Arctic Oscillation and Polar Vortex Analysis and Forecasts

April 7, 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 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 mostly positive pressure/geopotential height anomalies across Greenland and the NAO is predicted to trend positive and then remain near neutral to positive the next two weeks as pressure/geopotential height anomalies are predicted to become increasingly mixed to negative across Greenland.
- Over the next two weeks Europe is predicted to be mostly dominated by ridging/positive geopotential height anomalies with the main exception of troughing/negative geopotential height anomalies across Eastern Europe this week. This pattern will support widespread normal to above normal temperatures across Europe including the United Kingdom (UK) with the biggest exception of normal to below normal temperatures across Eastern Europe this week.
- Over the next two weeks Asia is predicted to be mostly dominated by ridging/positive geopotential height anomalies with the exception of troughing/negative geopotential height anomalies across Western Asia and in Western Siberia that propagates into East Asia next week. This pattern favors this week normal to above normal temperatures

widespread across Asia with normal to below normal temperatures across far Western Asia and Western Siberia this week and then next week also in parts of East Asia.

- The general pattern across North America the next two weeks 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. However for much of next week the pattern will relax across North America. This patten will favor widespread normal to above normal temperatures across Alaska, Western Canada and the Western US with normal to below normal temperatures across Eastern Canada and the Eastern US. Then next week normal to above normal temperatures will become more widespread across North America with normal to below normal temperatures limited to Alaska, the Northeastern and the Southeastern US.

- A long duration sudden stratospheric warming (SSW) continues with episodic influence on the weather across the Northern Hemisphere. Is the end in sight?

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 so far this spring (see **Figure**). Episodic influence from the PV disruption is bringing cooler weather to Eastern Europe, the Eastern US (see **Figure 3**) and even East Asia (see **Figure 6**) but overall, still looks like a mild pattern for the NH. The climatic impact from the PV disruption could occur as early as late April. This could bring cooler weather to the Eastern US and/or Europe and/or East Asia. Though the impacts will likely be less notable than had the whole cycle occurred two months earlier.

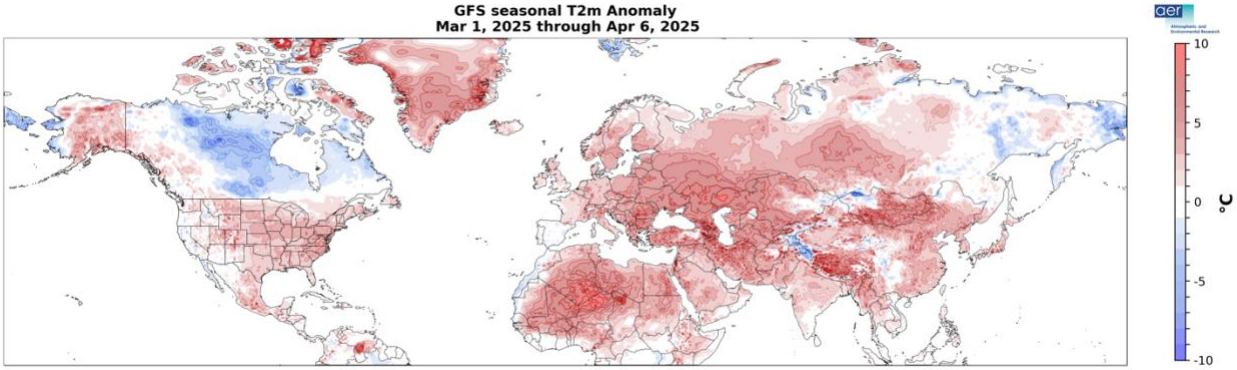

Figure. Estimate of the observed surface temperatures (°C; shading) from 01 Mar to 06 Apr 2025 based on GFS initializations and the GFS forecast from the 07 Apr 2025 run.

Impacts

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 likely result in a Final warming (PV will not return until next fall). Models predict that the PV will try to retake its throne over the North Pole over the weekend but fail (see **Figure i**). This was likely the last possible opportunity for the winds in the polar stratosphere to return to westerly before next fall. The SSW resulted in a PV split but currently there is only one discernable center over Hudson Bay that continues to circumnavigate the Northern Hemisphere from east to west in the prevailing easterly flow (see **Figure i**).

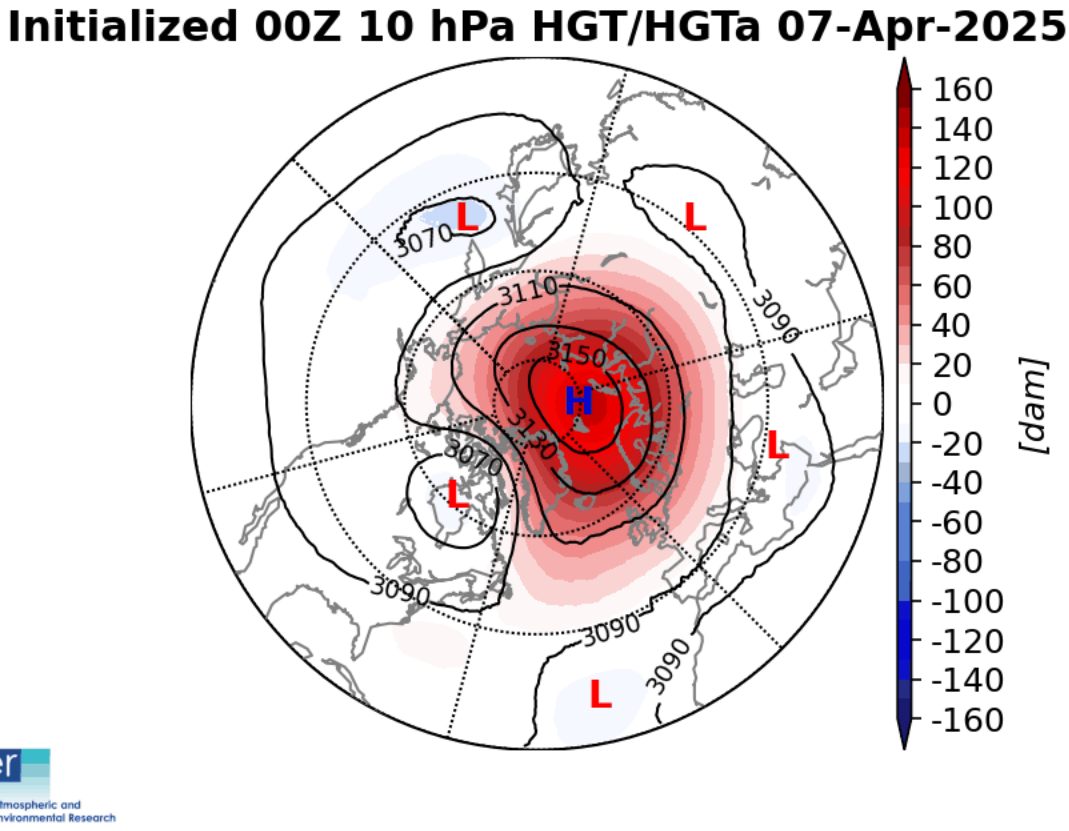

Figure ii. Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 07 Apr 2025 and forecasted from 08 Apr to 22 Apr 2025. The forecasts are from the 00Z 07 Apr 2025 GFS model ensemble.

In my opinion the tropospheric response or the impact to our weather is looking fairly textbook. 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. It returned the fourth week of March, this week, and it is looking increasingly likely to return in the third to maybe fourth week of April. This is consistent with the episodic influence of an SSW manifesting as dripping 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**. This week's "drip" shows up better in the PCH plot limited to the North Atlantic region (see **Figure ii**).

