

Arctic Oscillation and Polar Vortex Analysis and Forecasts

March 28, 2022

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. With the start of 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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Summary

- The Arctic Oscillation (AO) is currently negative and is predicted to trend positive towards neutral through mid-April with mixed to mostly positive pressure/geopotential height anomalies across the Arctic especially the North Atlantic side of the Arctic and mixed pressure/geopotential height anomalies across the mid-latitudes. The North Atlantic Oscillation (NAO) is also negative and is predicted to remain negative as pressure/geopotential height anomalies are predicted to remain positive across Greenland the next two weeks.
- The next two weeks, ridging/positive geopotential height anomalies across Greenland will favor troughing/negative geopotential height anomalies over Europe, especially Northern Europe centered over Scandinavia with the exception of ridging/positive geopotential height anomalies across Southeastern Europe. This pattern favors normal to below normal temperatures across Western and Northern Europe including the United Kingdom (UK) with normal to above normal temperatures across Southeastern Europe and Turkey.
- The general pattern across Asia the next two weeks is troughing/negative geopotential height anomalies across Northern Asia especially Siberia with ridging/positive geopotential height anomalies across Southern Asia. This

pattern favors normal to below normal temperatures across Northern Asia with normal to above normal temperatures across Southern Asia.

- The general pattern the next two weeks across North America is ridging/positive geopotential height anomalies across western North America with troughing/negative geopotential height anomalies across Alaska and eastern North America. The pattern favors normal to above normal temperatures in Western Canada and the Western United States (US) with normal to below normal temperatures across Alaska, Eastern Canada and the Eastern US. One exception is next week when the ridging/positive geopotential height anomalies in Western Canada relaxes allowing the brief return of normal to below normal temperatures to the region with widespread normal to above normal temperatures across the US.
- In the *Impacts* section I continue to discuss my expectations of the impacts of the polar vortex (PV) disruption that is resulting in a Final Warming, though the impacts could be similar to a more classical sudden stratospheric warming (SSW) across the Northern Hemisphere (NH).

Plain Language Summary

The large polar vortex disruption is behaving like a sudden stratospheric warming in both the stratosphere and the troposphere. This includes high latitude blocking including Greenland blocking/high pressure that favors colder and/or stormier weather across Europe and Northern Asia and possibly the Eastern US. In two weeks, there could also be another stretched polar vortex event that favors cold temperatures east of the Rockies.

Impacts

Though the polar vortex (PV) has been relatively strong to even record strong all winter (see **Figure i**) it is departing until next fall with a bang. The large PV disruption this month and its related impacts on the tropospheric circulation and weather are the dominant story over the next two weeks and likely beyond two weeks. The PV disruption will be listed or defined as a Final Warming but in my opinion dynamically is analogous to a major warming (where the zonal winds at 60°N and 10hPa reverse from westerly to easterly or from positive to negative) when understanding the relationship with the troposphere.

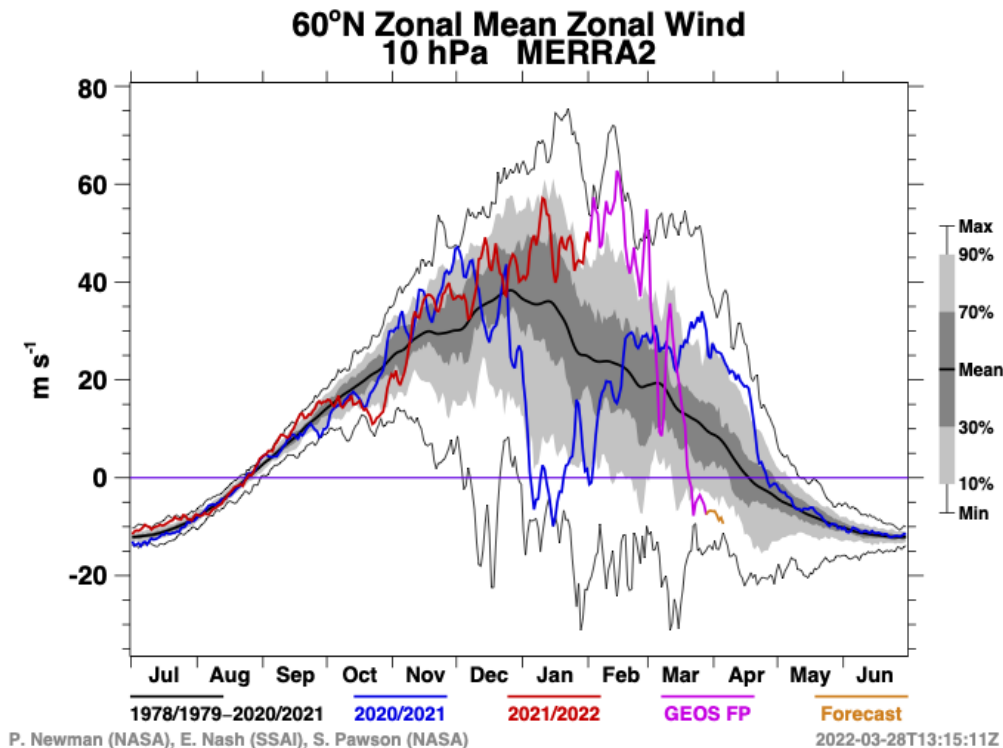
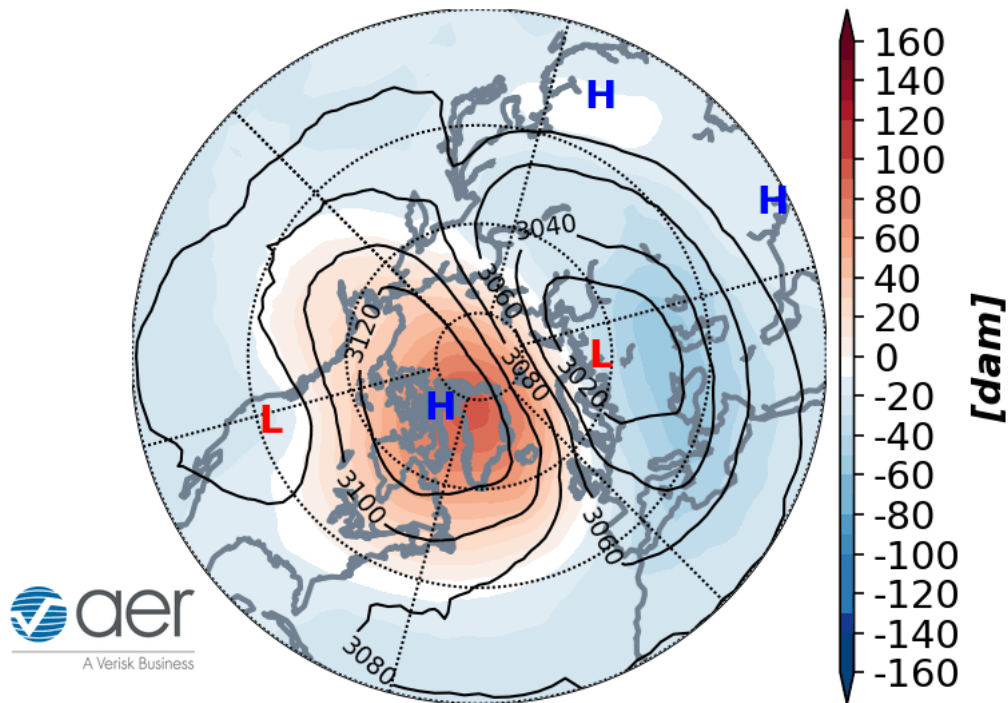


Figure i. Observed zonal-mean zonal wind at 60°N and 10hPa since (proxy for the strength of the polar vortex) July 1, 2021, and predicted for the next two weeks from the NASA GEOS model initialized 28 March 2022. Figure downloaded from https://acd-ext.gsfc.nasa.gov/Data_services/met/ann_data.html

As I discussed in the most recent blog from March 14, 2022, the relationship between the Final Warming and the tropospheric circulation of this March is likely to be similar to that of March 2016 that had a long-lasting connection with the tropospheric circulation across the NH for much of the spring. There have been major warmings in March but 2016 and now 2022 were so large that the PV could never recover, and the Final Warmings occurred at least a month earlier than average (see **Figure i**). Given that on average there is at least a month remaining in the NH PV season, there is always the chance that the PV could recover and return to the North Pole, but from what I can tell all model forecasts predict that the PV will not recover this spring. That is my impression from the latest PV animation shown in **Figure ii**.

