January 21, 2019

Special blog on winter 2016/2017 retrospective can be found here - http://www.aer.com/winter2017

Special blog on winter 2015/2016 retrospective can be found here - http://www.aer.com/winter2016

Dr. Judah Cohen from Atmospheric and Environmental Research (AER) recently embarked on an experimental process of regular research, review, and analysis of the Arctic Oscillation (AO). 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.

With transition to a fall/winter schedule, postings are once every week. Precipitation forecasts will be replaced by snow accumulation forecasts along with more 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 slightly positive and is predicted to generally trend negative for the next two weeks.
- The current positive AO is reflective of mostly negative 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 with negative pressure/geopotential height anomalies across Greenland and positive pressure/geopotential height anomalies across the mid-latitudes of the North Atlantic and is predicted to trend negative as height anomalies turn mostly positive across Greenland over the next two weeks.
- Ridging/positive geopotential height anomalies centered south of Iceland and extending into Western Europe are forcing troughing/negative geopotential height anomalies over the remainder of Europe and over the next two weeks this pattern is predicted to persist and slowly drift westward. This pattern is predicted to bring seasonable to below normal temperatures to much of Europe including the United Kingdom (UK) over the next wo weeks. The one exception is Southeastern Europe where southwesterly winds will transport relatively mild air into the region.

- Much of Asia is currently dominated by ridging/positive geopotential height anomalies and relatively mild temperatures with troughing/negative geopotential height anomalies and relatively cold temperatures mostly focused across northwestern Asia. However, over the next two weeks troughing/negative geopotential height anomalies and cold temperatures will become widespread across Northern Asia especially Siberia with ridging/positive geopotential height anomalies and relatively mild temperatures across Southern Asia including the Middle East, the northern Indian subcontinent and East Asia.
- This week ridging/positive geopotential height anomalies centered in the Gulf of Alaska are forcing troughing/negative geopotential height anomalies across eastern North America. This pattern is predicted to remain relatively stable over the next two weeks yielding normal to above normal temperatures across western North America including Alaska with cold temperatures across Canada and the United States (US) east of the Rockies.
- *I*n the Impacts section, I discuss my expectations of the remainder of the winter based on the stratospheric polar vortex (PV) split.

Impacts

Good news. It does seem that from now on the blog will be archived rather than overwritten so a welcome development.

We are in the place of the troposphere-stratosphere-troposphere coupling event that has been unfolding since November, where I don't feel that I have as much to offer. There is increasing confidence that the stratosphere and troposphere are going to couple by any accepted metric. The GFS forecast clearly shows downward propagation of positive polar cap geopotential height anomalies from the stratosphere to the troposphere, the surface AO is predicted to turn decisively negative and high latitude blocking is the norm rather than exception over the next two weeks. Also, warm temperatures are predicted across the North American Arctic including Alaska and Greenland. Therefore, relatively cold temperatures are expected to be widespread across the Northern Hemisphere (NH) including Northern Asia, Northern Europe and Eastern North America. Relatively warm temperatures are also expected in the Barents-Kara seas, the region of the Arctic with the greatest negative sea ice extent anomalies. I would expect the relatively cold pattern to last at a minimum of four weeks and up to eight weeks.

There is some question based on the latest model runs how long the relatively cold pattern will persist. Of course, there is the possibility that after a relatively cold couple of weeks the pattern turns overall milder pattern for the remainder of the winter. But as I have discussed many times the coupling from the stratosphere to the troposphere is described as "dripping paint." That is because the downward propagation or coupling doesn't come at once but in pieces. Therefore, the turn to colder and possibly snowier conditions are often episodic and not continuous. So, if there is a transition to milder

weather it would be a relaxation of the overall colder pattern and not a complete reversal. I would just add that this has been an extreme event in the stratosphere and sometimes an extreme event in the stratosphere does not translate into an extreme event in the troposphere and that could be true for this event as well.

With the help of my colleague Karl Pfeiffer I created an animation of the ongoing PV disruption from mid -December through last Friday shown in **Figure i.** Some readers have stated in the past that they enjoy the animations and here is an extended version. Maybe they are not much more than bubble game for the brain, but I am always fascinated by PV splits.

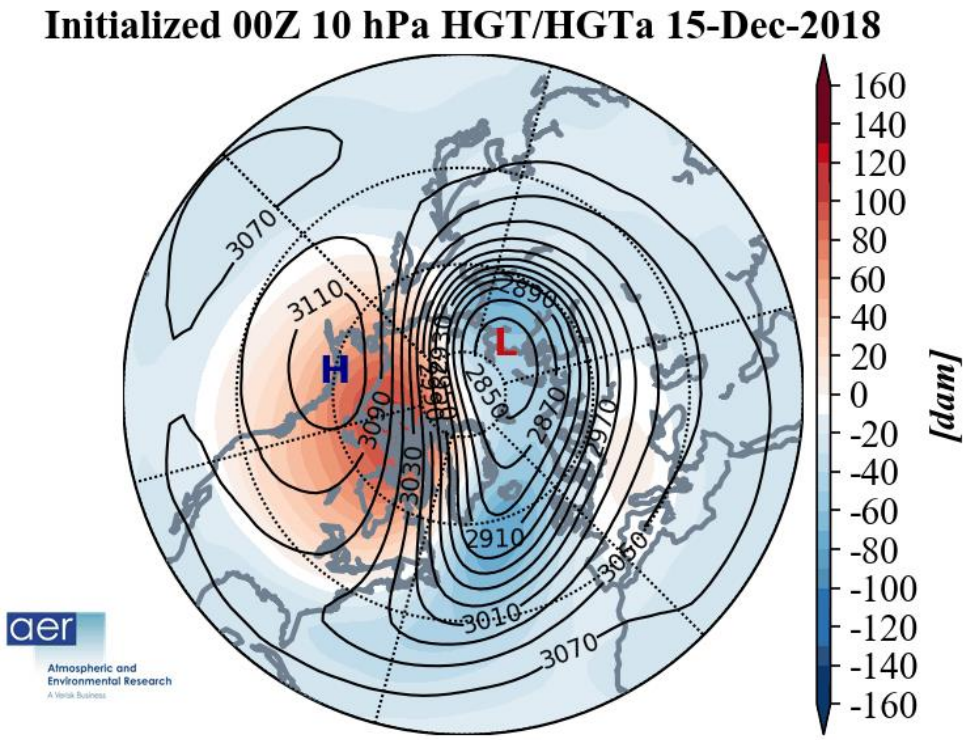

Figure i. Animation of observed 10 mb geopotential heights (contours) and geopotential height anomalies (m; shading) for 15 December 2018 - 18 January 2019.

Last week I explained how I am transitioning away from the AO paradigm and embracing the PV paradigm. However, seems that the old guard is not going away without a fight. Much of my early to mid-career has been trying to understand the relationship between October Siberian snow cover extent and the winter AO. But since then I have thought about the major NH temperature pattern or see saw in terms of warm Arctic/cold continents or cold Arctic/warm continents and its relationship to sea

ice extent variability. I have thought of the dramatic decline in sea ice as a disrupter of the normal climate and has likely contributed to the deterioration in the relationship of the Siberian snow cover and/or the AO with winter temperature variability since the winter of 2012/13.

