Arctic Oscillation and Polar Vortex Analysis and Forecasts

January 10, 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 go briefly positive for most of this week and then straddle neutral next week with mixed pressure/geopotential height anomalies across the Arctic and mixed pressure/geopotential height anomalies across the mid-latitudes. The North Atlantic Oscillation (NAO) is currently positive and is predicted to also straddle mostly neutral as pressure/geopotential height anomalies are predicted to remain weak and transitory across Greenland the next two weeks.
- This week, mostly troughing/negative geopotential height anomalies across Greenland will favor ridging/positive geopotential height anomalies coupled with normal to above normal temperatures across much of Europe including the United Kingdom (UK) with the exception of troughing/negative geopotential height anomalies coupled with normal to below normal temperatures across Southeastern Europe this week. However, beginning next week European ridging/positive geopotential height anomalies will retrograde westward into the

central North Atlantic promoting more troughing/negative geopotential height anomalies coupled with normal to below normal temperatures across Europe.

- The dominant pattern across Asia the next two weeks is troughing/negative geopotential height anomalies coupled with normal to below normal temperatures across Western Asia with ridging/positive geopotential height anomalies coupled with normal to above normal temperatures dominating much of Central and East Asia. However current troughing/negative geopotential height anomalies coupled with normal to below normal temperatures are predicted to persist across Far East Asia.
- The dominant pattern across North America the next weeks is strengthening 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 deepening troughing/negative geopotential height anomalies coupled with normal to below normal temperatures across Eastern Canada and the Eastern United States (US).
- In the *Impacts* section I continue to discuss my expectation of how another predicted stretched polar vortex (PV) starting this weekend will influence the weather of the Northern Hemisphere (NH).

Plain Language Summary

We just had one stretched polar vortex event, and another looks likely starting this weekend. These two events will contribute to a colder and snowier pattern in the Eastern US for possibly much of January. Our machine learning model suggest the cold could last into February. Europe will turn colder 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 the end of January and early February.

Impacts

I didn't think that the phase of the polar vortex (PV) that I like to call the stretched polar vortex (PV) that was the focus of our recent *Science* paper Cohen et al. 2021 would get marquee billing this winter but right now it is the star attraction in my opinion.

With three possible stretched PV events, I feel that our recently published *Science* paper is important for understanding the large-scale dynamics and atmospheric circulation of the winter so far, especially for North America. The paper argues that Arctic change increases the number of stretched PV days during the months of October through February. Since stretched PV events are associated with relatively cold temperatures than days when a stretched PV is not occurring east of the Rockies, an increasing number of these events is offsetting the overall global warming trend associated with climate change for the Eastern US. One of my co-author's, Laurie Agel, just completed new analysis that I think illustrates this idea very nicely. In **Figure i** is included the temperature trend for the years 1980-2021 for all days when a stretched PV is not

observed (left) and for only those days when a stretched PV is observed (right). As you can see from the figure temperatures are warming faster when a stretched PV is not occurring during all the months October through February. Therefore, if the number of stretched PV days are increasing, this will dampen the overall warming trend in the colder months across the US.

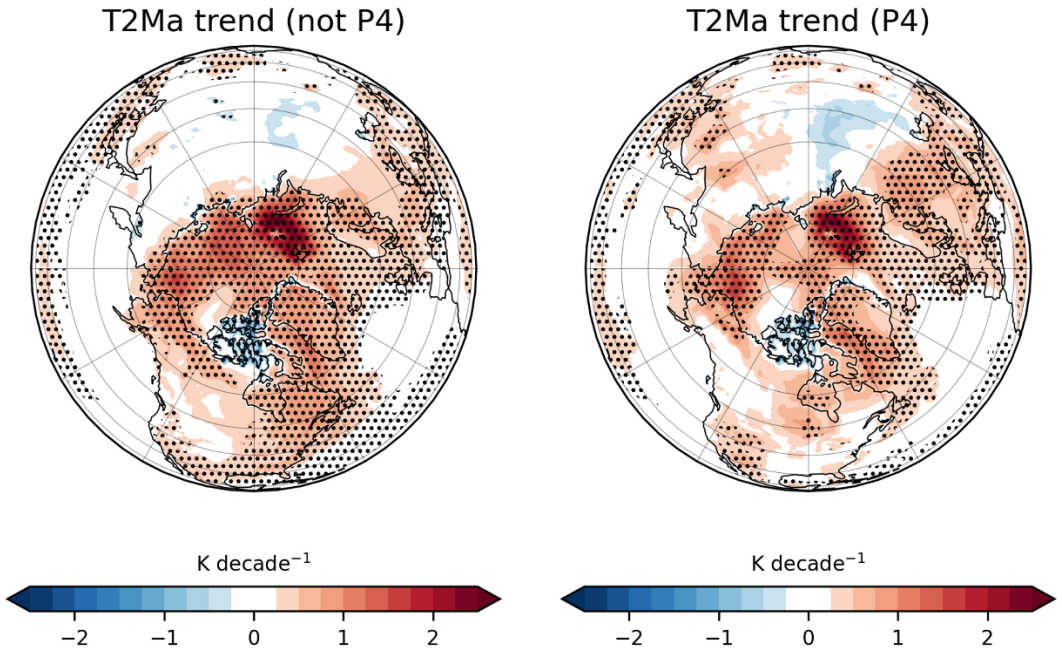

Figure i. Surface temperature trend (°C; shading) for all days except when a stretched polar vortex is observed (left). Surface temperature trend (°C; shading) for only those days when a stretched polar vortex is observed (right). Stippling indicates statistical significance greater than 95%. Trend shown for all days October through February. The seasonal cycle was removed before the trend was calculated.

I have a second manuscript on stretched PVs that I believe is also very relevant for this winter, but it has received no love from the reviewers so far. Hopefully a preprint will be posted to an archive website soon.

As I discussed last week, one event occurred in November that gave a relatively cold November to the Eastern US. None occurred in December contributing to a very warm to record warm month. We have had one stretched PV the first week of January and my diagnostics suggest another one will occur next week. I am not going to include the diagnostic here because I think for now it is too esoteric, but you can see the PV stretching in the latest PV animation (see **Figure** ii or alternatively in **Figure 13a**) from the GFS over the upcoming weekend.

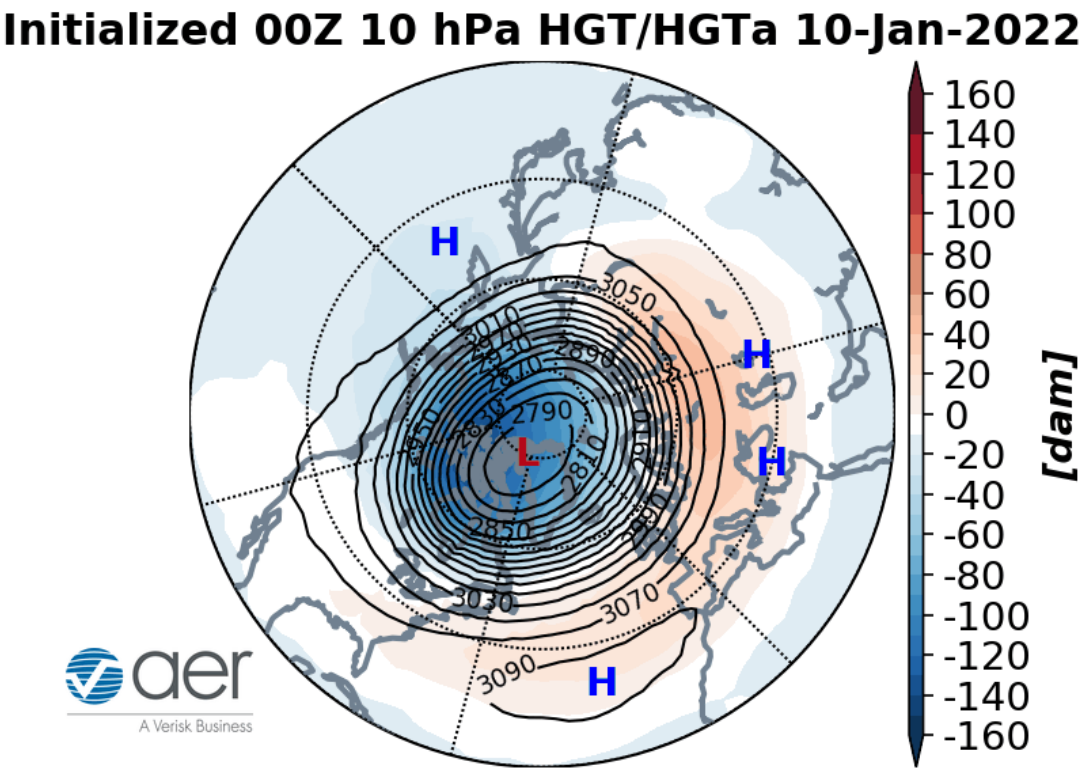

Figure ii. (a) Initialized 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 10 January 2022 and forecasted from 11 – 26 January 2022. The forecasts are from the 00Z 10 January 2022 GFS model ensemble.