Initialized 00Z 10 hPa HGT/HGTa 28-Mar-2022



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Figure ii. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere for 28 March 2022 and forecasted from 29 March – 13 April 2022. The forecasts are from the 00Z 28 March 2022 GFS model ensemble.

Once there is a large PV disruption it is always an important question how much coupling there will be between the stratosphere and the troposphere. Seems to me that there is fairly robust coupling already and we can already observe many of the classic characteristics related to a major warming. The AO and NAO are both negative which is obviously related to high latitude blocking currently focused near Greenland (see **Figure 2**). The stratospheric PV center is sprawled across northern Eurasia (see **Figure 13**) and is predicted to remain there for at least the next two weeks (see **Figure ii**) while high pressure dominates the Arctic. The stratospheric circulation is mirrored in the troposphere with low pressure strung across Northern Europe and Asia with high latitude blocking (see **Figures 2, 5 and 8**). And is often the case with major warmings, relatively widespread cold temperatures are predicted across Northern Europe and/or Asia (see **Figures 3, 6 and 9**). I was expecting to include in today's blog precipitation forecast plots, but because unusually widespread snowfall is possible in

the coming days, I have included snow depth change forecast plots for at least one more blog as snowfall could potentially be impressively widespread across Eurasia and North America in the coming week or so (see **Figures 4** and **7**).

I did try to use my words carefully describing the coupling between the stratospheric and tropospheric circulations as related rather than causal. This event seems to raise the age-old question of what came first the chicken or the egg. Looking at the polar cap geopotential height anomalies (PCHs) forecast in **Figure 11**, I think that I can convince myself that the warm/positive PCHs in the troposphere either “dripped” down from the stratosphere or developed simultaneously as it did in the stratosphere, and they eventually merged or met up in the lower stratosphere/upper troposphere. I will readily admit that I don’t fully understand the relationship between the stratosphere and troposphere during and following sudden stratosphere warmings (SSWs or major warmings) and what is exactly the cause and the effect. But I do believe that the tropospheric “response” is real regardless of the exact cause, and I expect the troposphere to follow the typical script following an SSW. I expect to see additional “drips” in the PCHs from the stratosphere to the troposphere in the coming weeks that are characterized by high-latitude blocking centered near Alaska, the Central Arctic and Greenland coupled with anomalous low pressure with relatively cold/wet weather across the mid-latitudes including Northern Europe, Northern Asia and eastern North America.

I discussed a lot this winter wave reflection or stretched PVs but what we observed this winter is not as described in the limited scientific literature on this topic because all the stretched PV events so far this winter occurred with a relatively strong PV. Maybe the first paper to describe the phenomenon as I understand it is from [Kodera et al. 2008](#). Ironically, he analyzes a single wave reflection or as I label a stretched PV event in March 2007 following an SSW (but not a Final Warming). Even in subsequent papers Kodera et al. only described wave reflection/stretched PVs following SSWs. As described by Kodera et al., SSWs precondition the atmosphere or structures the atmosphere to be more supportive of wave reflection. Therefore, there is reason now that what is likely the Final Warming has occurred, but I think should dynamically be considered an SSW, to anticipate wave reflection or a stretched PV in the coming weeks.

In fact, our new energy diagnostics mostly to identify wave energy reflection is predicting what looks like another wave reflection in week two (see **Figure iii**). Positive or upward vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere is predicted near the Urals (near 60°E) that is reflected downward near the Dateline and over towards Alaska (180-200°E).

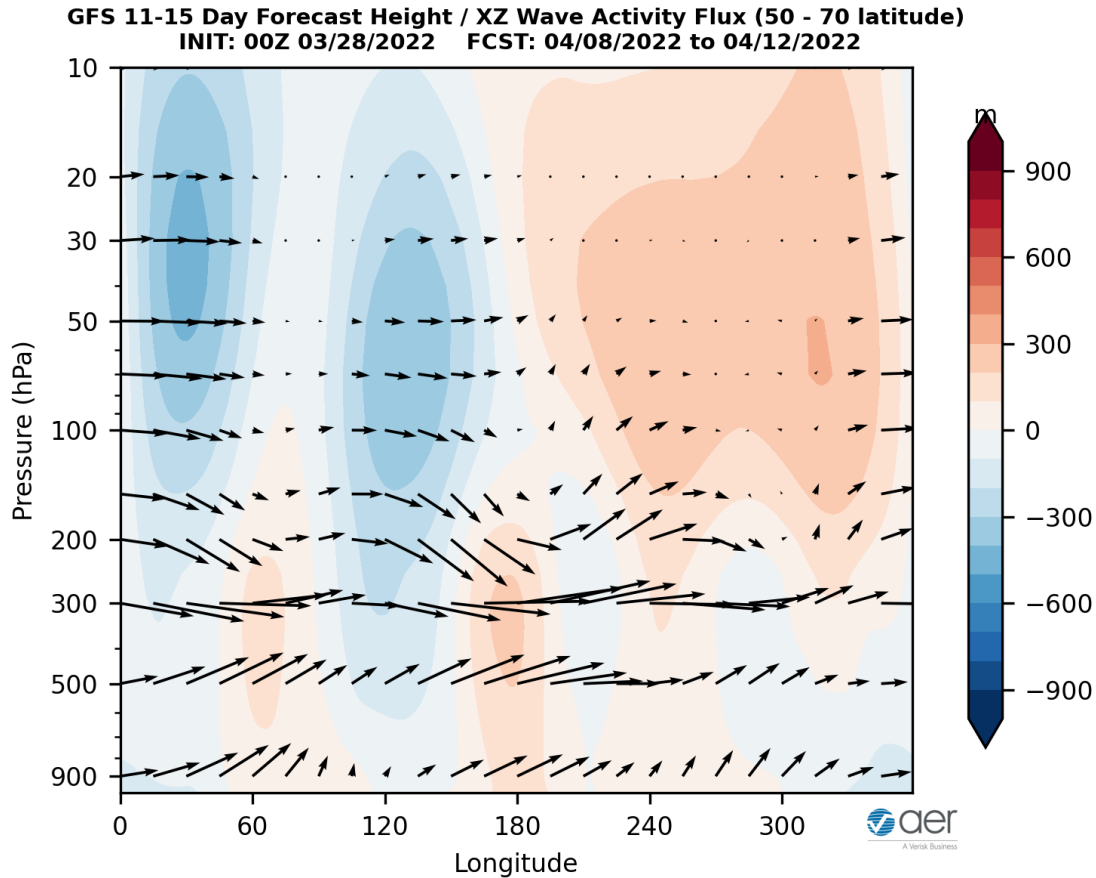


Figure iii. Predicted longitude-height cross section of geopotential eddy height anomalies and wave activity flux vectors and wave activity flux vectors in the longitudinal and height directions from the surface through 10-hPa for 8 – 12 April 2022. The forecast is from the 00Z 28 March 2022 operational GFS.

This is helping to develop a ridge center from the Dateline over towards Alaska (see **Figure 8**). Strengthening ridging near Alaska will likely help to amplify downstream troughing east of the Rockies resulting in a southward push of Arctic air across North America but of course modified by an April sun. I have found the energy diagnostics to be volatile, so this remains speculative but more cold weather is possible east of the Rockies across North America at least for a short period in April. I haven't discussed it in a while, but our experimental machine learning model predicts a temperature pattern across the US that is consistent with the temperature pattern related to stretched PVs/wave reflection for the following week in mid-April (see **Figure iv**).

T2m anom Forecast | Issued: 23 Mar 2022
Valid: 14-20 Apr 2022

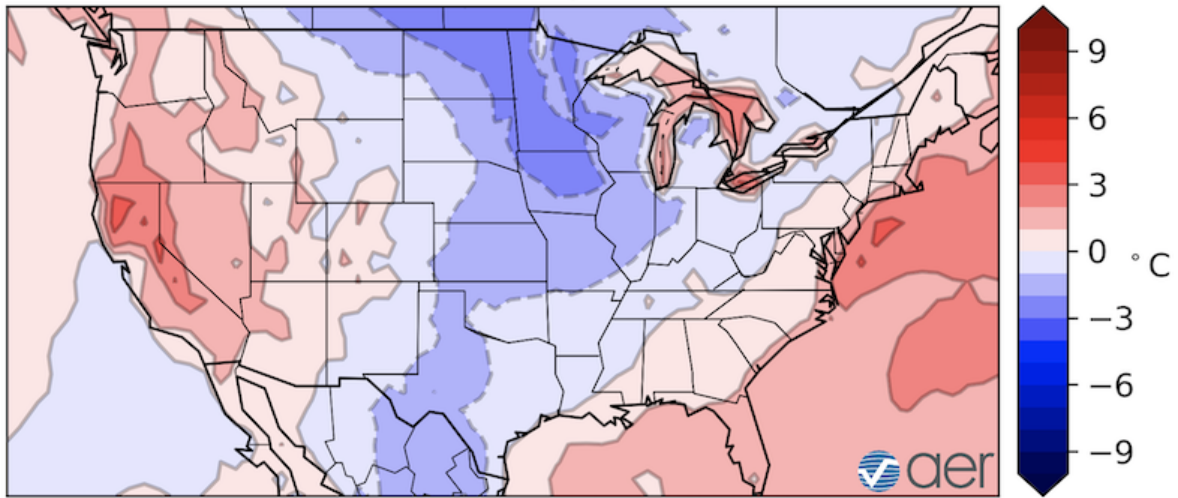


Figure iv. AER machine learning model predicted surface temperature anomalies ($^{\circ}\text{C}$; shading) for the US averaged 14 – 20 April 2022. Forecast based on observed data through 23 March 2022.

