Arctic Oscillation and Polar Vortex Analysis and Forecasts

January 24, 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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The AO/PV blog is partially supported by NSF grant AGS: 1657748.

Summary

- The Arctic Oscillation (AO) is currently positive and is predicted to remain positive through the end of the month and then straddle neutral in early February with mostly negative pressure/geopotential height anomalies through the end of January and then becoming increasingly positive in early February across 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 mostly negative across Greenland the next two weeks.
- Over the next two weeks, ridging/positive geopotential height anomalies centered west of and extending into the United Kingdom (UK) will force northwesterly flow across Central Europe and troughing/negative geopotential height anomalies across Eastern Europe. This will favor normal to below normal temperatures across Western and Eastern Europe including the UK with normal to above normal temperatures across Northern and Central Europe the next two week.
- The dominant pattern across Asia the next two weeks is troughing/negative geopotential height anomalies coupled with normal to below normal temperatures across Western and Southern Asia with ridging/positive geopotential height anomalies coupled with normal to above normal temperatures dominating across Siberia.
- The dominant pattern across North America this week is ridging/positive geopotential height anomalies coupled with normal to above normal temperatures in the Gulf of

Alaska and along the west coast of North America with troughing/negative geopotential height anomalies coupled with normal to below normal temperatures across Eastern Canada and the Eastern United States (US). However next week the pattern is predicted to transition to troughing/negative geopotential height anomalies coupled with normal to below normal temperatures across western North America with ridging/positive geopotential height anomalies coupled with normal to above normal temperatures in the Eastern US and Southeastern Canada.

- In the *Impacts* section I continue to discuss my expectations for the polar vortex (PV; hint lots of stretching) and the weather of the Northern Hemisphere (NH) as we transition into February.

Plain Language Summary

A third stretched polar vortex event for the month is looking likely a the end of the week that will persist the cold in the Eastern US before turning milder in early February. These three events contributed to a colder and snowier pattern in the Eastern US for much of January. This latest stretch could spawn a sizeable nor'easter over the weekend. Europe remain on either side of seasonable due to high pressure/ridging in the central North Atlantic that will induce a colder northerly flow across much of the continent. Still, lots of uncertainty heading into mid-February as the current pattern is highly anomalous.

Impacts

January in my opinion is all about the stretch, a stretched polar vortex (PV). It was absent in December, but I believe will have occurred three times in January when all is said and done reversing a record warm December to a surprisingly cold January especially relative to the forecasts (see **Figure i**). For example, I include the EPS forecast for January pulled from Twitter, which completely missed the cold Eastern US (see **Figure ii**). I show the forecast initiated from 1 December but even the forecast initiated 1 January missed the cold Eastern US. But the missed forecast is not unique to the EPS but common to the many if not all the dynamical models. The temperature anomaly pattern resembles the temperature pattern shown in my recent paper Cohen et al. 2021 and archived manuscript Cohen et al. 2022 and the supplementary information. That go into detail about a stretched PV.

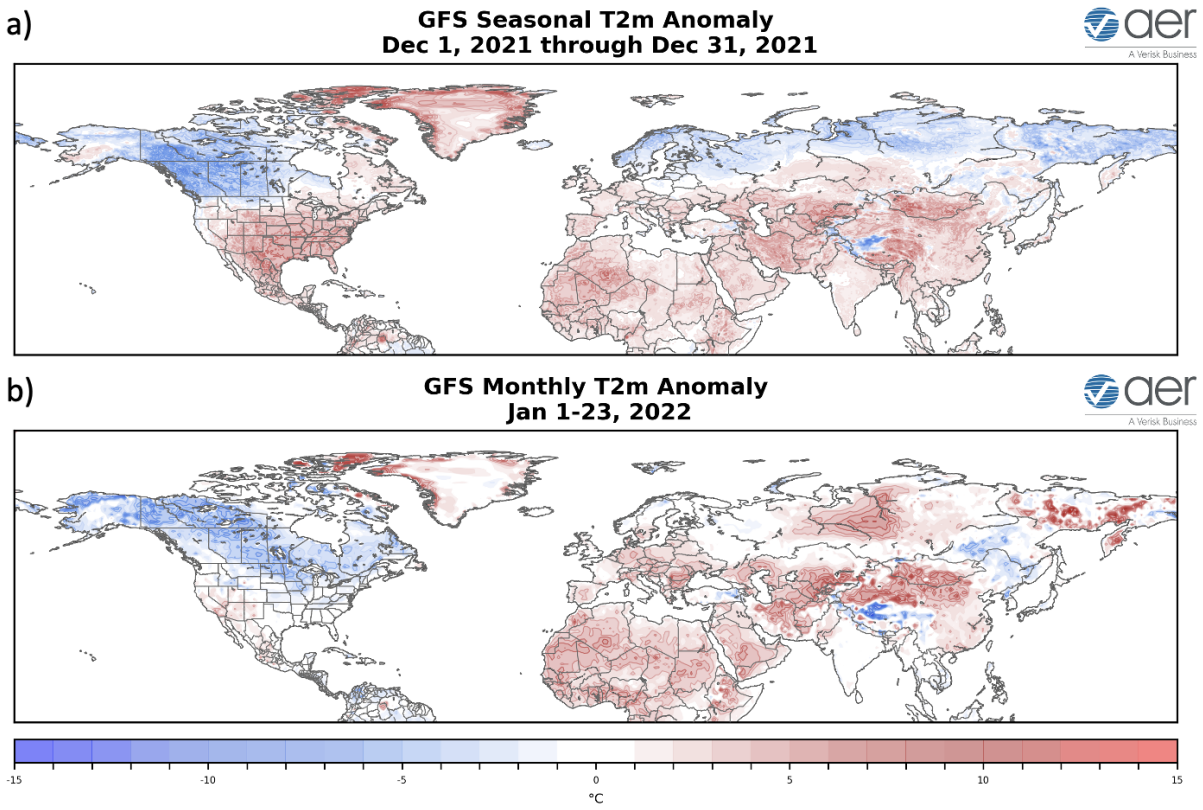


Figure i. (**a**) Observed surface temperature anomalies (°C; shading) from 1 – 31 December 2021. (**a**) Observed surface temperature anomalies (°C; shading) from 1 – 23 January 2022.The forecasts are from the 00z GFS analysis.

I focus on the cold associated with stretched PV events but the winter periods that are the focus of those two analyses were also snowy. And I think that it is no coincidence that this final stretch of the PV of January 2022 is accompanied by a winter storm threat for the Northeastern US.