The back-to-back stretched PV events are likely to make January a relatively cold month for the Eastern US and certainly compared to December. All the models are predicting a relatively cold pattern for the foreseeable future (up until the fourth week of January) for the Eastern US. I think confidence can be high the pattern will remain cold for at least the next ten days or so but what about the end of January and even into early February? That is a very tough call in my mind. There are signs that the next stretched PV starting this weekend could be the last for a while. Based in the PV animation (**Figure ii**) hard to know what is coming next and the GFS ensembles are predicting a strong more stable looking PV the fourth week of January. On the other hand, my diagnostics suggest it will last longer than that shown from the GFS ensembles. In summary, I think both more PV stretching, or a strong circular PV are possible, what I don't see any time soon is a major PV disruption associated with a sudden stratospheric warming (SSW). The Ural blocking is simply not persistent enough to force such an outcome.

As I have discussed previously, it seems to me that the impacts from a stretched PV can last on average one to two weeks but there have been exceptions and one of those exceptions is the subject of my manuscript. There are examples of the impact from the stretched PV whether it is of very large amplitude or repeats in relatively quick succession lasting three weeks or even longer and that would bring us to February. I haven't posted on Twitter our machine learning temperature forecast model for the US recently, but the latest forecasts suggest that the relatively cold pattern in the US east of the Rockies could last up to and into February.

I do believe that tropospheric patterns when they are not coupled to the stratosphere have a shelf life of 3-4 weeks. Across North America the western trough/eastern ridge pattern dominated during December. As soon as we entered January, the pattern quickly transitioned to a western ridge/eastern trough pattern. So based on this reasoning alone once January ends so should the western ridge/eastern trough pattern. And this could very well be especially if the strong stratospheric PV finally couples to the troposphere, a possibility that I have been watching all winter. But if the western ridge/eastern trough pattern can persist into early February, persistence could become a more dominant factor, especially if the snow cover across the Eastern US becomes extensive and relatively deep.

My thoughts for Europe haven't changed since the last blog and on Twitter. Stretched PV events bring colder weather to East Asia and eastern north America. I don't think that they have much impact on European temperatures but stretched PVs do tend to fire up the North Atlantic jet which tends to flood Europe with mild, maritime air. However, it is becoming increasingly likely that ridging/high pressure in the central North Atlantic is contributing to troughing, northerly flow and colder temperatures across Europe starting next week. I think this pattern change to colder weather is independent of the stretched PV and as I tweeted out last week seems to have origins in the stratosphere, but this is a completely unexplored and unsubstantiated idea as far as I know.

Wednesday Update

In Monday's blog I discussed a second PV stretching event starting at the end of this week and that is looking on track. I also discussed the possibility of future stretching PV event and based on my diagnostics a third stretched PV event is looking increasingly possible towards the end of the month. I think this is important because a third event would likely extend the cold period in the Eastern US into February consistent with our machine learning model forecast that I showed on Monday but is not included in today's update. But the latest long-range forecasts from the numerical weather prediction models are coming into agreement with the machine learning model. In **Figure iii** I include the latest 11-15 day forecast of the 500 mb geopotential heights and it is showing a highly amplified flow across North America with ridging in the Gulf of Alaska and along the west coast of North America and troughing in eastern North America.

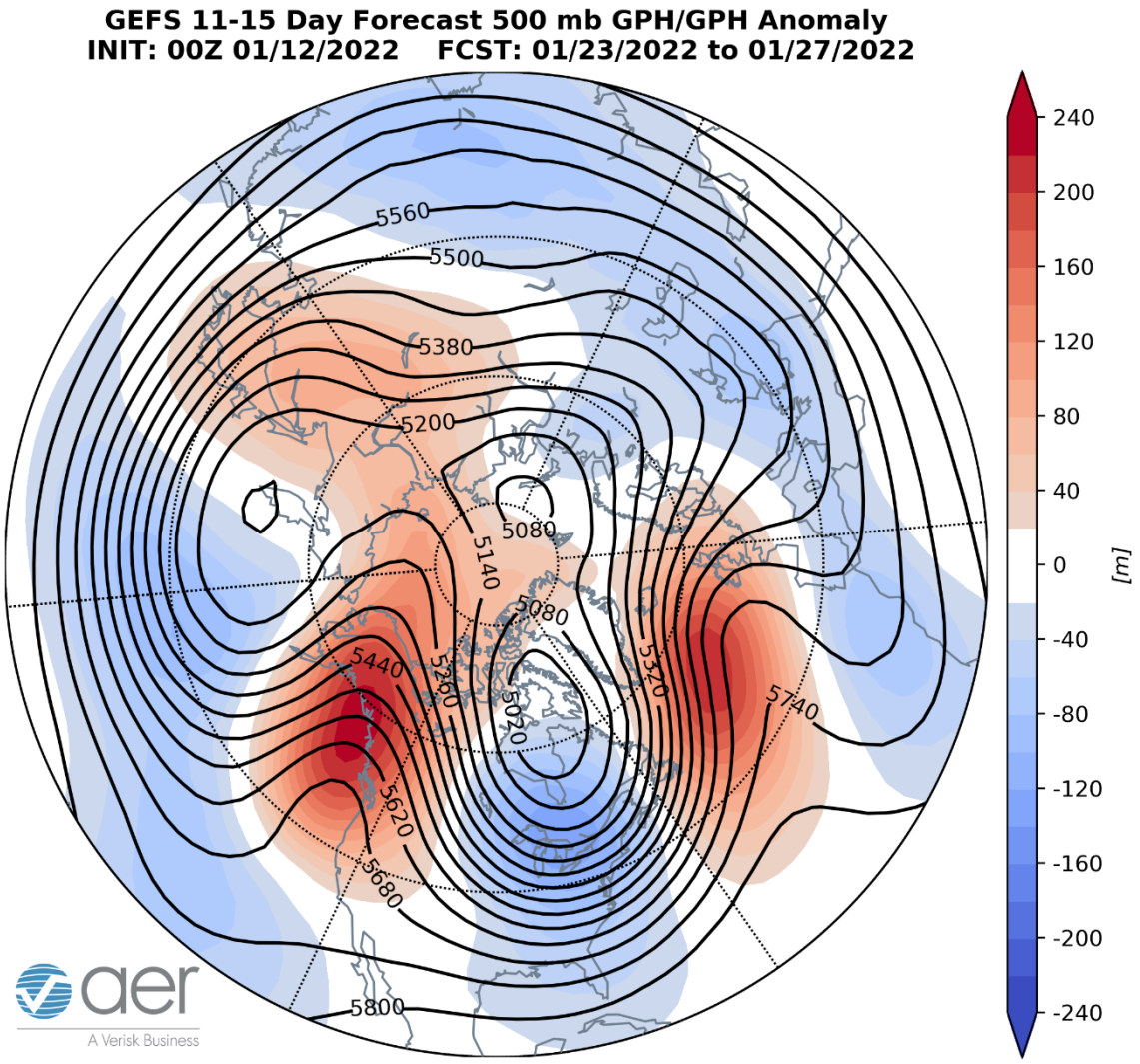

Figure iii. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 23 – 27 January 2022. The forecasts are from the 00z 12 January 2022 GFS ensemble.

The pattern looks stable and shows no signs of breaking down and if the model forecast verifies, would likely persist beyond the forecast period of January 27th. In addition, the North Atlantic ridging is predicted to persist through this period as well favoring troughing across Europe. And the corresponding surface temperature anomaly plot shows relatively cold temperatures for Eastern Canada, the Eastern US and Europe (see **Figure iv**). Our machine learning model also continues to suggest that the relatively cold temperatures in the Eastern US will persist into February.

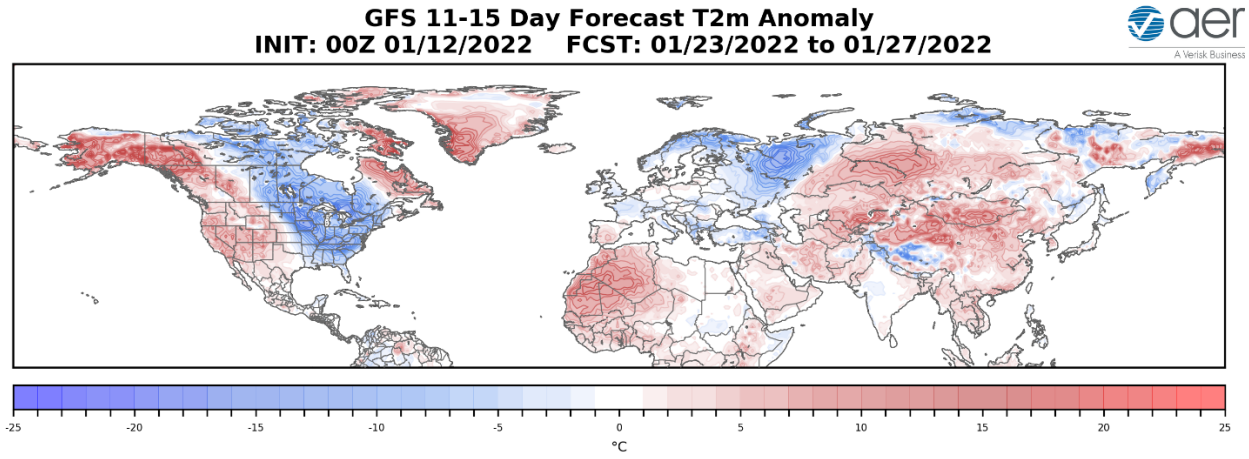

Figure iv. Forecasted surface temperature anomalies (°C; shading) from 23 – 27 January 2022. The forecast is from the 00Z 12 January 2022 GFS ensemble.

