Arctic Oscillation and Polar Vortex Analysis and Forecasts

March 3, 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.

Subscribe to our email list or follow me on Twitter (@judah47) for notification of updates.

The AO/PV blog is partially supported by NSF grant AGS: 1657748

Summary

- The Arctic Oscillation (AO) is currently positive and is predicted to remain positive this week but then but trend towards neutral later this week and next week as pressure/geopotential height anomalies across the Arctic are currently mostly negative and are predicted to become more mixed over the next two weeks. The North Atlantic Oscillation (NAO) is currently positive with negative pressure/geopotential height anomalies across Greenland and the NAO is predicted to trend towards neutral the next two weeks as pressure/geopotential height anomalies are predicted to become more mixed across Greenland.
- Over the next two weeks mostly troughing/negative geopotential height anomalies across Greenland will generally support ridging/positive geopotential height anomalies across most of Europe with the exception of troughing/negative geopotential height anomalies across Southwestern Europe. This pattern will support mostly normal to above normal temperatures across most of Europe including the United Kingdom (UK) with normal to below normal temperatures mostly limited to Spain and Portugal.
- The general pattern across Asia the next two weeks is ridging/positive geopotential height anomalies across Europe and Northwestern Asia supporting troughing/negative geopotential height anomalies across Central, Southwestern and Northeastern Asia with more ridging across Southeastern Asia. This pattern favors widespread normal to

above normal temperatures across Northwestern and Southeastern Asia with normal to below normal temperatures across Central and Northeastern Asia including much of Siberia and Southeastern Asia the next two weeks.

- The pattern this week across North America is ridging/positive geopotential height anomalies across Western Canada supporting troughing/negative geopotential height anomalies across Eastern Canada and the United States (US). Then next week troughing will become better established across western North America with ridging across eastern North America. This patten will favor widespread normal to above normal temperatures across much of Alaska, Western Canada and the US with normal to below normal temperatures limited to Eastern Canada and the Western US. However next week normal to below normal temperatures will become more widespread across Alaska, Western Canada and the Western US with normal to above normal temperatures spreading across Eastern Canada and the Eastern US.
- This winter has been all about the polar vortex (PV) alternating among three different states: strong, a Canadian warming but most of all a stretched PV. We have at least one more Canadian warming and a stretched PV but for the first time this season a sudden stratospheric warming. Lots to consider.

Plain Language Summary

Now that winter is over, estimates of the winter surface temperature anomalies are starting to emerge (see **Figure**). Clearly warm temperatures dominate the Northern Hemisphere (NH). Though relatively cold temperatures exist in Northern Europe, Southern Siberia and Northern China but especially Western and Central Canada and the US Upper Midwest. I included the AER winter forecast and the C3S forecasts in the blog of 26 November 2024. I hope to provide a more in depth postmortem on the winter forecasts in a later blog but once again I feel good about the AER forecast and seems to have captured the overall NH temperature pattern even if it missed details. And I would argue the AER statistical forecast (that includes Arctic predictors) performed better than the dynamical model forecasts that predict nearly universal warmth. With a large polar vortex disruption more cold weather can be expected but many unknowns remain.

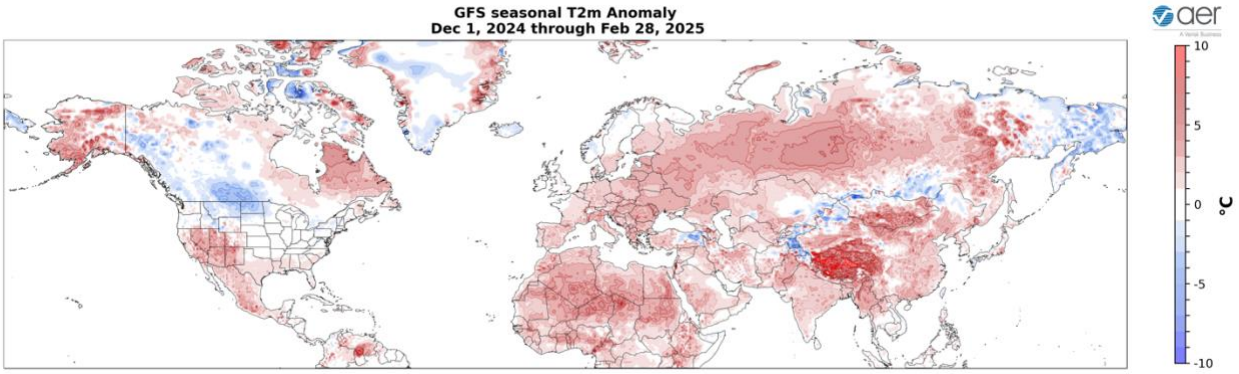


Figure. Estimate of the observed surface temperatures (°C; shading) from 01 Dec 2024 to 28 Feb 2025 based on GFS initializations and the GFS forecast from the 01 Mar 2025 run.

Impacts

I did provide further support for the idea that the cold in the US in February was indeed related to the multiple stretched polar vortex (PV) events that month in the Wednesday Update.

It could be that after a PV season that featured a baker's dozen (13) stretches, the PV is ready to finally get on the mat and perform gymnastics. First, we have currently an ongoing a Canadian warming, second of the winter as seen in the latest PV animation in **Figure i**. The Canadian warming lasts through 5th of March. Then the PV briefly transitions to the thirteenth stretched PV of the season or eleventh of the winter. Then the models are in consensus that a full blown sudden stratospheric warming (SSW) quickly follows the stretched PV mid-month. An SSW is defined to occur when the zonal-mean zonal wind at 10 hPa and 60°N drop below zero m/s (or easterly) on average for a twenty four-hour period. The GFS is most emphatic about a full PV split but a displacement is also possible. If the PV cannot reconstitute itself before next fall, then the SSW will de facto be defined as a Final warming rather than an SSW, though I don't think whether it is defined as an SSW or Final warming the impact on our weather will be the same. Last year an SSW took place in early March, and it was not a Final warming.

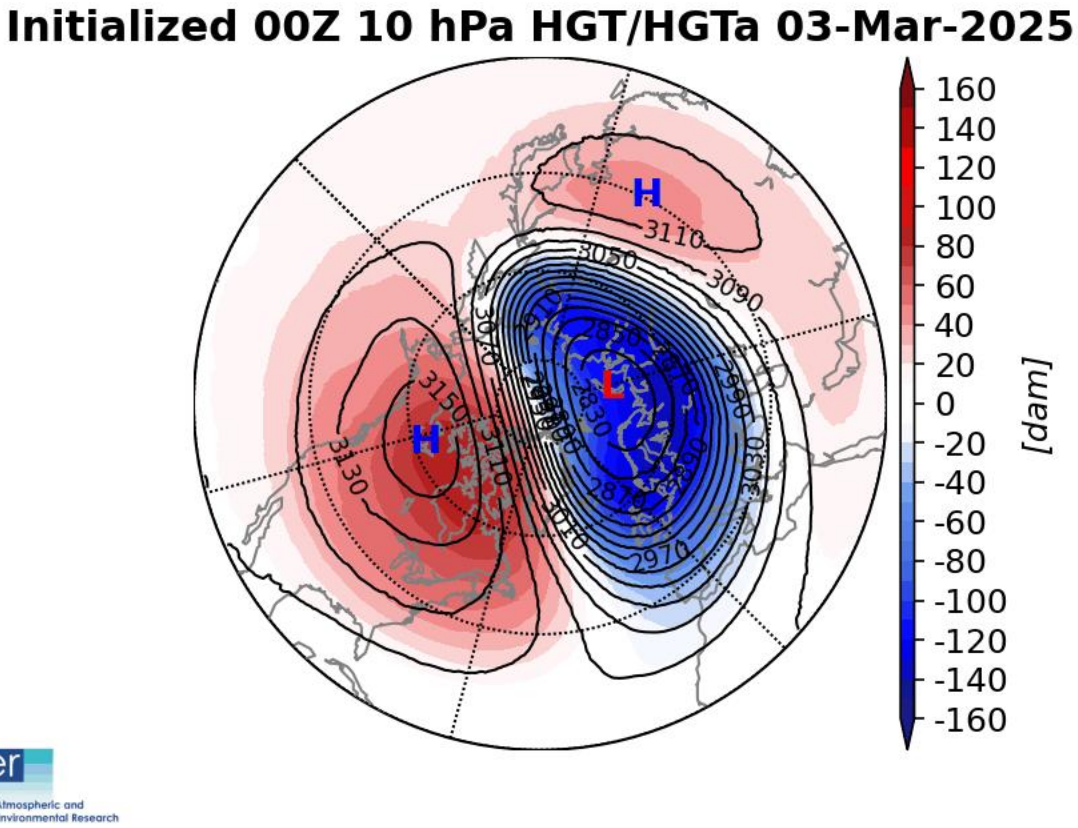


Figure i. Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 03 Mar 2025 and forecasted from 04 Mar to 18 Mar 2025. The forecasts are from the 00Z 03 Mar 2025 GFS model ensemble.

