

Arctic Oscillation and Polar Vortex Analysis and Forecasts

February 21, 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 positive and is predicted to remain positive through mid-March with mostly negative 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 positive and is predicted to remain positive as pressure/geopotential height anomalies are predicted to remain negative across Greenland the next two weeks.
- The next two weeks, troughing/negative geopotential height anomalies across Greenland will favor ridging/positive geopotential height anomalies and/or zonal flow coupled with normal to above normal temperatures across much of Europe including the Southern United Kingdom (UK) with the possible exception of troughing/negative geopotential height anomalies coupled with normal to below normal temperatures across the Northern UK and Scandinavia.
- The dominant pattern across Asia the next two weeks is ridging/positive geopotential height anomalies across Southern Asia with troughing/negative

geopotential height anomalies across Northern Asia. This will result in a strong zonal flow across Asia favoring widespread normal to above normal temperatures across Asia. One possible exception is troughing/negative geopotential height anomalies coupled with normal to below normal temperatures across Northern Siberia.

- The general pattern across North America the next two weeks is ridging/positive geopotential height anomalies in the Gulf of Alaska and Alaska anchoring troughing/negative geopotential height anomalies across Eastern Canada that extends southwestward into the Western United States (US) with more ridging/positive geopotential height anomalies in the Eastern US. This pattern mostly favors normal to above normal temperatures in Alaska, Northwest Canada and the Eastern US with normal to below normal temperatures across much of Canada and the Western United States. One exception will be next week when the Canadian troughing will extend into the Eastern US coupled with normal to below normal temperatures while ridging briefly returns to the Western US coupled with normal to above normal temperatures.
- In the *Impacts* section I continue to discuss my expectations of another possible stretched polar vortex (PV) event (the sixth for those keeping score at home) in midst of an indomitable PV overall and the related weather of the Northern Hemisphere (NH) into mid-March.

Plain Language Summary

Looks like spring wants to get a jump on Europe and Asia where the weather is more sensitive to the overall strong polar vortex and positive surface AO. Across North America relatively cold temperatures appear to be more persistent with Canada remaining a reservoir of cold that can enter the US when the polar vortex stretches or elongates driving cold air south. The fifth of the winter season is occurring this week, first bringing cold weather to the Western US but the cold air mass will make its way into the Eastern US by the end of the week. The question that I ask is, will there be a sixth stretching or elongation of the polar vortex in early March repeating the whole cycle. For now, I am favoring a sixth stretched polar vortex with the Eastern US firmly remaining on the weather roller coaster.

Impacts

Winter 2021/2022 is certainly giving new meaning to weather whiplash at least here in the Eastern US. 60's (Fahrenheit) one day followed by heavy snow and teens the next and then a couple of days later back into the 60's. Boston is the new Denver. Pretty strange if you ask me.

Even though winter is coming to an end the forecast challenges remain. I think the easier forecast is for Eurasia. As I have been saying for a while, winter in Europe pretty much looks done, with the possible exception following a sudden stratospheric

warming or an early Final Warming. And though it did look like the tropospheric circulation pattern was becoming more conducive to disrupting the polar vortex (PV) but that is looking less likely today. There were signs of a return of Scandinavian ridging/high pressure last week but not so much today. Instead, we have a circulation consistent with a positive AO, low geopotential heights to the north coupled with high geopotential heights to the south resulting in a mild zonal flow across all of Eurasia. This pattern is unlikely to force a major disruption of the PV. And as I have mentioned before it seems regardless, if the winter is mild or severe across Eurasia, spring advances across Eurasia aggressively and hard for me to remember the last relatively cold spring across Eurasia.

My thinking about the relationship between the stratospheric PV and/or the AO and the weather is stronger for Eurasia especially Europe than North America. The persistently strong PV that has at least sporadically coupled with a positive surface AO is dominating the weather across Eurasia with widespread relatively mild temperatures. North America less so and cold temperatures can exist even be widespread if the stratospheric PV stretches or becomes elongated. The same is true for Central to East Asia as witnessed by cold winter Olympics in Beijing the past two weeks but at least based on the GFS forecasts, though cold weather persists in North America, it is predicted to dissipate in East Asia.

As has been the case all winter in eastern North America, especially the Eastern US, when the strong PV is circular then it is mild, but if the PV stretches or elongates resulting in cross polar flow from Siberia east of the Rockies, even despite a relatively strong PV, it turns colder and is often accompanied by new snowfall. The fifth stretched PV since January 1st is well underway and will drag the cold air in Canada and the Western US into the Eastern US by the end of the week with one or possibly two chances of snow. But as has been the case all winter, as long as the PV remains strong, the cold and snow is ephemeral and will last for only a few days and milder temperatures quickly return, so the weather roller coaster continues.

If five different stretched PVs have occurred this winter (the fifth is currently occurring and can be seen in **Figure 13a**) can a sixth occur in early March? I think according to the Canadian ensembles and maybe even the ECMWF the answer seems to be increasingly yes, but the GFS configuration of the PV looks to become more circular and therefore no. If we have a sixth stretched PV then I would expect the predicted developing trough in the Western US the end of next week to propagate to the east into the Eastern US and with it the return of colder temperatures. The theme of this winter has been “lather, rinse, repeat” in the Eastern US in sync with a circular followed by an elongated or stretched PV and then the whole cycle repeats on a continuous loop. This late into the winter I see no compelling reason to anticipate a cessation of the cycle but my understanding of what is fully going on with the circulation is limited. So, my forecast for now is the overly simplistic “the trend is your friend” but that’s the best I got

for now. This whole cycle will eventually end if vertical wave energy is absorbed in the stratosphere instead of being reflected and/or the Final warming occurs.

I will just conclude that is an impressive ridge/blocking high pressure the models are predicting in the Gulf of Alaska and Alaska. It should result in highly anomalous weather, if nothing else some unseasonable warm temperatures to Alaska but what about cold temperatures downstream? The predicted southwest to northeast tilt of the ridge suggests to me more of a Rex block (high pressure to the north with low pressure to the south), which would then favor cold temperatures across Southwest Canada and the Northwestern US. But the ridge could take on more of a full longitude ridge favoring cold temperatures east of the Rockies and eventually the whole Alaskan block can cut off from the Jet Stream becoming an island onto itself with zonal flow to the south and the US turns mild coast-to-coast. So, lots of possibilities and is likely related to whether the PV is stretched or not and maybe all three possibilities will play out over time.

1-5 day

The AO is predicted to be positive this week (**Figure 1**) as geopotential height anomalies are predicted to be negative 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 negative geopotential height anomalies predicted across Greenland (**Figure 2**), the NAO is also predicted to be positive this week (**Figure 1**).