But it seems this winter the old guard are staging a comeback. The predicted NH temperature pattern is classic negative AO with cold temperature widespread across northern Eurasia including Europe and eastern North America. And unlike recent winters, temperatures are not relatively mild across the pan-Arctic but locally in Alaska and Greenland, again classic mild locations during negative AO regimes. I do think that the warm Arctic/cold continents pattern is distinct from the negative AO pattern as argued in Cohen et al. 2018. In my opinion the upcoming predicted NH temperature pattern projects more strongly onto the negative AO than the warm Arctic/cold continents pattern. One distinction in my mind is the continuous stripe of cold temperatures along the Eurasian north slope or the land areas adjacent to the Arctic ocean, they are solidly below normal in the negative AO pattern but mild in the warm Arctic/cold continents pattern. Also, as I argued in an earlier blog the timing of the troposphere-stratosphere coupling nicely matches the timing expected based on extensive October Siberian snow cover extent. Waiting for the remainder of the winter before passing judgement but so far this winter the relationship is strong.

Near Term Conditions

1-5 day

The AO is currently slightly positive **(Figure 1**), with mostly negative geopotential height anomalies across the Central Arctic **(Figure 2)**. Geopotential height anomalies are negative across Iceland and Greenland with positive geopotential height anomalies across the mid-latitudes of the North Atlantic **(Figure 2)** and therefore the NAO is positive.

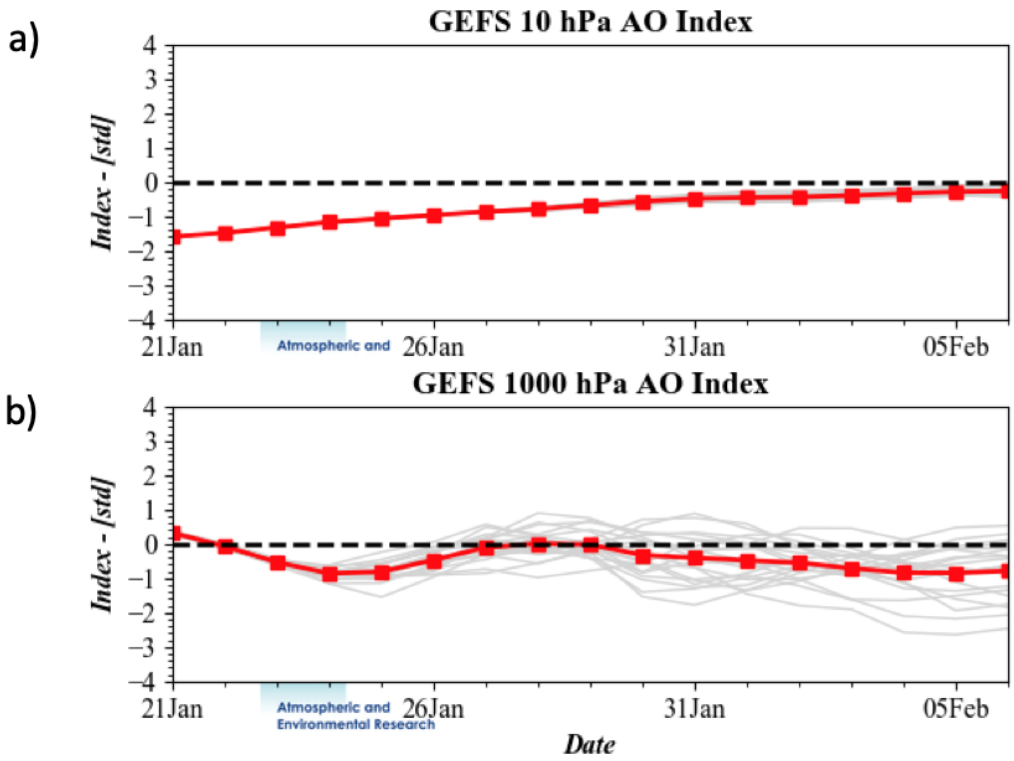

Figure 1. (**a**) The predicted daily-mean AO at 10 hPa from the 00Z 21 January 2019 GFS ensemble. (**b**) The predicted daily-mean near-surface AO from the 00Z 21 January 2019 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

Currently ridging/positive geopotential height anomalies centered south of Iceland and extending into far Western Europe (**Figure 2**) are forcing troughing/negative geopotential height anomalies downstream across much of Europe with the greatest negative departures focused across Southern Europe (**Figure 3**). With low heights and mostly northerly flow of air dominating, normal to below normal temperatures are widespread across much of Europe including the UK while southwesterly winds are bringing normal to above normal temperatures for Southeastern Europe and even into the Middle East (**Figure 3).** Troughing/negative geopotential height anomalies are mostly confined to northwestern Asia with ridging/positive geopotential height anomalies widespread across the remainder of Asia (**Figure 2**) yielding widespread normal to above normal temperatures across much of Asia including the Middle East, Central and East Asia with the exception of normal to below normal temperatures for Western Russia (**Figure 3).** However, regional troughing/negative geopotential height anomalies across the northern India subcontinent (**Figure 2**), are predicted to result in normal to below normal temperatures across Northern India and Pakistan **(Figure 3).**

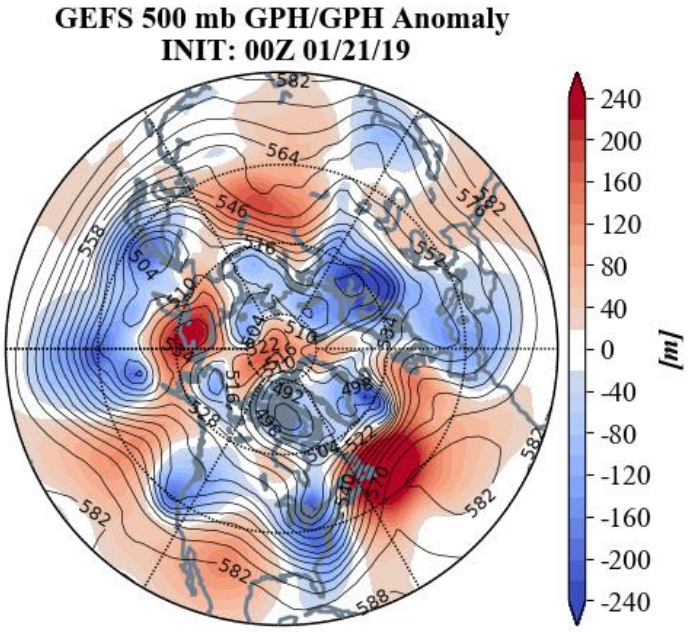

Figure 2. Observed 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) for 00Z 21 January 2019.

