February 18, 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.

Subscribe to our email list or follow me on Twitter (@judah47) for notification of updates.

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 over the next two weeks.
- The current positive AO is reflective of mostly negative pressure/geopotential height anomalies across the Arctic and mostly positive pressure/geopotential height anomalies across the mid-latitudes. The North Atlantic Oscillation (NAO) is currently slightly positive with weak pressure/geopotential height anomalies across Greenland and mostly positive pressure/geopotential height anomalies across the mid-latitudes of the North Atlantic and is predicted to remain slightly positive to neutral over the next two weeks.
- Ridging/positive geopotential height anomalies with normal to above normal temperatures are predicted to dominate much of Europe including the United Kingdom (UK) over the next two weeks. The one exception is Southeastern Europe where a deepening trough will usher colder temperatures starting next week.
- Currently ridging/positive geopotential height anomalies and/or southwesterly winds are resulting in normal to above normal temperatures across much of Asia except for troughing/negative geopotential height anomalies and relatively cold temperatures in parts of Siberia. However, deepening troughing/negative

geopotential height anomalies across Western Siberia downstream of the ridging/positive geopotential height anomalies in Europe will force troughing/negative geopotential height anomalies across Western Siberia bringing colder temperatures to much of Siberia and Western Asia.

- This week, ridging/positive geopotential height anomalies centered south of the Aleutians are predicted to force downstream troughing/negative geopotential height anomalies and relatively cold temperatures across much of Canada and the Western United States (US) with ridging and relatively mild temperatures for the Southeastern US. Some of the cold air in Eastern Canada will seep into the Northeastern US this week. However, ridging/positive geopotential height anomalies are predicted build across Alaska into early March forcing troughing/negative geopotential height anomalies across eastern North America allowing cold temperatures to sweep across the Eastern US except for Florida.
- In the *Impacts* section, I discuss my thoughts and the stratosphere troposphere coupling this winter and my expectations for March.

Impacts

I have seen over Twitter that the stratosphere-troposphere coupling has failed this winter and I don't necessarily agree. We had a stratospheric PV split in 2008/09 that was possibly the most extreme on record and was a displayed in a blog back in December as a possible analog for this winter. Here is the surface temperature anomaly that I showed for the remainder of the winter that year starting from two weeks after that event (**Figure i**). There are two regions of large negative temperature departures - Western North America but especially focused in Canada and an even stronger temperature anomaly in Siberia. Eastern North America was overall mild, and Europe was mixed.

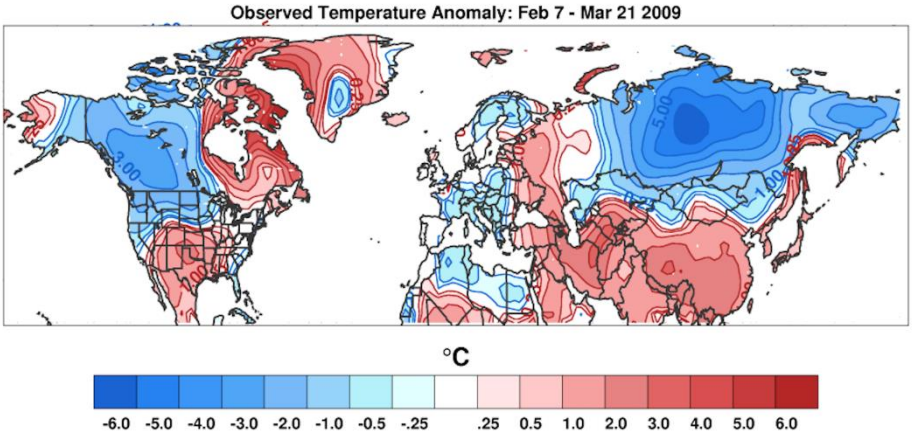

Figure i. Observed surface temperature anomalies (shading) for January 24-February 6, 2009.

This winter once again we had what I would refer to as a highly anomalous stratospheric PV split but not as extreme as 2009 and the temperature anomalies for the winter, or certainly post the PV split are probably not going to look that terribly different from 2009. The largest negative departures are likely to be in western North America and Siberia. I will show the winter temperature anomalies with the AER forecast posted in November and from the dynamical models but for today's blog a quick and dirty surface temperature plot from NOAA will do (**Figure ii**). The most striking temperature anomalies are what I would consider as a couplet - strong positive temperature anomalies in the Barents-Kara Seas and strong negative temperature anomalies in Siberia. This temperature couplet has been the most consistent feature of Northern Hemisphere winters of probably the past 15-20 years. This gets to the heart of the debate does Arctic change influence mid-latitude weather. I think I have been as emphatic as anybody on the planet that the answer is yes, and this winter will only strengthen my conviction. The other continental region that is likely to have negative departures is Canada and since the PV spit the largest negative departures are centered in Western Canada.

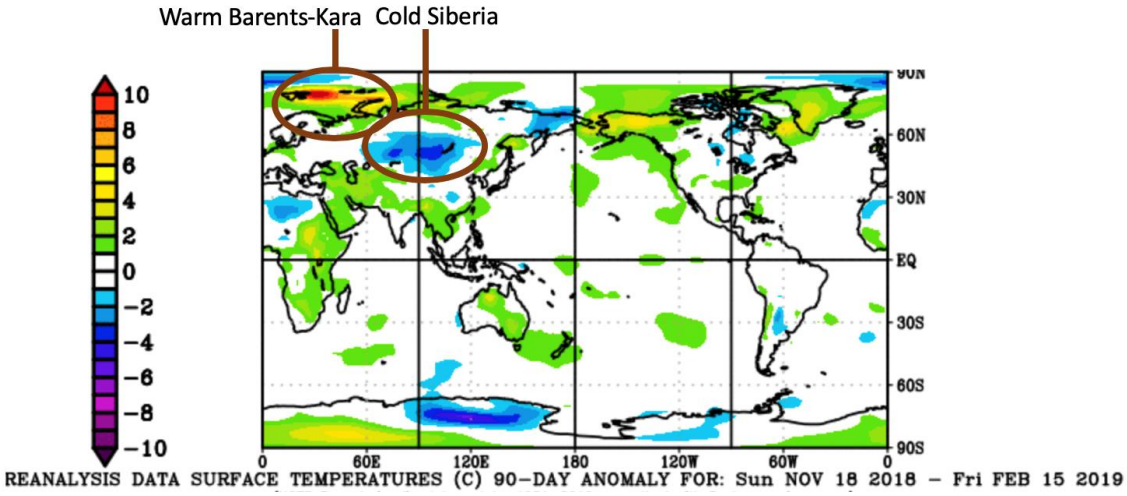

Figure ii. Analysis of surface temperature anomalies from 18 November 2018 until 15 February 2019. Taken from https://www.esrl.noaa.gov/psd/map/clim/glbcir_rnl.shtml.