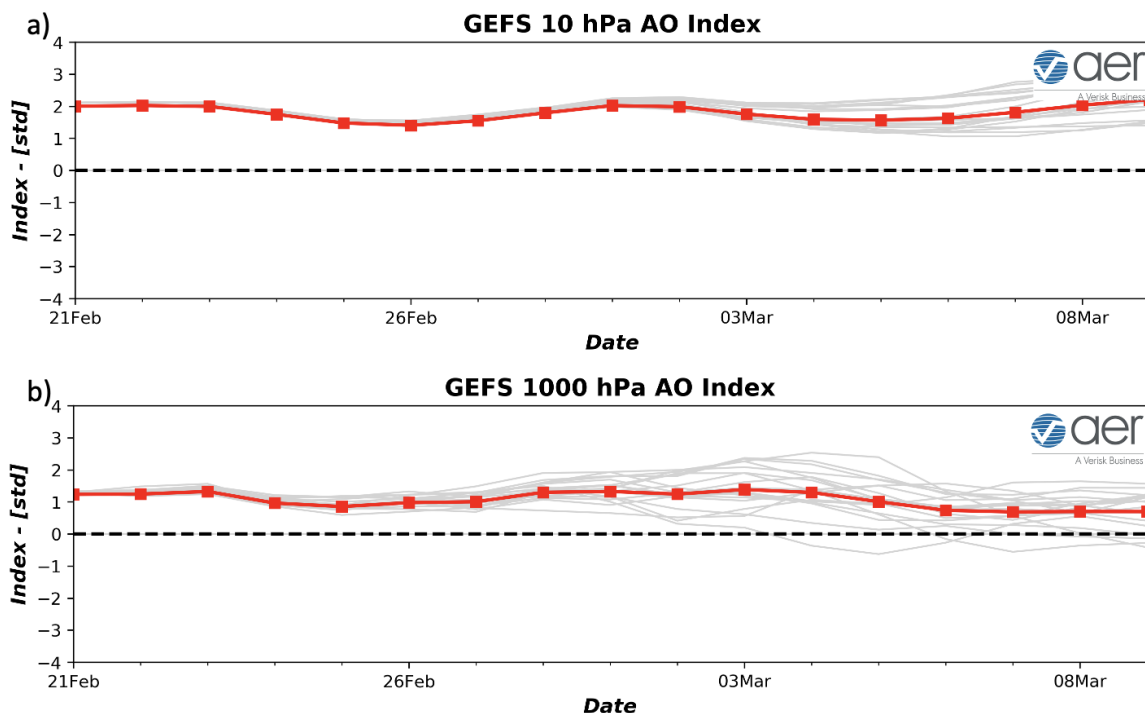


Figure 1. (a) The predicted daily-mean AO at 1000 hPa from the 00Z 21 February 2022 GFS ensemble. **(b)**The predicted daily-mean near-surface AO from the 00Z 21 February 2022 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

This week, troughing/negative geopotential height anomalies across Greenland will contribute to ridging/positive geopotential height anomalies across Central and Southern Europe with troughing/negative geopotential height anomalies across Northern Europe this period (**Figures 2**). This pattern will result in normal to above normal temperatures across most of Europe with normal to below normal temperatures limited to Scandinavia (**Figure 3**). This week, a mostly zonal flow pattern is predicted across Asia with ridging/positive geopotential height anomalies dominating much of Southern Asia with troughing/negative geopotential height anomalies across Northern Asia (**Figure 2**). This pattern favors widespread normal to above normal temperatures across much of Asia with the exception of troughing/negative geopotential height anomalies coupled with normal to below normal temperatures across Southeast Asia (**Figure 3**).

GEFS 1-5 Day Forecast 500 mb GPH/GPH Anomaly
INIT: 00Z 02/21/2022 FCST: 02/22/2022 to 02/26/2022

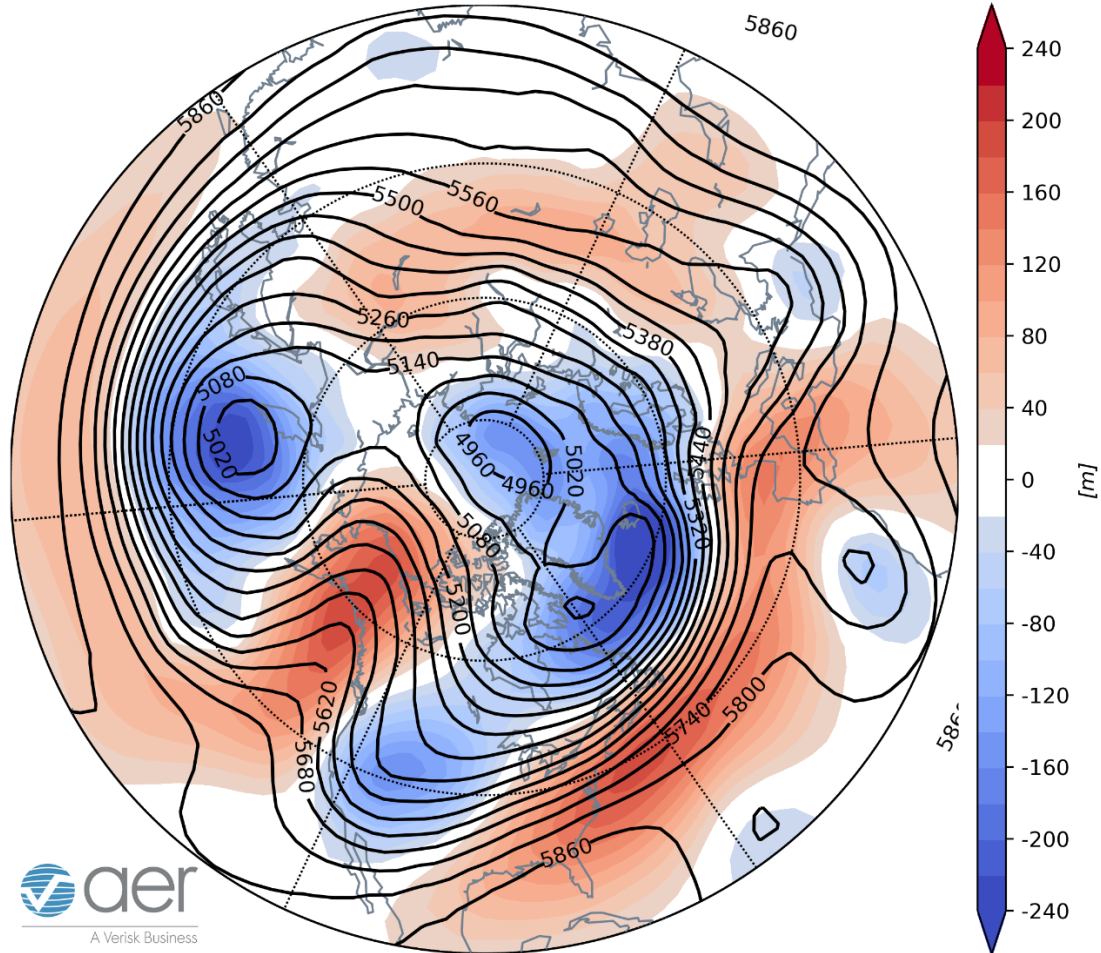


Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 22 – 26 February 2022. The forecasts are from the 00z 21 February 2022 GFS ensemble.

This week, the predicted pattern across North America is ridging/positive geopotential height anomalies in the Gulf of Alaska and Alaska with downstream troughing/negative geopotential height anomalies across the interior of Canada and extending southwestwards into the Western US with more ridging/positive geopotential height anomalies in the Eastern US (**Figure 2**). This will favor normal to above normal temperatures across Alaska, Northwestern Canada and the US East Coast with normal to below normal temperatures across much of Canada and the Western and Central US (**Figure 3**).

