

Arctic Oscillation and Polar Vortex Analysis and Forecasts

February 12, 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 negative and is predicted to remain negative this week and next week as pressure/geopotential height anomalies across the Arctic are currently mostly positive and are predicted to become increasingly positive over the next two weeks. The North Atlantic Oscillation (NAO) is currently neutral with mixed and weak pressure/geopotential height anomalies across Greenland and the NAO is predicted to become increasingly negative the next two weeks as pressure/geopotential height anomalies turn more strongly positive across Greenland.
- The general pattern across Europe this week is troughing/negative geopotential height anomalies across Northern Europe with ridging/positive geopotential height anomalies across Southern Europe. The zonal pattern will support normal to above normal temperatures across much of Europe including the United Kingdom (UK) with the exception of normal to below normal temperatures across Scandinavia this

week. However, starting next week increasing ridging/positive geopotential height anomalies across Greenland will support deepening troughing and colder temperatures slowly spreading south across Europe including the UK.

- The general predicted pattern across Asia the next two weeks is ridging/positive geopotential height anomalies centered over the Barents-Kara Seas and the Urals this week and then the central Arctic next week forcing troughing/negative geopotential height anomalies across Northern Asia especially Siberia. This pattern favors widespread normal to above normal temperatures across Asia with normal to below normal temperatures regionally limited in Northwestern Russia and Siberia. However, starting next week colder temperatures will spread south from Siberia into East Asia.
- The general predicted pattern across North America the next two weeks is ridging/positive geopotential height anomalies across Alaska and Western Canada forcing troughing/negative geopotential height anomalies across the United States (US). This pattern favors normal to above normal temperatures across Alaska, much of Canada and the US east of the Rockies this week with normal to below normal temperatures across Southwestern Canada and the Western US. However next week cold temperatures are predicted to become more widespread across Canada and the US.
- In the Impacts section I discuss a rapidly weakening polar vortex (PV) in mid-February and the impacts to Northern Hemisphere (NH) weather.

Plain Language Summary

Now that we have made it to the second week of February the temperature pattern for winter 2023/24 is pretty much known. Widespread warmth rules but also relatively cold in Alaska and adjacent Canada, Scandinavia, Northwest Russia and parts of Siberia (see **Figure**).

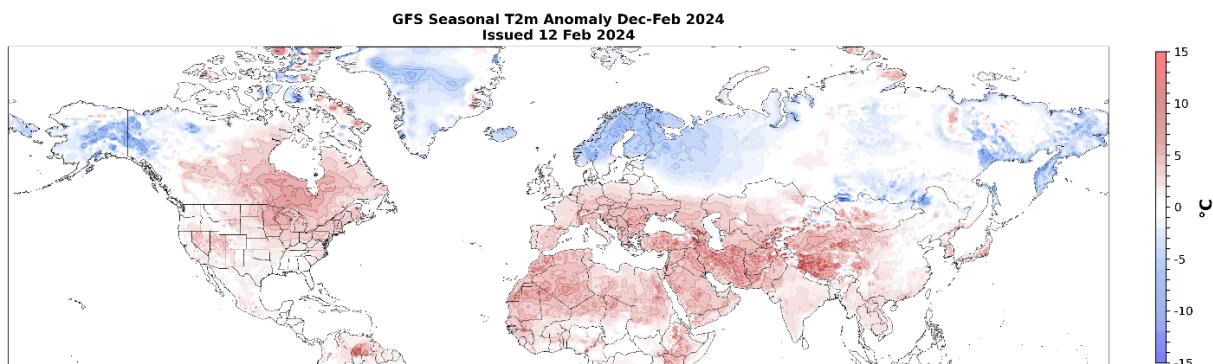


Figure. Estimate of the observed surface temperatures ($^{\circ}\text{C}$; shading) from 1 December 2023 – 20 February 2024 based on GFS initializations and the GFS forecast from the 12 February 2024 forecast.

Some cold for the Eastern US and Scandinavia but main action is looking to be in East Asia (see **Figure 9**). Could eventually turn colder for Northern Europe and then the Eastern US but still lots of certainty due to second large polar vortex disruption in two months.

Impacts

Still, lots of questions this week but hopefully more clarity. I certainly feel confident that this week into next week. This week the predicted blocking/ ridging in the Barents-Kara Seas and getting close to the Urals with troughing downstream in the northern North Pacific and even upstream in the northern North Atlantic (see **Figure 2**) will support Wave Activity Flux (WAF) in the vertical direction over Eurasia and into the North Pacific (see **Figure i**). And looking at the WAF in the zonal and vertical directions we can see the iconic signature wave reflection predicted for this week with upward and eastward WAF vectors over Asia, that then bounces or boomerangs off the PV and then is downward and eastward over North America (see **Figure i**). And unlike what I showed last week we can also observe an eastward tilting over North America, which is another signature of wave reflection and supportive of downward WAF over North America that deepens the trough over North America. And looking at the forecast this week for the Polar Vortex (PV), again in my opinion fairly classical PV stretching with the PV center over the Barents Sea coupled with high pressure ridging centered on the Dateline and extending into Alaska and Eastern Siberia (see **Figure 13a**). This stretches the PV along an axis from Western Siberia to Eastern Canada. This brings the colder air back to Canada and the US east of the Rockies (see **Figure 3**). And to my chagrin (but happy for all snow lovers) to resulting in the biggest snowstorm in Southern New England in two years (while I am plotzing in Miami Beach this week for family obligations).

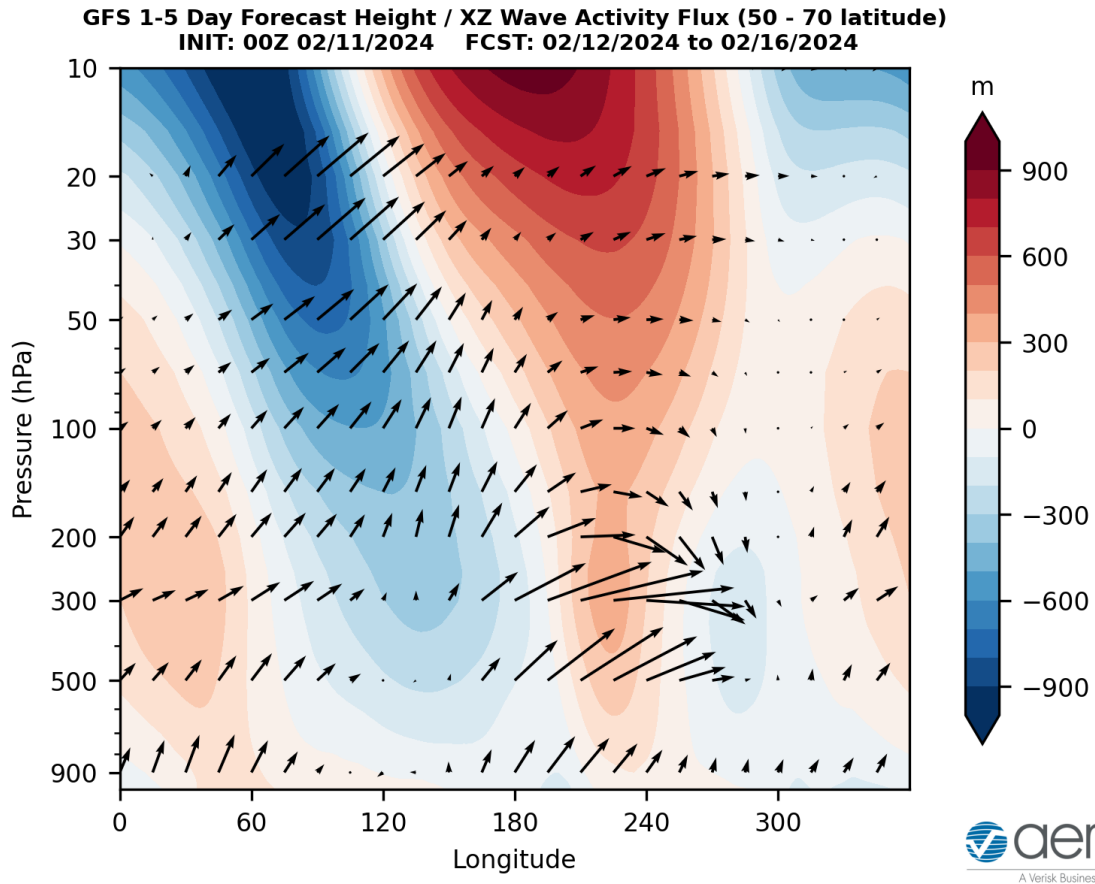


Figure i. Longitude-height cross section of geopotential eddy height anomalies (shading) and wave activity flux (vectors) averaged from 12 – 16 February 2024. The forecasts are from the 00z 11 February 2024 GFS ensemble.

