Arctic Oscillation and Polar Vortex Analysis and Forecasts

March 24, 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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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 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 positive with mostly negative 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 main exception of troughing/negative geopotential height anomalies traversing across Southern Europe from west to east over the next two weeks. 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 Southwestern Europe this week and then Southeastern Europe next week.
- The general pattern across Asia the next two weeks is ridging/positive geopotential height anomalies across Western Asia and troughing/negative geopotential height anomalies across Central and Eastern Asia. This pattern favors this week normal to

above normal temperatures across Western Asia with normal to below normal temperatures across Central and East Asia and then next week normal to above normal temperatures are predicted to become more widespread across Asia.

- The general pattern across North America this week is ridging/positive geopotential height anomalies across Alaska, Western Canada and the Western United States (US) with troughing/negative geopotential height anomalies across Eastern Canada and the Eastern US. The next week the pattern will begin to flip with troughing across western North America and ridging in eastern North America. This patten will favor widespread normal to above normal temperatures across Alaska, Southwestern Canada and much of the US with normal to below normal temperatures widespread across Canada and Northeastern US. Then next week normal to below normal temperatures will begin to spread across Alaska, Western Canada and the Western US with normal to above normal temperatures across Eastern Canada and the Eastern US.
- A long duration sudden stratospheric warming (SSW) will episodically influence the weather across the Northern Hemisphere. What might we expect?
- Next week I will officially start the summer schedule and there will be no blog.

Plain Language Summary

Despite the large polar vortex (PV) disruption of early March, surface temperatures across much of the Northern Hemisphere (NH) are above normal (see **Figure**). Looking ahead there are predicted pockets of colder temperatures such as Canada and Central and East Asia (see **Figure 3**) but overall, still looks like a mild pattern for the NH. The main impact from the PV disruption is still likely many weeks away.

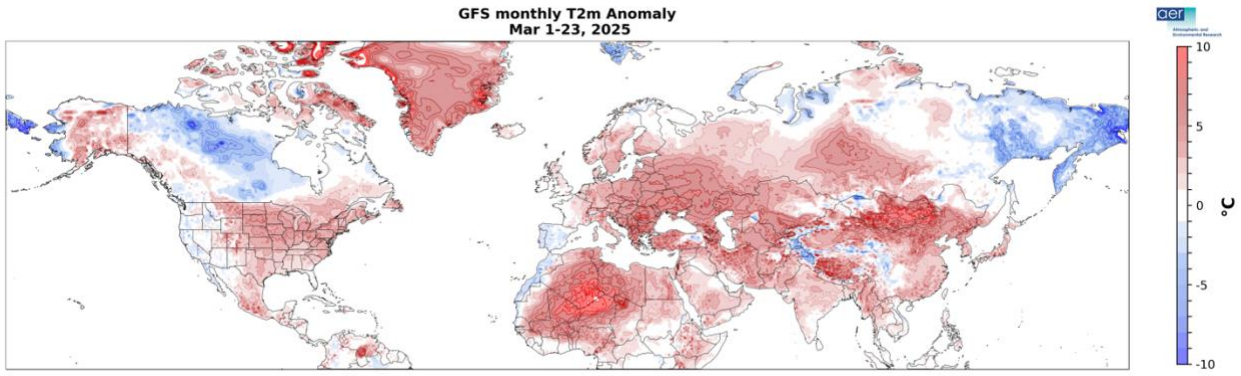

Figure. Estimate of the observed surface temperatures (°C; shading) from 01 Mar to 23 Mar 2025 based on GFS initializations and the GFS forecast from the 24 Mar 2025 run.

Impacts

Continuing last week's summary of the winter I show the Northern Hemisphere (NH) snowfall anomalies in **Figure i** (I also shared the plot on social media last week). Snowfall was on the sparse side across the mid-latitudes including the US, Europe and Eastern China. Some notable exceptions are the Southeastern US, the Northern Rockies, the eastern great Lakes and especially Japan. But based on our analysis snowfall was abundant at higher latitudes poleward of 50°N but especially 60°N.

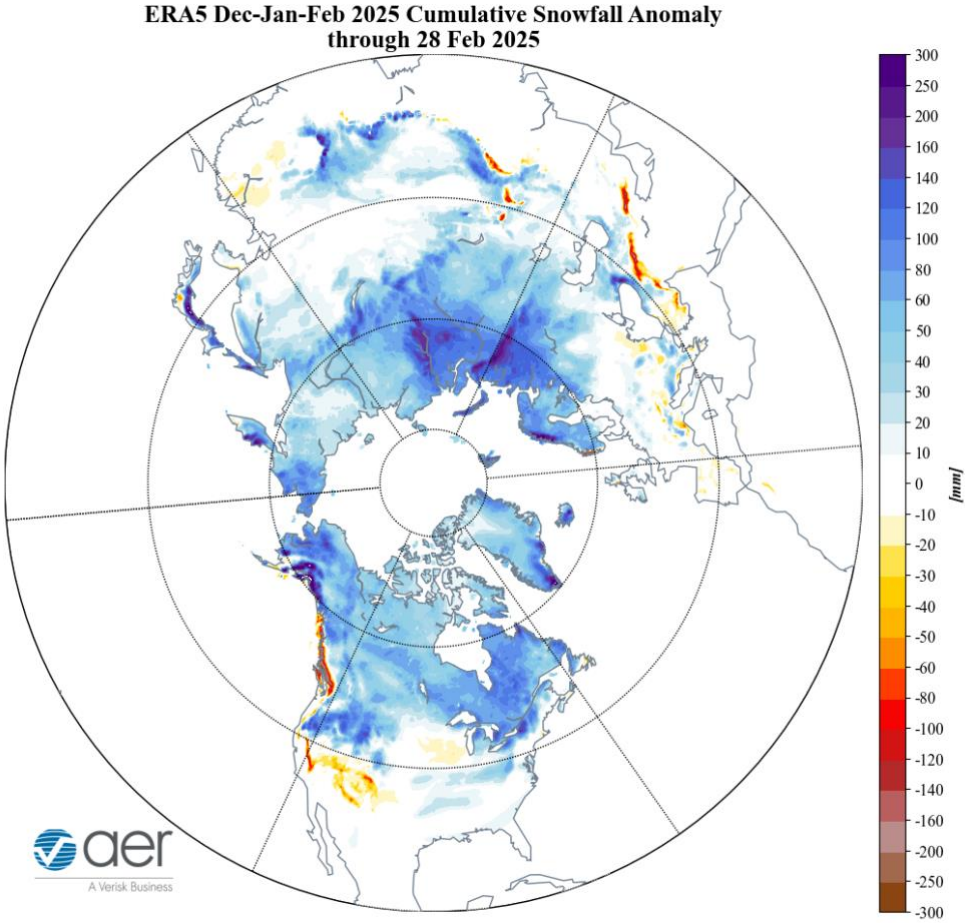

Figure i. a) The AER estimate of winter snowfall anomalies in mm (liquid water equivalent0 for December 2024, January and February 2025 using ERA5 reanalysis data.

All the models remain 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 Final warming (PV will not return until next fall). The SSW kind of resulted in a PV split with currently the major center over Scandinavia and a real minor PV center of the North Atlantic (see **Figure ii**). Eventually the main or only PV center will settle over Eastern Canada (see **Figure ii**).