Since at least November and expressed more than any single idea in the blog over the past three months is that the largest sea ice anomalies and consequently largest positive atmospheric temperature anomalies will be in the Barents-Kara Seas. I have also discussed how surprising I find it how cold the remainder of the Arctic has been this winter. As an example, I show in **Figure iii** the global temperature anomalies from yesterday February 17th the https://climatereanalyzer.org/. The Arctic positive temperature departure is 0.9°C equal to the NH and global temperature departure. This is a far cry from recent winters when the Arctic has warmed at a rate six times the rate of the remainder of the globe. Ironically the globe is currently experiencing Antarctic amplification and not Arctic amplification contrary to expectations.

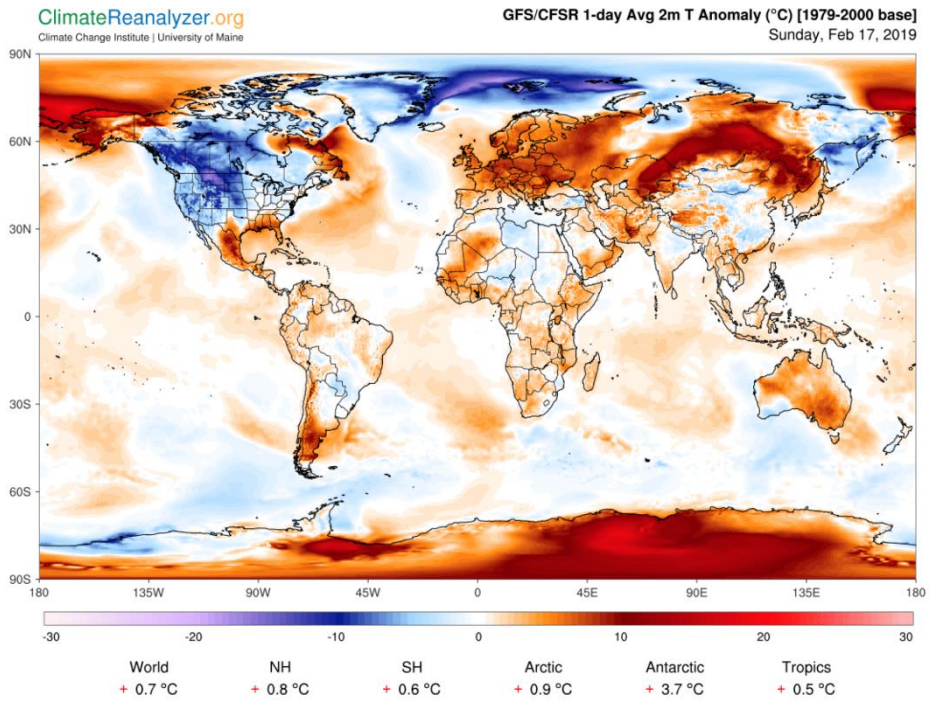

Figure iii. Analysis of surface temperature anomalies for the globe. The analysis is from the 17 February 2019 CFS.

The figure that I have shown the most this winter in the blog and will do it one more time is a figure from Cohen et al. 2018 (Figure 10d) and in my opinion may be the one best figure to explain this winter's surface temperature anomalies this winter (though I admit I am not a biased judge). Above normal temperatures in the Barents-Kara Seas and cold elsewhere is related to cold temperatures in Siberia but warm temperatures across Northern Europe and the Eastern US (**Figure iv**). I think it is very difficult to have sustained cold weather in the Eastern US and Northern Europe with the Arctic temperature anomaly pattern shown in **Figure iv**, which has also been the dominant Arctic temperature pattern this winter. Therefore, the overall mild winter in these two regions are consistent with the temperature anomaly pattern in the Arctic this winter.

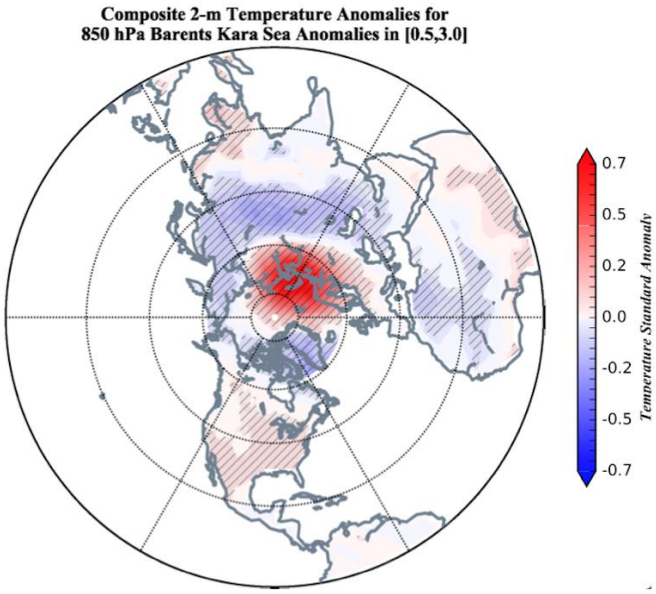

Figure iv. Association between surface temperature anomalies across the NH and in the Barents-Kara Seas. Climatological averages computed over the period 1981-2010.

Despite my argument that there has been robust stratosphere-troposphere coupling it has not manifested as we typically attribute to stratosphere-troposphere coupling. There hasn't been Arctic-wide warming but focused in Greenland, a persistent negative AO and/or NAO. I did see recently two interesting studies about this. One is a recent paper Hoshi et al. 2019 and another was a talk at AGU. Both studies suggest that a relatively warm Arctic increases stratosphere-troposphere coupling. Based on these studies the stronger or at least more conventional stratosphere-troposphere coupling of last winter compared to this winter may be in part related to a much warmer Arctic last winter relative to this winter.

My thoughts about March haven't changed much since last week. The stratosphere has worked well as a predictor of North American temperature anomalies and for the most part they seem to support a continuation of cold temperatures focused in western North America. Despite this it is my own experience that cold air focused in western North America tends to shift east with time especially in the late winter. Therefore, based on this empirical observation I was expecting possibly a return to more sustained cold in the eastern US as winter winds down. This is now being predicted by both the GFS and ECMWF models. It is my experience that models may be too quick to predict a pattern change but they are often correct in anticipating the pattern change. But even assuming the eastern US turns colder, will it persist for more than just a few days? My confidence in such an outcome would increase if the Arctic finally warms something that has not really happened so far this winter.

As far as Europe hard for me to see any sustained cold right through the end of winter with the exception of parts of Eastern Europe. The NAO does not want to turn decidedly negative this winter.