But then the upward WAF continues over Eurasia but any signs of wave reflection disappears and therefore more of the WAF is absorbed in the polar stratosphere. This leads to a larger PV disruption more akin to a sudden stratospheric warming (SSW) and possibly a major SSW (a reversal in the zonal mean zonal wind at 60°N and 10hpa from westerly to easterly/from positive to negative). Disruption of the PV and warming of the polar stratosphere continue but the shape of the PV becomes more contorted, the PV drifts further south over Scandinavia and gone is the strong cross polar flow from Siberia to Canada (see **Figure 13b**).

Given the increasing likelihood of an SSW and even a major SSW in the coming two weeks, I think that it is appropriate to revisit what I wrote in the blog earlier this winter. I described the six step troposphere stratosphere coupling in the [4 Dec 2023](#) blog forced from Arctic boundary conditions where above normal snow cover/depth and below normal sea ice in the Barents-Kara Seas favor a weaker PV including SSWs. As I have been showing with ERA5 plots snowfall is above normal in Siberia (see **Figure ii**) and as you can see in **Figure 16**, the biggest negative anomalies in Arctic sea ice extent are currently in the Barents-Kara Seas. Then in the [18 Dec](#)

2023 blog, I shortened it to a three step process or model, a tropospheric precursor, the PV disruption/SSW and the tropospheric response, i.e, T-S-T coupling event.

ERA5 Cumulative Snowfall Anomaly Nov 2023 - Jan 2024

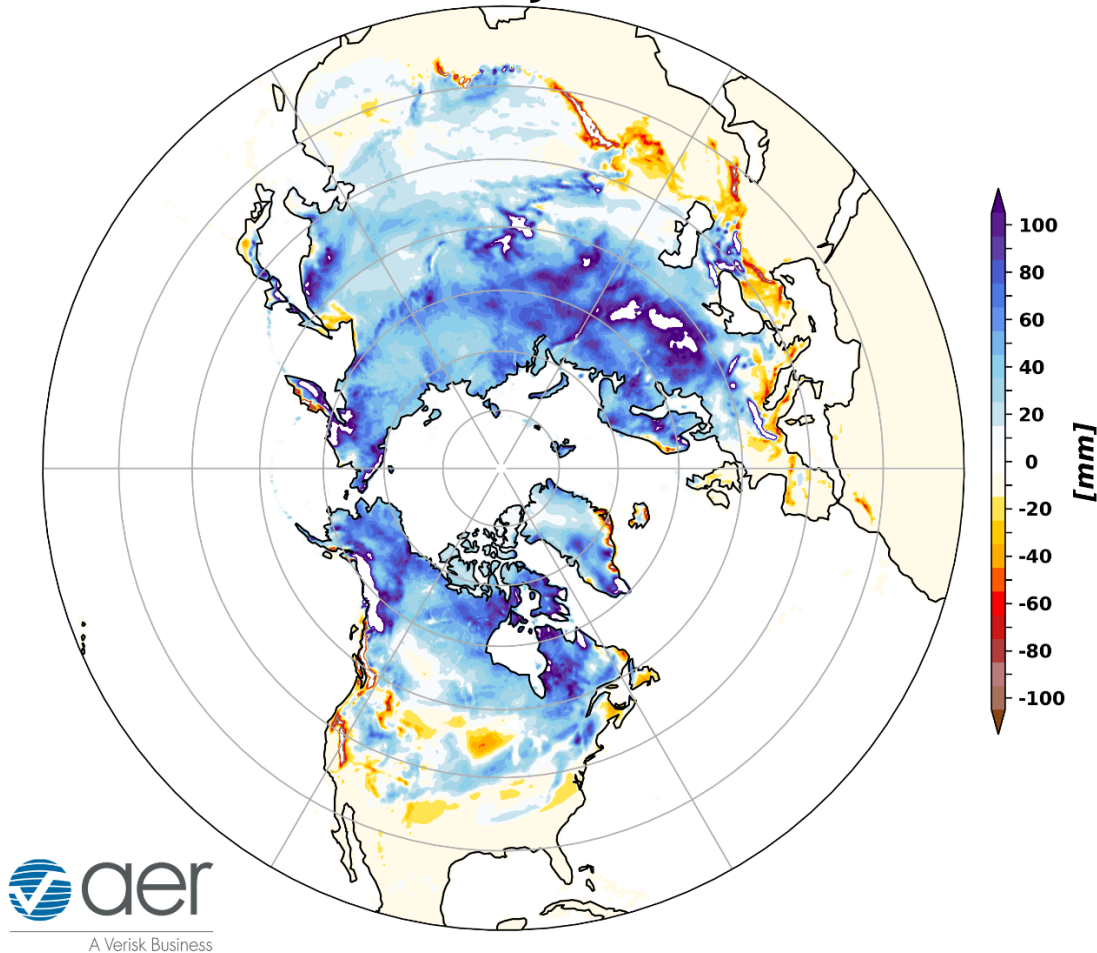


Figure ii. Snowfall anomalies since 1 November 2023 across the Northern Hemisphere based on ERA5 reanalysis.

I show the seasonal polar cap geopotential height anomalies (PCHs) in **Figure iii**. I also include the six steps for both January and now February. What is not shown is step 1, which is the above normal snow cover and/or below normal Barents-Kara seas ice anomalies. Though previous PCH forecast plots seemed a bit of a mess blurring steps 1-5 in one big red blotch I think the models are better resolving the individual steps. Lots of uncertainty with the SSW itself and the tropospheric response including the timing. But it does seem to be starting a composite of previous events. East Asia tends to get the cold leading up to the SSW and that is what is now predicted by the models. Northern Europe can be cold close to or soon after the SSW. The PV center is predicted to be over Scandinavia persisting the cold winter in that region but lots of

uncertainty if and how far south it spreads from there. I think the best scenario for a colder solution for Europe is if the PV sinks even further south and easterly flow develops in the polar stratosphere over Northern Europe. This would be helped if the PV splits. Possible but based on model forecasts not the most likely solution.

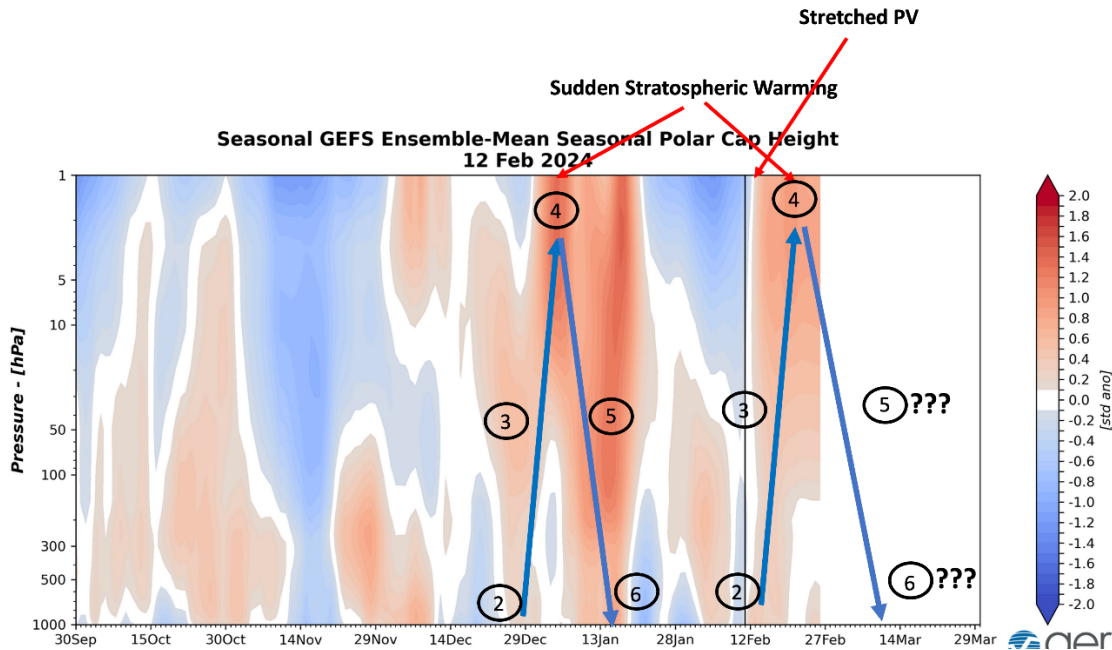


Figure iii. Seasonal and observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. Arrows indicate troposphere-stratosphere-troposphere coupling. Numbers explained in 4 December 2023 blog. The forecast is from the 00Z 12 February 2024 GFS ensemble.

