

Arctic Oscillation and Polar Vortex Analysis and Forecasts

March 4, 2024

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 neutral and is predicted to remain neutral and possibly negative the next two weeks as pressure/geopotential height anomalies across the Arctic are currently mixed and are predicted to remain mixed to slightly positive over the next two weeks. The North Atlantic Oscillation (NAO) is currently neutral with mixed pressure/geopotential height anomalies across Greenland and the NAO is predicted to be trend negative the next two weeks as pressure/geopotential height anomalies turn more positive across Greenland.
- Troughing/negative geopotential height anomalies in the North Atlantic will push relatively mild maritime air across Europe over the next two weeks. However next week, increasing ridging/positive geopotential height anomalies across Greenland will support Arctic air filter into Scandinavia. This pattern will support normal to above normal temperatures across much of Europe with the exceptions of the Iberian Peninsula this

week and Scandinavia next week. The United Kingdom (UK) will be close to seasonable the next two weeks.

- The general predicted pattern across Asia the next two weeks is ridging/positive geopotential height anomalies stretching from the Barents-Kara Seas to Greenland will force troughing/negative geopotential height anomalies across Northern and Western Asia with strengthening ridging/positive geopotential height anomalies in Southern and Eastern Asia. This pattern favors widespread normal to below normal temperatures across Western and Northern Asia with normal to above normal temperatures across Southern and Eastern Asia the next two weeks.
- The predicted pattern across North America this week is ridging/positive geopotential height anomalies centered near the Dateline forcing troughing/negative geopotential height anomalies across Alaska, Western Canada and the Western United States (US) with more ridging/positive geopotential height anomalies across Eastern Canada and the Eastern US. Then next week ridging/positive geopotential height anomalies will strengthen across western North America with deepening troughing/negative geopotential height anomalies across eastern North America. This pattern favors 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. However next week some of the colder air will start to flow eastward across the US.
- In the Impacts section I discuss the rapidly weakening polar vortex (PV) and the possible impacts to Northern Hemisphere (NH) weather as now that we have entered spring.

Plain Language Summary

In **Figure i**, I show the observed surface temperature anomalies for February. Quite warm across North America with the largest pocket of relatively cold temperatures along the Alaskan/Canadian border. There was more widespread cold across Eurasia stretching from Scandinavia to Siberia and Eastern China with the most impressive cold in Central Asia. There has been an impressive (giving how much the globe has warmed) multi-decade cooling trend in the interior of North America during February but clearly not this year.

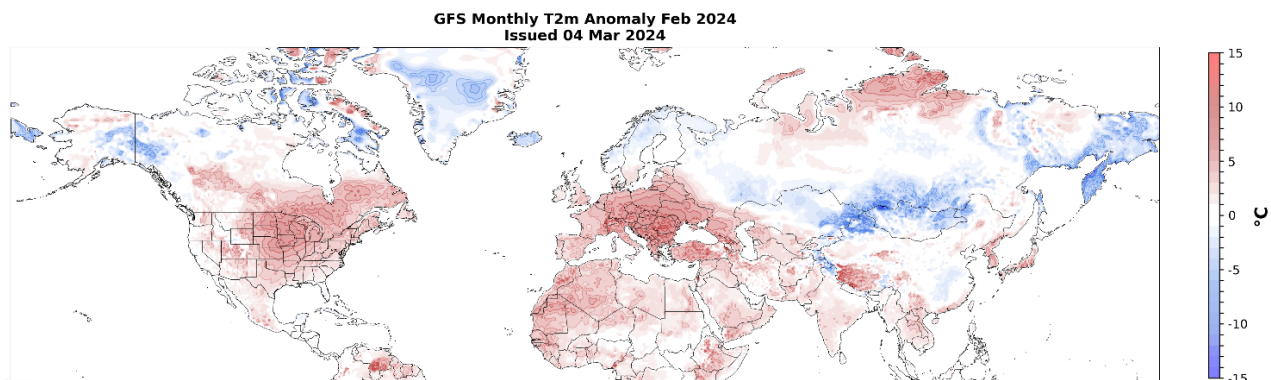


Figure. Estimate of the observed surface temperatures (°C; shading) from 1 February 2024 – 26 February 2024 based on GFS initializations and the GFS forecast from the 26 February 2024 forecast.

Chance of one last hurrah for winter but winter can fight the sun for just so long. Any large departures from normal to the cold side will not likely happen until after astronomical spring begins. At that point any winter weather are highly anomalous, short events and not for extended periods.

Impacts

I don't feel like writing much else than waxing poetic about the winter than wasn't and what could have been in the Impacts section.

I feel pretty strongly that it is difficult to get proper winter weather across the mid-latitudes when the polar vortex (PV) is centered on the North Pole, strong and circular in shape. This may not have been true fifty years ago but is certainly true today. My position is fairly absolutist though I readily admit that in weather there are no absolutes, so I am sure there are exceptions.

However, the inverse is not necessarily true. A weak PV increases your odds or probabilities of wintry weather but is far from a guarantee. I have written previously that the most spectacular PV disruption can occur, and it doesn't necessarily translate into notable winter weather. This winter is a prime example of just that. The PV started to weaken in late November and early December, sort of speak has been on its back foot ever since and will likely never really recover right up to the Final warming (see **Figure i**). However, for a winter weather enthusiast in much of Europe and the Eastern US, the lack of winter was indistinguishable from a strong PV with some episodic exceptions. In Scandinavia, Western Russia, Siberia and East Asia there was real winter weather. Siberia is the region most sensitive to the strength of the PV, so I do take comfort in that Siberia was at least seasonably cold this winter and much colder than the dynamical winter forecasts. Alaska was also cold, but I don't think that is necessarily related to a weak PV.

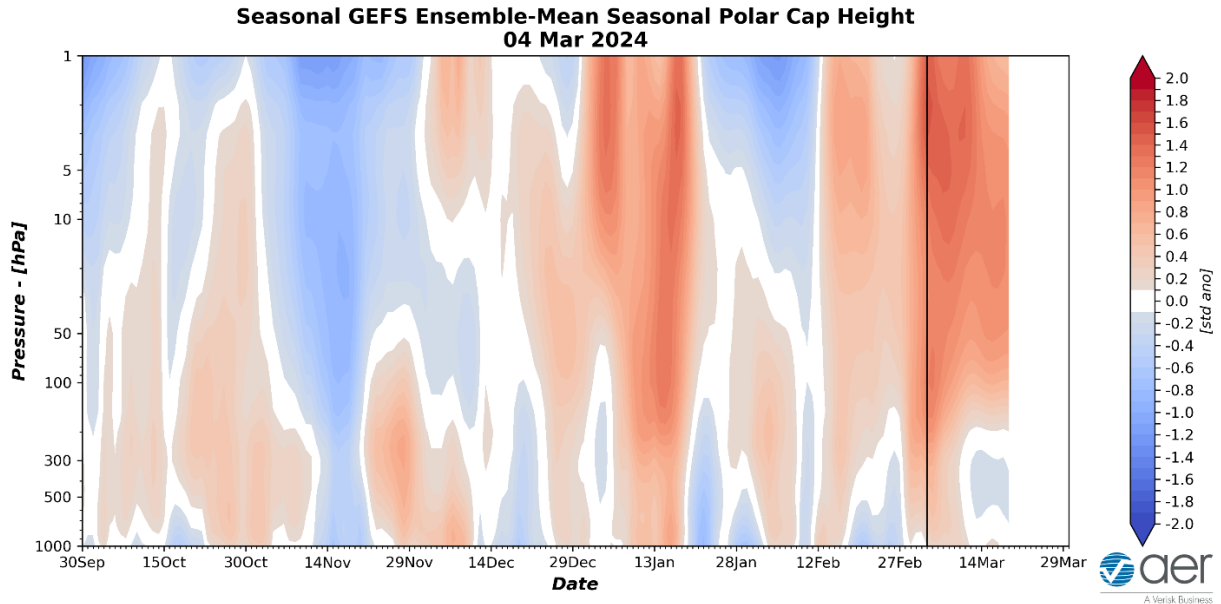


Figure i. Seasonal observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies for the North Atlantic regional (see insert). The forecast is from the 00Z 4 March 2024 GFS ensemble.

The frustrating part for a winter weather enthusiast like me is that this week we have the most impressive PV disruption of the winter still evolving. All weather models are predicting a PV split with one center over Europe and the other center over the Northeastern US and Southeastern Canada (see **Figure 13b**). Again, no guarantees but with two PV centers in these locations had the potential to anchor a sustained period of cold and/or snow for the Eastern US and Northern Europe for weeks and maybe even months had this occurred in December or January. In March this PV disruption crashed into the reality of the sun returning to the Northern Hemisphere. I would argue from **Figure i** that the return of some cooler weather and even the possibility of snow in early March has returned to parts of the Eastern US and Northern Europe is the arrival of the downward influence from the minor sudden stratospheric warming (SSW) back in February. However, the potentially longer duration downward influence of the major SSW ongoing this week will not reach the surface until after the spring equinox or astronomical spring. At that point a freak event is always possible, but any sustained winter weather is not going to happen for much of the US and Europe.