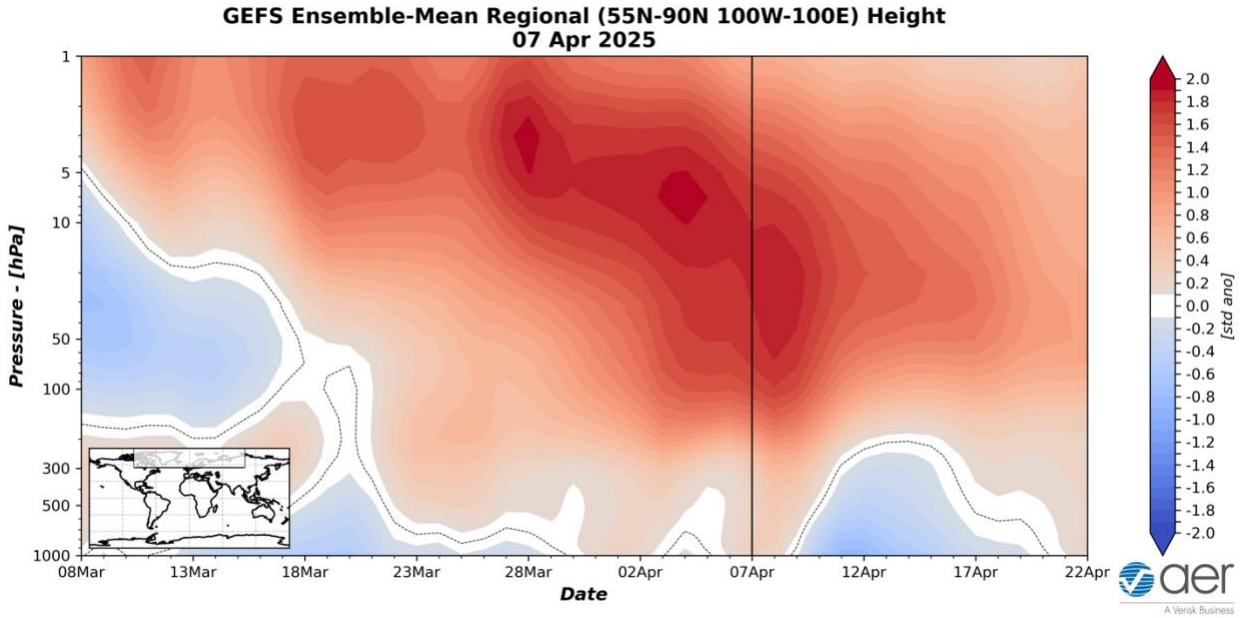

Figure ii. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) limited to the North Atlantic region (see insert) standardized anomalies. The forecast is from the 00Z 07 Apr 2025 GFS ensemble.

This coincided with an increase in high latitude blocking focused near Greenland (see **Figure iii**). This is supporting cooler weather for Eastern Europe, Eastern Canada and the Eastern US this week (see **Figure 3**). But it is fleeting or transitory (see **Figure iii**). I would look for Greenland blocking to likely return with the next "drip" predicted around 20 April. Not showing up very well in **Figure iii** until the last frame (and even then barely), but the Greenland blocking is more robust in the European model than the GFS. I would favor the European model over the GFS model. With the expected return of Greenland in late April I would look for cooler temperatures in the Europe and/or the Eastern US once again.

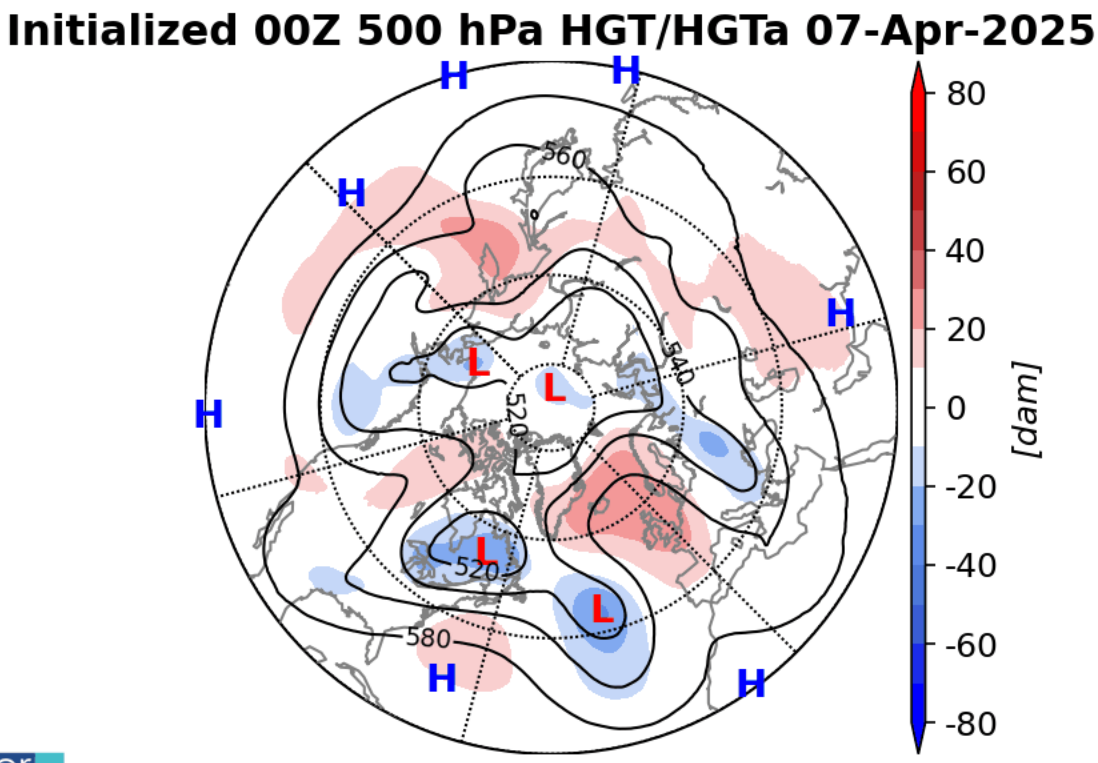

Figure iii. Initialized 500 mb geopotential heights (dam; contours) and decameter anomalies (dam; shading) across the Northern Hemisphere for 07 Apr 2025 and forecasted from 08 Apr to 22 Apr 2025. The forecasts are from the 00Z 07 Apr 2025 GFS model ensemble.

As I have been discussing since the beginning of the SSW, the main warm/positive PCHs have been in the upper stratosphere since the beginning of the SSW but have finally made it to the middle stratosphere (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 are finally signs of that occurring in the two-week forecasts. The earliest that would occur is sometime in late April and possibly even early May. But we are already in late spring by then, so likely to result in just more chilly damp weather like this week here in the Northeastern US, even with a few decorative snowflakes thrown in. I think the most impactful weather is likely to be flooding from slow moving troughs or cutoff lows.

As I have been discussing as well, 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. I do believe that the cool weather in the Eastern US was intensified by wave reflection as I shared on social media last week tweet from 31Mar2025.

Once again, I present the energy diagnostics that are used to display the presence or absence of wave reflection. To me there is no obvious wave reflection either before (see **Figure iva**) or around the time of the next drip (see **Figure ivb**). If wave reflection does occur in late April, it could bring a climatic ending to the SSW/Final Warming and its impacts to our weather. This could intensify the cool period in the Eastern US similar to this week, seasonally adjusted of course.

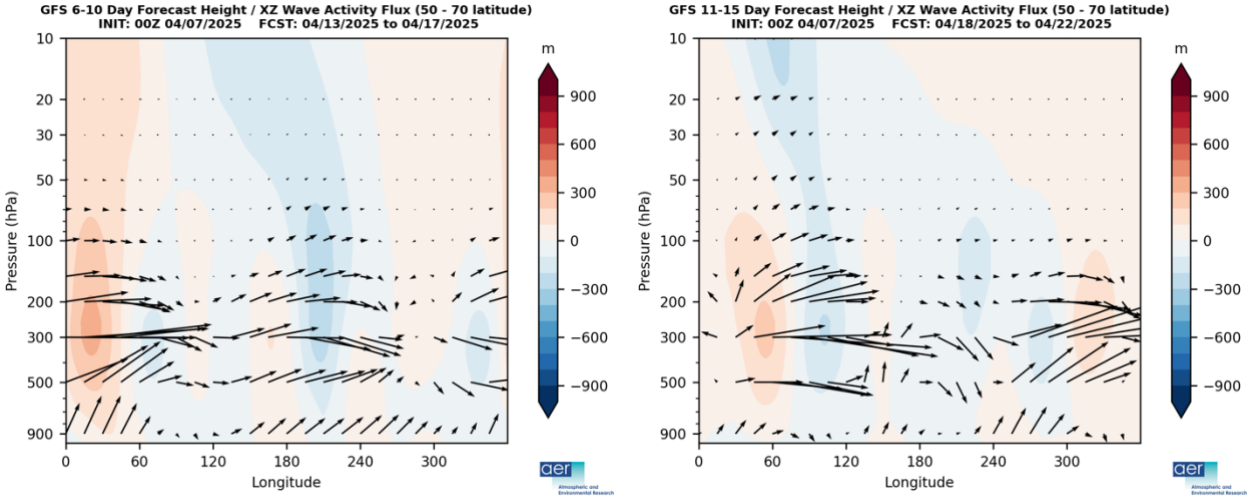

Figure iv. Longitude-height cross section of geopotential eddy height anomalies (shading) and wave activity flux (vectors) a) predicted for 13 Apr through 17 Apr 2025 and b) forecasted for 18 Apr through 22 Apr 2025. The forecasts are from the 00Z 07 Apr 2025 GFS ensemble.

