

# Arctic Oscillation and Polar Vortex Analysis and Forecasts

March 11, 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 fairly close to neutral the next two weeks as pressure/geopotential height anomalies across the Arctic are currently mixed to positive and are predicted to remain mixed to slightly positive over the next two weeks. The North Atlantic Oscillation (NAO) is currently negative with positive pressure/geopotential height anomalies across Greenland and the NAO is predicted to remain close to neutral the next two weeks as pressure/geopotential height anomalies turn more mixed across Greenland.
- Troughing/negative geopotential height anomalies south of Iceland will support air ridging/positive geopotential height anomalies across much of Europe with the exception of troughing/negative geopotential height anomalies across Scandinavia the next two weeks. This 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 the next two weeks.

- The general predicted pattern across Asia the next two weeks is troughing/negative geopotential height anomalies across the Urals and Northern Asia with ridging/positive geopotential height anomalies dominating much of the rest of Asia. This pattern favors widespread normal to above normal temperatures across much of Asia with the exception of normal to below normal temperatures across the Urals and Northern Siberia the next two weeks.
- The predicted pattern general pattern across North America the next two weeks is strengthening ridging/positive geopotential height anomalies centered over Alaska and the Gulf of Alaska forcing deepening troughing/negative geopotential height anomalies across Eastern Canada and the Eastern United States (US) with more ridging/positive geopotential height anomalies along the US East Coast. This pattern favors normal to above normal temperatures across Alaska, Western Canada and the Western US and the US East Coast with normal to below normal temperatures beginning in Central Canada and spreading into Eastern Canada and the Central US.
- In the Impacts section I discuss the large disruption of the polar vortex (PV) and the possible impacts to Northern Hemisphere (NH) weather even though we have entered spring.

## Plain Language Summary

In **Figure iii**, I show the observed surface temperature anomalies for December, January and February 2024 with the three different winter forecasts shown back in November 2023. As I describe below looks like a cold sandwich with warm to the north and south. Everyone should make their own impression, but I do think that the AER forecast performed best.

At least the initial impacts from the large polar vortex (PV) disruption are building cold in Canada while most of Europe remains mild (see **Figure 9**). Europe could turn colder if the more traditional impacts occur in very late March but more likely in April.

## Impacts

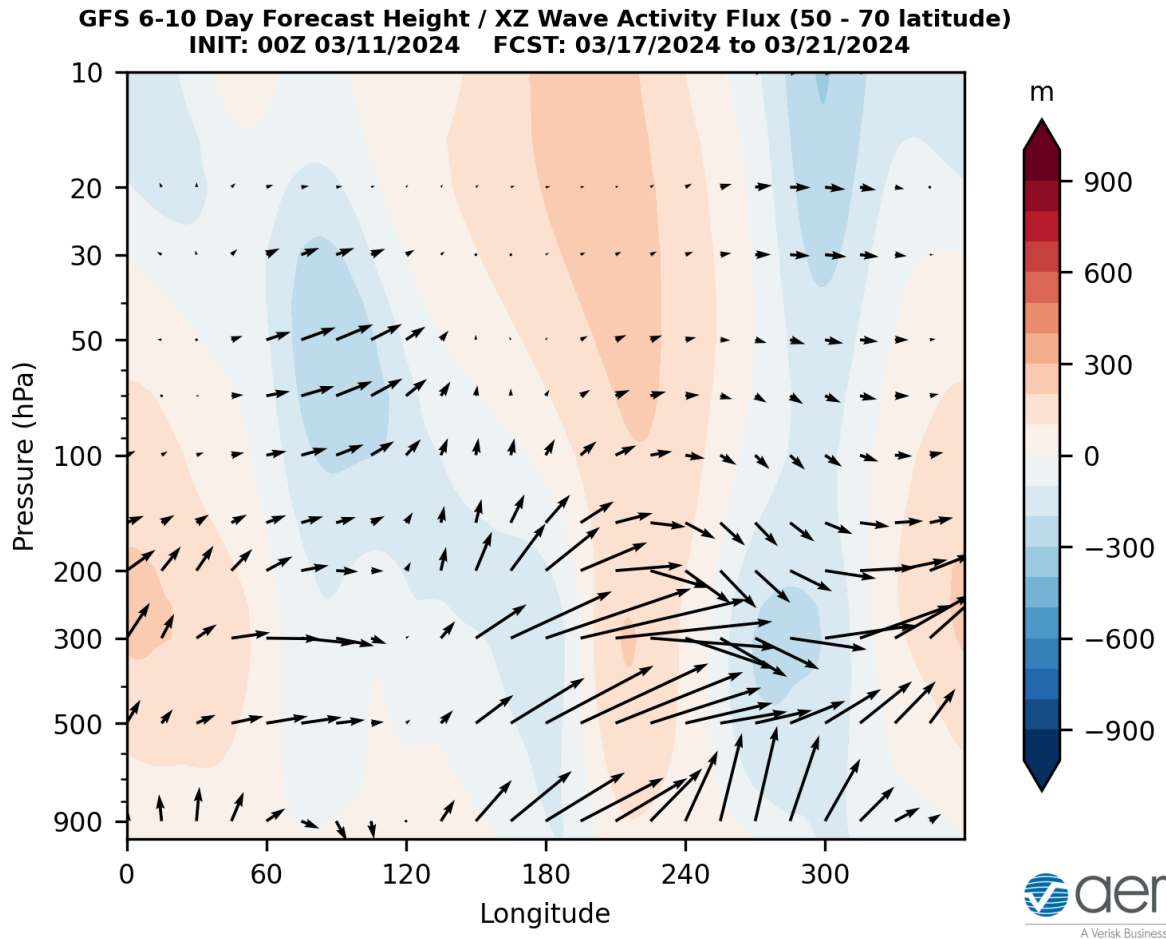
Again, looking at the weather maps and the impressive polar vortex (PV) disruption/ sudden stratospheric warming (SSW), I can't help but think how things could have been different this winter had this occurred in December or January. I do think that the Arctic forcing is better for weak PV in late winter than it was in late Fall and early winter and may have played a role.

Though even if the resultant weather is not that notable or memorable the PV disruption is very interesting. From the latest polar cap geopotential height anomalies (PCHs) forecast maybe the influence of the SSW reaches the troposphere the very last days of March (see **Figure 11**). Yet all the models are in consensus that the pattern will turn colder across North America next week, with potentially widespread and deep cold air pooling across Canada that should enter the Contiguous US Lower 48 to some degree with models disagreeing on the strength of the cold air

in the US. The GFS for now is the most aggressive and maybe the Canadian the least aggressive (unusual for the Canadian).

I don't have much experience with this type of event, where wave reflection precedes the downward influence from the SSW, so this event might be somewhat unusual. February 2021 the wave reflection took place after the downward influence from the SSW. And Kodera the first who discussed these events, it is my impression that he discussed wave reflection as either the main downward influence (e.g., January 2011) or that it followed the more traditional downward influence (Greenland blocking, e.g., March 2003). Please refer to [Kodera et al. \(2013\)](#). I guess if in the end there is no more traditional downward influence such as Greenland blocking then it won't be all that interesting.

At least for today, the wave reflection is showing up nicely in the Wave Activity Flux (WAF) vectors in the vertical and latitudinal direction with upward and eastward WAF over Asia and downward and eastward WAF over North America (see **Figure i**). Also, the trough over North America tilts to the east with height. For me the challenge is, how long does the cold last over North America and is it followed by the more traditional downward influence such as a negative NAO and Greenland blocking? Typically, the influence of wave reflection is on the order of days. Some models predict the cold pattern over North America to be transitory and others more persistent, we shall see.