Once again, I present the energy diagnostics that are used to display wave reflection. Wave reflection is present yet again this week (see **Figure iia**) supportive of at least one more stretched PV event this week (see **Figure i**). However in the coming weeks, the wave energy is directed instead upward and absorbed in the polar stratosphere (see **Figure iib**) resulting in the SSW.

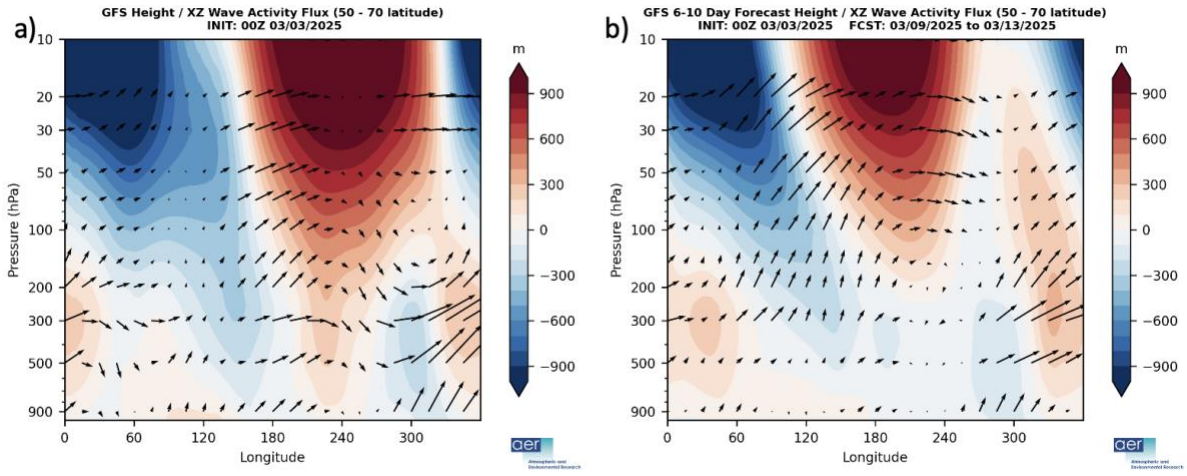


Figure ii. Longitude-height cross section of geopotential eddy height anomalies (shading) and wave activity flux (vectors) a) predicted for 09 Mar through 013 Mar 2025 and b) forecasted for 14 Mar through 18 Mar 2025. The forecasts are from the 00Z 03 Mar 2025 GFS ensemble.

Stretched PVs are related to severe winter weather not only to North America but also East Asia. The troughing and associated cold temperatures began in Siberia and are spreading southeast into East Asia this week (see **Figure 3**). Not much cold is predicted next week in Asia including Siberia (see **Figures 6** and **9**). SSWs are most strongly related to cold temperatures across Northern Eurasia in particular Siberia but so far cold is not showing up in the model forecasts but this could change with time.

Not much cold is predicted for Europe over the next two weeks (see **Figures 3, 6** and **9**). The circulation feature most closely associated with cold in Europe is Greenland blocking. Some weak Greenland blocking is predicted next week (see **Figure iii**) but not strong or persistent enough to significantly influence European temperatures. Greenland blocking is also the feature that is most closely associated as the tropospheric response to SSWs so again something to watch.

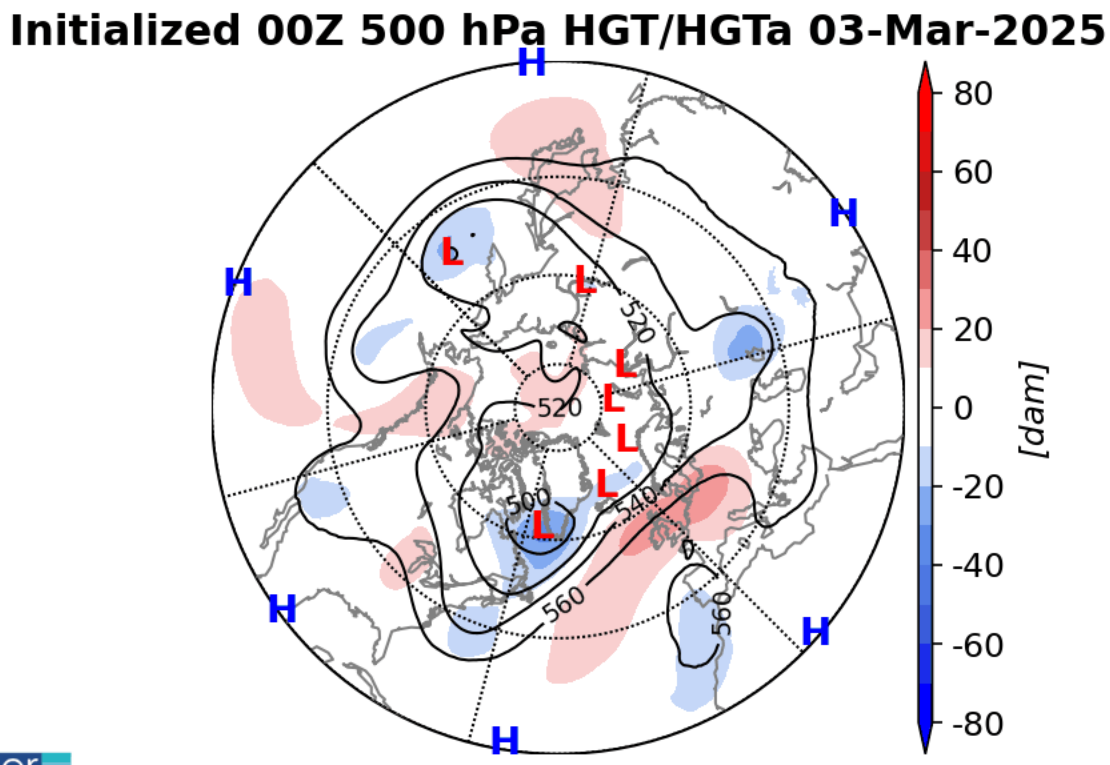


Figure iii. Initialized 500 mb geopotential heights (dam; contours) and decameter anomalies (dam; shading) across the Northern Hemisphere for 03 Mar 2025 and forecasted from 04 Mar to 18 March 2025. The forecasts are from the 00Z 03 Mar 2025 GFS model ensemble.

Now getting to the elephant in the room, what will be the impact to the Northern Hemisphere (NH) temperatures of the upcoming SSWs. First let's be clear 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. Certainly, the upcoming SSW could have important implications for NH weather but more likely to result in chilly and wet weather rather than cold and snowy weather, outside of higher elevations and higher latitudes.

Often ahead of SSWs it si cold in East Asia and mild in the Eastern US, which often involves colder temperatures in the Western US. This is consistent with the forecasts of a cold Western US and a mild Eastern US heading into the SSW. It is cold in East Asia this week but not sure that it can be connected to the SSW. Not sure I would characterize the precursor to the SSW as textbook.

I have discussed before about there is usually an immediate impact of SSWs and a lag impact of SSWs. The immediate impact would be colder weather located under the PV center. Models disagree if there will be one or two PV centers post 10 March, but the main or only PV center is predicted to be over Northwest Russia and even possibly extending into Europe (see **Figure iii**).

So far, the models are not predicting cold temperatures in this region, but I would expect the forecasts to turn colder in this region with time.

The GFS is predicting a minor PV center over Southeastern Canada and the Northeastern US and other models are predicting more of a tail or trough extending from the main PV center to Southeastern Canada and the Northeastern US. I think this could also bring colder weather to the Southeastern Canada and the Northeastern US (see **Figure iv**). It does seem that the European ensembles and the latest GFS ensembles are trying to bring colder weather to the region, but the anomalies are relatively muted.