Troughing/negative geopotential height anomalies centered near the Dateline are forcing downstream ridging/positive geopotential height anomalies centered in the Gulf of Alaska with more troughing/negative geopotential height anomalies across eastern North America **(Figure 2).** This pattern is predicted to result in normal to above normal temperatures for Alaska, Western Canada and the Western US with normal to below normal temperatures for Eastern Canada and the Eastern US **(Figure 3).**

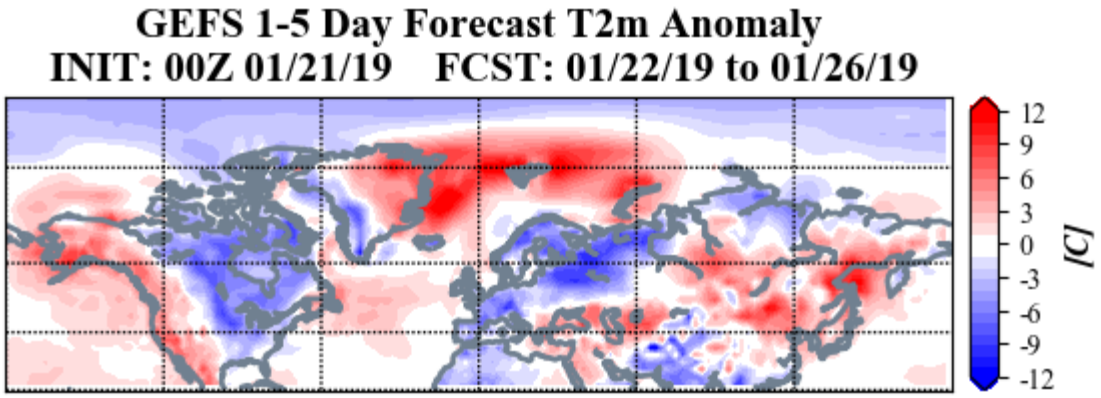

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 22 – 26 January 2019. The forecast is from the 00Z 21 January 2019 GFS ensemble.

Troughing and/or cold temperatures will bring widespread new snowfall to Europe, Turkey, Central, Northern and Eastern Asia (**Figure 4**). Across North America, troughing and cold temperatures will bring widespread new snowfall across Canada and the Northcentral US while milder temperatures at the end of the week will result in snowmelt across parts of Alaska and the Northeast (**Figure 4**).

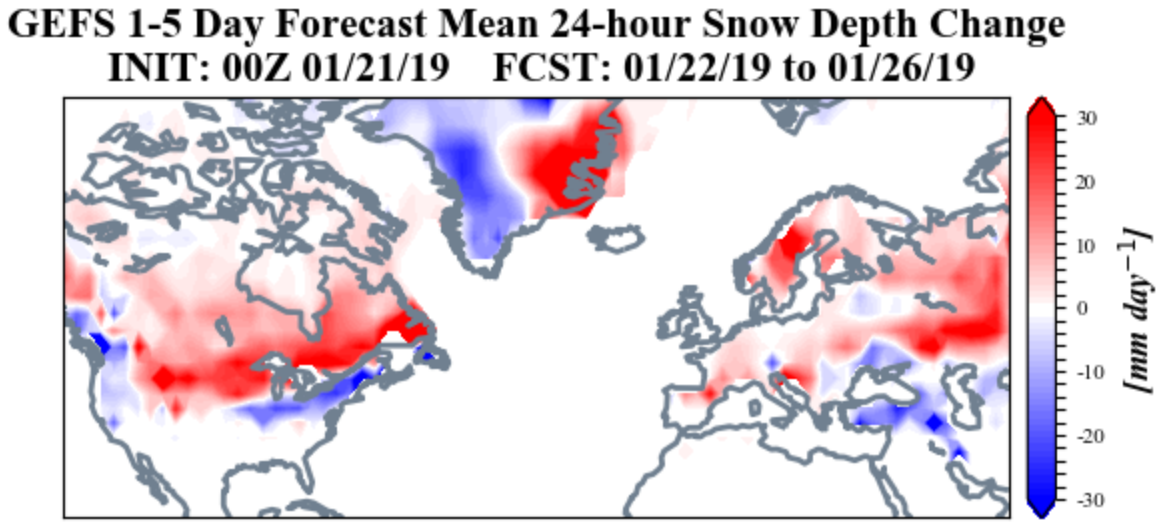

Figure 4. Forecasted snowfall anomalies (mm/day; shading) from 22 – 26 January 2019. The forecast is from the 00Z 21 January 2019 GFS ensemble. I changed the projection to provide better resolution to regions of interest.

Mid-Term

6-10 day

The AO is predicted to remain near neutral to slightly negative next week **(Figure 1**) with mixed geopotential height anomalies across the Arctic and mixed geopotential height anomalies across the mid-latitudes (**Figure 5a**). And with weak geopotential height anomalies across Greenland, the NAO will likely be near neutral as well next week.

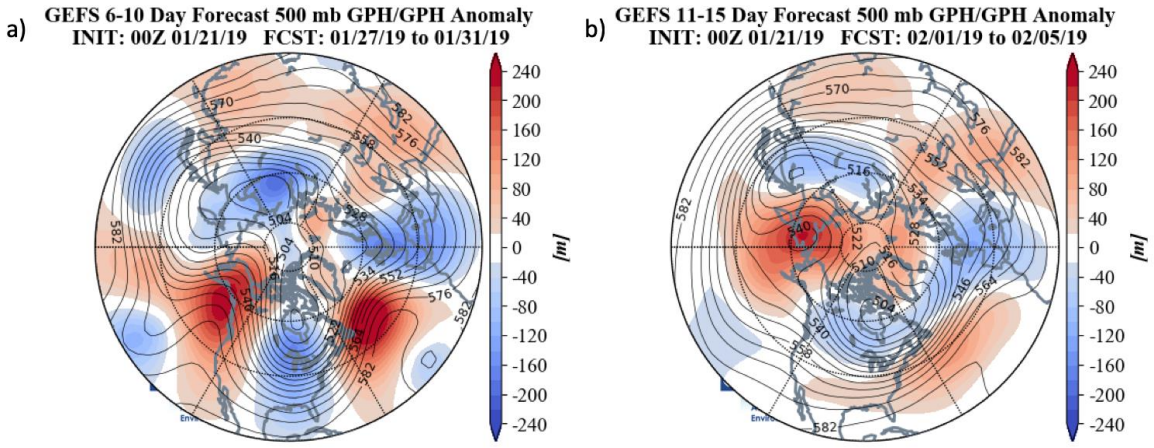

Figure 5. (a) Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 27 – 31 January 2019. (b) Same as (a) except averaged from 1 – 5 February 2019. The forecasts are from the 21 January 2019 00z GFS ensemble.