In my opinion and as I have tried to support for the past several months in the blog, the stratospheric polar vortex has been active and intimately related to Northern Hemisphere weather all winter long and now for a good part of the spring as well. That coupling has been most evident in the Eastern US and also East Asia (impressive snow tunnels in Japan tweet from ThierryGooseBC). I know that not everyone agrees with me, but I remain undeterred or unwavering in my beliefs. And as always there are winners and losers when it comes to the impacts from coupling between the polar vortex and our weather. And I leave it to everyone individually to decide who is considered a winner and who is considered a loser. As an unabashed snow lover, for me this winter came up short.

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

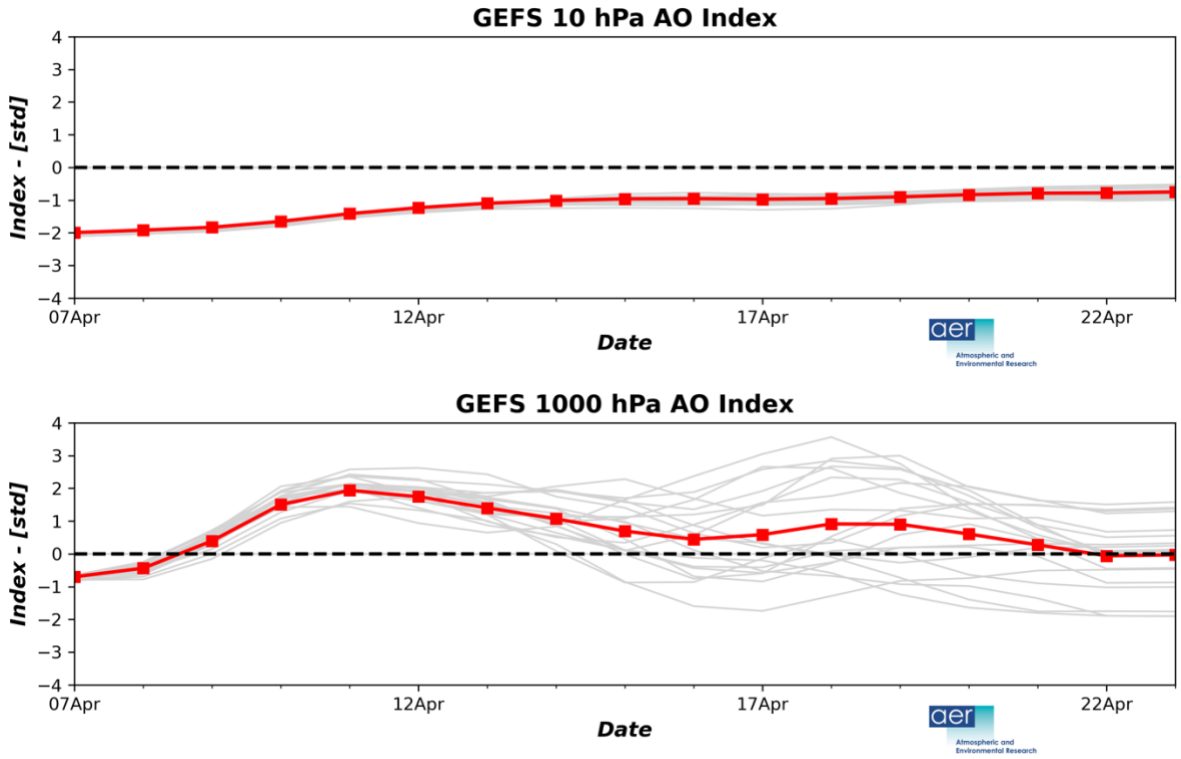

Figure 1. a) The predicted daily-mean AO at 10 hPa from the 00Z 07 Apr 2025 GFS ensemble. b) The predicted daily-mean AO at 1000 hPa from the 00Z 07 Apr 2025 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble mean AO index given by the red line with squares.

This week predicted ridging/positive geopotential height anomalies across Greenland will favor troughing/negative geopotential height anomalies across Eastern Europe with ridging/positive geopotential height anomalies across Western Europe (**Figure 2).** This pattern will favor normal to above normal temperatures across Western Europe including the UK with normal to below normal temperatures across Eastern Europe this period (**Figure 3**). This week ridging/positive geopotential height anomalies are predicted to dominate most of Asia with troughing/negative geopotential height anomalies limited to far Western Asia and Western Siberia (**Figure 2**). This pattern favors normal to above normal temperatures widespread across Asia with normal to below normal temperatures limited far Western Asia and Western Siberia **(Figure 3**).

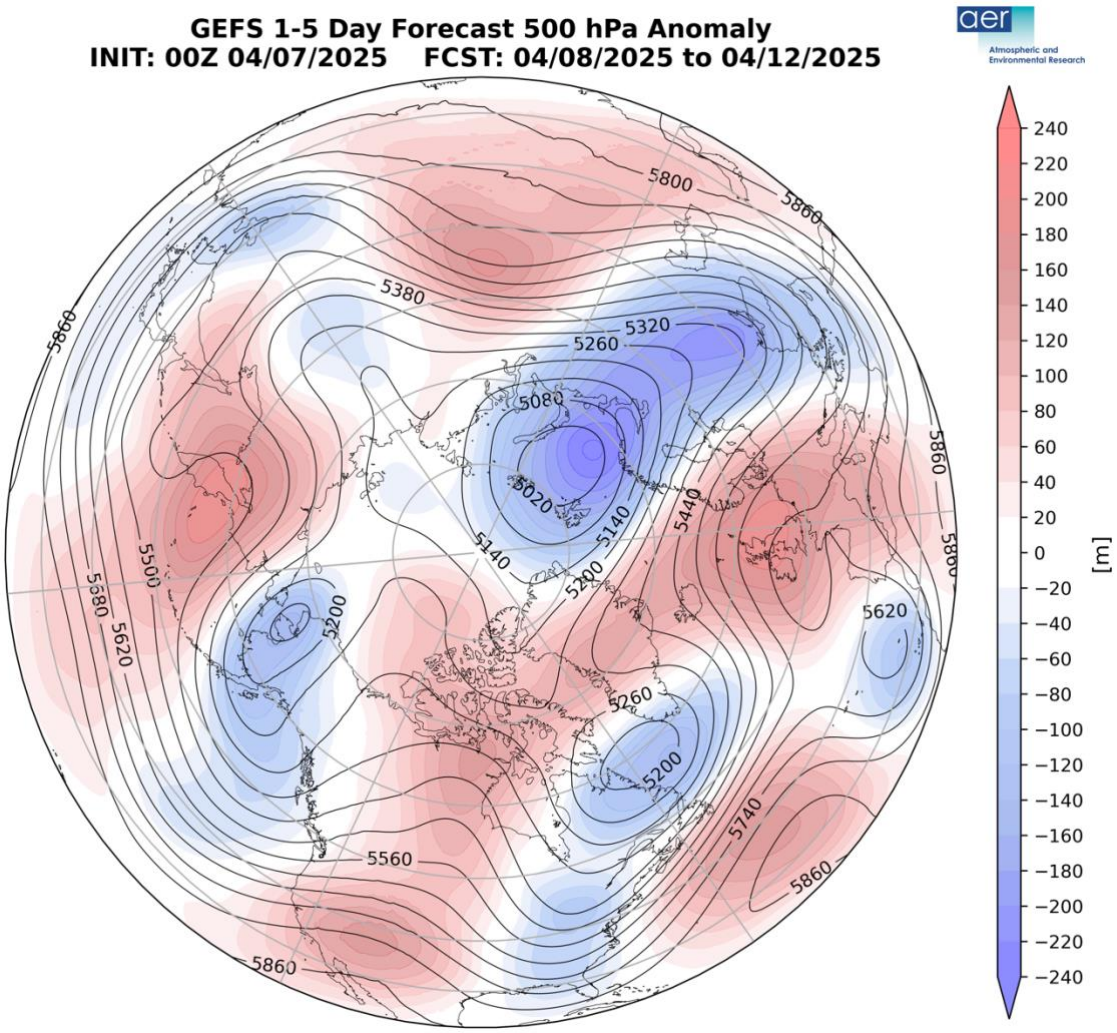

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 08 Apr to 12 Apr 2025. The forecasts are from the 00Z 07 Apr 2025 GFS ensemble.

