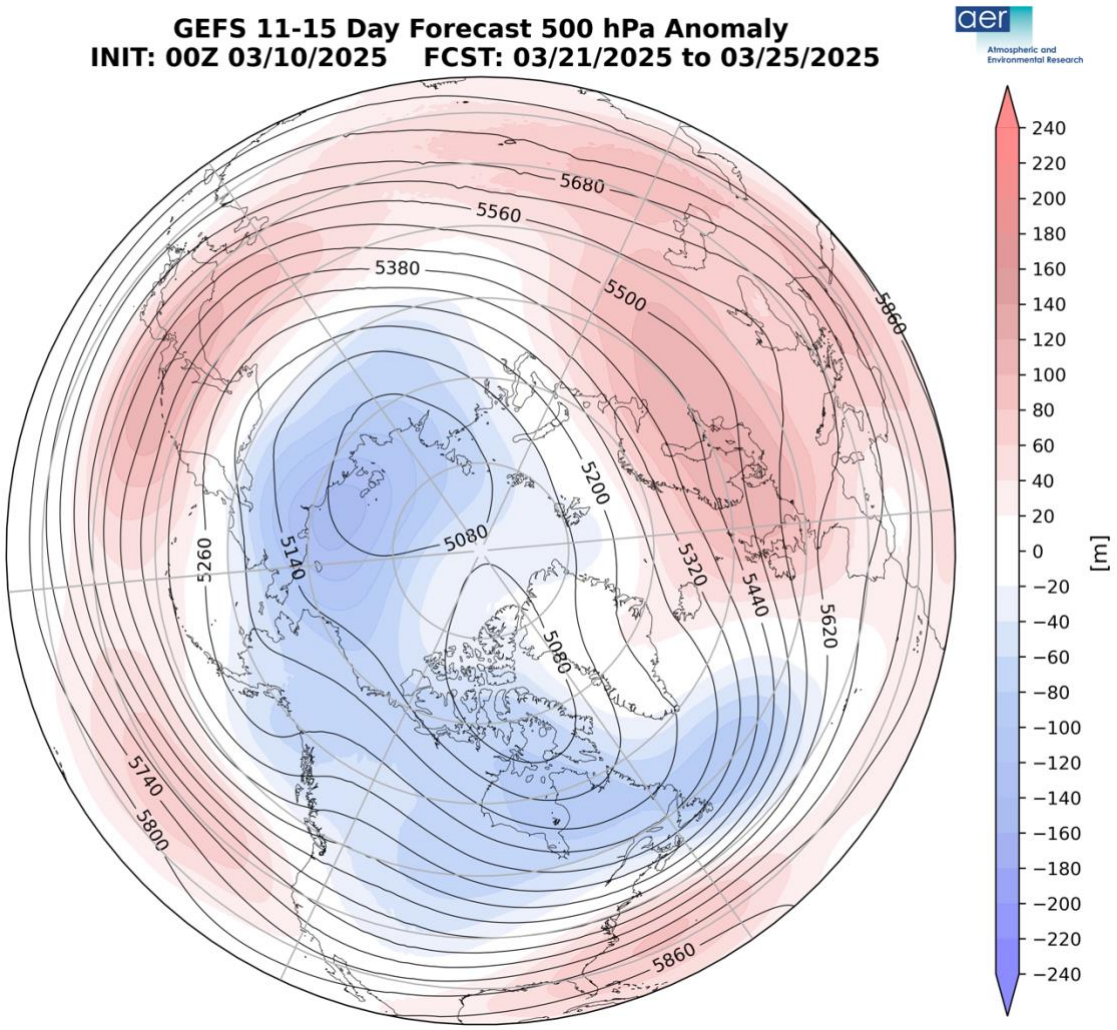

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 21 Mar to 25 Mar 2025. The forecasts are from the 00Z 10 Mar 2025 GFS ensemble.

Continued troughing/negative geopotential height anomalies across Greenland will support widespread ridging/positive geopotential height anomalies across Europe this period (**Figure 8**). This pattern should favor normal to above normal temperatures widespread across Europe including the UK this period (**Figures 9**). Persistent ridging/positive geopotential height anomalies across Southern and Central Asia with troughing/negative geopotential height anomalies limited to Northern Siberia will result in a mostly zonal flow across 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 Northern and Eastern Siberia this period (**Figure 9**).