Ridging/positive geopotential height anomalies centered previously south of Iceland are predicted to drift south of Greenland allowing troughing/negative geopotential height anomalies across much of Europe this period (**Figure 5a**). This is likely to result in a normal to below normal temperatures for much of Europe including the UK with normal to above normal temperatures for Southeastern Europe due to a persistent southwesterly flow of milder air (**Figure 6**). Troughing/negative geopotential height anomalies previously in Northwestern Asia will push into Siberia while ridging/positive geopotential height anomalies will dominate much of the remainder of Asia (**Figure 5a**). This is predicted to yield normal to below normal temperatures for most of Russia but especially Siberia with normal to above normal temperatures for the rest of Asia including the Middle East, East Asia and likely most of Central Asia (**Figure 6**). Some residual troughing/negative geopotential height anomalies across Northern India (**Figure 5a**) are predicted to yield normal to below normal temperatures for Northern India and possibly into Pakistan **(Figure 6**).

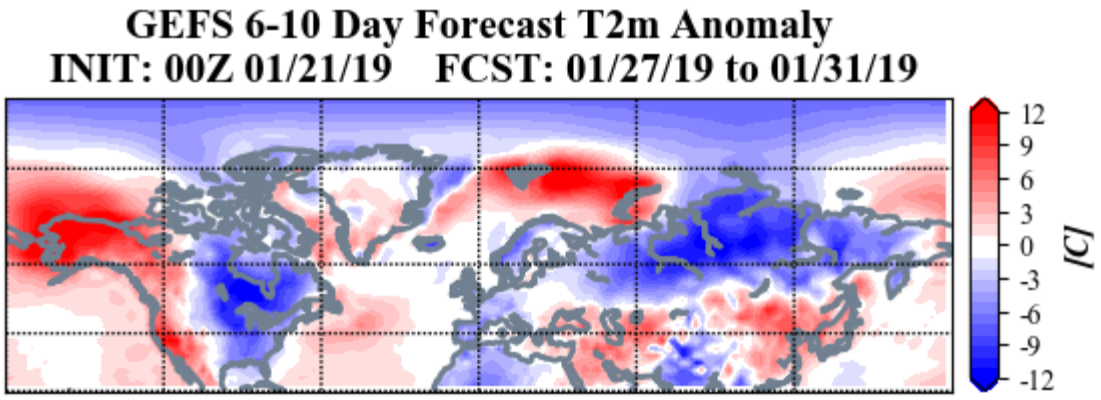

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 27– 31 January 2019. The forecasts are from the 00Z 21 January 2019GFS ensemble.

Ridging/positive geopotential height anomalies are predicted to remain focused across Alaska and the Gulf of Alaska with deepening troughing/negative geopotential height anomalies in Eastern Canada and the Eastern US (**Figure 5a**). The resultant temperature anomalies across North America are predicted to be normal to above normal temperatures across much of Alaska, the West Coast of Canada and the West Coast of the US with normal to below normal temperatures for Canada and the US from the Rockies to the Atlantic coast **(Figure 6).**

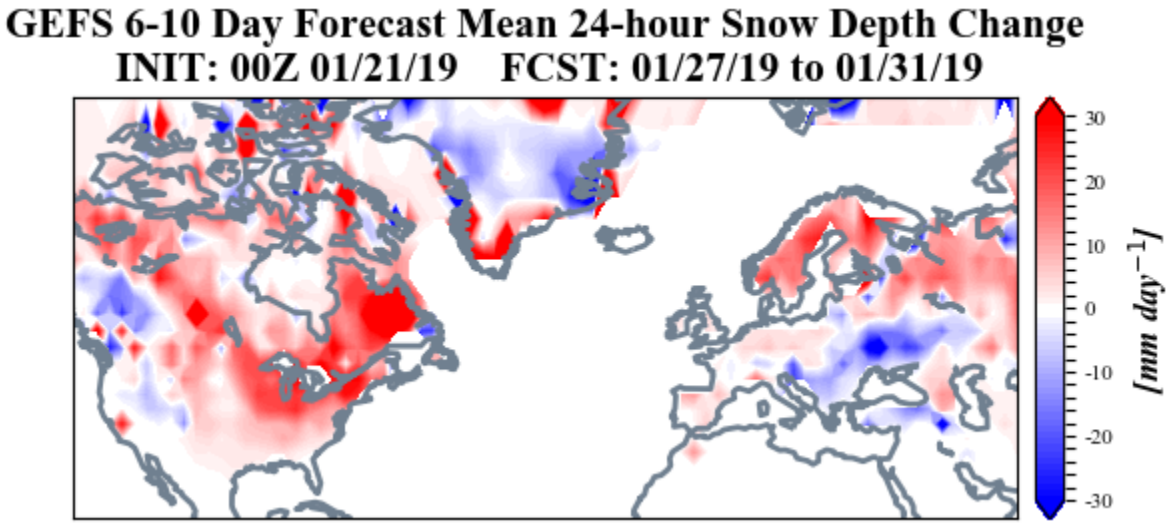

Figure 7. Forecasted snowfall anomalies (mm/day; shading) from 27 – 31 January 2019. The forecasts are from the 00Z 21 January 2019 GFS ensemble. I changed the projection to provide better resolution to regions of interest.

Troughing and cold air will bring the potential for new snowfall across almost all of Europe Northern and Central Asia and even possibly North Africa (**Figure 7**). Across North America, new snowfall is possible in Alaska, much of Canada and the entire Eastern US (**Figure 7**). Increasingly milder temperatures could result in snowmelt in parts of Turkey, Southeastern Europe, and even possibly parts of Western Canada and the Western US (**Figure 7**).

11-15 day

With mostly positive geopotential height anomalies predicted for the Arctic (**Figure 5b**), the AO is likely to be negative this period (**Figure 1**). With positive pressure/geopotential height anomalies across Greenland, the NAO is predicted to turn negative this period as well (**Figure 1**). The predicted negative AO is related to more substantive "dripping" of warm/positive polar cap geopotential height anomalies from the stratosphere to the troposphere.

Ridging/positive geopotential height anomalies across Greenland to Svalbard are predicted to persist troughing/negative geopotential height anomalies for much of Europe (**Figure 5b**). Low heights and northerly flow are likely to result in normal to below normal temperatures for much of Europe including the UK (**Figure 8**). However, a more southwesterly flow of air across Southeastern Europe will likely persist relatively mild temperatures to Southeastern Europe (**Figure 8**). Widespread troughing/negative geopotential height anomalies are predicted to persist across Siberia and extend into Northeast Asia with ridging/positive geopotential height anomalies predicted for Southern Asia (**Figure 5b**). This pattern favors normal to below normal temperatures for Northern Asia, including Western and Central Siberia and Northeast Asia with normal to above normal temperatures for Southern and Central Asia including the Middle East, Northern India, Pakistan and Southeast Asia (**Figure 8**). High geopotential height anomalies drifting west from Alaska could bring normal to above normal temperatures for Eastern Siberia (**Figure 8**).