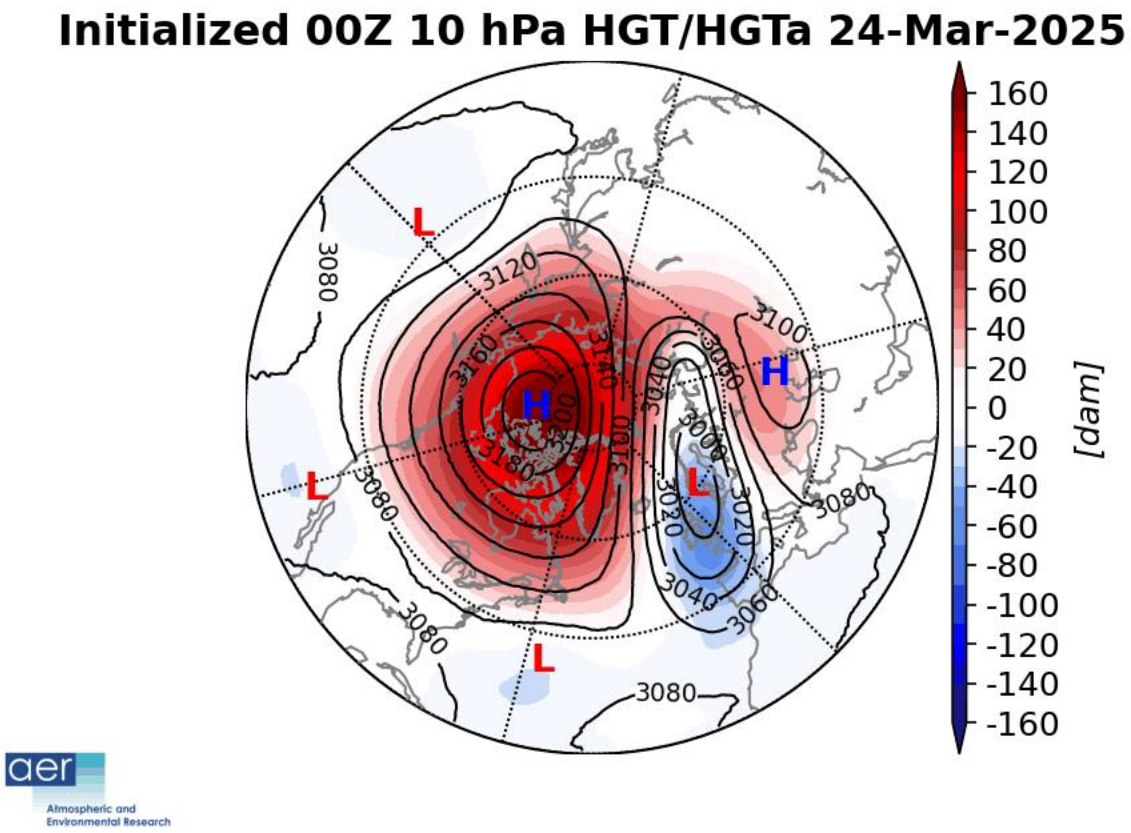

Figure ii. Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 24 Mar 2025 and forecasted from 25 Mar to 08 Apr 2025. The forecasts are from the 00Z 24 Mar 2025 GFS model ensemble.

Many on social media seem to be disappointed in the apparent lackluster response of the weather to the SSW. 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 during the second week of March. 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 shown in **Figure 11**. And as can be seen in **Figure 11**, maybe you can convince there was an initial drip from the SSW right at the start that coincided with Greenland blocking (see **Figure 11).** I think that the the first real drip of PCHs is predicted to occur this week. This will result in an increase in high latitude blocking but not really Greenland blocking but rather blocking near the Dateline (see **Figure iii**). This is supporting cooler weather for much of Canada and the Northeastern US (see **Figure 3**). Ural blocking is also predicted this week (see **Figure iii**) bringing cooler weather to Central and East Asia (see **Figure 3**).

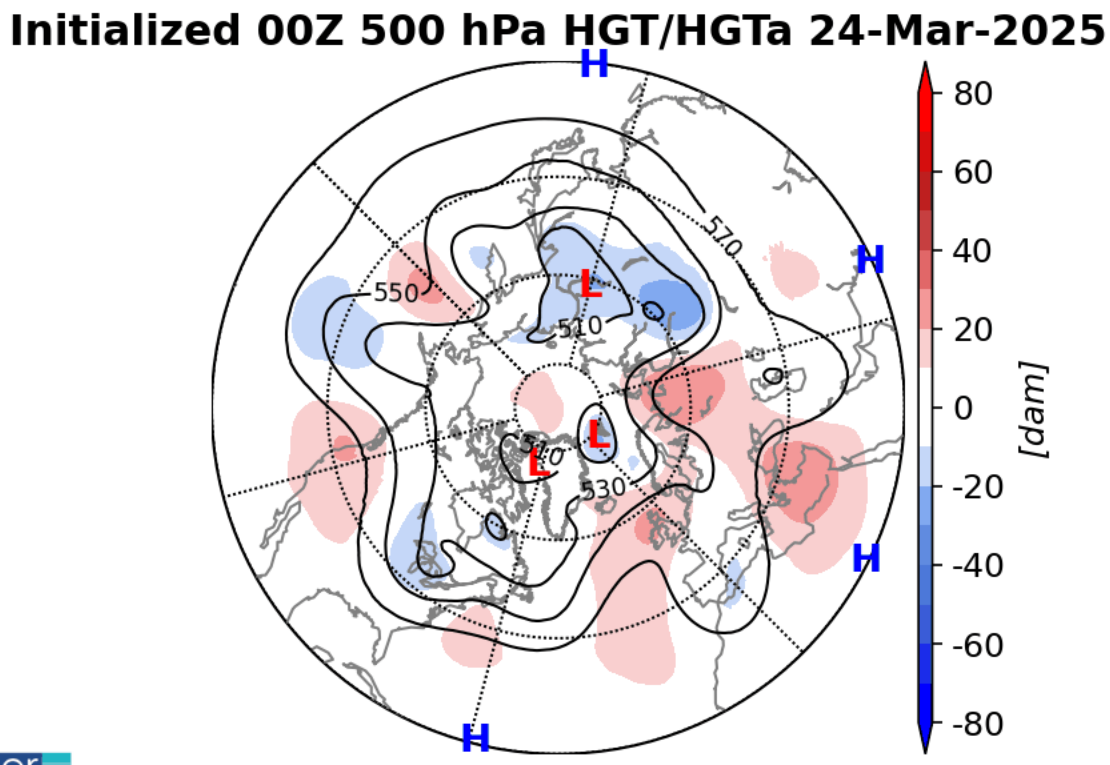

Figure iii. Initialized 500 mb geopotential heights (dam; contours) and decameter anomalies (dam; shading) across the Northern Hemisphere for 24 Mar 2025 and forecasted from 25 Mar to 08 Apr 2025. The forecasts are from the 00Z 24 Mar 2025 GFS model ensemble.

As I have been discussing since the beginning of the SSW, the main warm/positive PCHs are in the stratosphere since the beginning of the SSW and is predicted to remain in the upper to mid-stratosphere over 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, for those that are hoping to see a larger impact from the SSW, it takes time for the main region of anomalies to make its way from the upper stratosphere to the surface. That is why more memorable or notable SSWs and subsequent severe winter weather occur in early to mid-winter and not late winter.

Besides waiting for the slow descent of the largest anomalies from the stratosphere to the surface, the alternative 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. There appears to be some weak wave reflection predicted for next week (see **Figure iva**). The reflection takes place relatively far to the west supporting ridging closer to the Dateline and troughing over western North America

This wave reflection seems to at least partially be responsible for the predicted ridging near the Dateline in the troposphere and deepening troughing in western North America (see **Figures 5** and **8**) and cooler temperatures spreading across western North America (see **Figures 9**). In contrast, the energy diagnostics for the end of the first week of April does not predict wave reflection and that of the previous week will disappear (see **Figure ivb**).

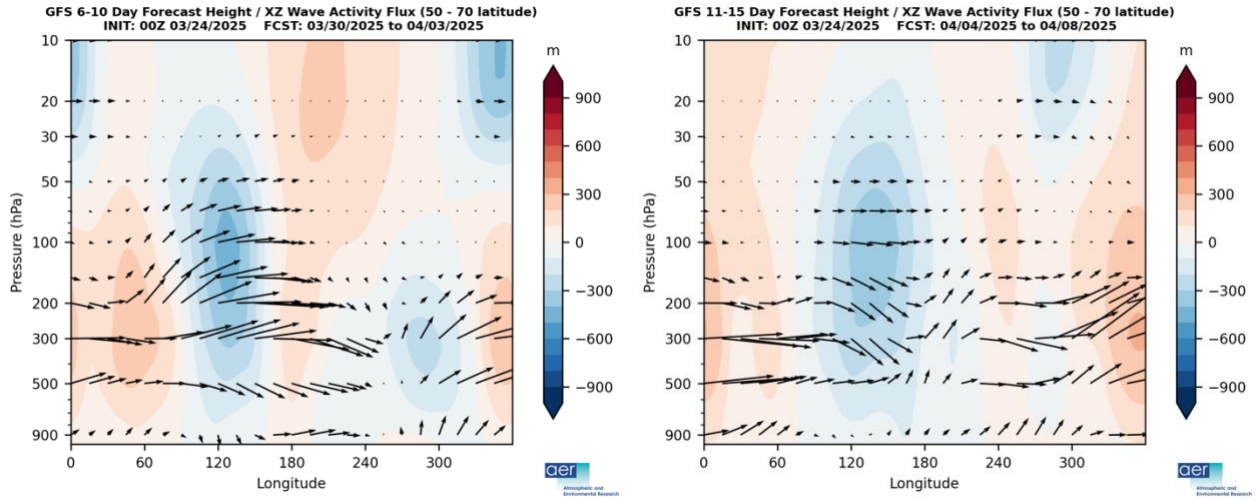

Figure iv. Longitude-height cross section of geopotential eddy height anomalies (shading) and wave activity flux (vectors) a) predicted for 30 Mar through 03 Apr 2025 and b) forecasted for 04 Apr through 08 Apr 2025. The forecasts are from the 00Z 24 Mar 2025 GFS ensemble.