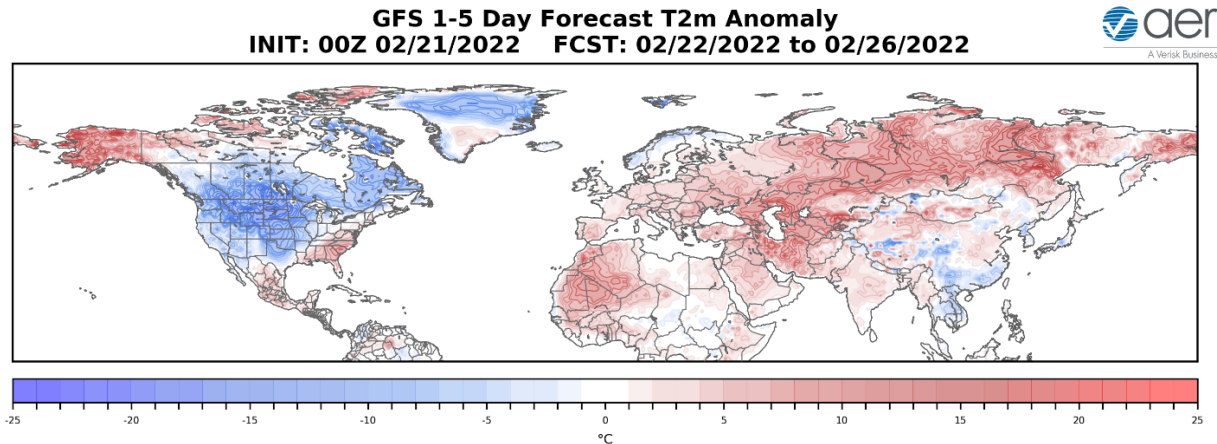


Figure 3. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 22 – 26 February 2022. The forecast is from the 00Z 21 February 2022 GFS ensemble.

Trouging and/or cold temperatures are predicted to support new snowfall across Scotland, Norway, Eastern Siberia and the Tibetan Plateau while mild temperatures promote snowmelt in Eastern Europe and Central Asia (**Figure 4**). Trouging and/or cold temperatures are predicted to support new snowfall across the interior of Alaska, Southern and Eastern Canada and the US Great Lakes and Northeast while mild temperatures promote snowmelt in Alaska, Western Canada and the Western US (**Figure 4**).

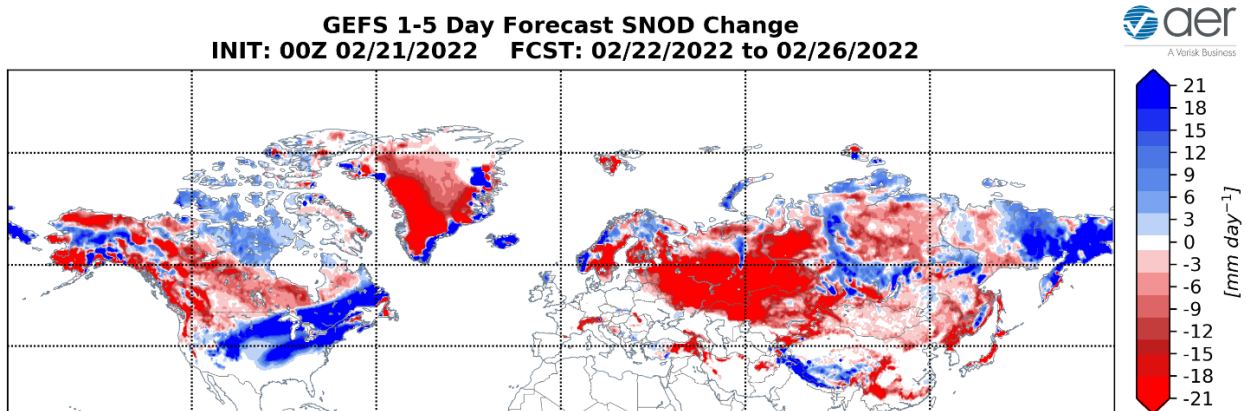


Figure 4. Forecasted snow depth changes (mm/day ; shading) from 22 – 26 February 2022. The forecast is from the 00Z 21 February 2022 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to remain positive this period (**Figure 1**) with mostly negative geopotential height anomalies spread across the Arctic especially the North Atlantic side of 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 positive this period.

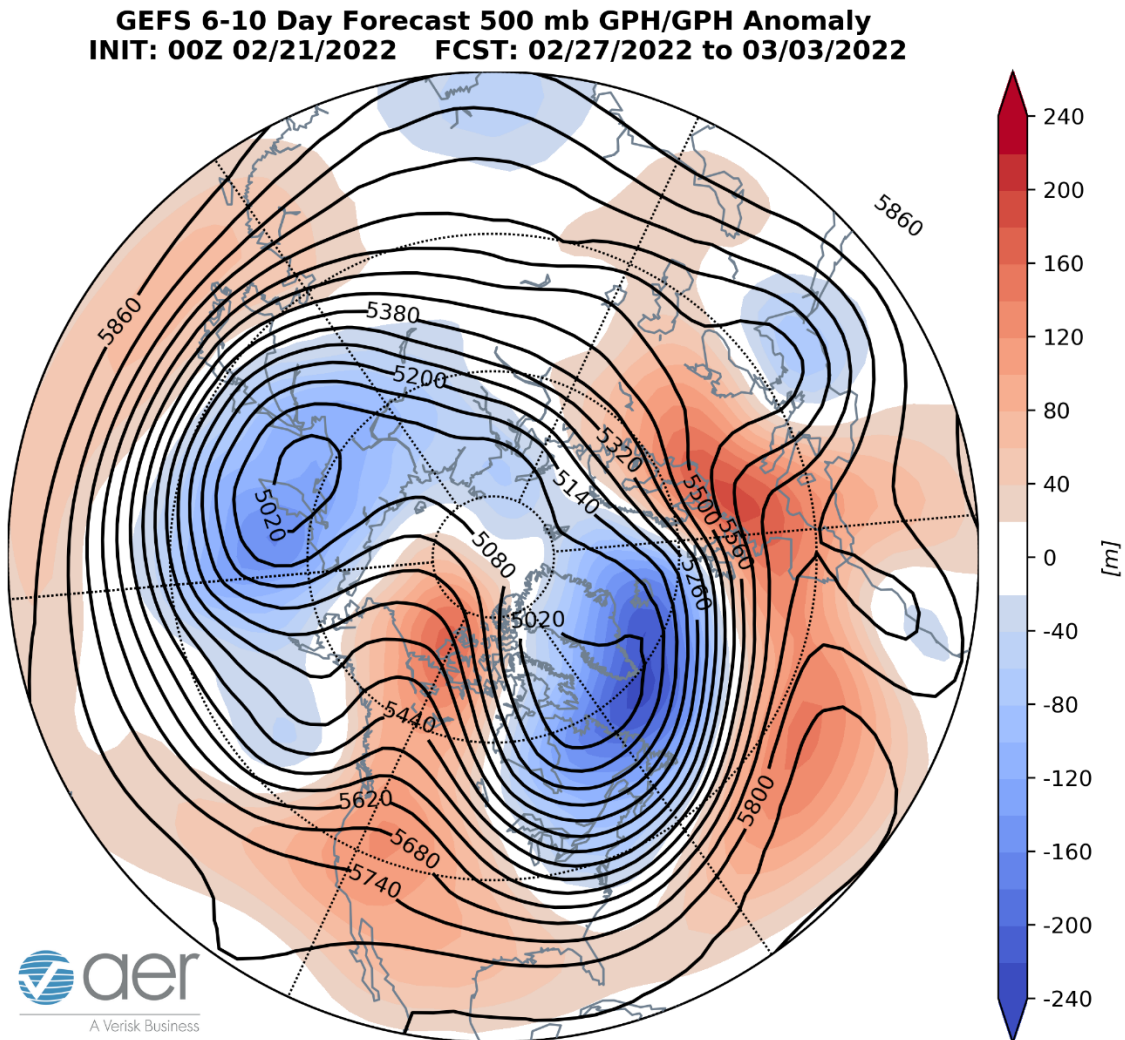


Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 27 February – 3 March 2022. The forecasts are from the 00z 21 February 2022 GFS ensemble.