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

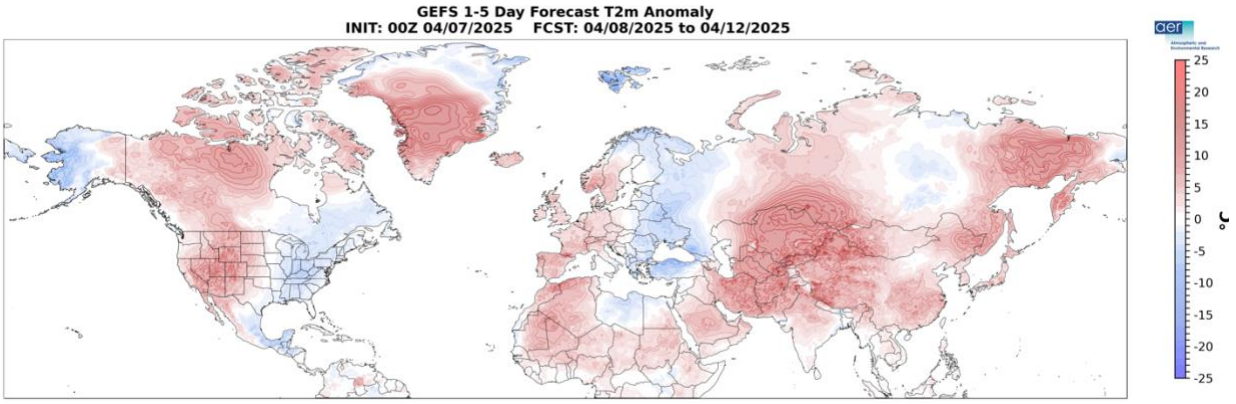

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 08 Apr to 12 Apr 2025. The forecasts are from the 00Z 07 Apr 2025 GFS ensemble.

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

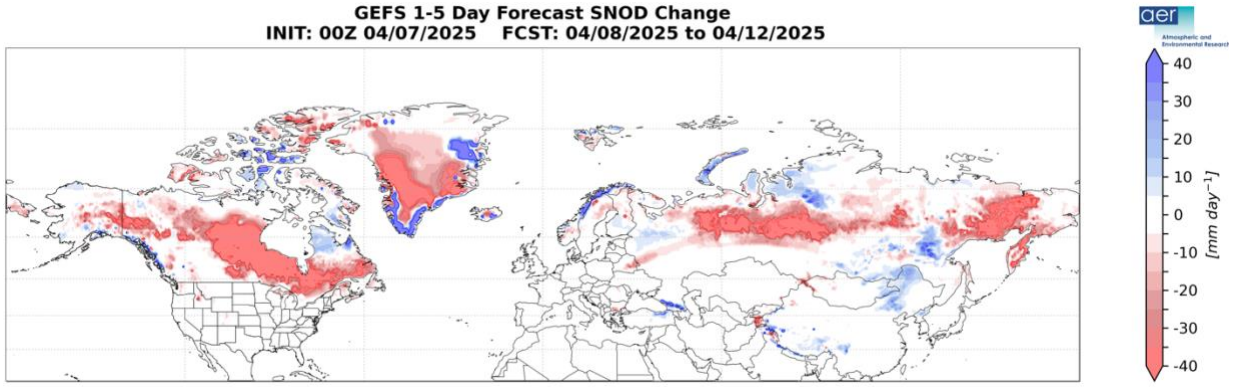

Figure 4. Forecasted snow depth changes (mm/day; shading) from 08 Apr to 12 Apr 2025. The forecasts are from the 00Z 07 Apr 2025 GFS ensemble.

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 be positive this period (**Figure 1**). With predicted negative pressure/geopotential height anomalies across Greenland (**Figure 5**), the NAO will likely be positive this period.

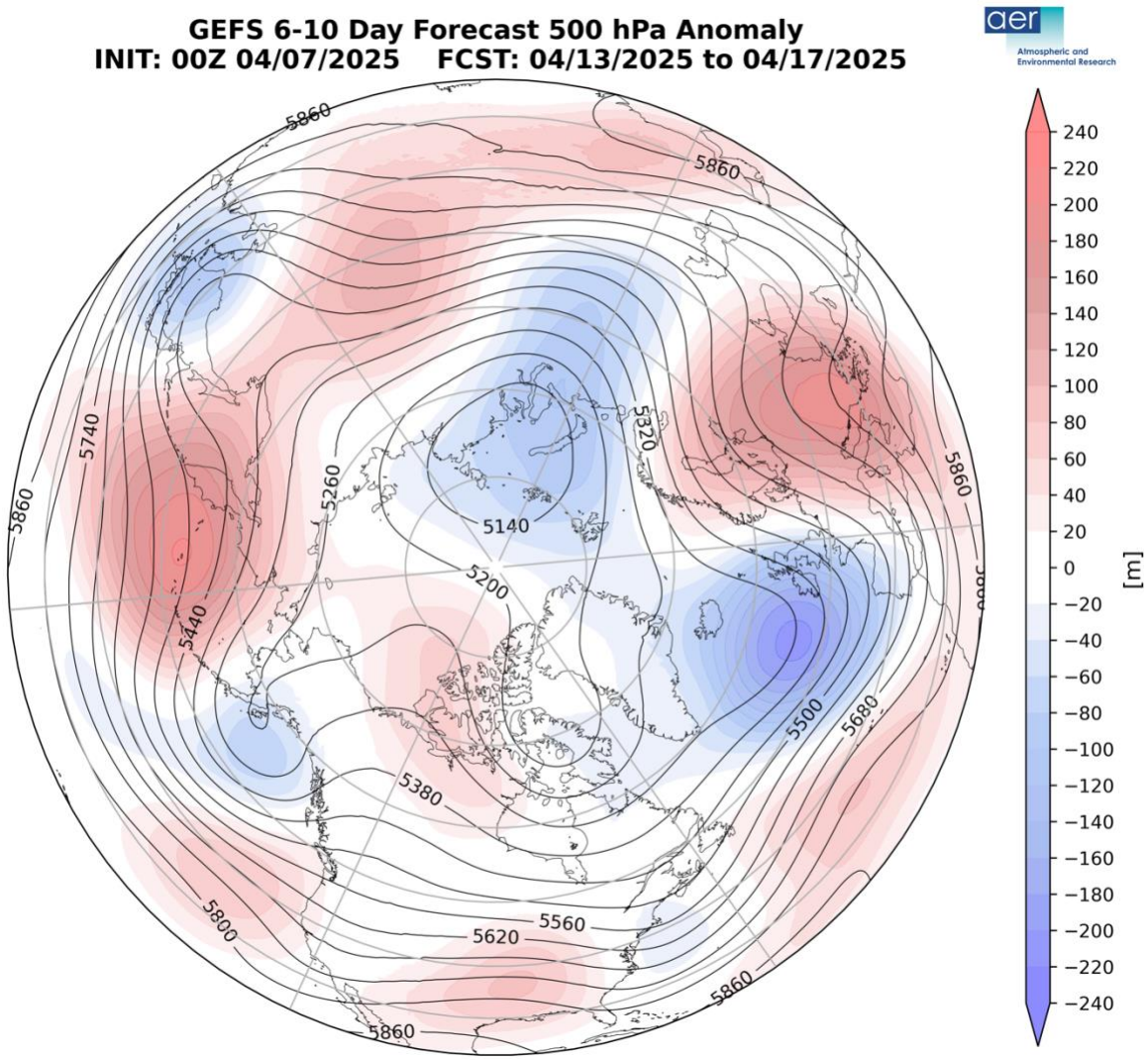

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 13 Mar to 17 Apr 2025. The forecasts are from the 00Z 07 Apr 2025 GFS ensemble.

Once again ridging/positive geopotential height anomalies are predicted to dominate Europe with troughing/negative geopotential height anomalies in the North Atlantic just west of the UK (**Figure 5**). Ridging and southwesterly flow favor widespread normal to above

normal temperatures across much of Europe including the UK with normal to below normal temperatures limited to the western half of the Iberian Peninsula this period (**Figure 6**). Ridging/positive geopotential height anomalies will continue to dominate Asia with troughing/negative geopotential height anomalies limited to Western and Eastern 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 far Western Asia and Northeast China and Korea this period (**Figure 6**).