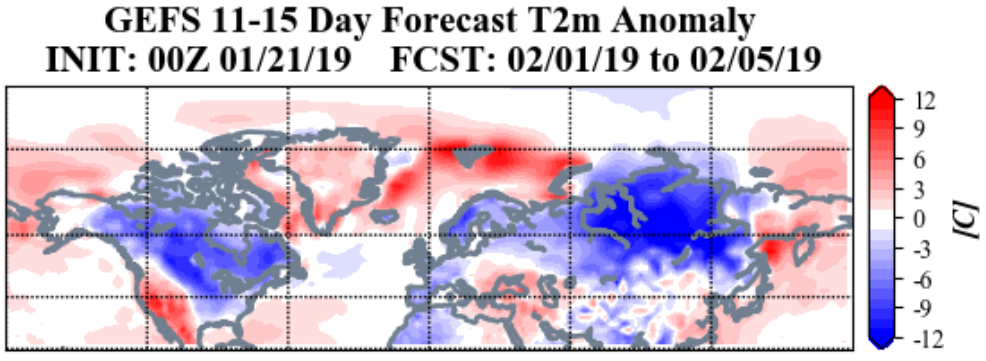

Figure 8. Forecasted surface temperature anomalies (°C; shading) from 1 – 5 February 2019. The forecasts are from the 00Z 21 January 2019 GFS ensemble.

Ridging/negative geopotential height anomalies previously centered across Alaska will drift to near the Dateline but will continue to support troughing/negative geopotential height anomalies across eastern North America (**Figure 5b**). However, the trough axis will shift west this period. This will favor normal to above normal temperatures across Alaska, and the Western US with normal to below normal temperatures for all of Canada and the US east of the Rockies (**Figure 8**).

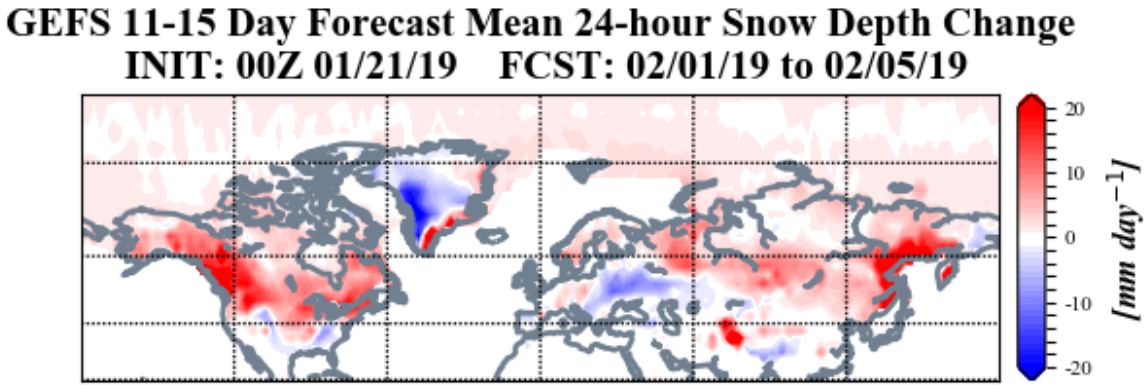

Figure 9. Forecasted snowfall anomalies (mm/day; shading) from 1 – 5 February 2019. The forecasts are from the 00Z 21 January 2019 GFS ensemble.

Once again additional snowfall is possible across much of northern Eurasia including Siberia, Northwestern Asia, Scandinavia, Central and even possibly Western Europe (**Figure 9**). Seasonable to cold temperatures across Alaska, Canada and even the Northern US will also support potentially new snowfall (**Figure 9**). Mild temperatures could result in snowmelt across Southeastern Europe, Turkey, Central Asia and the Eastern US (**Figure 9**).

Longer Term

30–day

The latest plot of the polar cap geopotential heights (PCHs) shows in general predicted normal to above normal PCHs in the stratosphere with normal PCHs in the troposphere (**Figure 10**). The near normal PCHs in the lower troposphere are consistent with a predicted near neutral AO this week (**Figure 1**). The above normal PCHs in the stratosphere are also consistent with the negative stratospheric AO for the next two weeks, though by early February it is close to neutral (**Figure 1**). The strongly positive PCHs and negative stratospheric AO are related to a sudden stratospheric warming (SSW) and a major mid-winter warming (MMW; where the zonal mean zonal wind reverses from westerly to easterly at 60°N and 10 hPa). The strongest positive stratospheric PCHs are no longer in the mid-stratosphere but are in the lower stratosphere, consistent with downward propagation expected with these events. So

far and in the near term only weak “dripping” of the positive PCHs through the troposphere to the surface are seen in the plot. There have been two relatively minor drips since the second week of January. However, a more substantial “drip” is predicted at the end of the month coincident with a more decisive negative turn in the AO.

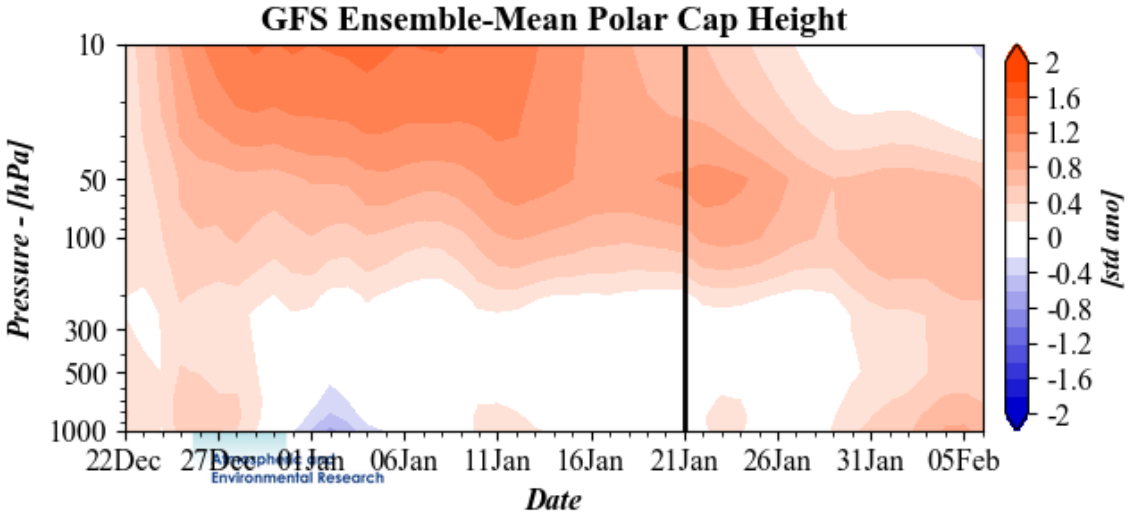

Figure 10. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecasts are from the 00Z 21 January 2019 GFS ensemble.

The plot of Wave Activity Flux (WAFz) or poleward heat transport indicates mostly negative WAFz **(Figure 11**). Below normal WAFz is consistent with a reversal in the winds in the stratosphere. The below normal WAFz is also likely related to the downward propagation of warm PCHs through the stratosphere and troposphere.