The easterly flow north of the PV center over Europe in the stratosphere see (**Figure 13b**) could promote some easterly flow in the troposphere over Northern Europe ushering in colder air from Siberia. And I think to a certain degree the models are suggesting such a scenario with colder temperatures predicted to return to Scandinavia starting next week. But at least for now widespread and deep cold are not predicted for Europe even with all the caveats of the strong sun and lack of snow cover. Still, I am keeping an open mind for a turn to colder weather.

Similarly, the other PV center over eastern North America (see **Figure 13b**) could also bring colder and/or snowier weather and even cutoff/closed lows to the Eastern US. Closed lows are in the forecast and a ton of rain for Boston but no strong signals for snow. But we are starting to see the signs of a western ridge/eastern trough pattern across North America (e.g., see **Figure 8**) for what it's worth. I do think that the chance of more notable cold is better in the Eastern US than Europe (maybe with the exception of Scandinavia) because the models are predicting that the North American PV center will become stronger than the European PV center and hence the dominant center (see **Figure ii**). It is my impression that when this does happen the cold becomes focused in North America rather than Eurasia. A nice example was January 2019.

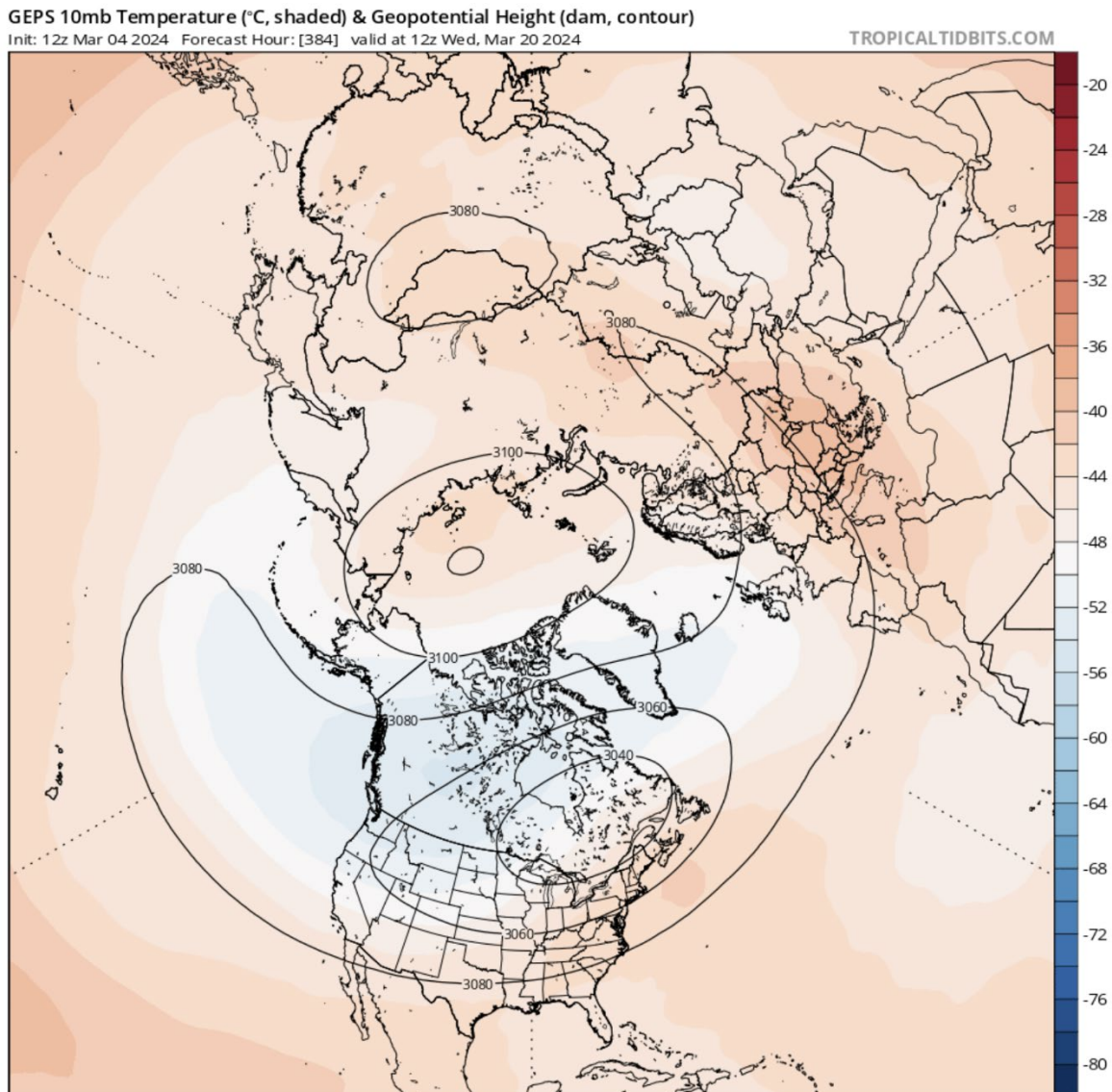


Figure ii. Forecasted average 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 20 March 2024. The forecasts are

from the 12z 4 March 2024 Canadian ensemble. Plot taken from <https://www.tropicaltidbits.com/analysis/models/>.

As I have been writing for several weeks now, an SSW is a favorable background for wave reflection. I do think that the strengthening PV center over eastern North America and the western ridge/eastern trough pattern across North America is likely a sign or related to wave reflection. No strong evidence in our energy diagnostics. However, in the Wave Activity Flux (WAF) vectors in the vertical and meridional direction wave reflection can start to be observed occurring at the critical line (where the zonal mean zonal wind is negative or easterly above and positive or westerly below) in the lower stratosphere (see **Figure iii**). Being able to visualize upward WAF being denied going higher by the critical line seems a bit messy to me but at least here we see a nice example of it.

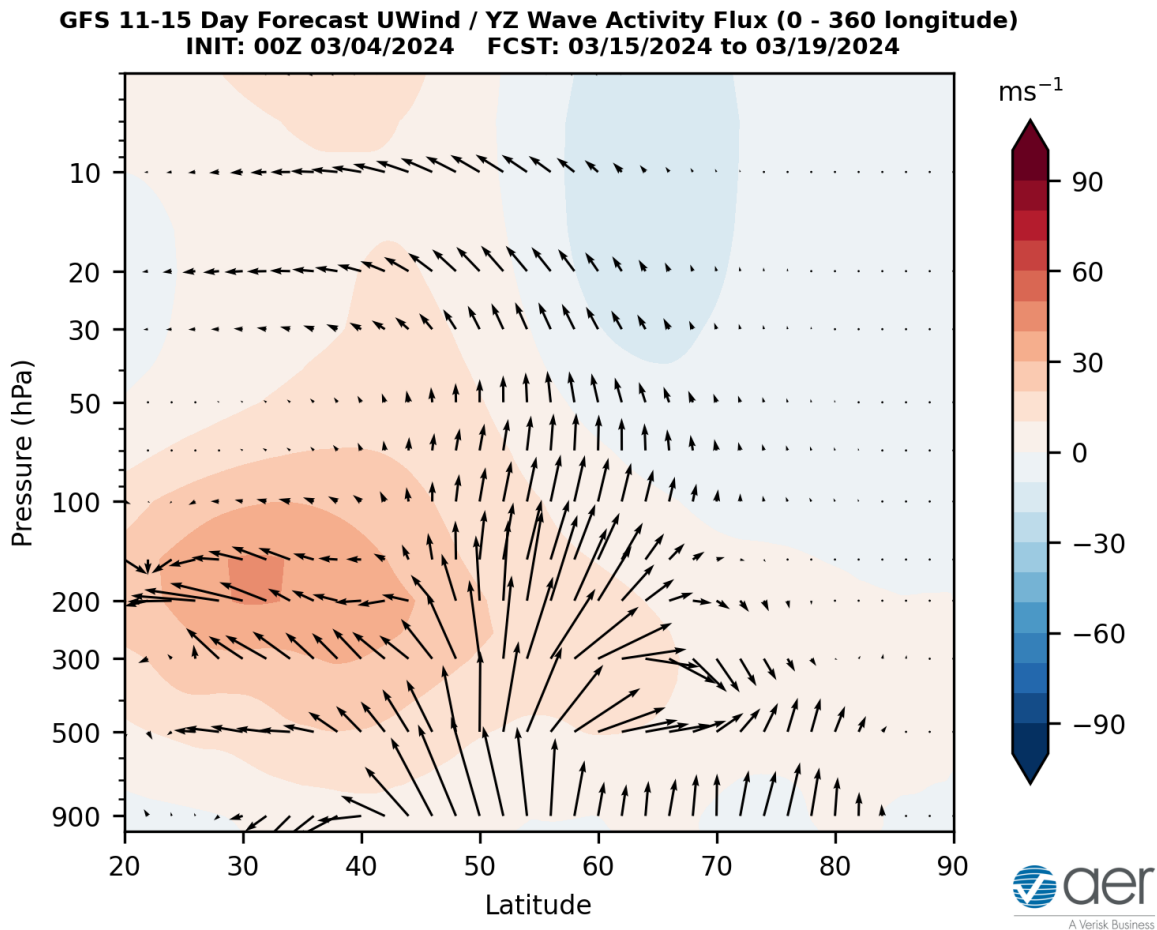


Figure iii. Latitude-height cross section of zonal mean zonal wind (shading) and wave activity flux (vectors) forecasted 15 – 19 March 2024. The forecast is from the 00Z 26 February 2024 GFS ensemble.