1-5 day

The AO is predicted to be negative this week (**Figure 1**) as geopotential height anomalies are predicted to be mostly positive across the Arctic especially the North Atlantic side of the Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 2**). And with positive geopotential height anomalies predicted across Greenland (**Figure 2**), the NAO is predicted to be negative this week (**Figure 1**).

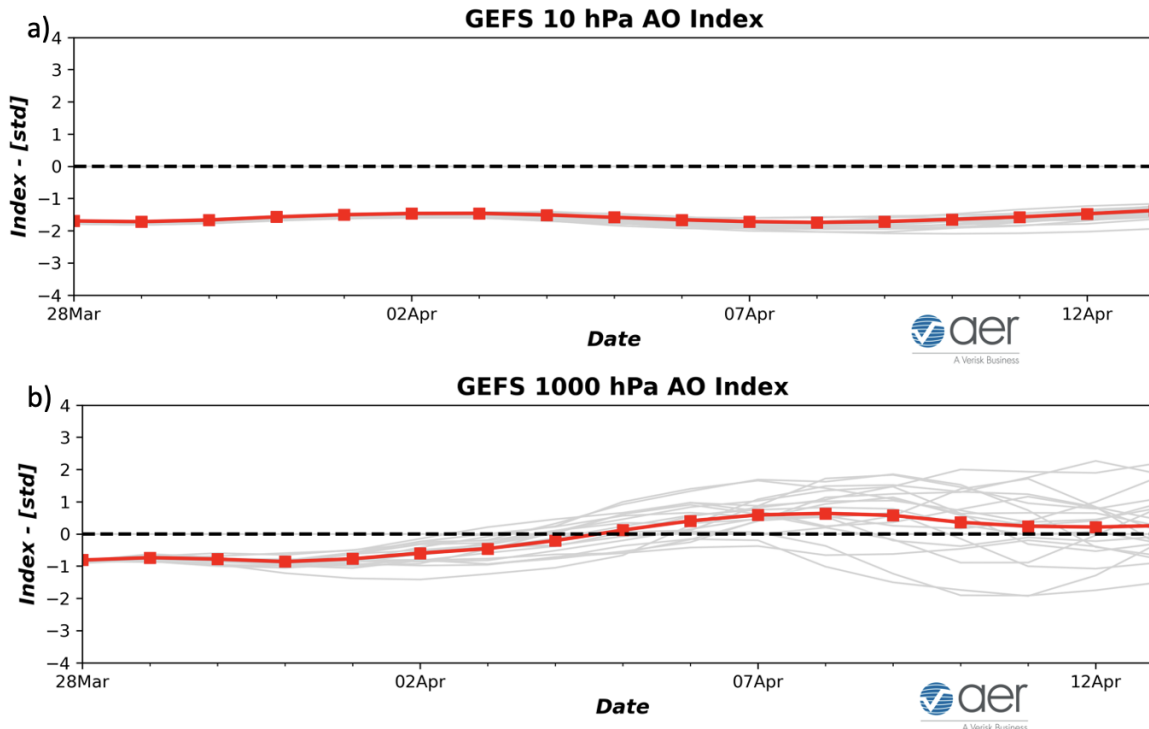


Figure 1. (a) The predicted daily-mean AO at 1000 hPa from the 00Z 28 March 2022 GFS ensemble. (b) The predicted daily-mean near-surface AO from the 00Z 28 March 2022 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

Ridging/positive geopotential height anomalies across Greenland will support troughing/negative geopotential height anomalies across Europe centered near Scandinavia with ridging/positive geopotential height anomalies across Southeastern Europe (**Figures 2**). This will result in normal to below normal temperatures across Western and Northern Europe including the UK with normal to above normal temperatures across Southern and Eastern Europe including Turkey (**Figure 3**). The current displacement of the stratospheric PV over northern Eurasia will help to anchor troughing/negative geopotential height anomalies across Northern Asia with ridging/positive geopotential height anomalies widespread across Southern and Central Asia this period (**Figure 2**). This pattern favors normal to below normal temperatures across Northwestern and Northeastern Asia with normal to above normal temperatures across Southern and Central Asia (**Figure 3**).

**GEFS 1-5 Day Forecast 500 mb GPH/GPH Anomaly
INIT: 00Z 03/28/2022 FCST: 03/29/2022 to 04/02/2022**

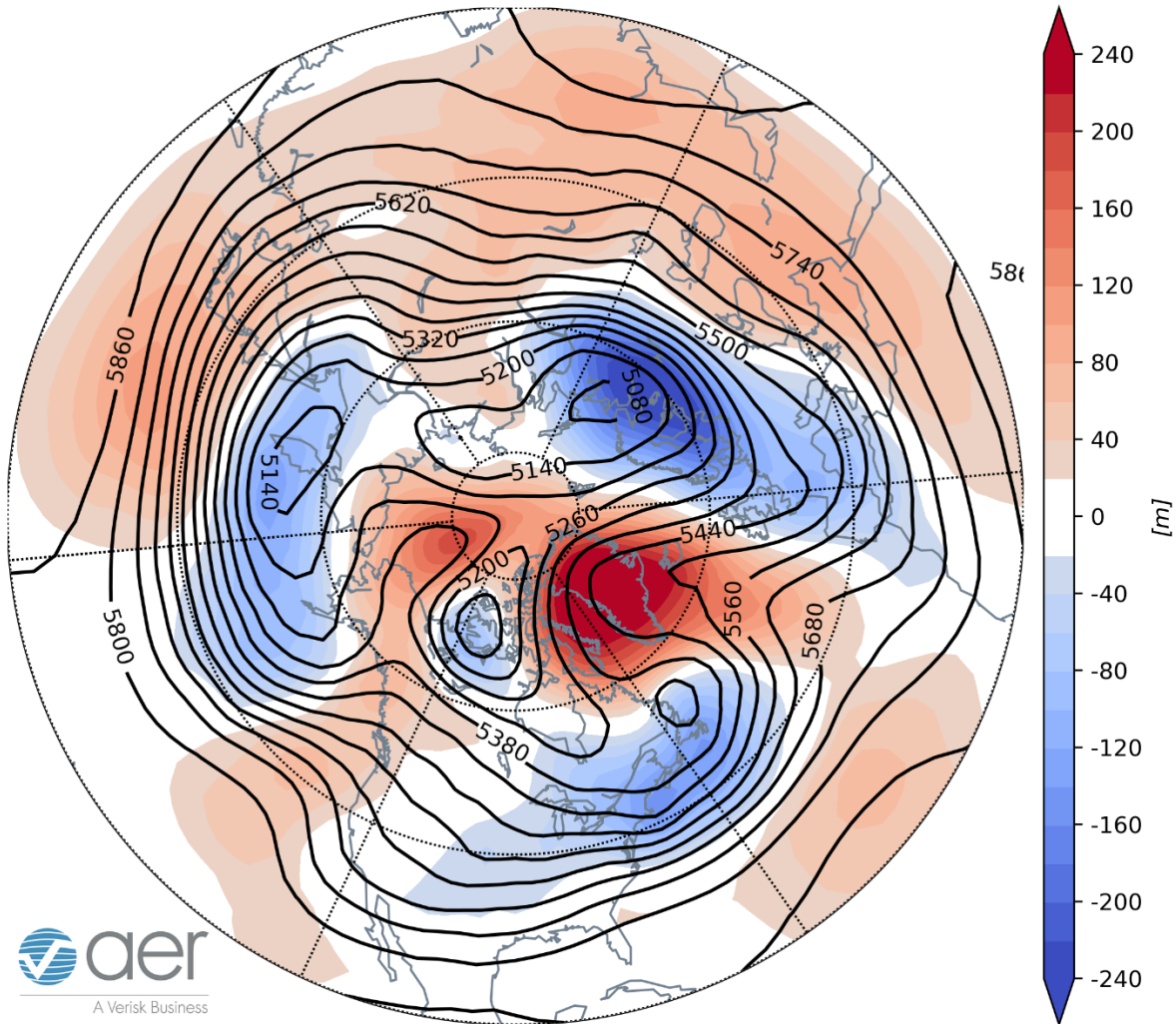


Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 29 March – 2 April 2022. The forecasts are from the 00z 28 March 2022 GFS ensemble.