Near Term Conditions

1-5 day

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

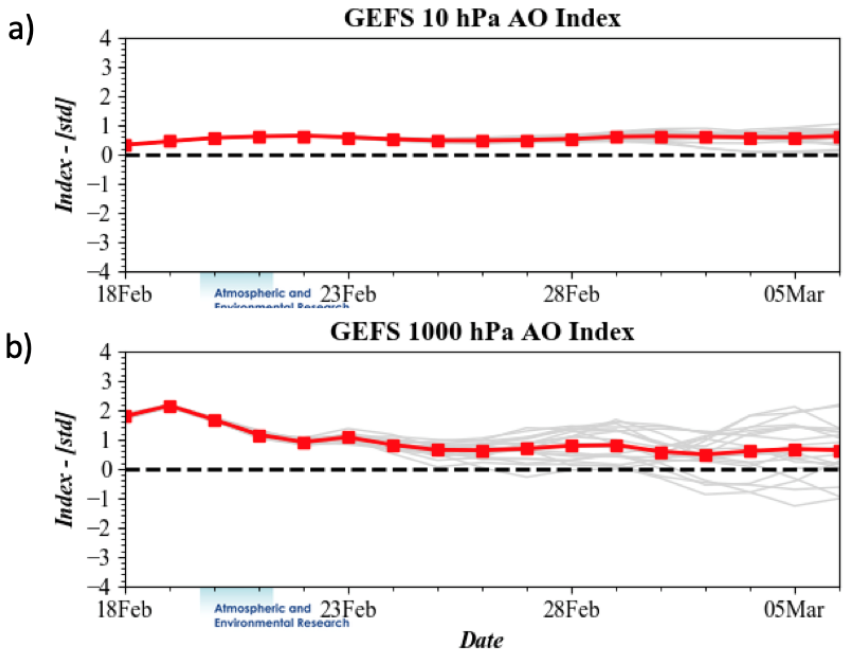

Figure 1. (**a**) The predicted daily-mean AO at 10 hPa from the 00Z 18 February 2019 GFS ensemble. (**b**) The predicted daily-mean near-surface AO from the 00Z 18 February 2019 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

Currently ridging/positive geopotential height anomalies centered over Central Europe dominate much of Europe this week (**Figure 2**) yielding mostly normal to above normal temperatures for Europe including the UK (**Figure 3**). Ridging/positive geopotential height anomalies dominate much of Asia except for troughing/negative geopotential height anomalies in Western and Eastern Siberia (**Figure 2**). This pattern is predicted to yield widespread normal to above normal temperature for Asia including Central Asia

and Southeast Asia with normal to below normal temperatures in Northern Siberia (**Figure 3).** Some troughing/negative geopotential height anomalies from the Middle East that extends across to Northern India (**Figure 2**) are predicted to yield normal to below normal temperatures for the Middle East, Northern India and into Pakistan **(Figure 3**).

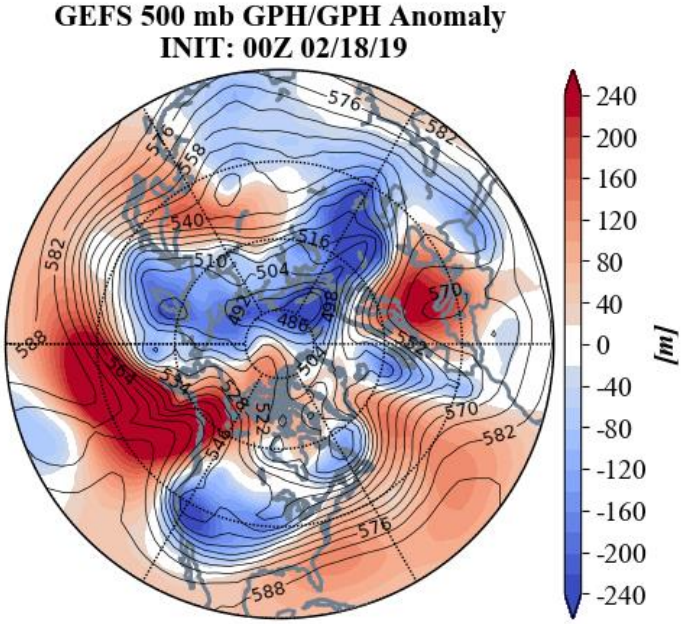

Figure 2. Observed 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) for 00Z 18 February 2019.

Ridging/positive geopotential height anomalies across Alaska and south of the Aleutians are anchoring downstream troughing/negative geopotential height anomalies across the West Coast of North America with more ridging/positive geopotential height anomalies across the Eastern US **(Figure 2).** This pattern is predicted to result in normal to below normal temperatures for Western and Central and the Western US with normal to above normal temperatures for Alaska and the Southeastern US **(Figure 3).** Troughing/negative geopotential height anomalies in Quebec **(Figure 2)** will deepen this week pulling the cold air in Central Canada into Eastern Canada and the Northeastern US this week as well **(Figure 3).**

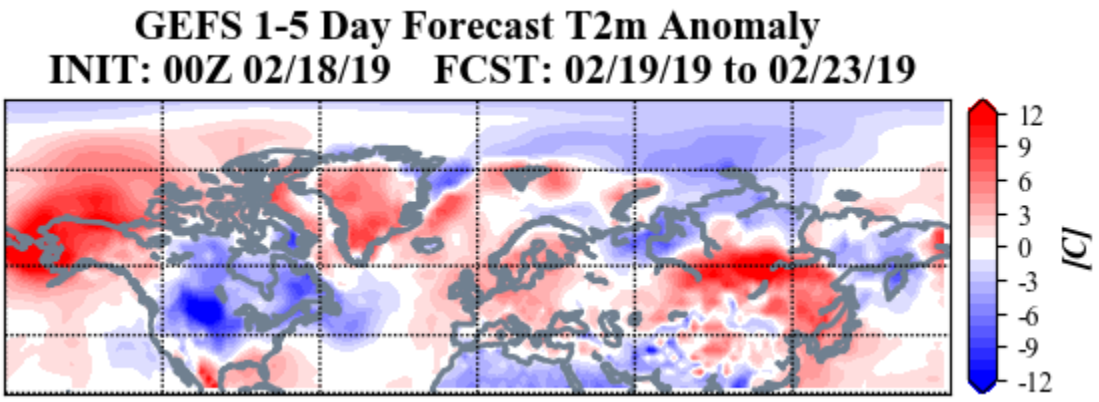

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 19 – 23 February 2019. The forecast is from the 00Z 18 February 2019 GFS ensemble.

Troughing and/or cold temperatures will bring new snowfall to Siberia and the Tibetan Plateau (**Figure 4**). Across North America, troughing and cold temperatures will bring widespread new snowfall across Alaska, Canada and the Northern US (**Figure 4**). Milder temperatures will result in snowmelt across Northern and Eastern Europe and Central Asia (**Figure 4**).

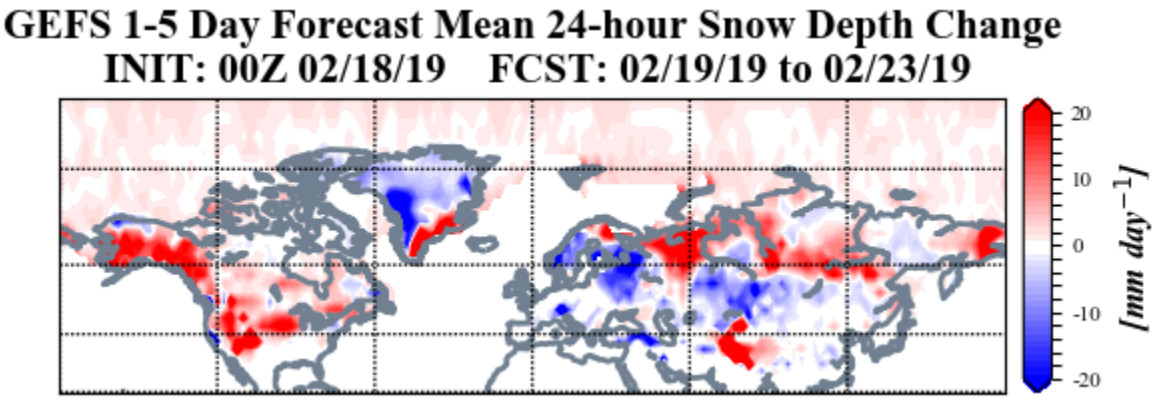

Figure 4. Forecasted snowfall anomalies (mm/day; shading) from 19 – 23 February 2019. The forecast is from the 00Z 18 February 2019 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to remain positive next week **(Figure 1**) with mostly negative geopotential height anomalies across the Arctic and mixed geopotential height

anomalies across the mid-latitudes of the NH (**Figure 5a**). And with weak geopotential height anomalies across Greenland, the NAO will likely be near neutral next week.