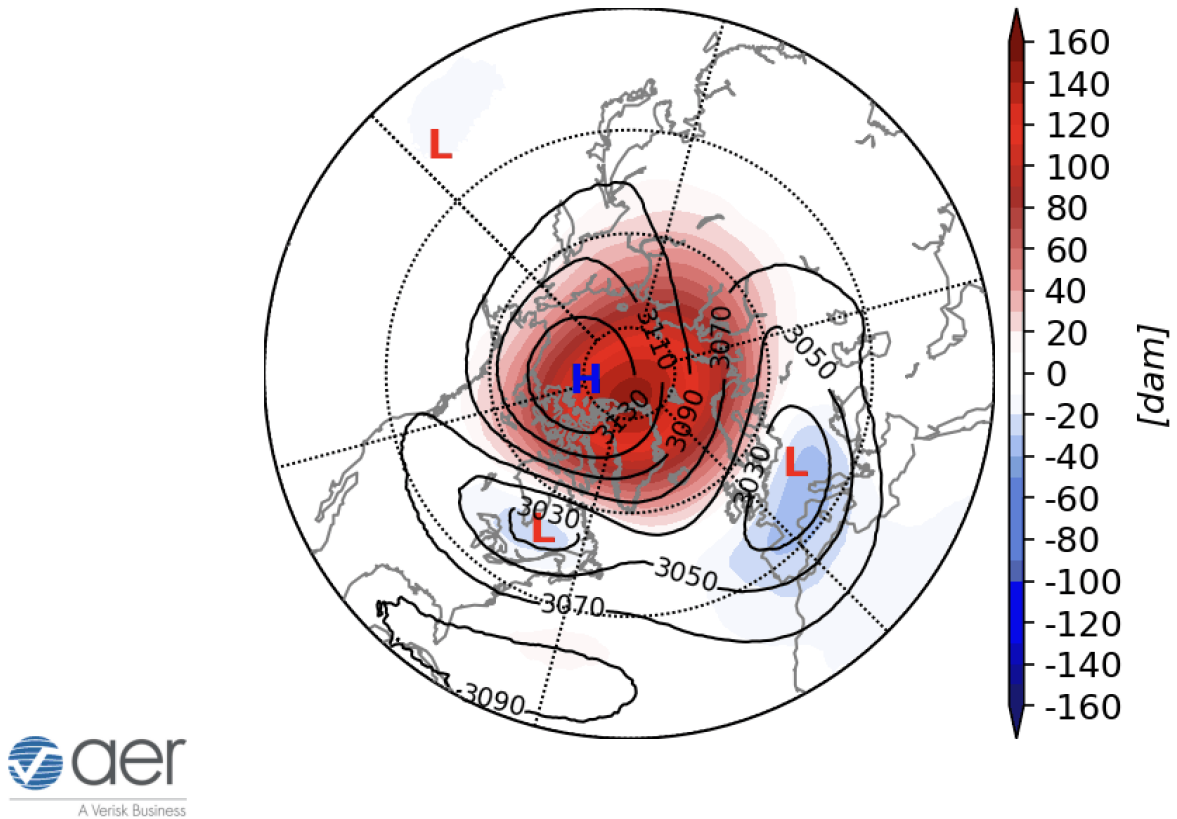
**Figure i.** Longitude-height cross section of geopotential eddy height anomalies (shading) and wave activity flux (vectors) forecasted for 17 – 21 March 2024. The forecasts are from the 00z 11 March 2024 GFS ensemble.

During wave reflection, relative cold occurs in Asia and North America but not typically in Europe and I think that explains the predicted temperature anomalies next week mild (see **Figure 9**). Also at least East Asia tends to colder ahead of an SSW rather than post an SSW, so I would expect the coldest departures to be found in North America rather than East Asia. Though consistent with the trends in recent years, it does look like the cold will have a difficult time moving east and looks to remain focused in the center of the continent.

Most major SSWs are followed by a negative NAO and Greenland blocking. Those odds are further increased when the PV splits rather just becomes displaced (see **Figure ii**), which I believe is the case here. Furthermore, the pattern in the polar stratosphere has such a classical negative NAO (or at least negative AO) look to it (see **Figure 13**), one must believe that the odds of a negative NAO/AO to follow in the troposphere are quite elevated, but we shall see. The models will likely not consolidate around a reliable forecast until the largest PCH positive/warm

anomalies reach the lower stratosphere and based on **Figure 11** that hasn't happened even in two weeks' time. So, we wait and see but the longer the downward influence takes to reach the surface the more of an academic question it becomes as the sun moves closer to full strength across the Northern Hemisphere (NH).

## Forecast 00Z 10 hPa HGT/HGTa 15-Mar-2024

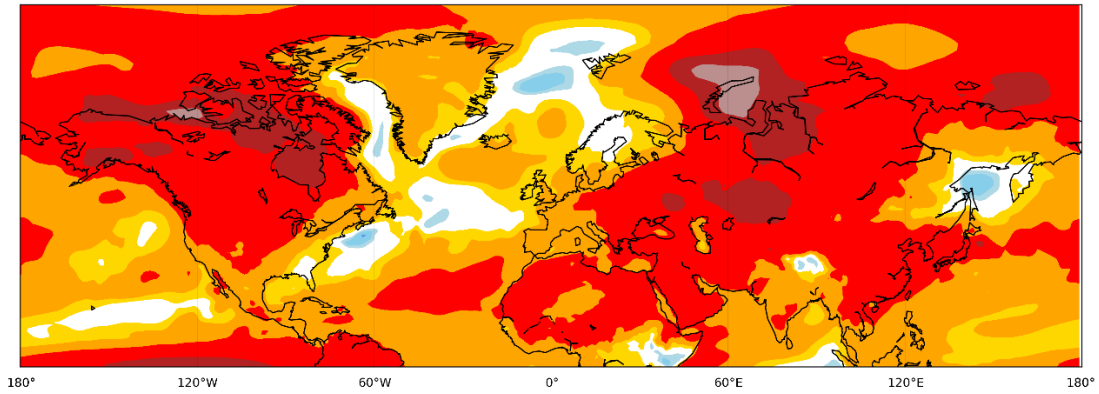


**Figure ii.** Forecasted average 10 mb geopotential heights (dam; contours) and geopotential height anomalies (dam; shading) across the Northern Hemisphere for 15 March 2024. The forecasts are from the 0z 11 March 2024 operational GFS.

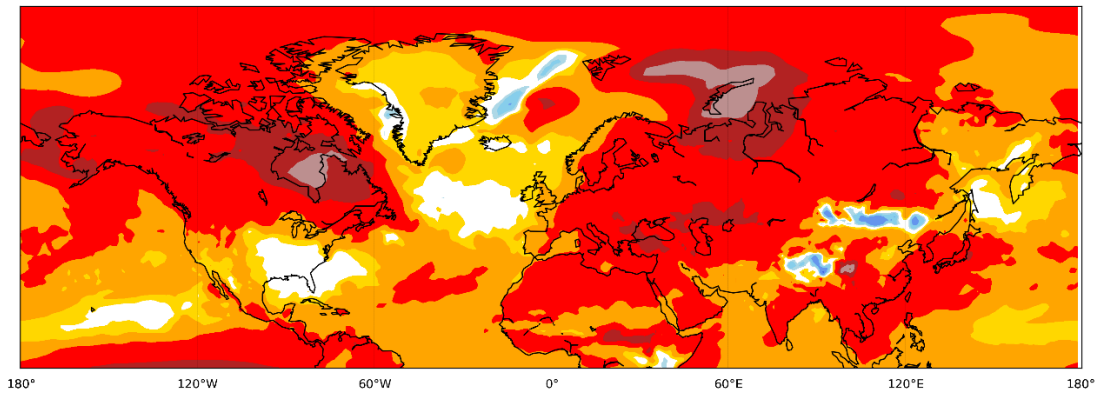
I will just end with the observed temperatures for winter 2023/24 included in the plot of forecasts shown in the blog from [27 November 2023](#). I include the North American Multi Model Ensemble (NMME) winter surface temperature anomaly forecast (top) and the C3S (a European model ensemble) winter forecast (second) and the AER winter forecast (third) and the observed surface temperature anomaly (bottom; see **Figure iii**). The observations are based on the daily initialized analysis used for the GFS. I still think that the AER forecast outperformed the NMME and C3S forecasts, but the different plotting doesn't look as good as what I showed in late February. The NH pattern looks like a cold sandwich with a cold layer

approximately between 60-75°N circling the NH with warm to the north and warm to the south. The AER forecast came closest to matching that pattern but as typical with statistical model forecast, underpredicted the magnitude of the anomalies.