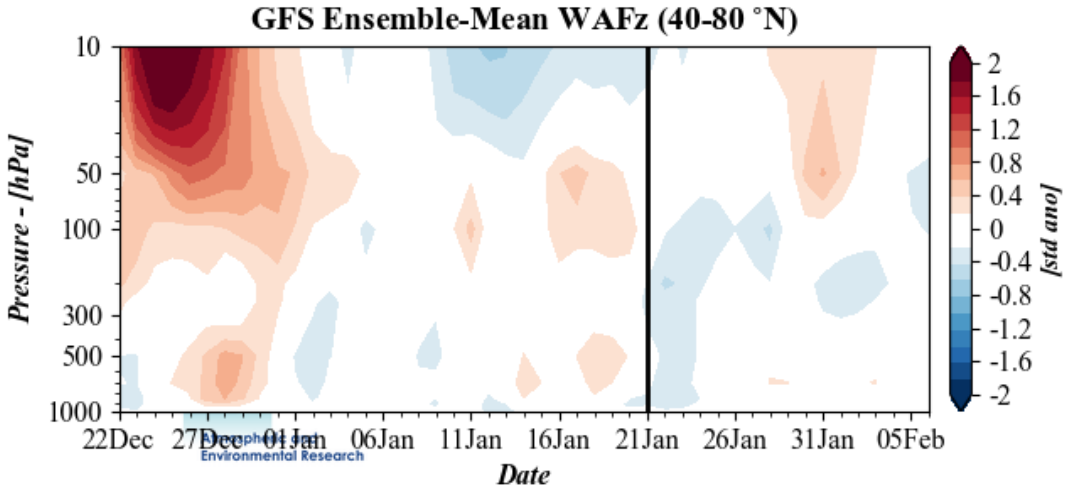

Figure 11. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 21 January 2019 GFS ensemble.

Currently the stratospheric PV remains split into two pieces or daughter vortices. The major daughter vortex is now centered over Hudson Bay and a minor daughter vortex is centered over the Urals with ridging centered near the North Pole (**Figure 12)**. The daughter vortex over the Urals is predicted to drift west across Siberia and fill with time while the other daughter vortex over Hudson Bay remains nearly stationary. However, the anomalous warmth in the polar stratosphere is gone and is a sign that the stratospheric PV is recovering. The cold temperatures in the stratosphere are focused in Siberia and western North America and could be a sign where the coldest temperatures at the surface may be focused as well during the month of February, something to watch.

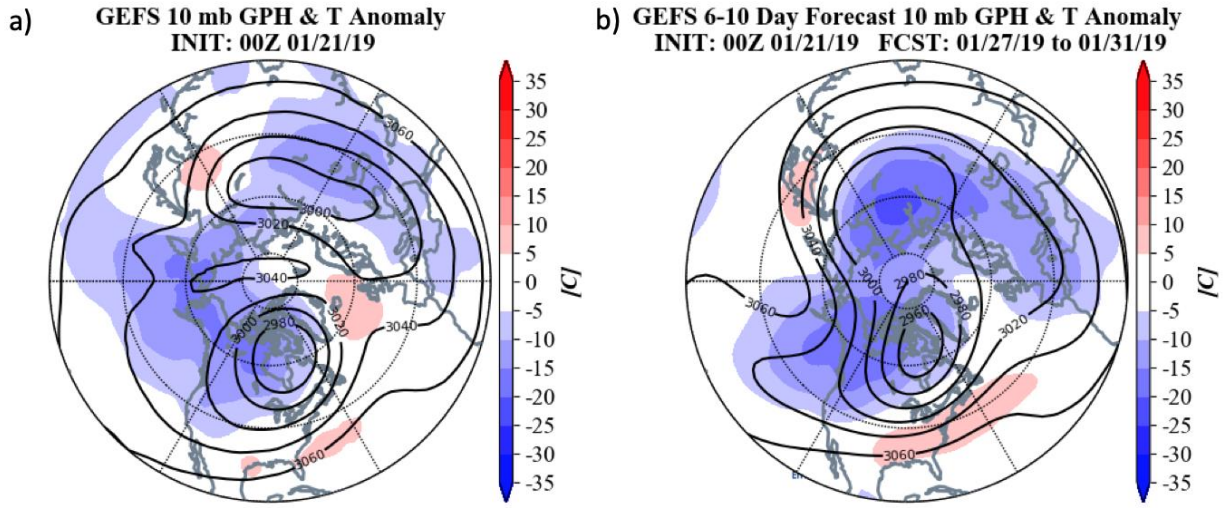

Figure 12. (a) Analyzed 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 14 January 2019. (**b**) Same as (**a**) except forecasted averaged from 27 – 31 January 2019. The forecasts are from the 00Z 21 January 2019 GFS operational model.

With the descent of the peak positive PCHs from the mid to lower stratosphere confidence is increasing that the PV disruption will have a significant and extended impact on the NH weather. It also appears that the models are coming into better agreement with their forecasts with all models predicting colder temperatures for eastern North America and Europe. I expect the warm/positive PCHS to continue to "drip" down into the troposphere in February as well. A sudden stratospheric warming not only leads to a warm Arctic in the stratosphere but also at the surface as well. And a warmer Arctic favors more severe winter weather in the NH midlatitudes including the Eastern US. I do think there still remains uncertainty how warm much the Arctic warms

in the lower troposphere and surface and could play a major role in the duration and magnitude of the weather impacts of the PV split. However, the models are predicting more blocking and warming near Greenland which is consistent with previous significant stratospheric disruptions.

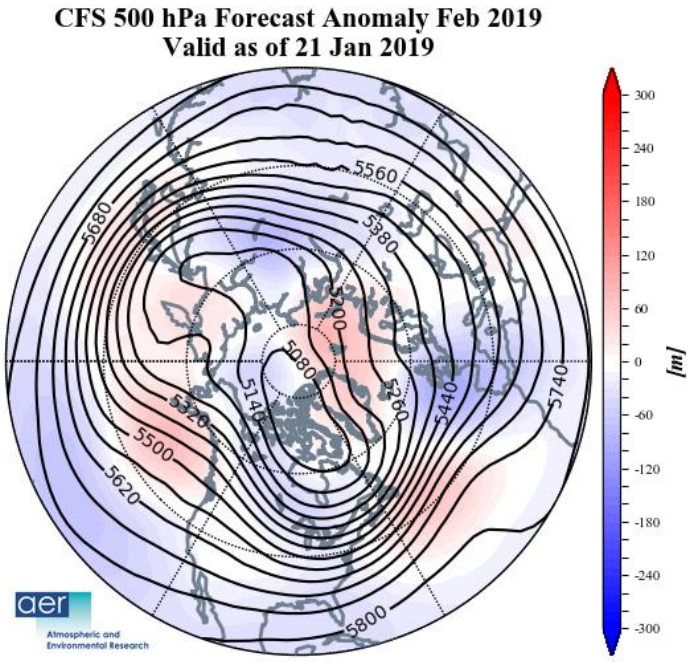

Figure 13. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for February 2019. The forecasts are from the 21 January 2019 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 13**) and the surface temperatures (**Figure 14**) forecast for February from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging centered in the Gulf of Alaska, Greenland, the Barents-Kara Seas, Eastern Siberia and the Middle East with troughs across eastern North America, Western Europe and Siberia (**Figure 13).** This pattern favors cold temperatures for Western Europe, Northern Asia especially Siberia, Eastern Canada and the Eastern US with relatively mild temperatures for most of the remainder of Eastern Europe, the Middle East, Southeast Asia and much western North America. This forecast is consistent with expectations following an SSW. However, the CFS forecast has not been consistent.