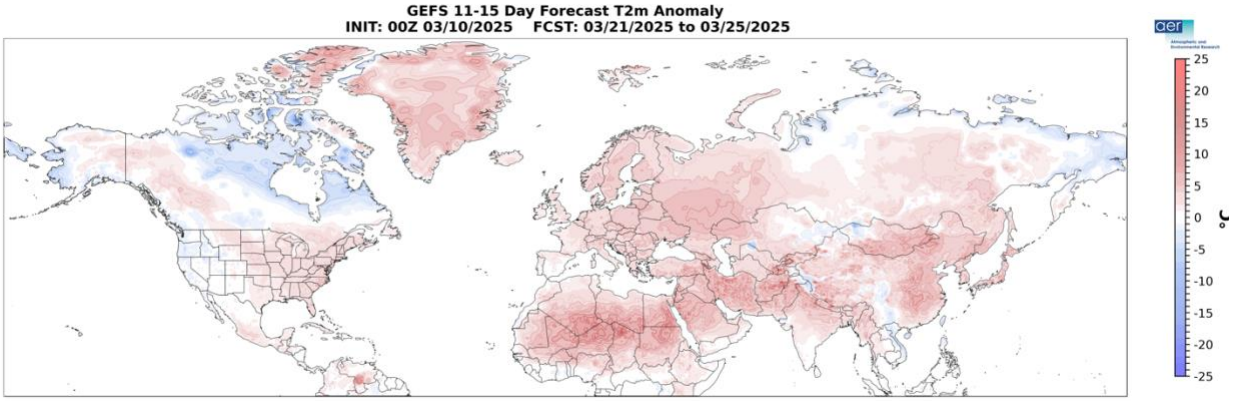

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 21 Mar to 25 Mar 2025. The forecasts are from the 00Z 10 Mar 2025 GFS ensemble.

Persistent troughing/negative geopotential height anomalies across Alaska and Northern Canada with ridging/positive geopotential height anomalies across the Eastern US will also favor mostly zonal flow across North America this period (**Figure 8**). This pattern supports normal to below normal temperatures across Alaska, Northeastern Canada and the Western US with normal to above normal temperatures across Western and Southeastern Canada and the Eastern US this period (**Figure 9**).

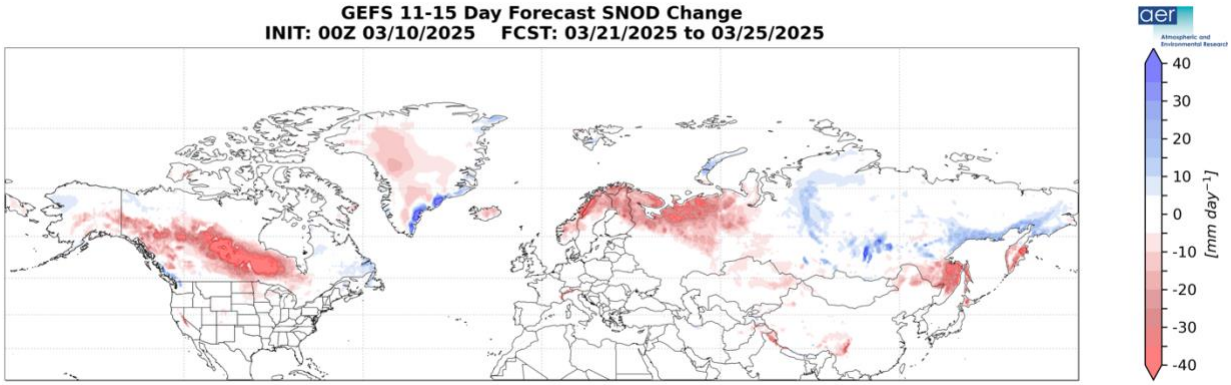

Figure 10. Forecasted snow depth changes (mm/day; shading) from 21 Mar to 25 Mar 2025. The forecasts are from the 00Z 10 Mar 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across parts of Siberia while warm temperatures will support snowmelt in Scandinavia, Southern Siberia, Northeast Asia and the Tibetan Plateau this period (**Figure 10**). Troughing and/or cold temperatures will support new snowfall across parts of western Alaska and Northeastern Canada while warm temperatures will support snowmelt in Western and Southern 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 troposphere (**Figure 11**). The strong warm/positive PCHs in the upper stratosphere are predicted to descend into the lower stratosphere next week. Meanwhile cold/negative PCHs are predicted to return to the troposphere next week. The warm/positive PCHs in the stratosphere represent a sudden stratospheric warming (SSW) or even possibly a Final warming.