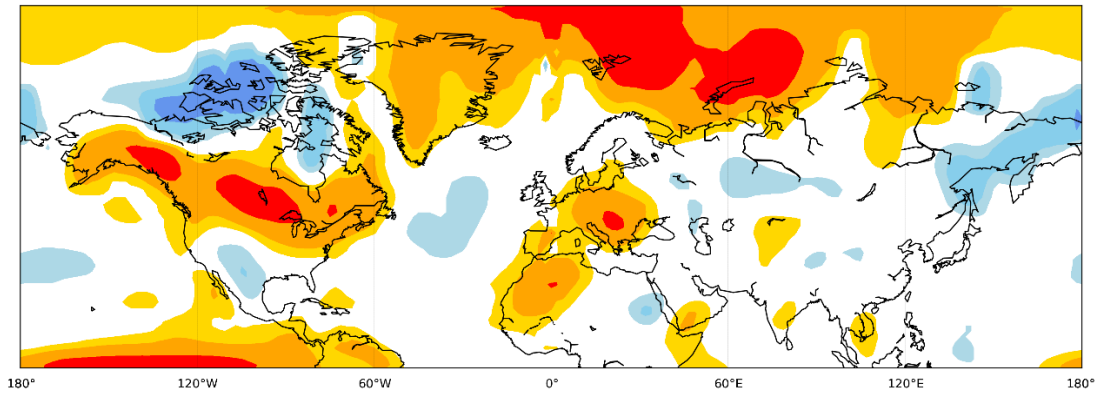
**NMME Ts Forecast for Dec-Feb 2023**



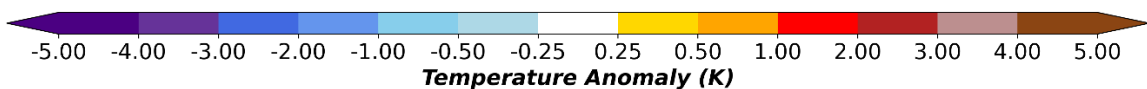
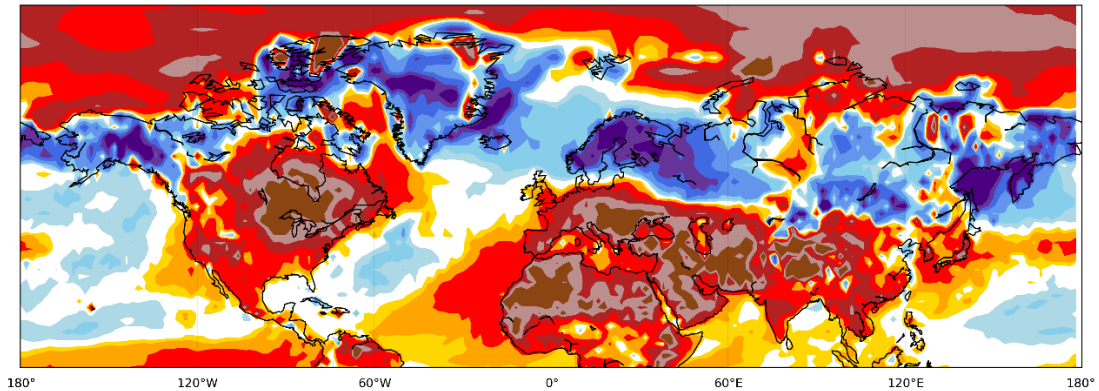
**C3S Ts Forecast for Dec-Feb 2023**



**AER Forecast of Ts for Dec-Feb 2023**



**Observed Ts for Dec-Feb 2023**



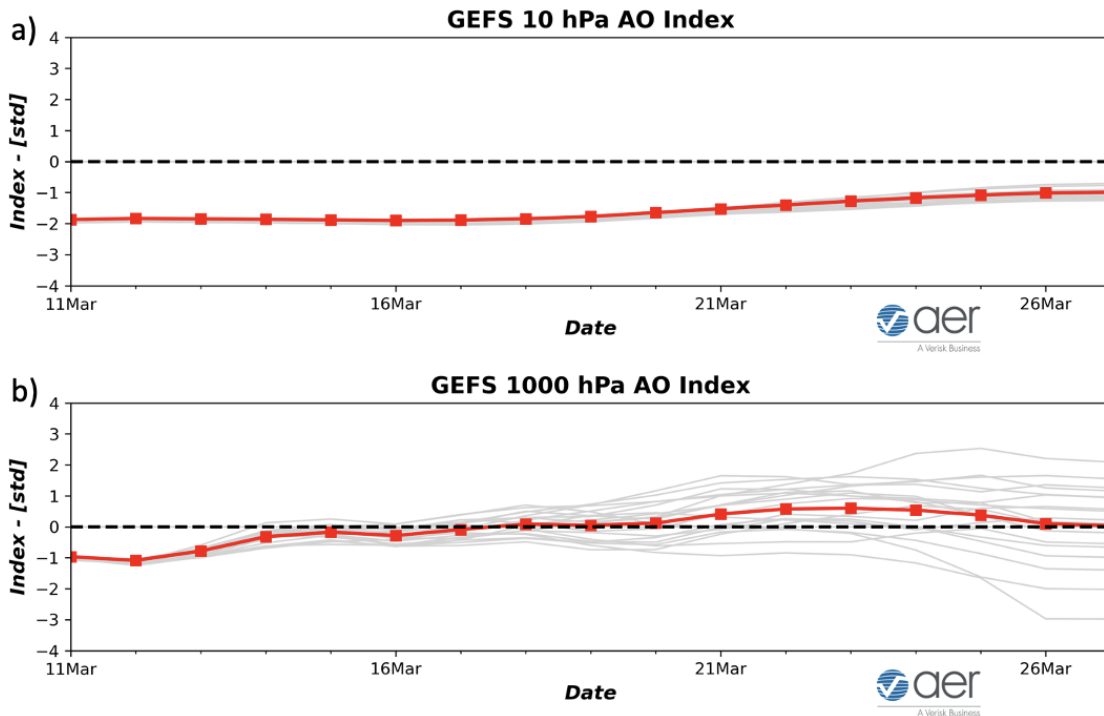
**Figure iii.** The NMME winter temperature anomaly forecast for December, January and February 2024 from <https://www.cpc.ncep.noaa.gov/products/NMME/> (top). The C3S winter temperature anomaly forecast for December, January and February 2022 from <https://www.copernicus.eu/en> (second). c) The AER winter temperature anomaly forecast for December, January and February 2022 third). d) Observed winter surface temperature anomalies for December, January and February 2024 from the GFS analysis.

The region that is most sensitive to PV behavior is Siberia, so I think that at least in regard to my own ideas and forecasting methodology, it is important that much of Siberia was cold this winter. Also, Siberia is the region that the dynamical models predict most consistently to be warm and by the largest departures or magnitude. And for me it is Siberia that may be more than any other region, the battleground on whether there is influence from Arctic change that extends to the continents.

## Near-Term

*This week*

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

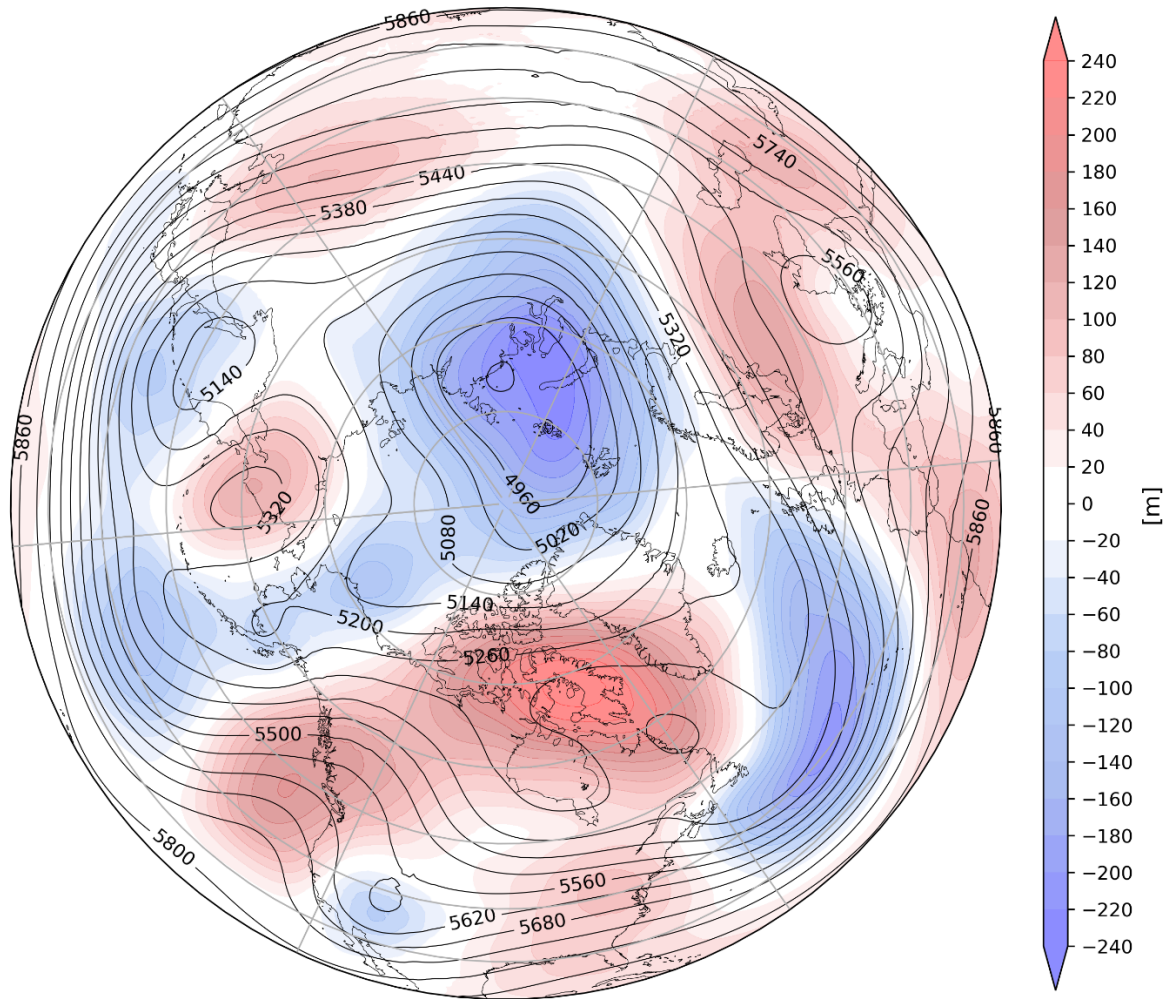




**Figure 1.** (a) The predicted daily-mean AO at 1000 hPa from the 00Z 11 March 2024 GFS ensemble. (b) The predicted daily-mean near-surface AO from the 00Z 11 March 2024 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the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