It is at least hinted at in the PCHs plot the next drip will occur the second week of April (see **Figure 11**). I don't expect a large impact since the largest PCH anomalies are still predicted in the stratosphere. However, I am watching for the possibility of Greenland blocking that would bring cooler weather to Europe and or the Eastern US. But even in the absence of Greenland blocking, I think Southeastern Canda and the Northeastern US can turn cooler with the arrival of the main PV center the second week of April (see **Figure ii**).

For me it is interesting how the PV whether minor or major will make a pass over the Northeastern US. Maybe the impact is minimized by the short duration of residency in the region. But I do wonder what if this had been winter and not spring. Oh well there is always next year.

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 mostly negative geopotential height anomalies across Greenland (**Figure 2**), the NAO is predicted to be positive this week as well.

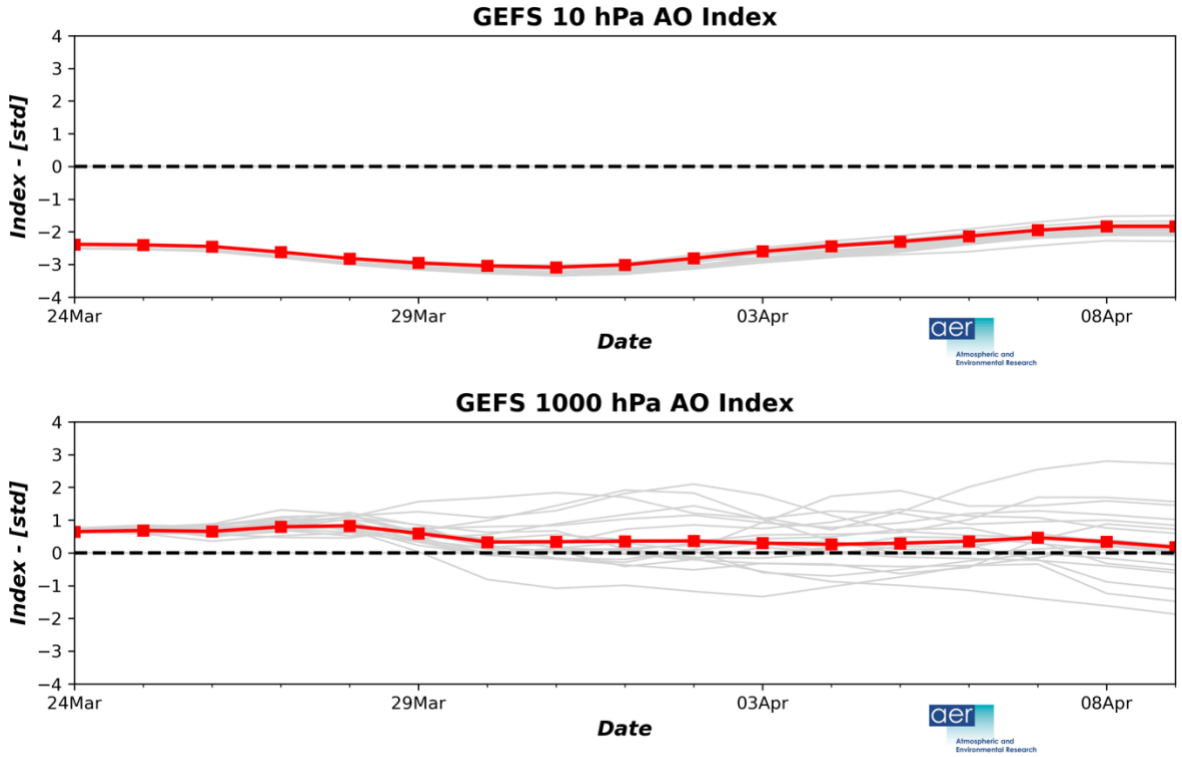

Figure 1. a) The predicted daily-mean AO at 10 hPa from the 00Z 24 Mar 2025 GFS ensemble. b) The predicted daily-mean AO at 1000 hPa from the 00Z 24 Mar 2025 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble mean AO index given by the red line with squares.

This week predicted troughing/negative geopotential height anomalies across Greenland will favor ridging/positive geopotential height anomalies across most of Europe with the exception of troughing/negative geopotential height anomalies across the Western Mediterranean (**Figure 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 the Iberian Peninsula this period (**Figure 3**). This week ridging/positive geopotential height anomalies will dominate Western Asia with troughing/negative geopotential height anomalies across Central and East Asia (**Figure 2**). This pattern favors normal to above normal temperatures widespread across Western and Southeastern Asia with normal to below normal temperatures across Central and Northeast Asia **(Figure 3**).

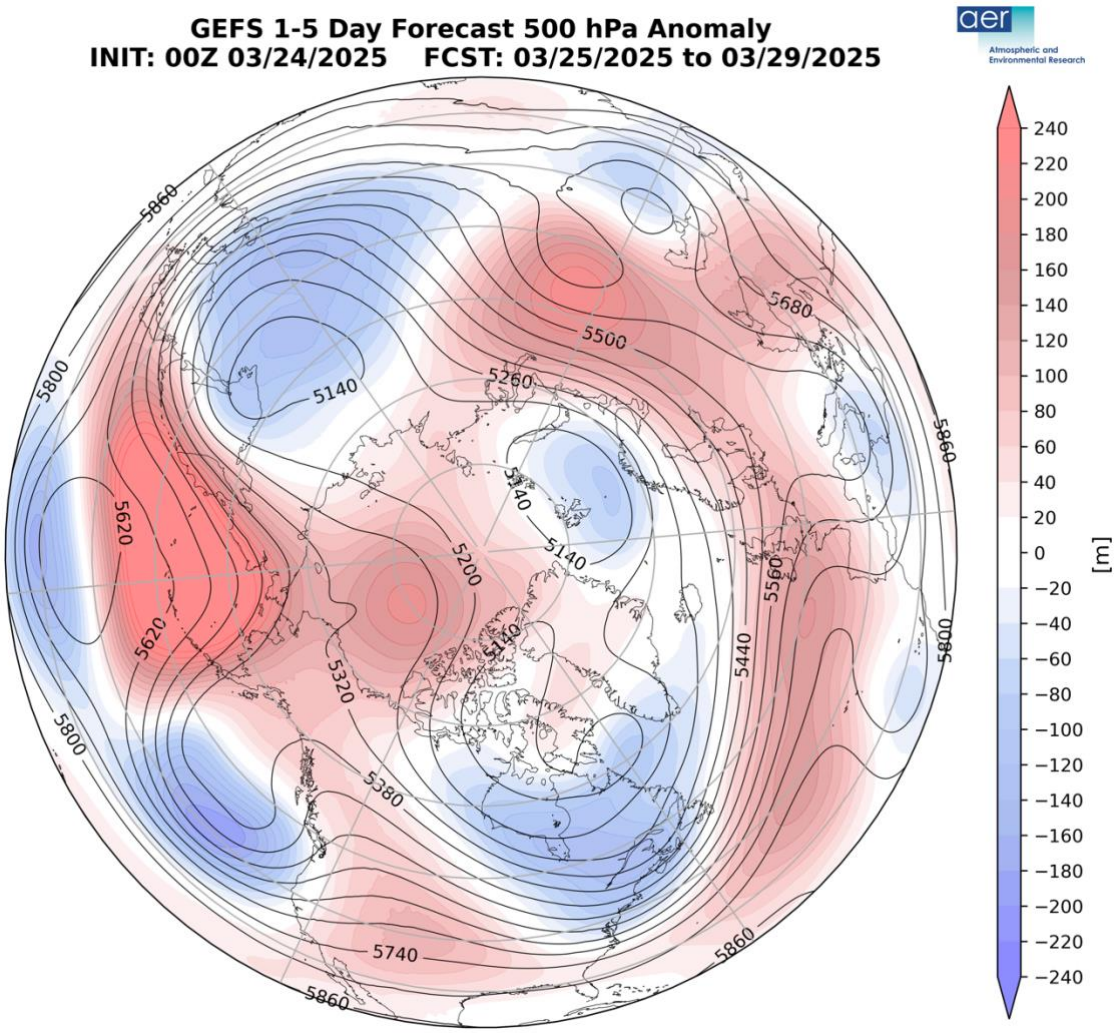

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 25 Mar to 29 Mar 2025. The forecasts are from the 00Z 24 Mar 2025 GFS ensemble.