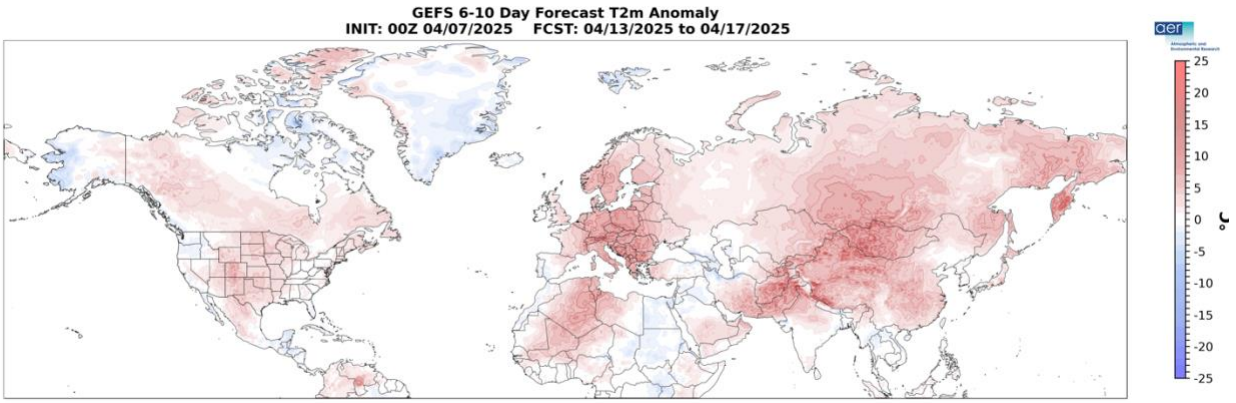

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 13 Apr to 17 Apr 2025. The forecasts are from the 00Z 07 Apr 2025 GFS ensemble.

The pattern across North America is predicted to relax with ridging/positive geopotential height anomalies in Western Canada and the Central US with weak troughing/negative geopotential height anomalies across western Alaska and both coasts of the US this period (**Figure 5**). This pattern will favor normal to below normal temperatures widespread across eastern Alaska, much of Canada and the US with normal to below normal temperatures across western Alaska, the Northwestern US and the US East Coast (**Figure 6**).

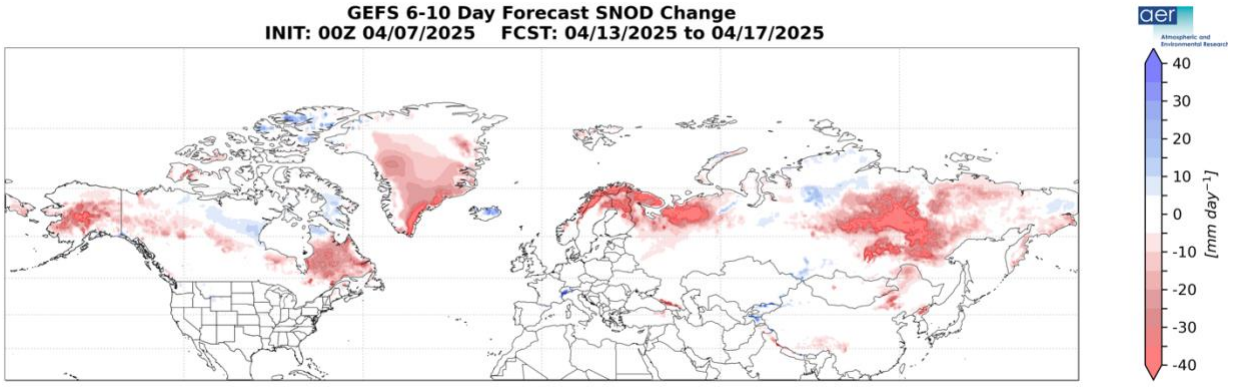

Figure 7. Forecasted snow depth changes (mm/day; shading) from 13 Apr to 17 Apr 2025. The forecasts are from the 00Z 07 Apr 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across parts of Northern Siberia while warm temperatures will support snowmelt in Scandinavia, Northwest Russia,

Siberia and Northeast Asia this period (**Figure 7**). Troughing and/or cold temperatures will support new snowfall across Northern Canada while warm temperatures will support snowmelt across Alaska, Central and Eastern Canada this period (**Figure 7**).

Mid Term

Week Two

With predicted persistent mostly mixed to 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 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.

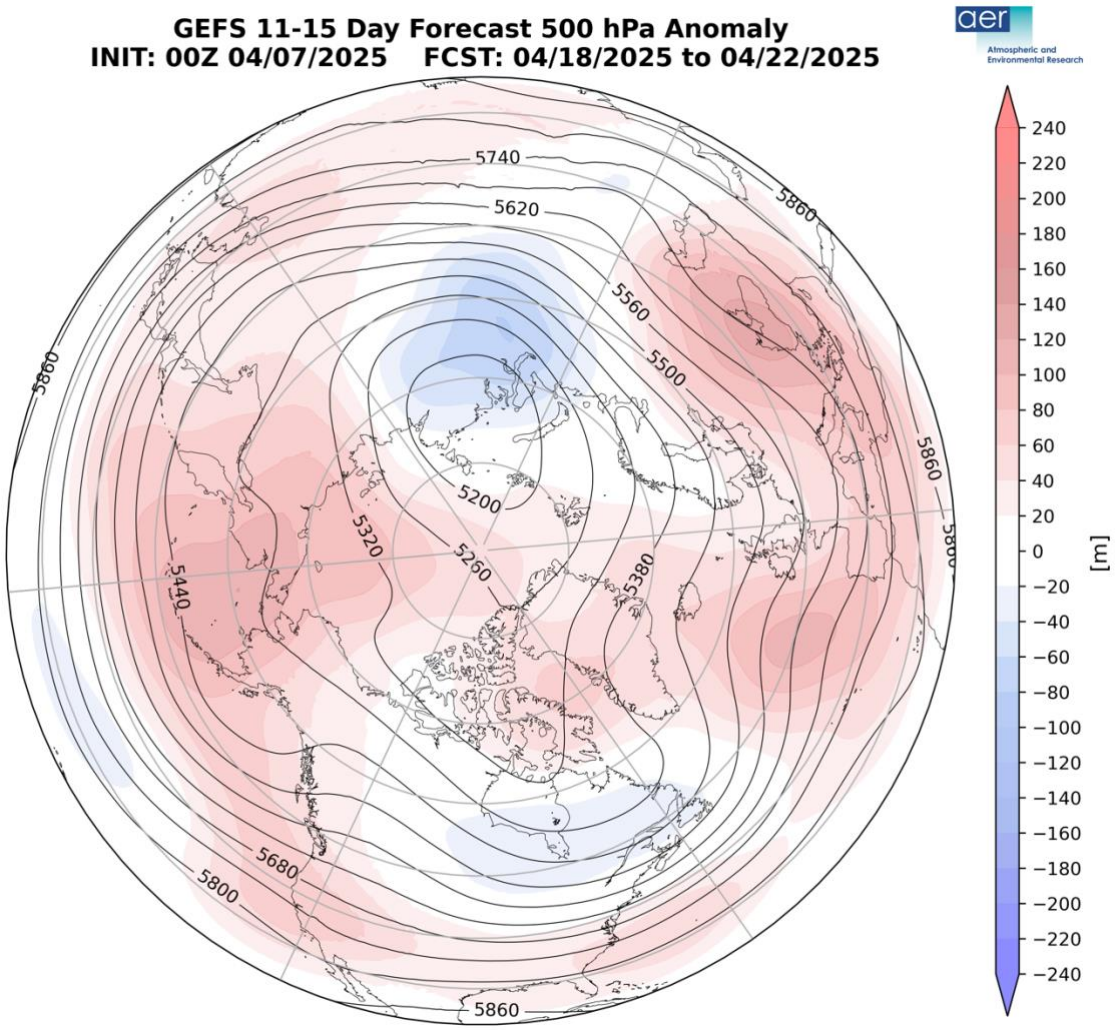

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 18 Apr to 22 Apr 2025. The forecasts are from the 00Z 07 Apr 2025 GFS ensemble.

Ridging/positive geopotential height anomalies are predicted to continue to dominate much of Europe this period (**Figure 8**). This pattern should favor normal to above normal temperatures widespread across much of Europe including the UK this period (**Figures 9**). Ridging/positive geopotential height anomalies are predicted to dominate Asia with persistent weak troughing/negative geopotential height anomalies in Western 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 Southwestern Asia this period (**Figure 9**).