If this wave reflection matures, the cold air in eastern North America could deepen with time relative to normal. Looks to me the Canadian and ECMWF are more aggressive at deepening the trough over the Eastern US than the GFS.

Near-Term

This week

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

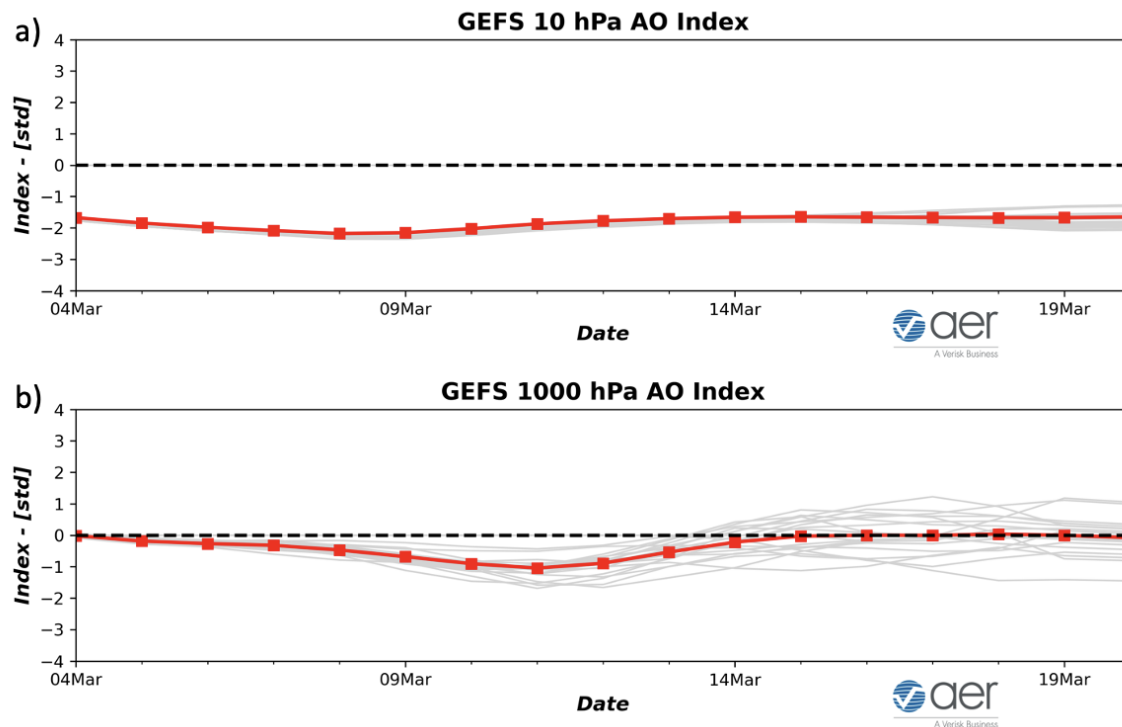


Figure 1. (a) The predicted daily-mean AO at 1000 hPa from the 00Z 4 March 2024 GFS ensemble. (b) The predicted daily-mean near-surface AO from the 00Z 4 March 2024 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

This week, ridging/positive geopotential height anomalies centered in the North Atlantic stretching from Scandinavia to Greenland are predicted to force troughing/negative geopotential height anomalies south of Iceland and into Western Europe with more ridging/positive geopotential height anomalies across Central and Eastern Europe (**Figures 2**). This pattern favors

normal to below normal temperatures across Western Europe including the UK with normal to above normal temperatures across Central and Eastern Europe (Figure 3). Predicted ridging/positive geopotential height anomalies stretching from Scandinavia to Greenland will support troughing/negative geopotential height anomalies across Western and Northern Asia with more ridging/positive geopotential height anomalies across Central Asia this period (Figure 2). This pattern favors widespread normal to above normal temperatures across much of Asia but focused in Central Asia with normal to below normal temperatures across Western Asia and Northern Siberia (Figure 3).

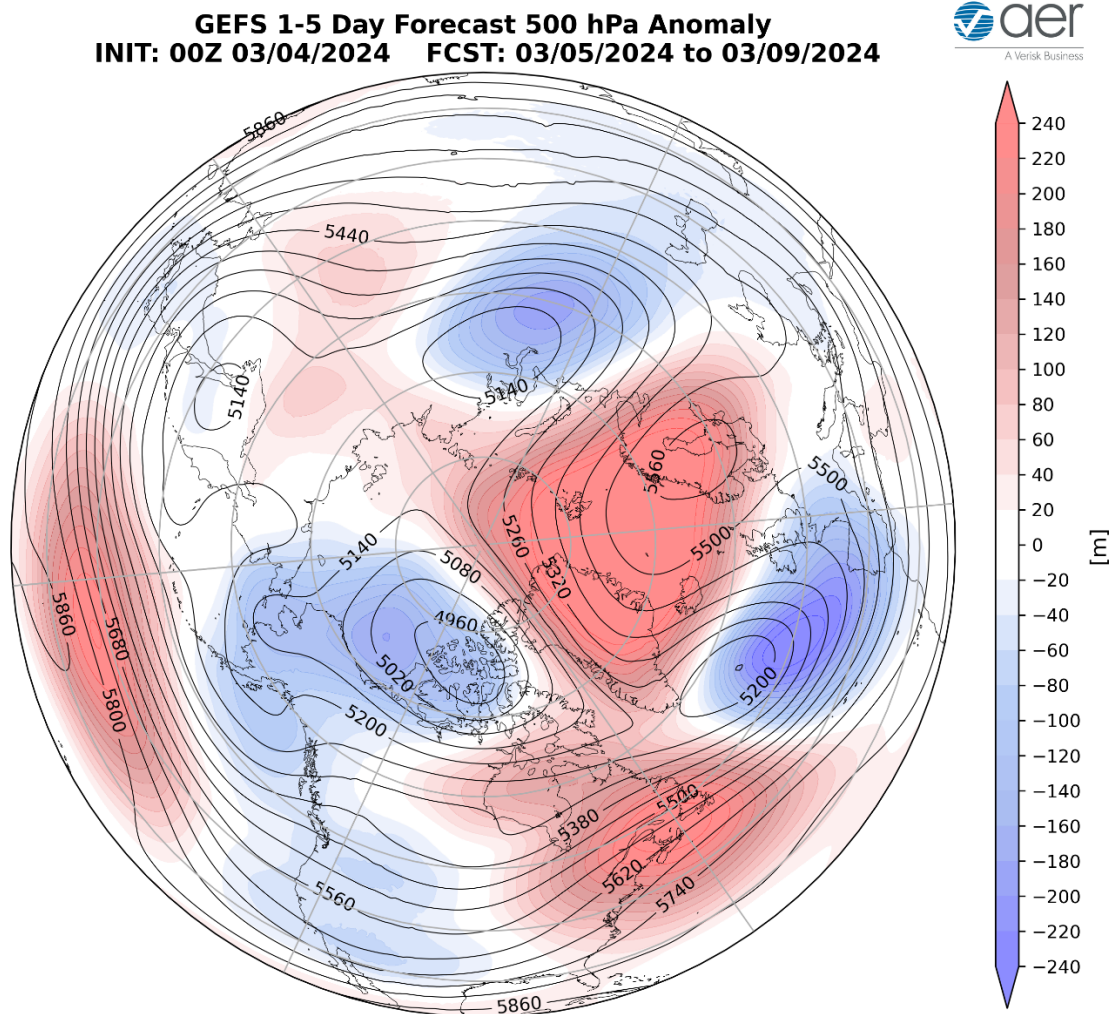


Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 5 – 9 March 2024. The forecasts are from the 00z 4 March 2024 GFS ensemble.

The pattern this week across North America is ridging/positive geopotential height anomalies centered near the Dateline forcing troughing/negative geopotential height anomalies across Alaska, Western Canada and the Western US with more ridging/positive

geopotential height anomalies across Eastern Canada and the Eastern US (**Figure 2**). This pattern will favor normal to below normal temperatures across Alaska, Western Canada and the Western US with normal to above normal temperatures across Eastern Canada and the US east of the Rockies (**Figure 3**).