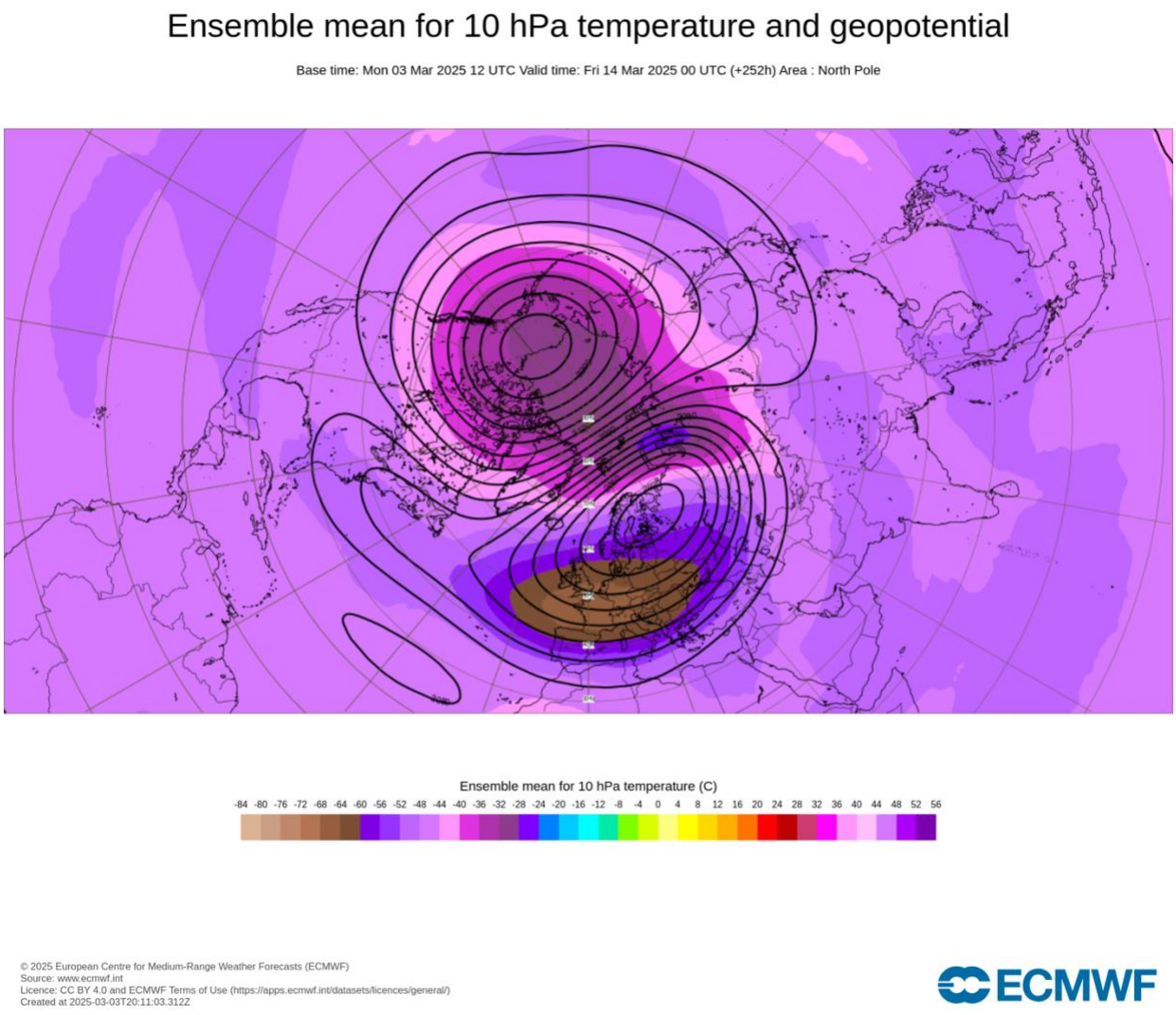


Figure iv. Forecasted 10 mb geopotential heights (dam; contours) and temperatures (°C; shading) across the Northern Hemisphere for 14 March 2025. The forecasts are from the 12Z 3 March 2025 ECMWF ensembles. Plot taken from https://charts.ecmwf.int/.

The lagging tropospheric response is thought to typically occur about two weeks on average after the start of the SSW. The most closely associated tropospheric response to SSWs is Greenland blocking resulting in relatively cold temperatures to Northern Eurasia, including Northern Europe, and later on often to the Eastern US. It has been my experience that the impact isn't fully realized until the largest warm/positive polar cap geopotential height anomalies (PCHs) reach the troposphere. From looking at **Figure 11**, the largest PCH anomalies are predicted to be in the upper stratosphere with no signs of the warm/positive PCHs reaching the troposphere. Therefore, I think that we are still a long way off from realizing a multi week impact on our weather.

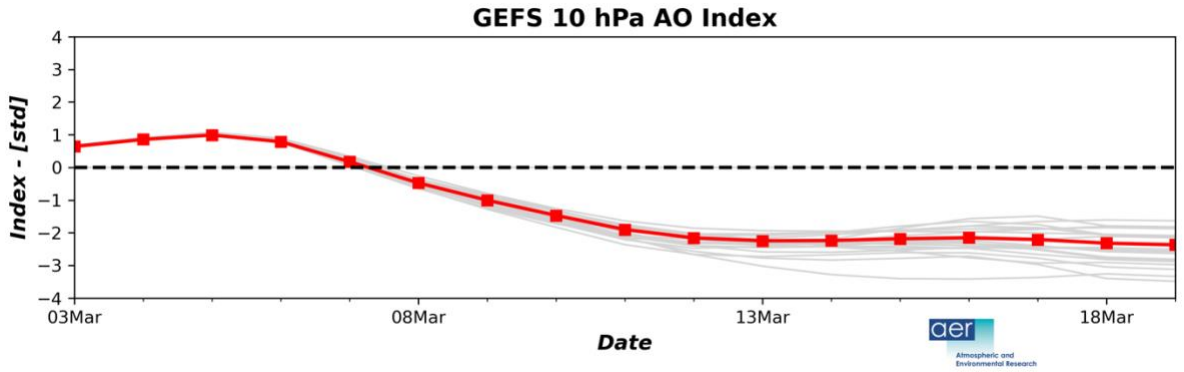
One interesting (at least to me) circulation feature is when winds in the lower and mid-troposphere blow from east to west over Northwestern Eurasia bringing cold air from Siberia into Europe. This often results in the coldest weather for Europe as in February and March 2018. At least the GFS is predicting easterly flow in the mid-stratosphere over Northern Eurasia (see **Figure i**) and will be interesting to see if the same develops in the troposphere. This is not guaranteed and obviously will not have the same impact if this were January and not March, but still something to watch.

One last thing to watch is that SSWs is a favorable environment for stretched PVs as in February 2021 (too soon?). Too early to tell if this will happen but again something to watch. Again, not the same impact had this occurred two months earlier.

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



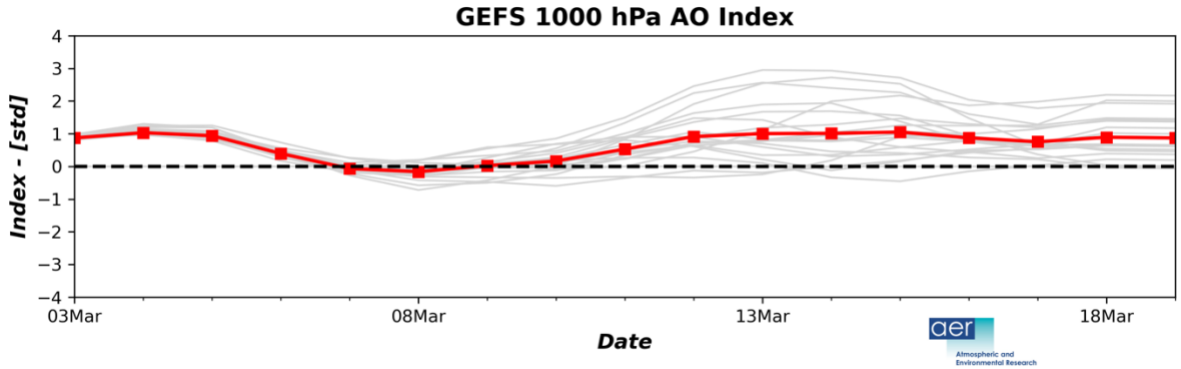


Figure 1. a) The predicted daily-mean AO at 10 hPa from the 00Z 03 Mar 2025 GFS ensemble. b) The predicted daily-mean AO at 1000 hPa from the 00Z 03 Mar 2025 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble mean AO index given by the red line with squares.

This week troughing/negative geopotential height anomalies across Greenland will support ridging/positive geopotential height anomalies across much of Europe with troughing/negative geopotential height anomalies just west of Spain and Portugal (**Figures 2).** This pattern will favor normal to above normal temperatures across much of Europe including the UK this period (**Figure 3**). This week ridging/positive geopotential height anomalies across Europe and Northwestern Europe will support troughing/negative geopotential height anomalies across Western and Northeastern Asia (**Figure 2**). This pattern favors normal to above normal temperatures widespread across Western, parts of Central and Southeastern Asia with normal to below normal temperatures across parts of Central and Northeast Asia including Siberia **(Figure 3**).