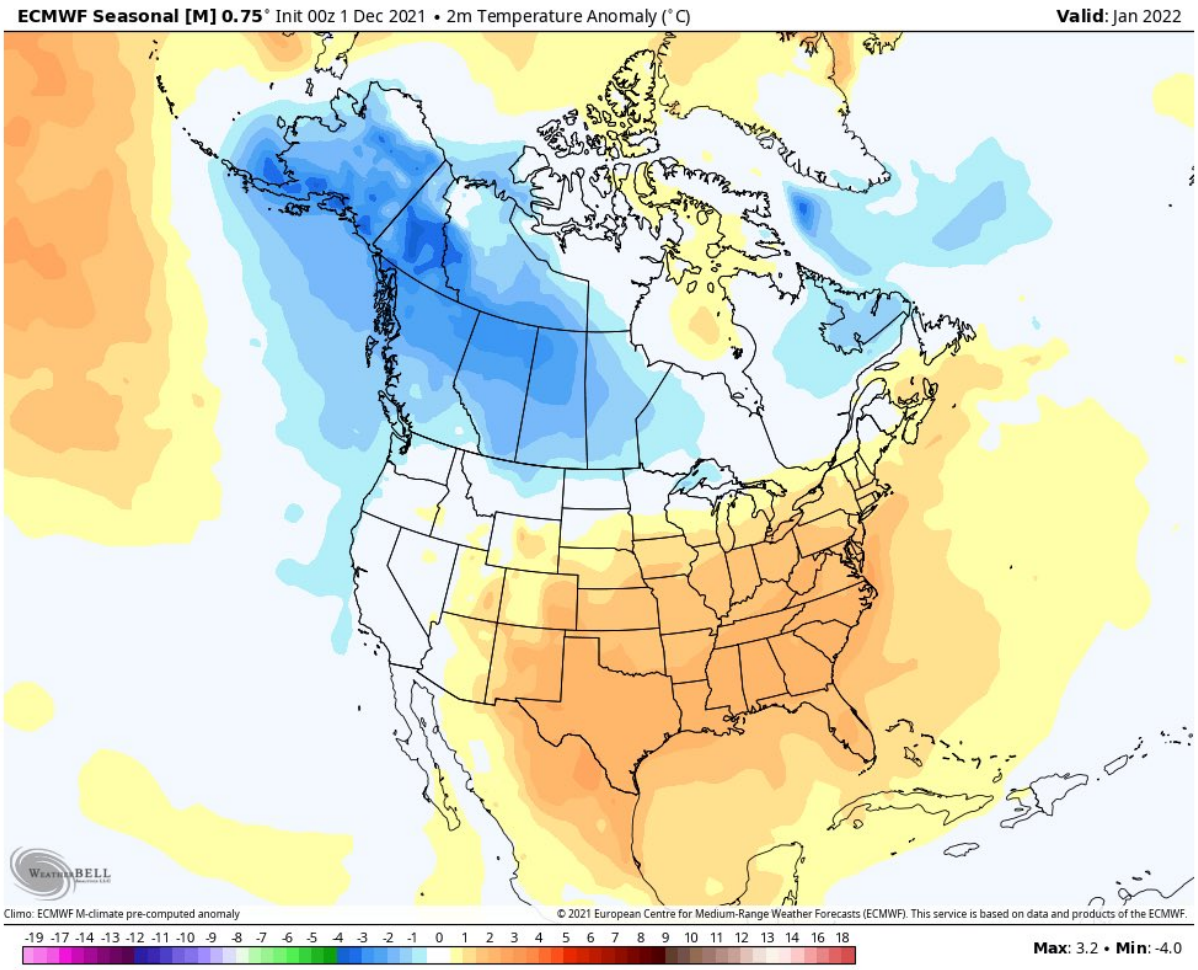
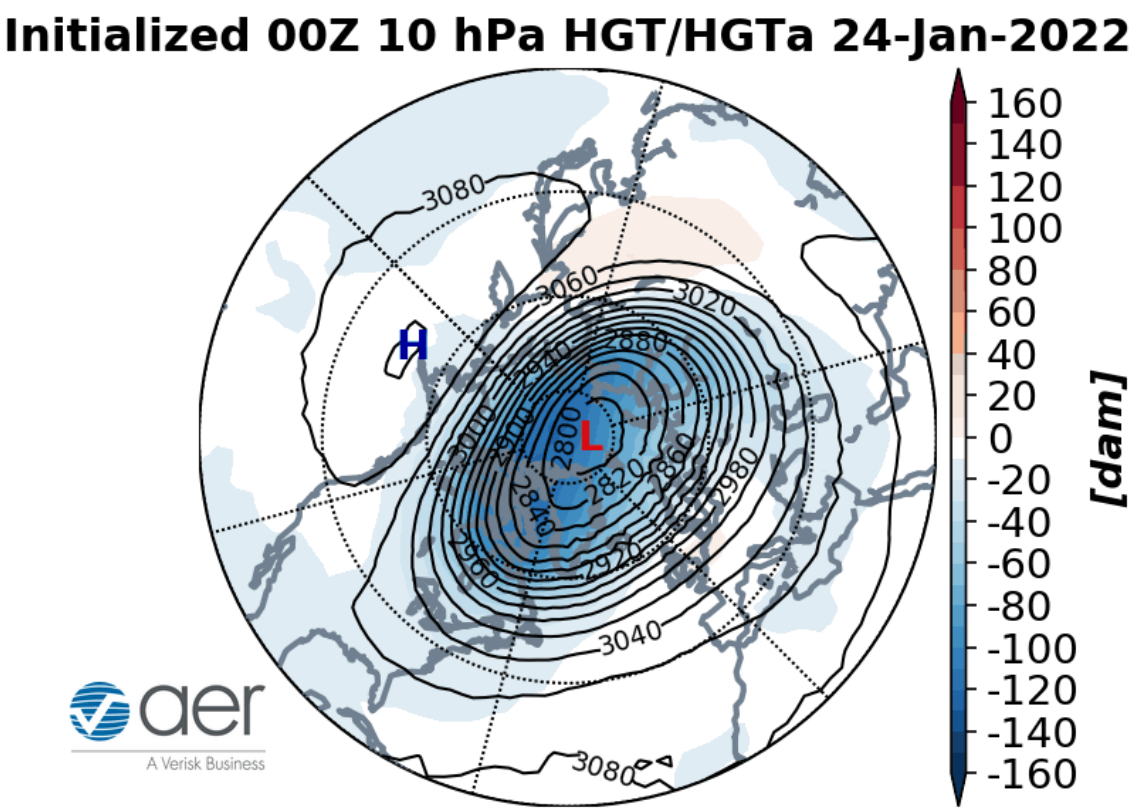


Figure ii. Forecasted surface temperature anomalies (°C; shading) for January from the EPS ensemble initiated 1 December 2021. Pulled from Twitter but graphic courtesy of Weatherbell.

Last week I discussed the unusual lack of coupling between the stratosphere and troposphere this winter (in the classical sense of the AO or polar cap geopotential height anomalies and there is no obvious coupling through the first week of February (see **Figure 11**). The best analog that I could find and mentioned last week is winter 2014. In that winter there were observed stretched PV events in January, February and March. In general, those events were stronger than anything that we have seen so far this winter, but I am feeling more confident that the stretched PV events this winter will not limited to January and the GFS forecasts (see **Figure iii**), including our diagnostics for just such occasions, are suggestive of another possible event in early February.



CLICK to Loop

Figure iii. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 24 January 2022 and forecasted from 25 January – 9 February 2022. The forecasts are from the 00Z 24 January 2022 GFS model ensemble.

I also discussed last week our machine learning model that was predicting a warmup in the Eastern US in early February. Well, the latest forecasts from the model have been trending colder in the Eastern US and milder in the Western US. I believe that pattern transitions don't happen all at once but come in stages. So, I am growing more confident that the anticipated warmup in early February is more of a relaxation of the cold pattern in the Eastern US and not a full reversal, at least for now. And whether the return to relatively colder weather in the Eastern US around the second week of February in our model is brief or of longer duration is hard to know just yet and both scenarios seem plausible. I will just say that the mid-tropospheric pattern looks highly anomalous to me and therefore it could bring anomalous weather and is likely very challenging for the dynamical models to predict correctly beyond or week, maybe even less.

Overall, I do think that the pattern is becoming more conducive to initiating wave energy transfer from the troposphere to the stratosphere that disrupts the stratospheric PV with ridging/high pressure predicted to return to the Urals region coupled with troughing low pressure in East Asia and into the North Pacific (see **Figure 8**). I haven't been sold on the idea of a PV disruption larger than a stretch but if the GFS forecast is correct, it would be more likely. The very end of the PV animation in **Figure iii** is even suggestive of a PV split. I am not ready to believe it, but I am also not going to discount it as a possibility sometime in February. That particular GFS forecast is probably premature. Also if the vertical wave energy converges in the polar stratosphere, which occurs prior to major PV disruptions (splits and displacements) rather than reflected as in PV stretches, then the Eastern US could be looking at a more extended mild period until well after the central date of the PV disruption.

As far as Europe and East Asia not much new. I really think in order for widespread significant winter weather to occur in Europe, a larger disruption of the PV needs to occur, preferably a PV split, which this week has increased somewhat in probability. Any cold this month in Europe can be attributed to North Atlantic ridging. And though I believe this atmospheric feature to be transient, based on the model forecasts it will persist into the foreseeable future. This could be due to coupling to the very warm sea surface temperatures in the North Atlantic (see **Figure 14**), an admittedly speculative presumption. Though this feature should not be confused with Greenland blocking and a negative NAO and that is why Greece and Turkey are in the news for anomalous snowstorms and not London and Paris.

Central and East Asia should also be cold during stretched PV events, but I have been underwhelmed by the temperature anomalies in Asia and relative cold seems to be mostly localized. But strong high pressure predicted for Northern Asia (see **Figure 8**) could yield more widespread cold in early February.