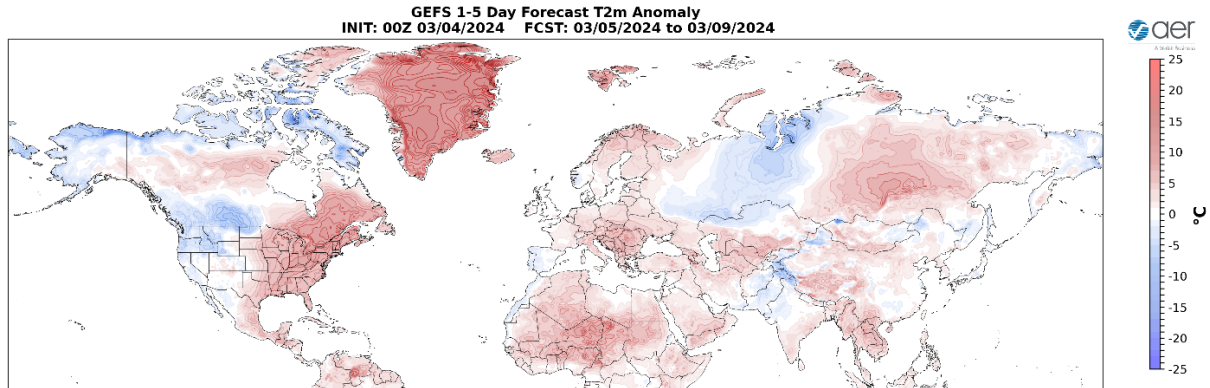


Figure 3. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 5 – 9 March 2024. The forecast is from the 00Z 4 March 2024 GFS ensemble.

Trouging and/or cold temperatures will support new snowfall across parts of Siberia, while mild temperatures will support snowmelt across Scandinavia and widespread across Asia this week (**Figure 4**). Trouging and/or cold temperatures will support new snowfall across Northern Canada, the West Coast of Canada and New England while mild temperatures will support snowmelt across Southern Canada and the Western US this week (**Figure 4**).

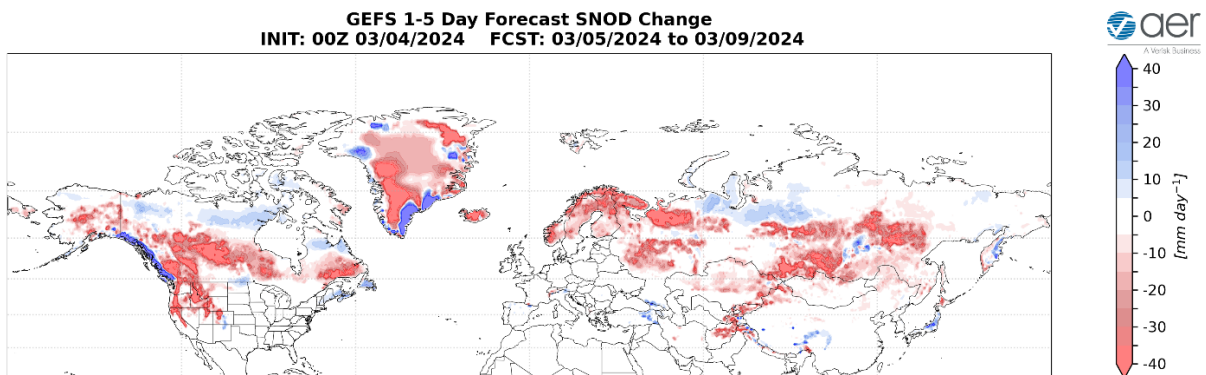


Figure 4. Forecasted snow depth changes (mm/day ; shading) from 5 – 9 March 2024. The forecast is from the 00Z 4 March 2024 GFS ensemble.

Near-Mid Term

Next week

With geopotential height anomalies becoming increasingly positive across the North Atlantic sector of the Arctic and with mixed geopotential height anomalies across the mid-latitudes this period (**Figure 5**), the AO will be negative to neutral this period (**Figure 1**). With pressure/geopotential height anomalies across Greenland also turning more positive(**Figure 5**), the NAO will be negative as well this period.

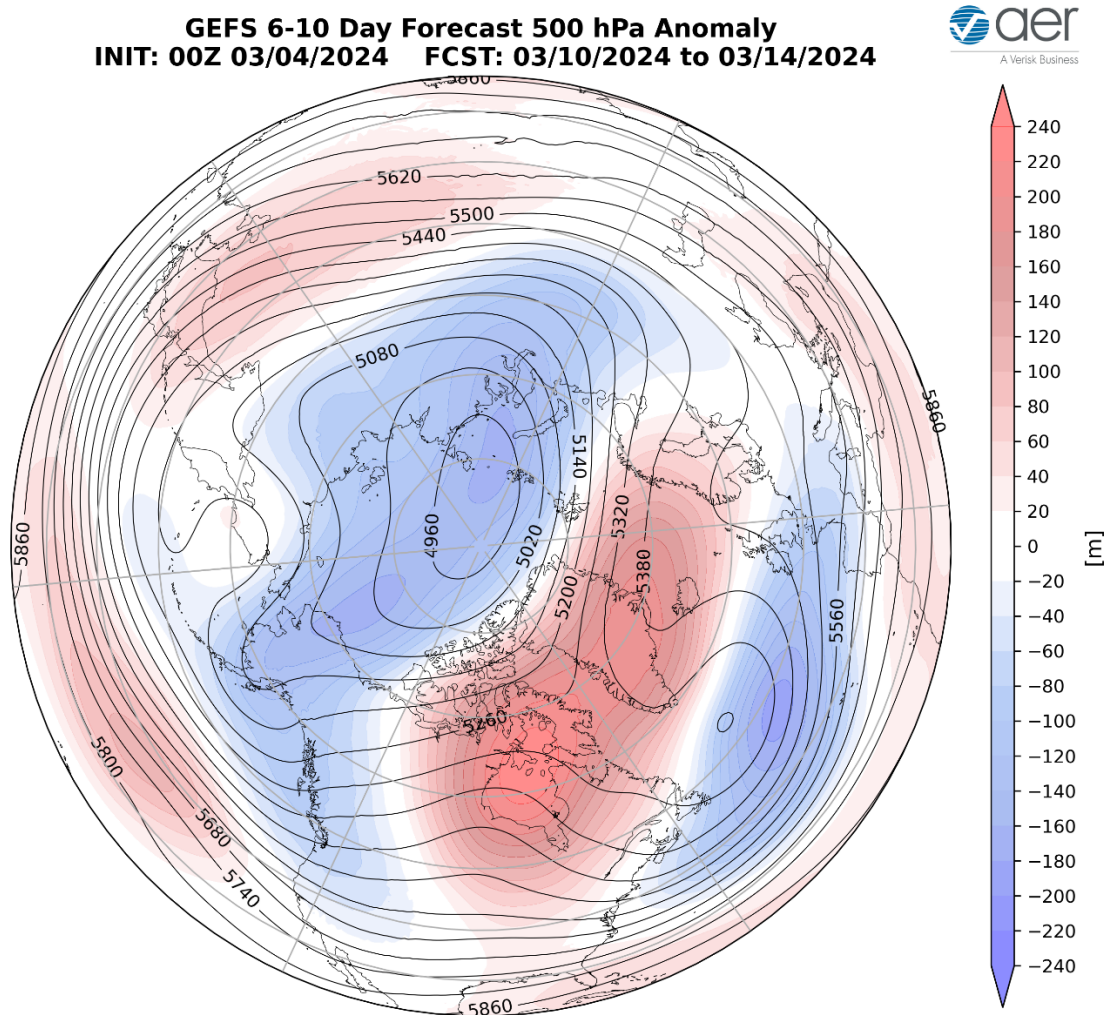


Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 10 – 14 March 2024. The forecasts are from the 00z 4 March 2024 GFS ensemble.

Increasing ridging/positive geopotential height anomalies stretching across the northern North Atlantic will support troughing/negative geopotential height anomalies south of Greenland and extending into Western Europe this period (**Figure 5**). This pattern will favor an overall maritime, westerly flow with widespread normal to above normal temperatures across much of Europe including the UK with normal to below normal temperatures limited to Scandinavia due to northerly flow (**Figures 6**). Predicted ridging/positive geopotential height anomalies centered

near Greenland will support troughing/negative geopotential height anomalies across Northern and Western Asia with more ridging/positive geopotential height anomalies across Southern and Eastern Asia this period (**Figure 5**). This pattern favors widespread normal to below normal temperatures across Northern and Western Asia with normal to above normal temperatures across Southern and Eastern Asia this period (**Figure 6**).