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

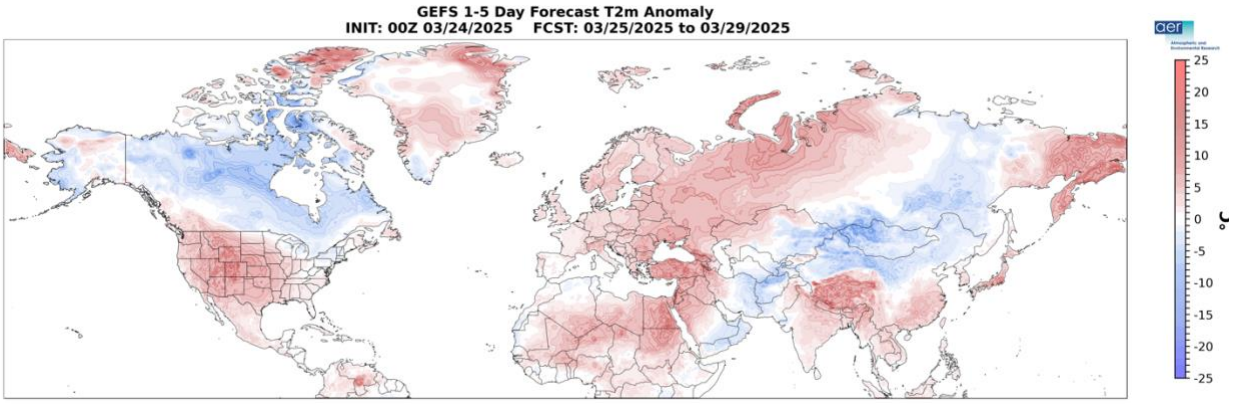

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 25 Mar to 29 Mar 2025. The forecasts are from the 00Z 24 Mar 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across 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 Central Canada and parts of the US Upper Midwest while warm temperatures will support snowmelt in Alaska, Western and Southeastern Canada and the Northwestern and Northeastern US this week (**Figure 4**). Figure 4 is a bit deceiving as new snow will also fall in Southeastern Canada and New England before melting as depicted in the figure.

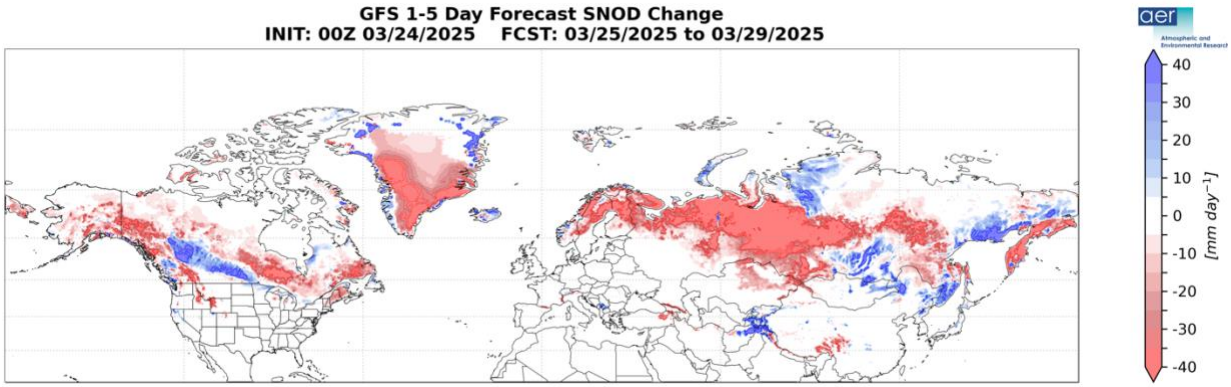

Figure 4. Forecasted snow depth changes (mm/day; shading) from 25 Mar to 29 Mar 2025. The forecasts are from the 00Z 24 Mar 2025 GFS ensemble.

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.

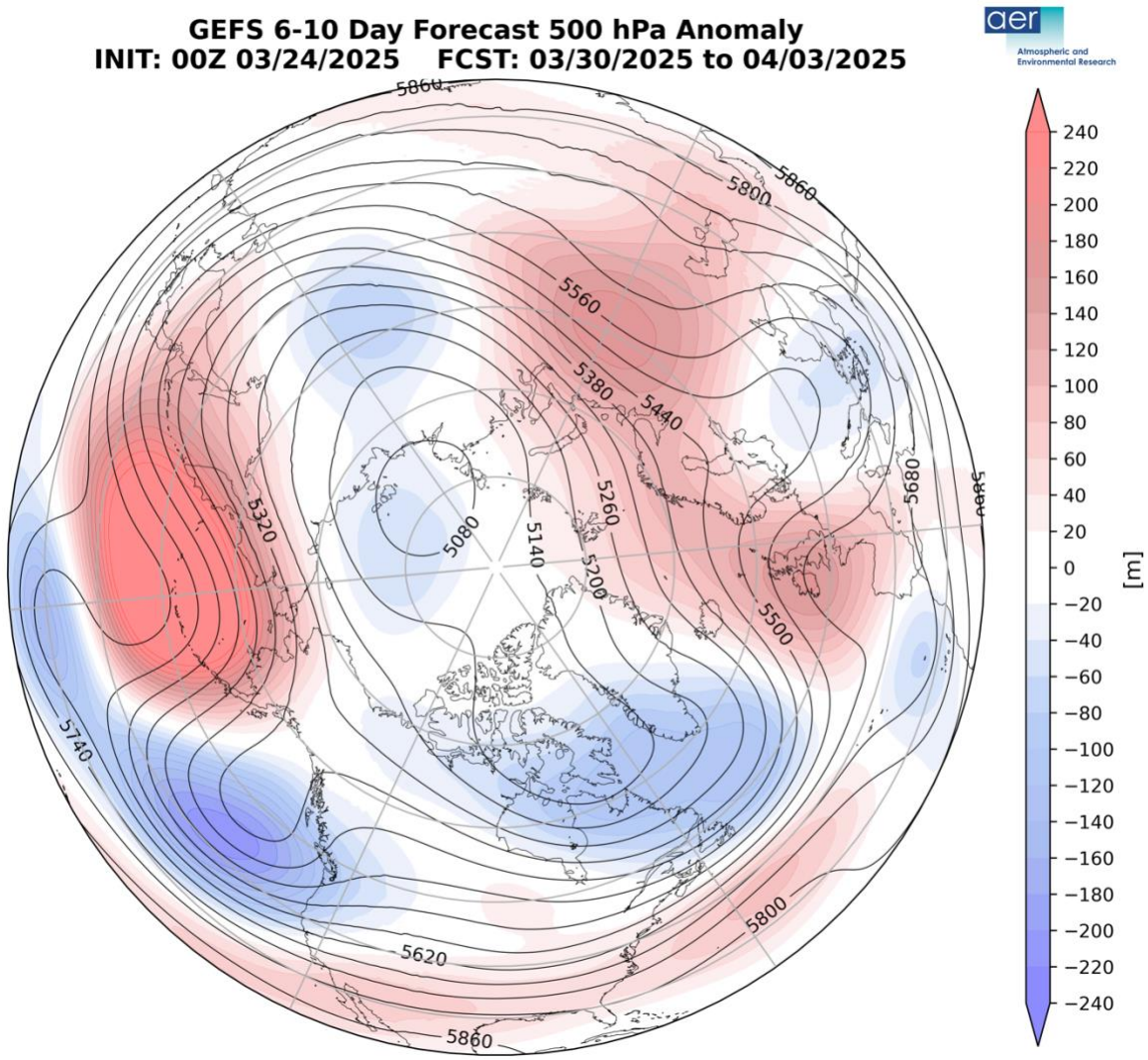

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 30 Mar to 03 Apr 2025. The forecasts are from the 00Z 24 Mar 2025 GFS ensemble.

Once again ridging/positive geopotential height anomalies are predicted to dominate Europe with the exception of troughing/negative geopotential height anomalies across the Eastern Mediterranean (**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 along the Mediterranean from Spain to Italy and the Balkans this period (**Figure 6**). Ridging/positive geopotential height anomalies will continue to dominate Western Asia and now in the Far East as well with troughing/negative geopotential height anomalies in Central Asia (**Figure 5**). This pattern favors widespread normal to above normal temperatures across most of Asia with normal to below normal temperatures limited to parts of Central and Southeast Asia this period (**Figure 6**).