1-5 day

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

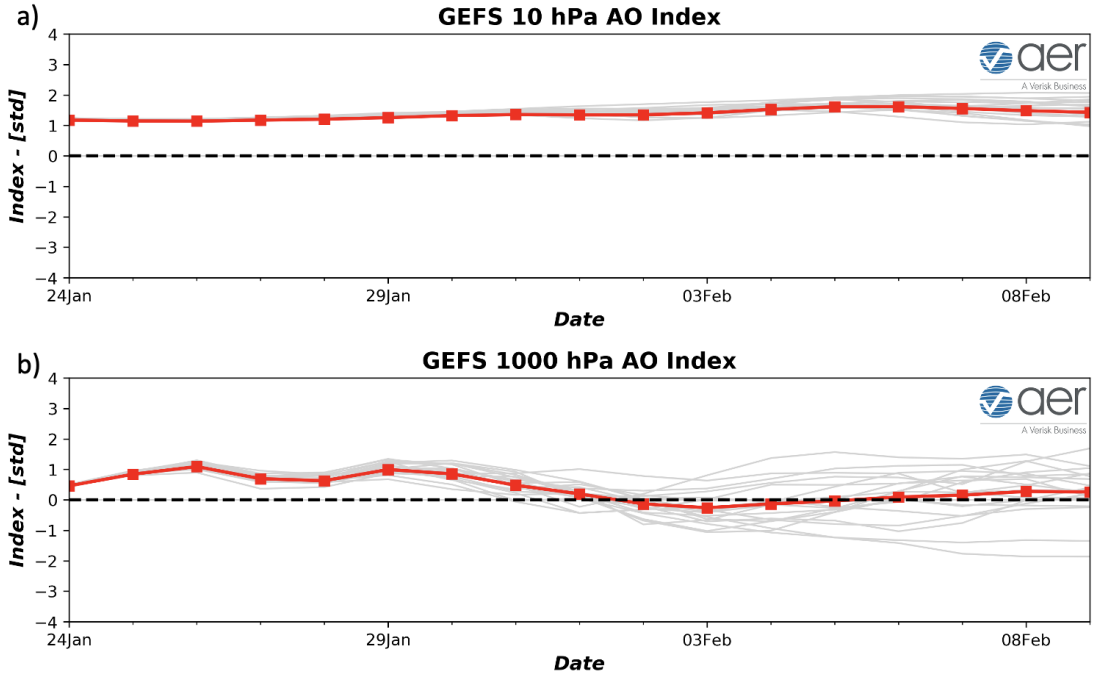


Figure 1. (a) The predicted daily-mean AO at 1000 hPa from the 00Z 24 January 2022 GFS ensemble. (b)The predicted daily-mean near-surface AO from the 00Z 24 January 2022 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

This week, ridging/positive geopotential height anomalies centered just west of the UK and extending into Western Europe will promote northerly flow across Central Europe and troughing/negative geopotential height anomalies in Eastern Europe this period (**Figures 2).** The resultant northerly flow and/or low heights will result in normal to below normal temperatures across Southern and Eastern Europe with normal to above normal temperatures across Northern and Western Europe (**Figure 3**). This week, a quasi-omega block pattern is predicted across Asia with ridging/positive geopotential height anomalies dominating Northcentral Asia sandwiched by troughing/negative geopotential height anomalies in Western Asia and Northeast Asia and across the Indian subcontinent (**Figure 2**). This pattern favors widespread normal to above normal temperatures across much of Northern Asia with normal to below normal temperatures across Western and Southern Asia **(Figure 3**).

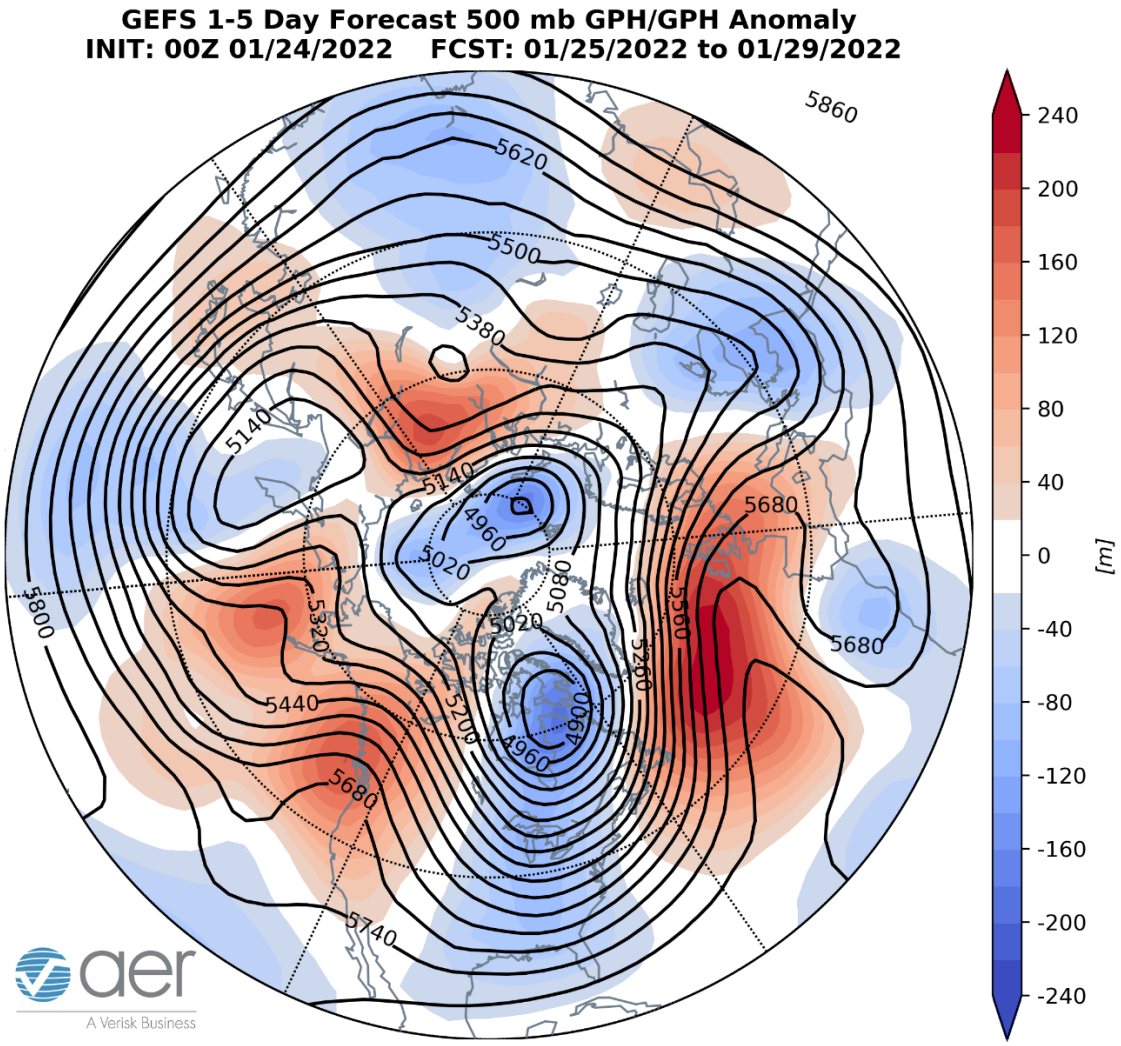


Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 25 – 29 January 2022. The forecasts are from the 00z 24 January 2022 GFS ensemble.

This week, the predicted pattern across North America is ridging/positive geopotential height anomalies across Alaska, Western Canada and the Western US which will contribute to troughing/negative geopotential height anomalies across Eastern Canada and the Eastern US **(Figure 2).** This will favor normal to above normal temperatures across eastern Alaska, Western Canada and the Western US with normal to below normal temperatures in western Alaska, Central and Eastern Canada and the Central and Eastern US **(Figure 3).**

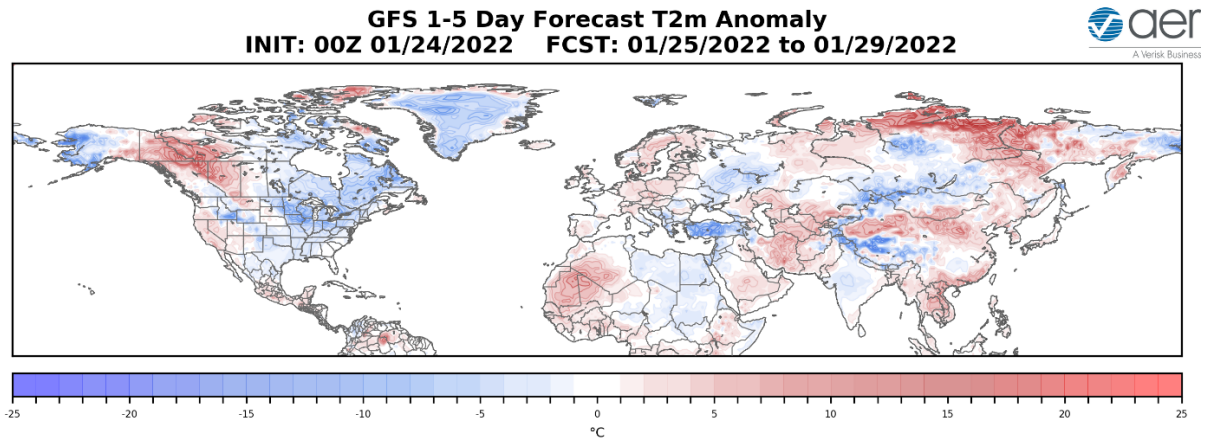


Figure 3. Forecasted surface temperature anomalies (°C; shading) from 25 – 29 January 2022. The forecast is from the 00Z 24 January 2022 GFS ensemble.

Troughing and/or cold temperatures are predicted to support new snowfall across Norway, Turkey, Central Asia and the Tibetan Plateau while mild temperatures promote snowmelt in Eastern Europe, Western Asia and Central Asia (**Figure 4**). Troughing and/or cold temperatures are predicted to support new snowfall across Northern and Eastern Canada and possibly the Northeastern US while mild temperatures promote snowmelt in Western Canada and the Western US (**Figure 4**).