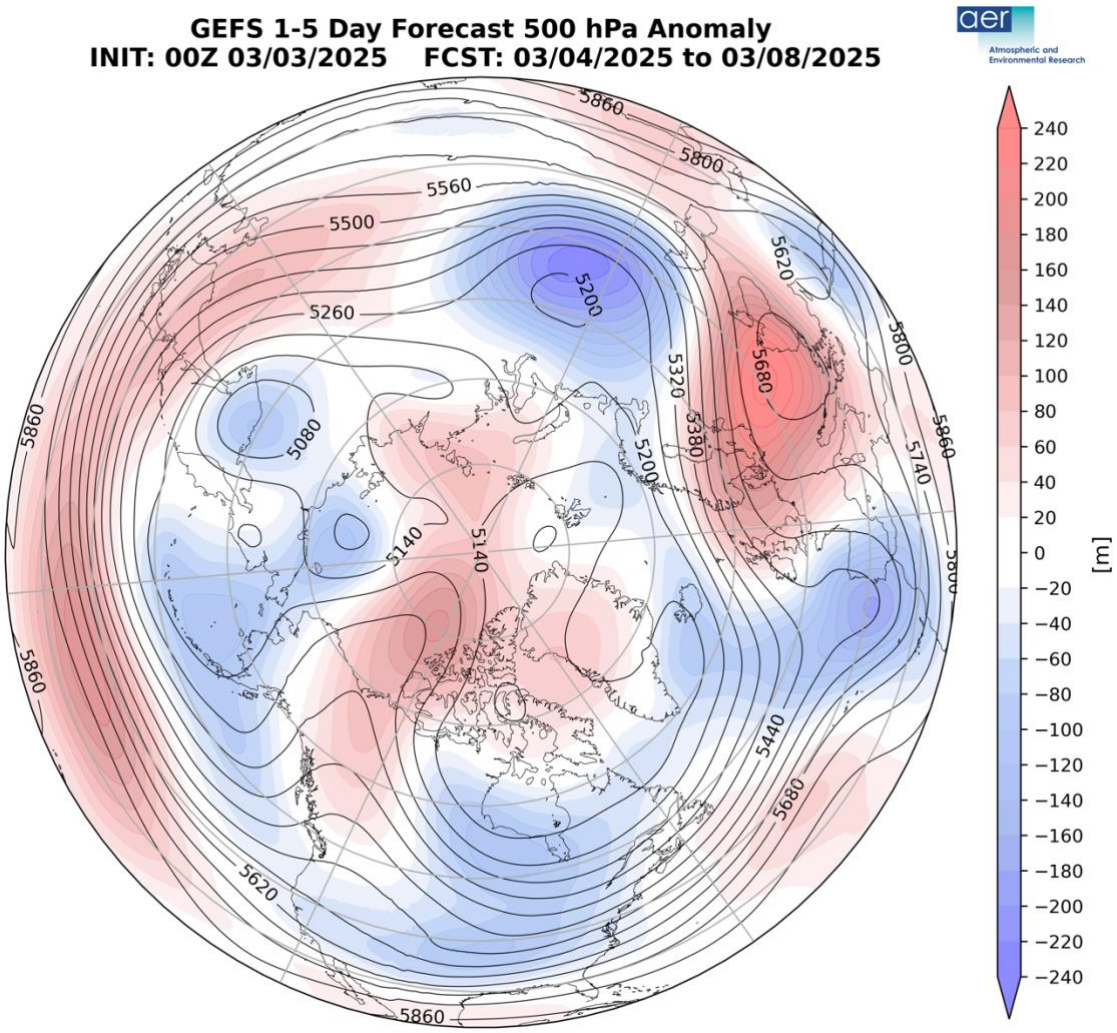


Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 04 Mar to 08 Mar 2025. The forecasts are from the 00Z 03 Mar 2025 GFS ensemble.

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

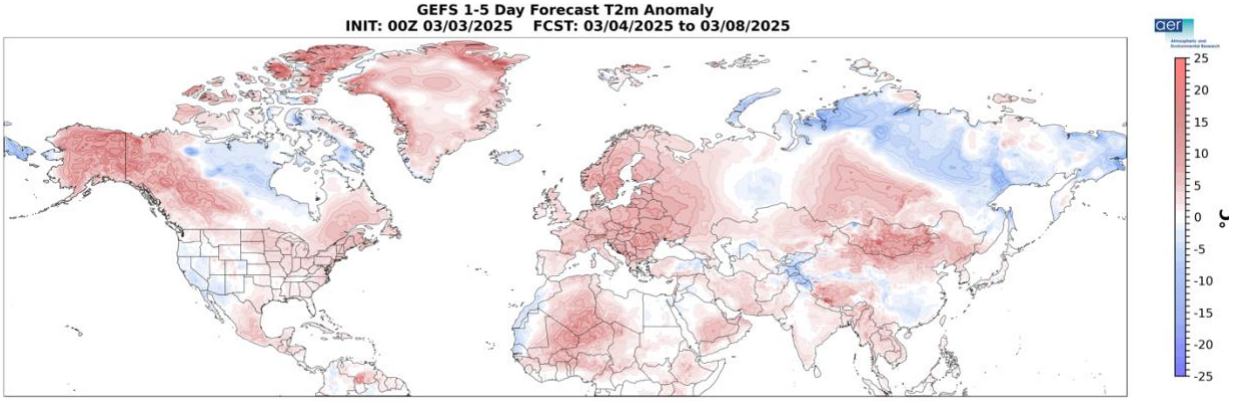


Figure 3. Forecasted surface temperature anomalies (°C; shading) from 04 Mar to 08 Mar 2025. The forecasts are from the 00Z 03 Mar 2025 GFS ensemble.

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 Northern Europe and Asia this week (**Figure 4**). Troughing and/or cold temperatures will support new snowfall across Alaska, Eastern Canada and the US Rockies while warm temperatures will support snowmelt in central Alaska, Western and Southeastern Canada and the Northeastern US this week (**Figure 4**).

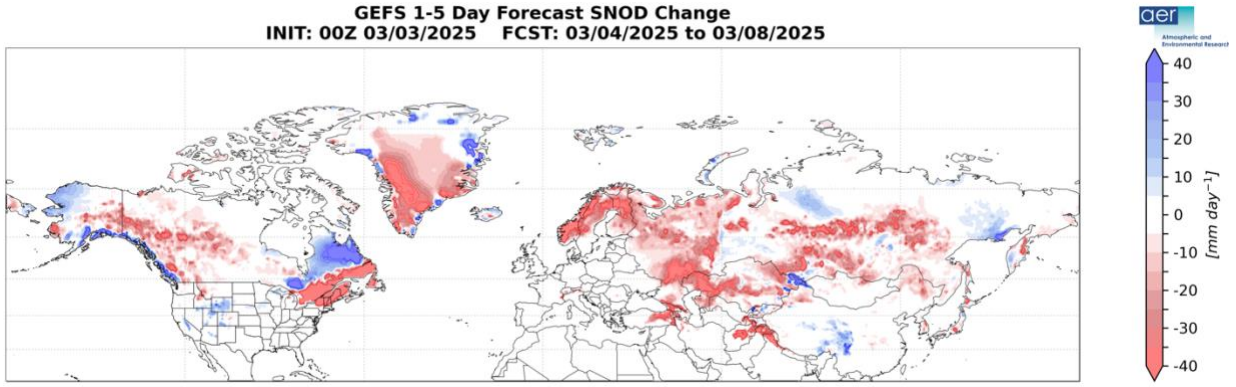


Figure 4. Forecasted snow depth changes (mm/day; shading) from 04 Mar to 08 Mar 2025. The forecasts are from the 00Z 03 Mar 2025 GFS ensemble.

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 close to neutral this period (**Figure 1**). With predicted mostly mixed pressure/geopotential height anomalies across Greenland (**Figure 5**), the NAO will likely be near neutral this period.