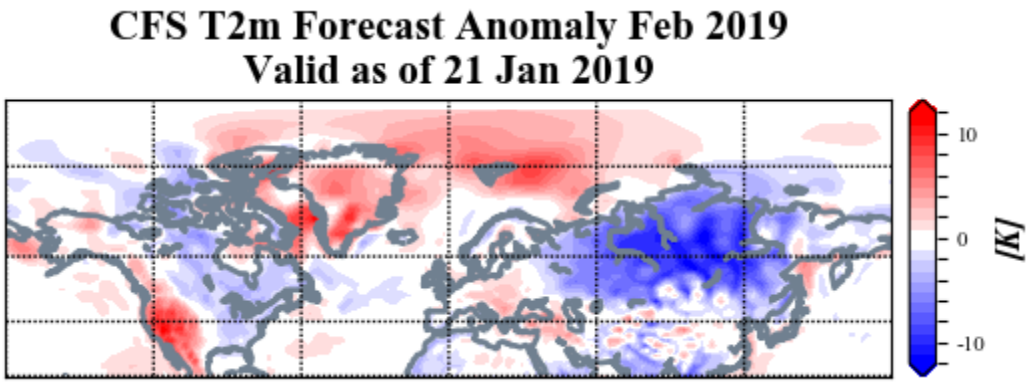

Figure 14. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for February 2019. The forecasts are from the 21 January 2019 CFS.

Surface Boundary Conditions

Arctic Sea Ice

Arctic sea ice growth rate continues at a slow rate and remains well below normal but higher than recent years. However the negative sea ice anomalies are now mostly confined to one region - the Barents-Kara Seas (**Figure 13**) though it is below normal in the Sea of Okhotsk as well. Normal to above normal sea ice in and around Greenland and the Canadian Archipelagos may favor a positive winter NAO. Based on recent research low sea ice anomalies in the Chukchi and Bering seas favors cold temperatures in central and eastern North America while low sea ice in the Barents-Kara seas favor cold temperatures in Central and East Asia, however this topic remains controversial. Recent research has shown that 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. However it is looking more and more like the greatest negative anomalies are going to persist in the Barents-Kara Seas this winter and this may be the region most favored for ridging/blocking during the winter months. I expect that the forecasts of lower heights and colder temperatures near Alaska will continue to help sea ice grow in the Chukchi and Bering seas in the near term.

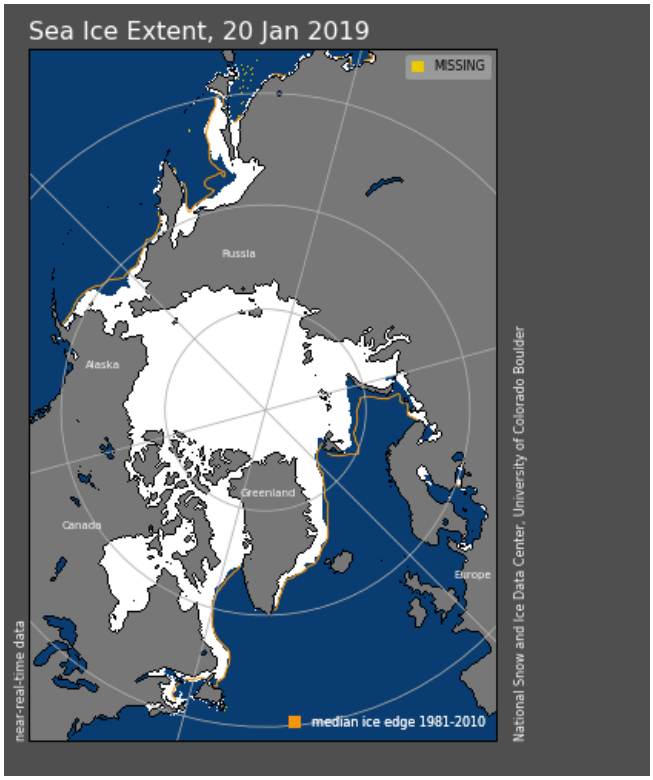

Figure 15. Observed Arctic sea ice extent on 20 January 2019 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image courtesy of National Snow and Ice Data Center (NSIDC). Snow and Ice Data Center (NSIDC).

SSTs/El Niño/Southern Oscillation (no update for SST map due to government shutdown)

Equatorial Pacific sea surface temperatures (SSTs) anomalies remain warm and support El Niño conditions (**Figure 13**), and the forecast is for likely weak to possibly moderate El Niño conditions for this winter. The expectations have been for a Central Pacific El Niño however, the warmest SST anomalies are now near the South American coast more similar to a canonical El Niño, though uncertainty continues. Observed SSTs across the NH remain well above normal though below normal SSTs exist regionally. Cold SSTs south of Iceland and in the subtropics of the North Atlantic with above normal SSTs in the mid-latitudes are thought to favor a positive winter NAO.