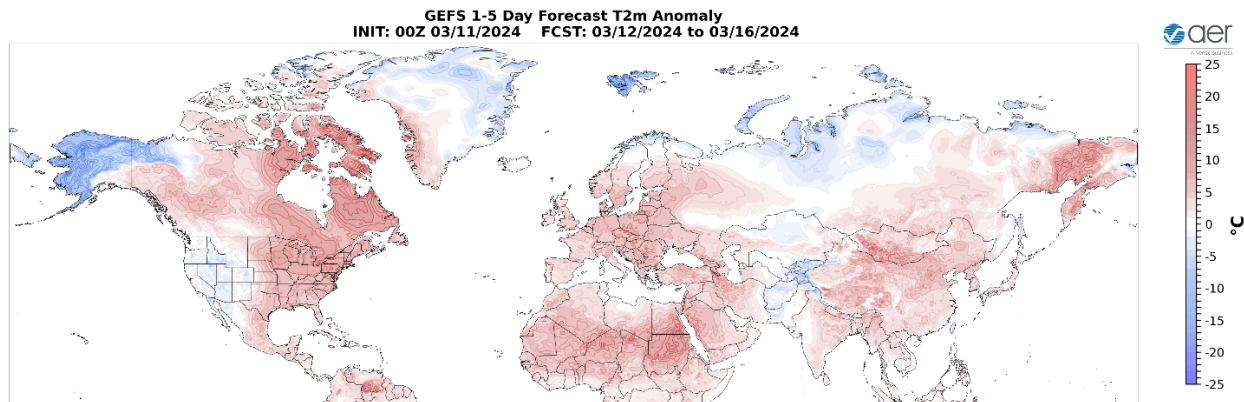
This week, troughing/negative geopotential height anomalies south of Iceland will force ridging/positive geopotential height anomalies across much of Europe with the exception of troughing/negative geopotential height anomalies across northern Scandinavia (**Figure 2**). This pattern favors normal to above normal temperatures across much of Europe including the UK with the exception of normal to below normal temperatures across northern Scandinavia (**Figure 3**). Predicted ridging/positive geopotential height anomalies stretching from Greenland to the Gulf of Alaska will support troughing/negative geopotential height anomalies across Western and Northern Asia with more ridging/positive geopotential height anomalies across Eastern Asia this period (**Figure 2**). This pattern favors widespread normal to above normal temperatures across much of Asia but focused in Eastern Asia with normal to below normal temperatures centered across the Urals and Northern Siberia (**Figure 3**).

**GEFS 1-5 Day Forecast 500 hPa Anomaly**  
**INIT: 00Z 03/11/2024 FCST: 03/12/2024 to 03/16/2024**



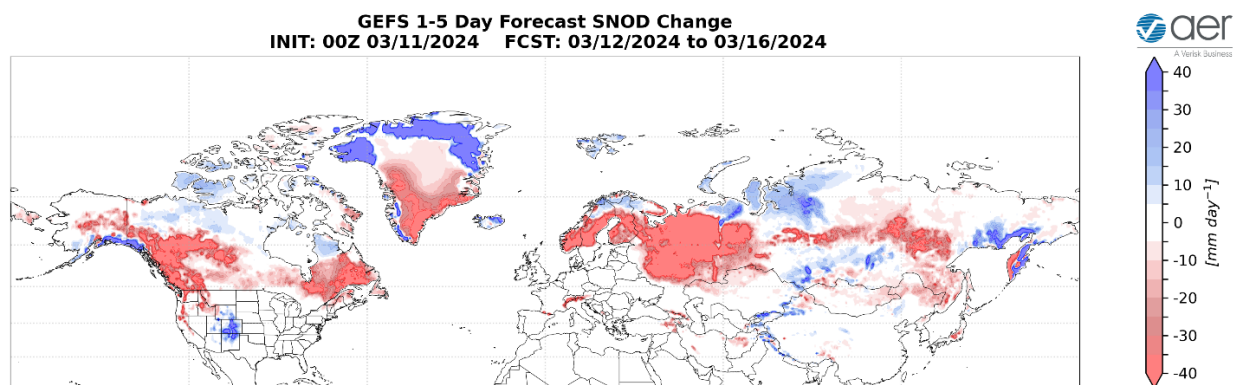
**Figure 2.** Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 12 – 16 March 2024. The forecasts are from the 00z 11 March 2024 GFS ensemble.

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



**Figure 3.** Forecasted surface temperature anomalies (°C; shading) from 12 – 16 March 2024. The forecast is from the 00Z 11 March 2024 GFS ensemble.

Trouging and/or cold temperatures will support new snowfall across northern Scandinavia, Central Asia and Northern Siberia, while mild temperatures will support snowmelt across Scandinavia, the Alps and widespread across Western Russia and Southern Siberia this week (**Figure 4**). Trouging and/or cold temperatures will support new snowfall across southeastern Alaska, Northern Canada, and the front range of the Central Rockies while mild temperatures will support snowmelt across Western and Southern Canada, the Western US and northern New England this week (**Figure 4**).



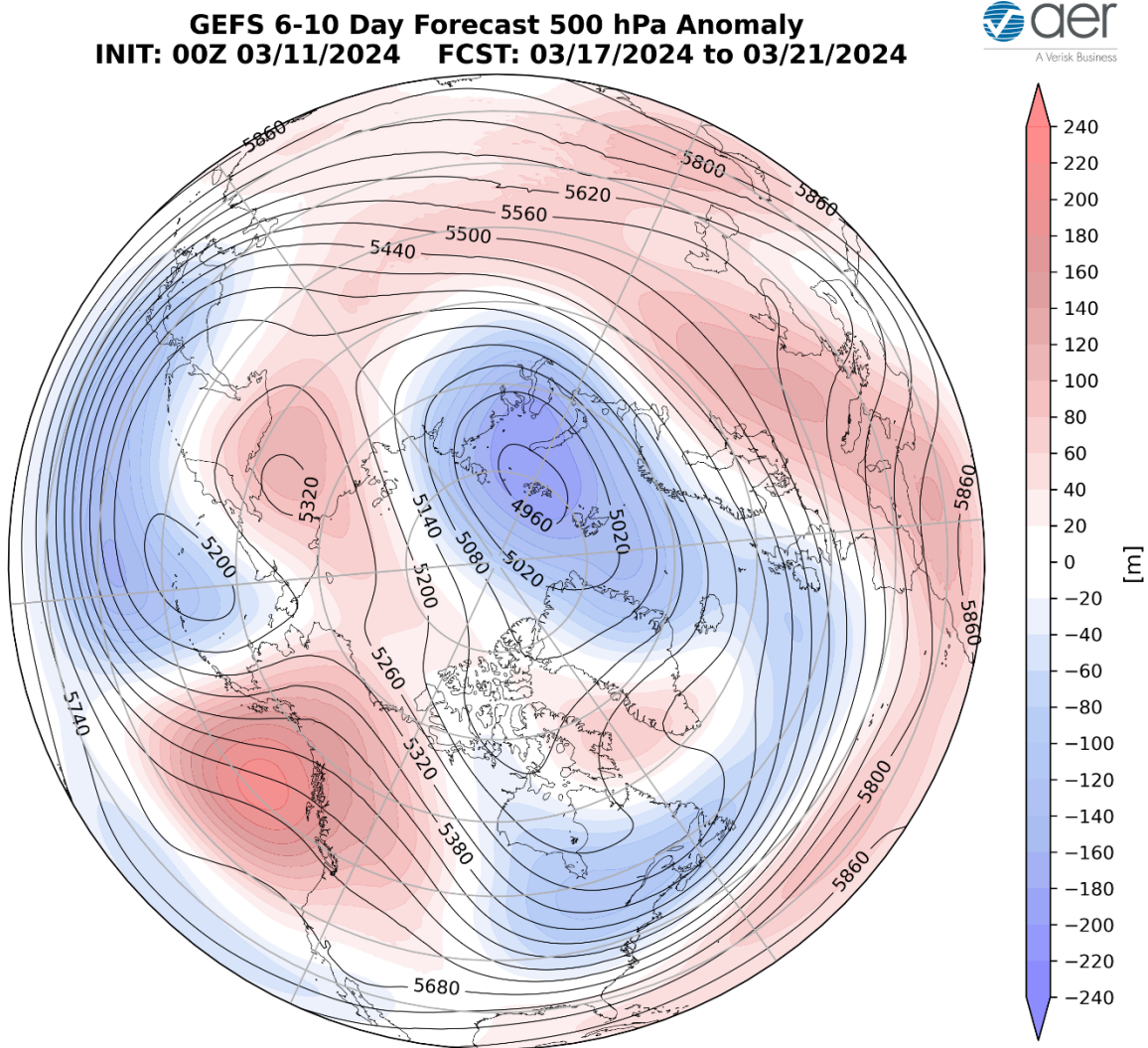
**Figure 4.** Forecasted snow depth changes (mm/day; shading) from 12 – 16 March 2024. The forecast is from the 00Z 11 March 2024 GFS ensemble.

## Near-Mid Term

### *Next week*

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

tethered to neutral this period (Figure 1). With pressure/geopotential height anomalies across Greenland also turning more mixed (Figure 5), the NAO will be close to neutral as well this period.