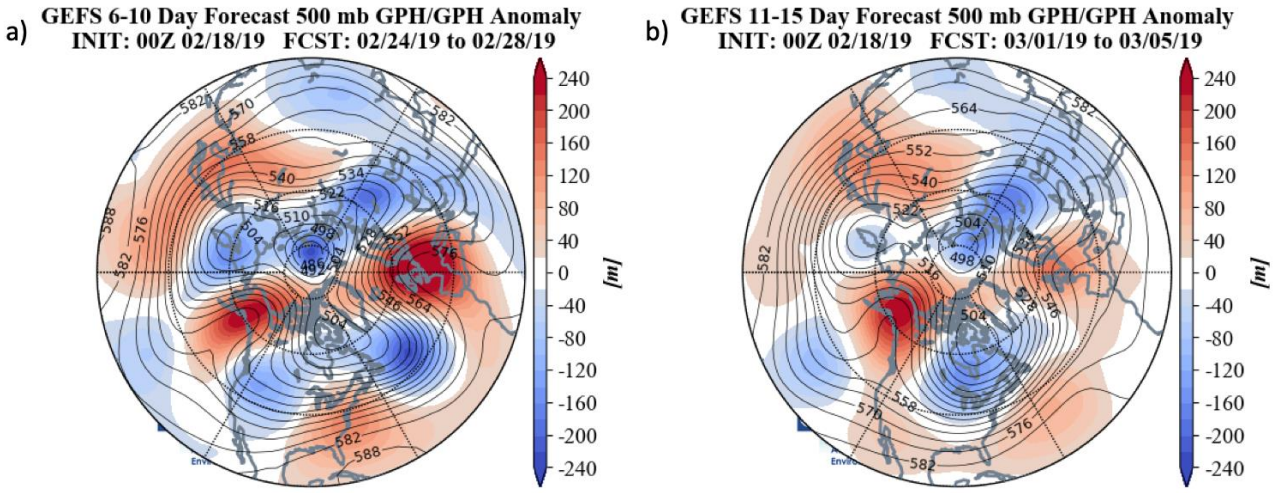

Figure 5. (a) Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 24 – 28 February 2019. (b) Same as (a) except averaged from 1 – 5 March 2019. The forecasts are from the 18 February 2019 00z GFS ensemble.

Ridging/positive geopotential height anomalies are predicted to continue to dominate much of Europe while drifting west into Western Europe allowing for troughing/negative geopotential height anomalies across Southeast Europe this period (**Figure 5a**). Widespread high heights are predicted to result in normal to above normal temperatures widespread across Europe including the UK while low heights will favor normal to below normal temperatures for parts of Southeastern Europe (**Figure 6**). Ridging/positive geopotential height anomalies in Europe favor troughing/negative geopotential height anomalies downstream across Western Asia and most of Siberia with ridging/positive geopotential height anomalies across East Asia (**Figure 5a**). This is predicted to yield normal to below normal temperatures for most of Northern Siberia and Western Asia with normal to above normal temperatures for Central and East Asia (**Figure 6**). Persistent troughing/negative geopotential height anomalies from the Middle East and across to Northern India (**Figure 5a**) are predicted to yield normal to below normal temperatures for the Middle East, Northern India and Pakistan **(Figure 6**).

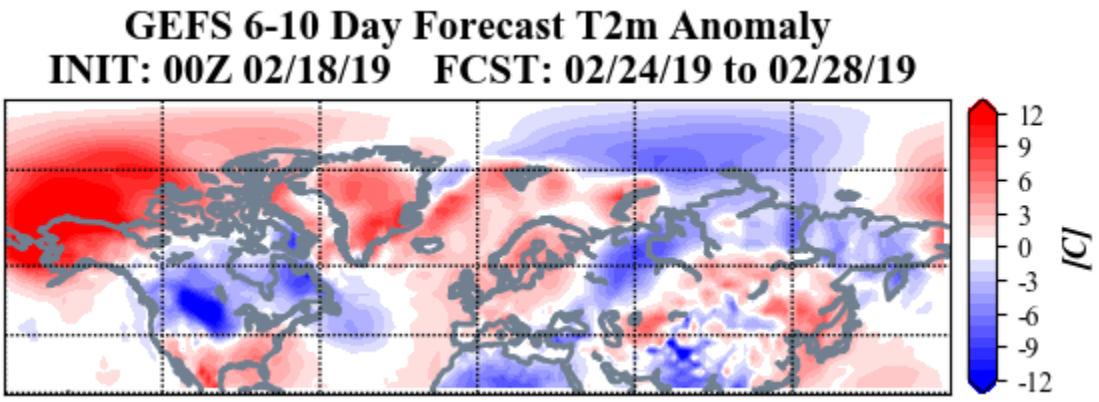

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 24 – 28 February 2019. The forecasts are from the 00Z 18 February 2019GFS ensemble.

Ridging/positive geopotential height anomalies previously south of the Aleutians are predicted to push north into Alaska while still anchoring troughing/negative geopotential height anomalies in Western Canada and the Western US with more ridging/positive geopotential height anomalies in the Eastern US **(Figure 5a).** However, low heights are predicted to persist across Northeastern Canada this period (**Figure 5a**). The resultant temperature anomalies across North America are predicted to be normal to below normal temperatures across much of Canada and the Western US with normal to above normal temperatures for Alaska and the Eastern US **(Figure 6).**

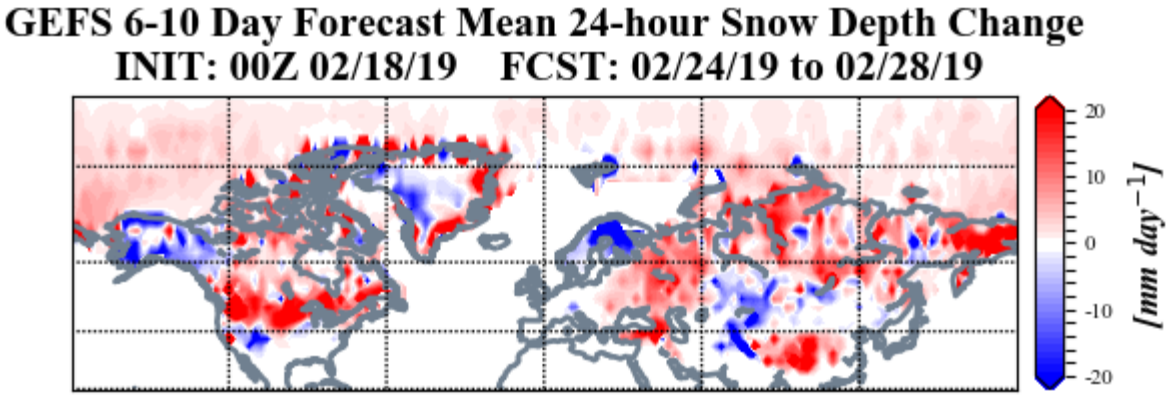

Figure 7. Forecasted snowfall anomalies (mm/day; shading) from 24 – 28 February 2019. The forecasts are from the 00Z 18 February 2019 GFS ensemble.