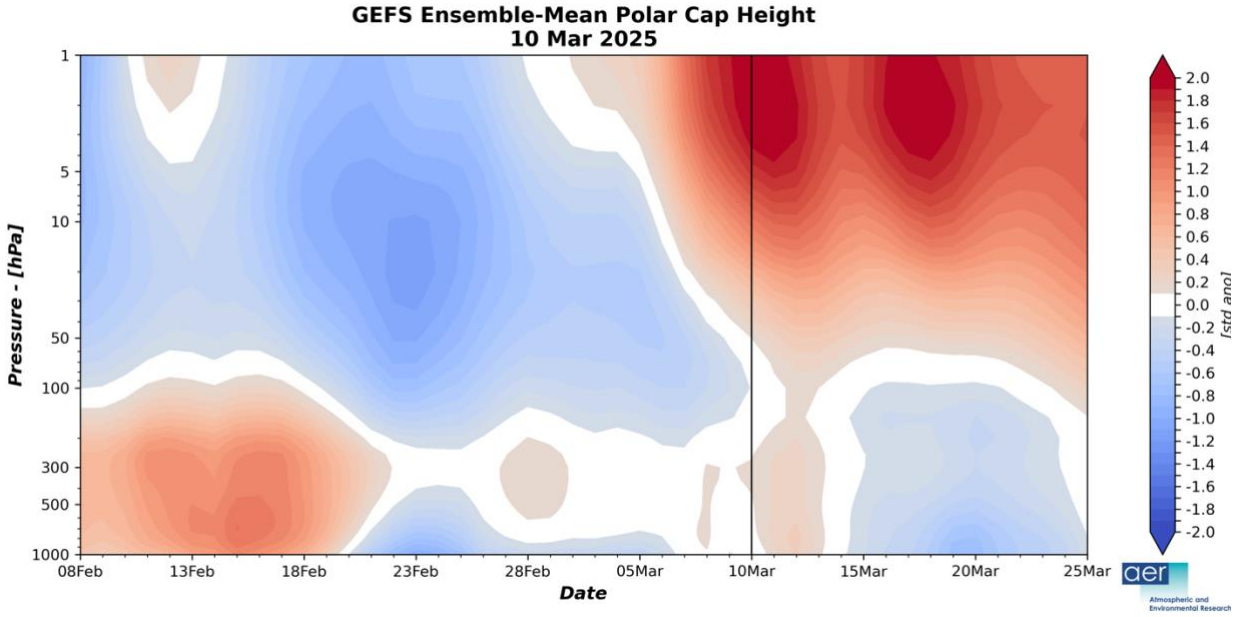

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 10 Mar 2025 GFS ensemble.

The predicted warm/positive PCHs in the lower troposphere this week (**Figure 11**) are consistent with the predicted negative surface AO this week (**Figure 1**). Then as the cold/negative PCHs return to the lower troposphere next week, the surface AO is predicted to turn positive.