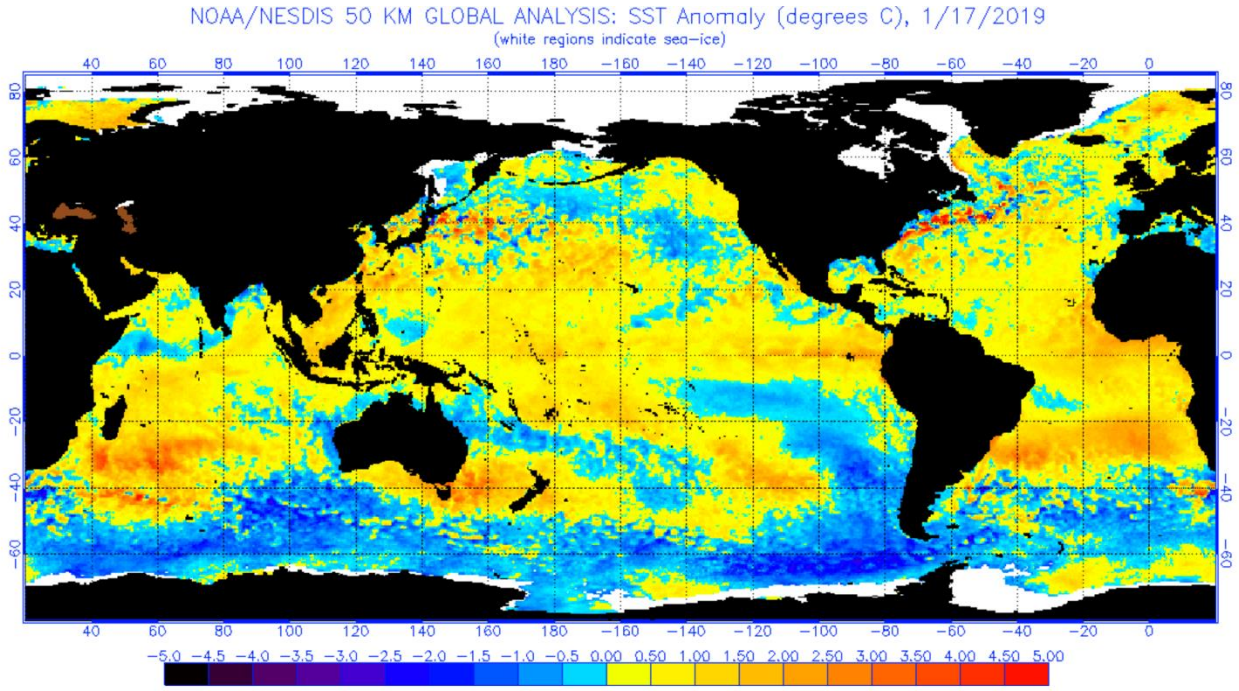

Figure 16. The latest weekly-mean global SST anomalies (ending 17 January 2019). Data from NOAA OI High-Resolution dataset. *(Updated from https://www.ospo.noaa.gov/Products/ocean/sst/anomaly/anim_full.html due to US Government shutdown)*.

Currently phase four of the Madden Julian Oscillation (MJO) is favored (**Figure 14**). However the MJO is expected to transition to five and six over the next two weeks. MJO phases 4-6 favors ridging over eastern North America with mild temperatures and troughing over western North America with cold temperatures. It is not obvious to me that the MJO is influencing North American weather.

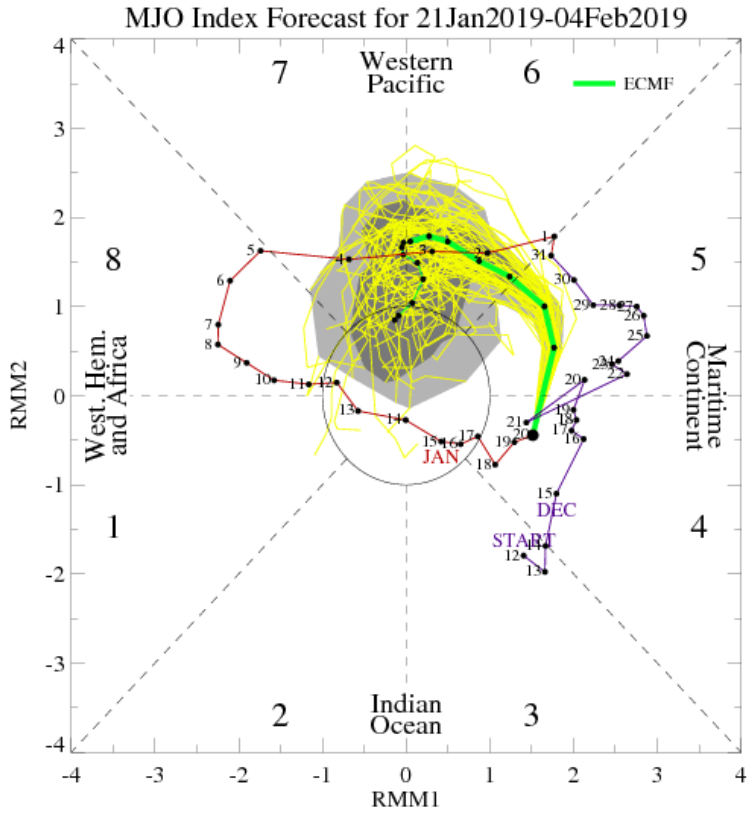

Figure 17. Past and forecast values of the MJO index. Forecast values from the 00Z 21 January 2019 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model "spread" is denoted by the gray shading. Sector numbers indicate 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

Northern Hemisphere Snow Cover

Snow cover advance continues has stalled across Eurasia and is now near decadal lows. Snow cover advance could advance further as cold temperatures become more widespread across Europe next week. Above normal snow cover extent this past October, favors a strengthened Siberian high, cold temperatures across northern Eurasia and a weakened polar vortex/negative AO this upcoming winter followed by cold temperatures across the continents of the NH.

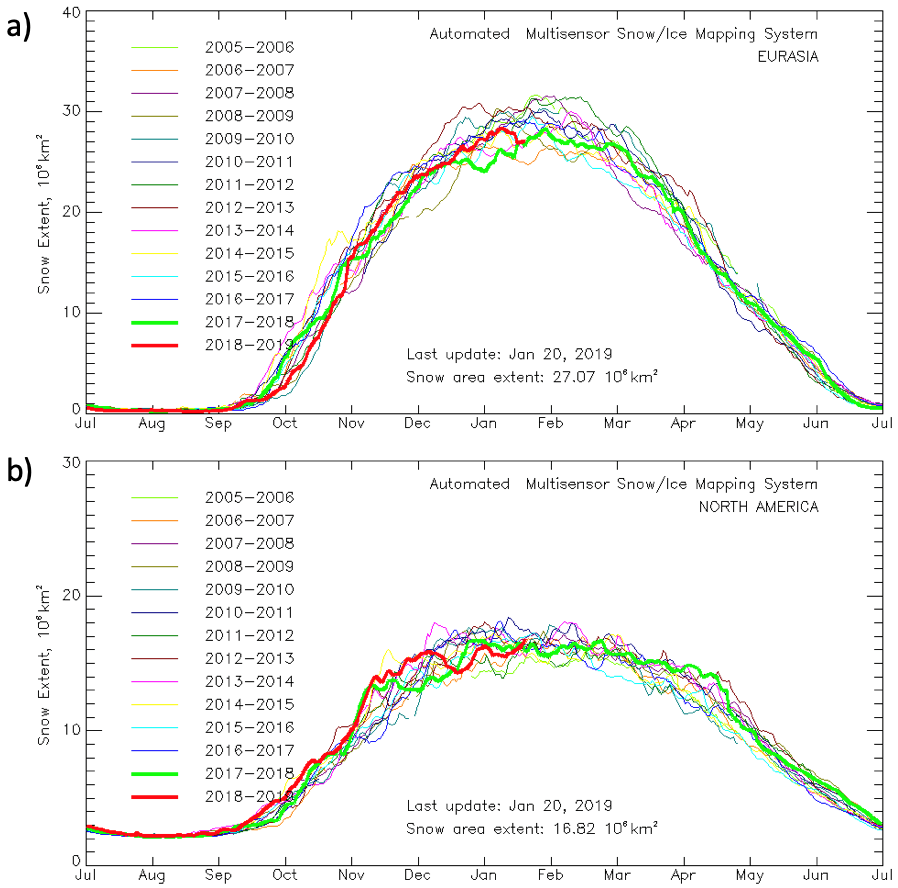

Figure 18. Observed Eurasian (top) and North American (bottom) snow cover extent through 20 January 2019. Image source:

https://www.star.nesdis.noaa.gov/smcd/emb/snow/HTML/snow_extent_plots.html

North American snow cover has advanced once again back to near decadal means following this weekend's snowstorm. The early advance of snow cover across Canada this fall, has likely contributed to an early start to winter across the Northern US.