1-5 day

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

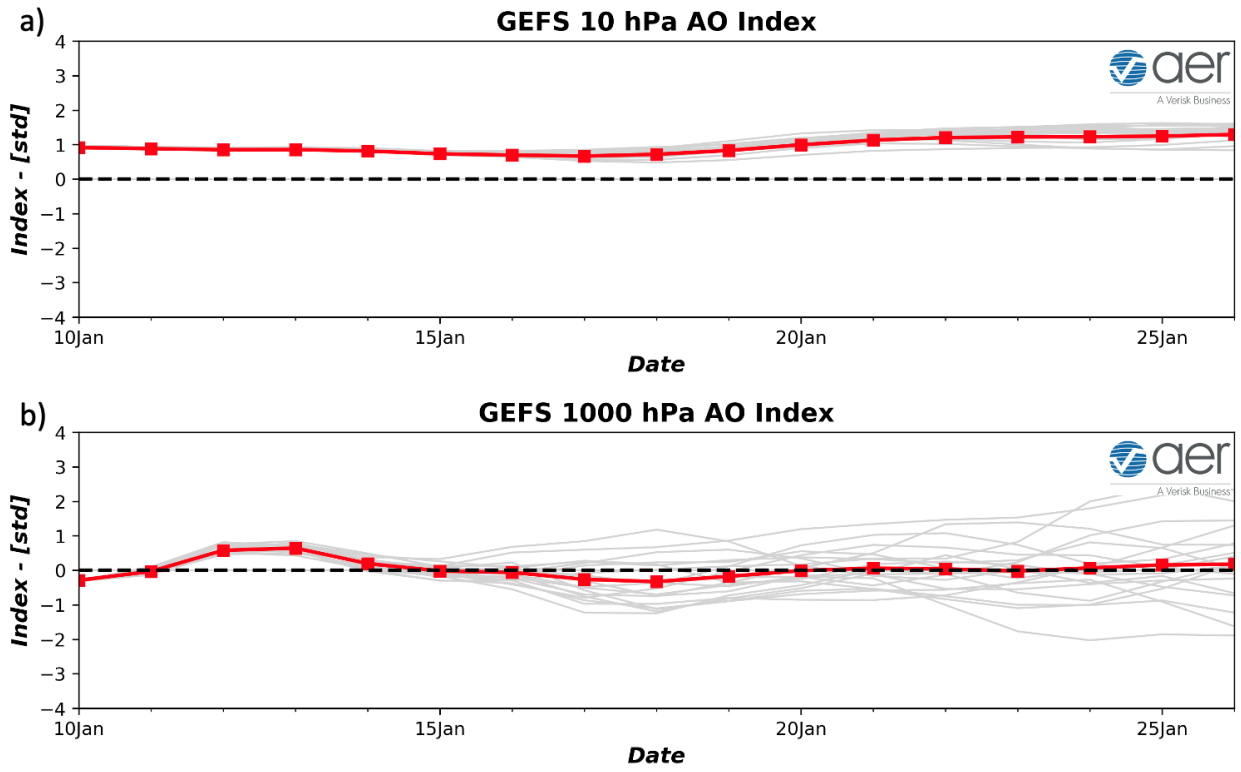

Figure 1. (a) The predicted daily-mean AO at 1000 hPa from the 00Z 10 January 2022 GFS ensemble. (b)The predicted daily-mean near-surface AO from the 00Z 10 January 2022 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

This week, troughing/negative geopotential height anomalies will dominate the northern North Atlantic including Northern Scandinavia with ridging/positive geopotential height across Western and Central Europe including the UK with more troughing/negative geopotential height anomalies in the Eastern Mediterranean this period (**Figures 2).** The resultant zonal flow will result in normal to above normal temperatures across much of Europe except for normal to below normal temperatures across Eastern Europe due to the resultant northerly flow from the low center in the eastern Mediterranean (**Figure 3**). This week, weak ridging/positive geopotential height anomalies will dominate Western Asia and Eastern Siberia with troughing/negative geopotential height anomalies across Eastern Asia (**Figure 2**). This pattern favors widespread normal to above normal temperatures across much of Asia with normal to below normal temperatures confined to parts of Western and Far East Asia **(Figure 3**). As an aside, though the Ural ridging/high pressure is awfully modest looking, it is likely sufficient to trigger a stretched PV event but obviously not an SSW.

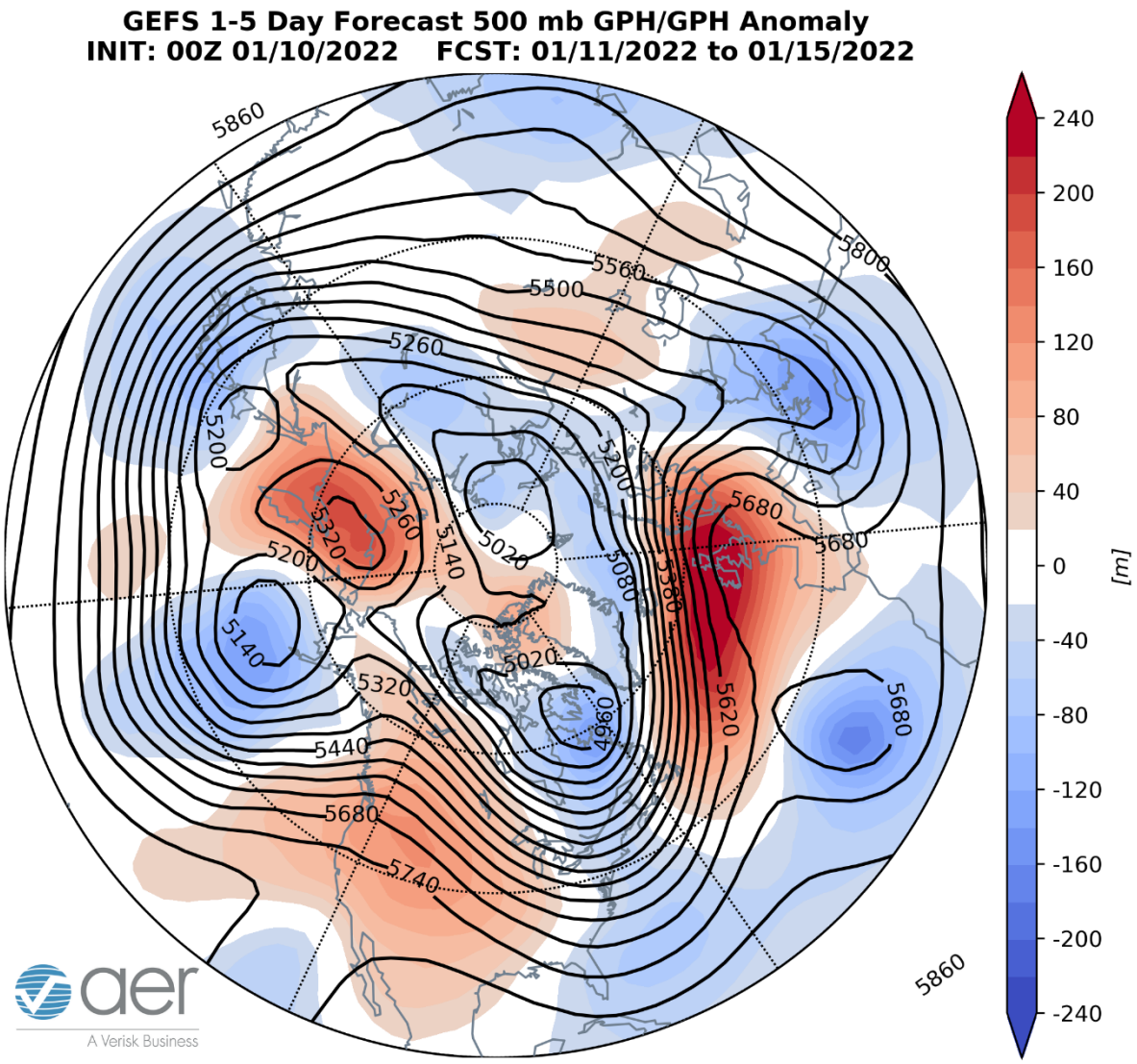

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 11 – 15 January 2022. The forecasts are from the 00z 10 January 2022 GFS ensemble.