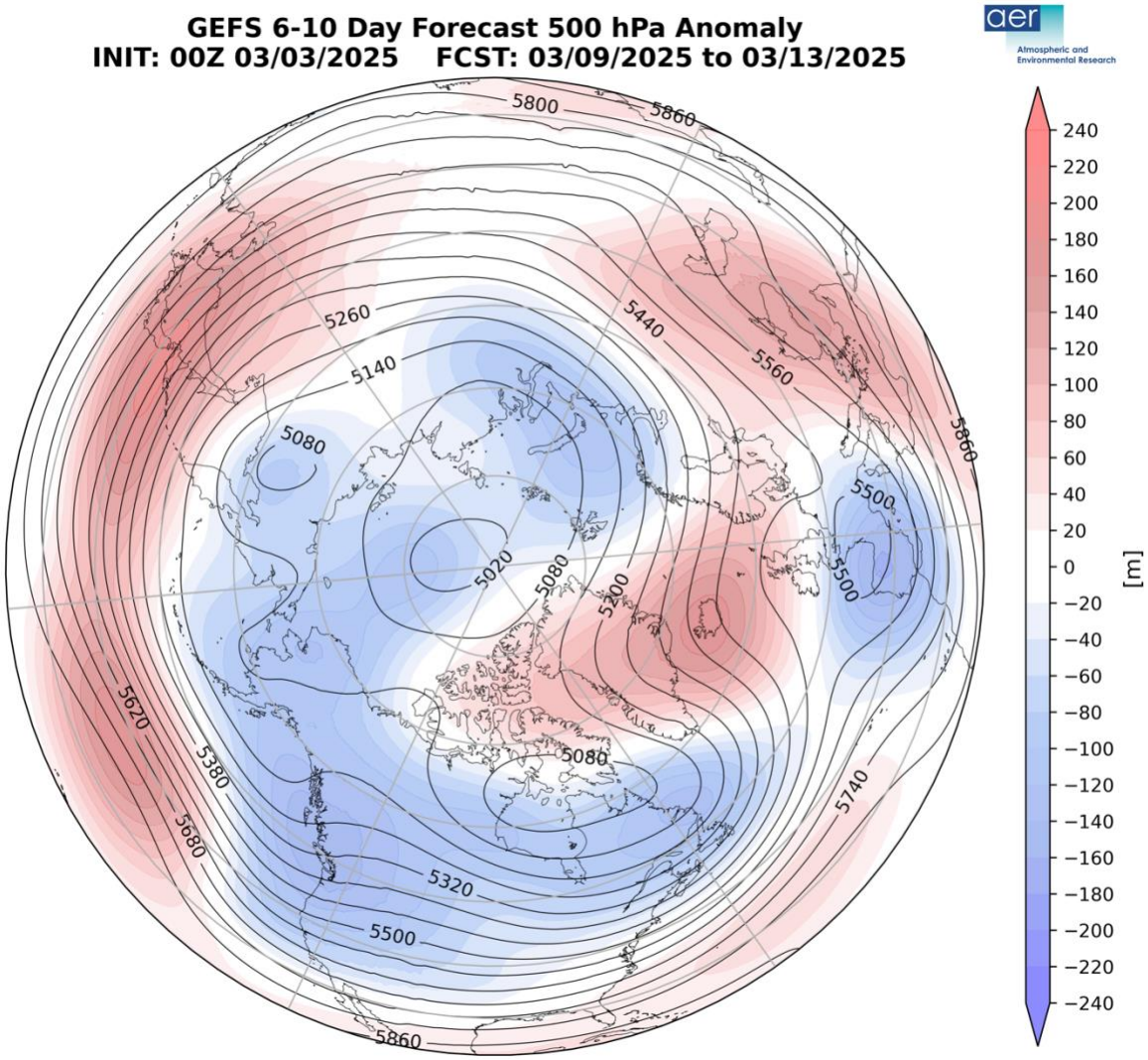


Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 09 Mar to 13 Mar 2025. The forecasts are from the 00Z 03 Mar 2025 GFS ensemble.

The return of ridging/positive geopotential height anomalies to southern Greenland will support troughing/negative geopotential height anomalies across Western Europe centered over France and Spain with ridging/positive geopotential height anomalies across Eastern

Europe (**Figure 5**). This pattern favors widespread normal to above normal temperatures across much of Europe including the UK with normal to below normal temperatures mostly limited to Spain and Portugal this period (**Figure 6**). Ridging/positive geopotential height anomalies across Europe and Western Asia are predicted to support troughing/negative geopotential height anomalies across Siberia and Central Asia with more ridging/positive geopotential height anomalies mostly across Southeast Asia (**Figure 5**). This pattern favors normal to above normal temperatures across Western and Southeastern Asia with normal to below normal temperatures across Central and Northeastern Asia including much of Siberia this period (**Figure 6**).

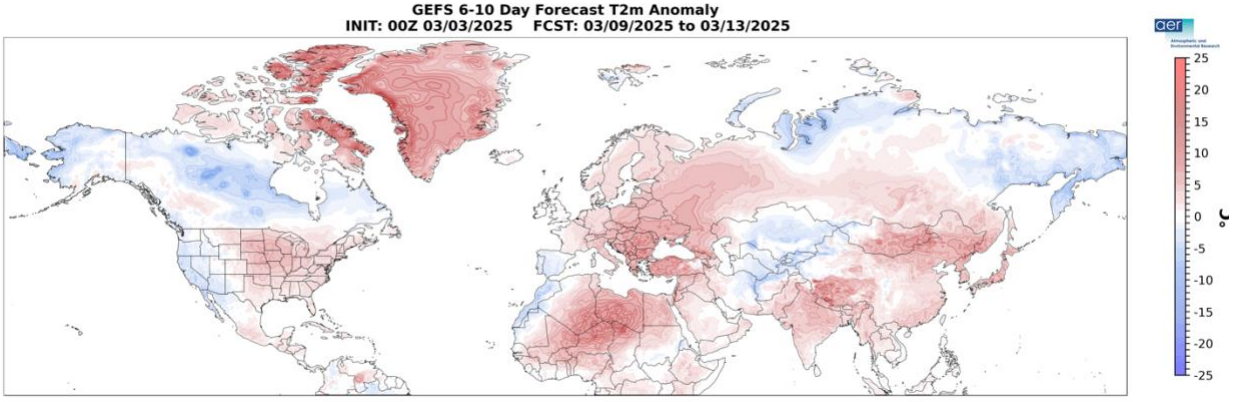


Figure 6. Forecasted surface temperature anomalies (°C; shading) from 09 Mar to 13 Mar 2025. The forecasts are from the 00Z 03 Mar 2025 GFS ensemble.

Ridging/positive geopotential height anomalies predicted south of the Aleutians and across Greenland will support troughing/negative geopotential height anomalies across Alaska and much of Canada and the Western US with more ridging across the Southeastern US this period (**Figure 5**). This pattern will favor normal to below normal temperatures widespread across Alaska, Canada and the Western US with normal to above normal temperatures limited across the Central and Eastern US (**Figure 6**).

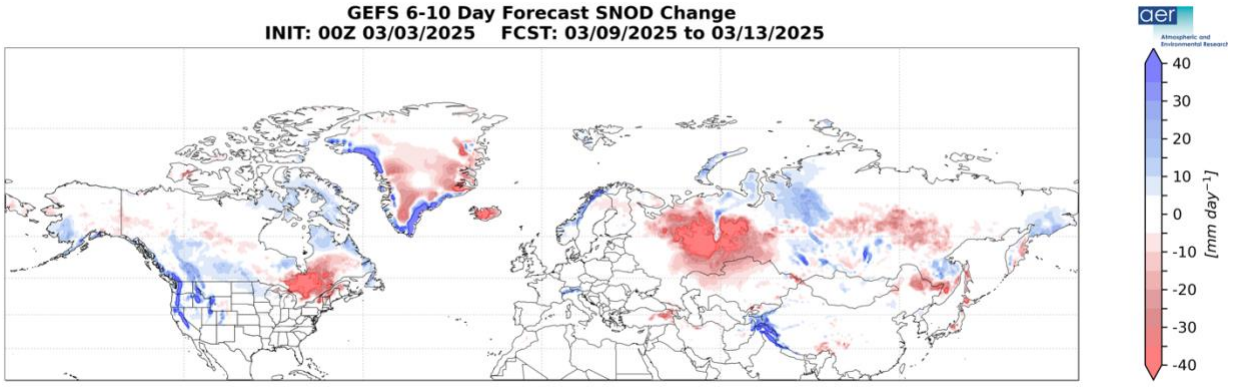


Figure 7. Forecasted snow depth changes (mm/day; shading) from 09 Mar to 13 Mar 2025. The forecasts are from the 00Z 03 Mar 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across Scandinavia, the Alps, Siberia and the Tibetan Plateau while warm temperatures will support snowmelt in parts of Western Russia, the Caucuses, Siberia and Northeast Asia this period (**Figure 7**). Troughing and/or cold temperatures will support new snowfall across western Alaska, Western and Northeastern Canada and the Western US while warm temperatures will support snowmelt in Southeastern Canada and the Northeastern US this period (**Figure 7**).