Finally, the Eastern US tends to be mild to very mild during the SSW and only turns colder about two weeks later. Instead, it tends to be colder in western North America initially during and following the SSW. Certainly, looks like the model forecasts are trending in that direction. The longer blocking high pressure can persist across Greenland and/or the Central Arctic that could be a cap on temperatures in the Eastern US. Take those away and the sky is the limit. Until we get the tropospheric response from the SSW, which is currently an open question.

One last wild card is the lobe of the PV predicted over the Eastern US (see **Figure 13b**). Maybe it implies colder weather but date unknown. And let's face it winter is winding down quickly.

Near-Term

This week

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

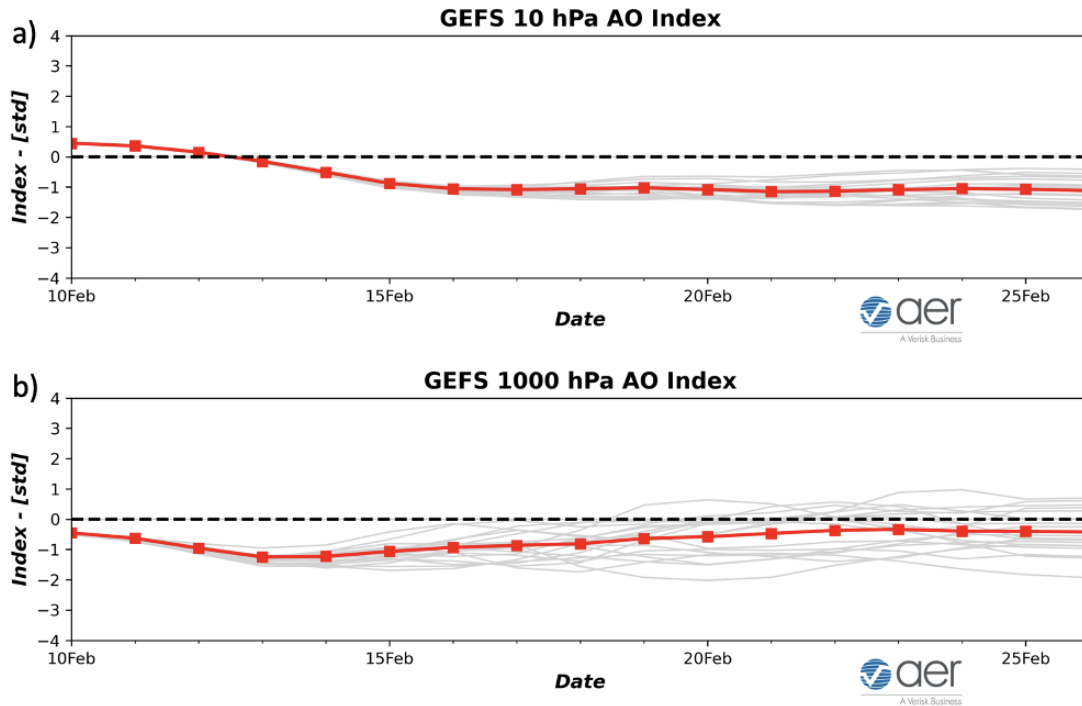


Figure 1. (a) The predicted daily-mean AO at 1000 hPa from the 00Z 11 February 2024 GFS ensemble. (b) The predicted daily-mean near-surface AO from the 00Z 11 February 2024 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

This week, the predicted pattern across Europe is troughing/negative geopotential height anomalies centered over Northern Europe with ridging/positive geopotential height anomalies across Southern Europe this week (**Figures 2**). **This zonal pattern favors widespread normal to above normal temperatures across Europe including the UK with normal to below normal temperatures limited to Scandinavia (Figure 3).** Predicted ridging/positive geopotential height anomalies centered in the Barents-Kara Seas and Urals/Western Russia will deepen troughing/negative geopotential height anomalies across the Siberia with more ridging/positive geopotential height anomalies across Southern Asia this period (**Figure 2**). This pattern favors widespread normal to above normal temperatures across Southern Asia with normal to below normal temperatures across parts of Northwestern Russia and Siberia (**Figure 3**).

GEFS 1-5 Day Forecast 500 hPa Anomaly
INIT: 00Z 02/12/2024 FCST: 02/13/2024 to 02/17/2024

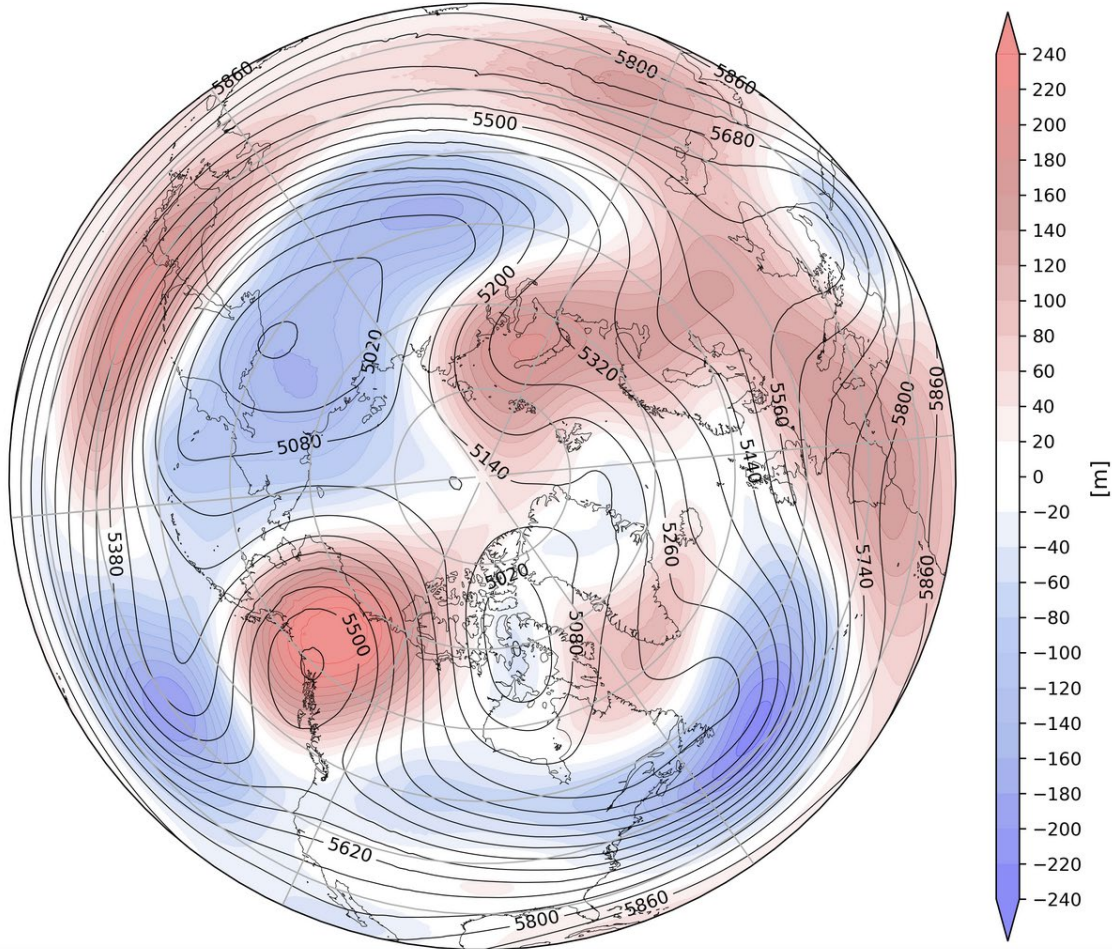


Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 13 – 17 February 2024. The forecasts are from the 00z 12 February 2024 GFS ensemble.

The pattern this week across North America is ridging/positive geopotential height anomalies centered across Alaska and Western Canada forcing troughing/negative geopotential height anomalies across Eastern Canada and the US (**Figure 2**). This pattern will favor normal to above normal temperatures across Alaska, much of Canada and the Eastern US with normal to below normal temperatures across Southwestern Canada and the Western US (**Figure 3**).