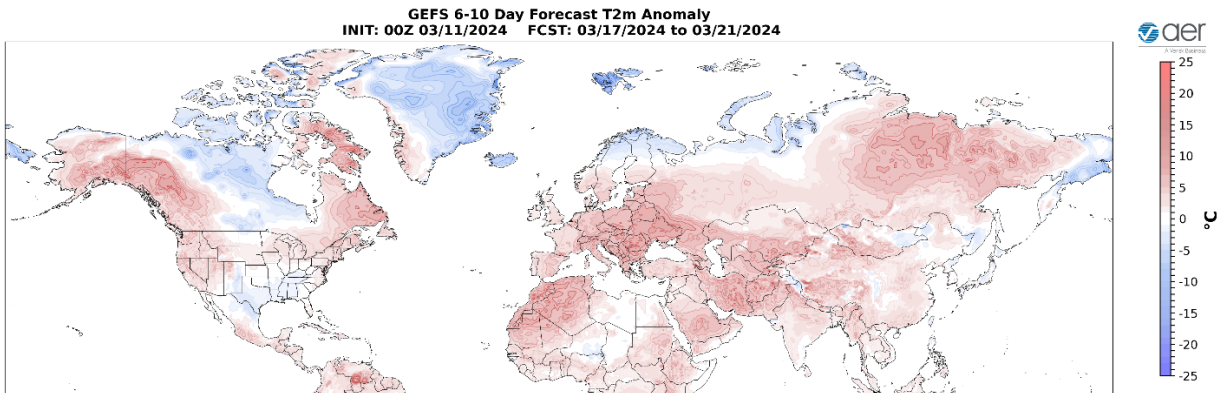


**Figure 5.** Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 17 – 21 March 2024. The forecasts are from the 00z 11 March 2024 GFS ensemble.

Persistent troughing/negative geopotential height anomalies south of Iceland will force ridging/positive geopotential height anomalies across much of Europe with the exception of troughing/negative geopotential height anomalies across northern Scandinavia 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 northern Scandinavia due to low geopotential heights (Figures 6). Predicted ridging/positive geopotential height anomalies centered from

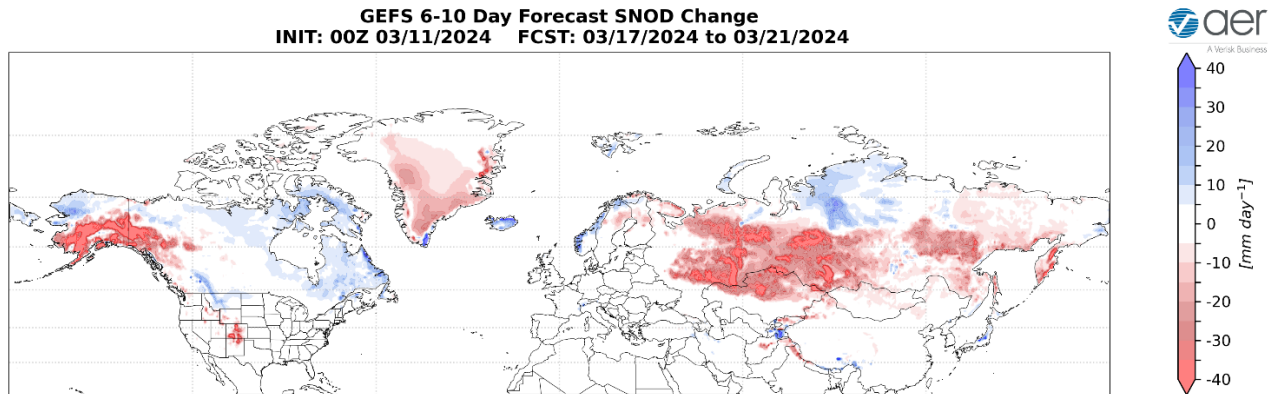


southern Greenland to the Gulf of Alaska will support troughing/negative geopotential height anomalies across Northern and Western Asia with more ridging/positive geopotential height anomalies across Southern and Eastern Asia this period (**Figure 5**). This pattern favors widespread normal to above normal temperatures across much of Asia with the exception of normal to below normal temperatures limited to northwestern Asia and far Eastern Siberia this period (**Figure 6**).



**Figure 6.** Forecasted surface temperature anomalies (°C; shading) from 17 – 21 March 2024. The forecasts are from the 00z 11 March 2024 GFS ensemble.

Predicted ridging/positive geopotential height anomalies across Alaska, the Gulf of Alaska and Western Canada will support troughing/negative geopotential height anomalies across Eastern Canada and the Eastern US this period (**Figure 5**). This pattern favors normal to above normal temperatures across Alaska, Western Canada, the Western US and along the East Coast of Canada and the US with normal to below normal temperatures across Central Canada and the Central US (**Figure 6**).



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

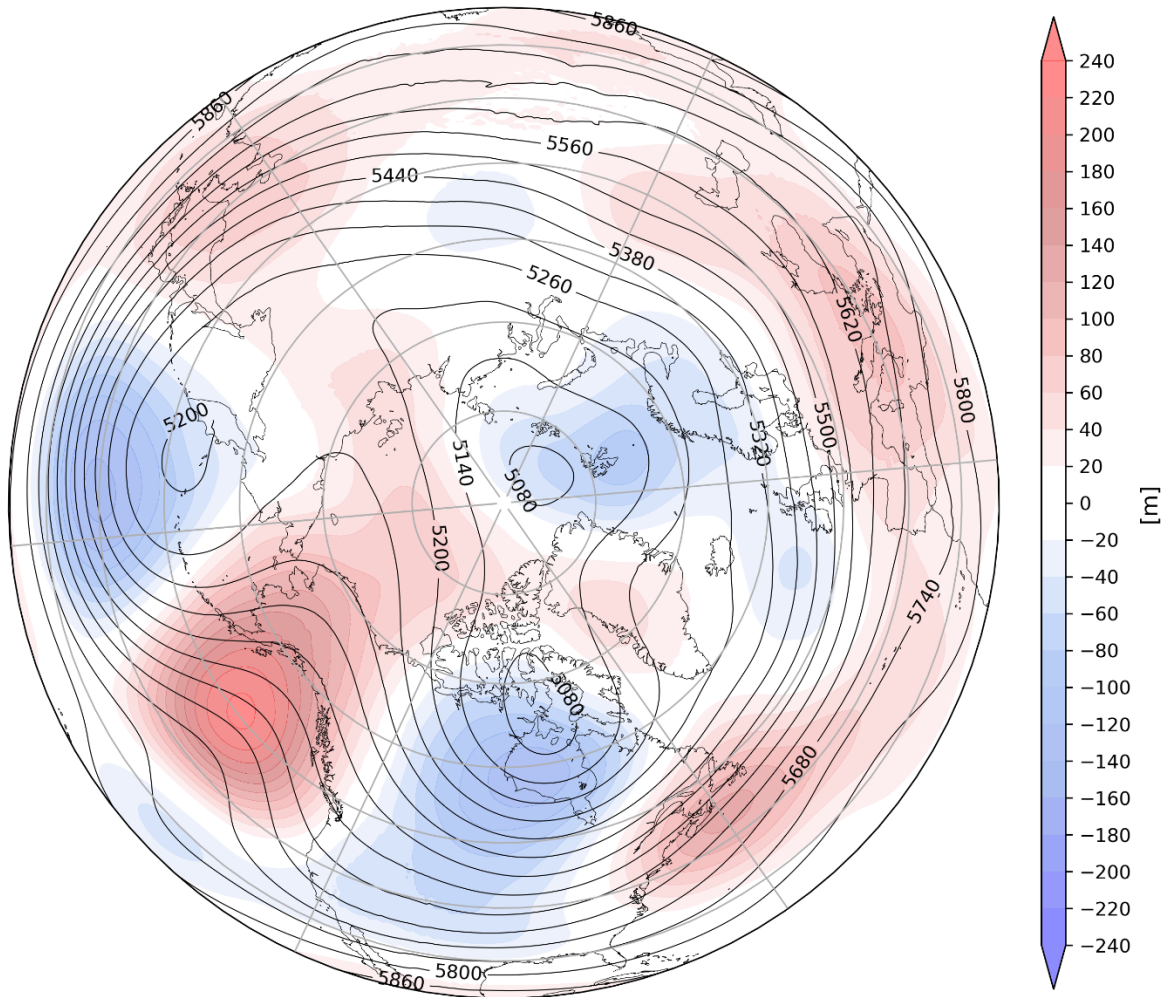
Trouching and/or cold temperatures will support new snowfall across Norway and parts of Northern Siberia and the Tibetan Plateau while mild temperatures will support widespread snowmelt across Northern Asia this period (**Figure 7**). Trouching and/or cold temperatures will support new snowfall across northern Alaska, Alberta, and Northern and Eastern Canada while mild temperatures will support snowmelt across southern Alaska, Western and Colorado 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 mixed pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO should be neutral to negative this period.