Troughing and cold air will bring the potential for new snowfall across Eastern Europe, Northern and Western Asia and the Tibetan Plateau (**Figure 7**). Across North America, new snowfall is possible in much of Canada and the Northern US (**Figure 7**). Mild

temperatures could result in snowmelt in parts of Northern Europe, Central Asia, Alaska and the Southwestern US (**Figure 7**).

11-15 day

With mostly positive geopotential height anomalies predicted for the Arctic (**Figure 5b**), the AO is likely to be close to be slightly positive this period (**Figure 1**). With weak pressure/geopotential height anomalies across Greenland, the NAO is predicted to remain neutral to slightly positive this period as well (**Figure 1**).

Persistent ridging/positive geopotential height anomalies across Western Europe (**Figure 5b**) are predicted to result in normal to above normal temperatures for much of Europe including the UK once again with the exception of Southeastern Europe where persistent troughing/negative geopotential height anomalies will result in normal to below normal temperatures (**Figure 8**). European ridging is predicted to anchor downstream troughing/negative geopotential height anomalies across Western Asia that extends across Siberia with ridging/positive geopotential height anomalies predicted for East Asia (**Figure 5b**). This pattern favors normal to below normal temperatures for much of Northern and Western Asia, with normal to above normal temperatures for East Asia (**Figure 8**). Persistent residual troughing/negative geopotential height anomalies that extends from the Middle East and across Northern India (**Figure 5a**) are predicted to yield normal to below normal temperatures for the Middle East, Northern India and Pakistan **(Figure 6**).

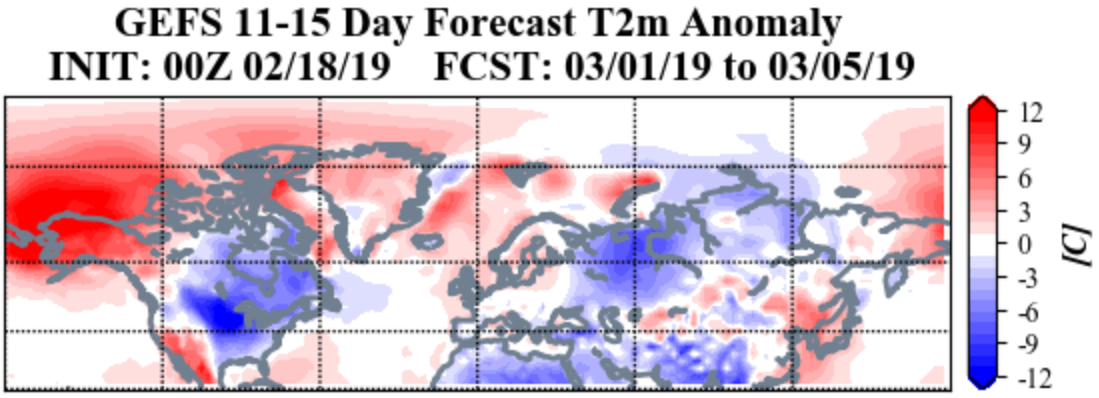

Figure 8. Forecasted surface temperature anomalies (°C; shading) from 1 – 5 March 2019. The forecasts are from the 00Z 18 February 2019 GFS ensemble.

Ridging/negative geopotential height anomalies centered across Alaska will support troughing/negative geopotential height anomalies across eastern North America with ridging/negative geopotential height anomalies building across the west coast of North America (**Figure 5b**). This will favor normal to below normal temperatures across

much of Canada and the US with normal to above normal temperatures confined to Alaska, Northwestern Canada and Florida (**Figure 8**).

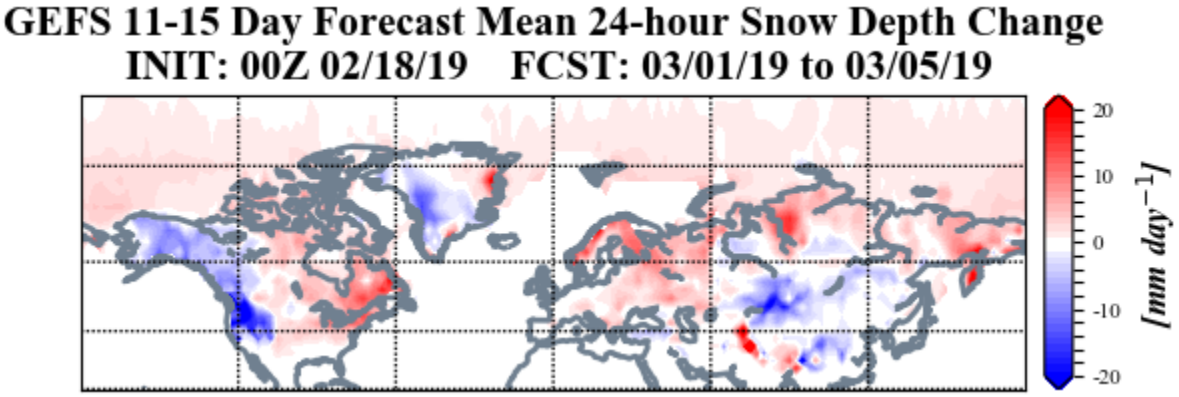

Figure 9. Forecasted snowfall anomalies (mm/day; shading) from 1 – 5 March 2019. The forecasts are from the 00Z 18 February 2019 GFS ensemble.

Once again additional snowfall is possible across much of northern Eurasia including Scandinavia, Eastern Europe, Siberia and Western Asia (**Figure 9**). Cold temperatures across Central and Eastern Canada and even the Northeastern US will also support potentially new snowfall (**Figure 9**). Mild temperatures could result in snowmelt across Central Asia, Alaska, Western Canada and the Western 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 lower stratosphere and upper troposphere with normal to below normal PCHs in both the mid stratosphere and the lower troposphere (**Figure 10**). The below normal PCHs in the lower troposphere are consistent with a positive AO predicted for this week and into next week (**Figure 1**). The below normal PCHs in the mid stratosphere are consistent with positive stratospheric AO for the next two weeks (**Figure 1**). The positive PCHs in the lower stratosphere are related to downward propagation of circulation anomalies related to the 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) back in January.