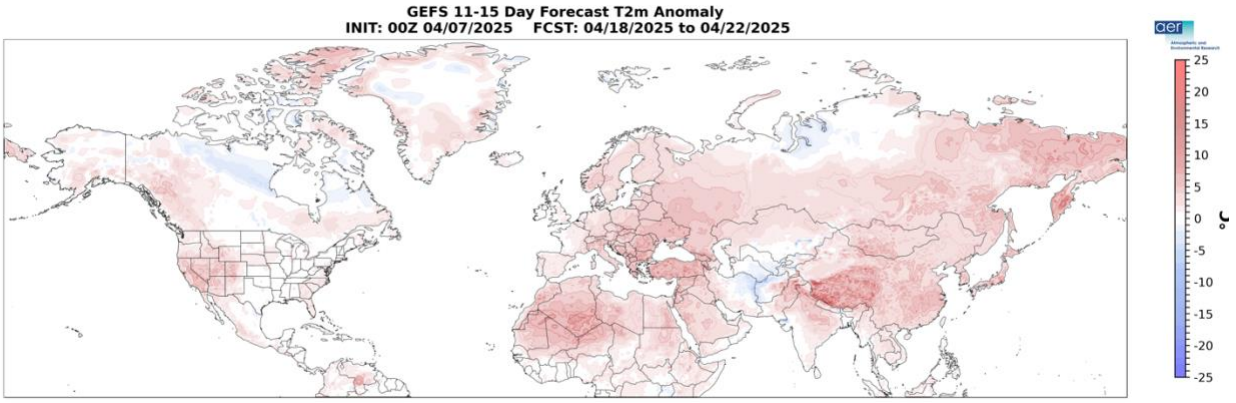

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 14 Apr to 22 Apr 2025. The forecasts are from the 00Z 07 Apr 2025 GFS ensemble.

Ridging/positive geopotential height anomalies are predicted to return across Alaska, Western Canada and the Western US supporting deepening troughing/negative geopotential height anomalies across Eastern Canada and the Eastern US this period (**Figure 8**). This pattern supports normal to above normal temperatures across Alaska, Western Canada and the Western US with normal to below normal temperatures across Southeastern Canada and the Northeastern US this period (**Figure 9**).

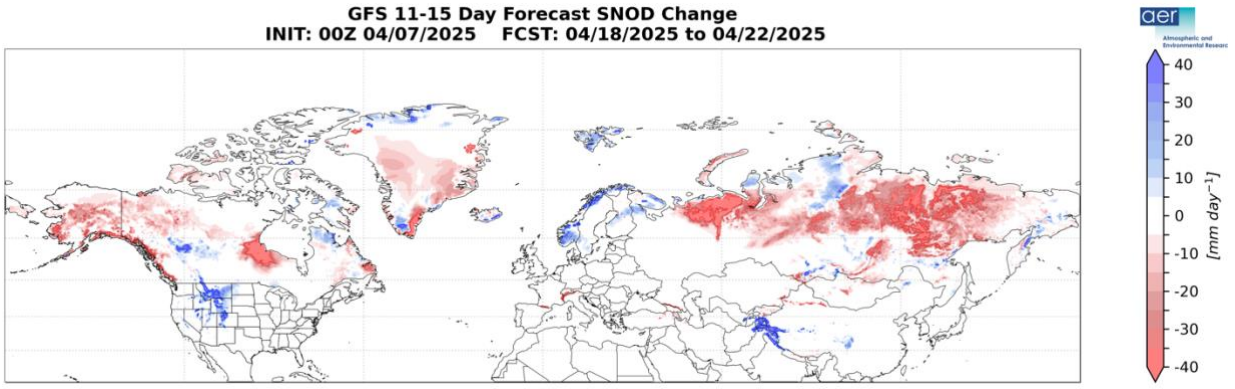

Figure 10. Forecasted snow depth changes (mm/day; shading) from 18 Apr to 22 Apr 2025. The forecasts are from the 00Z 07 Apr 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across parts of Scandinavia, far Northern Siberia and the Tibetan Plateau while warm temperatures will support widespread snowmelt across Siberia this period (**Figure 10**). Troughing and/or cold temperatures will support new snowfall across the Canadian and US Rockies while warm temperatures will support snowmelt in Alaska, Western and 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 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 get close to descending all the way to the surface this week. This a quickly followed by a return of cold/negative PCHs over the weekend and then warm/positive PCHs to descend to the surface the third and into the fourth week 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) but increasingly likely will be defined as a Final Warming.

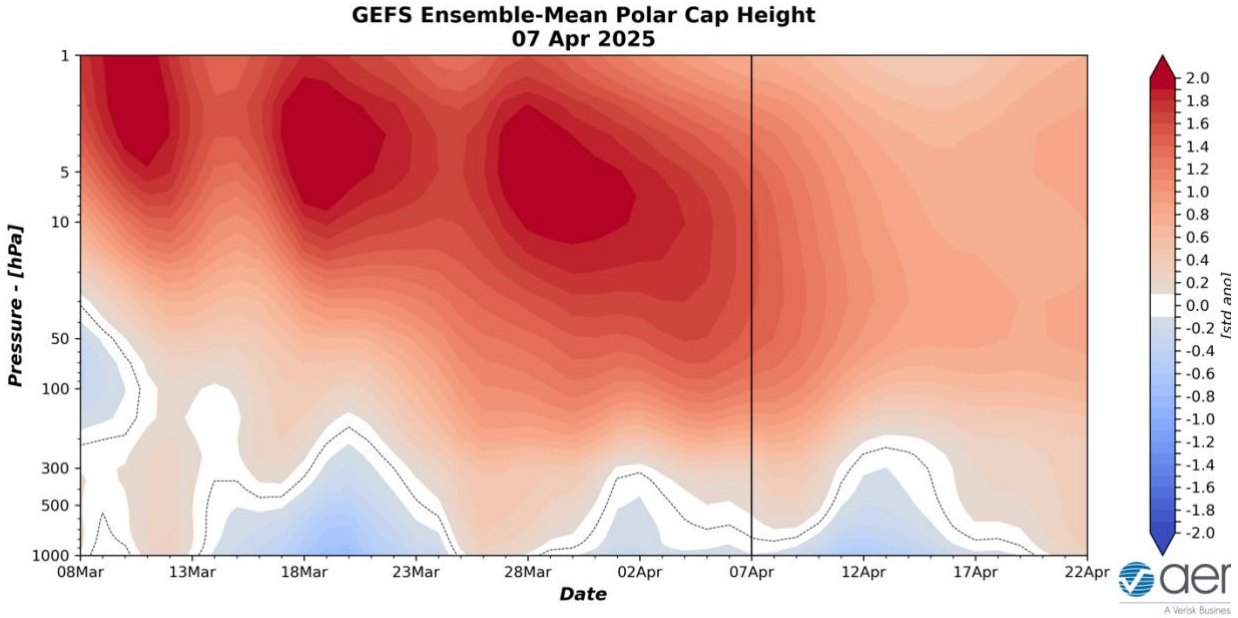

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 07 Apr 2025 GFS ensemble.

The predicted cold/negative PCHs in the lower troposphere for most of the next two weeks (**Figure 11**) are consistent with the predicted positive surface AO the next two weeks (**Figure 1**). Then as the warm/positive PCHs descend to the lower troposphere around 20 April, 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 half of April.

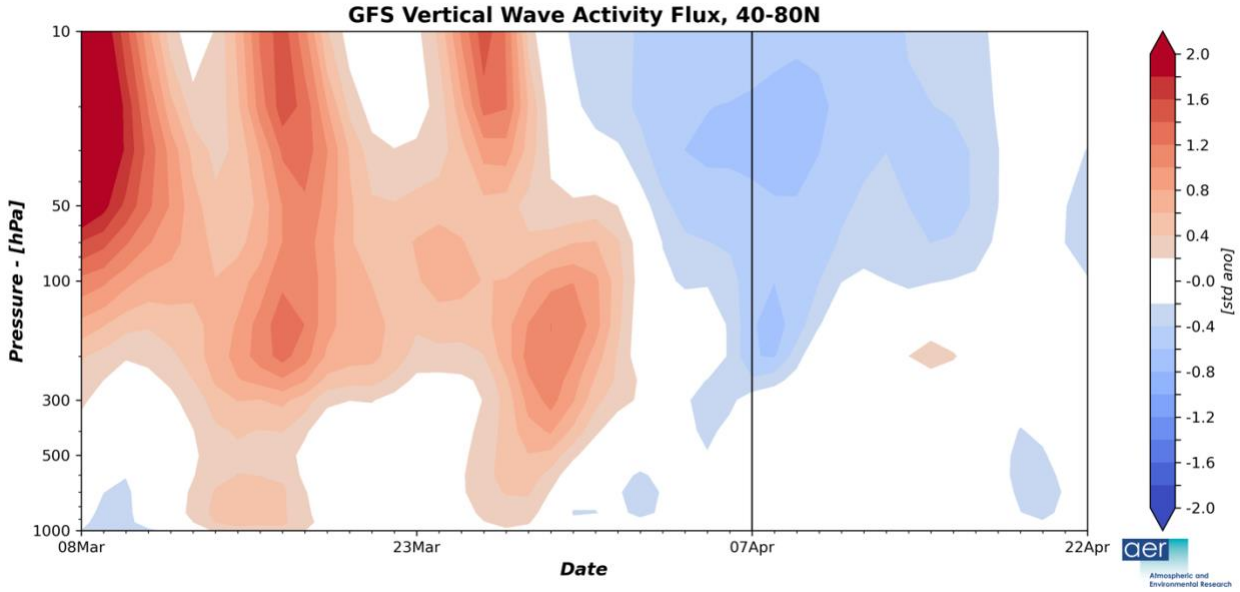

Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 07 Apr 2025 GFS ensemble.