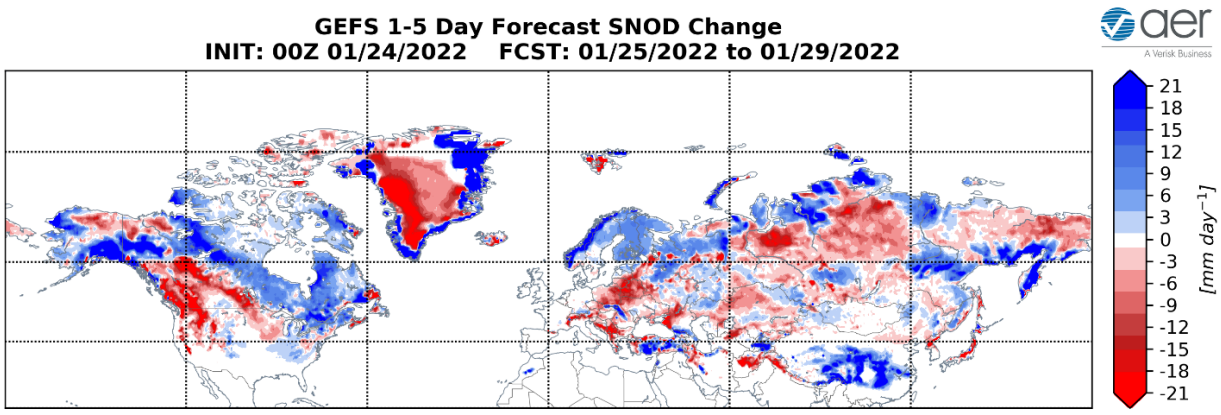


Figure 4. Forecasted snow depth changes (mm/day; shading) from 25 – 29 January 2022. The forecast is from the 00Z 24 January 2022 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to trend negative towards neutral this period **(Figure 1**) as positive geopotential height anomalies spread across the North Pacific side of the Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 5**). And with weak and

mostly negative geopotential height anomalies across Greenland (**Figure 5**), the NAO is predicted to remain slightly positive this period.

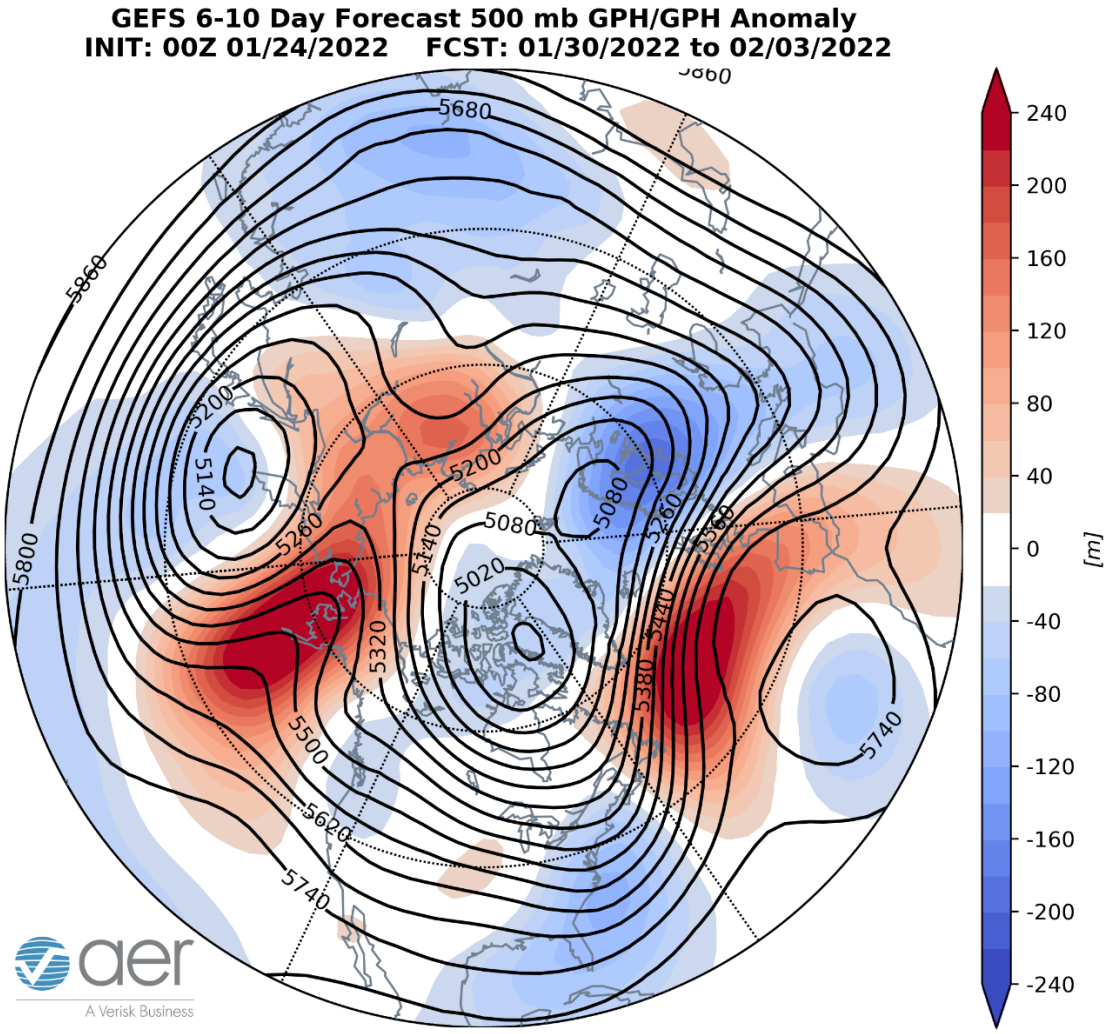


Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 30 January – 3 February2022. The forecasts are from the 00z 24 January 2022 GFS ensemble.

Persistent ridging/positive geopotential height anomalies in the North Atlantic just west of the UK and extending into Western Europe will support northerly flow across Central Europe and troughing/negative geopotential height anomalies across Eastern Europe (**Figures 5).** This will result in normal to below normal temperatures across Western and Southern Europe including the UK with normal to above normal temperatures across Northern and Eastern Europe (**Figure 6**). Ridging/positive geopotential height anomalies are predicted overspread much of Siberia with troughing/negative geopotential height anomalies in far Western and Southern Asia and far Eastern Asia this period (**Figure 5**). This pattern favors normal to above normal temperatures across much of Northern Asia with normal to below normal temperatures limited to parts of Western and Southern Asia and far Eastern Asia **(Figure 6**).

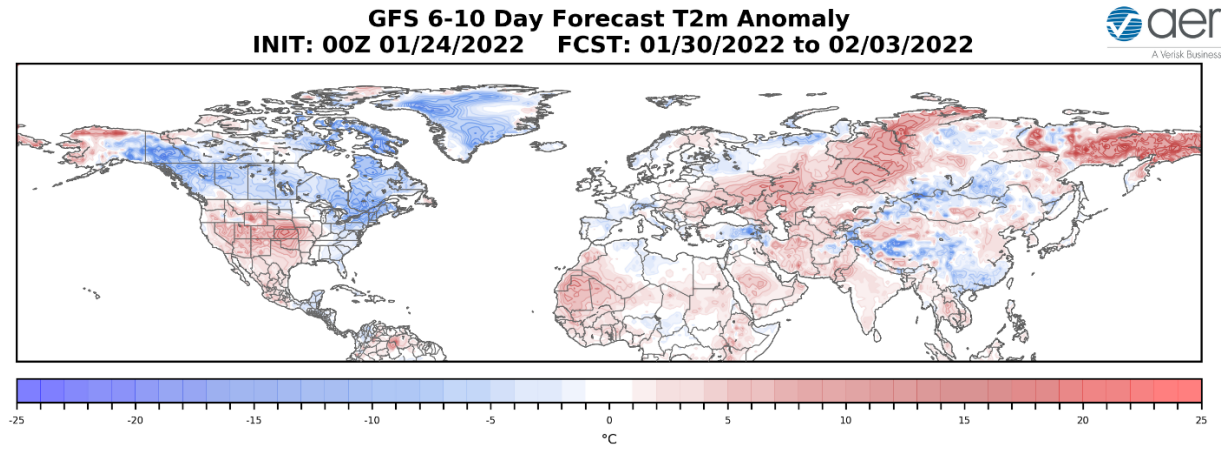


Figure 6. Forecasted surface temperature anomalies (°C; shading) from 30 January – 3 February 2022. The forecasts are from the 00Z 24 January 2022 GFS ensemble.