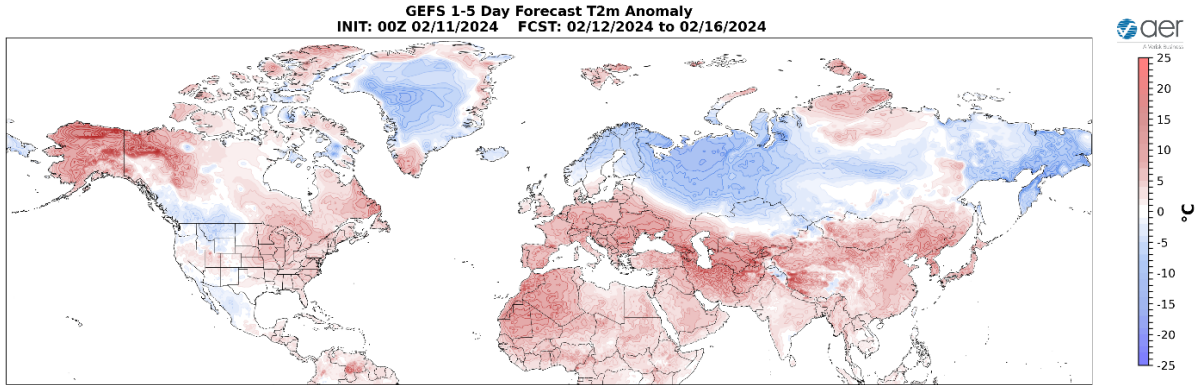


Figure 3. Forecasted surface temperature anomalies (°C; shading) from 13 – 17 February 2024. The forecast is from the 00Z 12 February 2024 GFS ensemble.

Trouching and/or cold temperatures will support new snowfall across parts of Norway, Sweden, Finland, and Southern Siberia while mild temperatures will support snowmelt across the Alps, parts of Eastern Europe, Western Russia and Southern Siberia this week (**Figure 4**). Trouching and/or cold temperatures will support new snowfall across Eastern Canada the US Northern Plains and the Northeastern US including Boston while mild temperatures will support snowmelt across Alaska, Western Canada and the US Rockies this week (**Figure 4**).

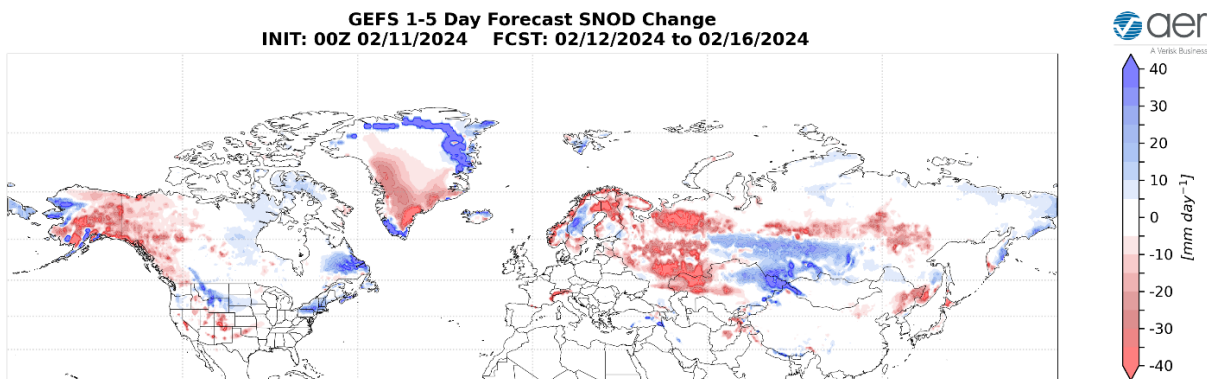


Figure 4. Forecasted snow depth changes (mm/day; shading) from 12 – 16 February 2024. The forecast is from the 00Z 11 February 2024 GFS ensemble.

Near-Mid Term

Next week

With geopotential height anomalies becoming increasingly positive across the Arctic and with mixed geopotential height anomalies across the mid-latitudes this period (**Figure 5**), the AO will become more negative 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.

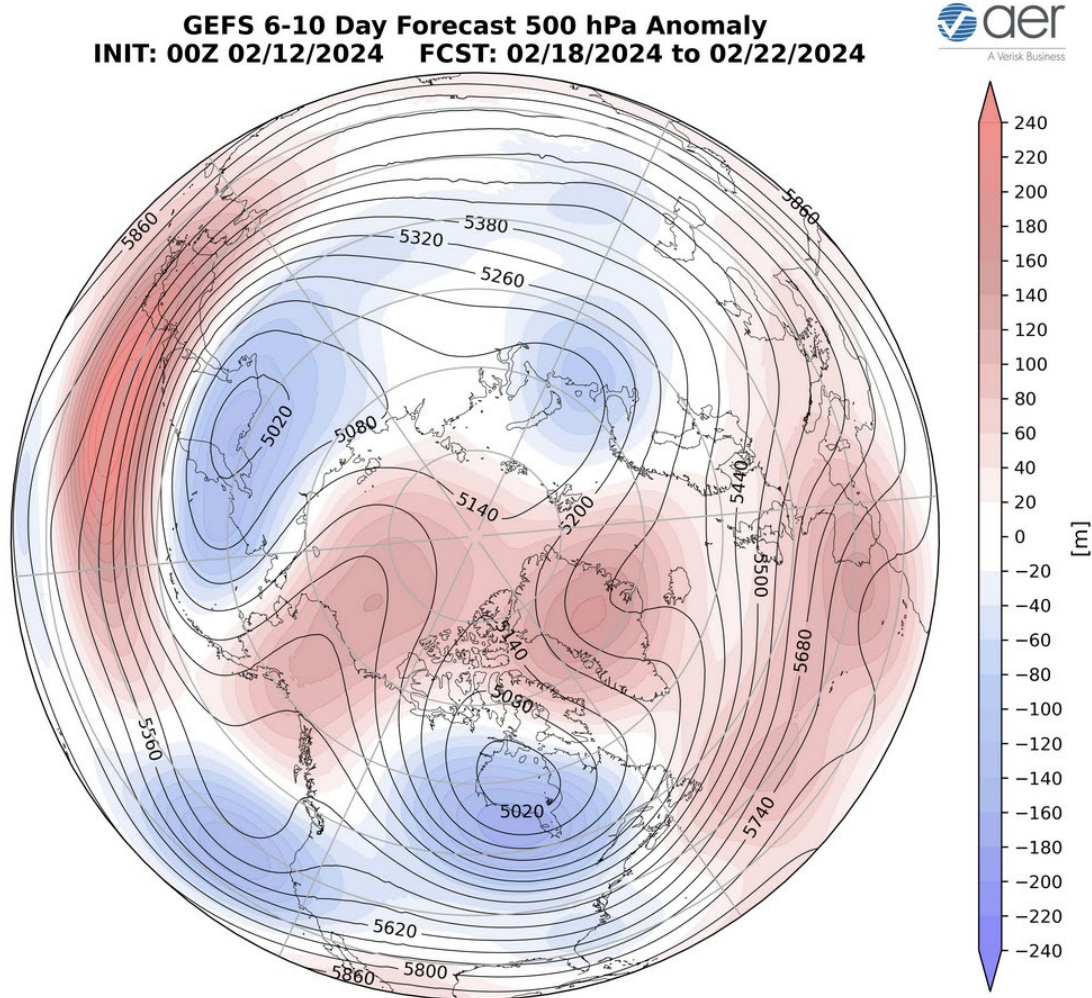


Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 18 – 22 February 2024. The forecasts are from the 00z 12 February 2024 GFS ensemble.

Increasing ridging/positive geopotential height anomalies across Greenland will support deepening troughing/negative geopotential height anomalies across Europe with ridging/positive geopotential height anomalies retreating into Southwestern Europe this period (**Figure 5**). This pattern will favor widespread normal to above normal temperatures across much of Europe including the UK with normal to below normal temperatures spreading across all of Scandinavia and into the Baltics (**Figures 6**). Predicted spreading ridging/positive geopotential height anomalies across the Arctic and persisting over the Urals will support deepening troughing/negative geopotential height anomalies across Siberia and now spreading into Central Asia with more ridging/positive geopotential height anomalies across

Southern and Eastern Asia this period (**Figure 5**). This pattern favors widespread normal to above normal temperatures across Southern and Eastern Asia with normal to below normal temperatures spreading out across Siberia and into Central Asia this period (**Figure 6**).