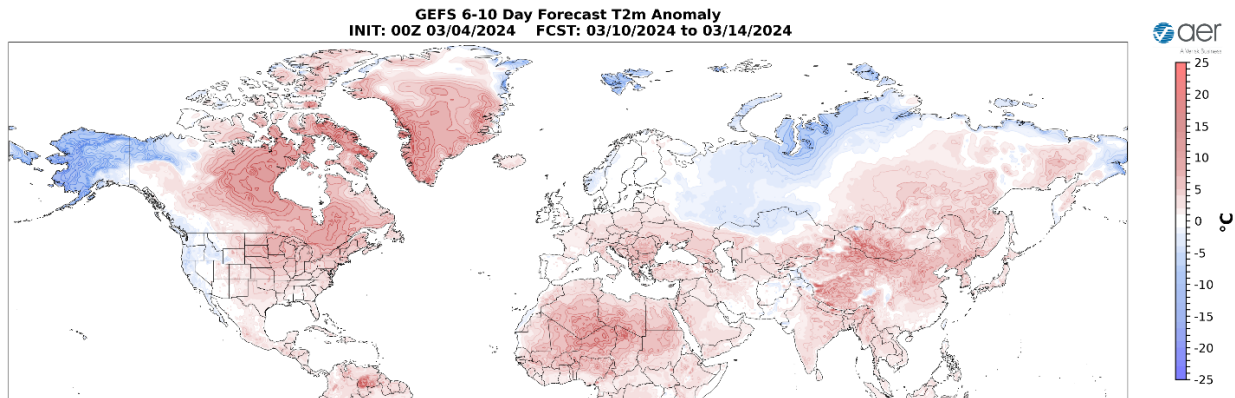


Figure 6. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 10 – 14 March 2024. The forecasts are from the 00z 4 March 2024 GFS ensemble.

Predicted ridging/positive geopotential height anomalies south of the Aleutians will support troughing/negative geopotential height anomalies across Alaska, Western Canada and the Western US with more ridging/positive geopotential height anomalies across Eastern Canada and the Eastern US this period (**Figure 5**). This favors normal to below normal temperatures across Alaska, Western Canada and the Western US with normal to above normal temperatures across Canada and the US east of the Rockies (**Figure 6**).

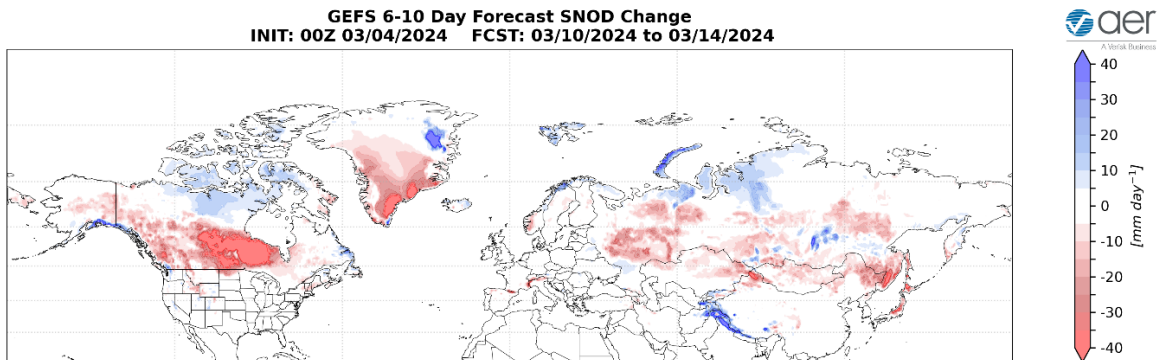


Figure 7. Forecasted snow depth changes (mm/day ; shading) from 10 – 14 March 2024. The forecast is from the 00Z 4 March 2024 GFS ensemble.

Trouging and/or cold temperatures will support new snowfall across parts of Northern Siberia and the Tibetan Plateau while mild temperatures will support snowmelt in Scandinavia, Northwestern Russia, and parts of Siberia, and East Asia this period (**Figure 7**). Trouging and/or cold temperatures will support new snowfall along the West Coast of Canada and Northern Canada while mild temperatures will support snowmelt across Western and Southern Canada and the Western US this period (**Figure 7**).

Mid Term

Week Two

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

GEFS 11-15 Day Forecast 500 hPa Anomaly
INIT: 00Z 03/04/2024 FCST: 03/15/2024 to 03/19/2024

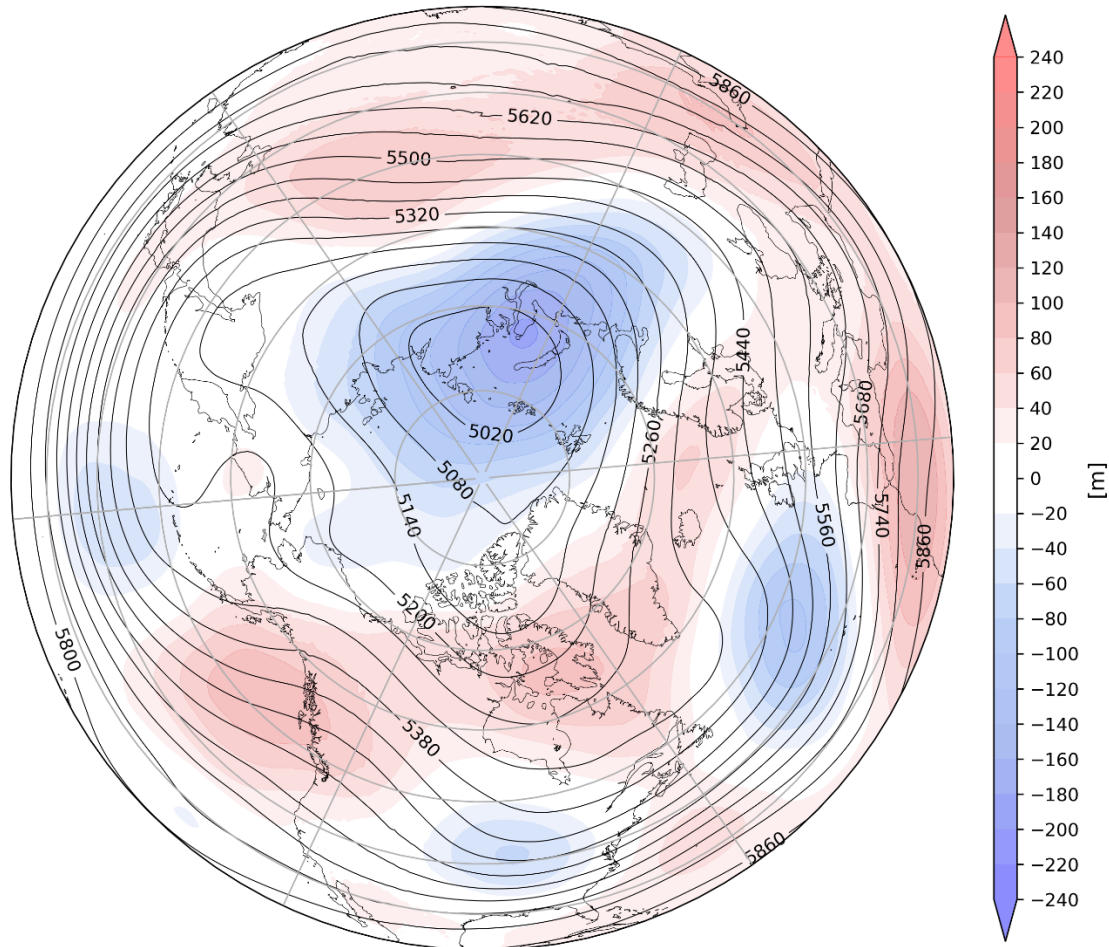


Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 15 – 19 March 2024. The forecasts are from the 00z 4 March 2024 GFS ensemble.

Persistent ridging/positive geopotential height anomalies across the northern North Atlantic possibly including Greenland will continue to support troughing/negative geopotential height anomalies south of Iceland extending into Western Europe with more ridging/positive geopotential height anomalies across Eastern Europe this period (**Figure 8**). The mostly zonal flow pattern should favor normal to above normal temperatures across much of Europe including the UK with normal to below normal temperatures across Scandinavia due to northerly flow this period (**Figures 9**). Ridging/positive geopotential height anomalies stretching from Greenland to Scandinavia will continue to support troughing/negative geopotential height anomalies across Northern and Western Asia with more ridging/positive geopotential height anomalies across Southern and Eastern Asia this period (**Figure 8**). The predicted pattern favors widespread normal to above normal temperatures across Southern and Eastern Asia with normal to below normal across Western and Northern Asia this period (**Figure 9**).

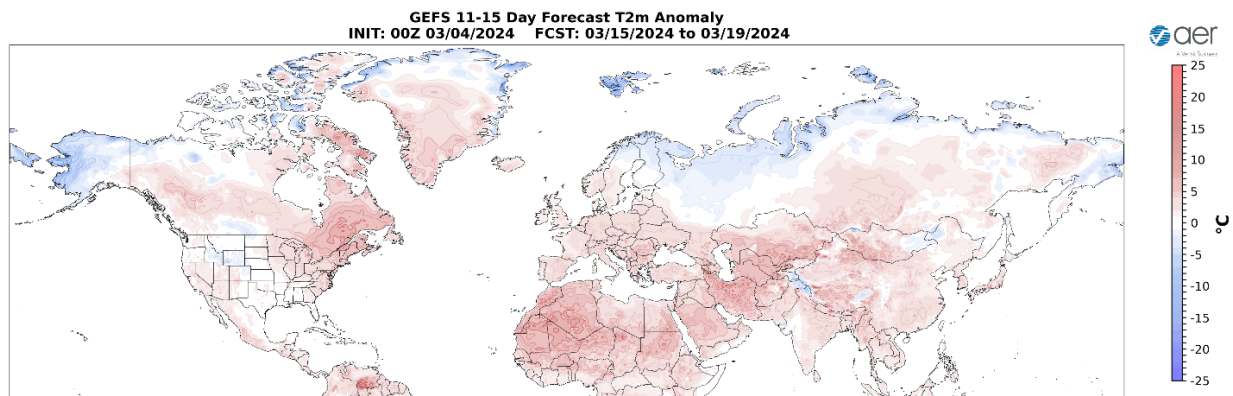


Figure 9. Forecasted surface temperature anomalies (°C; shading) from 15 – 19 March 2024. The forecasts are from the 00z 4 March 2024 GFS ensemble.