Mid Term

Week Two

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

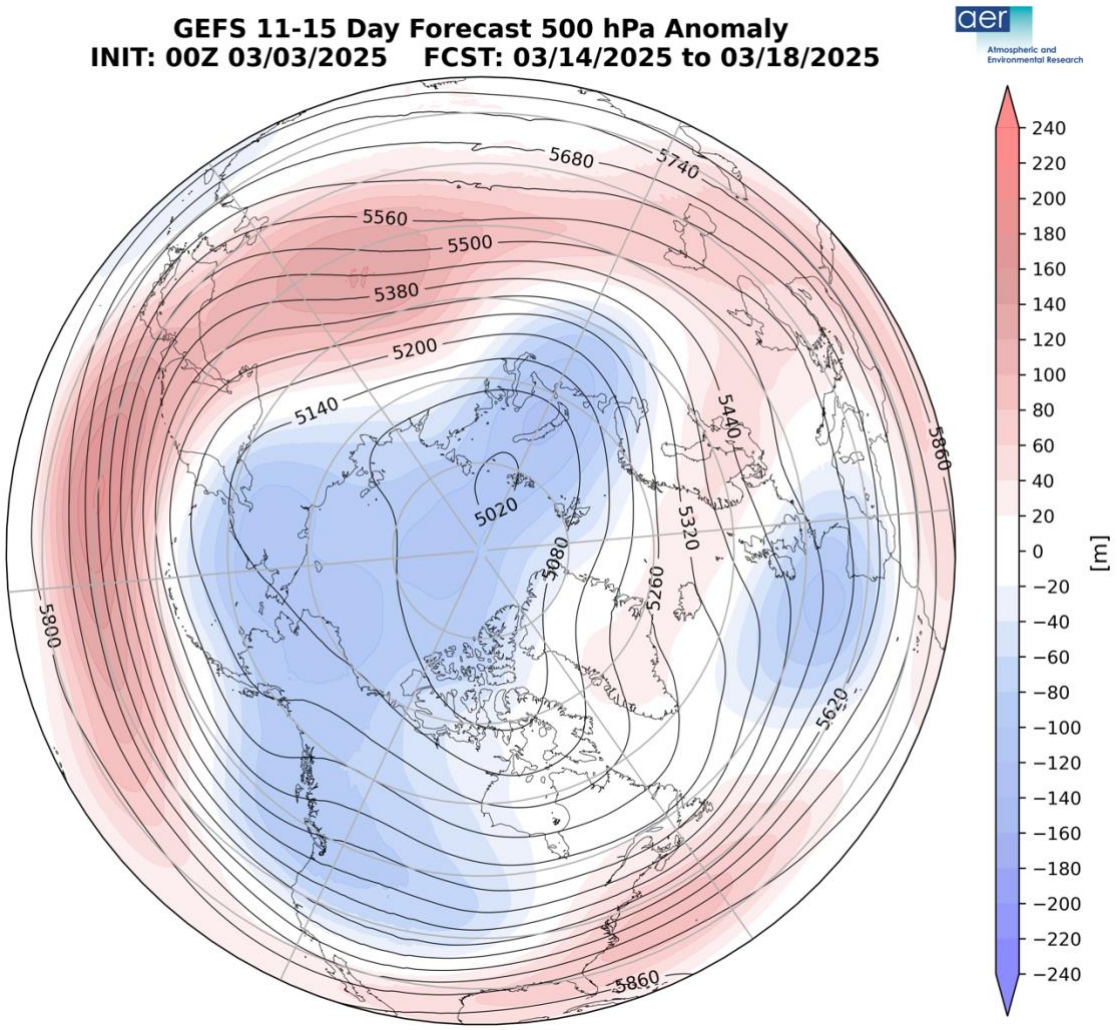


Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 14 Mar to 18 Mar 2025. The forecasts are from the 00Z 03 Mar 2025 GFS ensemble.

Persistent ridging/positive geopotential height anomalies are predicted across most of Europe with lingering troughing/negative geopotential height anomalies across the Southwestern Europe are predicted this period (**Figure 8**). This pattern should favor 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 (**Figures 9**). The persistent ridging/positive geopotential height anomalies across Europe are predicted to support troughing/negative geopotential height anomalies across Northern with ridging/positive geopotential height anomalies across Central Asia with more troughing/negative geopotential height anomalies across Southeastern 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 Southeastern Asia and Eastern Siberia this period (**Figure 9**).

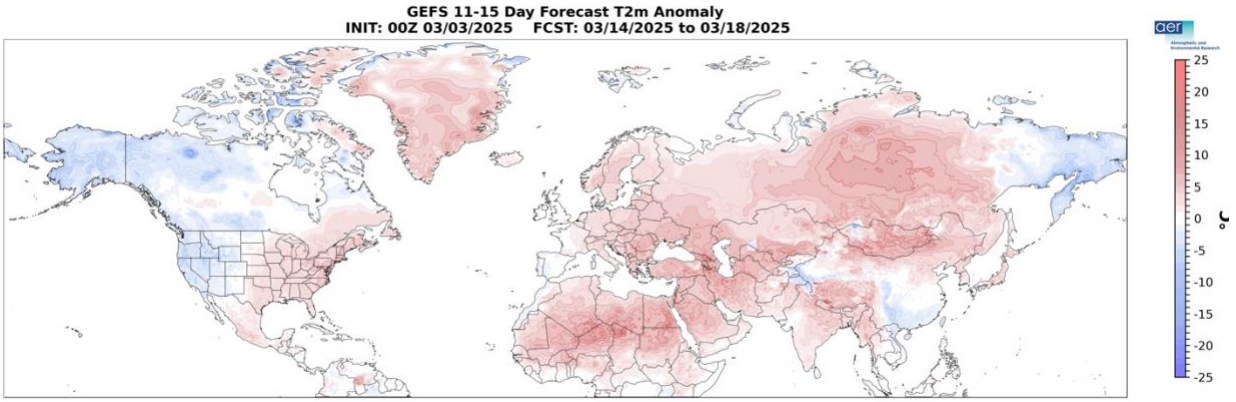


Figure 9. Forecasted surface temperature anomalies (°C; shading) from 14 Mar to 18 Mar 2025. The forecasts are from the 00Z 03 Mar 2025 GFS ensemble.

Persistent ridging/positive geopotential height anomalies south of the Aleutians will support troughing/negative geopotential height anomalies across Canada and the Western US with more ridging/positive geopotential height anomalies across the Eastern US this period (**Figure 8**). This pattern continues to support normal to below normal temperatures across Alaska, Western and Northern Canada and the Western US with normal to above normal temperatures across Southeastern Canada and the Eastern US this period (**Figure 9**).

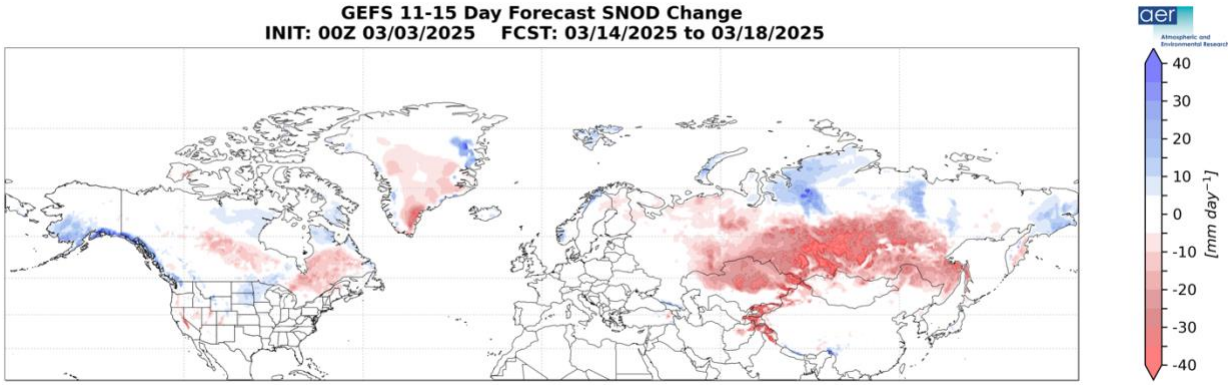


Figure 10. Forecasted snow depth changes (mm/day; shading) from 14 Mar to 18 Mar 2025. The forecasts are from the 00Z 03 Mar 2025 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across Northern Siberia while warm temperatures will support snowmelt in Southern Siberia and the Tibetan Plateau this period (**Figure 10**). Troughing and/or cold temperatures will support new snowfall across western Alaska the higher elevations of the West Coast of Canada and the US Upper Midwest while warm temperatures will support snowmelt in Central and Southeastern Canada this period (**Figure 10**).

Longer Term

30–day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows cold/negative PCHs in the lower troposphere and in the lower to mid stratosphere warm/positive PCHs in the upper stratosphere and mid-troposphere (**Figure 11**). The warm/positive PCHs in the upper stratosphere are predicted to descend into the lower stratosphere next week. The cold/negative PCHs in the lower troposphere are predicted overspread the entire troposphere. The warm/positive PCHs in the stratosphere represent a sudden stratospheric warming (SSW) or even possibly a Final warming.

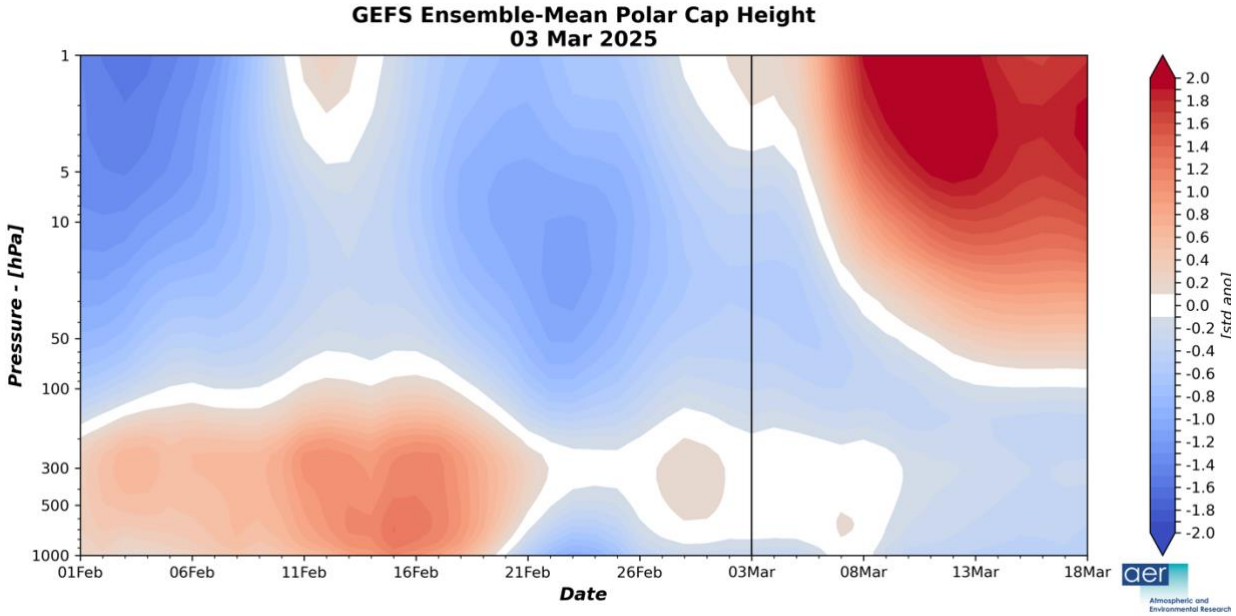


Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 03 Mar 2025 GFS ensemble.