Across North America the general pattern is ridging/positive geopotential height anomalies across Alaska and much of Western Canada and US with troughing/negative geopotential height anomalies across Eastern Canada and the Eastern US (**Figure 2**). The amplified flow will favor normal to above normal temperatures across much of Alaska, Western Canada and the Western US with normal to below normal temperatures in Central and Eastern Canada and the Eastern US (**Figure 3**).

GFS 1-5 Day Forecast T2m Anomaly
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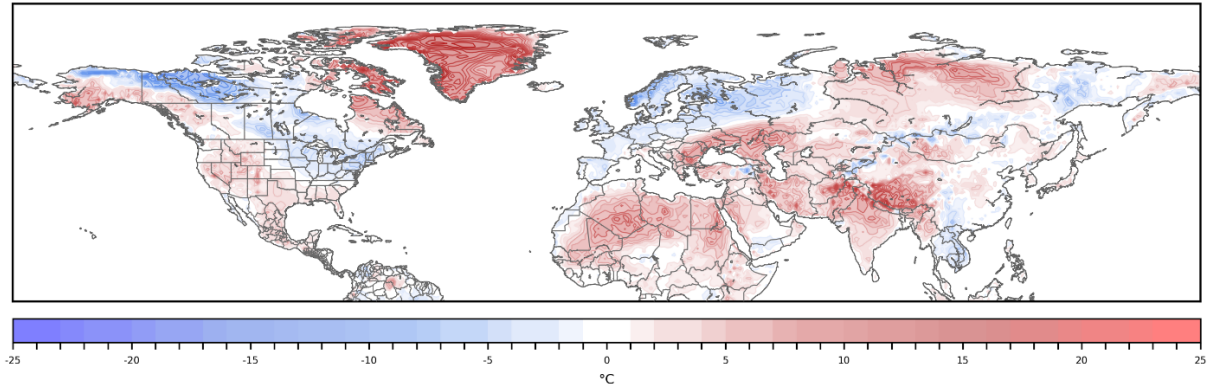


Figure 3. Forecasted surface temperature anomalies (°C; shading) from 29 March – 2 April 2022. The forecast is from the 00Z 28 March 2022 GFS ensemble.

Strong Greenland blocking will support unusually widespread late season snowfall across Northern and Central Europe and UK, Northern and Central Asia, Tibet/Southwest China, widespread across Canada, the Rockies, the Great Lakes and Northern New England (**Figure 4**).

GEPS 1-5 Day Forecast SNOD Change
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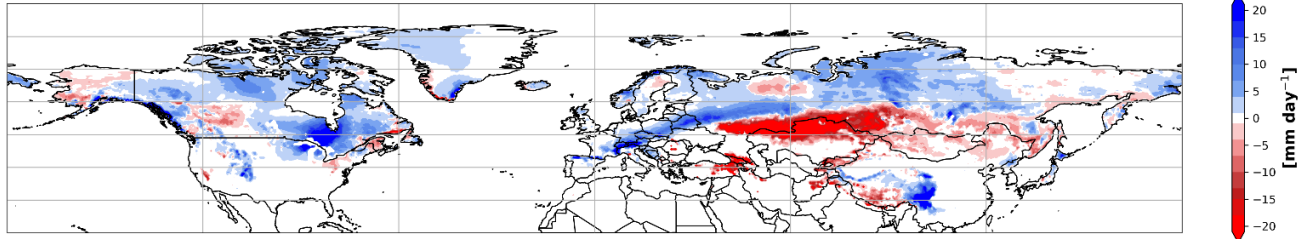


Figure 4. Forecasted snow depth changes (mm/day; shading) from 29 March – 2 April 2022. The forecast is from the 00Z 14 March 2022 GEPS ensemble.

Mid-Term

6-10 day

The AO is predicted to remain neutral to positive this period (**Figure 1**) with mixed geopotential height anomalies spread across the Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 5**). And with negative geopotential height anomalies across Greenland (**Figure 5**), the NAO is predicted to remain negative this period.

GEFS 6-10 Day Forecast 500 mb GPH/GPH Anomaly
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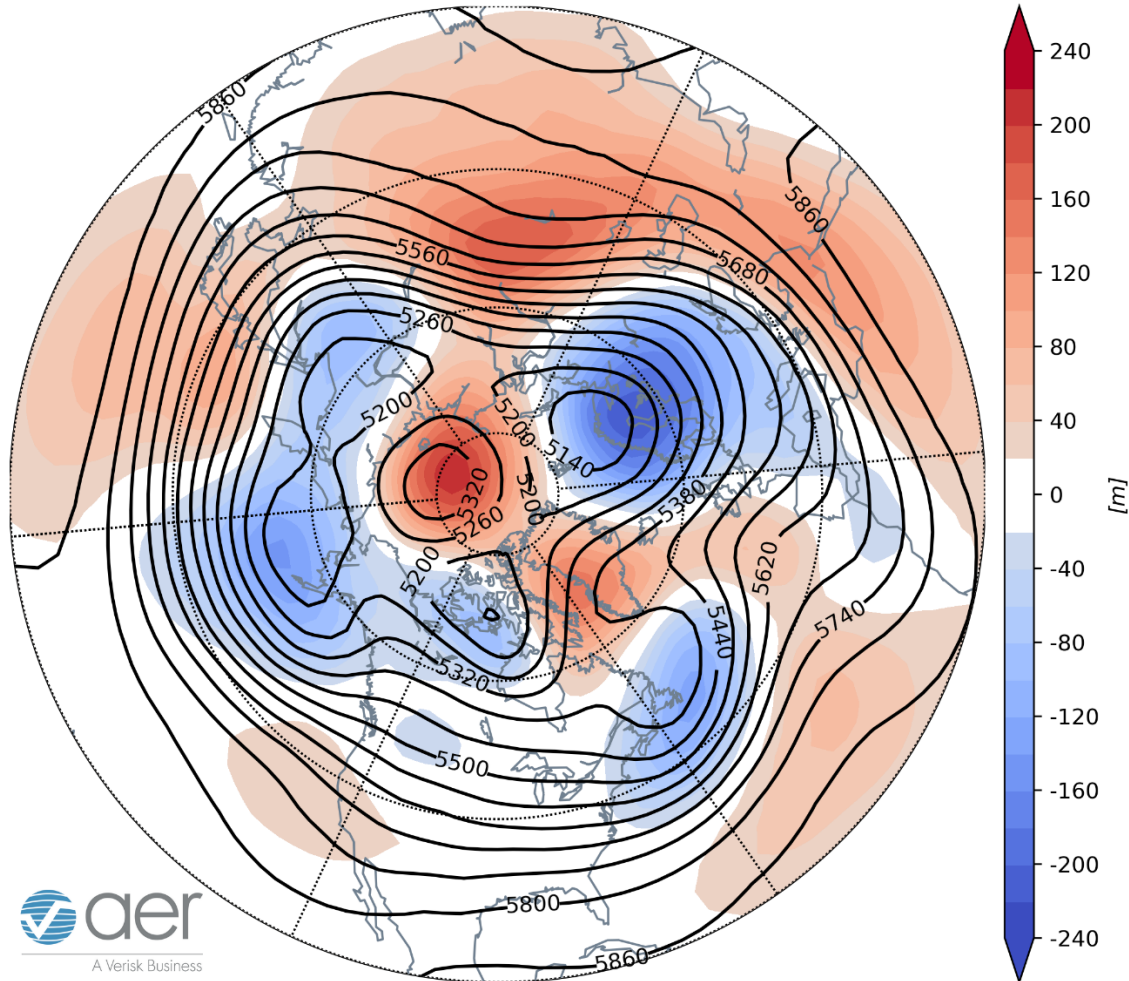


Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 3 – 7 April 2022. The forecasts are from the 00z 28 March 2022 GFS ensemble.