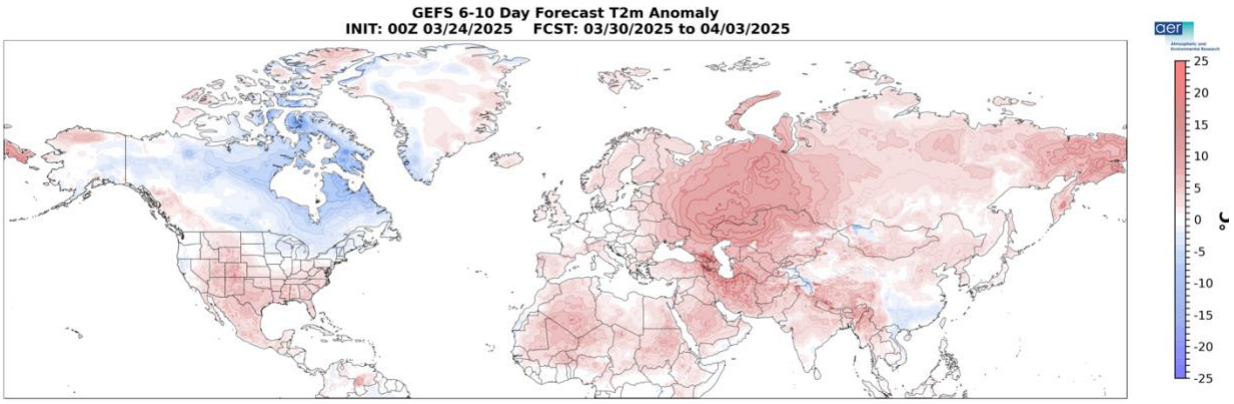

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 30 Mar to 03 Apr 2025. The forecasts are from the 00Z 24 Mar 2025 GFS ensemble.

The pattern across North America is predicted to begin reversing with deepening troughing/negative geopotential height anomalies across Western Canada and the Western US but still lingering across Eastern Canada with ridging/positive geopotential dominating much of the US this period (**Figure 5**). This pattern will favor normal to below normal temperatures widespread across Alaska, much of Canada, the US West Coast and the Northeastern US with normal to below normal temperatures across Southwestern Canada and the Northeastern US (**Figure 6**).

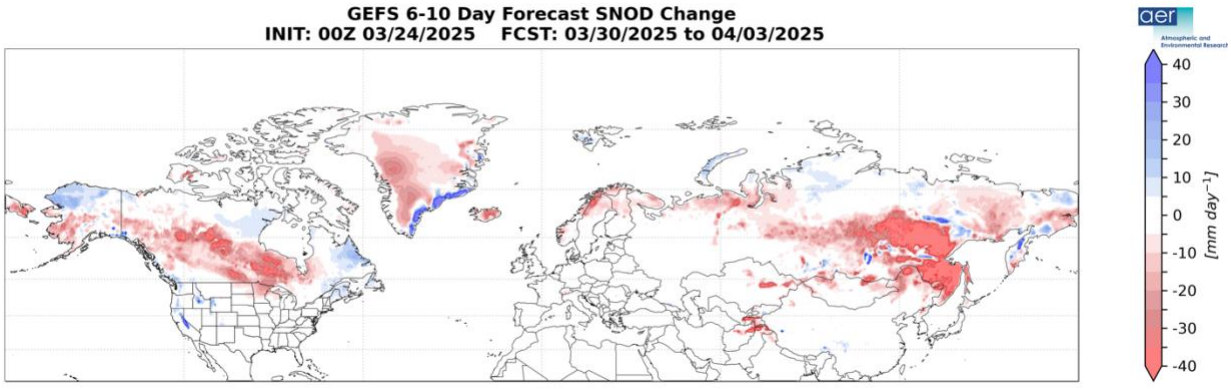

Figure 7. Forecasted snow depth changes (mm/day; shading) from 30 Mar to 03 Apr 2025. The forecasts are from the 00Z 24 Mar 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across parts of Northern Siberia 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 northern Alaska, Eastern Canada and the high elevations of the Western US while warm temperatures will support snowmelt across southern Alaska, Western and Central Canada and the US Upper Midwest 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 mixed pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO will likely be near neutral this period.

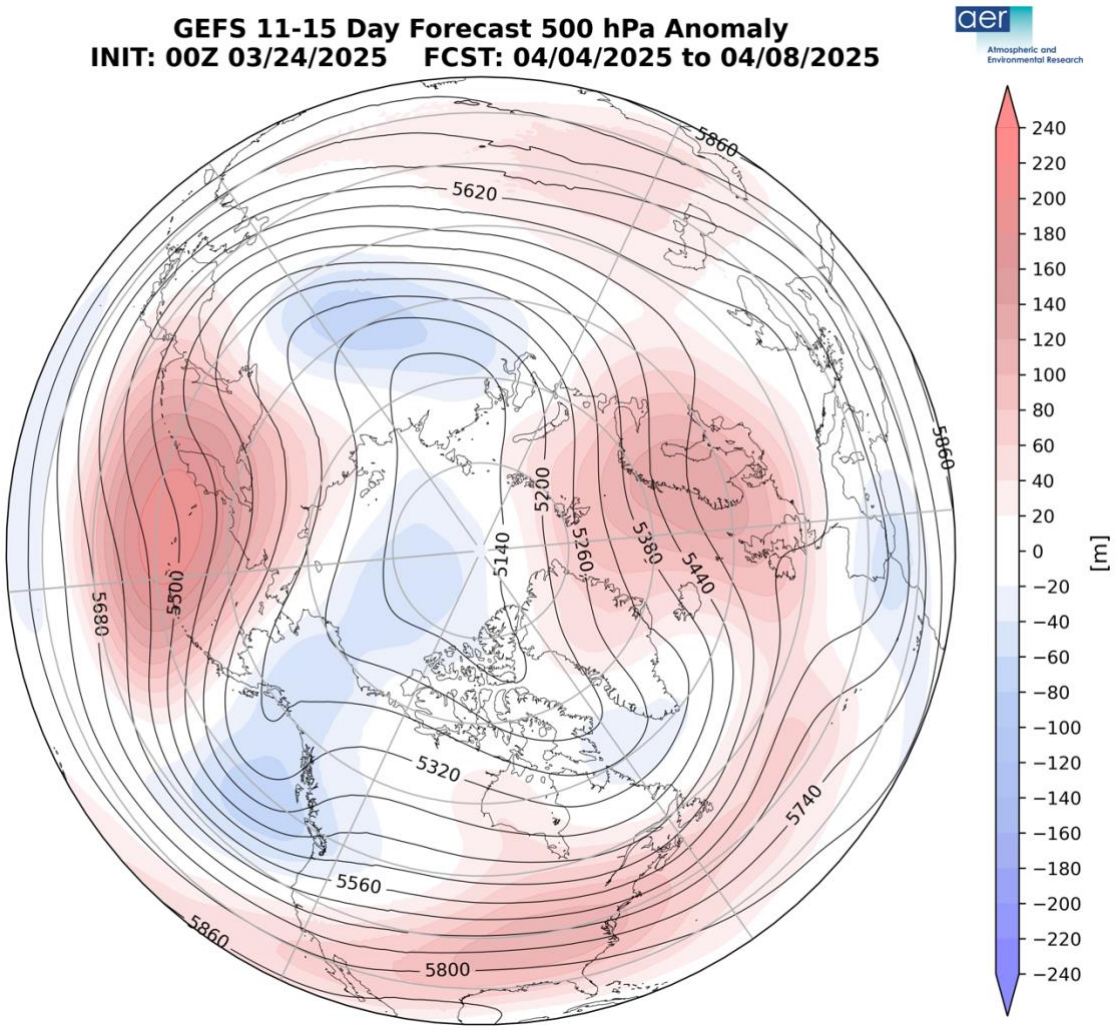

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 04 Apr to 08 Apr 2025. The forecasts are from the 00Z 24 Mar 2025 GFS ensemble.

Ridging/positive geopotential height anomalies are predicted to continue to dominate much of Europe with the exception of troughing/negative geopotential height anomalies once again across the Iberian Peninsula this period (**Figure 8**). This pattern should favor normal to above normal temperatures widespread across much of Europe including the UK with normal to below normal temperatures limited to Spain and Portugal this period (**Figures 9**). Ridging/positive geopotential height anomalies will persist across Western, Eastern and Southern Asia with troughing/negative geopotential height anomalies in Central 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 Western and Central Siberia this period (**Figure 9**).