The predicted cold/negative PCHs in the lower troposphere this week (**Figure 11**) are consistent with the predicted positive surface AO this week (**Figure 1**). Then as the cold/negative PCHs in the troposphere to become more mixed through mid-March, the surface AO is predicted to turn neutral.

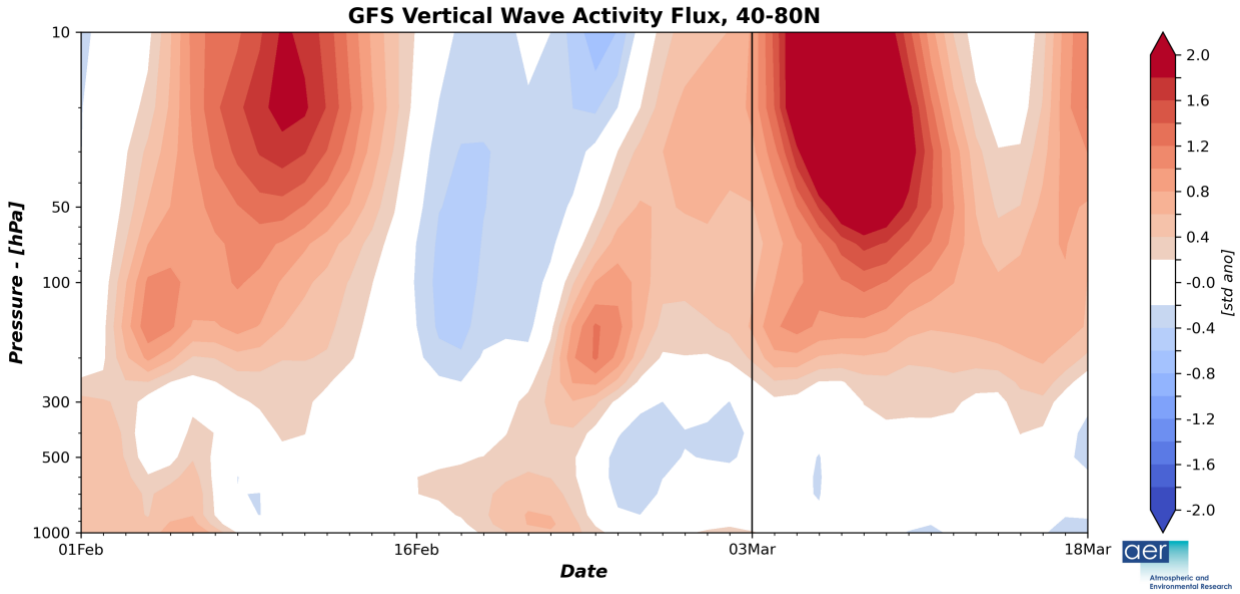


Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 03 Mar 2025 GFS ensemble.

Vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere has become more active after a relatively quiet this entire season (**Figure 12**). The strongest WAFz pulse of the season is predicted starting this week (**Figure 12**). This larger pulse is predicted to trigger an SSW by mid-March.

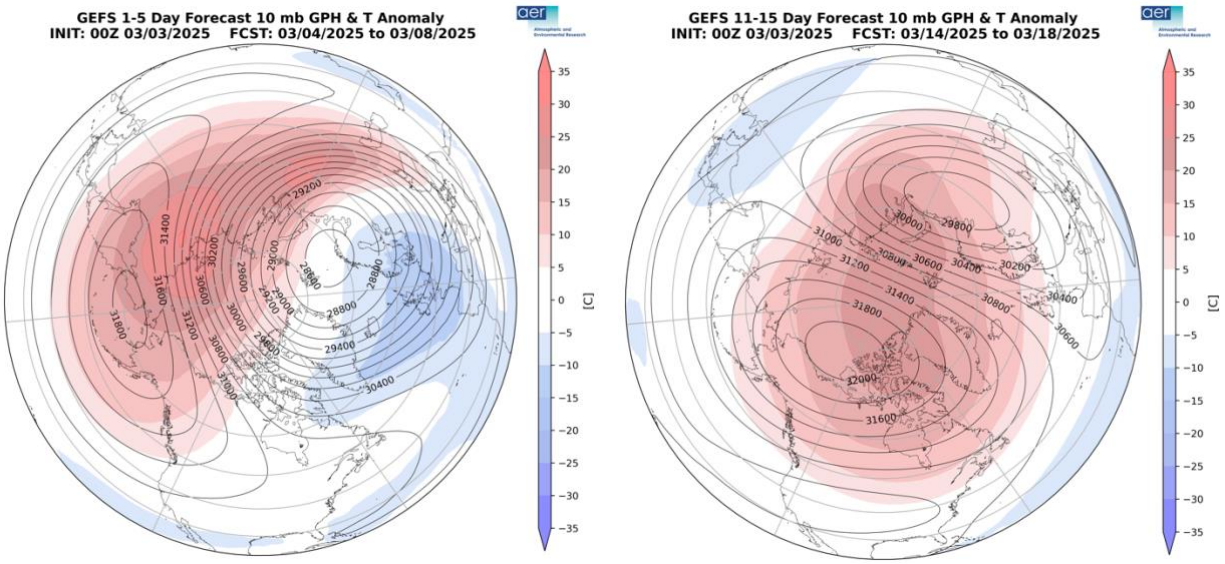


Figure 13. (a) Forecasted 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 04 to 08 Mar 2025. (b) Same as (a) except forecasted averaged from 14 Mar to 18 Mar 2025. The forecasts are from the 00Z 03 Mar 2025 GFS model ensemble.

This week the polar vortex (PV) is centered over the Barents-Kara Seas wound up like a tight ball with relatively coldest temperatures across Europe with high-pressure ridging near Alaska but extending into Canada and the relatively warmest temperatures across Siberia, Alaska and Northern Canada in the polar stratosphere (**Figure 13a**). This is consistent with a developing stretched PV that favors colder temperatures across eastern North America including the Eastern US. Then in mid-March the PV is predicted to be centered over 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 continues to remain positive. However, it does look like the stratospheric AO will finally weaken turn negative with the predicted SSW.

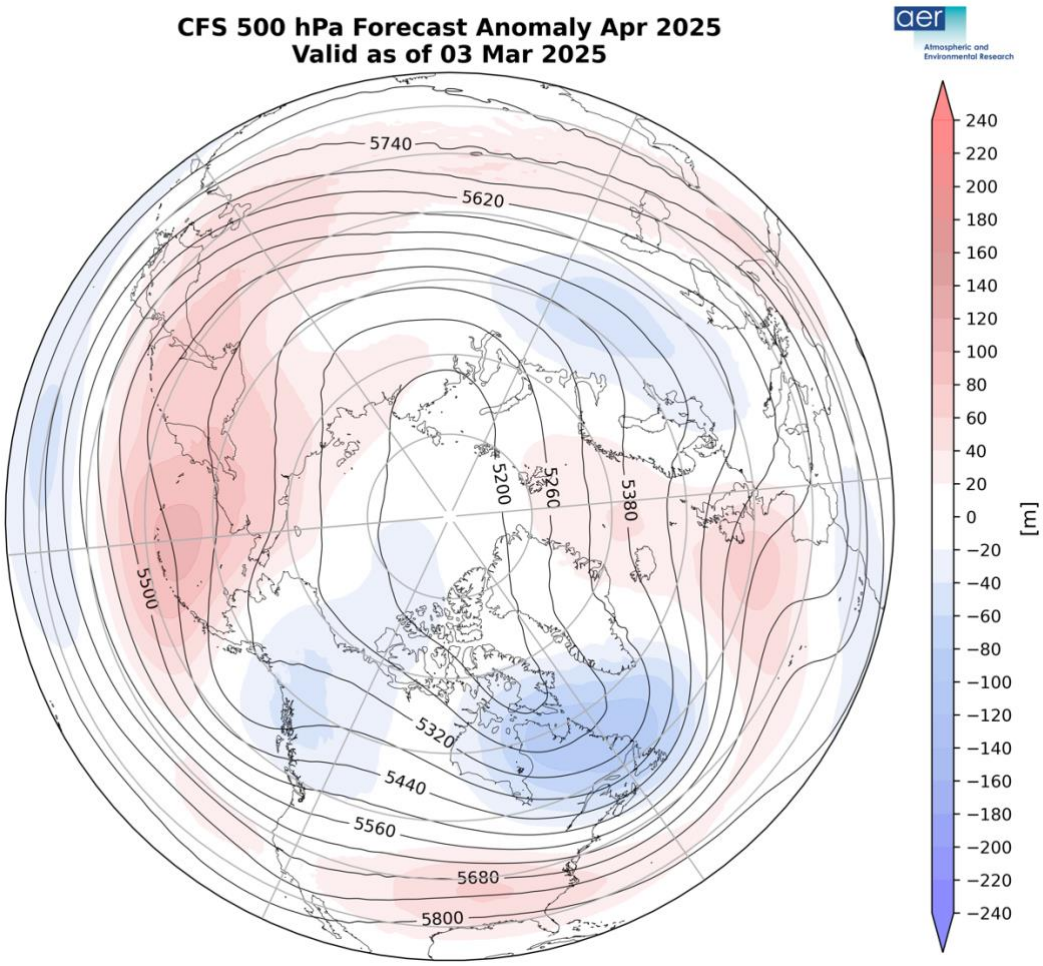


Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for April 2025. The forecasts are from the 00Z 03 Mar 2025 CFS.