Persistent ridging/positive geopotential height anomalies across Greenland will continue to support troughing/negative geopotential height anomalies across Europe centered over Scandinavia with ridging/positive geopotential height anomalies across far Southeastern Europe (**Figures 5**). This will result in widespread normal to below normal temperatures across much of Europe including the UK with normal to above normal temperatures limited to in and around Turkey (**Figure 6**). The continued displacement of the stratospheric PV over Northern Asia will help to persist troughing/negative geopotential height anomalies across Northern Asia with ridging/positive geopotential height anomalies widespread across Southern Asia this period (**Figure 5**). This pattern favors widespread normal to below normal temperatures across much of Northern Asia with normal to above normal temperatures across Southern Asia (**Figure 6**).

GFS 6-10 Day Forecast T2m Anomaly
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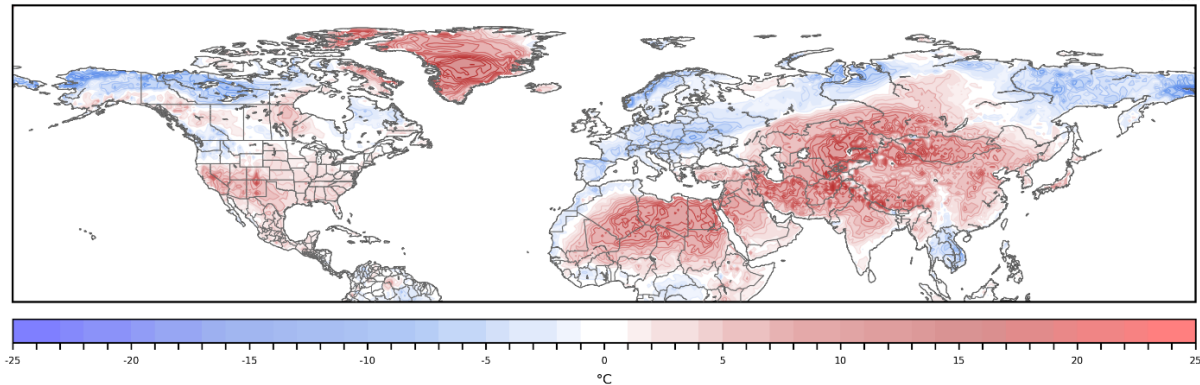


Figure 6. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 3 – 7 April 2022. The forecasts are from the 00Z 28 March 2022 GFS ensemble.

Across western North America ridging/positive geopotential height anomalies will briefly relax resulting in troughing/negative geopotential height anomalies across Alaska and Northern Canada with ridging/positive geopotential height anomalies across the US (**Figure 5**). This will favor normal to below normal temperatures across Alaska, Canada and the Northwestern US with normal to above normal temperatures across much of the US (**Figure 6**).

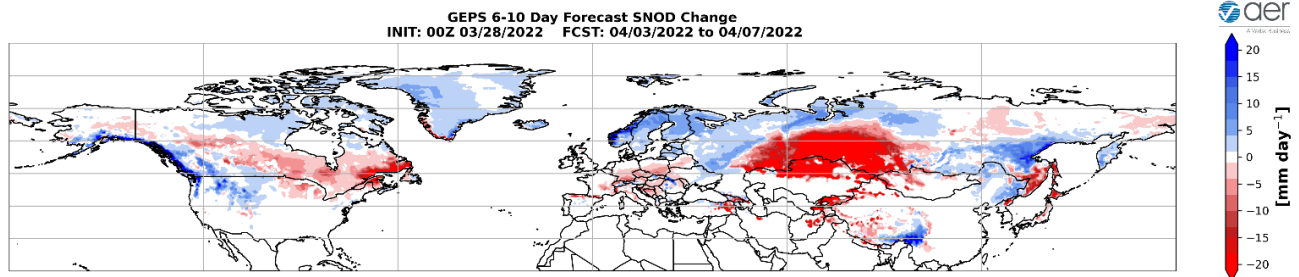


Figure 7. Forecasted snow depth changes (mm/day; shading) from 3 – 7 April 2022. The forecast is from the 00Z 28 March 2022 GEPS ensemble.

Persistent Greenland blocking will support late season snowfall across Northern Europe and UK, Northern Asia, Tibet/Southwest China, Western and Northern Canada and the Rockies with snowmelt in Central Europe and Asia and Southern Canada (**Figure 7**).

11-15 day

Negative geopotential height anomalies are predicted to become widespread across the North Atlantic and Eurasian sides of the Arctic with positive geopotential height anomalies across the North Pacific side of the Arctic (**Figure 8**), therefore the AO

should remain near neutral this period (**Figure 1**). With predicted weak positive pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO is also predicted to be near neutral this period.

GEFS 11-15 Day Forecast 500 mb GPH/GPH Anomaly
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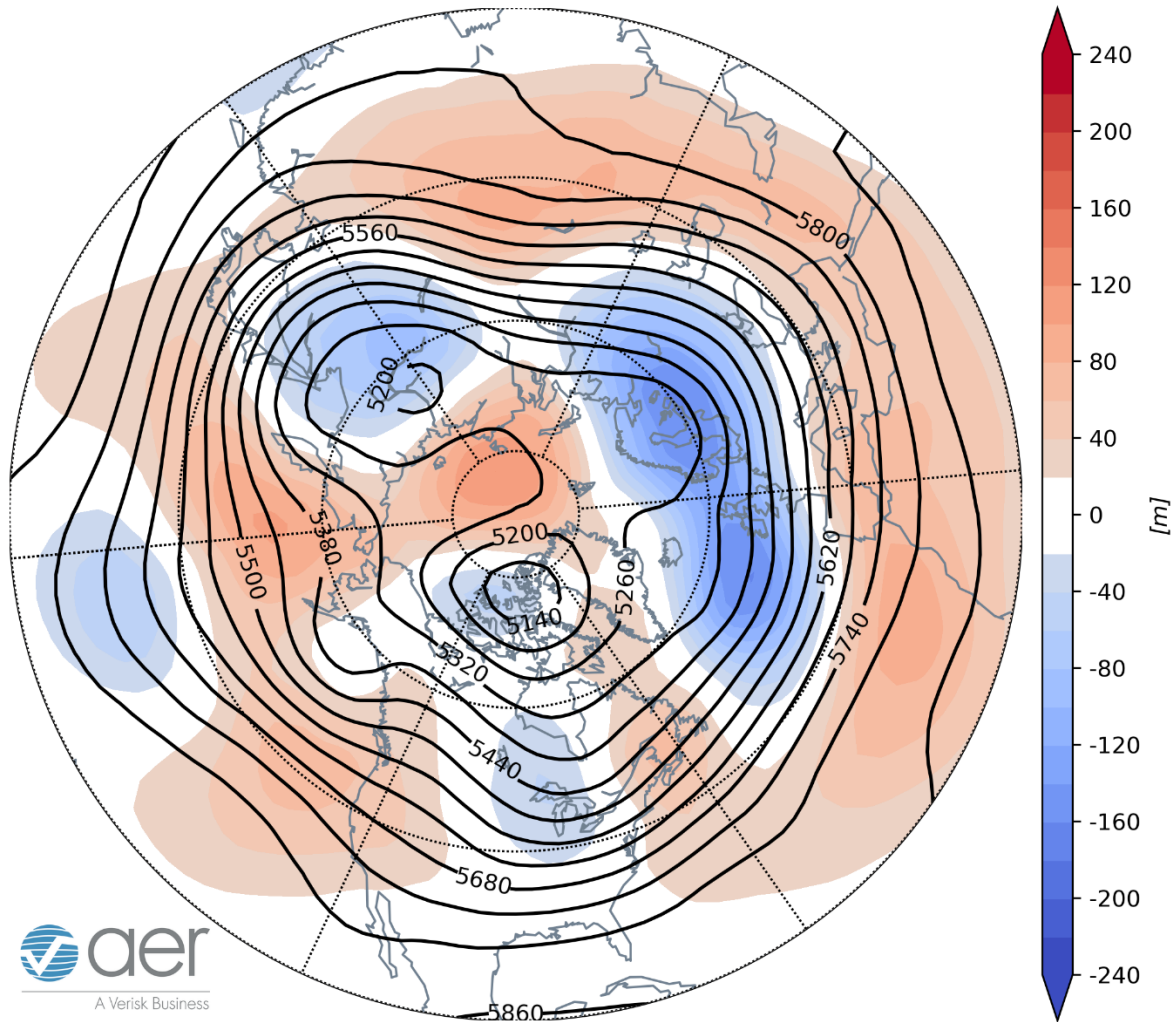


Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 8 – 12 April 2022. The forecasts are from the 00z 28 March 2022 GFS ensemble.