Strengthening ridging/positive geopotential height anomalies across Alaska, Western Canada and the Western US will contribute to deepening troughing/negative geopotential height anomalies across Eastern Canada and the Eastern US this period **(Figure 2).** This will favor normal to below normal temperatures across northern Alaska, Central and Eastern Canada and the Eastern US with normal to above normal temperatures in southern Alaska, Western Canada and the Western US and the US Plain States **(Figure 3).**

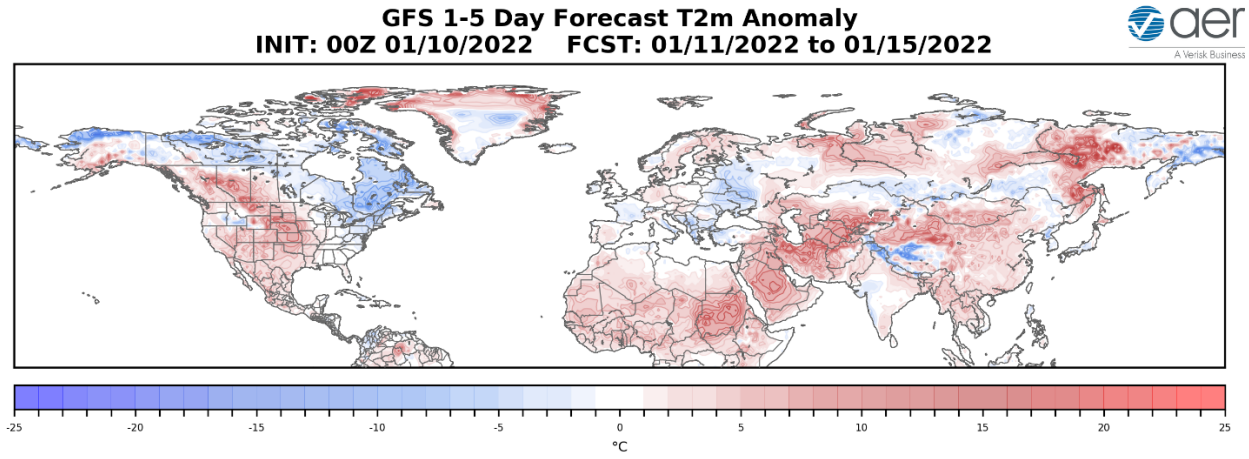

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 11 – 15 January 2022. The forecast is from the 00Z 10 January 2022 GFS ensemble.

Troughing and/or cold temperatures are predicted to support new snowfall across Norway, Southeastern Europe including Turkey, Western Asia, the Tibetan Plateau and the Far East while mild temperatures promote snowmelt in and around the Baltic Sea, the Alps, Central Asia and Eastern Siberia (**Figure 4**). Troughing and/or cold temperatures are predicted to support new snowfall across Alaska, Northern and Eastern Canada and the US Great Lakes while mild temperatures promote snowmelt in Western Canada, the Western US and the Northeastern US (**Figure 4**).

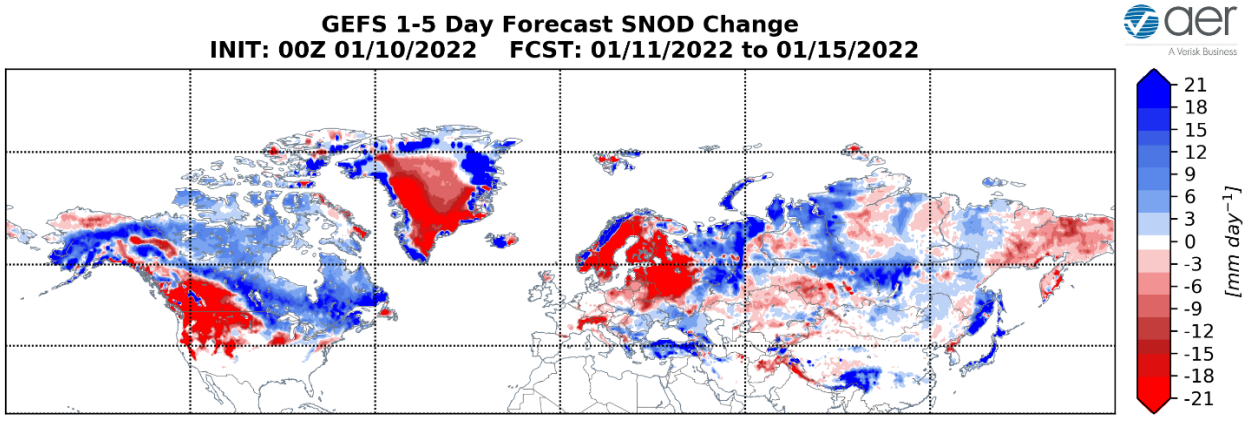

Figure 4. Forecasted snow depth changes (mm/day; shading) from 11 – 15 January 2022. The forecast is from the 00Z 10 January 2022 GFS ensemble.

Mid-Term

6-10 day

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

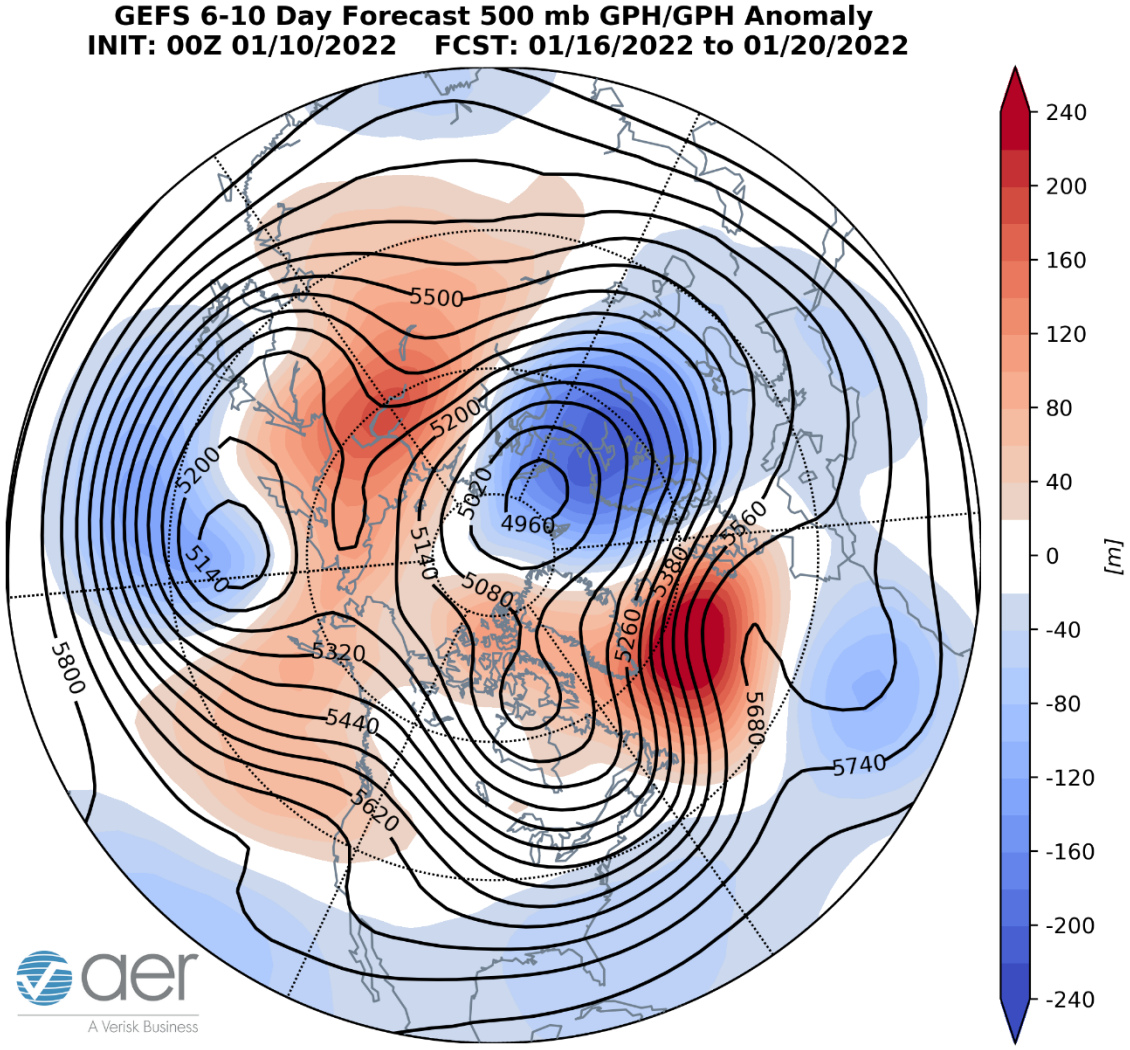

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 16 – 20 January 2022. The forecasts are from the 00z 10 January 2022 GFS ensemble.

Ridging/positive geopotential height anomalies across the central North Atlantic including Greenland will support deepening troughing/negative geopotential height anomalies across most of Europe with the exception of ridging/positive geopotential height anomalies centered near the UK (**Figures 5).** This will result in normal to below normal temperatures across most of Europe with the exception of normal to above

normal temperatures across Northwest Europe including the UK (**Figure 6**). Ridging/positive geopotential height anomalies are predicted to still dominate much of Central and Eastern Asia though Northwest Asia troughing/negative geopotential height anomalies are predicted to deepen with troughing persisting in Far Eastern Asia this period (**Figure 5**). This pattern favors normal to above normal temperatures across much of Asia with normal to below normal temperatures limited to Western and parts of Far Eastern Asia **(Figure 6**).