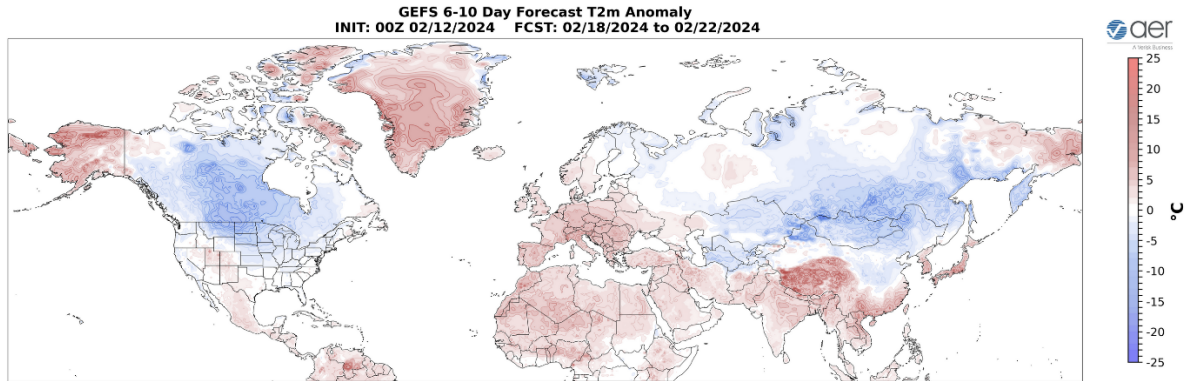


Figure 6. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 18 – 22 February 2024. The forecasts are from the 00z 12 February 2024 GFS ensemble.

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

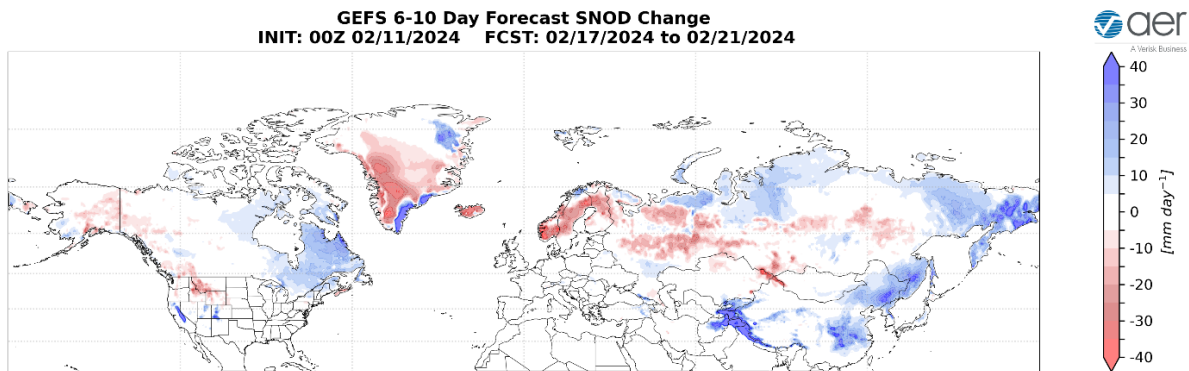


Figure 7. Forecasted snow depth changes (mm/day ; shading) from 17 – 21 February 2024. The forecast is from the 00Z 11 February 2024 GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across Siberia, the Tibetan Plateau and East Asia while mild temperatures will support snowmelt in Scandinavia, Western Russia, and parts of Siberia and Central Asia this period (**Figure 7**). Troughing and/or cold

temperatures will support new snowfall in Eastern Canada and the Southwestern US while mild temperatures will support snowmelt in across eastern Alaska, Western Canada and the Northwestern US this period (**Figure 7**).

Mid Term

Week Two

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

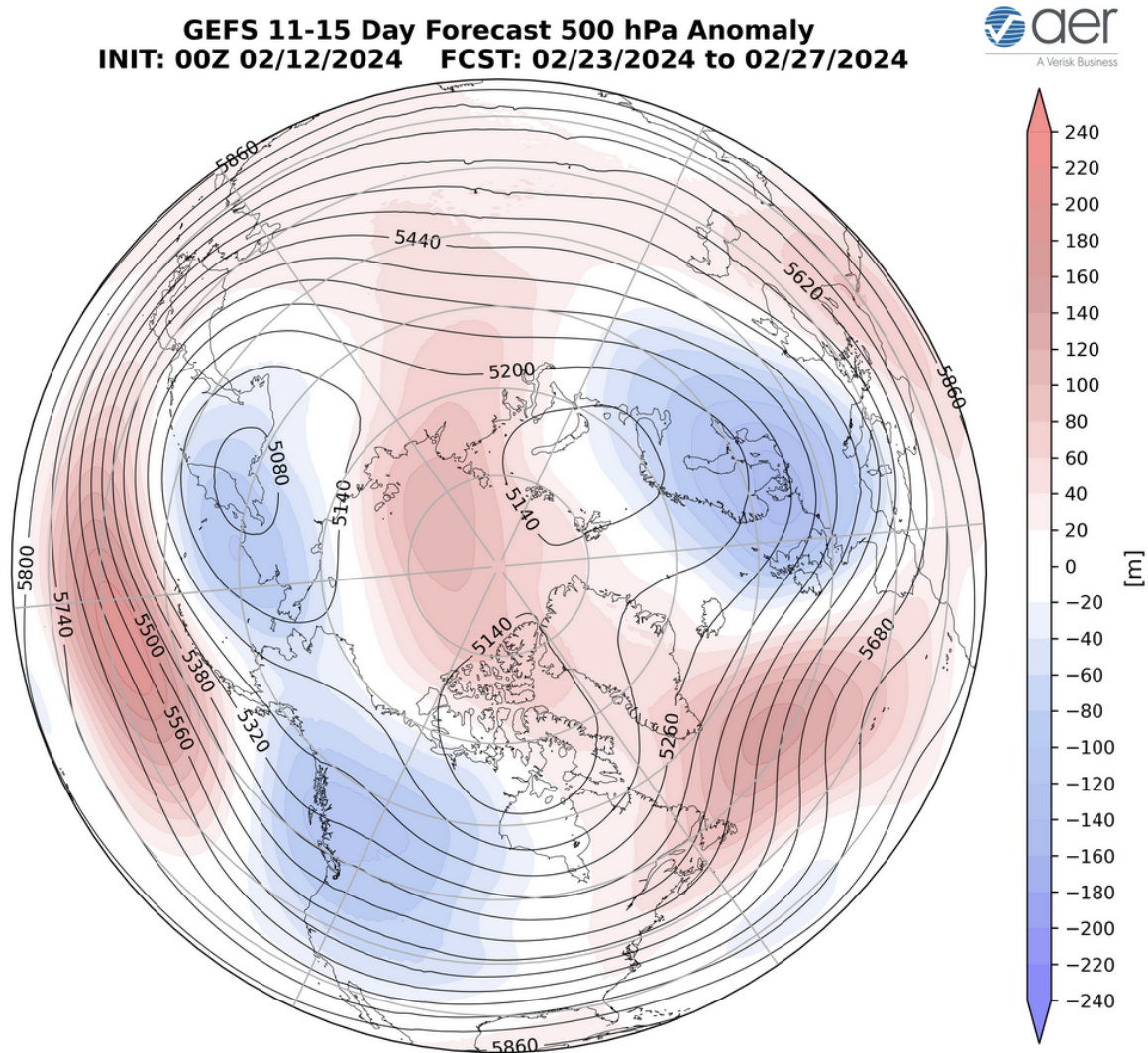


Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 23 – 27 February 2024. The forecasts are from the 00z 12 February 2024 GFS ensemble.

Persistent ridging/positive geopotential height anomalies across Greenland will continue to support deepening troughing/negative geopotential height anomalies across Europe with ridging/positive geopotential height anomalies mostly limited to across Mediterranean Europe this period (**Figure 8**). This pattern should favor normal to below normal temperatures to spread across Northern Europe including the UK with normal to above normal temperatures across Central and Southern Europe this period (**Figures 9**). Persistent ridging/positive geopotential height anomalies across the Arctic and Greenland will support troughing/negative geopotential height anomalies across Siberia and East Asia with more ridging/positive geopotential height anomalies across Southern Asia this period (**Figure 8**). The predicted pattern favors widespread normal to above normal temperatures across Southern and Central Asia with normal to below normal across Northern and Eastern Asia this period (**Figure 9**).