Ridging/positive geopotential height anomalies previously near the Dateline will slide into the Gulf of Alaska and Western Canada will support troughing/negative geopotential height anomalies across Eastern Canada and the Eastern US with more ridging/positive geopotential height anomalies along the US East Coast this period (**Figure 8**). This pattern favors normal to below normal temperatures across Alaska, Northwestern Canada and the US Plains with normal to above normal temperatures across much of Canada and the Eastern US this period (**Figure 9**).

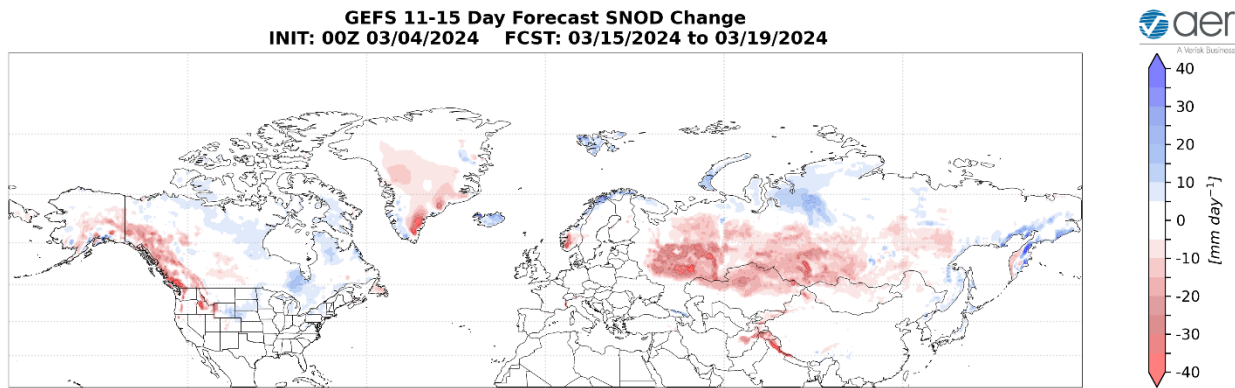


Figure 10. Forecasted snow depth changes (mm/day; shading) from 15 – 19 March 2024. The forecast is from the 00Z 4 March 2024 GFS ensemble.

Trouging and/or cold temperatures will support new snowfall across parts of Northern Siberia while mild temperatures will support snowmelt in Scandinavia, Southern Siberia and the Tibetan Plateau this period (**Figure 10**). Trouging and/or cold temperatures will support new snowfall across Eastern Canada and the US Plains. Mild temperatures will support snowmelt Southern Canada and the higher elevations of Western Canada and the Western US this period (**Figure 10**).

Longer Term

30-day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows warm/positive PCHs throughout the troposphere but strongest in the stratosphere (**Figure 11**). Then for the next two weeks warm/positive PCHs will dominate the stratosphere but fade in the troposphere (**Figure 11**). The increasing warm/positive throughout the stratosphere (**Figure 11**) is related to the PV becoming increasingly disrupted while warming/positive PCHs this week in the troposphere are associated with descent of the warm/positive PCHs associated with the PV disruption/minor SSW in the stratosphere back in February. The possible flip of PCHs to cold/negative next week in the troposphere are due to the vacuum created when the downward influence from the minor SSW fades but the downward influence from the major SSW still hasn't reached the mid to lower troposphere.

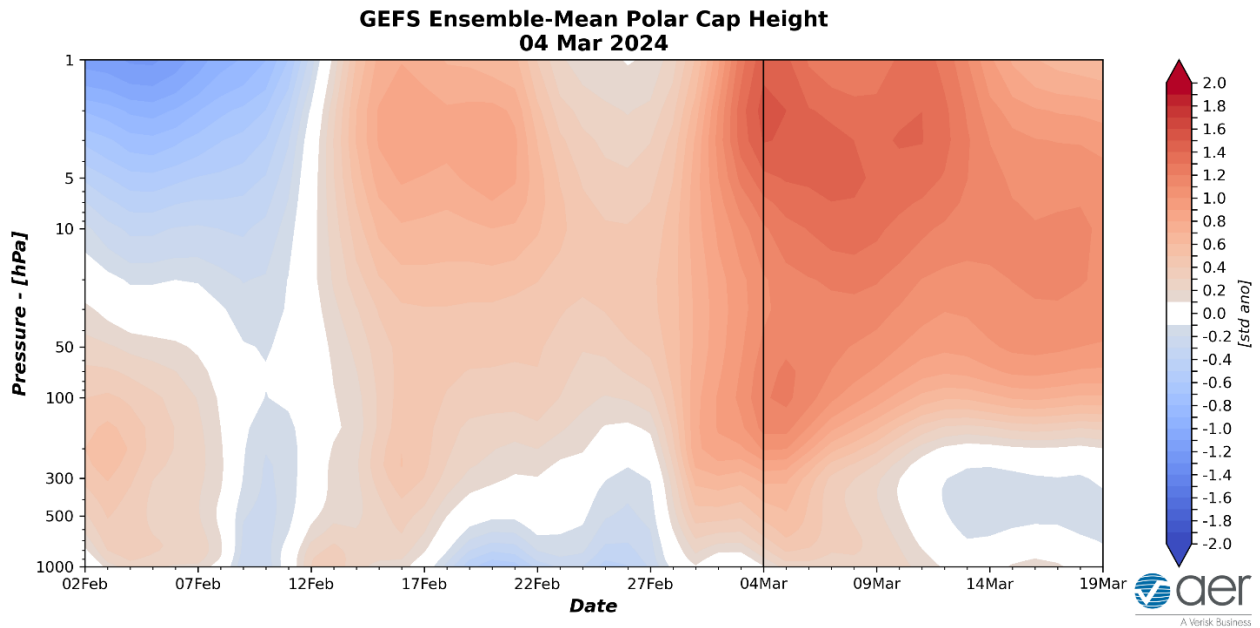


Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 4 March 2024 GFS ensemble.

The predicted warm/positive PCHs in the lower troposphere for this week (**Figure 11**) are consistent with the predicted neutral to negative surface AO this week (**Figure 1**). However, as the warm/positive PCHs begin to retreat into the stratosphere, the tropospheric AO is more likely to rise back to neutral and even possibly positive territory.

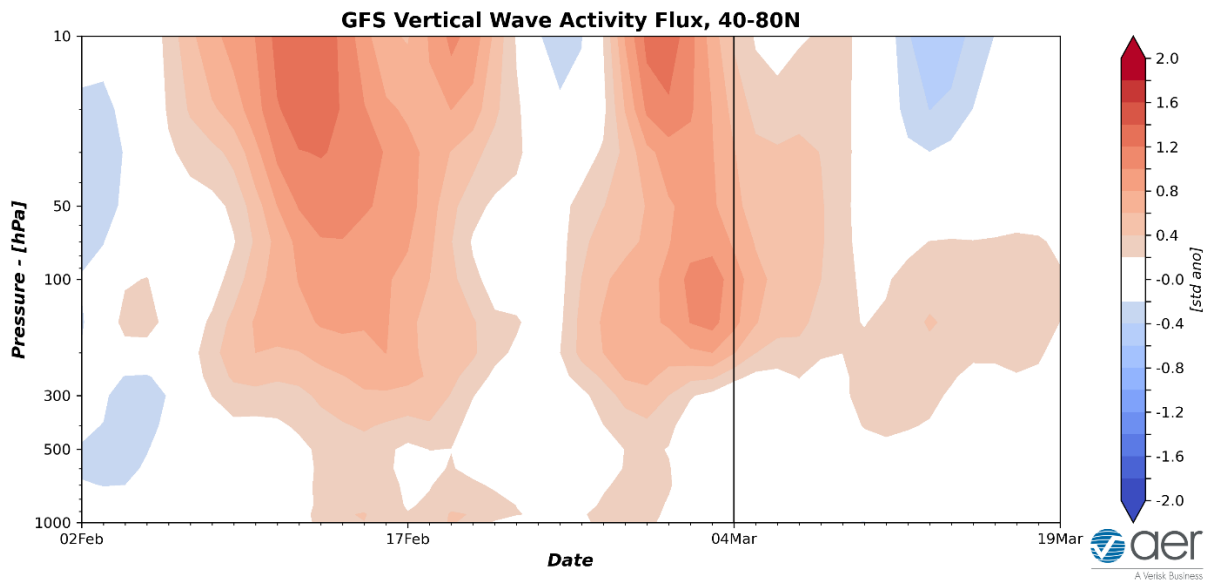


Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 4 March 2024 GFS ensemble.