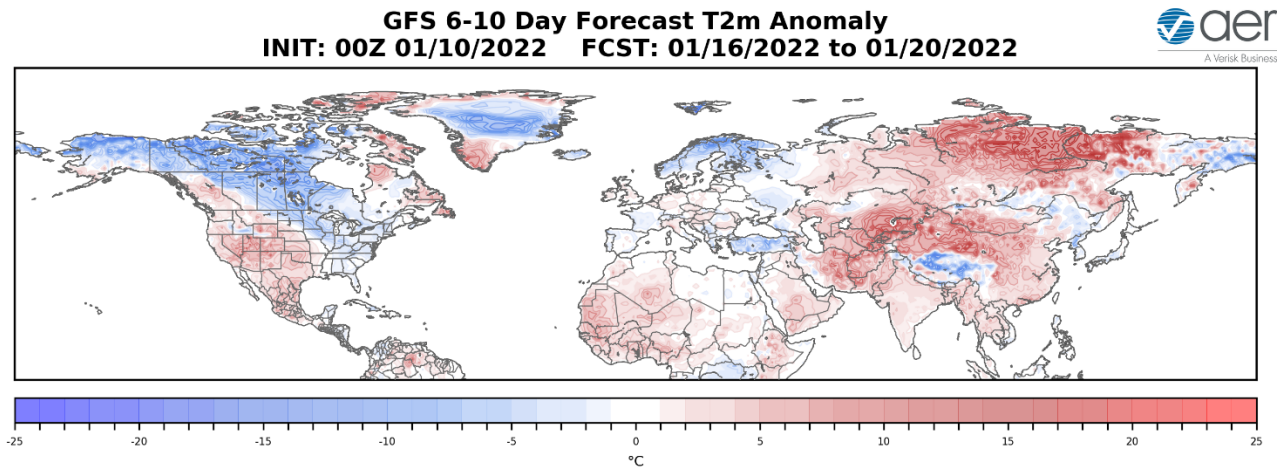

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 16 – 20 January 2022. The forecasts are from the 00Z 10 January 2022 GFS ensemble.

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

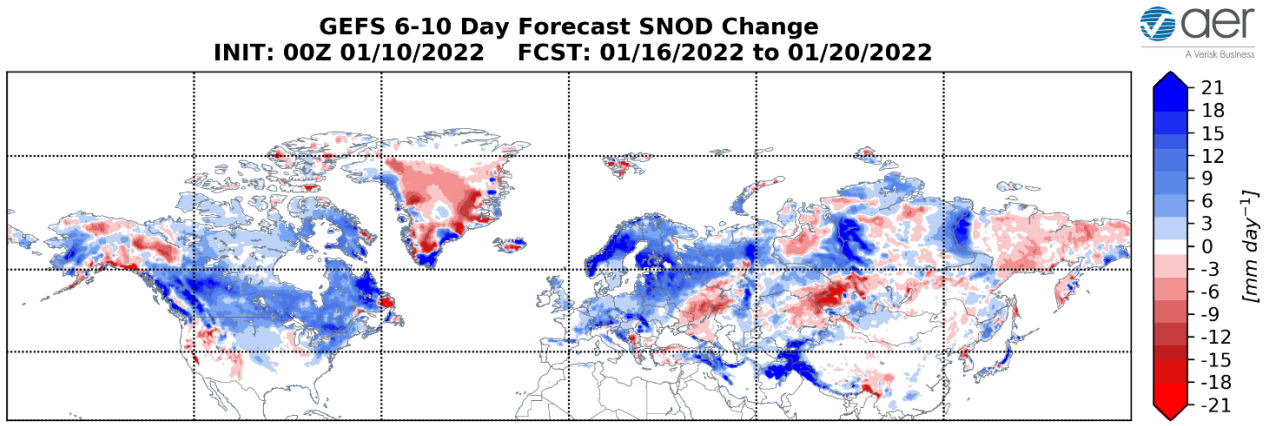

Figure 7. Forecasted snow depth changes (mm/day; shading) from 16 – 20 January 2022. The forecast is from the 00Z 10 January 2022 GFS ensemble.

Troughing and/or cold temperatures are predicted to support new snowfall across Central and Eastern Europe, the higher elevations of Southern Europe including the Alps and Pyrenees, the UK, Northern Asia, the Tibetan Plateau and East Asia while milder temperatures promote snowmelt across Southeastern Europe, Southwestern and Central Asia (**Figure 7**). Troughing and/or cold temperatures are predicted to support new snowfall across western Alaska, much of Canada, the Northern Plains and the Northeastern US while milder temperatures promote snowmelt across Southern Alaska and the Western US (**Figure 7**).

11-15 day

With geopotential height anomalies predicted to be positive across the North Pacific side of the Arctic but negative across the North Atlantic side of the Arctic and mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 8**), the AO should remain close to neutral this period (**Figure 1**). With predicted mostly negative pressure/geopotential height anomalies but weak across Greenland (**Figure 8**), the NAO is forecasted to remain neutral to positive this period.

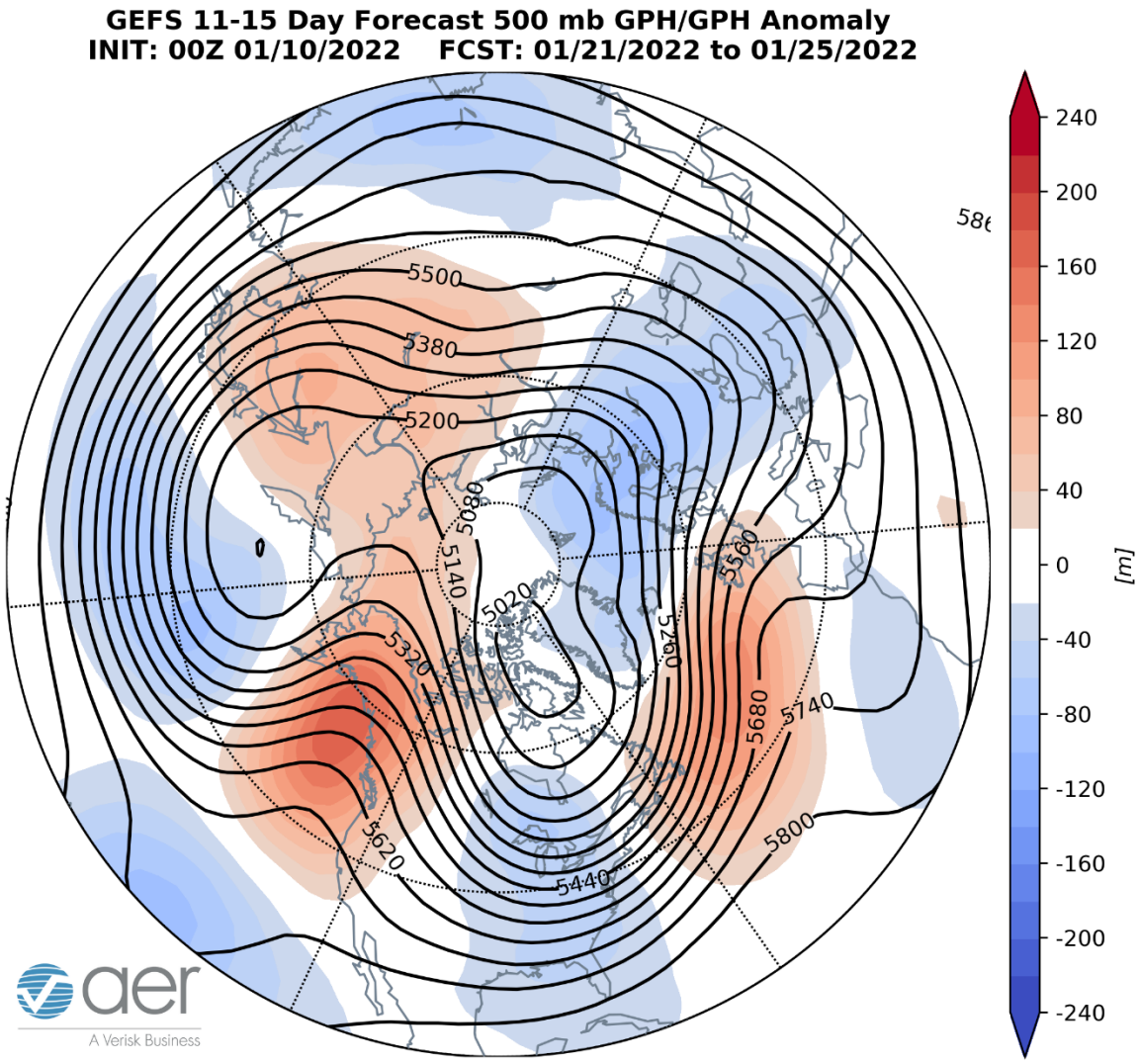

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 21 – 25 January 2022. The forecasts are from the 00z 10 January 2022 GFS ensemble.

Persistent ridging/positive geopotential height anomalies in the central North Atlantic are predicted to continue to support troughing/negative geopotential height anomalies across Central and Eastern Europe with ridging mostly confined to the UK this period (**Figure 8**). This pattern favors more normal to below normal temperatures across much of Europe with the possible exception of normal to above normal temperatures across Western Europe including the UK this period (**Figures 9**). Troughing/negative geopotential height anomalies are predicted in Northwestern and Northeastern Asia with ridging/positive geopotential height anomalies across Central and Eastern Asia this period (**Figure 8**). This pattern favors more widespread normal to below normal temperatures across Western Asia and parts of Northeastern Asia with normal to above

normal temperatures widespread across much of Central and Southern Asia this period (**Figure 9**).