Persistent troughing/negative geopotential height anomalies across Greenland will support widespread ridging/positive geopotential height anomalies across much of Europe with the limited exception of troughing/negative geopotential height anomalies across the Northern British Isles (**Figures 5**). This will result in normal to above normal

temperatures across almost all of Europe including the Southern UK with normal to below normal temperatures limited to the Northern UK due to low heights (**Figure 6**). Ridging/positive geopotential height anomalies are predicted to remain widespread across Southern Asia with troughing/negative geopotential height anomalies across Northern Asia this period (**Figure 5**). This mostly zonal flow pattern favors widespread normal to above normal temperatures across Asia with normal to below normal temperatures limited to parts of Eastern Asia and the Tibetan Plateau (**Figure 6**).

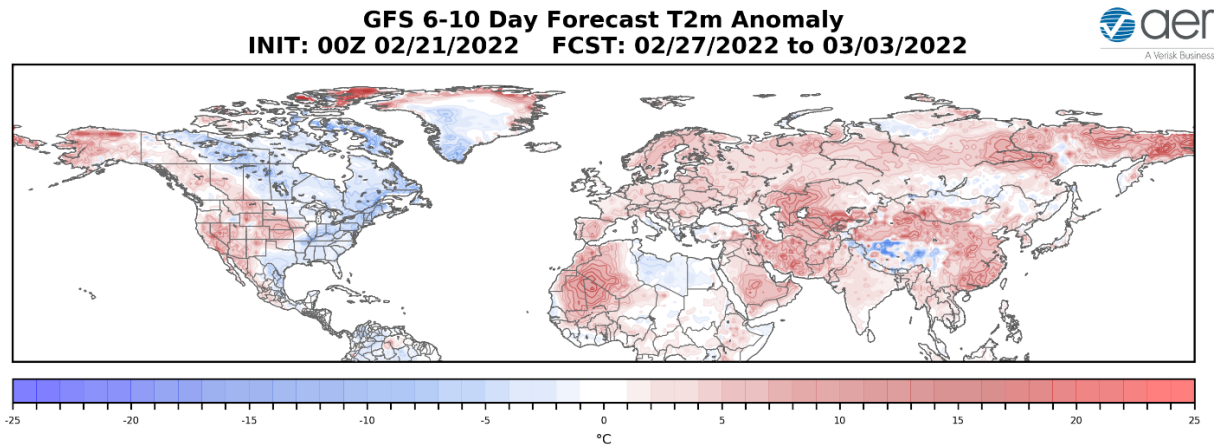


Figure 6. Forecasted surface temperature anomalies (°C; shading) from 27 February – 3 March 2022. The forecasts are from the 00Z 21 February 2022 GFS ensemble.

Ridging/positive geopotential height anomalies are predicted to persist in the Gulf of Alaska, Alaska, Western Canada and the Western US this period helping to anchor troughing/negative geopotential height anomalies across Eastern Canada and the Eastern US (**Figure 5**). This will favor normal to above normal temperatures across Alaska, Western Canada and the Western US with normal to below normal temperatures in Eastern Canada and the Eastern US (**Figure 6**).

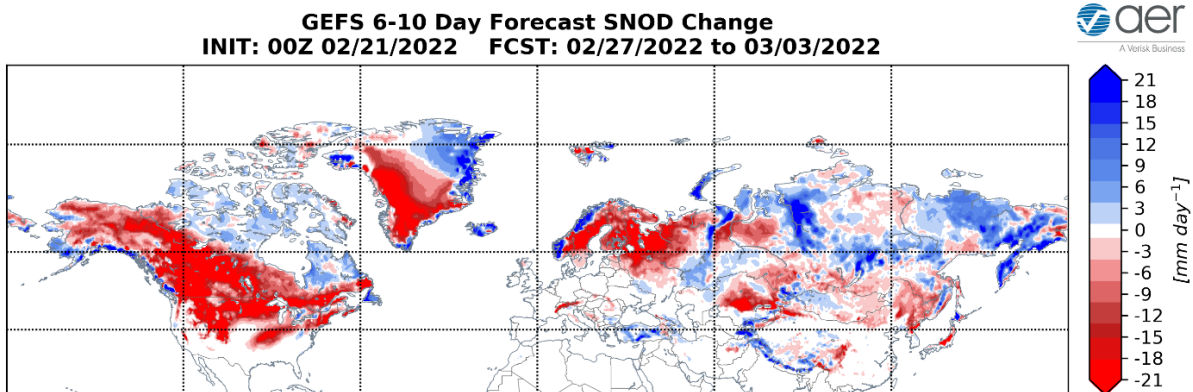


Figure 7. Forecasted snow depth changes (mm/day; shading) from 27 February – 3 March 2022. The forecast is from the 00Z 21 February 2022 GFS ensemble.

Trouching and/or cold temperatures are predicted to support new snowfall across Norway, Northern Asia and the Tibetan Plateau while milder temperatures promote snowmelt across Sweden, Finland and Central Asia (**Figure 7**). Trouching and/or cold temperatures are predicted to support new snowfall across Southern Alaska, the West Coast of Canada and Northeastern Canada while milder temperatures promote snowmelt across much of Alaska, Western and Southern Canada and the Western and Northern US (**Figure 7**).

11-15 day

Negative geopotential height anomalies are predicted to remain widespread across the North Atlantic and Eurasian sides of the Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 8**), therefore the AO should remain positive this period (**Figure 1**). With predicted mostly negative pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO is forecasted to remain positive this period.

GEFS 11-15 Day Forecast 500 mb GPH/GPH Anomaly
INIT: 00Z 02/21/2022 FCST: 03/04/2022 to 03/08/2022