Ridging/positive geopotential height anomalies are predicted to persist across Alaska, and the Gulf of Alaska this period helping to allow troughing/negative geopotential height anomalies across Eastern Canada and the Eastern US to spread west into Western Canada and the Western US as well **(Figure 5).** This will favor normal to below normal temperatures across far eastern Alaska, much of Canada and the Eastern US with normal to above normal temperatures in western Alaska, and the Western US **(Figure 6).**

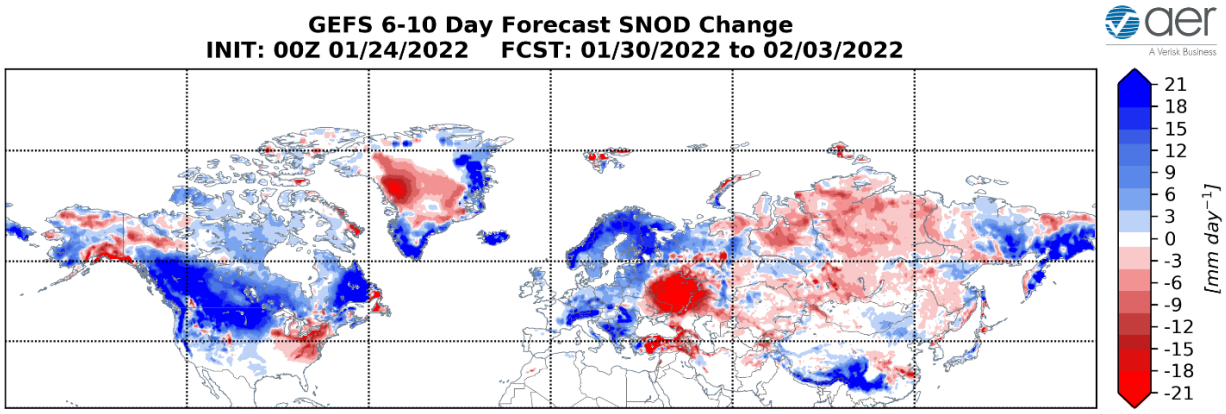


Figure 7. Forecasted snow depth changes (mm/day; shading) from 30 January – 3 February 2022. The forecast is from the 00Z 24 January 2022 GFS ensemble.

Troughing and/or cold temperatures are predicted to support new snowfall across Northern and Central Europe and the Tibetan Plateau while milder temperatures promote snowmelt across Eastern Europe and scattered throughout Asia (**Figure 7**). Troughing and/or cold temperatures are predicted to support new snowfall across western Alaska, Southern Canada, and the Western US while milder temperatures promote snowmelt across Southern Alaska and the Northeastern US (**Figure 7**).

11-15 day

Positive geopotential height anomalies previously confined to the North Pacific side of the Arctic are predicted to spread across all of Northern Eurasia with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 8**), therefore the AO should remain close to neutral to slightly negative this period (**Figure 1**). With predicted mostly negative but weak pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO is forecasted to remain positive to near neutral this period.

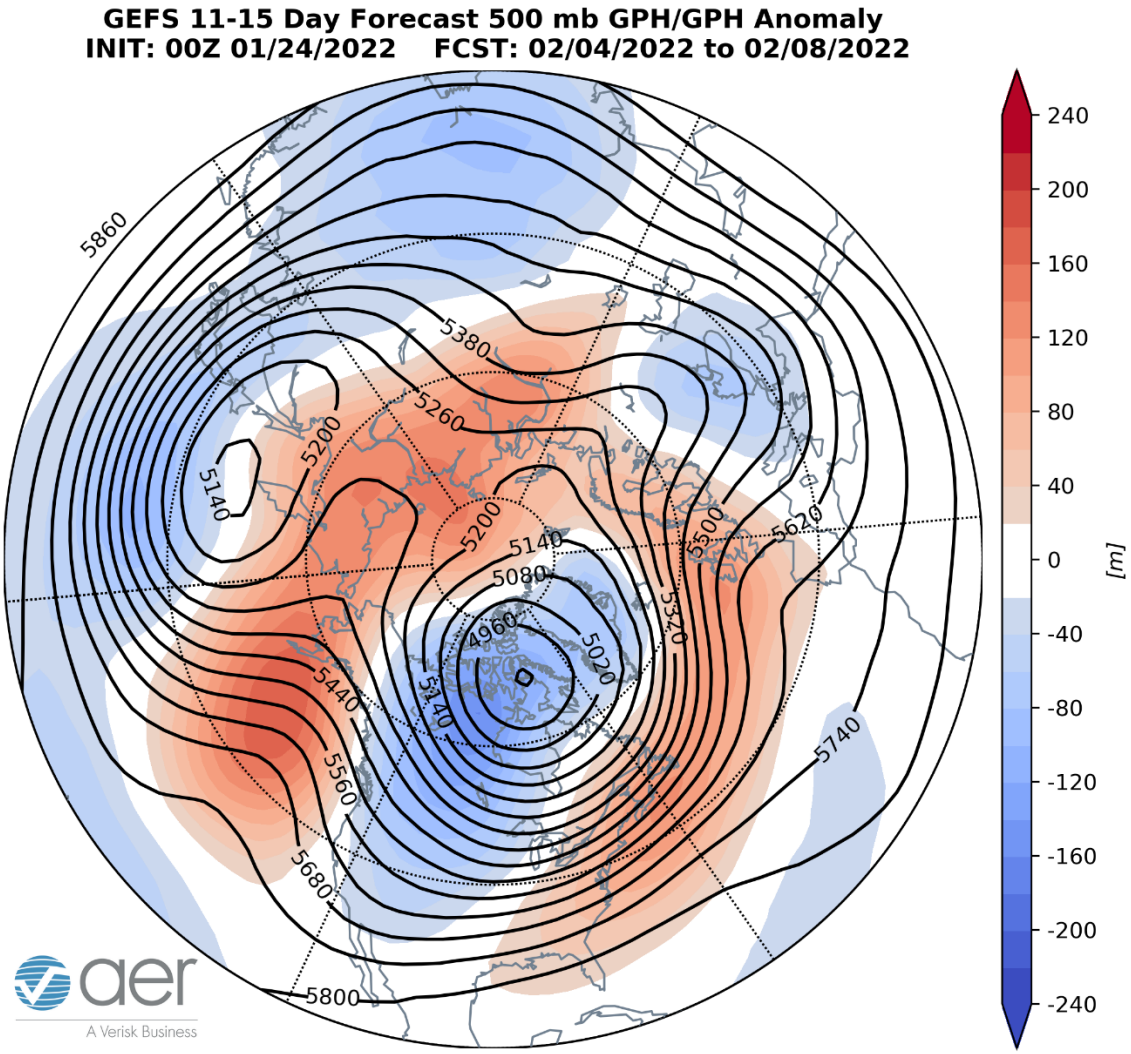


Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 4 – 8 February2022. The forecasts are from the 00z 24 January 2022 GFS ensemble.

Persistent ridging/positive geopotential height anomalies in the central North Atlantic that extends into Western Europe are predicted to continue to support northerly flow across Central Europe and troughing/negative geopotential height anomalies across Eastern Europe this period

(**Figure 8**). This pattern favors more normal to below normal temperatures across Southern and Eastern Europe with normal to above normal temperatures across Northern and Western Europe including the UK this period (**Figures 9**). Ridging/positive geopotential height anomalies are predicted to spread across all of Northern Asia forcing troughing/negative geopotential height anomalies across Southern Asia with this period (**Figure 8**). This pattern favors more widespread normal to below normal temperatures across Western and Southern Asia with normal to above normal temperatures widespread across much of Northern and Eastern Asia this period (**Figure 9**).

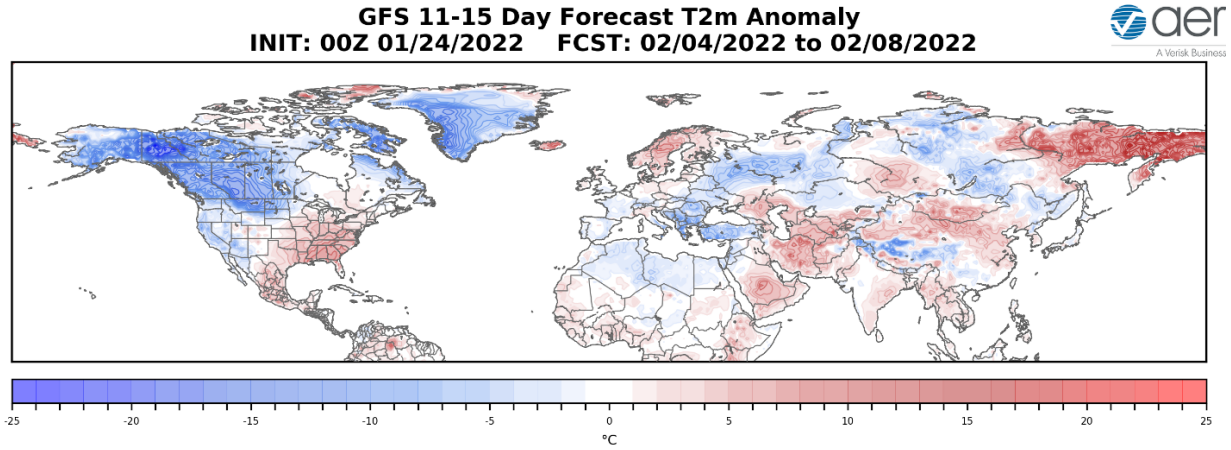


Figure 9. Forecasted surface temperature anomalies (°C; shading) from 4 – 8 February 2022. The forecasts are from the 00z 24 January 2022 GFS ensemble.