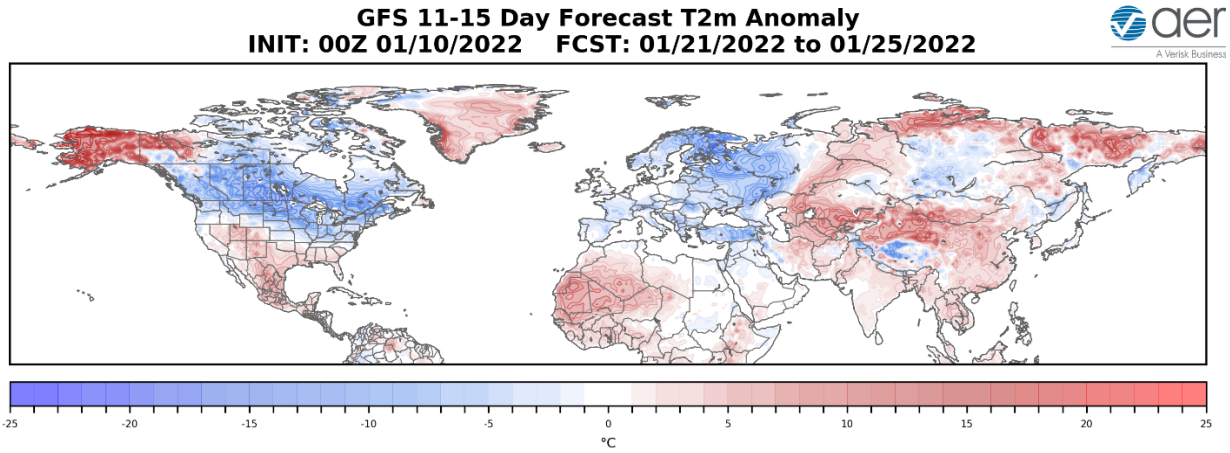

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 21 – 25 January 2022. The forecasts are from the 00z 10 January 2022 GFS ensemble.

Ridging/positive geopotential height anomalies are predicted to continue to amplify across western North America contributing to deepening troughing/negative geopotential height anomalies in eastern North America this period (**Figure 8**). This pattern favors normal to above normal temperatures across Alaska, Western Canada and the Western US with normal to below normal temperatures in Central and Eastern Canada and the Central and Eastern US (**Figure 9**).

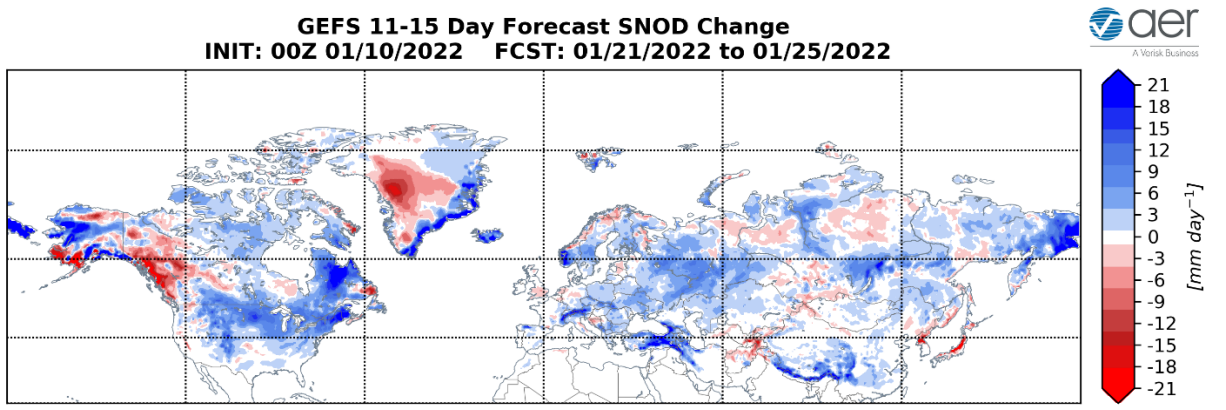

Figure 10. Forecasted snow depth changes (mm/day; shading) from 21 – 25 January 2022. The forecast is from the 00Z 10 January 2022 GFS ensemble.

Troughing and/or cold temperatures are predicted to support possible new snowfall across Central and Eastern Europe including Turkey, Western and Eastern Asia and the

higher elevations of Southern Asia while milder temperatures promote snowmelt across Korea and Japan (**Figure 10**). Troughing and/or cold temperatures are predicted to support possible new snowfall across central Alaska, Northern and Eastern Canada, the US Rockies and the Northern US while milder temperatures promote snowmelt across parts of Southern Alaska, Western Canada and the US West Coast (**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 over the next two weeks (**Figure 11**). Currently the stratosphere and troposphere are decoupled and waiting for coupling to resume, though exactly how remains an open question to me.

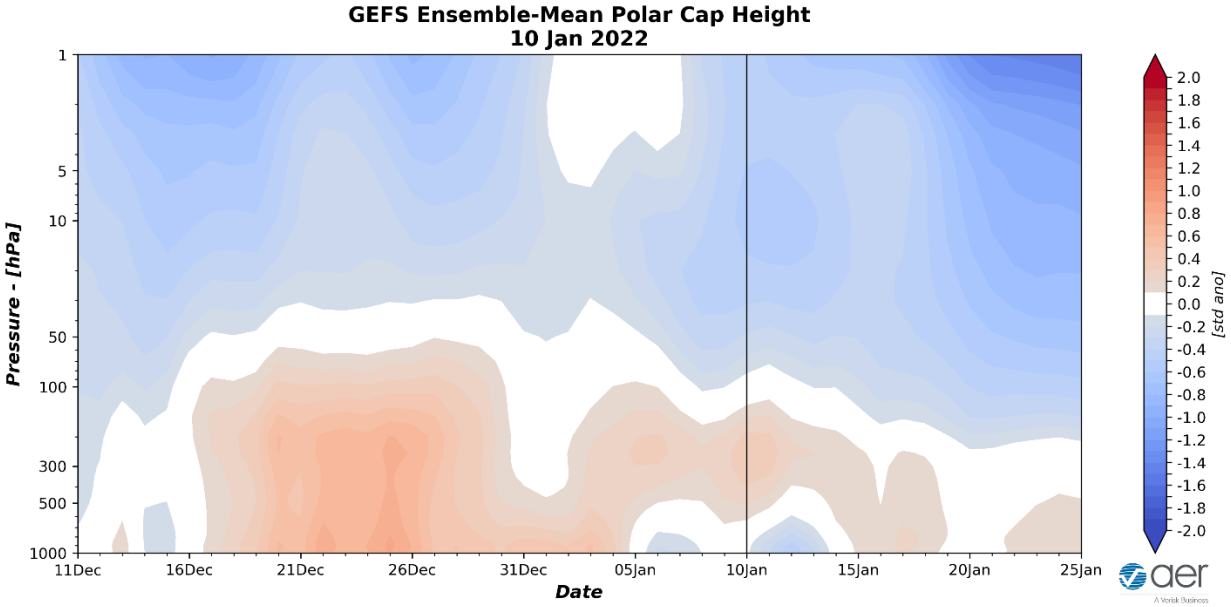

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 10 January 2022 GFS ensemble.

The normal to below normal PCHs predicted this week in the lower troposphere are consistent with the predicted positive surface AO this week (**Figure 1**). The PCH forecast surely looks strange today and suggests a troposphere- (very) low stratosphere-troposphere coupling event that is 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 below normal (**Figure 12**). The negative WAFz anomalies predicted over the next two weeks will continue to support a relatively strong PV through mid- to late-January 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 critical right now.

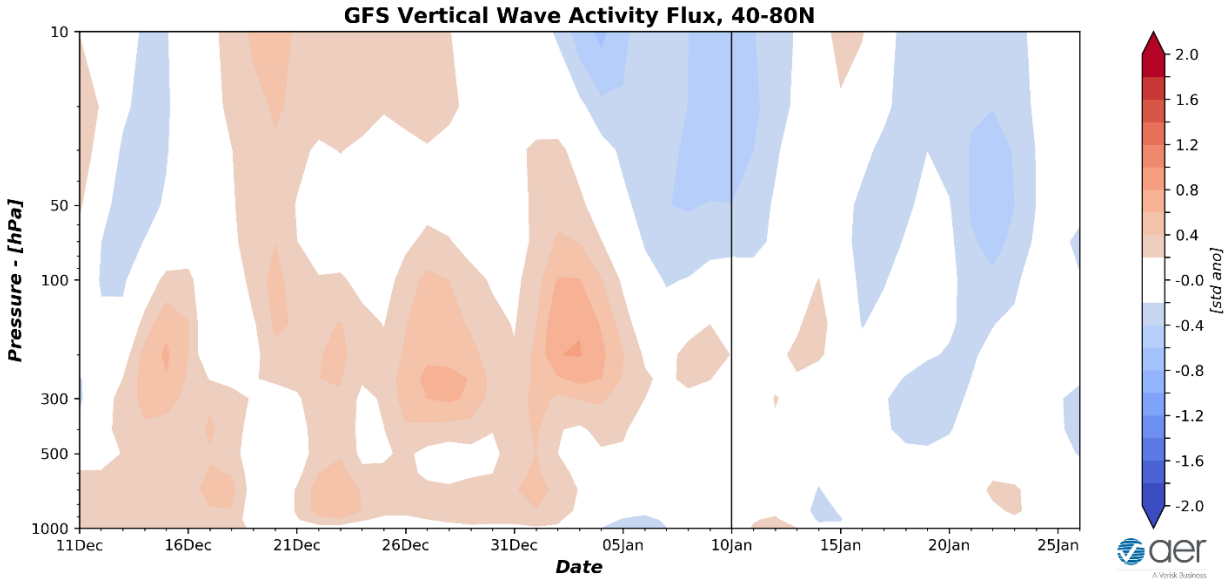

Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 10 January 2022 GFS ensemble.