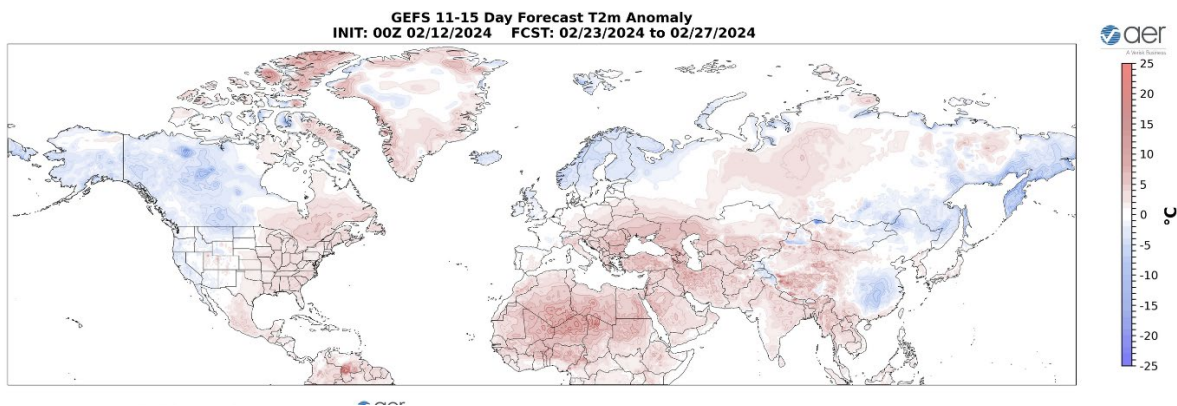


Figure 9. Forecasted surface temperature anomalies (°C; shading) from 23 – 27 February 2024. The forecasts are from the 00z 12 February 2024 GFS ensemble.

With ridging/positive geopotential height anomalies peeling away from Alaska into the Arctic and Greenland are predicted to support widespread but weak troughing/negative geopotential height anomalies across much of North America this period (**Figure 8**). This pattern favors normal to above normal temperatures across parts of Alaska, Eastern Canada and the Central US with normal to below normal temperatures across Western Canada and the Eastern this period (**Figure 9**).

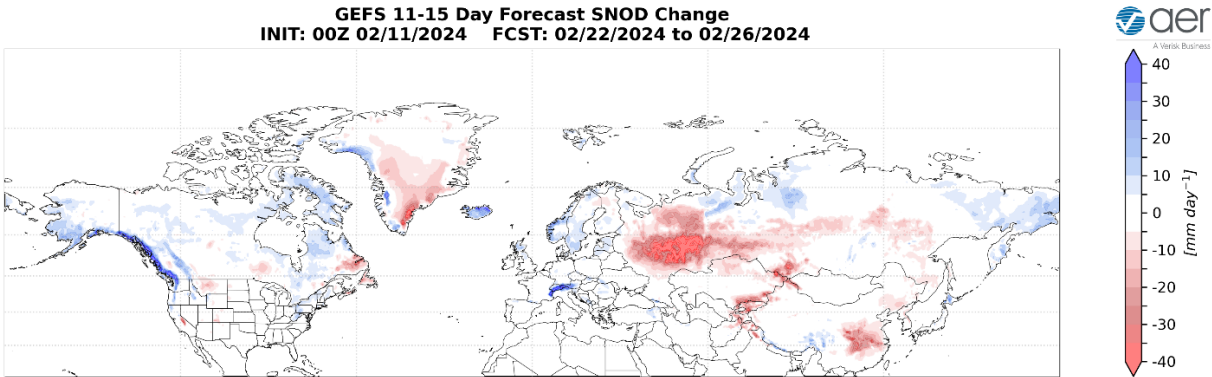


Figure 10. Forecasted snow depth changes (mm/day; shading) from 22 – 26 February 2024. The forecast is from the 00Z 11 February 2024 GFS ensemble.

Trouging and/or cold temperatures will support new snowfall across the Tibetan Plateau, Siberia and Northeast Asia while mild temperatures will support snowmelt in Scandinavia this period (**Figure 10**). Trouging and/or cold temperatures will support new snowfall across California, Eastern Canada and the Northeastern US. Mild temperatures will support snowmelt in Southern Alaska, the West Coast of Canada and the US Rockies this period (**Figure 10**).

Longer Term

30-day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows cold/negative PCHs throughout the troposphere and stratosphere (**Figure 11**). However, for much of the next two weeks warm/positive PCHs will dominate both the stratosphere (**Figure 11**). The increasing warm/positive throughout the stratosphere (**Figure 11**) is related to the PV becoming increasingly disrupted while warming/positive PCHs in the troposphere are associated with increasing high latitude blocking.

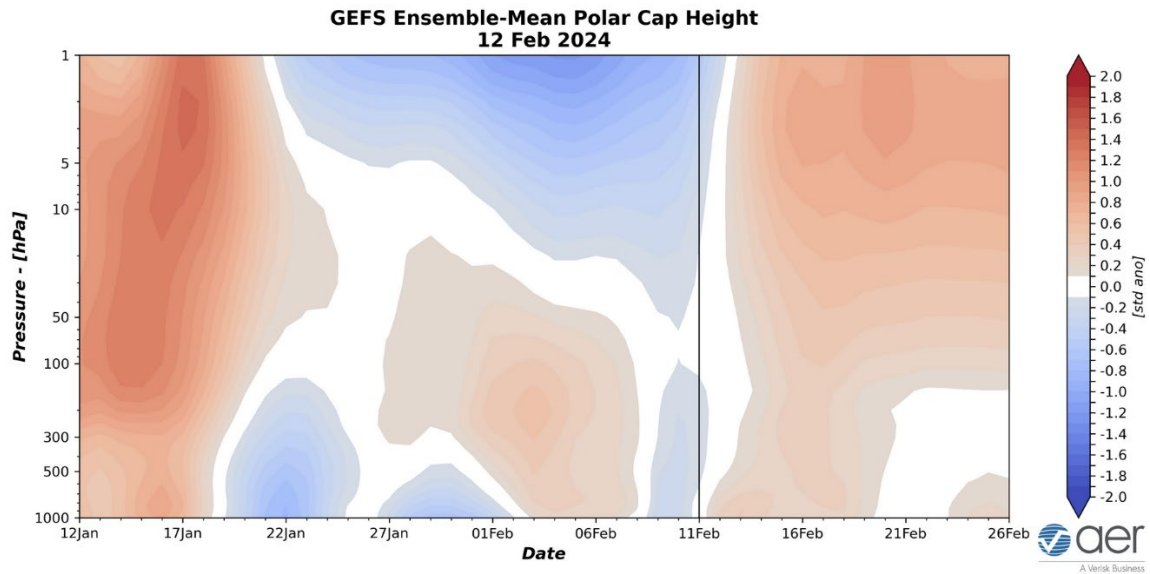


Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 12 February 2024 GFS ensemble.

The predicted warm/positive PCHs in the lower troposphere for most of the next two weeks (**Figure 11**) are consistent with the predicted negative surface AO the next two weeks (**Figure 1**).

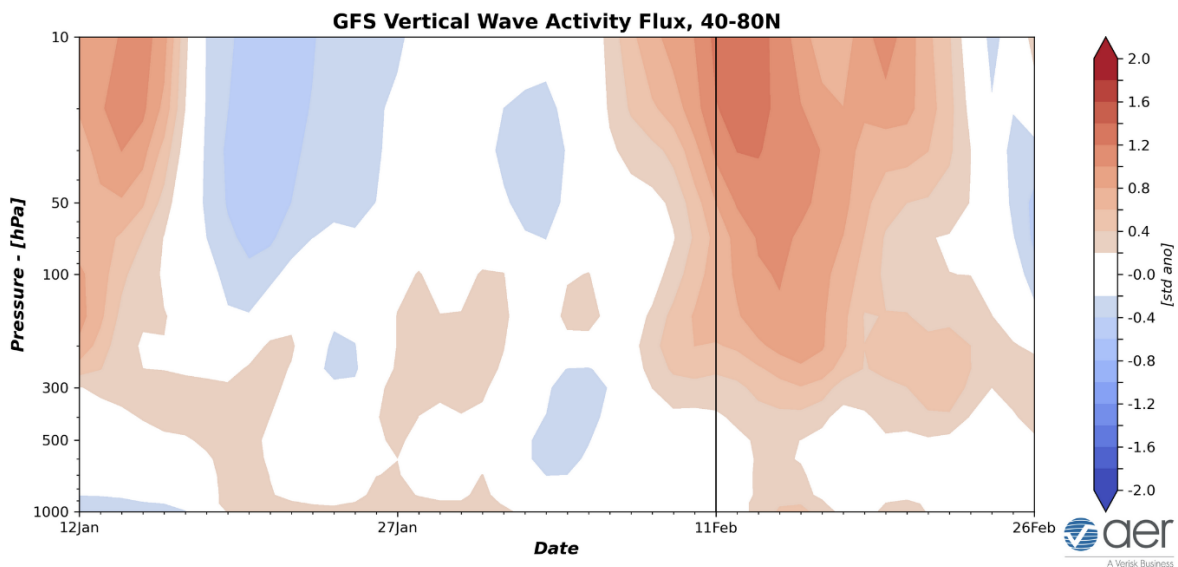


Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of $40\text{-}80^{\circ}\text{N}$. The forecast is from the 00Z 12 February 2024 GFS ensemble.