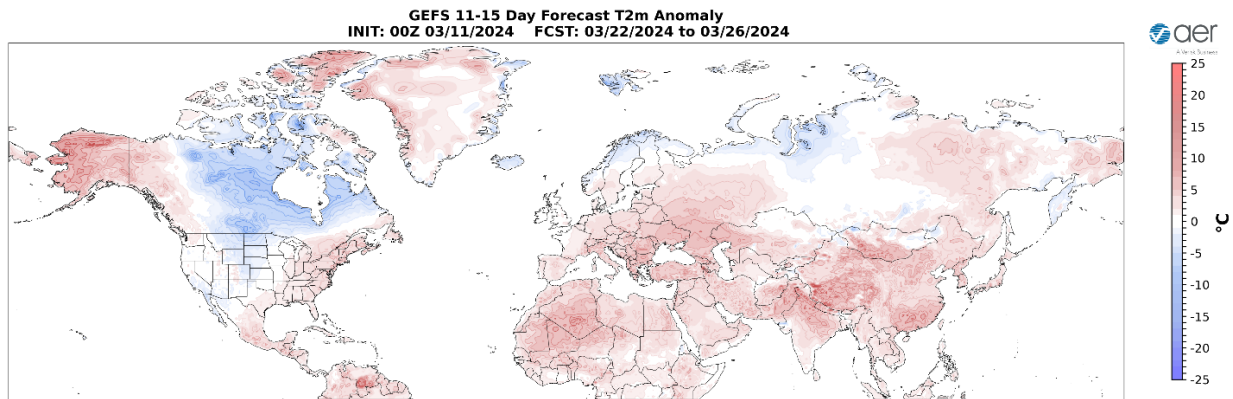
**GEFS 11-15 Day Forecast 500 hPa Anomaly**  
**INIT: 00Z 03/11/2024 FCST: 03/22/2024 to 03/26/2024**



**Figure 8.** Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 22 – 26 March 2024. The forecasts are from the 00z 11 March 2024 GFS ensemble.

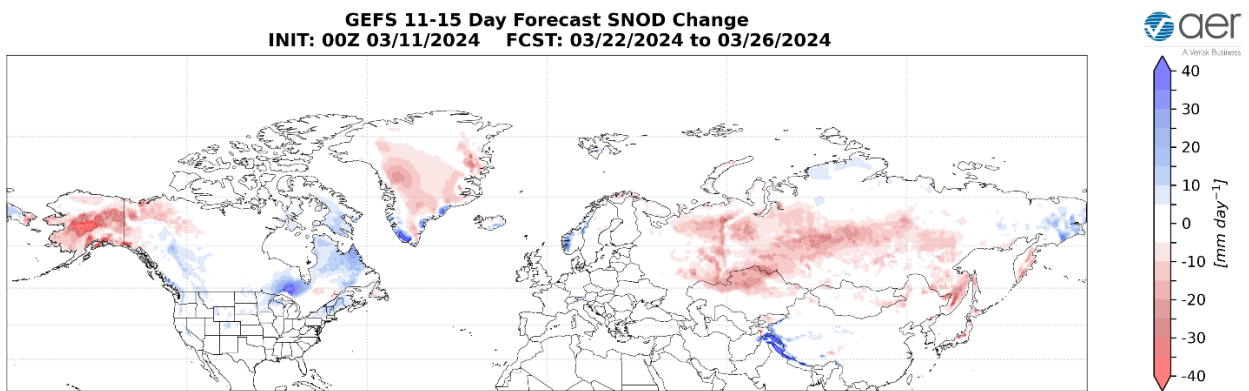
The general pattern across Europe is persistent ridging/positive geopotential height anomalies across Southern Europe with troughing/negative geopotential height anomalies across Northern Europe this period (**Figure 8**). The mostly zonal flow pattern should favor normal to above normal temperatures across much of Europe including the UK with normal to below normal temperatures limited to northern Scandinavia due to low geopotential heights this period (**Figures 9**). The general pattern of ridging/positive geopotential height anomalies across Southern Asia with troughing/negative geopotential height anomalies across Northern Asia with more ridging/positive geopotential height anomalies across Eastern Asia is predicted to persist this period (**Figure 8**). The predicted pattern favors widespread normal

to above normal temperatures across Western, Southern and Eastern Asia with normal to below normal limited to the Urals region and Western Siberia this period (**Figure 9**).



**Figure 9.** Forecasted surface temperature anomalies ( $^{\circ}\text{C}$ ; shading) from 22 – 26 March 2024. The forecasts are from the 00z 11 March 2024 GFS ensemble.

Ridging/positive geopotential height anomalies is predicted to persist in the Gulf of Alaska and Alaska forcing troughing/negative geopotential height anomalies across Central Canada and the Central US with more ridging/positive geopotential height anomalies along the US East Coast this period (**Figure 8**). This pattern favors normal to above normal temperatures across Alaska, Western Canada and the Western and Eastern US with normal to below normal temperatures across Central Canada and the Central US this period (**Figure 9**).



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

Troughing and/or cold temperatures will support new snowfall across parts of Norway, Northern Siberia and the Tibetan Plateau while mild temperatures will support snowmelt across much of Northern Asia this period (**Figure 10**). Troughing and/or cold temperatures will support new snowfall across the Canadian and US Rockies, Eastern Canada and New England. Mild

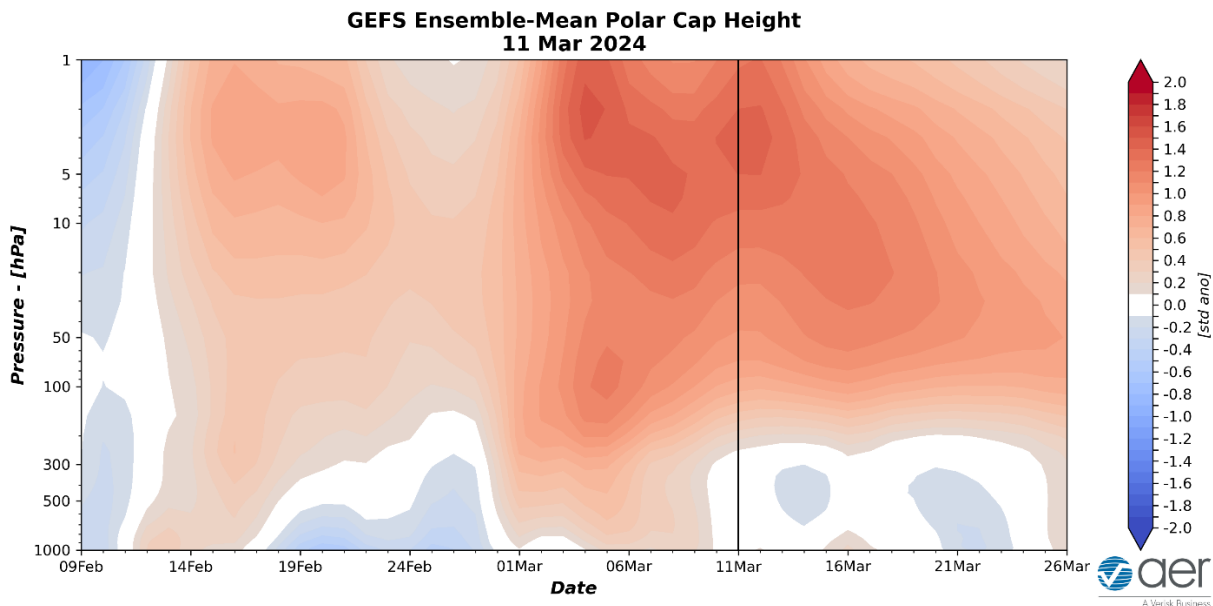


temperatures will support snowmelt across Alaska and northwestern Canada this period (**Figure 10**).

## Longer Term

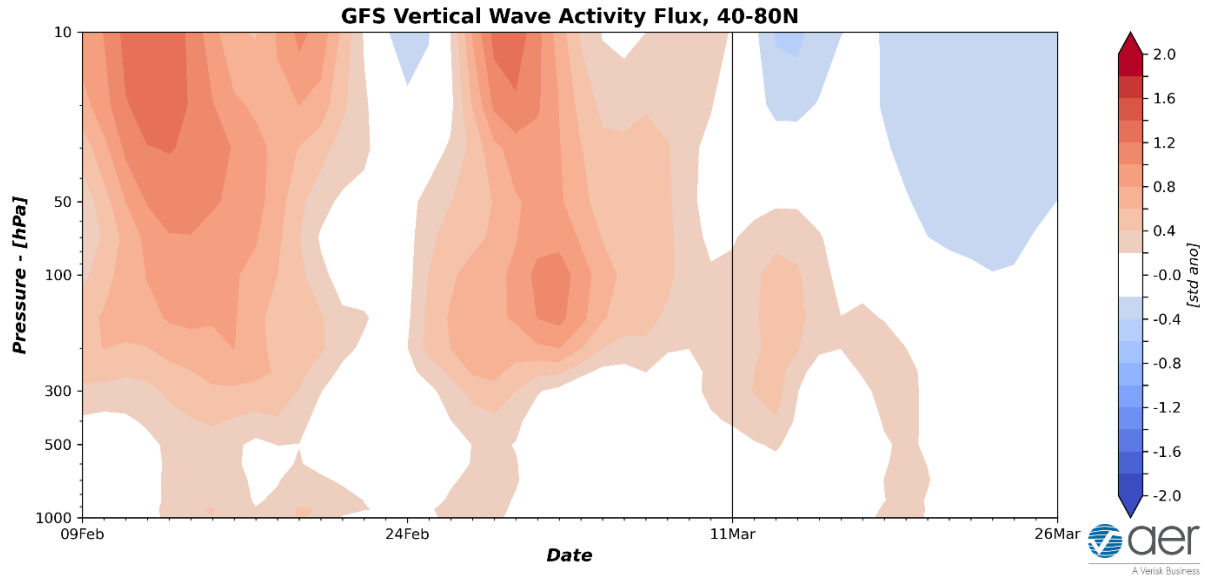
### 30-day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows warm/positive PCHs throughout the stratosphere and near neutral PCHs in the troposphere (**Figure 11**). Then for the next two weeks warm/positive PCHs will dominate the stratosphere with neutral to cold/negative PCHs in the troposphere (**Figure 11**). The increasing warm/positive throughout the stratosphere (**Figure 11**) is related to the PV becoming increasingly disrupted while we await the descent of warming/positive PCHs into the troposphere. We should have a better idea once the maximum warm/positive PCHs reach the lower stratosphere.