Though zonally averaged WAFz is weak, the GFS is predicting that regional WAFz will support another stretched stratospheric PV later this week with the PV centered near the North Pole with ridging centered on the Dateline and polar stratospheric warming across Eurasia (**Figure 13**). However, the perturbation is relatively minor, and the PV is relatively strong resulting in a current positive stratospheric AO (**Figure 11**).

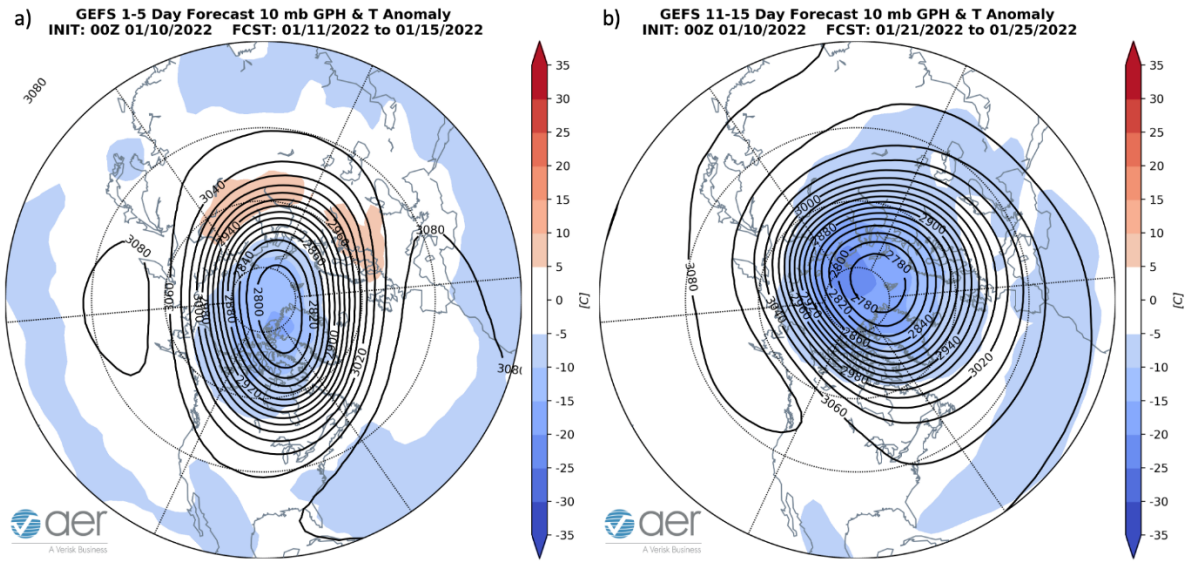

Figure 13. (a) Forecasted averaged from 11 – 15 January 2022 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere. (b) Same as (a) except forecasted averaged from 21 – 25 January 2022. The forecasts are from the 00Z 10 January 2022 GFS model ensemble.

The below normal WAFz is predicted to allow the PV to strengthen and become quite strong with the PV remaining centered near the North Pole for late January (**Figure 13**) with a persistent positive stratospheric AO the next two weeks (**Figure 11**). The strengthening stratospheric PV could couple with the surface commencing a relatively mild period across the US and Europe, sometime in February.

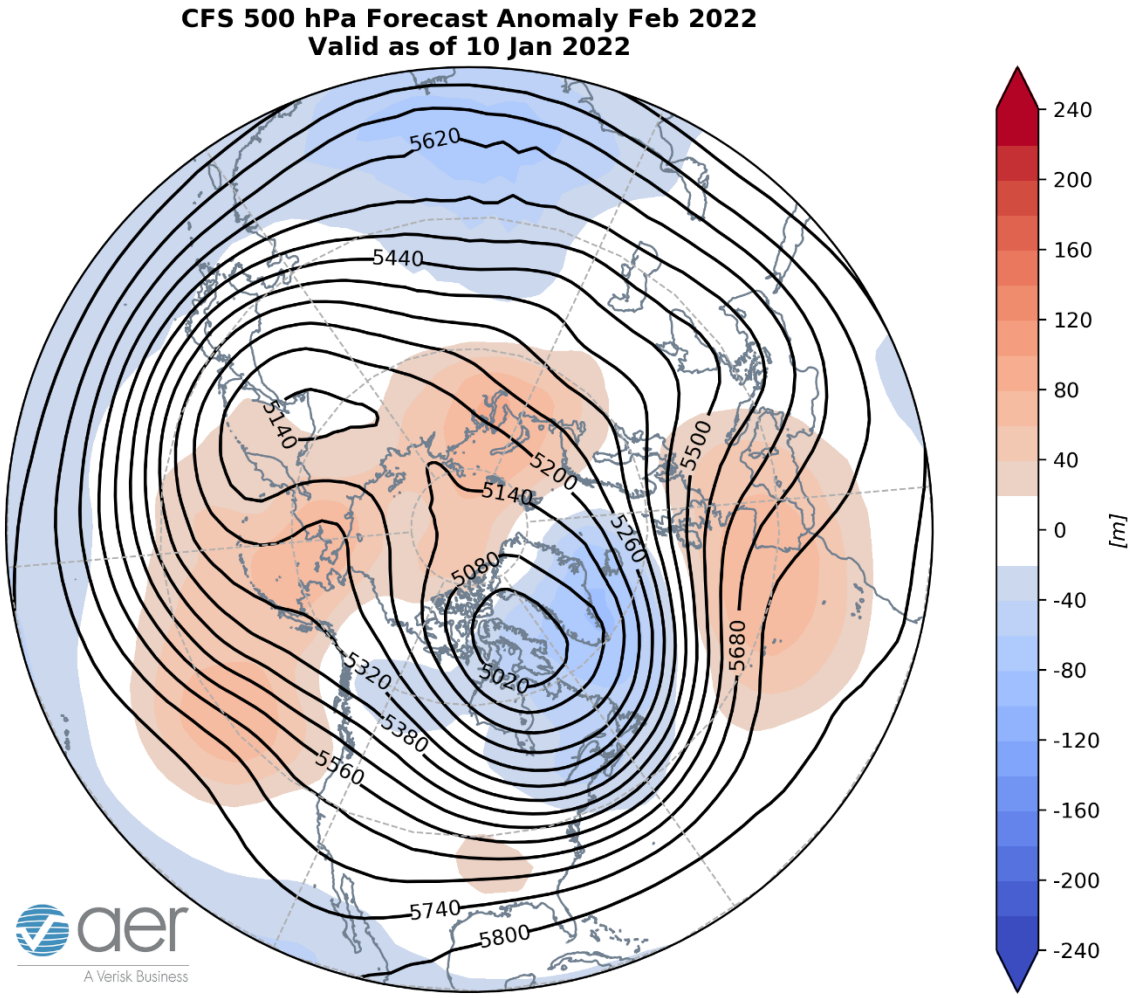

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for February 2022. The forecasts are from the 00Z 10 January 2022 CFS.

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 centered over Western Europe, the Central Arctic, the Barents-Kara Seas region, the Gulf of Alaska and in the Southeastern US with troughing across Western Asia, Eastern Asia, most of Canada and the Northeastern US (**Figure 14).** This pattern favors seasonable to relatively warm temperatures widespread across much of Europe, much of Siberia, Northern Alaska and Canada and the Western and Southern US with seasonable to relatively cold temperatures across Western Europe, Western and Eastern Asia, southern Alaska, much of Canada and the Northeastern US (**Figure 15**)**.**

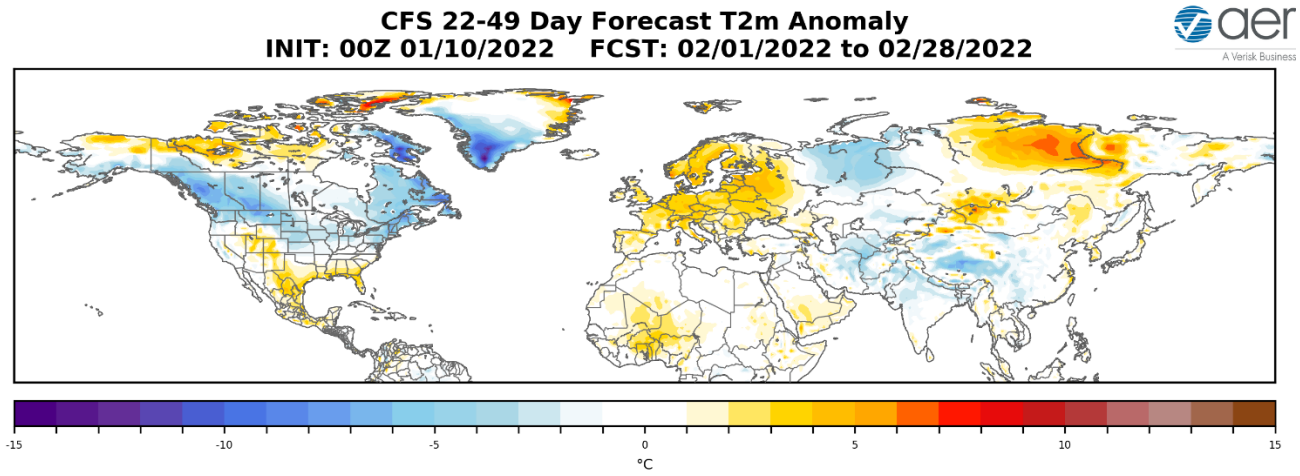

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for February 2022. The forecasts are from the 00Z 10 January 2022 CFS.