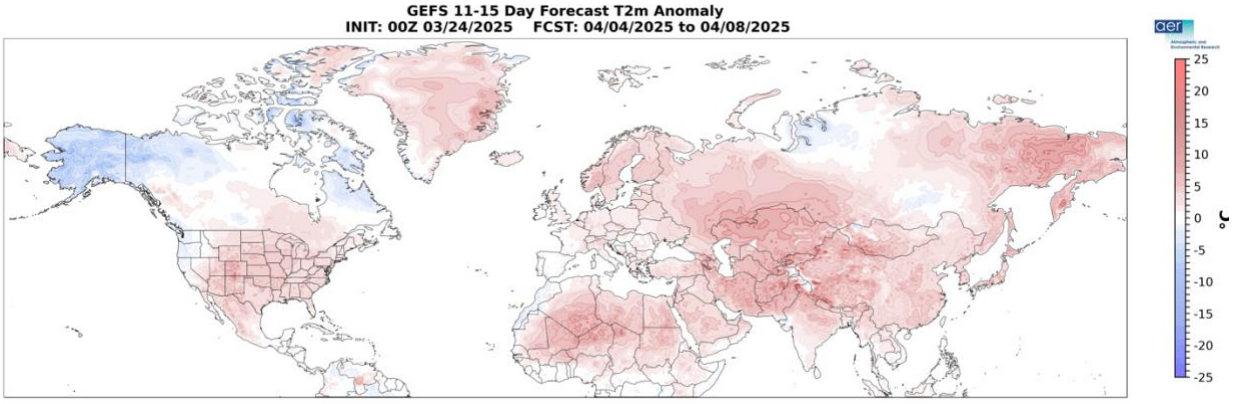

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 04 Apr to 08 Apr 2025. The forecasts are from the 00Z 24 Mar 2025 GFS ensemble.

Troughing/negative geopotential height anomalies are predicted to continue to dig across Alaska and Western Canada helping to strengthen ridging/positive geopotential height anomalies across Eastern Canada and the US east of the Rockies this period (**Figure 8**). This pattern supports normal to below normal temperatures across Alaska, Western Canada and the Western US with normal to above normal temperatures across Eastern Canada and the Eastern US this period (**Figure 9**).

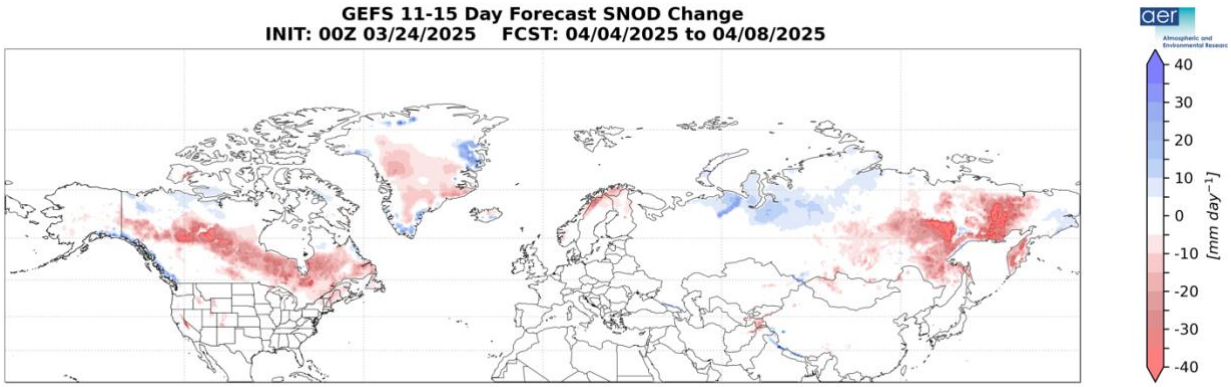

Figure 10. Forecasted snow depth changes (mm/day; shading) from 04 Apr to 08 Apr 2025. The forecasts are from the 00Z 24 Mar 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across Western Siberia and the Tibetan Plateau while warm temperatures will support snowmelt in Scandinavia, and widespread across Eastern Siberia and Northeast Asia this period (**Figure 10**). Troughing and/or cold temperatures will support new snowfall across the higher elevations of southern Alaska and the West Coast of Canada while warm temperatures will support snowmelt in Central and Eastern 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 and mid-troposphere with cold/negative PCHs in the lower troposphere (**Figure 11**). The strong warm/positive PCHs in the upper stratosphere are predicted to descend all the way to the surface this week. Then rapid transitions are predicted for the lower troposphere with the return of cold/negative PCHs next week and then warm/positive PCHs for the second eek of April while PCHs in the stratosphere and upper troposphere remain warm/positive for the foreseeable future. The warm/positive PCHs in the stratosphere represent a sudden stratospheric warming (SSW) or even possibly a final warming.

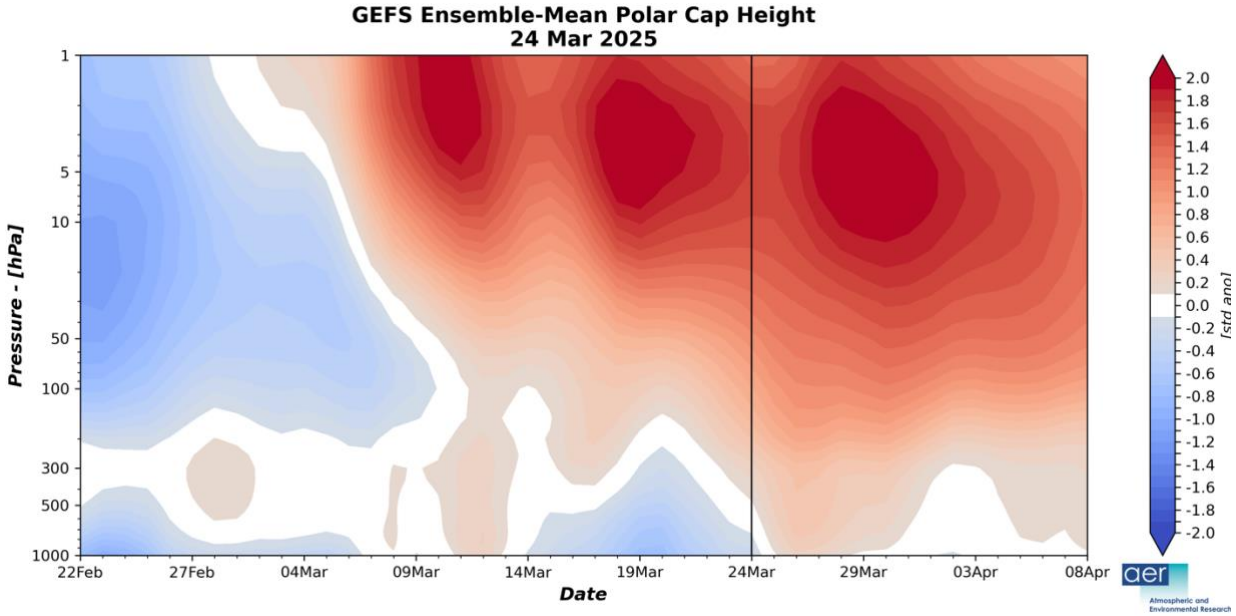

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 24 Mar 2025 GFS ensemble.

The predicted cold/negative PCHs in the lower troposphere early 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 mixed. I feel that the AO could eventually become more negative than currently predicted for the second week of April.

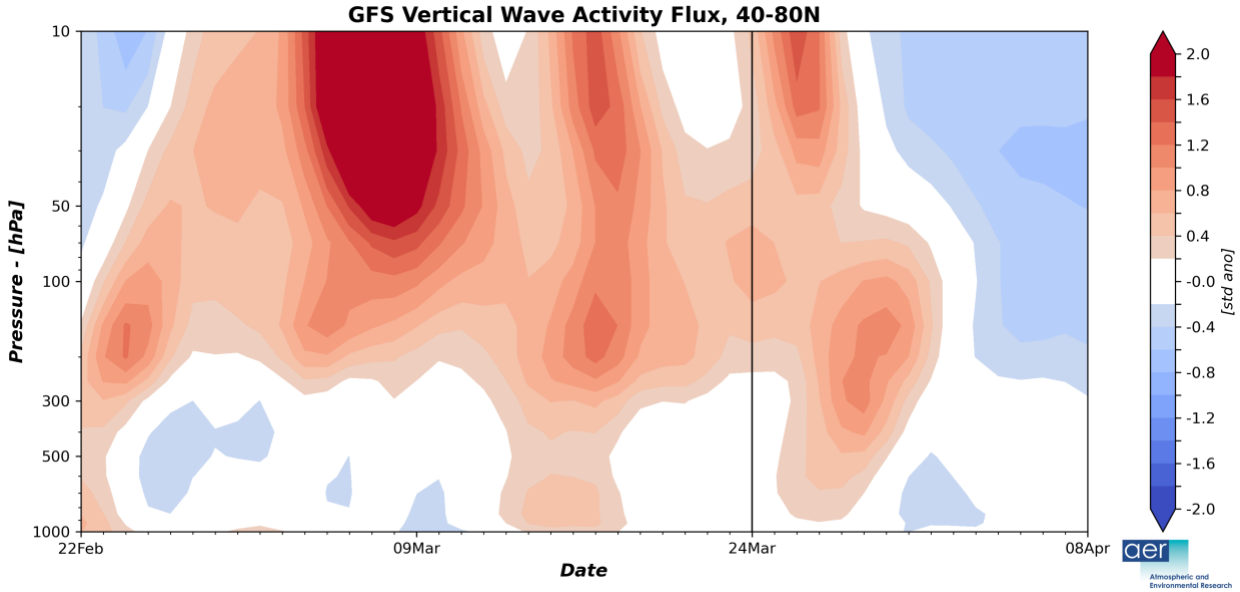

Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from

the 00Z 24 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 the first wek of March (**Figure 12**). This large pulse triggered the ongoing SSW this month. Now that we have a mature SSW, WAFz is predicted to turn quieter.