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. The strongest WAFz pulse of the season peaked the first week of March (**Figure 12**). This large pulse triggered the ongoing SSW this month. Now that we have a mature SSW, WAFz is predicted to remain quiet and mostly below normal.

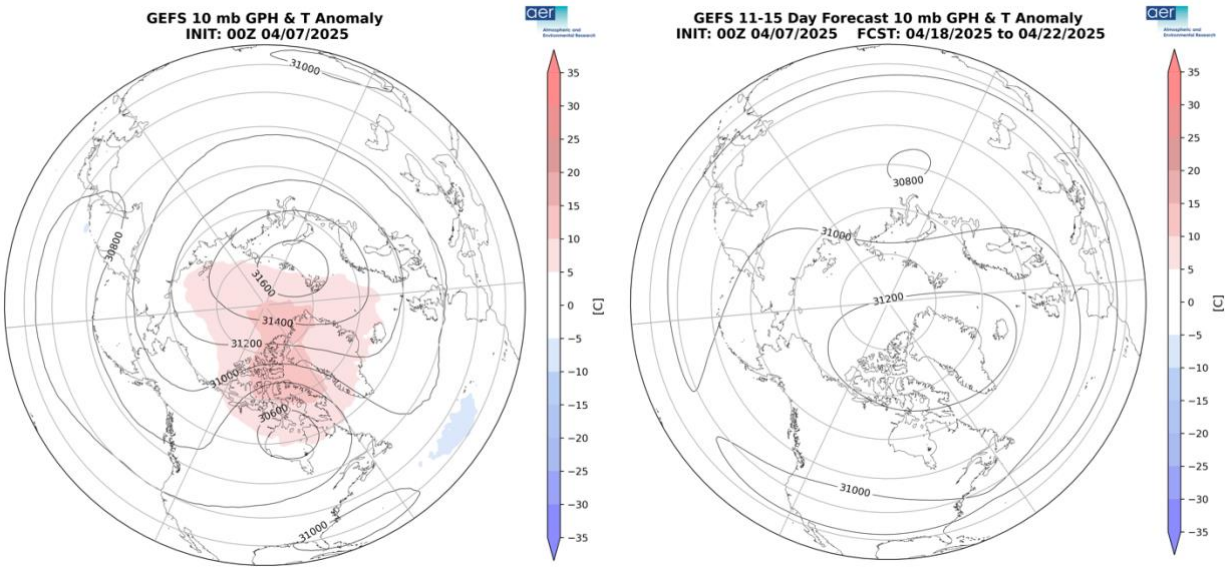

Figure 13. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 07 Apr 2025. (b) Same as (a) except forecasted averaged from 18 Apr to 22 Apr 2025. The forecasts are from the 00Z 07 Apr 2025 GFS model ensemble.

Currently the polar vortex (PV) is diffuse with the center over Hudson Bay with relatively coldest temperatures across lower latitudes with high pressure over the central Arctic and the relatively warmest temperatures across the Arctic Ocean in the polar stratosphere (**Figure 13a**). This is consistent with an ongoing SSW. Then in late April the PV is predicted to become even more diffuse centered over the Urals with high pressure centered over Greenland in the polar stratosphere. The relatively coldest temperatures are predicted across mid-latitudes and the warmest temperatures spread across the Arctic Ocean 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.

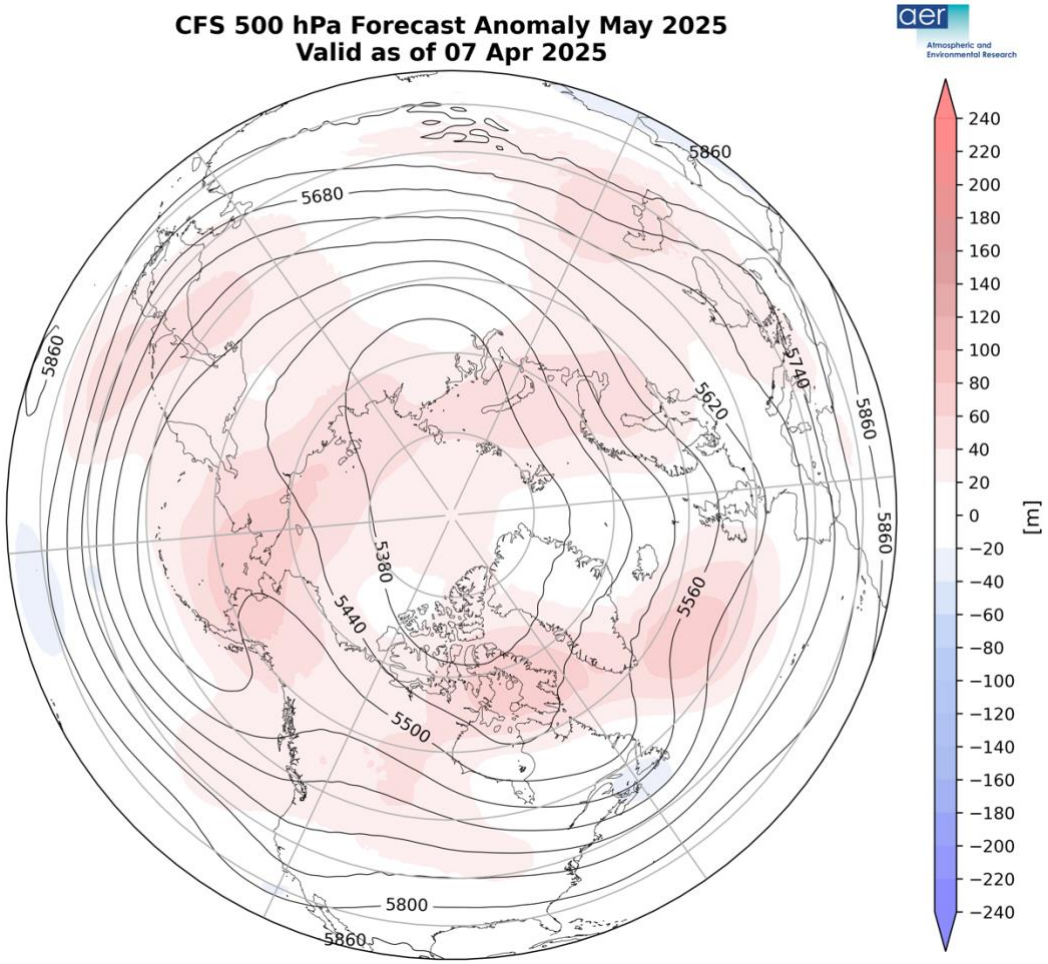

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for May 2025. The forecasts are from the 00Z 07 Apr 2025 CFS.

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

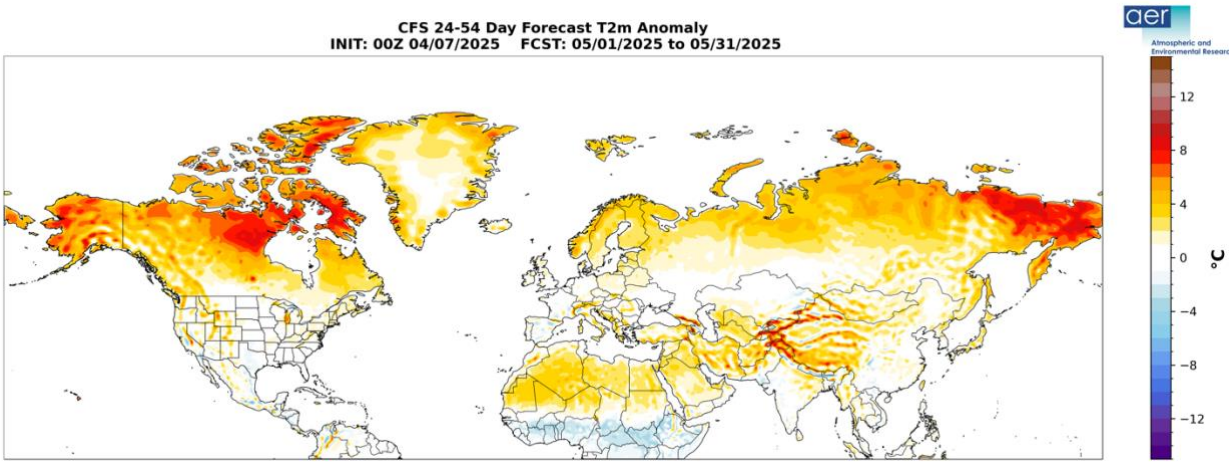

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for May 2025. The forecasts are from the CFS 00Z 07 Apr 2025.