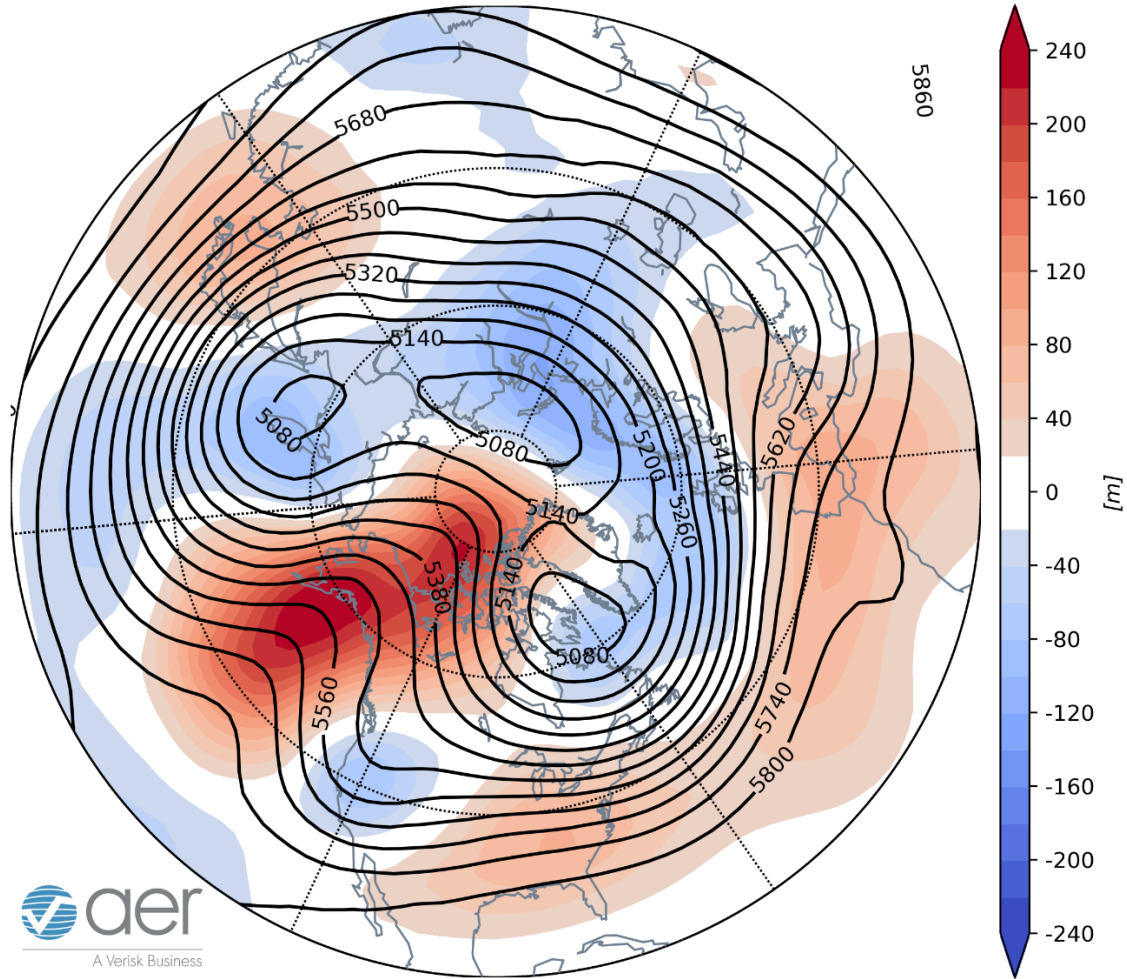


Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 4 – 8 March 2022. The forecasts are from the 00z 21 February 2022 GFS ensemble.

Persistent troughing/negative geopotential height anomalies across Greenland will continue to support ridging/positive geopotential height anomalies across much of Central and Southern Europe with troughing/negative geopotential height anomalies across Northern Europe this period (**Figure 8**). The resultant zonal flow pattern favors more normal to above normal temperatures across much of Europe including the Southern UK with normal to below normal temperatures limited across the Northern UK and Scandinavia due to low geopotential heights (**Figures 9**). The mostly zonal flow is predicted to persist across Asia this period with ridging/positive geopotential height anomalies widespread cross Southern Asia with troughing/negative geopotential height anomalies across Northern Asia (**Figure 8**). This pattern favors widespread normal to above normal temperatures across much of Asia with normal to below normal

temperatures limited to the north slope of Asia due to low geopotential heights this period (**Figure 9**).

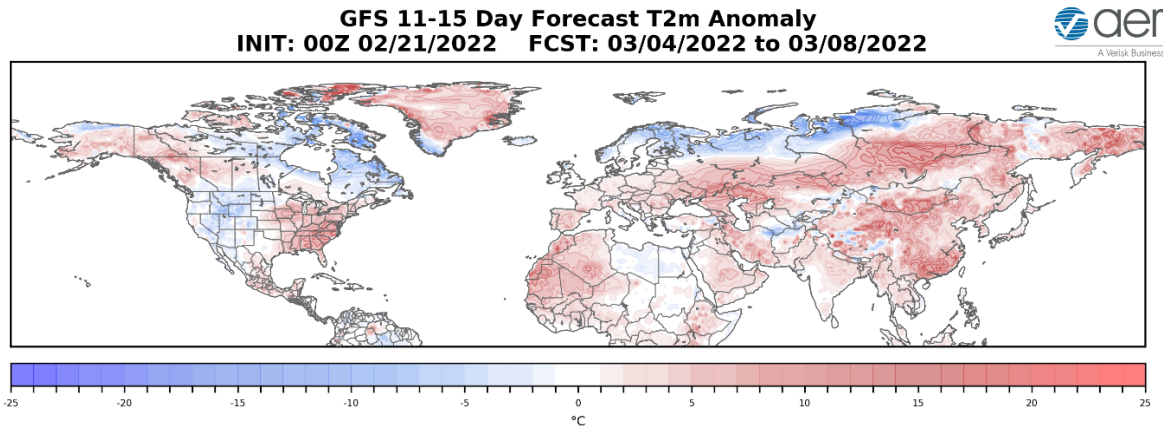


Figure 9. Forecasted surface temperature anomalies (°C; shading) from 4 – 8 March 2022. The forecasts are from the 00z 21 February 2022 GFS ensemble.

Ridging/positive geopotential height anomalies in the Gulf of Alaska, Alaska and Western Canada are predicted to persist and anchor troughing/negative geopotential height anomalies across Eastern Canada that extends into the Western US with more ridging/positive geopotential height anomalies across the Eastern US this period (**Figure 8**). This pattern favors normal to above normal temperatures across Alaska, Western Canada and the Eastern US with normal to below normal temperatures in much Eastern Canada and the Western US (**Figure 9**).

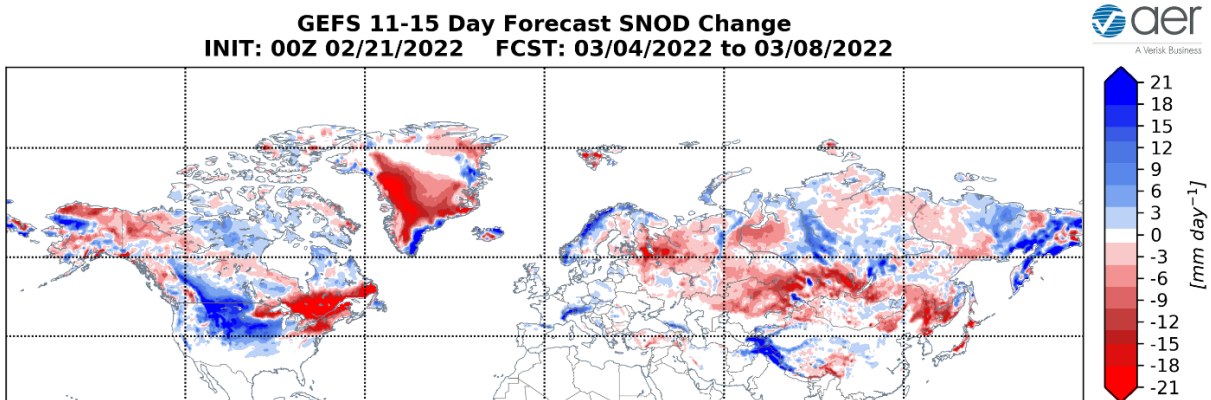


Figure 10. Forecasted snow depth changes (mm/day; shading) from 4 – 8 March 2022. The forecast is from the 00Z 21 February 2022 GFS ensemble.

Troughing and/or cold temperatures are predicted to support possible new snowfall across Norway, the Alps, Central Asia, Eastern Siberia and the Tibetan Plateau while

milder temperatures promote snowmelt across Eastern Europe and much of Asia (**Figure 10**). Troughing and/or cold temperatures are predicted to support possible new snowfall across parts of Alaska, the higher elevations of the US West Coast, the Rockies and the Plains of Canada and the US while milder temperatures promote snowmelt across parts of Alaska, Canada and the Northeastern US (**Figure 10**).