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 and from what I can tell the most extensive for this date since 2004, 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.

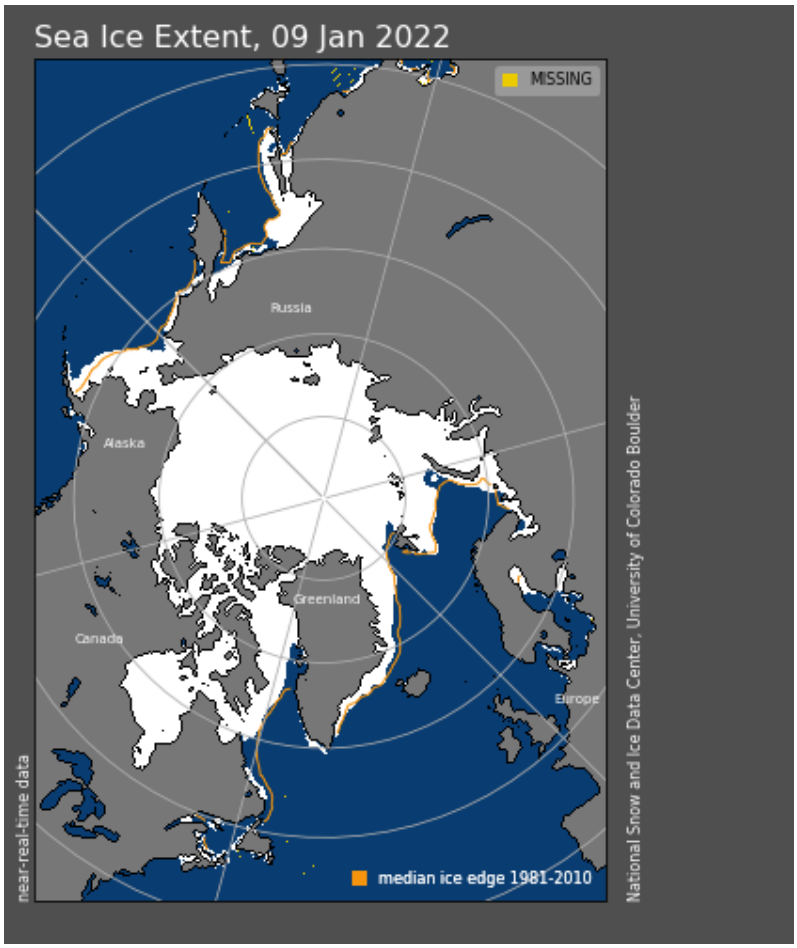

Figure 16. Observed Arctic Sea ice extent on 9 January 2022 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image from the National Snow and Ice Data Center (NSIDC).

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.

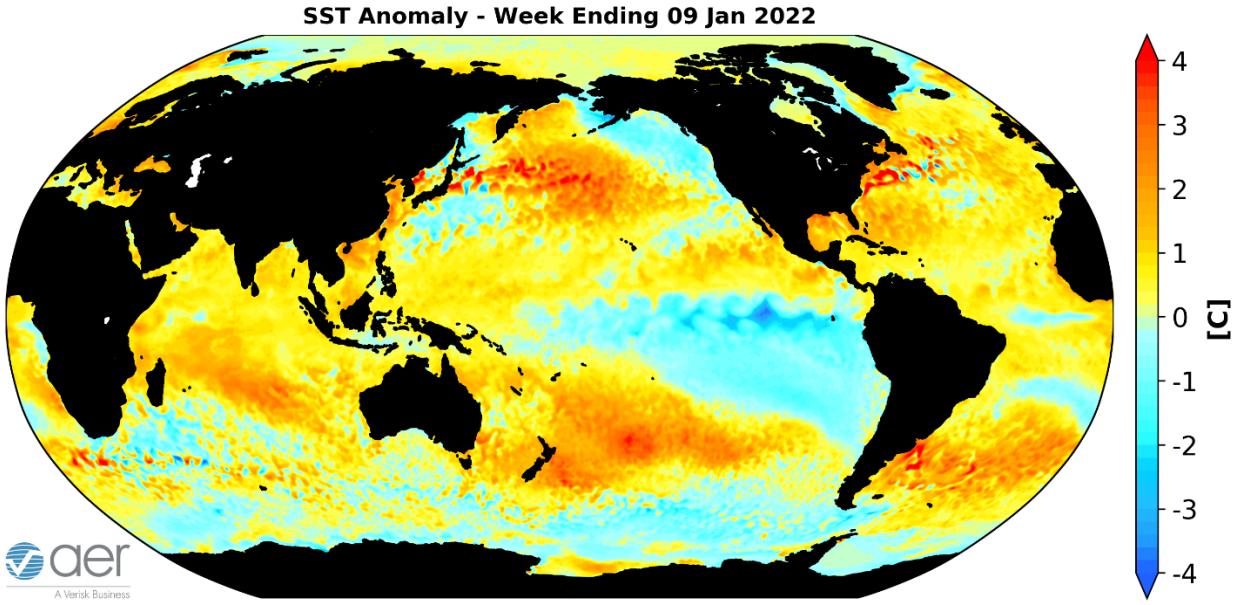

Figure 17. The latest weekly-mean global SST anomalies (ending 9 January 2022). Data from NOAA OI High-Resolution dataset.

Currently the Madden Julian Oscillation (MJO) is in phase seven (**Figure 18**). The forecasts are for the MJO to linger mostly in phase seven and eight through mid-January before weakening to where no phase is favored. MJO phase seven favors high latitude blocking including Alaska. Initially phase seven favors troughing and cold temperatures in the Western US and ridging and mild temperatures in the Eastern US but then reverses. To be honest not sure what to make of the MJO forcing this week and next week. The MJO has been hanging out in phase seven for a very long time and the weather has been very different over the period but admittedly this is outside of my expertise.

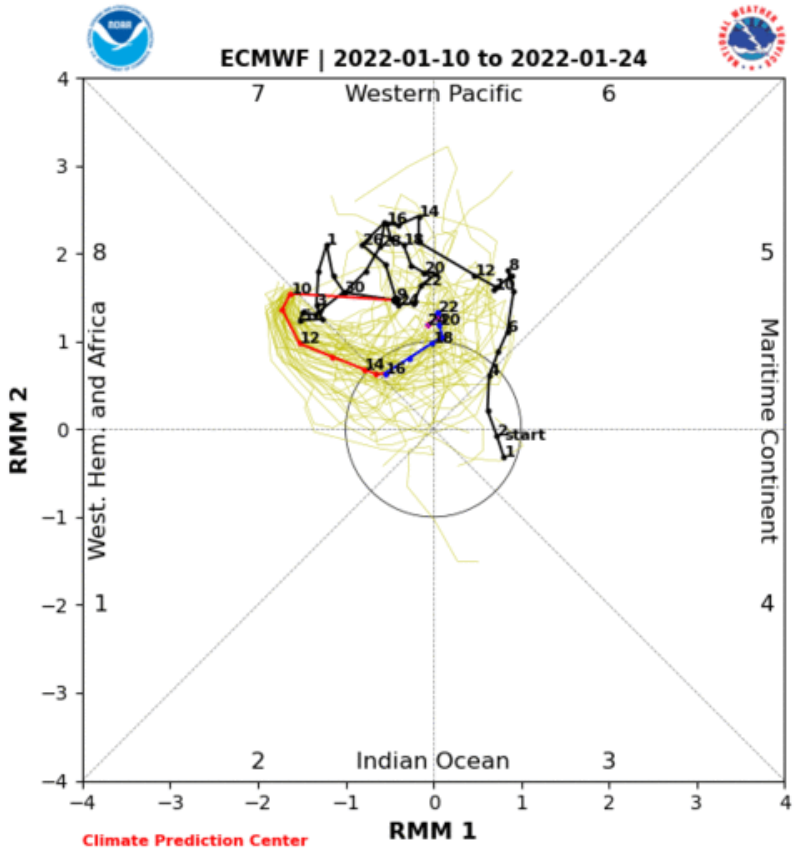

Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 10 January ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model "spread" is denoted by the gray shading. Sector numbers indicate 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