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, centered near the Dateline and the Southeastern US with troughing across the Western Mediterranean, Western and Northern Asia, Alaska, Western and Eastern Canada, the Northwestern and Northeastern US (**Figure 14**). This pattern favors seasonable to relatively warm temperatures across Europe, much of Asia, including Siberia and the Central and Southern US with seasonable to relatively cold temperatures across Southwestern Europe, Western Asia, parts of Northeast Asia, Alaska, Canada and the Northwestern and Northeastern US (**Figure 15**).

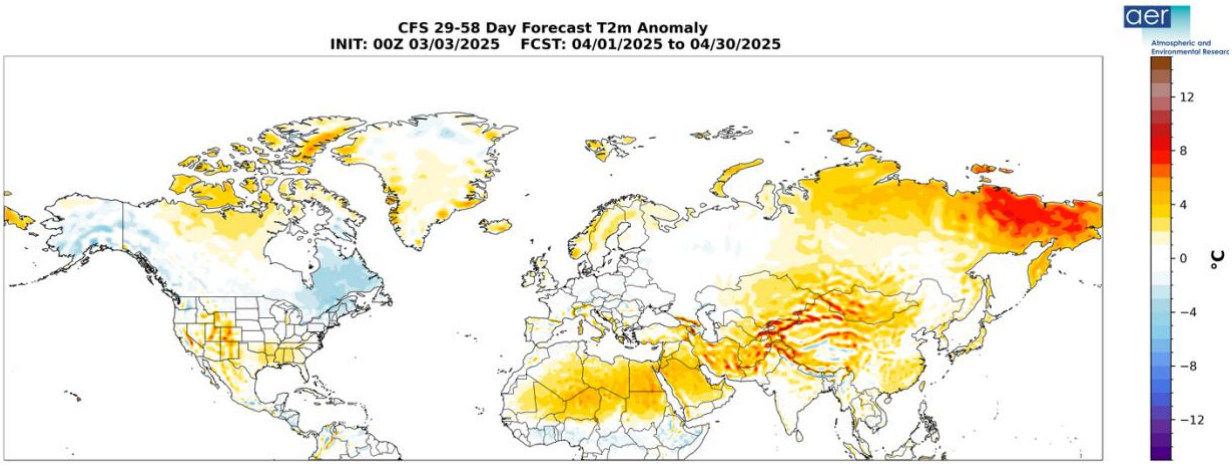


Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for April 2025. The forecasts are from the CFS 00Z 03 Mar 2025.

Boundary Forcings

Arctic Sea Ice

Sea ice growth continues relatively slowly 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 02 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. 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.

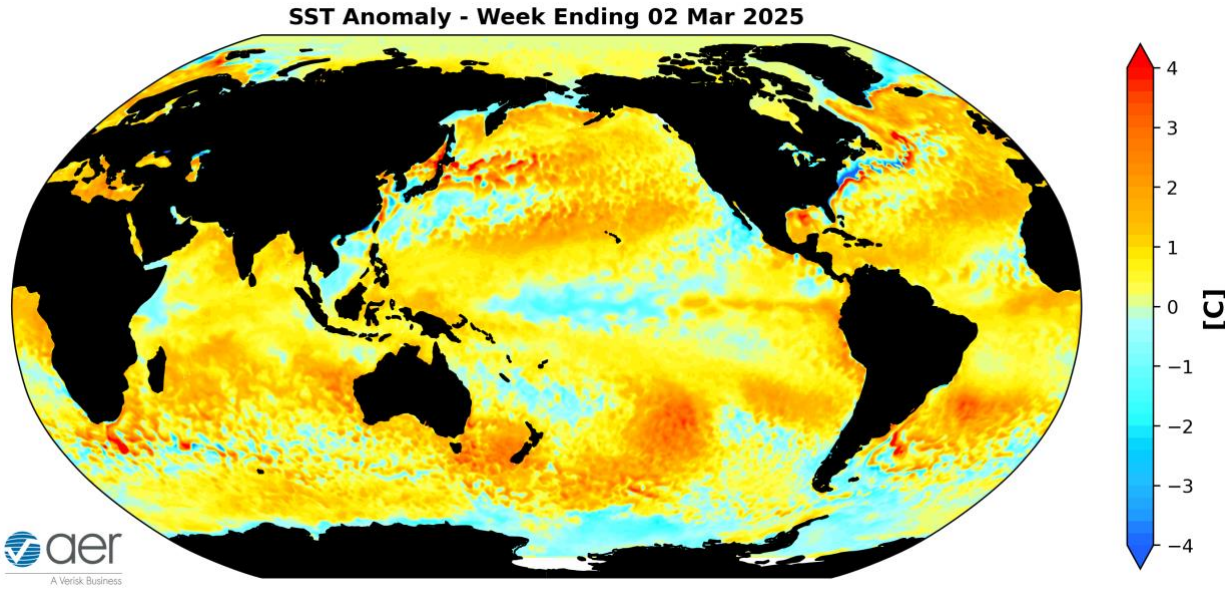


Figure 17. The latest daily-mean global SST anomalies (ending 02 Mar 2025). Data from NOAA OI High-Resolution dataset.

Madden Julian Oscillation

Currently the Madden Julian Oscillation (MJO) is in phase one (**Figure 18**). The forecasts are for the MJO to just hang out in phase one, slip into phase two and then weaken to where no phase is favored. Phases one favors Western US ridging and Eastern US troughing initially but then transitions to 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.

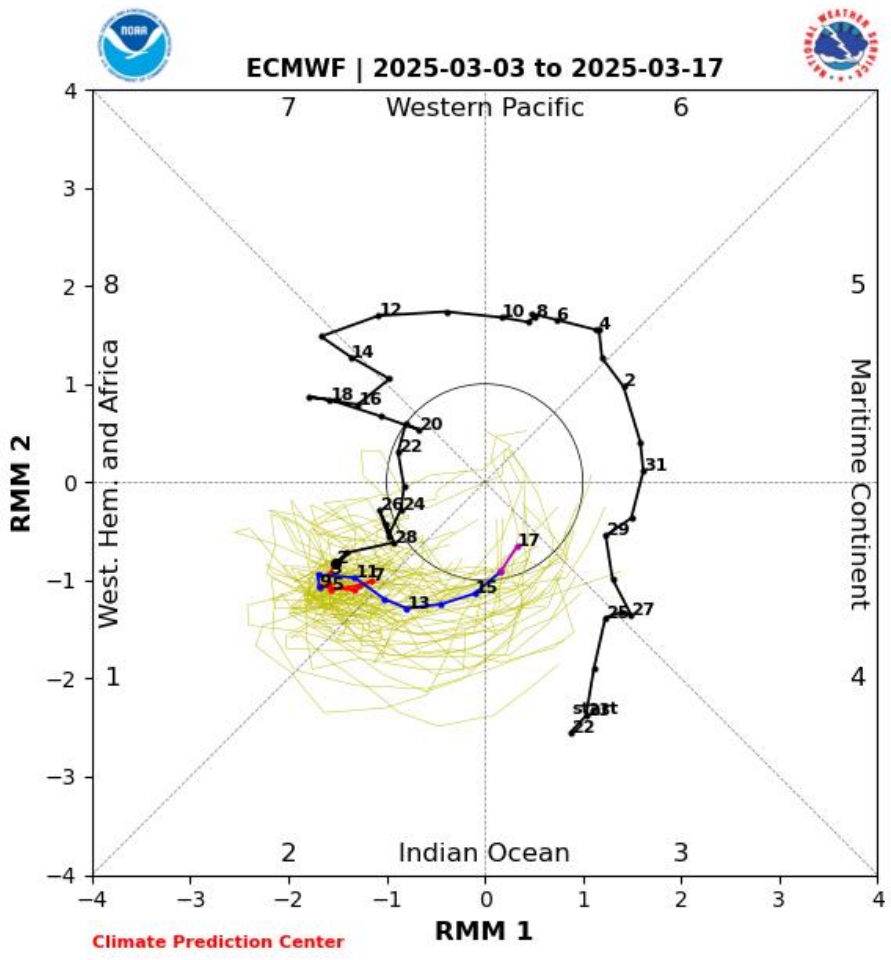


Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 03 Mar 2025 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model 'spread' is denoted by the gray shading. Sector numbers indicate 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

aer
Atmospheric and Environmental Research

Get Detailed Seasonal Weather Intelligence with sCast

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

Dr. Cohen's detailed monthly seasonal forecast, sCast, is also available. 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!