Also shown in **Figure 1** is the stratospheric AO. The stratospheric AO is currently negative and is predicted to be negative to possibly strongly negative for the next two weeks. This is consistent with increasingly warm/positive stratospheric PCHs in the mid-stratosphere associated with a weakening PV that is dynamically consistent with a sudden stratospheric warming.

Vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere was relatively quiet from mid-January to early February (**Figure 12**). However, the quieter WAFz ended the second week of February and is continuing into this week and even next week (**Figure 12**). This should result in a weakening PV. The strongest pulse of WAFz likely occurred in mid-February but the predicted WAFz pulses should be sufficient to continue to weaken the PV into next week and resulting into an impressive major SSW.

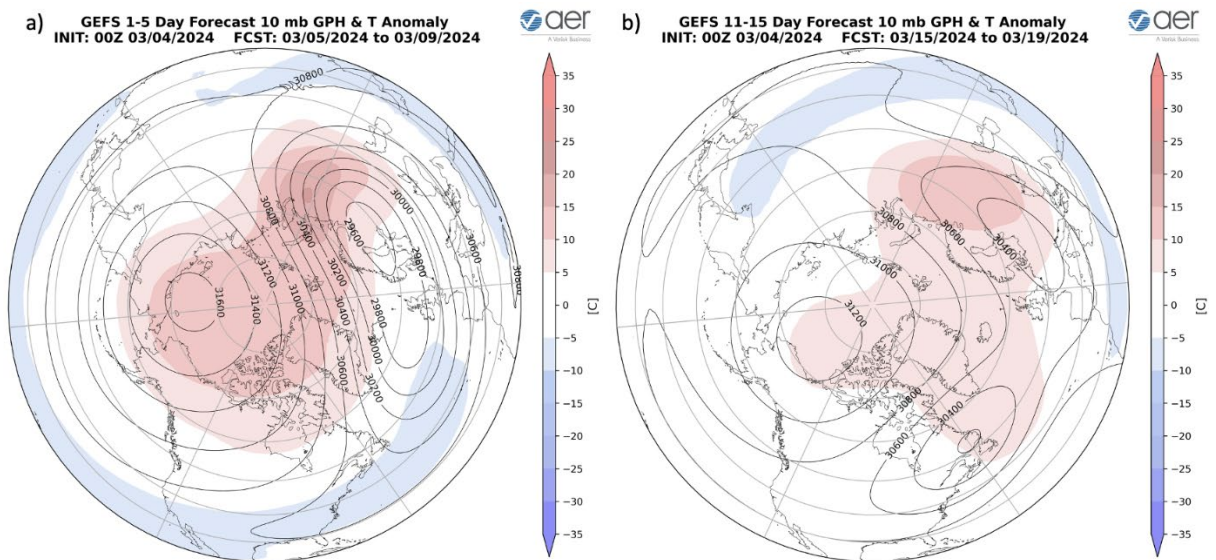


Figure 13. (a) Forecasted 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere from 5– 9 March 2024 . (b) Same as (a) except forecasted averaged from 15 – 19 March 2024. The forecasts are from the 00Z 4 March 2024 GFS model ensemble.

This week the polar vortex (PV) is predicted to be shifted south of the North Pole centered over Scandinavia and stretched out from the Urals to the US East Coast (**Figure 13a**). The ridging in the polar stratosphere is centered over the Beaufort Sea with the greatest warming aimed into the Central Arctic. This is consistent with an evolving SSW. For the third week of March the PV center is predicted to split into two centers with one center over Central Europe and the second center over the Canadian Maritimes and the Northeastern US with ridging predicted to remain

anchored over the Beaufort Sea and with warming spread across the northern North Atlantic (Figure 13b).

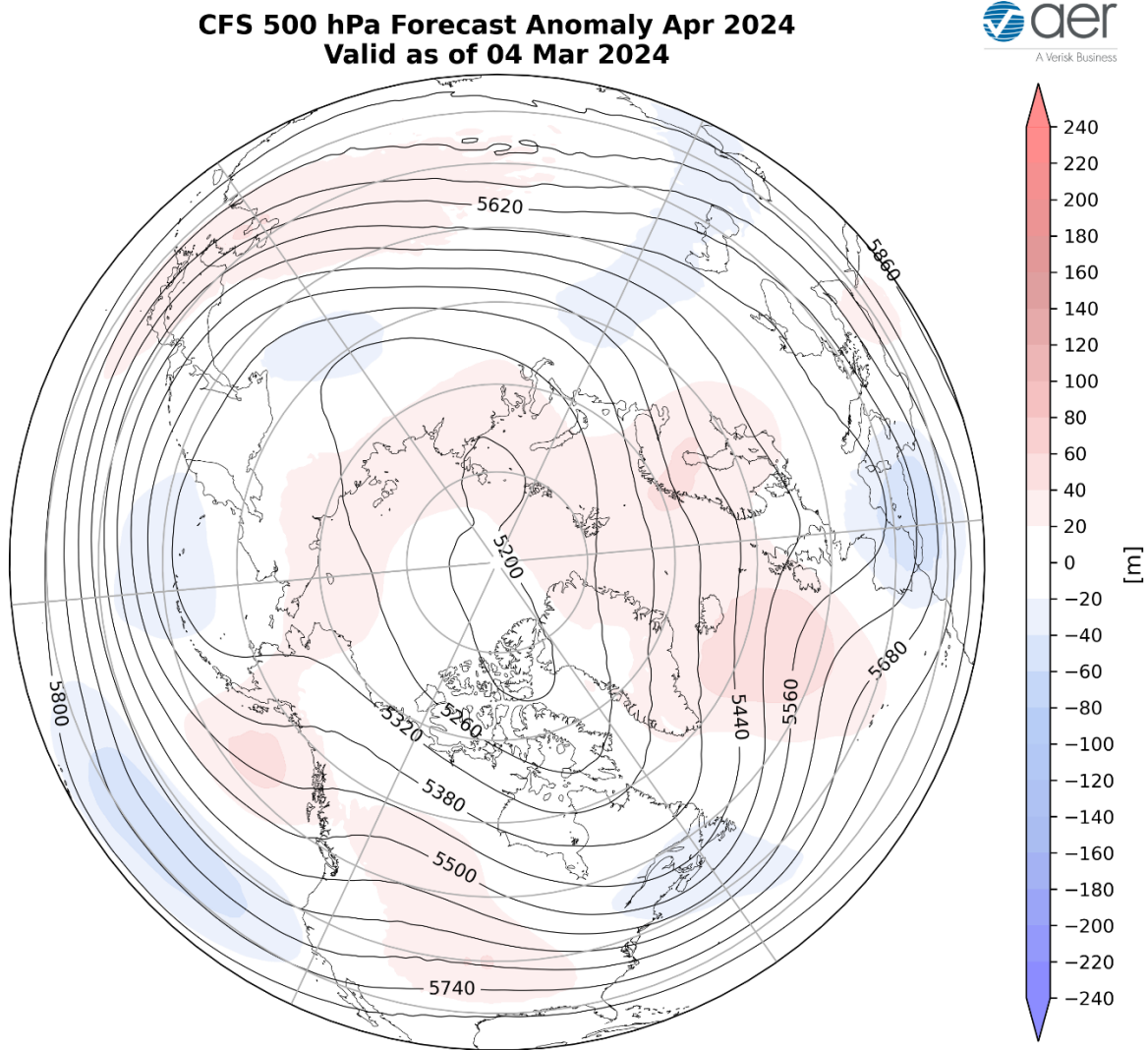


Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for April 2024. The forecasts are from the 00Z 4 March 2024 CFS.

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 south of Iceland, Northern Europe, Southeast Asia, the Gulf of Alaska, Western Canada and the Central US with troughing in Southern Europe, Siberia, Western Asia, the Southwestern US, Eastern Canada and the Northeastern US (**Figure 14**). This pattern favors seasonable to relatively warm temperatures across Northern Europe, Southern and Central Asia, Eastern

Siberia, Alaska, Western Canada and the Western US with seasonable to relatively cold temperatures across Southern Europe, Western and Northern Asia, Eastern Canada and the Eastern US (**Figure 15**).