Also shown in **Figure 1** is the stratospheric AO. The stratospheric AO is currently slightly positive but is predicted to trend towards neutral and then negative for mid- to late-February. This is consistent with increasingly warm/positive stratospheric PCHs in the mid-stratosphere. The forecast of warming PCHs in the stratosphere signals a weakening PV.

Vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere has been relatively quiet since mid-January (**Figure 12**). However the quieter WAFz ended last week and is predicted to be much more active this week (**Figure 12**). This should result in a weakening PV. The strongest pulse of WAFz is predicted for this week and could potentially result in a major SSW.

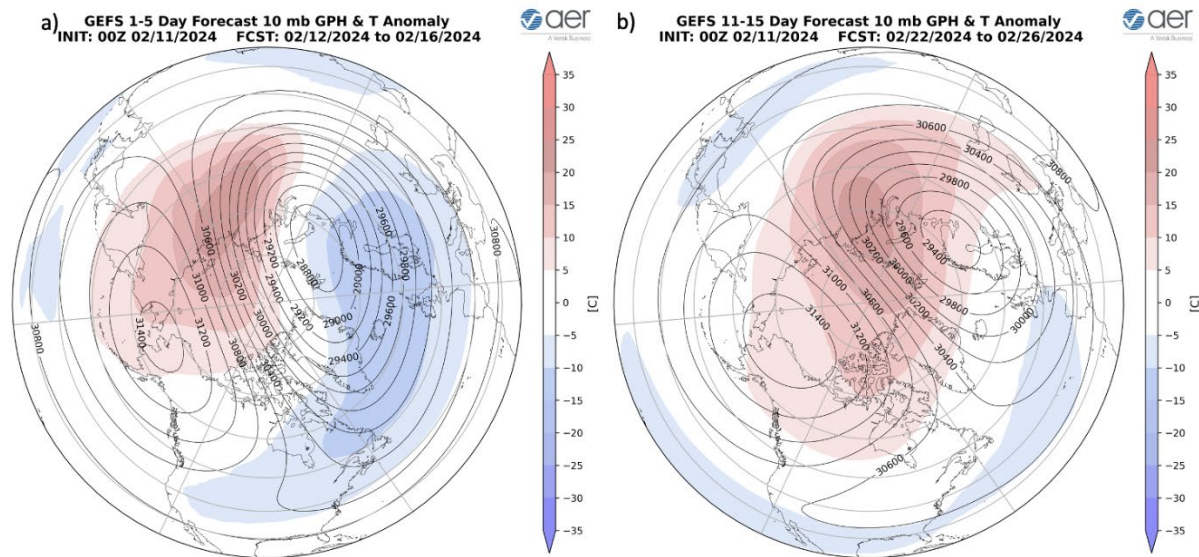


Figure 13. (a) Forecasted 10 mb geopotential heights (dam; contours) and temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere from 12 – 16 February 2024 . (b) Same as (a) except forecasted averaged from 22 – 26 February 2024. The forecasts are from the 00Z 11 February 2024 GFS model ensemble.

This week the polar vortex (PV) is predicted to be shifted south of the North Pole centered over the Barents-Kara Seas with an elongated shape from Western Siberia to Eastern Canada (**Figure 13a**), reminiscent of a stretched PV. The ridging and warming in the polar stratosphere are predicted to become much more pronounced centered over the Dateline Alaska with the greatest warming over the entire Western Arctic. It does appear that the stretched PV event will quickly transition to a larger disruption more consistent with an SSW. For the fourth week of February the PV center is predicted to drift even further south over Scandinavia and the configuration to become more distorted (**Figure 13b**).

**CFS 500 hPa Forecast Anomaly Mar 2024
Valid as of 11 Feb 2024**

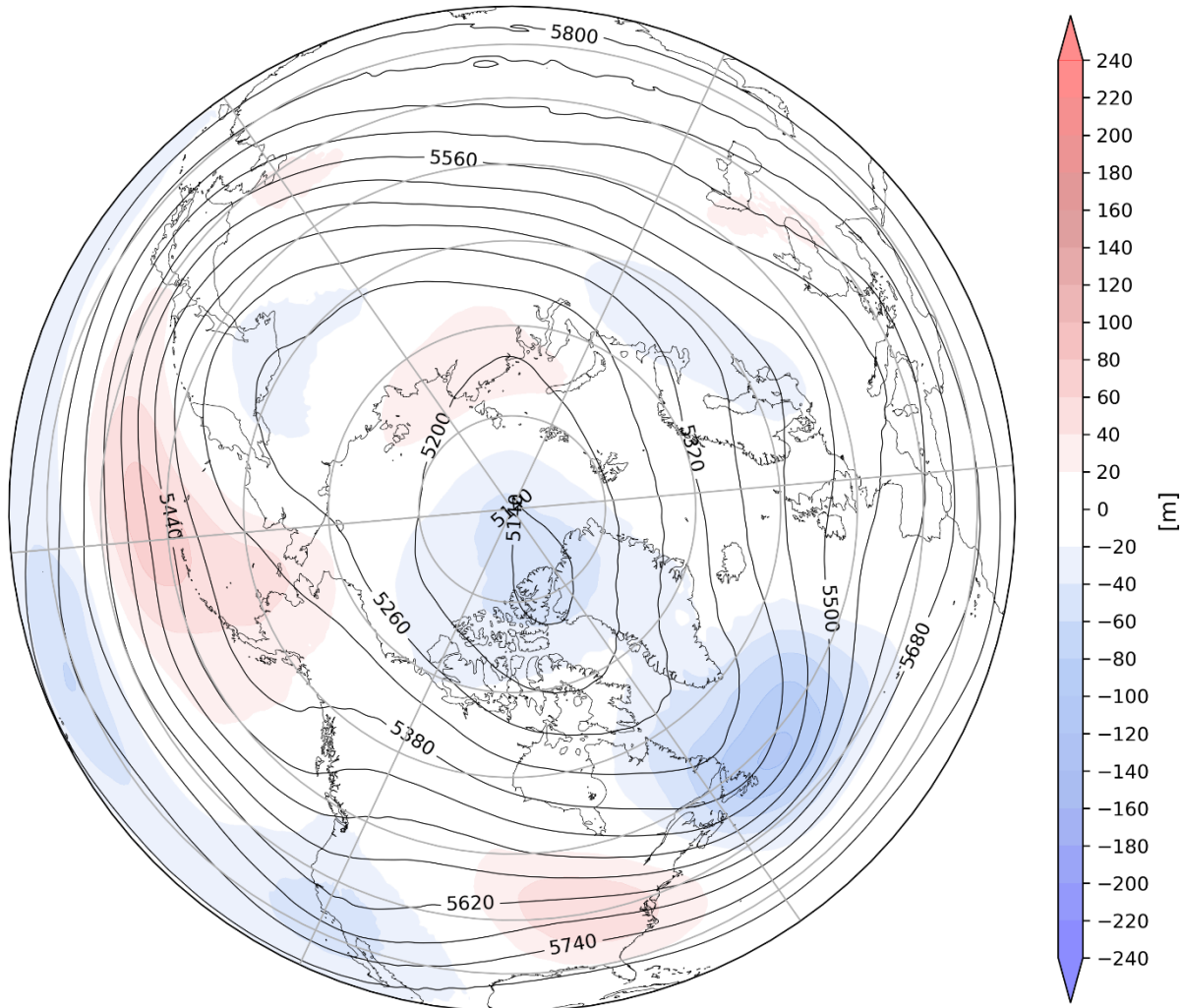


Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for March 2024. The forecasts are from the 00Z 11 February 2024 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and surface temperatures for March (**Figure 15**) from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging centered near Dateline, Alaska and Western Canada with troughing in Northern Europe, Siberia, Northeast Asia, the Southwestern US, Eastern Canada and the Northeastern US (**Figure 14**). This pattern favors seasonable to relatively warm temperatures across Southern Europe, Southern Asia, Eastern Siberia, Alaska, Western Canada and the Northwestern US with seasonable to relatively cold temperatures across Northern Europe, Siberia, Northeast Asia Eastern Canada, the Southwestern US and the Eastern US (**Figure 15**).