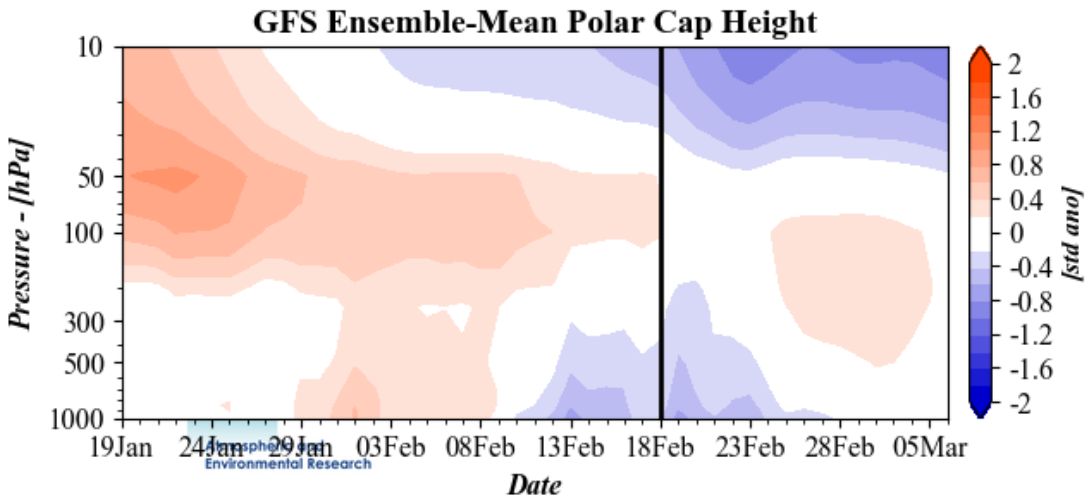

Figure 10. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecasts are from the 00Z 18 February 2019 GFS ensemble.

The GFS forecast of PCHs still gives an ambiguous impression of when the coupling between the PV disruption and the troposphere will end. The argument could be made that the impact of the SSW on the weather ended in early February or that it may continue into late February and early March. It has been shown previously that the impact of the SSW on the weather can be from four to eight weeks. Both scenarios are within that general range. Either way I would argue that the influence of the SSW on our weather will likely continue into March at least across North America. The PV split created favorable conditions for the buildup of cold air in western North America that is predicted to persist and slide east in early March.

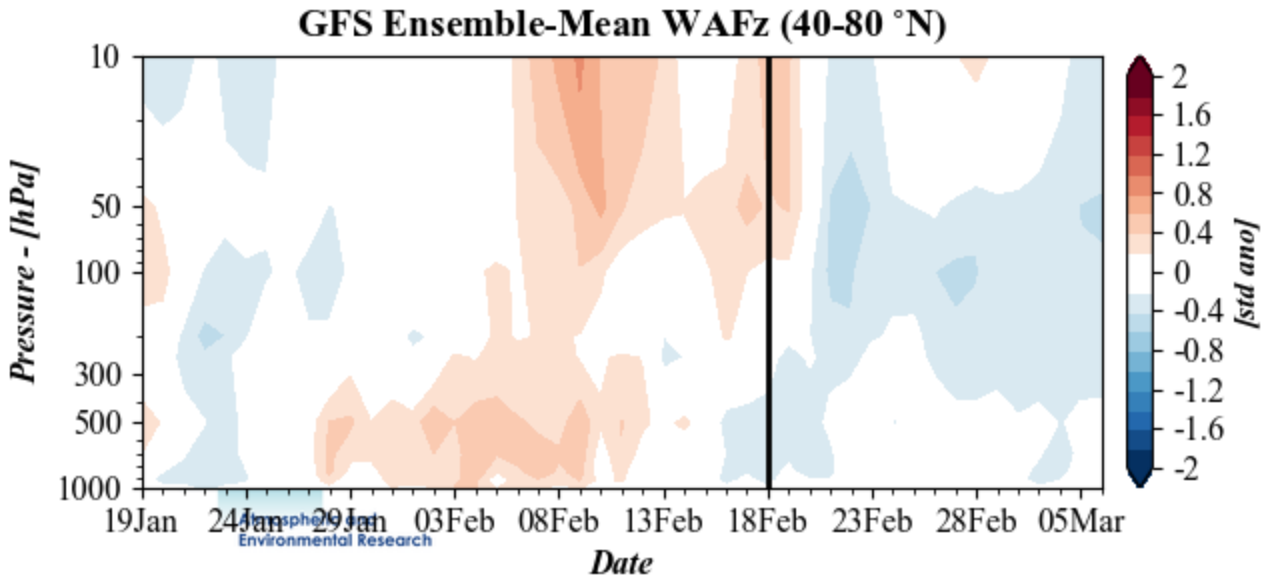

Figure 11. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 18 February 2019 GFS ensemble.

The plot of Wave Activity Flux (WAFz) or poleward heat transport shows below normal WAFz for the next two weeks **(Figure 11**). This could be interpreted as a reflective wave with upward WAFz last week bouncing off the stratospheric PV and reflecting back down into the troposphere. Such relatively minor polar stratospheric warmings tend to favor cold in Central and Eastern North America, which is now predicted by the models. However, the core of the cold temperatures over western North America in the stratosphere could suggest a westward shift of the cold anomalies despite the model forecasts. I do admit that I am ambivalent whether to attribute the predicted return of cold to the Eastern US as one last hurrah of the PV split back in January or due to a new reflective perturbation of the stratospheric PV, or maybe both.

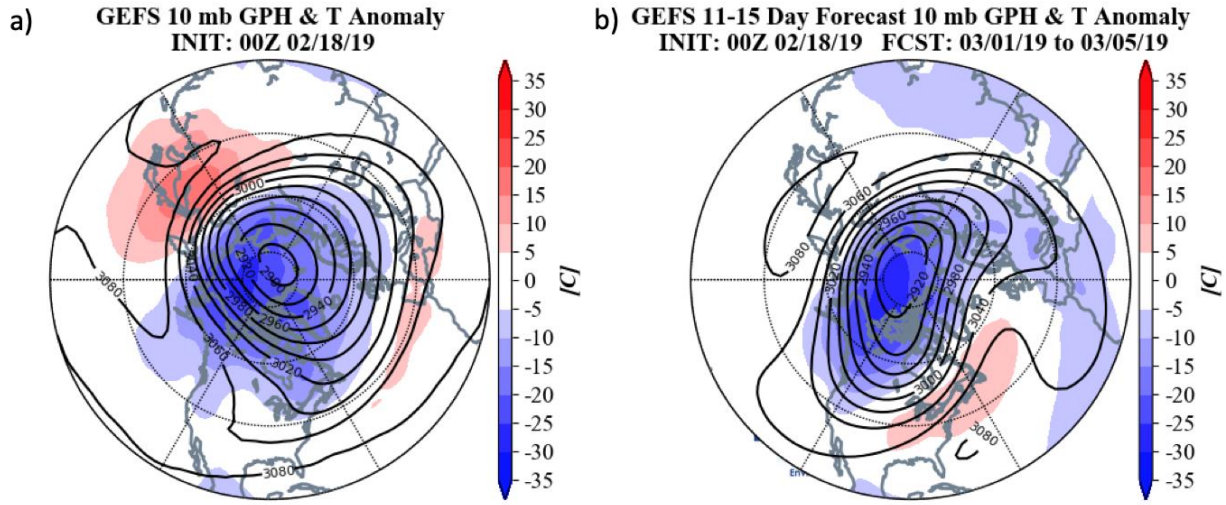

Figure 12. (a) Analyzed 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 18 February 2019. (**b**) Same as (**a**) except forecasted averaged from 1 – 5 March 2019. The forecasts are from the 00Z 18 February 2019 GFS operational model.