Ridging/positive geopotential height anomalies are predicted to persist across Alaska but now centered near the Aleutians contributing to troughing/negative geopotential height anomalies previously in eastern North America sliding into western North America with ridging/positive geopotential height anomalies in the Eastern US this period (**Figure 8**). This pattern favors normal to above normal temperatures across Alaska, Northern and Western Canada and the Western US with normal to below normal temperatures in Southeastern Canada and the Eastern US (**Figure 9**).

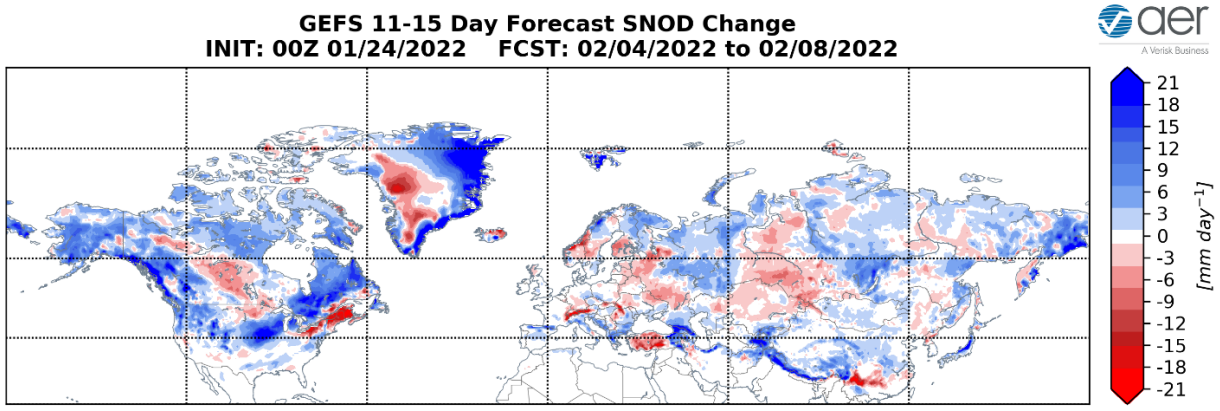


Figure 10. Forecasted snow depth changes (mm/day; shading) from 4 – 8 February 2022. The forecast is from the 00Z 24 January 2022 GFS ensemble.

Troughing and/or cold temperatures are predicted to support possible new snowfall across northern Eurasia, the higher elevations of Southern Europe and the higher elevations of Southern Asia while milder temperatures promote snowmelt across Eastern Europe and Central Asia (**Figure 10**). Troughing and/or cold temperatures are predicted to support possible new snowfall across Alaska, much of Canada and the Western and Central US while milder temperatures promote snowmelt across the Canadian Plains 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 lower troposphere with warm/positive PCHs in the mid to upper troposphere (**Figure 11**). The negative departures are predicted to deepen in the upper stratosphere next week while the PCHs are predicted to turn warm/positive throughout the troposphere (**Figure 11**). The highly unusual persistent state of the atmosphere where the stratosphere and troposphere are decoupled continues and when coupling resumes remains an open question to me.

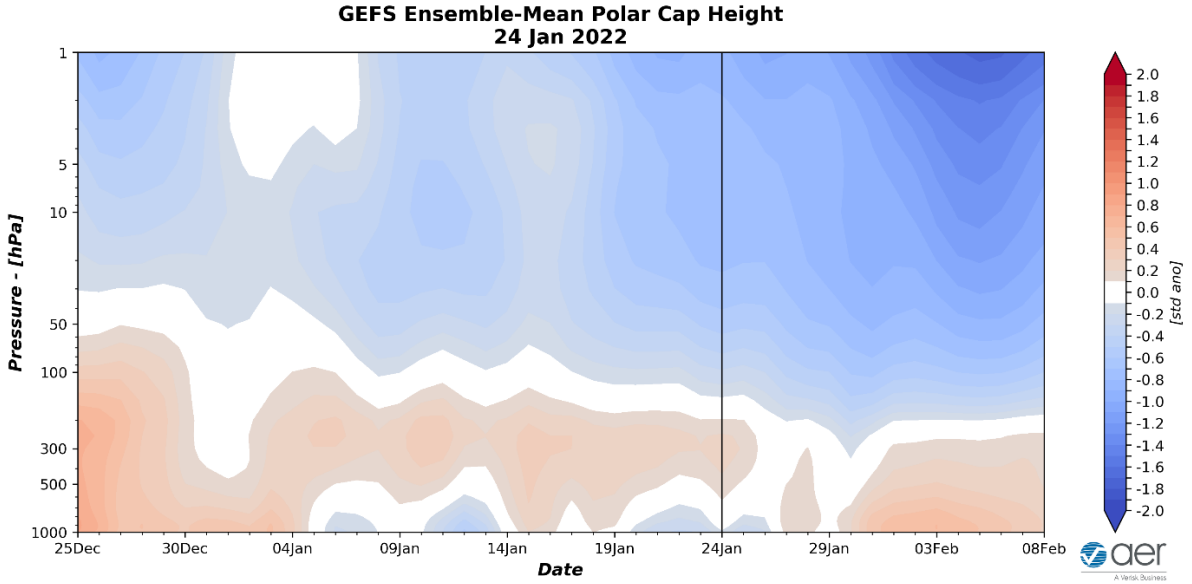


Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 24 January 2022 GFS ensemble.

The normal to below normal PCHs predicted early this week in the lower troposphere are consistent with the predicted positive surface AO this week (**Figure 1**). The PCH forecast continues to look strange today and suggests repetitive troposphere- (very) low stratosphere-

troposphere coupling events that are quite shallow and condensed in time. Regardless I believe that a stretched PV is the best way to understand stratosphere-troposphere coupling this month.

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 the end of the month (**Figure 12**). A more active period is possible in early February. Though today's plot looks very active please keep in mind that it is from the operational GFS which tends to be very noisy. The negative WAFz anomalies predicted this week will continue to support a relatively strong PV through early-February as suggested by the relatively cold stratospheric PCHs. Though again not all strong PVs are created equal, and I think a stretched polar vortex is what is most critical right now.

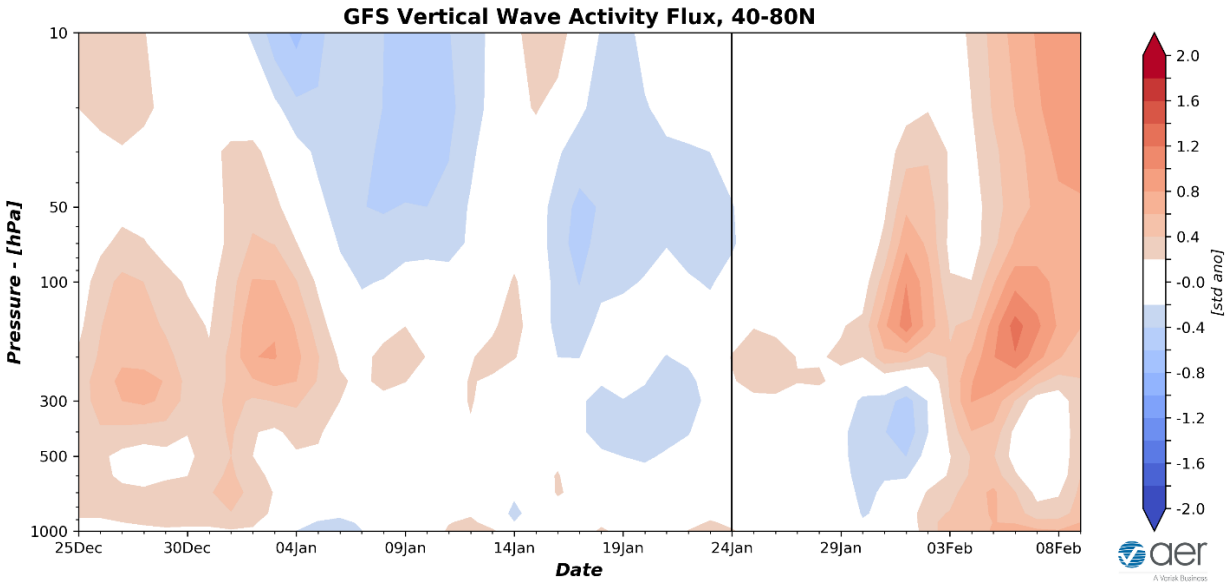


Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 24 January 2022 GFS ensemble.