Persistent but weakening ridging/positive geopotential height anomalies across Greenland will continue to support troughing/negative geopotential height anomalies across Northern Europe with ridging/positive geopotential height anomalies across Southern Europe this period (**Figure 8**). This pattern favors more normal to below normal temperatures widespread across Northern Europe including the UK with normal to above normal temperatures across the Mediterranean countries across Southern Europe (**Figures 9**). The pattern of troughing/negative geopotential height anomalies

across Northern Asia with ridging/positive geopotential height anomalies across Southern Asia is predicted to persist this period (**Figure 8**). This pattern favors widespread normal to below normal temperatures across much of Northern Asia with normal to above normal temperatures across Southern Asia (**Figure 9**).

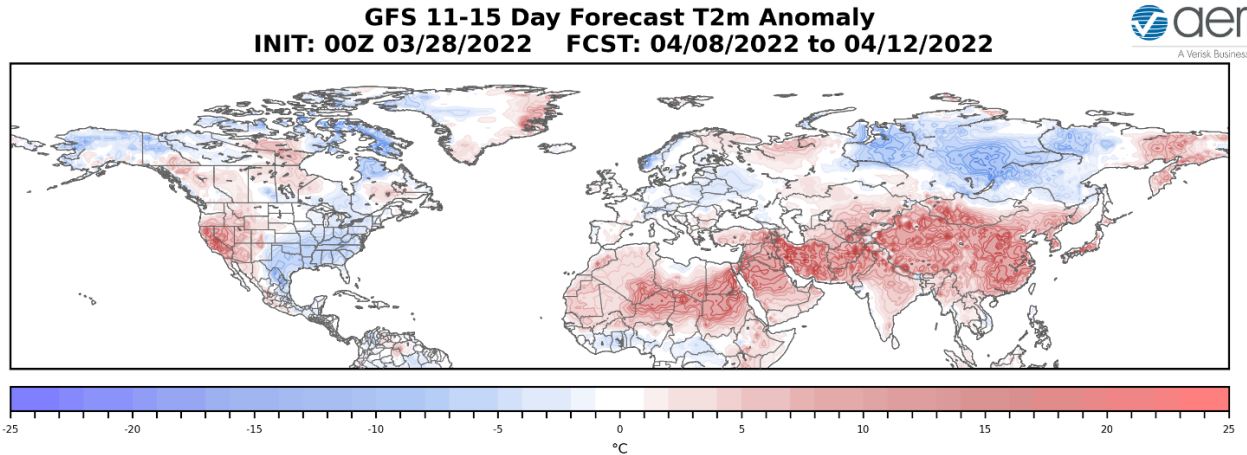


Figure 9. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 8 – 12 April 2022. The forecasts are from the 00z 28 March 2022 GFS ensemble.

The pattern across North America of ridging/positive geopotential height anomalies across Alaska and Western Canada and the Western US with troughing/negative geopotential height anomalies across Central and Eastern Canada that extends southwards into the Central US is predicted to return this period (**Figure 8**). This pattern favors normal to below normal temperatures across Alaska, Central and Eastern Canada and the Eastern US with normal to above normal temperatures in Western Canada and the Western US (**Figure 9**).

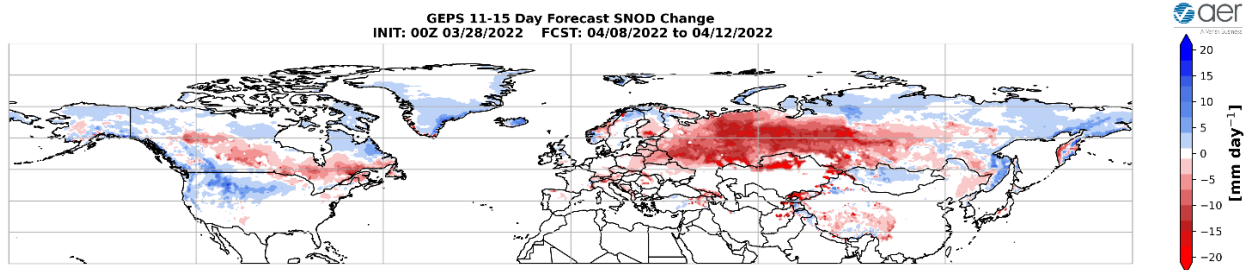


Figure 10. Forecasted snow depth changes (mm/day; shading) from 8 – 12 April 2022. The forecast is from the 00Z 14 March 2022 GEPS ensemble.

Snowmelt is predicted to remain widespread across Eurasia and North America with new snowfall limited to parts of Scandinavia, Siberia, Alaska, Western and Northern Canada and the Northwestern US (**Figure 10**).

Longer Term

30-day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows warm/positive PCHs throughout stratosphere and troposphere. Warm/positive PCHs are predicted to persist in the stratosphere for the foreseeable future (**Figure 11**). The largest positive departures in the upper stratosphere are predicted to descend to the mid-stratosphere and is related to a significant disruption to the PV (**Figure 11**). Meanwhile the warm/positive PCHs in the lower troposphere are predicted to transition to cold/negative PCHs next week (**Figure 11**).

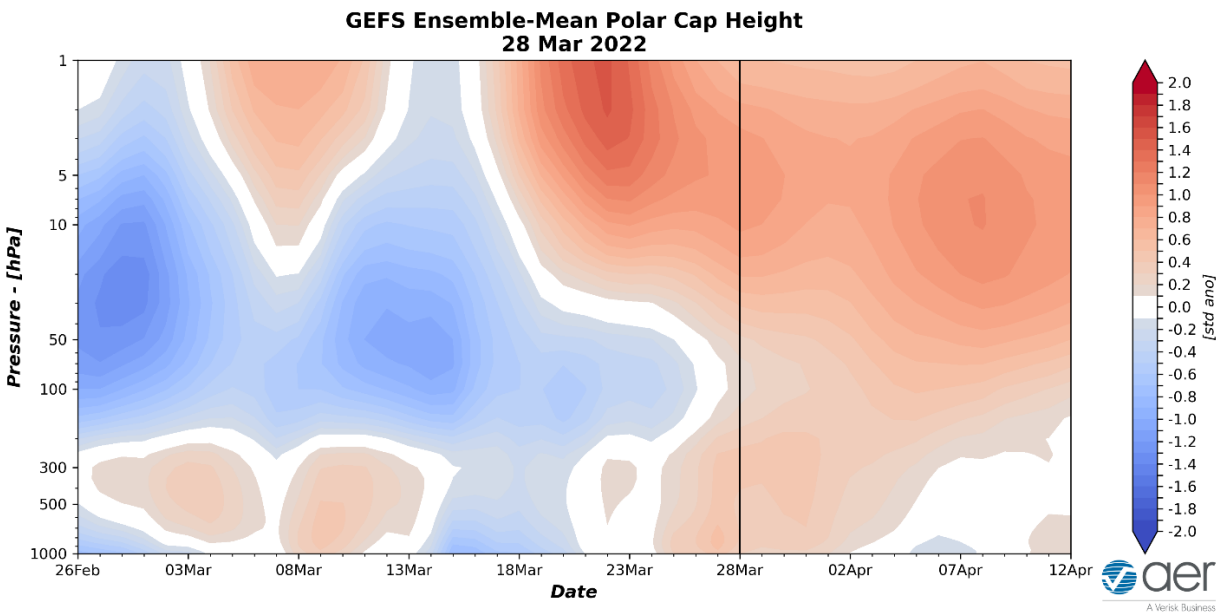


Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 28 March 2022 GFS ensemble.

The normal to above normal PCHs predicted this week in the lower troposphere are consistent with the predicted negative surface AO during the same period (**Figure 1**). The AO is predicted to transition next week to neutral to positive as PCHs become colder/more negative in the lower troposphere.

Though the largest pulse of the year in vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere is now over (**Figure 12**), more positive WAFz anomalies are predicted this week and will continue to support a relatively weak PV as suggested by the relatively warm PCHs in the stratosphere.