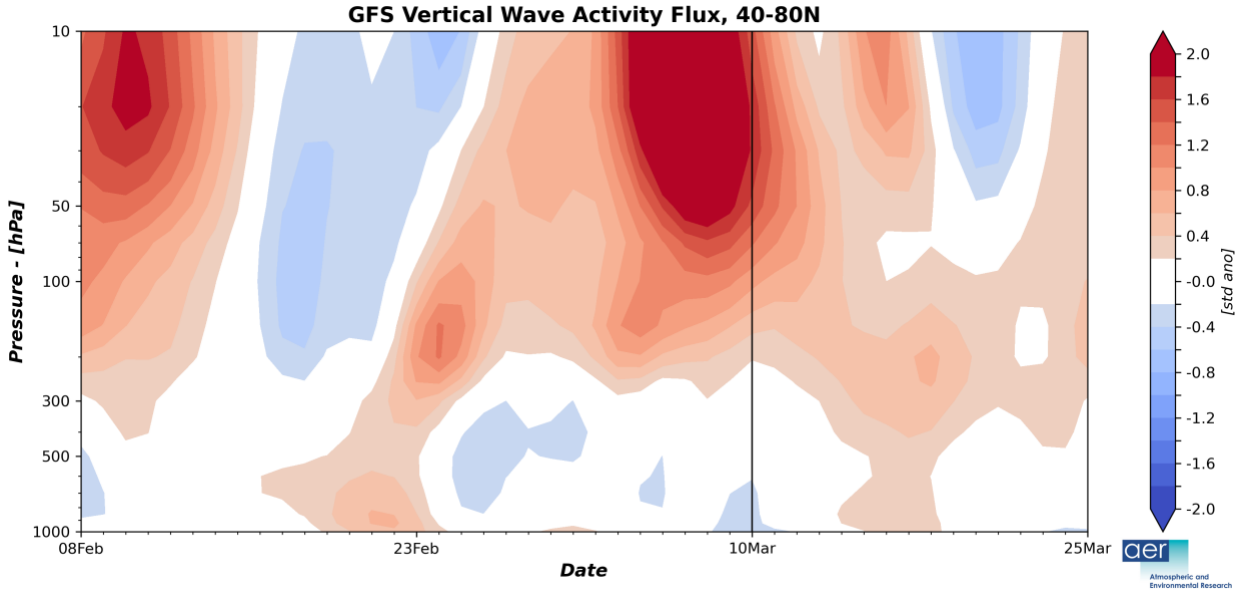

Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 10 Mar 2025 GFS ensemble.

Vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere has very active since early February (**Figure 12**). The strongest WAFz pulse of the season peaked last week (**Figure 12**). This large pulse is predicted to trigger an SSW this week.

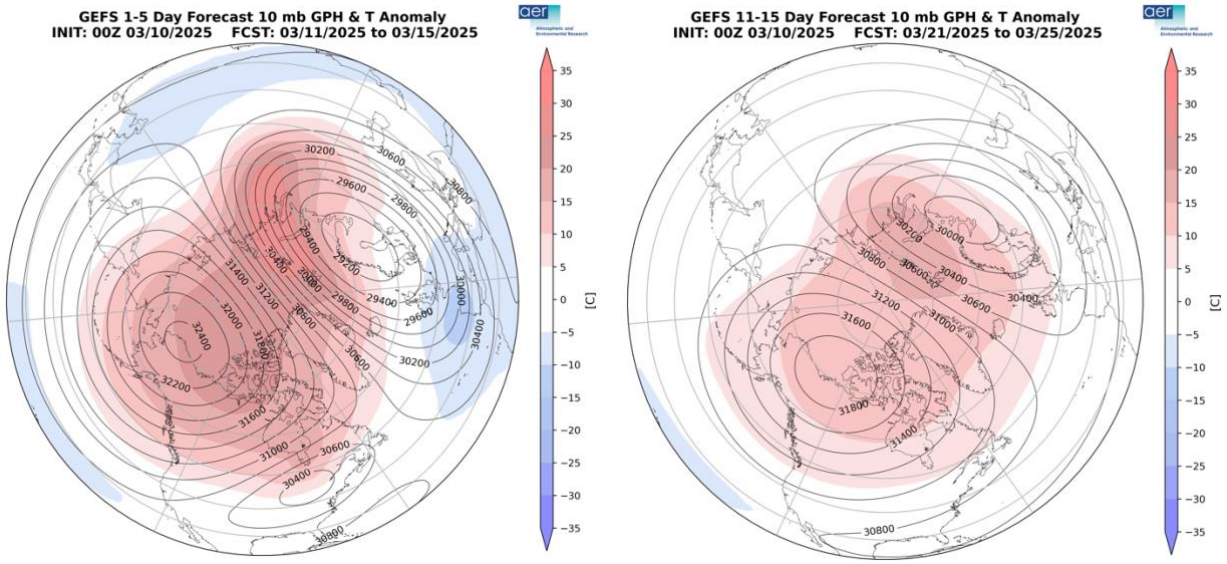

Figure 13. (a) Forecasted 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 11 to 15 Mar 2025. (b) Same as (a) except forecasted averaged from 21 Mar to 25 Mar 2025. The forecasts are from the 00Z 10 Mar 2025 GFS model ensemble.