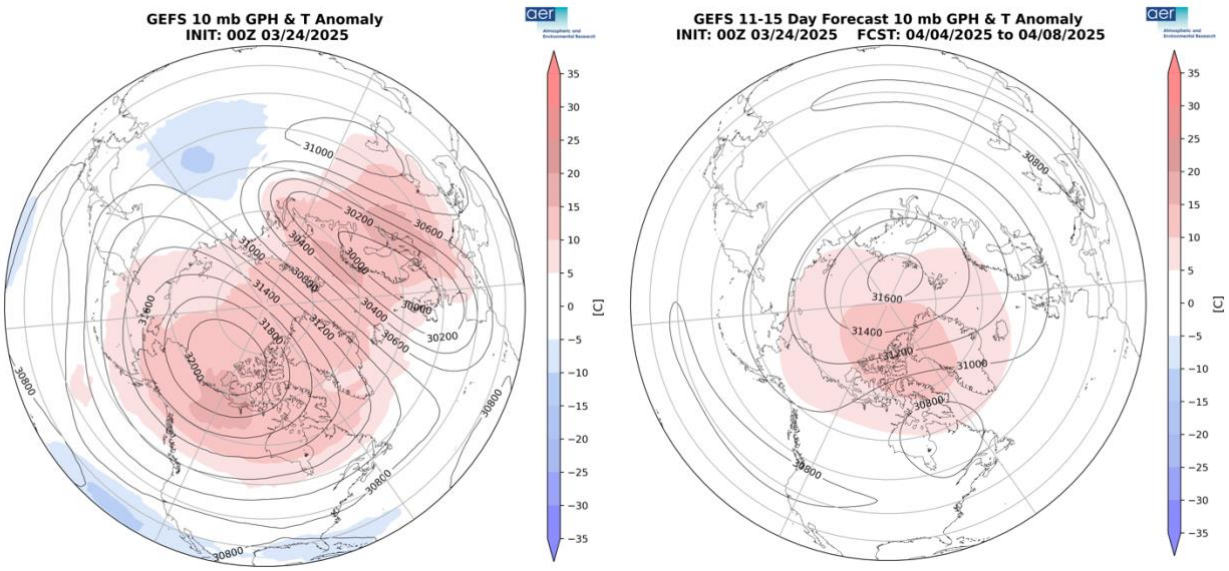

Figure 13. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 24 Mar 2025. (b) Same as (a) except forecasted averaged from 04 Apr to 08 Apr 2025. The forecasts are from the 00Z 17 Mar 2025 GFS model ensemble.

Currently the polar vortex (PV) is split with the major center over Scandinavia and the minor center over the North Atlantic (though not visible in the figure) with relatively coldest temperatures across lower latitudes with ridging centered over the Canadian Archipelagos and the relatively warmest temperatures across western Eurasia, the Arctic and Canada in the polar stratosphere (**Figure 13a**). This is consistent with a PV split type of SSW. Then in early April the PV is predicted to be centered over Hudson Bay with ridging centered over the Laptev Sea in the polar stratosphere. The relatively coldest temperatures are predicted across mid-latitudes and the warmest temperatures spread across the Arctic and Northern Canada 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.

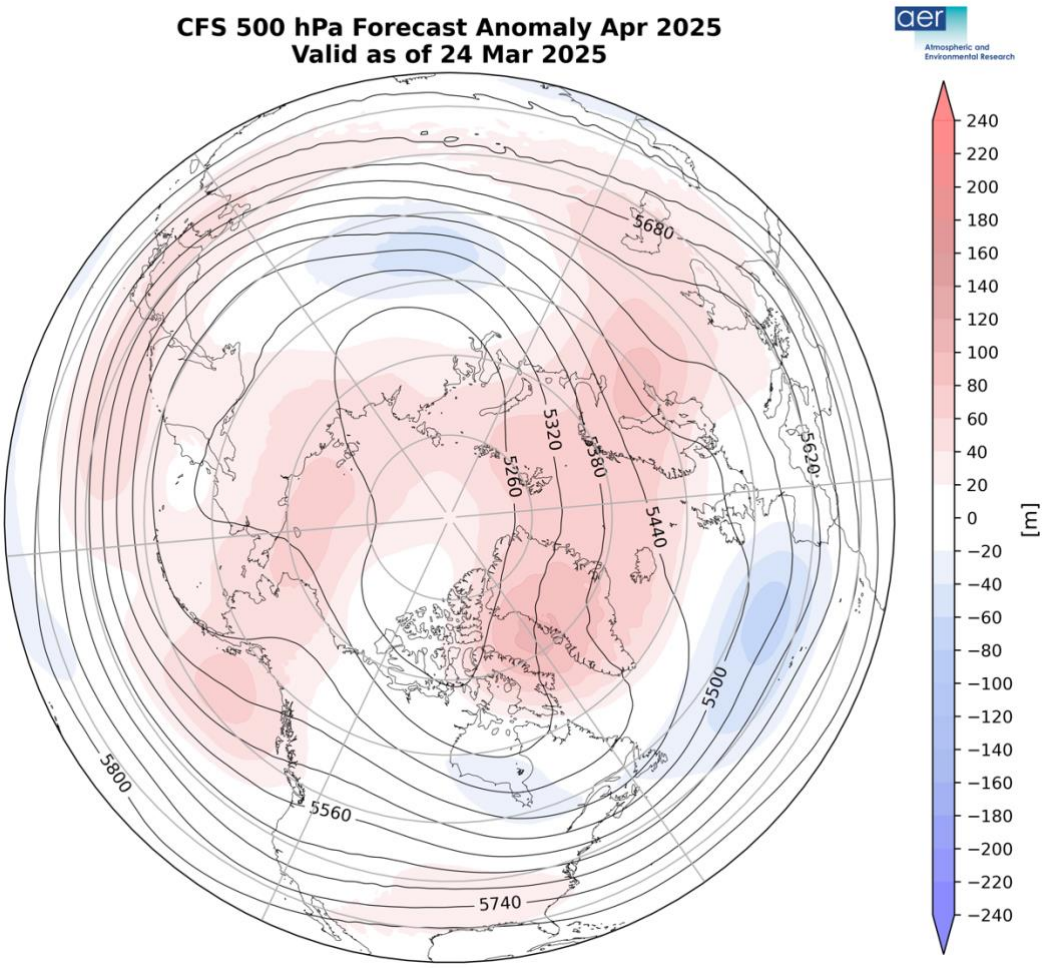

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for April 2025. The forecasts are from the 00Z 24 Mar 2025 CFS.

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, Eastern Europe, Southwest Asia, Eastern Siberia, the Gulf of Alaska, 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, especially Southern Asia and Northern 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**).