Though zonally averaged WAFz is weak, another stretched stratospheric PV and third of this month will likely occur at the end of the week with the PV centered near Svalbard with ridging centered on the Aleutians. In addition, the PV exhibits a stretched configuration from the Western Siberia to Eastern Canada and not circular (**Figure 13**). However, the perturbation is relatively minor, and the PV is relatively strong resulting in a current positive stratospheric AO (**Figure 11**).

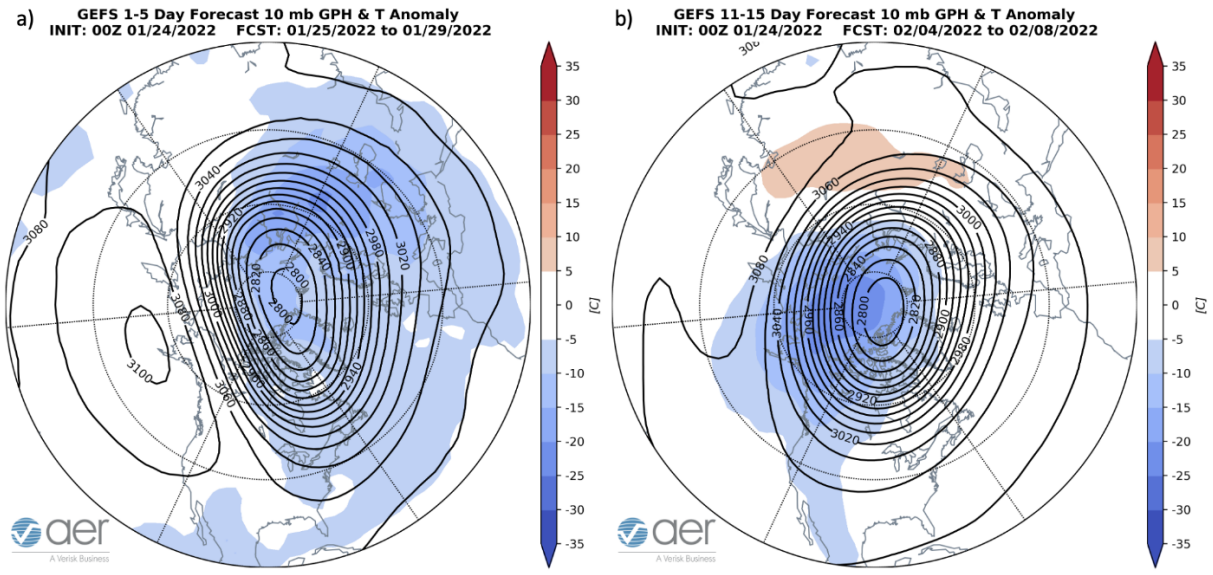


Figure 13. (a) Forecasted averaged from 25 – 29 January 2022 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere. (b) Same as (a) except forecasted averaged from 4 – 8 February 2022. The forecasts are from the 00Z 24 January 2022 GFS model ensemble.

The below normal WAFz is predicted to allow the PV to strengthen and become quite strong with the PV remaining centered between the North Pole and Svalbard in early February (**Figure 13**) with a persistent positive stratospheric AO the next two weeks (**Figure 11**). Though more stretching seems increasingly likely. The strengthening stratospheric PV could couple with the surface commencing a relatively mild period across the US and Europe, sometime in February but any signs of this remain elusive.

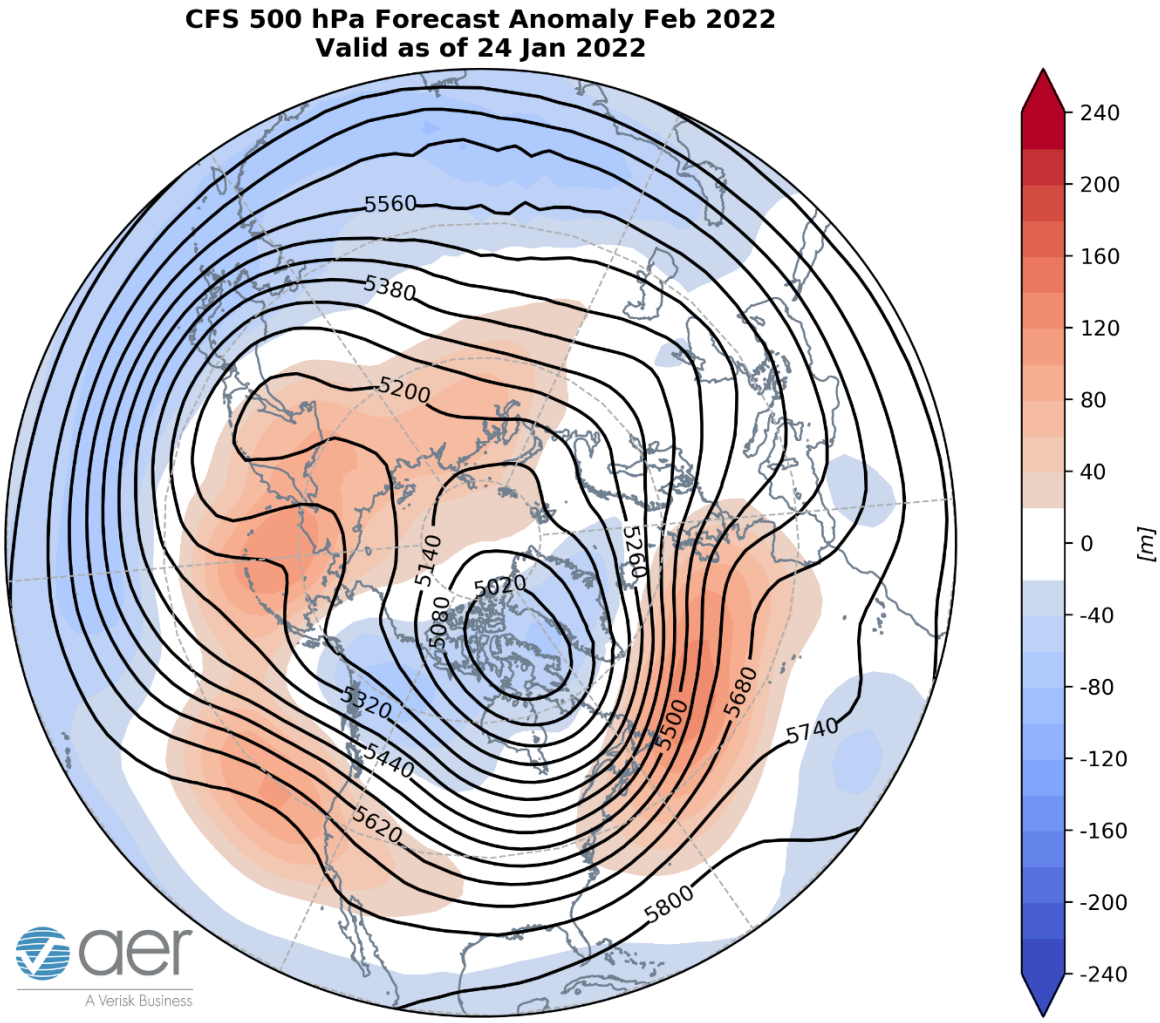


Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for February 2022. The forecasts are from the 00Z 24 January 2022 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and surface temperatures for February (**Figure 15**) from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging in the western North Atlantic, centered over the Urals, Eastern Siberia, the Aleutians and off the US West Coast with troughing across Europe, Eastern Asia, Alaska, Western Canada and Hudson Bay (**Figure 14).** This pattern favors seasonable to relatively warm temperatures across Western Europe, Northern Asia, Southeastern Canada and much of the US with seasonable to relatively cold temperatures across Eastern Europe, Southern and Eastern Asia, much of Canada and the Northern and the US Pacific Northwest (**Figure 15).**

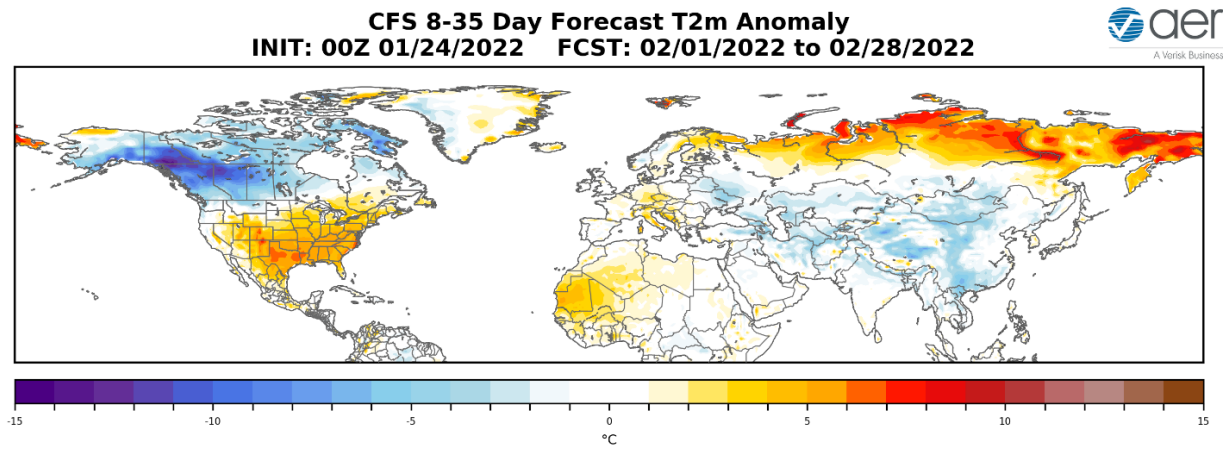


Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for February 2022. The forecasts are from the 00Z 24 January 2022 CFS.