This week the polar vortex (PV) is predicted split with the major center over Scandinavia and the minor center over the Eastern US with relatively coldest temperatures across Europe with high-pressure ridging near Alaska but extending into the Central Arctic and the relatively warmest temperatures across Siberia, Alaska and Northern Canada 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 between Scandinavia and the Urals with ridging centered over the Canadian Archipelagos in the polar stratosphere. The relatively coldest temperatures are predicted across mid-latitudes and the warmest temperatures spread across the Arctic 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 negative, consistent with an SSW.

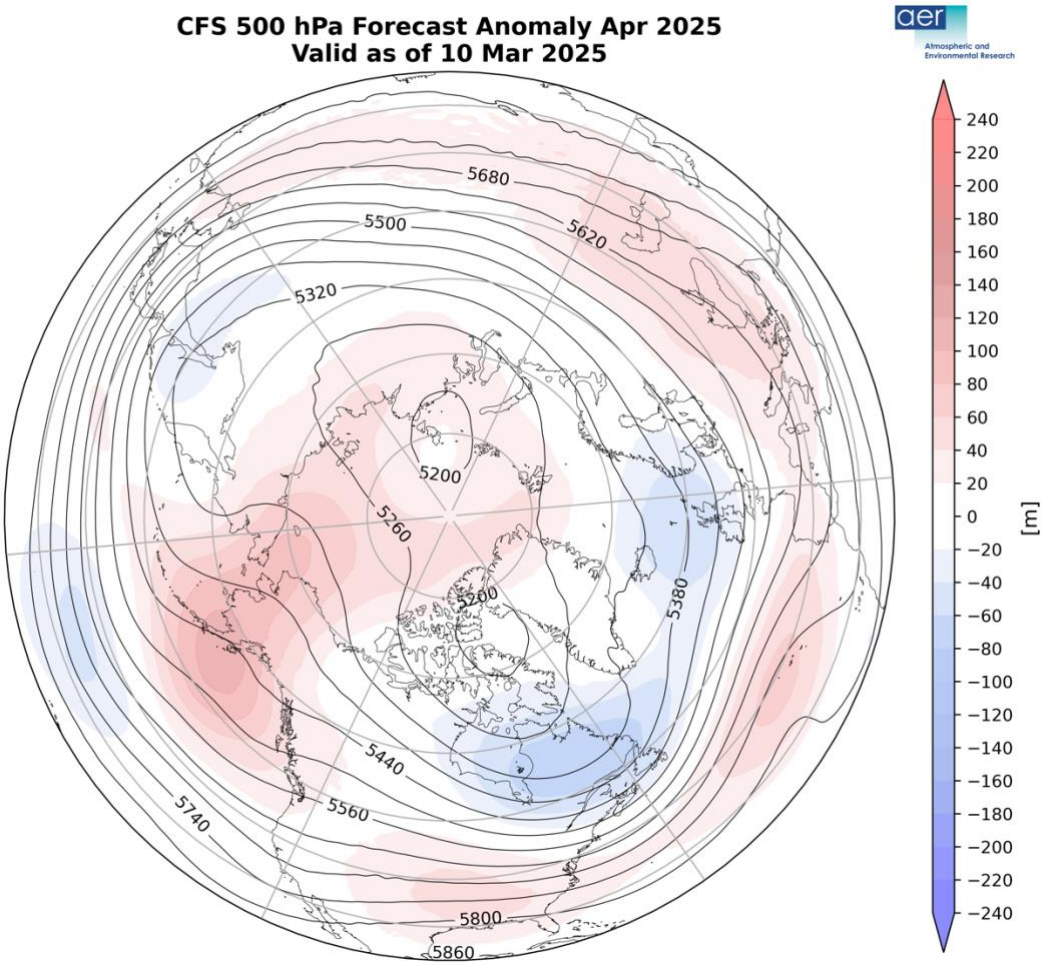

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for April 2025. The forecasts are from the 00Z 10 Mar 2025 CFS.

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 central North Atlantic, Southern Europe, Southwest Asia, Eastern Siberia, Alaska and the Southeastern US with troughing across Western Europe, Northern and Eastern Asia, Eastern Canada and the Northeastern US (**Figure 14**). This pattern favors seasonable to relatively warm temperatures across Eastern Europe, much of Asia, including Eastern Siberia, Alaska, Western Canada and the Western US with seasonable to relatively cold temperatures across Western Europe, Southern Siberia, Northeast Asia, Eastern Canada and the Northeastern US (**Figure 15**).