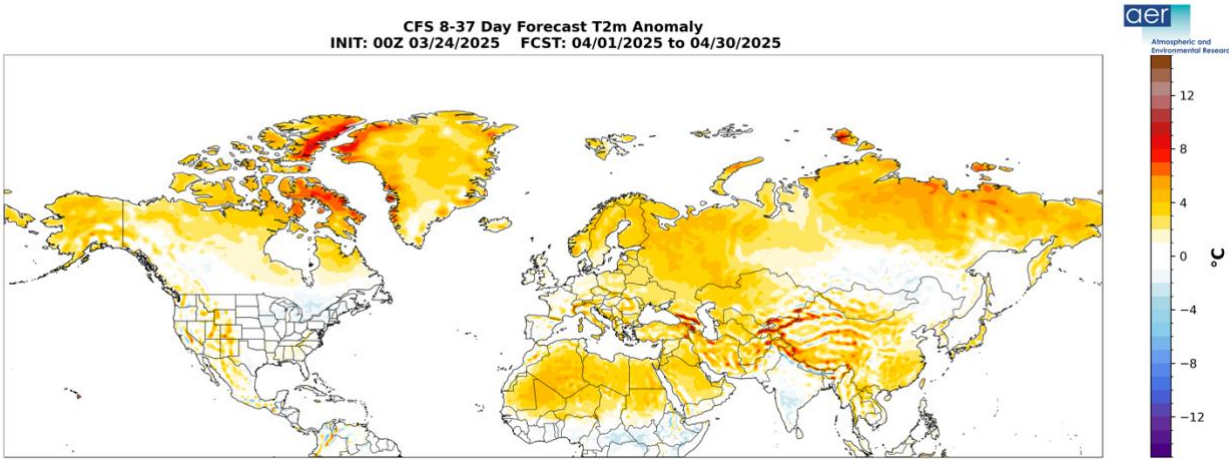

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for April 2025. The forecasts are from the CFS 00Z 24 Mar 2025.

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 sea ice maximum should occur imminently. 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.

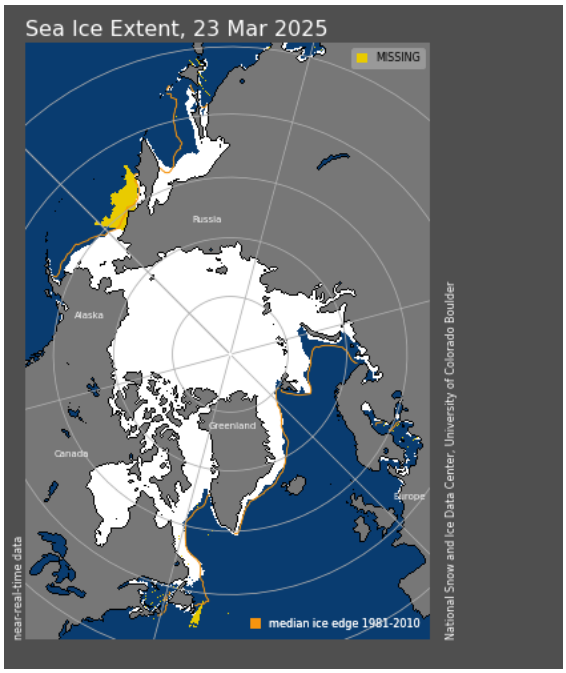

Figure 16. Observed Arctic sea ice extent on 23 Mar 2025 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image from the National Snow and Ice Data Center (NSIDC). URL: https://nsidc.org/sea-ice-today

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.

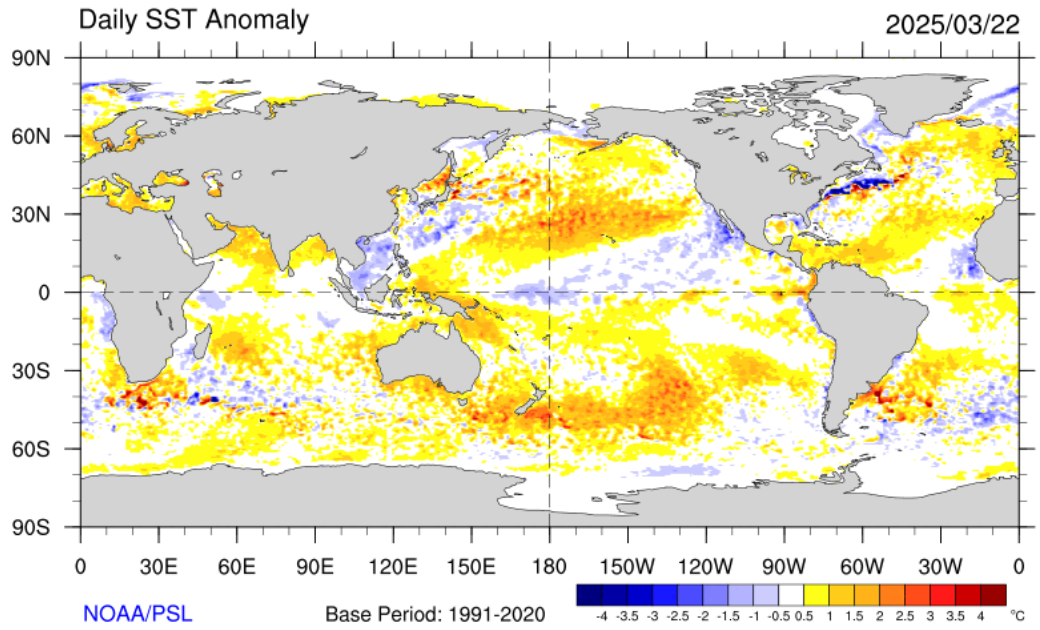

Figure 17. The latest daily-mean global SST anomalies (ending 22 Mar 2025). Data from NOAA OI High-Resolution dataset.

Madden Julian Oscillation

Currently the Madden Julian Oscillation (MJO) is in phase six but very weak (**Figure 18**). The forecasts are for the MJO to remain overall weak and hang out in 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 some influence on North American weather for the next two weeks. But admittedly this is outside of my expertise.

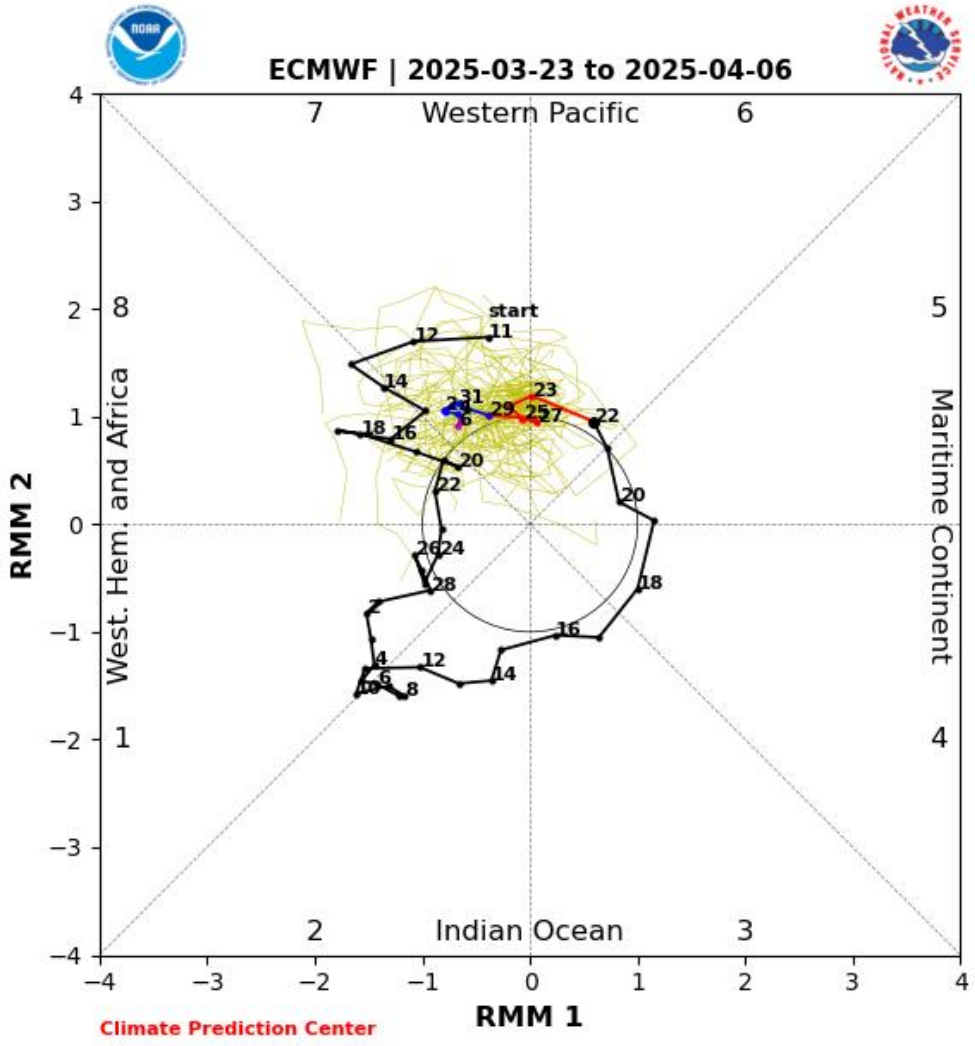

Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 23 Mar 2025 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model 'spread' is denoted by the gray shading. Sector numbers indicate 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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