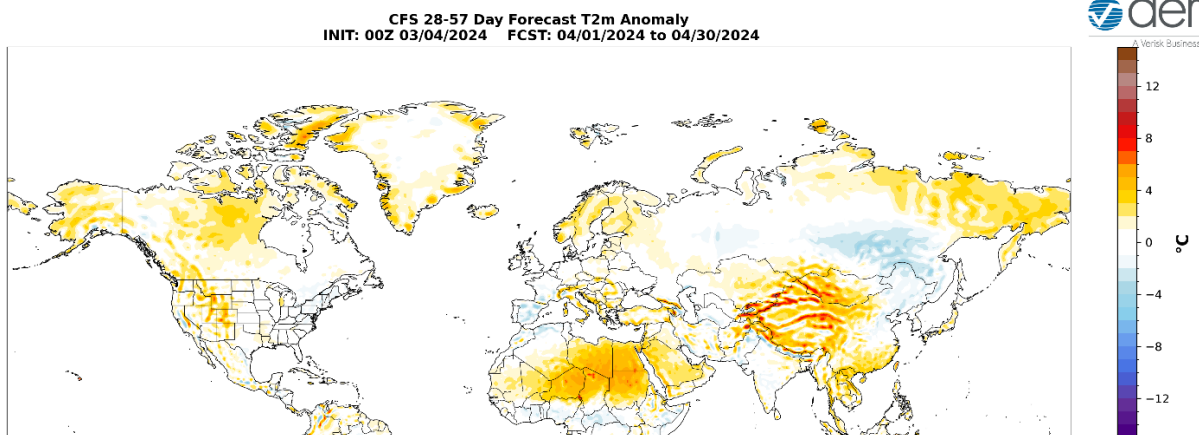


Figure 15. Forecasted average surface temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere for April 2024. The forecasts are from the 00Z 4 March 2024 CFS.

Arctic sea ice extent

Arctic sea ice extent grew again slowly this week. I continue to expect that the negative sea ice anomalies will remain focused in the North Atlantic sector, which is currently more so than previously this winter. Blocking in the Barents-Kara sea region is critical for weakening the PV that is favorable for widespread and meaningful cold in Northern Eurasia and eastern North America, which can persist for weeks.

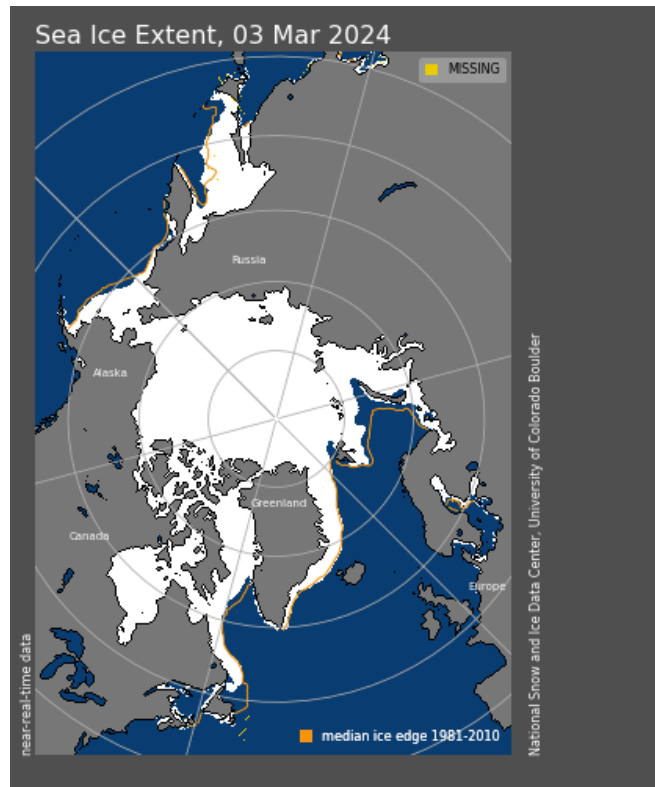


Figure 16. Observed Arctic sea ice extent on 25 February 2024 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image courtesy of National Snow and Ice Data Center (NSIDC). Snow and Ice Data Center (NSIDC).

SSTs/El Niño/Southern Oscillation

Equatorial Pacific sea surface temperatures (SSTs) anomalies are well above normal, especially along the South America coast, indicating that and El Niño remains strong (**Figure 17**) and El Niño conditions are expected through the end of the winter. Observed SSTs across the NH remain well above normal especially in the central North Pacific (west of recent years), the western North Pacific, the eastern North Atlantic and offshore of eastern North America though below normal SSTs exist regionally especially in the South and North Pacific and the North Atlantic.

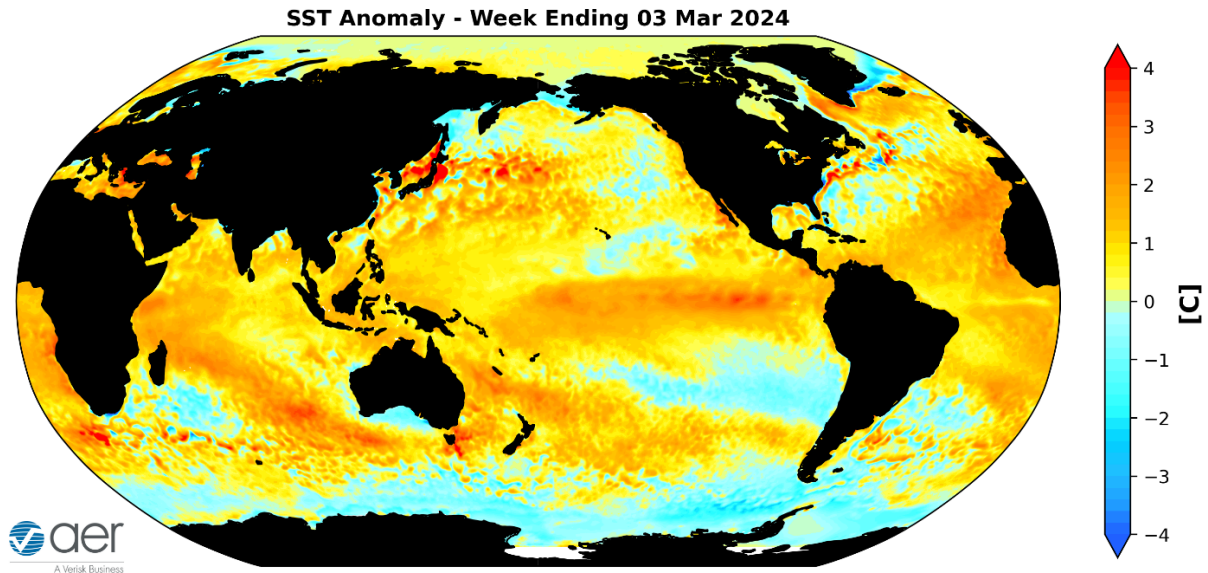


Figure 17. The latest weekly-mean global SST anomalies (ending 3 March 2024). Data from NOAA OI High-Resolution dataset.

Madden Julian Oscillation

Currently the Madden Julian Oscillation (MJO) is in phase three (**Figure 18**). The forecasts are for the MJO to quickly rifle through phases four, five and six. Phases three through six favor ridging near the Dateline with troughing in Alaska, Western Canada and the Western US with more ridging in the Eastern US. Therefore the MJO could be having an influence on the weather across North America weather this week into next week. But admittedly this is outside of my expertise.

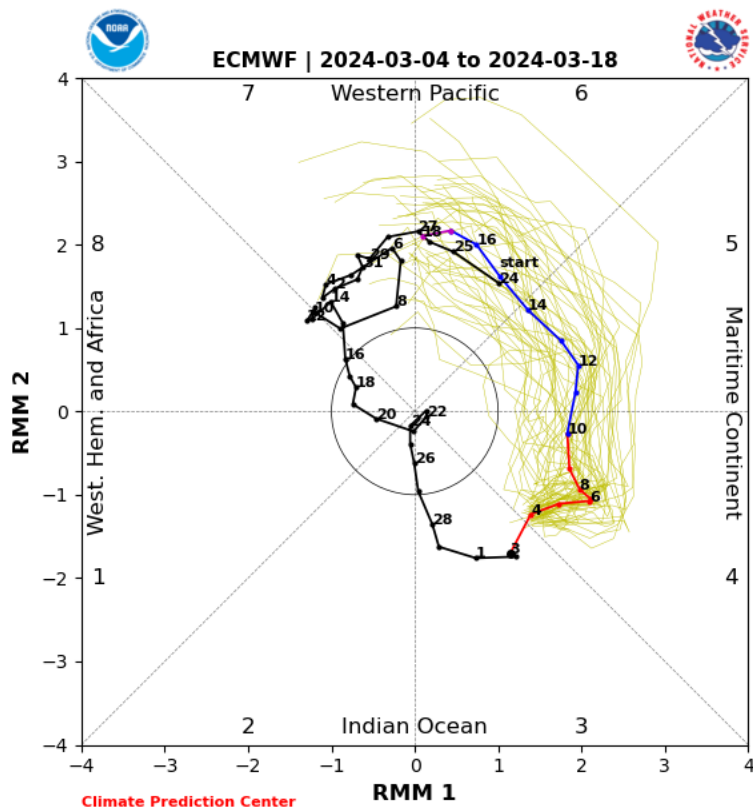


Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 26 February 2024 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model “spread” is denoted by the gray shading. Sector numbers indicate 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/clivar_wh.shtml

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