Surface Boundary Conditions

Arctic Sea ice

Arctic sea ice is growing but remains below normal mostly in Baffin Bay and is above normal in the Bering Sea. Overall sea ice is relatively extensive compared to recent winters, though it remains relatively thin. In the Barents-Kara Seas extent is close to normal. Below normal sea ice in the Barents-Kara seas favors cold temperatures in Central and East Asia, while below normal sea ice in Baffin Bay favors cold temperatures in the Eastern and Northern Europe 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.

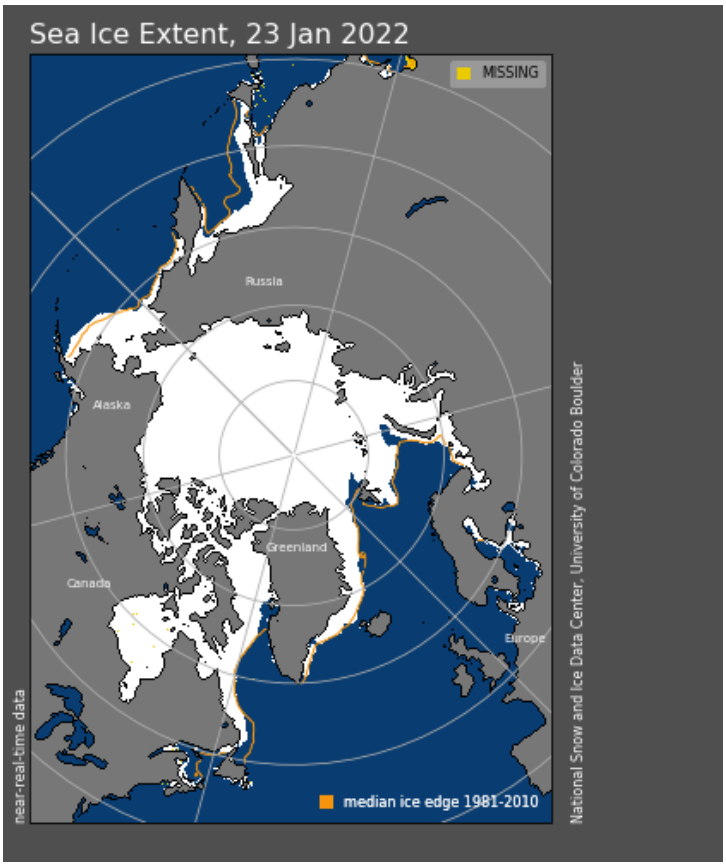


Figure 16. Observed Arctic Sea ice extent on 23 January 2022 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image from the National Snow and Ice Data Center (NSIDC).

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 through the winter. Observed SSTs across the NH remain well above normal especially in the central North Pacific (west of recent years), the western North Pacific 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.

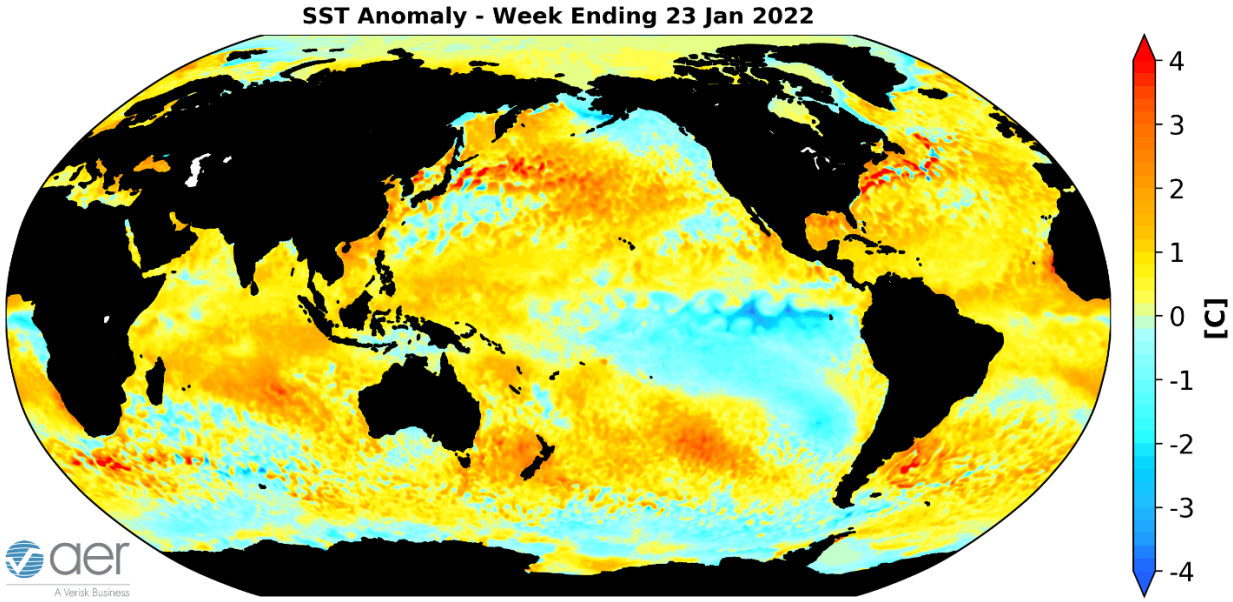


Figure 17. The latest weekly-mean global SST anomalies (ending 23 January 2022). Data from NOAA OI High-Resolution dataset.

Currently no phase of the Madden Julian Oscillation (MJO) is favored (**Figure 18**). The forecasts are for the MJO to remain weak but could briefly pop into phases five and seven before weakening again to where no phase is favored. Hard for me to see the MJO is having much influence on the weather. But admittedly this is outside of my expertise.

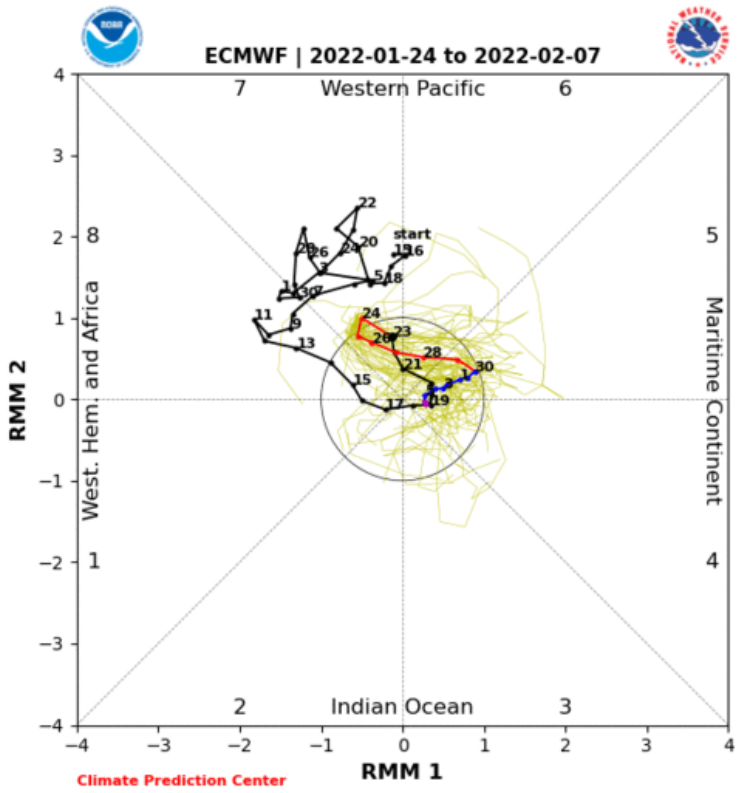


Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 24 January ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model "spread" is denoted by the gray shading. Sector numbers indicate 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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