Longer Term

30-day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows cold/negative PCHs throughout the stratosphere and in the troposphere (**Figure 11**). The negative departures are predicted to deepen in the mid stratosphere this week into next week while PCHs in the troposphere are predicted to turn warm/positive the end of this week and into next week (**Figure 11**). Clearly the stratosphere and troposphere are coupled early this week but then will once again become increasingly uncoupled especially next week.

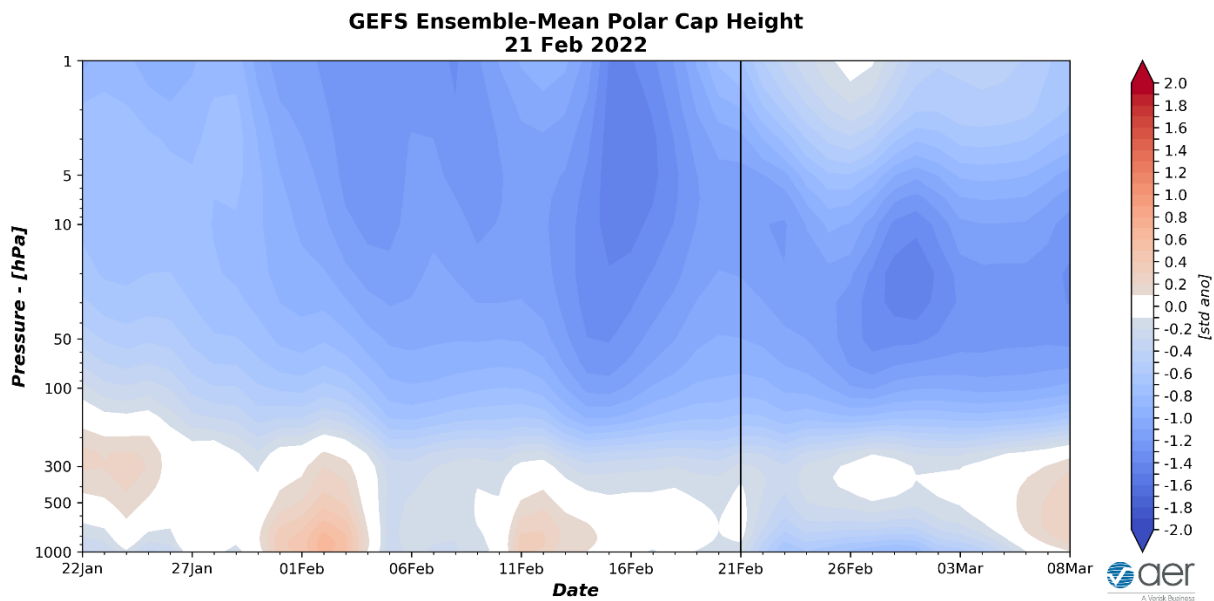


Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 21 February 2022 GFS ensemble.

The normal to below normal PCHs predicted in the lower troposphere for much of the next two weeks are consistent with the predicted positive surface AO during the same time period (**Figure 1**). Overall, the PCHs are indicating stratosphere-troposphere coupling at least for this week in contrast to much of the latter half of December and January.

The vertical Wave Activity Flux (WAFz) from the troposphere to the stratosphere or poleward heat transport in the stratosphere is predicted to remain mostly below normal through early-March (**Figure 12**). The negative WAFz anomalies predicted the next two weeks will continue to support a relatively strong PV through mid-March as suggested by the relatively cold stratospheric PCHs.

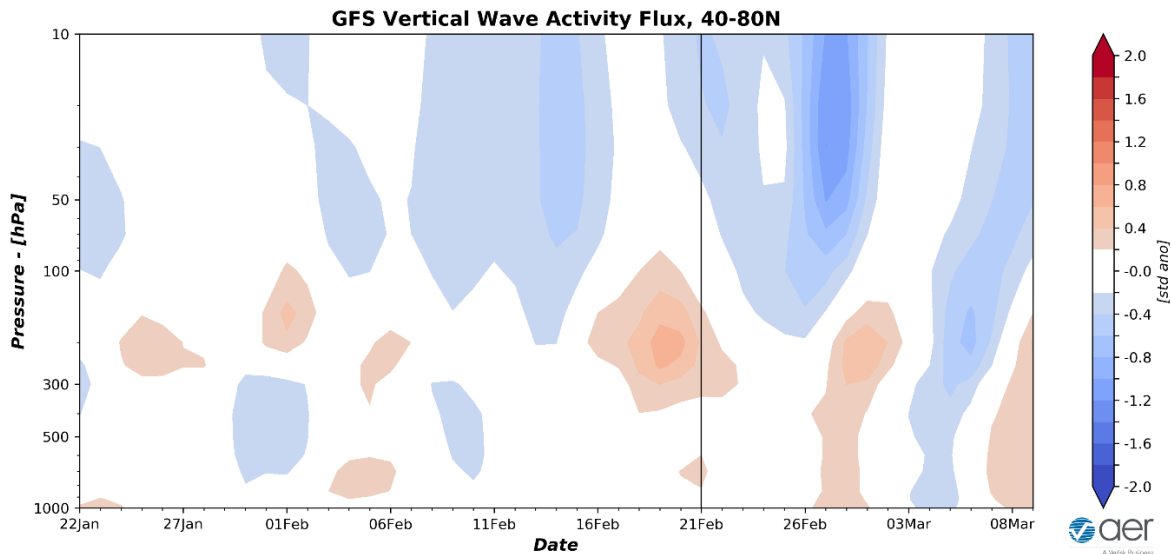


Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 21 February 2022 GFS ensemble.

Though zonally averaged WAFz has remained weak, a fifth stretched stratospheric PV since early January seems to be underway with the PV becoming more elongated in shape and centered between the North Pole and Greenland with ridging centered near the Dateline (**Figure 13a**). The elongated circulation from Siberia to east of the Rockies across North America this week (**Figure 13a**) will help drive cold temperatures in Canada and the Western US into the Central and Eastern US by the end of the week. However, the PV perturbation is relatively minor, allowing the PV to remain relatively strong resulting in a current positive stratospheric AO (**Figure 11**).