**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 11 March 2024 GFS ensemble.

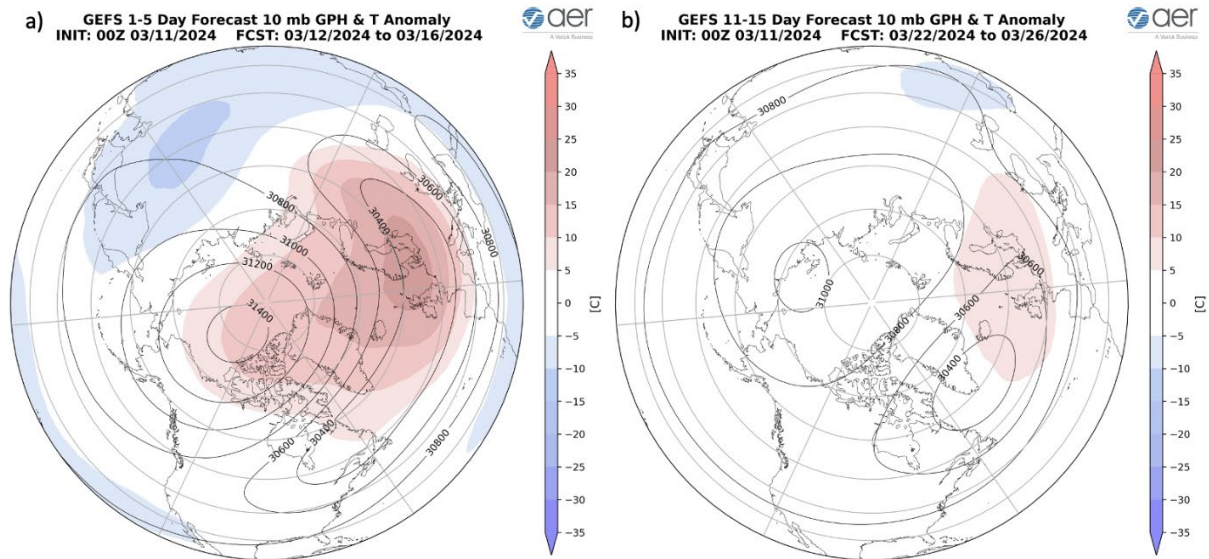
The predicted neutral to weakly warm/positive PCHs in the lower troposphere for this week (**Figure 11**) are consistent with the predicted neutral to negative surface AO this week (**Figure 1**). However, as the neutral to weak warm/positive PCHs flip to cold/negative PCHs in the troposphere, the surface 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 11 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 the warm/positive stratospheric PCHs in the mid-stratosphere associated with a weakening PV that is dynamically consistent with a sudden stratospheric warming.

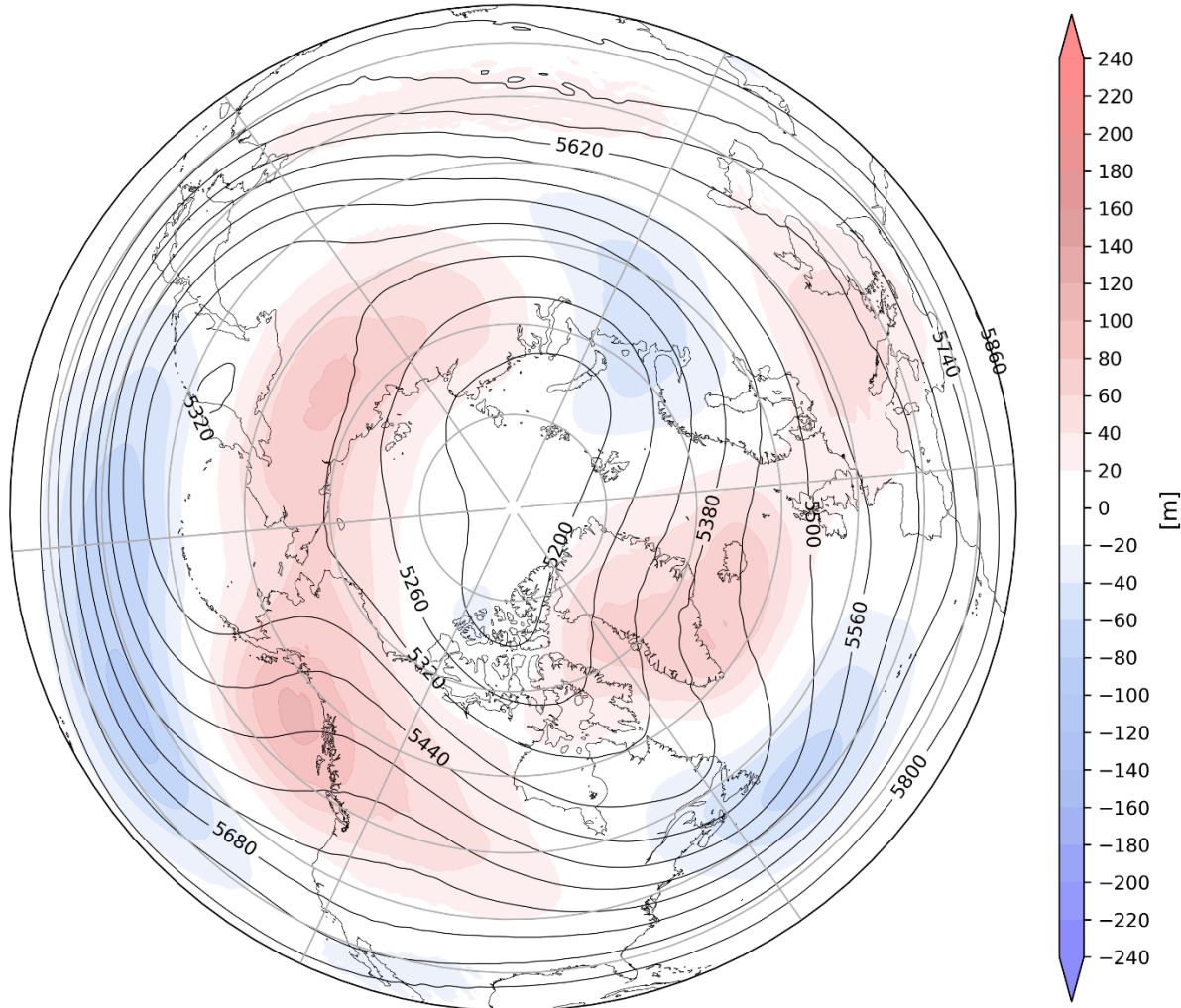
Vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere has been active since the second week of February and is continuing into this week though for the most part is turning quieter (**Figure 12**). The active WAFz has resulted in an impressive major SSW. The below normal WAFz predicted the next two weeks is consistent with an SSW but may also be characteristic of wave reflection.