Boundary Forcings

Arctic Sea Ice

Sea ice has started its seasonal decline, which will continue until the sea ice minimum in September 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 Gulf of Saint Lawrence (see **Figure 16**). The influence of sea ice on remote weather is waning and I will not discuss sea ice any longer until next fall.

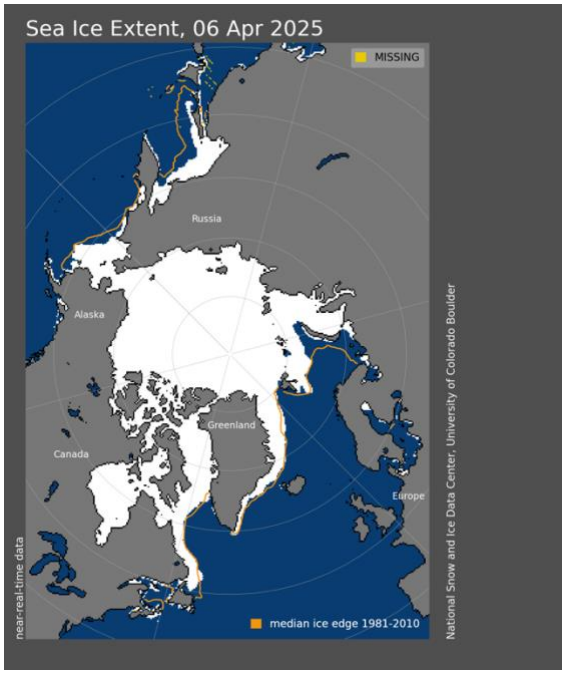

Figure 16. Observed Arctic sea ice extent on 06 Apr 2025 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image from the National Snow and Ice Data Center (NSIDC). URL: https://nsidc.org/sea-ice-today

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. Warming of SSTs along the equator near South America are suggestive of an emerging El Niño. However current forecasts show large spread and plenty of uncertainty. 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.

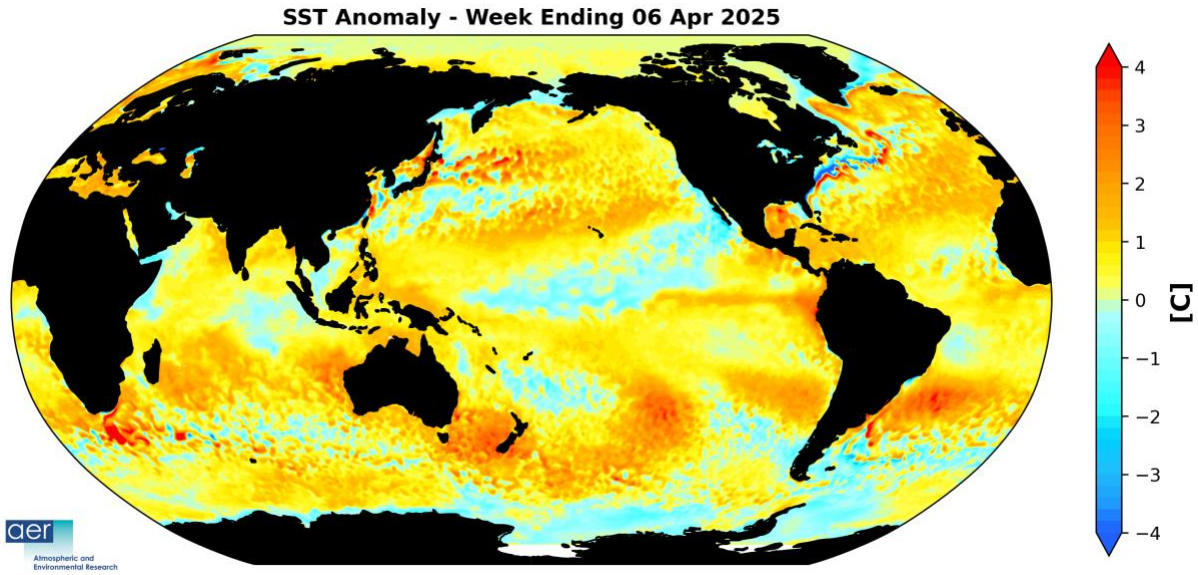

Figure 17. The latest daily-mean global SST anomalies (ending 06 Apr 2025). Data from NOAA OI High-Resolution dataset.

Madden Julian Oscillation

Currently the Madden Julian Oscillation (MJO) is weak where no phase is favored (**Figure 18**). The forecasts are for the MJO to remain overall weak and possibly emerge in phase seven in late April. 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.

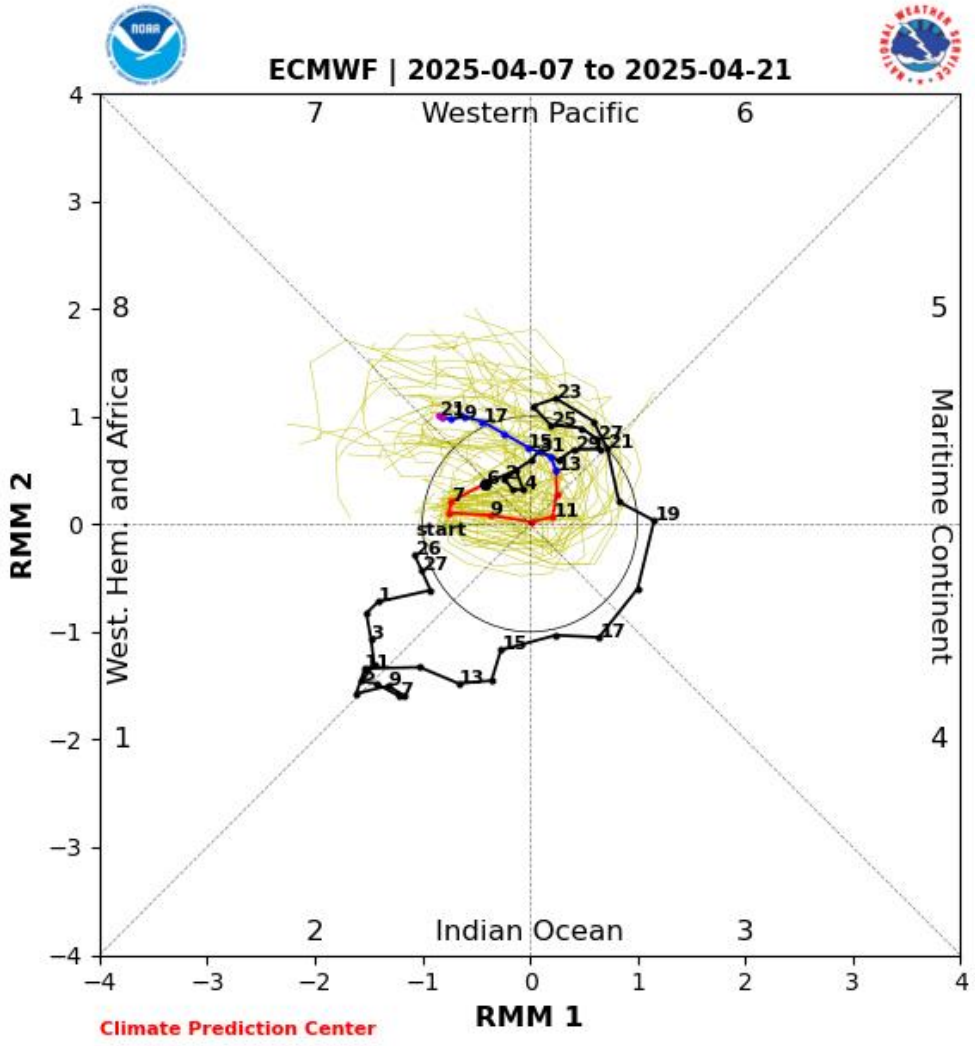

Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 07 Apr 2025 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model 'spread' is denoted by the gray shading. Sector numbers indicate 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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