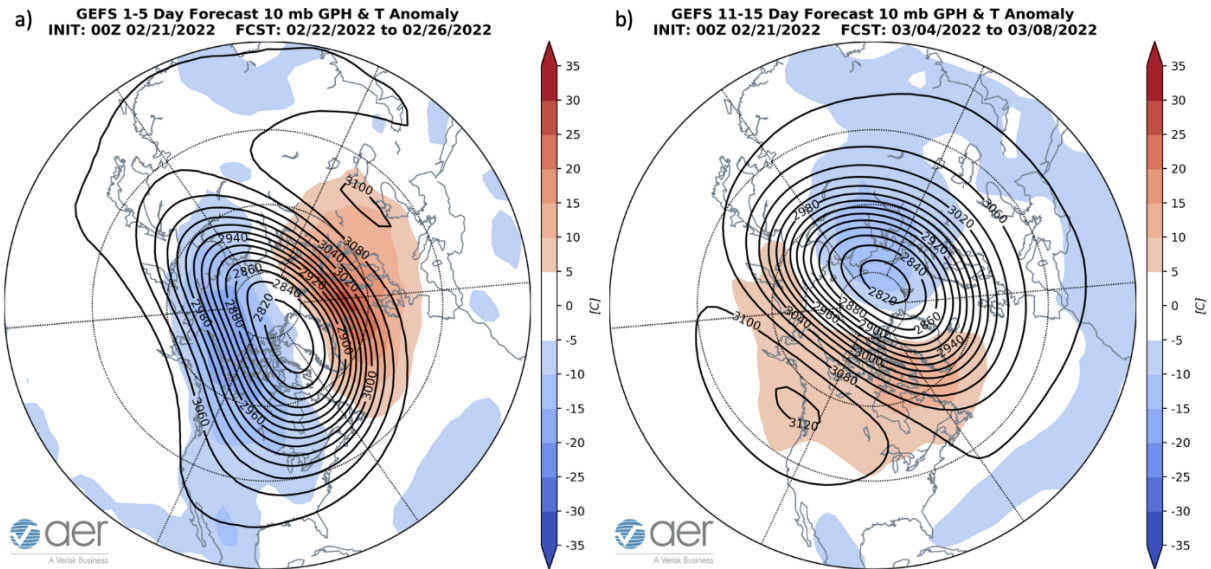


Figure 13. (a) Forecasted 10 mb geopotential heights (dam; contours) and temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere averaged from 22 – 26 February 2022. (b) Same as (a) except forecasted averaged from 4 – 8 March 2022. The forecasts are from the 00Z 21 February 2022 GFS model ensemble.

The below normal WAFz is predicted to allow the PV to remain strong with the PV returning to a position close to the North Pole with a persistent positive stratospheric AO the next two weeks (**Figure 11**). However, a relatively large warming coupled with ridging (compared to what has happened this winter and not other winters) is predicted across northwest North America (**Figure 13b**). There seems to be model disagreement on whether this could be yet a sixth stretched PV or not.

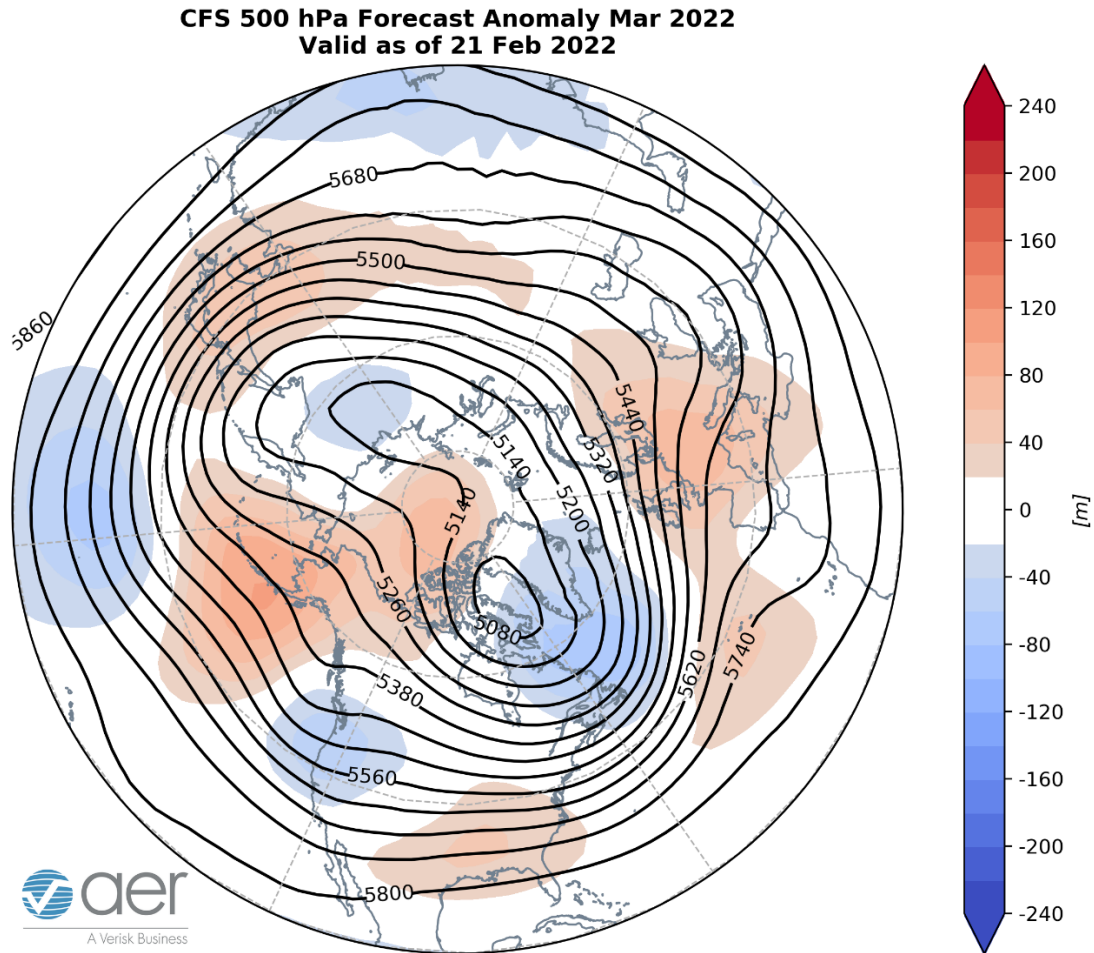


Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for March 2022. The forecasts are from the 00Z 21 February 2022 CFS.

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 over Europe, East Asia, the Aleutians, the Central Arctic, Eastern US with troughing across Southeastern Europe, Western Asia, Eastern Canada and the Western US (**Figure 14**). This pattern favors seasonable to relatively warm temperatures across Europe, most of Asia, Alaska, Northwestern Canada and the Southern and Eastern US with seasonable to relatively cold temperatures across the Middle East, Southeast Asia, much of Canada and the Northern and Western US (**Figure 15**).

CFS 8-38 Day Forecast T2m Anomaly
INIT: 00Z 02/21/2022 FCST: 03/01/2022 to 03/31/2022

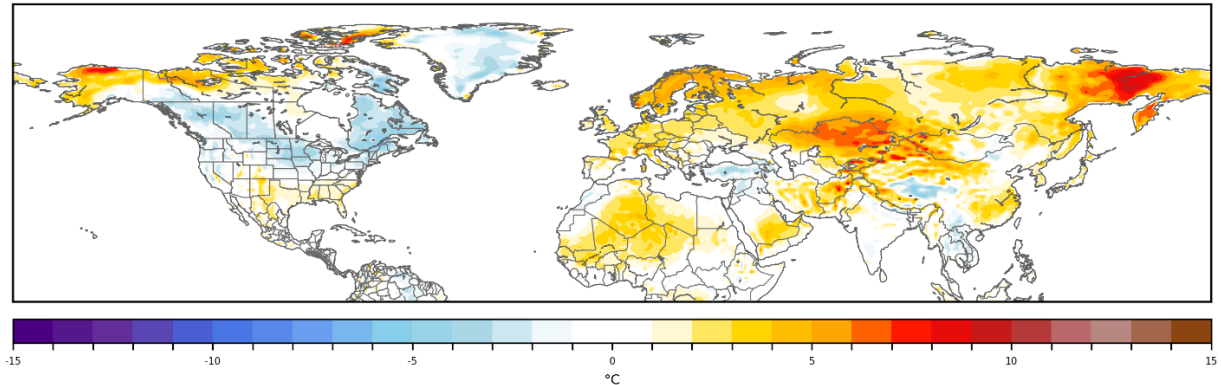


Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for March 2022. The forecasts are from the 00Z 21 February 2022 CFS.