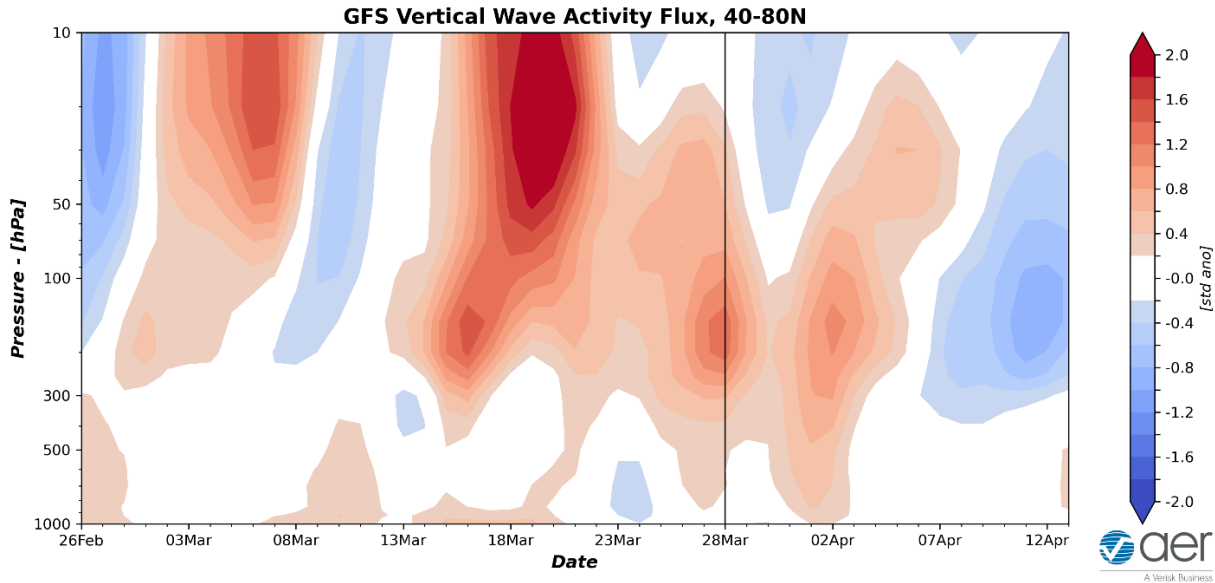


Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 28 March 2022 GFS ensemble.

The additional pulse of WAFz this week is likely to persist the current PV disruption long enough to qualify as a Final Warming (but is analogous to a major sudden stratospheric warming where the zonal winds at 60°N and 10hPa reverse from westerly to easterly only temporarily). This is predicted to persist the negative stratospheric AO (**Figure 11**). Next week the WAFz is predicted to turn negative, and a positive pulse followed by negative WAFz values is characteristic of wave reflection that favors colder temperatures in eastern North America; something that I am monitoring.

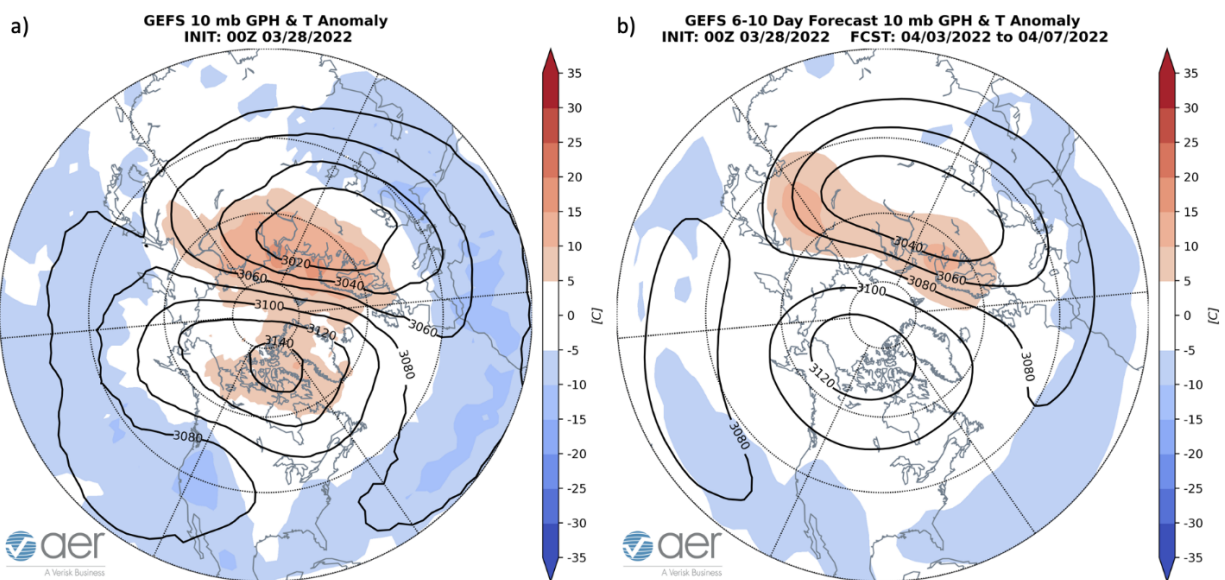


Figure 13. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere averaged for 28 March 2022. (b) Same as (a) except forecasted averaged from 3 – 7 April 2022. The forecasts are from the 00Z 28 March 2022 GFS model ensemble.

The PV is already disrupted because of the strong pulses of WAFz earlier this month (**Figure 12**). The PV is displaced towards Urals and spread across much of northern Eurasia with polar stratospheric warming spread across much of Arctic with ridging centered across the Canadian Archipelagos (**Figure 13a**). Little is predicted to change across the polar stratosphere over the next two weeks with the PV center spread across northern Eurasia with ridging across the North American Arctic (see **Figure 13b**).

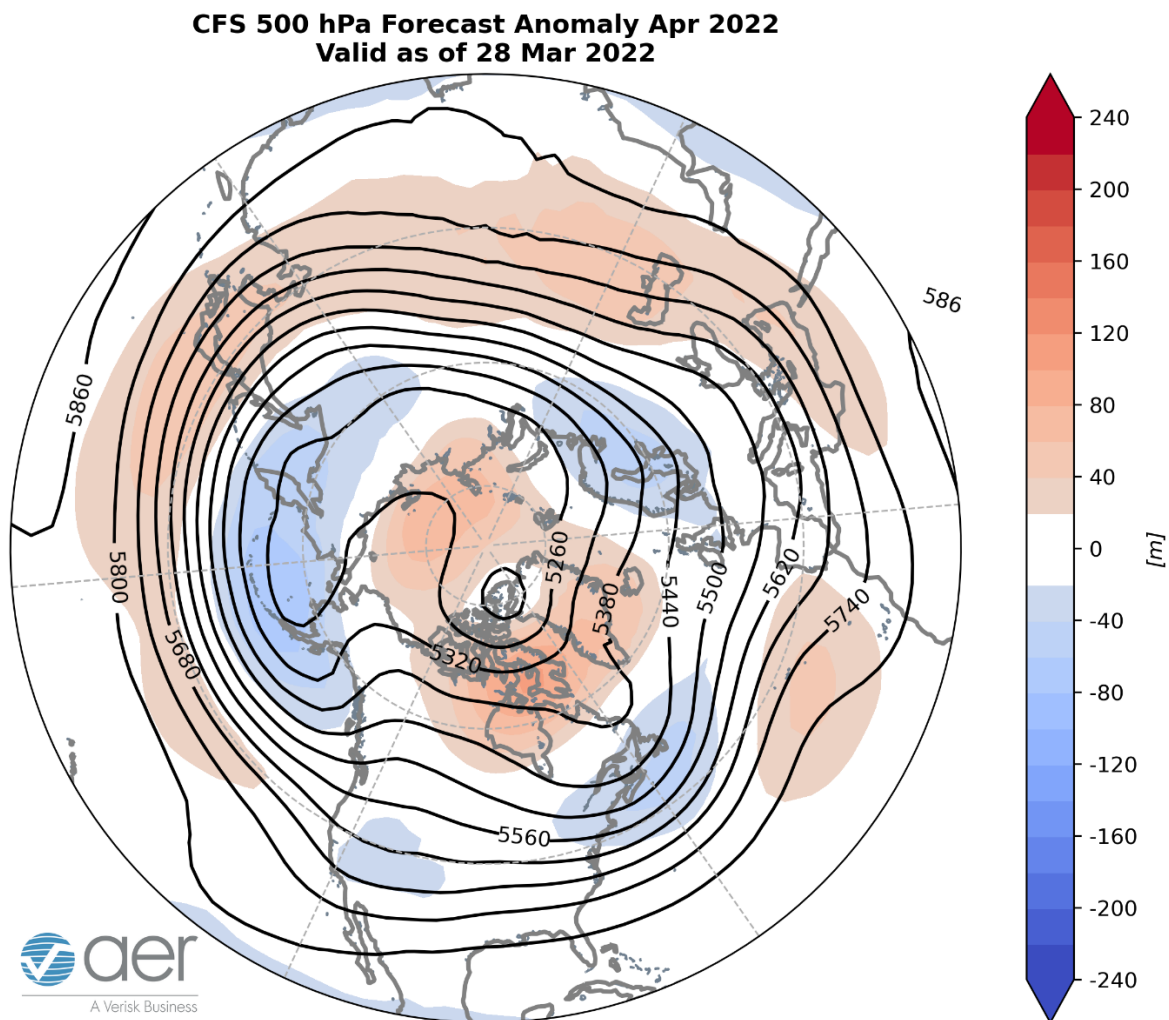


Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for April 2022. The forecasts are from the 00Z 28 March 2022 CFS.