The stratospheric PV is currently centered close to the North Pole (**Figure 12)**. The coldest temperatures in the stratosphere are focused in Western Siberia and Canada and seems to be co-located with the coldest temperatures at the surface may be focused as well during the remainder of the month of February and into early March.

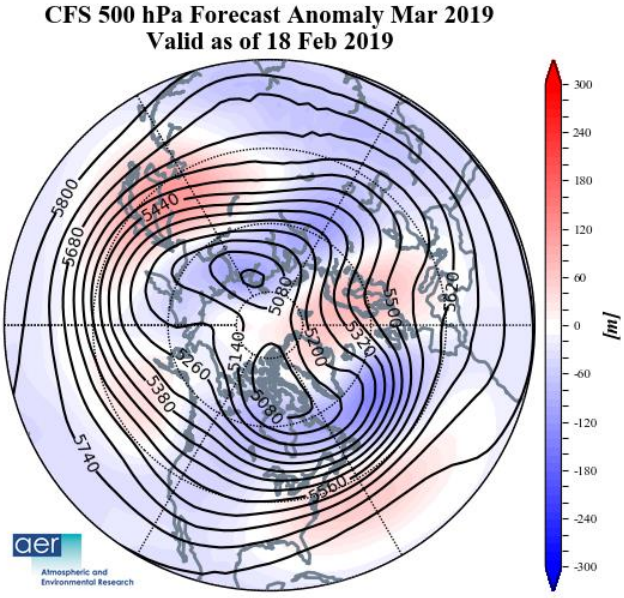

Figure 13. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for March 2019. The forecasts are from the 18 February 2019 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 13**) and the surface temperatures (**Figure 14**) forecast for March from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging centered south of the Aleutian Islands, The Eastern US, Europe and East Asia with troughs in the Western US, Canada, Siberia, Western Asia (**Figure 13).** This pattern favors cold temperatures for Northern and Western Asia but especially Siberia, the Middle East, Northern India and Eastern Canada with relatively mild temperatures for much of western North America, the Southeastern US, Europe and East Asia (**Figure 14**). This forecast seems to be simply an extension of the current pattern and I am a bit skeptical.

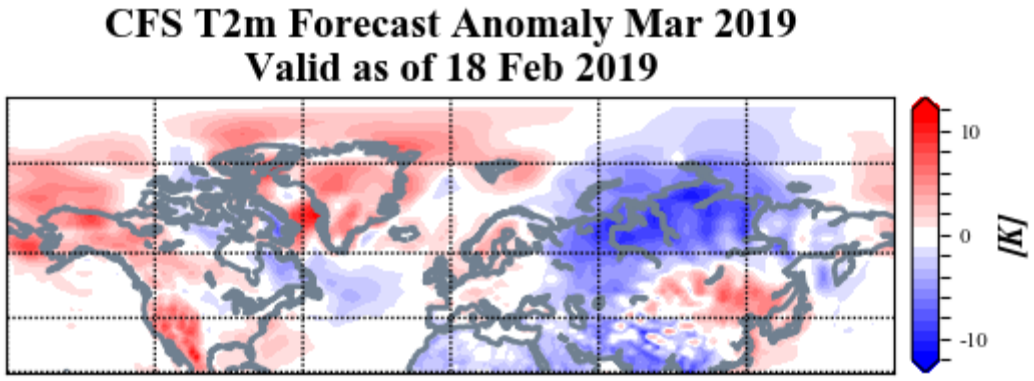

Figure 14. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for March 2019. The forecasts are from the 18 February 2019 CFS.

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. The regions with the largest negative departures are the Barents-Kara and Bering Seas (**Figure 13**). I would argue that the greatest negative anomalies so far this winter in the Barents-Kara Seas has favored this region for ridging/blocking during the winter months. However the anomalies in the Bering sea now seem to be the greatest negative departures and may help shift the greatest Arctic warming closer to Alaska. Some research shows low sea ice in the Sea of Okhotsk favors a positive AO/NAO. Normal to above normal sea ice in and around Greenland and the Canadian Archipelagos may also 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.

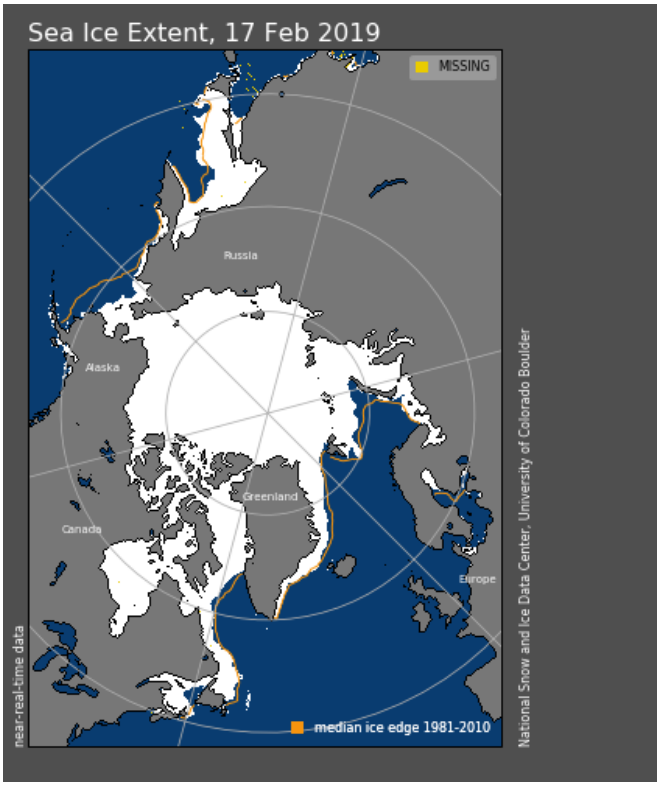

Figure 15. Observed Arctic sea ice extent on 17 February 2019 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image courtesy of National Snow and Ice Data Center (NSIDC). Snow and Ice Data Center (NSIDC).

SSTs/El Niño/Southern Oscillation

Equatorial Pacific sea surface temperatures (SSTs) anomalies remain warm and NOAA has declared the return of El Niño conditions (**Figure 13**). 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.