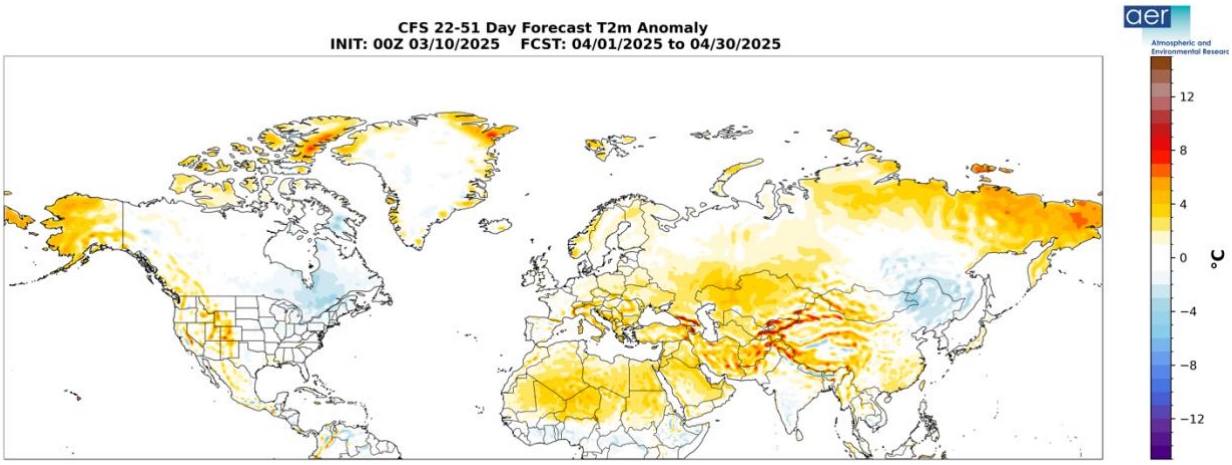

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for April 2025. The forecasts are from the CFS 00Z 10 Mar 2025.

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 lack of sea ice in the that favors a weak PV, more high latitude blocking and colder temperatures across the interior of the NH continents. 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 09 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 the South America coast, indicating that a La Niña event has emerged but is focused more near the Dateline rather than close to the South American coast (**Figure 17**) and weak La Niña conditions are expected through the end of winter and into early 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.