Surface Boundary Conditions

Arctic Sea ice

Arctic sea ice growth has stalled and remains below normal mostly in Sea of Okhotsk and recently in the Barents Sea. Overall sea ice is relatively extensive compared to recent winters, though it remains relatively thin. In the Barents-Kara Seas extent is actually above normal. Below normal sea ice in the Barents-Kara seas favors cold temperatures in Central and East Asia, however this topic remains controversial. Recent research has shown that the regional anomalies that are most highly correlated with the strength of the stratospheric PV are across the Barents-Kara seas region where low Arctic sea ice favors a weaker winter PV. Low sea ice in the Chukchi, Beaufort and Bering seas may favor colder temperatures across North America but has not been shown to weaken the PV.

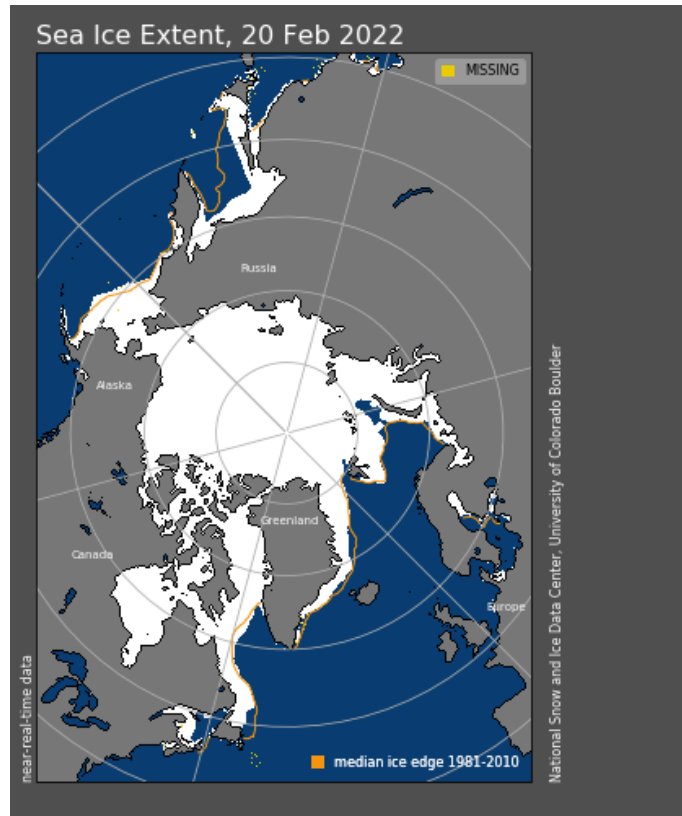


Figure 16. Observed Arctic sea ice extent on 20 February 2022 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image from the National Snow and Ice Data Center (NSIDC).

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 17**) 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.

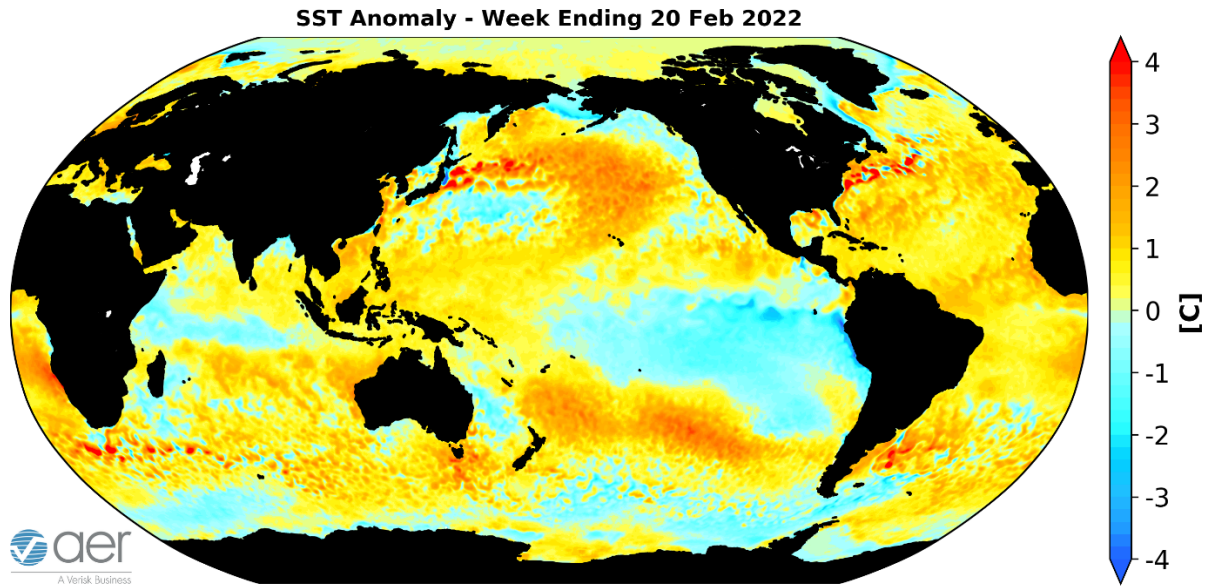


Figure 17. The latest weekly-mean global SST anomalies (ending 20 February 2022). Data from NOAA OI High-Resolution dataset.

Currently the Madden Julian Oscillation (MJO) is in phases three (**Figure 18**). The forecasts are for the MJO to eventually very briefly enter phase four and then weaken where no phase is favored. MJO phase three favors ridging in the Gulf of Alaska with downstream troughing across the interior of North America consistent with the forecasts and is likely influencing the weather across North America. But admittedly this is outside of my expertise.

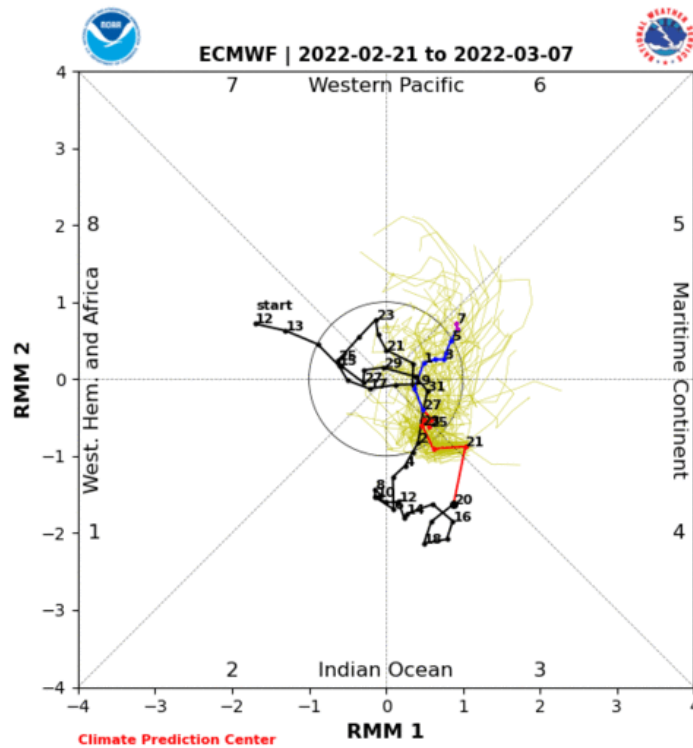


Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 21 February ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model “spread” is denoted by the gray shading. Sector numbers indicate 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>