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 over the eastern North Atlantic, the Central Arctic and Southern Asia with troughing across Europe, Northern Asia, the Aleutians, the Gulf of Alaska into the west coast of the US, Eastern Canada and the Northeastern US (**Figure 14**). This pattern favors seasonable to relatively warm temperatures across the Mediterranean, the Middle East, Southern and Central Asia, Alaska, Northern Canada and the Southwestern US with seasonable to relatively cool temperatures across Europe, Northern Asia, Southern Canada and the Eastern US (**Figure 15**).

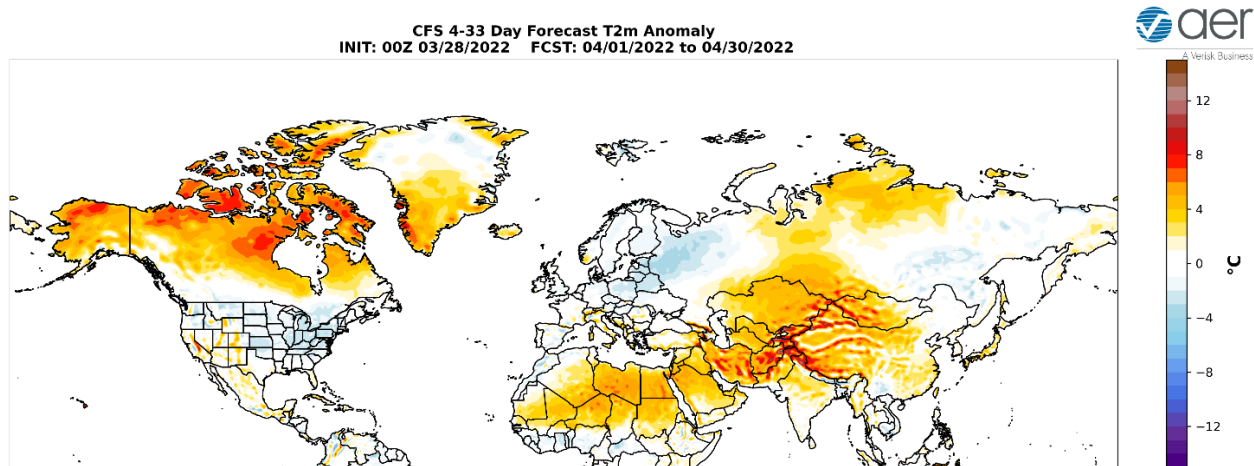


Figure 15. Forecasted average surface temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere for April 2022. The forecasts are from the 00Z 28 March 2022 CFS.

Surface Boundary Conditions

SSTs/El Niño/Southern Oscillation

Equatorial Pacific Sea surface temperatures (SSTs) anomalies are below normal and we continue to observe weak to possibly moderate La Niña conditions (**Figure 16**) and La Niña conditions are expected into 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 and offshore of eastern North America though below normal SSTs exist regionally especially in the North Pacific. Not my expertise but the SST pattern in the North Pacific are strongly resembling a negative Pacific Decadal Oscillation (PDO) pattern that favors colder temperatures across northwestern North America and milder temperatures across southeastern North America.

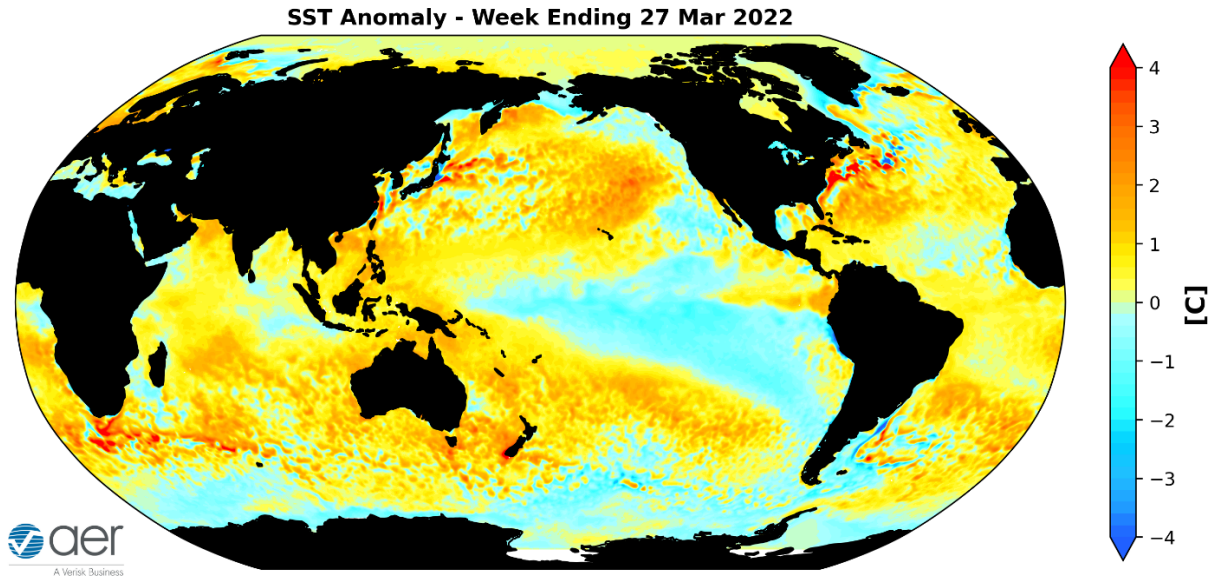


Figure 16. The latest weekly-mean global SST anomalies (ending 27 March 2022).
Data from NOAA OI High-Resolution dataset.

Currently NO PHASE OF the Madden Julian Oscillation (MJO) is favored (**Figure 17**). The forecasts are for the MJO to remain weak where no phase is favored. Therefore it is hard to for me to see that the MJO is likely influencing the weather across North America. But admittedly this is outside of my expertise.

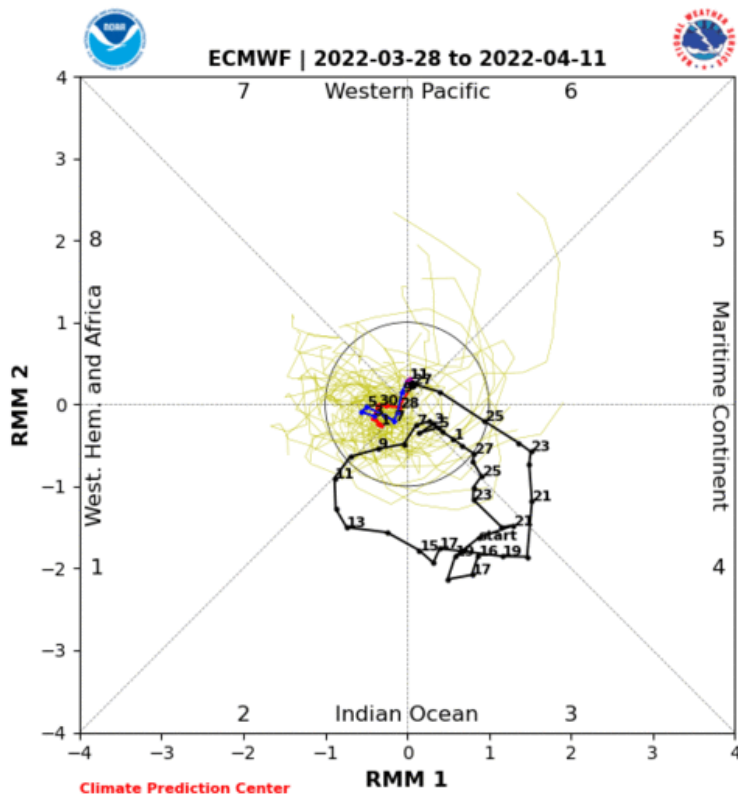


Figure 17. Past and forecast values of the MJO index. Forecast values from the 00Z 28 March ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model “spread” is denoted by the gray shading. Sector numbers indicate the phase of the MJO, with geographical labels indicating where anomalous convection occurs during that phase. Image source: <http://www.atmos.albany.edu/facstaff/roundy/waves/phasediags.html>

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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.

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