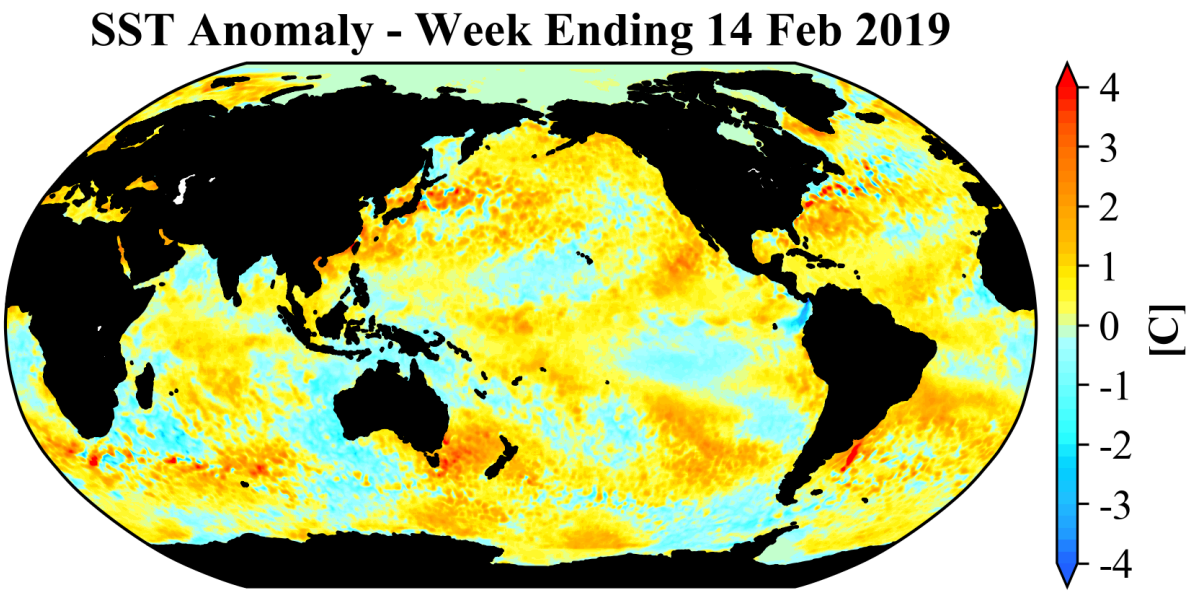

Figure 16. The latest weekly-mean global SST anomalies (ending 14 February 2019). Data from NOAA OI High-Resolution dataset. *(Updated from https://www.ospo.noaa.gov/Products/ocean/sst/anomaly/anim_full.html due to US Government shutdown)*.

Currently phase eight of the Madden Julian Oscillation (MJO) is favored (**Figure 14**). However the MJO is expected to transition to phase one and then two. Phases 8, 1 and 2 first favor troughing over eastern North America with cold temperatures and ridging over western North America with mild temperatures. However eventually they favor the opposite ridging over eastern North America with mild temperatures and troughing over western North America with cold temperatures. This is opposite of model forecasts.

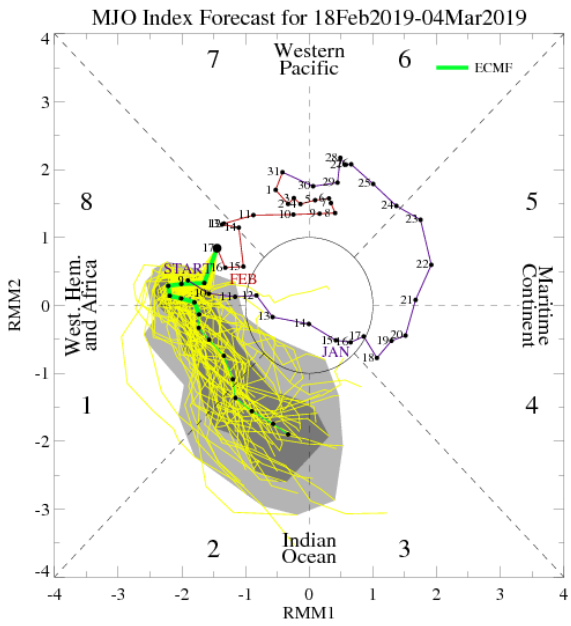

Figure 17. Past and forecast values of the MJO index. Forecast values from the 00Z 11 February 2019 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model "spread" is denoted by the gray shading. Sector numbers indicate 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 may have ended across Eurasia for this winter season but remains near decadal means. Snow cover advance is unlikely in the next couple of weeks as Europe remains mild. 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.

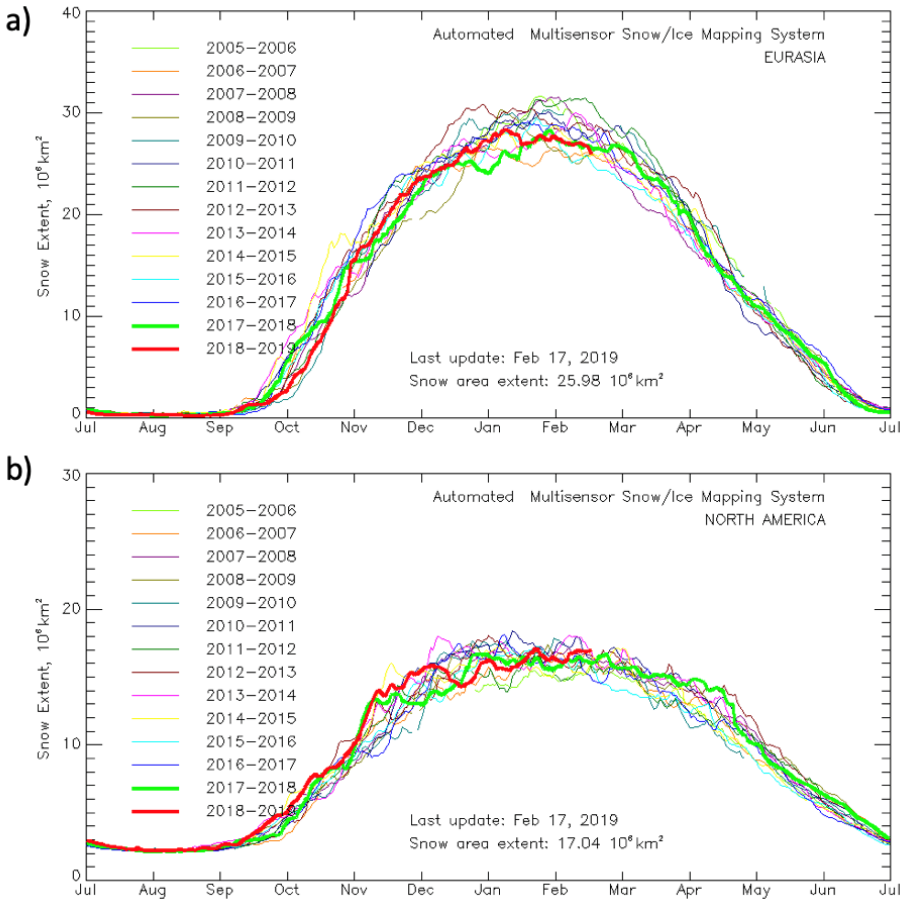

Figure 18. Observed Eurasian (top) and North American (bottom) snow cover extent through 17 February 2019. Image source:

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

North American snow cover has remained steady and is near decadal highs mostly helped by above normal snow cover in the Western US. Snow cover could advance further as cold air becomes more widespread across the continent.