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

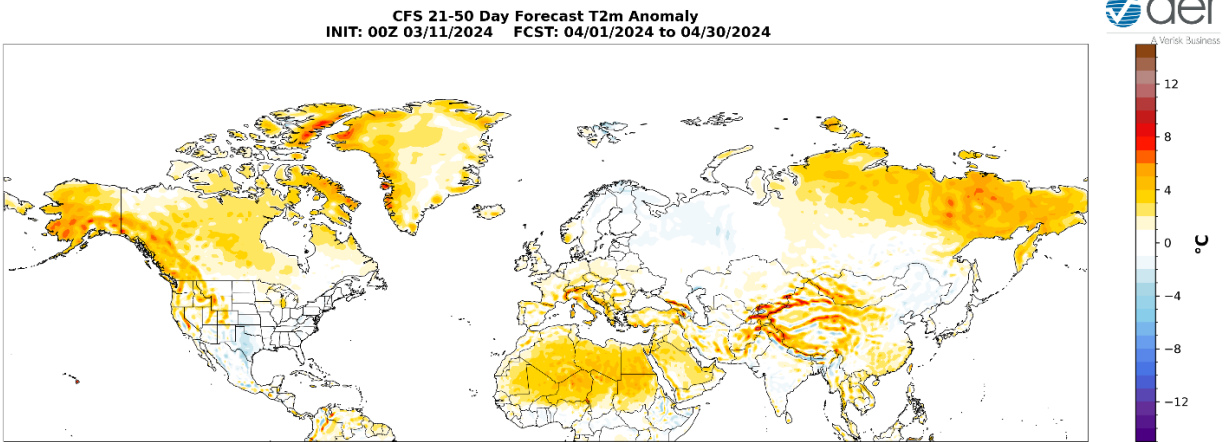
This week the polar vortex (PV) is predicted to be shifted way south of the North Pole and spread across the North Atlantic sector from Europe to Southeastern Canada and the Northeastern US (**Figure 13a**). The ridging in the polar stratosphere is centered near the North Pole Sea with the greatest warming centered across Northwest Europe. This is consistent with an evolving SSW while it is transitioning from a PV displacement to a PV split. For the fourth week of March the PV center is predicted to consolidate over southern Greenland with ridging predicted over the Laptev Sea and with warming spread across the eastern North Atlantic and western Europe (**Figure 13b**). There seems to be disagreement on the evolution of the PV disruption but striking how the configuration in the polar stratosphere resembles a negative AO.

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



**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 11 March 2024 CFS.

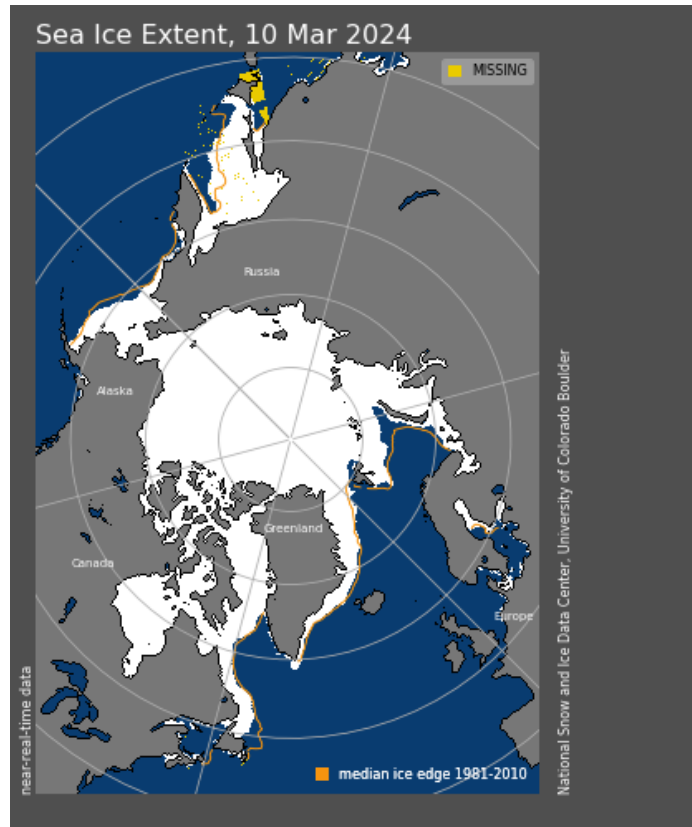
I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and surface temperatures for April (**Figure 15**) from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging centered across Greenland and Iceland, Southern Europe, Siberia, Alaska, the Gulf of Alaska, Western Canada and the Western US with troughing in Northern Europe, Western Asia, East Asia, the Southwestern US, Eastern Canada and the Northeastern US (**Figure 14**). This pattern favors seasonable to relatively warm temperatures across Southern Europe, Southern and Central Asia, Siberia, Alaska, Western Canada and the Western US with seasonable to relatively cold temperatures across Northern Europe, Western and Northern Asia, Southeastern 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 11 March 2024 CFS.

#### *Arctic sea ice extent*

Arctic sea ice extent grew staid nearly steady 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.

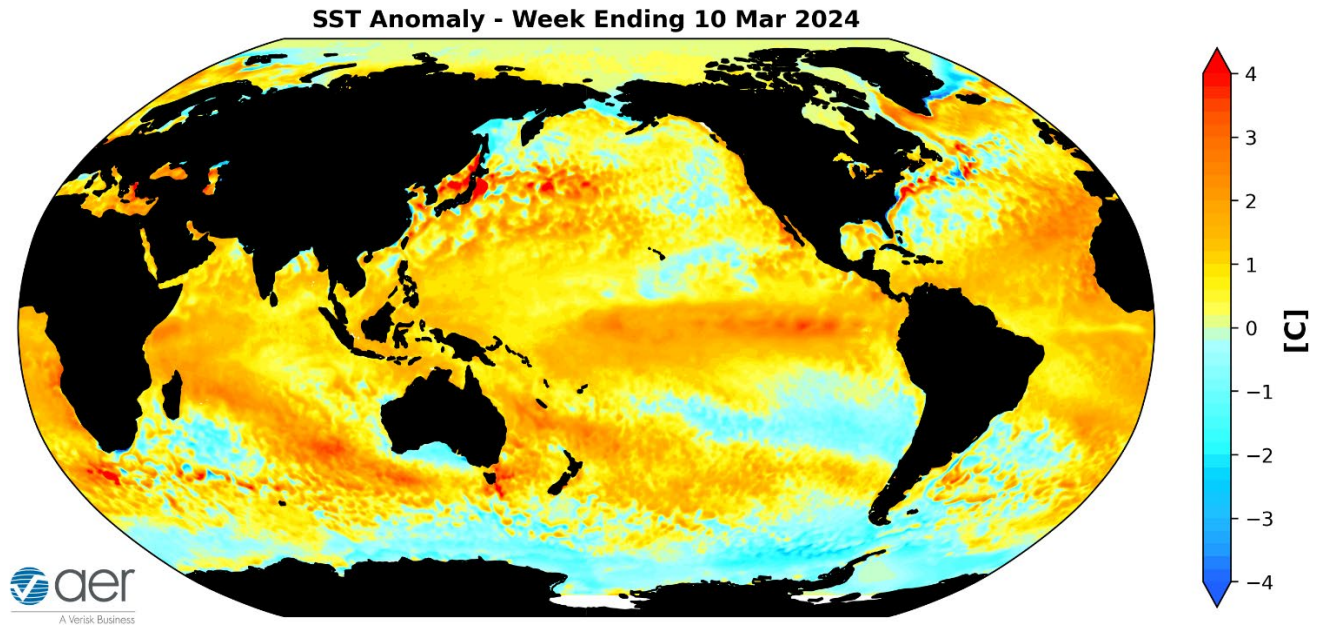


**Figure 16.** Observed Arctic sea ice extent on 10 March 2024 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image courtesy of National Snow and Ice Data Center (NSIDC). Snow and Ice Data Center (NSIDC).

### *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 spring. 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.

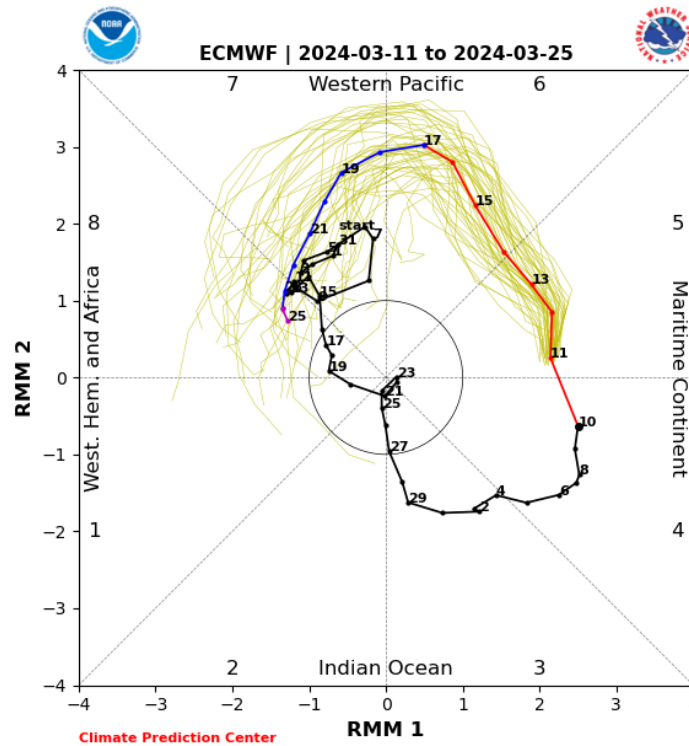




**Figure 17.** The latest weekly-mean global SST anomalies (ending 10 March 2024). Data from NOAA OI High-Resolution dataset.

### *Madden Julian Oscillation*

Currently the Madden Julian Oscillation (MJO) is in phase six (**Figure 18**). The forecasts are for the MJO to move quickly into phase seven and then eight. Phase six favors ridging in the Gulf of Alaska and the Eastern US with troughing in Alaska, Northern and Western Canada and the Western US. Phase seven favors ridging across Canada with troughing in the US. Therefore the MJO could be having an influence on the weather across North America 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 11 March 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](https://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/CLIVAR/clivar_wh.shtml)

### 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 for purchase. 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!