CFS 18-48 Day Forecast T2m Anomaly
INIT: 00Z 02/11/2024 FCST: 02/29/2024 to 03/30/2024

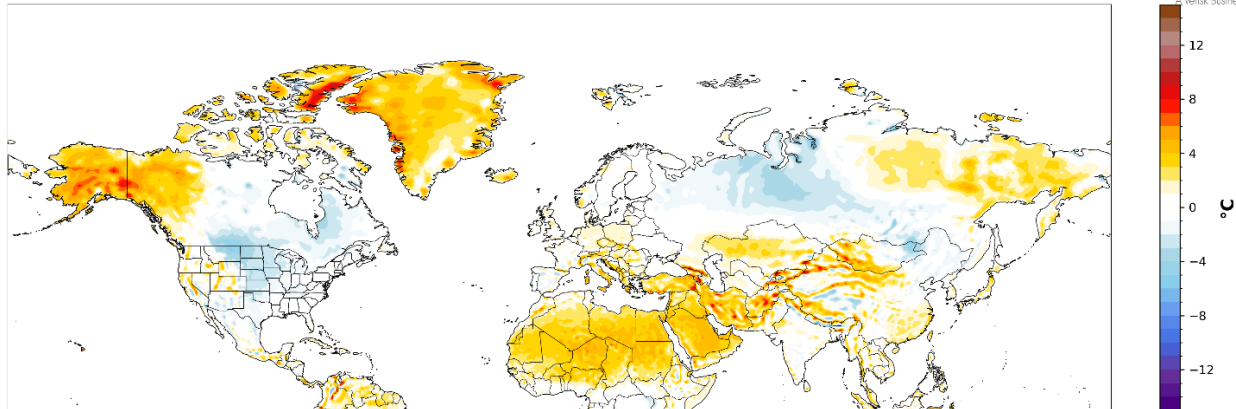


Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for March 2024. The forecasts are from the 00Z 11 February 2024 CFS.

Arctic sea ice extent

Arctic sea ice extent grew very little this week, unusual for February and likely related to incredible warmth in the Arctic 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.

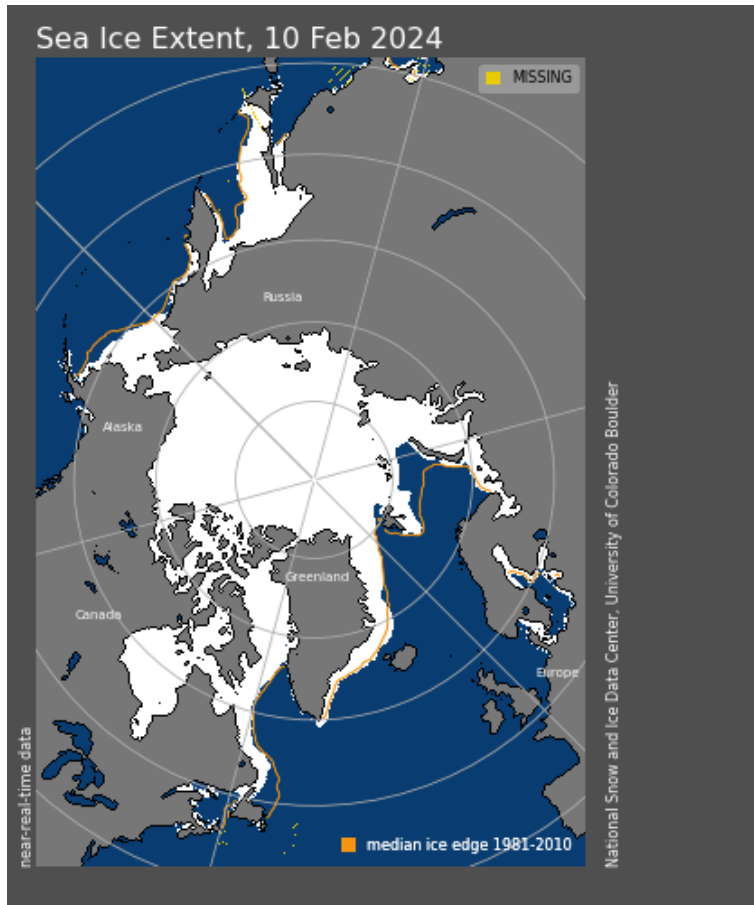


Figure 16. Observed Arctic sea ice extent on 11 February 2024 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image courtesy of National Snow and Ice Data Center (NSIDC). Snow and Ice Data Center (NSIDC).

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.

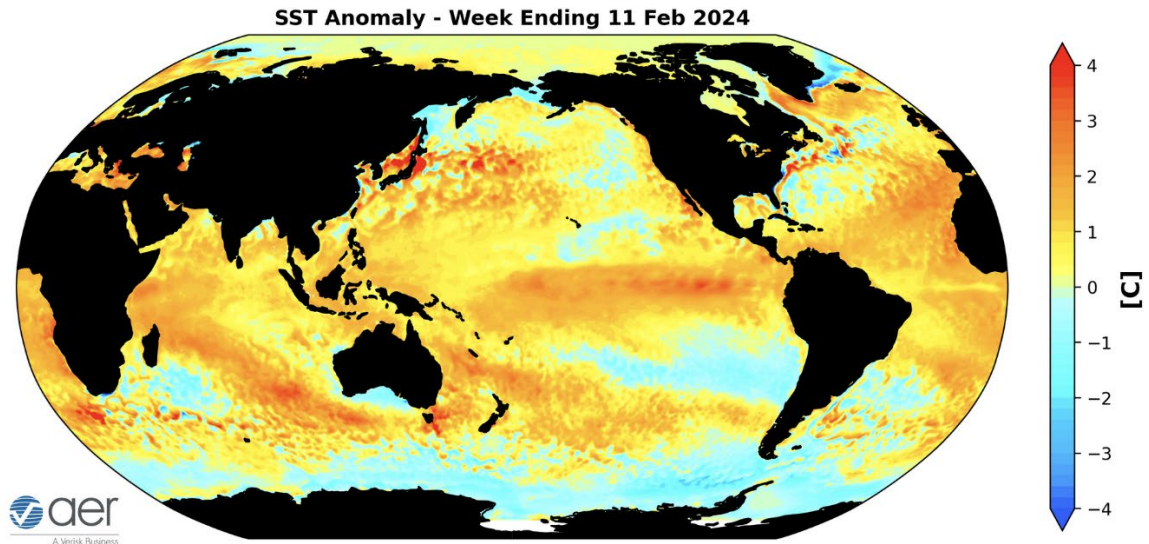


Figure 17. The latest weekly-mean global SST anomalies (ending 11 February 2024). Data from NOAA OI High-Resolution dataset.

Madden Julian Oscillation

Currently the Madden Julian Oscillation (MJO) is in phase seven (**Figure 18**). The forecasts are for the MJO to stall in phase seven and then weaken to where no phase is favored. Phase seven favors troughing near the Aleutians, ridging across Canada forcing troughing across the US. Therefore it seems that the MJO may be having some influence on the weather across North America weather this week and next week. But admittedly this is outside of my expertise.

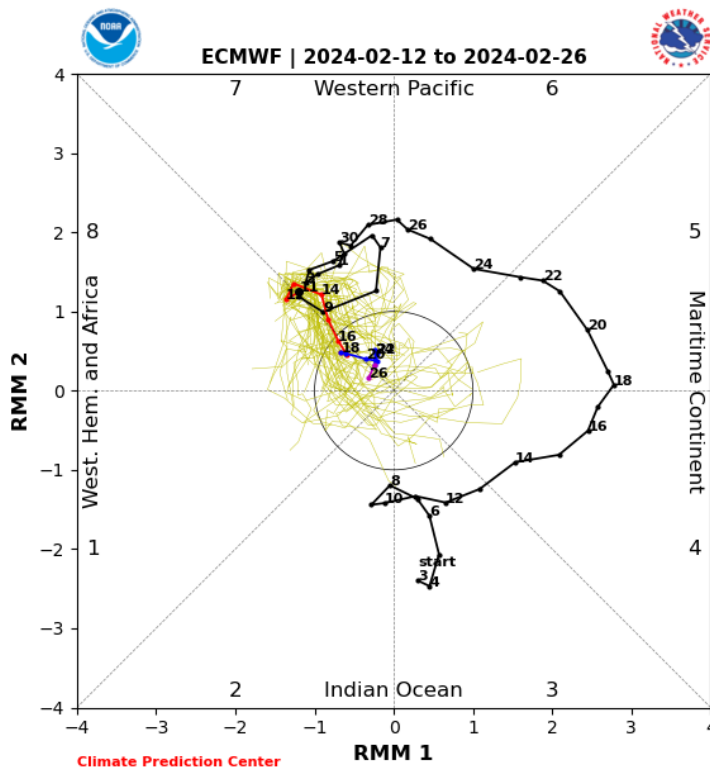


Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 5 February 2024 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model “spread” is denoted by the gray shading. Sector numbers indicate 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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