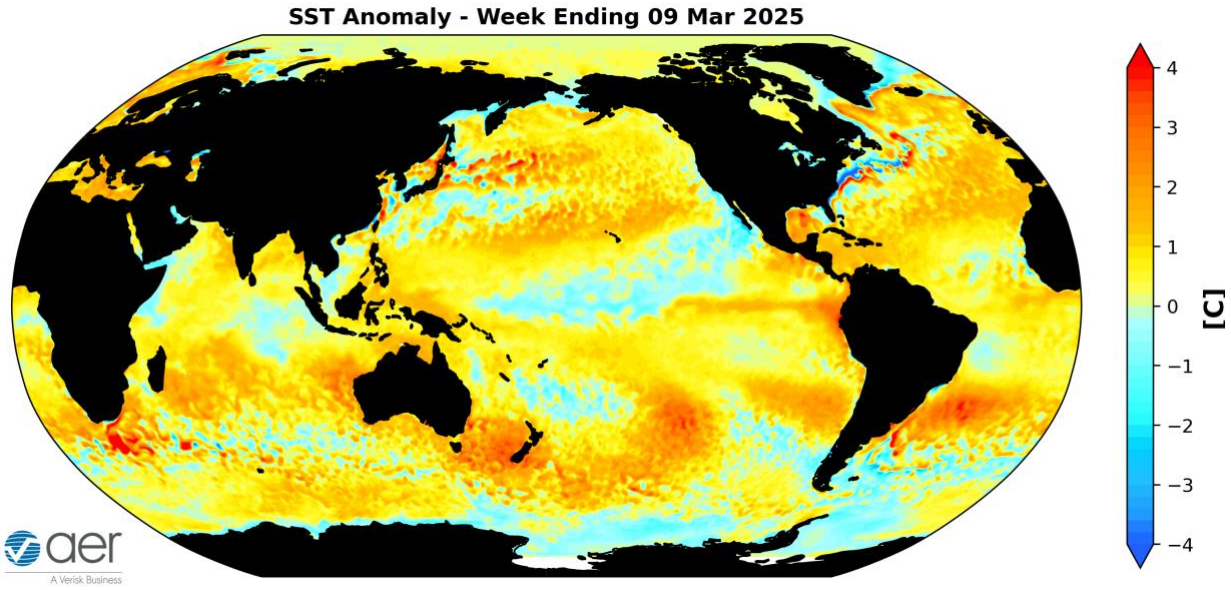

Figure 17. The latest daily-mean global SST anomalies (ending 09 Mar 2025). Data from NOAA OI High-Resolution dataset.

Madden Julian Oscillation

Currently the Madden Julian Oscillation (MJO) is in phase two (**Figure 18**). The forecasts are for the MJO to just hang out between phases one and two and then weaken to where no phase is favored. Phase one favors Western US ridging and Eastern US troughing while phase two favors broad troughing in western North America. Therefore, it seems that the MJO may be having some influence on North American weather for the next two weeks. But admittedly this is outside of my expertise.

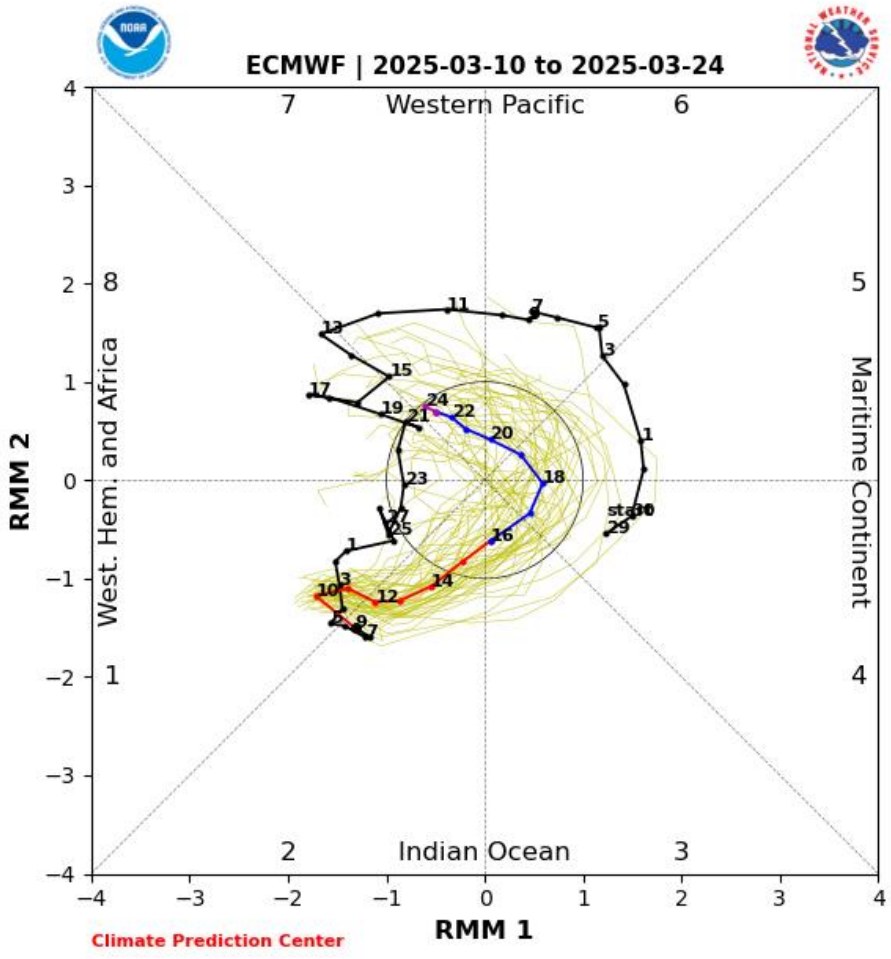

Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 10 Mar 2025 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model 'spread' is denoted by the gray shading. Sector numbers indicate 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

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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. 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.

Our sCast principal engineer, Karl Pfeiffer, can help you use sCast and other AER seasonal forecast products to deliver important, long-lead time weather intelligence to your business. Please reach out to Karl today!