

Arctic Oscillation and Polar Vortex Analysis and Forecasts

March 8, 2021

Special blog on winter 2018/2019 retrospective can be found here
- <http://www.aer.com/winter2019>

Special blog on winter 2017/2018 retrospective can be found here
- <http://www.aer.com/winter2018>

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) 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.

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 the next two weeks and even briefly go strongly positive this week as pressure/geopotential height anomalies are predicted to remain mostly negative pressure/geopotential height anomalies across the Arctic with mixed pressure/geopotential height anomalies across the mid-latitudes the next two

weeks. The North Atlantic Oscillation (NAO) is also predicted to remain positive the next two weeks as persistent negative pressure/geopotential height anomalies are predicted across Greenland and Iceland.

- This week troughing/negative geopotential height anomalies and relatively colder temperatures will dominate Northern Europe including the United Kingdom (UK) while a strong westerly flow of maritime air ushers in milder temperatures for Southern Europe. However next week ridging/positive geopotential height anomalies are predicted to become more widespread across Europe favoring normal to above normal temperatures across much of Europe.
- Continuous troughing/negative geopotential height anomalies coupled with normal to below temperatures will persist this week and into next across Northern and Western Asia while ridging/positive geopotential height anomalies coupled with normal to above normal temperatures dominate Southern and Eastern Asia. However, by next week European ridging/positive geopotential height anomalies are predicted to force the troughing/negative geopotential height anomalies further east into Central Asia allowing normal to below normal temperatures to be pushed into Northern and Eastern Asia with normal to above normal temperatures in Southern Asia.
- This week, troughing/negative geopotential height anomalies coupled with normal to below temperatures are predicted across Alaska, Western and Northern Canada and the Western United States (US) with ridging/positive geopotential height anomalies coupled with normal to above normal temperatures across Southeastern Canada and the Eastern US. However next week troughing/negative geopotential height anomalies coupled with normal to below temperatures will slowly shift into the Eastern US while ridging/positive geopotential height anomalies coupled with normal to above normal temperatures return to the Western US. With predicted widespread troughing across Canada, much of Canada will remain relatively cold.
- In the Impacts section I present validation of the winter forecast and I discuss the implications of yet one more relatively minor vortex (PV) disruption on the weather across the Northern Hemisphere (NH).

Impacts

With the conclusion of meteorological winter (December through February) I posted on Twitter last week the AER winter forecast compared with the observed winter temperature anomalies for the NH. In **Figure i**, I include the three winter surface temperature anomaly forecasts I posted in the [November 30, 2020](#) blog, from the North American multi-Model Ensemble (NMME), the C3S multi model ensemble, which includes the models from ECMWF, UK Met Office and Meteo France, the AER model and also the observed winter surface temperature anomalies. I can't claim to be objective, but I do believe that the AER model performed well if not exceptionally well correctly predicting the widespread relatively cold temperatures across Northern and Eastern Asia the slightly below normal temperatures in Western Europe, relatively warmer

temperatures for Eastern Europe, relatively cold temperatures from Northwestern Canada into the Central US and the widespread warmth across the Arctic but focused in the Barents-Kara Seas and Baffin Bay. As is typical with statistical models, if the model does predict the correct pattern it tends to underpredict the anomalies. One consequential miss by the AER model were the relatively cold temperatures in Texas.

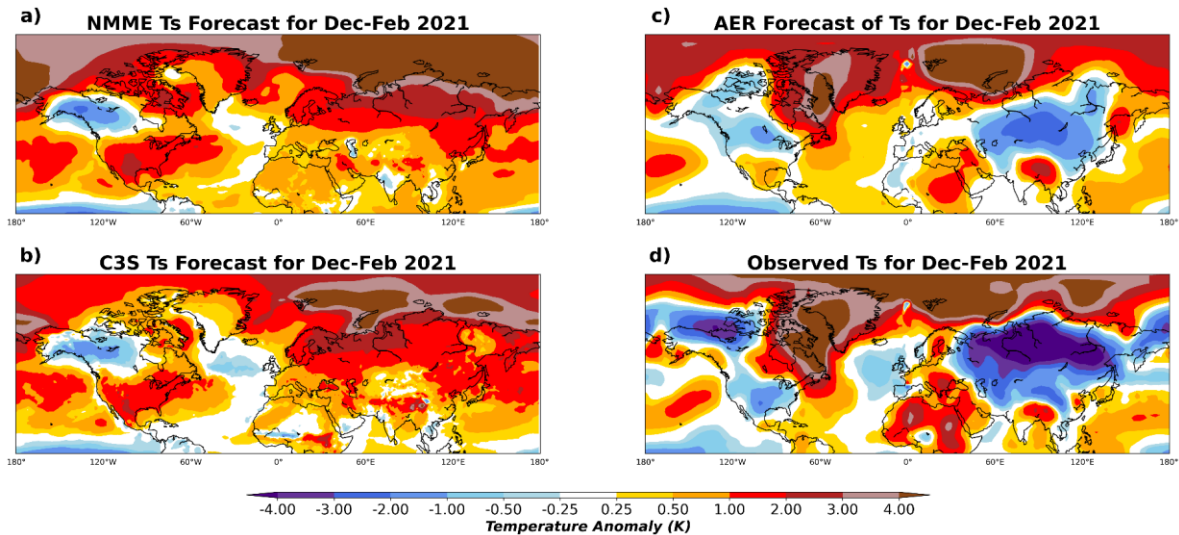


Figure i. a) The NMME winter temperature anomaly forecast from <https://www.cpc.ncep.noaa.gov/products/NMME/> b) the C3S winter temperature anomaly forecast from <https://www.copernicus.eu/en>. c) The AER winter temperature anomaly forecast all for December, January and February 2021. d) The observed temperature anomalies for December, January and February 2021 from the NCEP/NCAR reanalysis.

But however you may rate the AER winter forecast, it looks better when compared to the dynamical models. The models missed all the cold in Eurasia and were also too warm for the US. In the Arctic the models also missed the warming regional maximum in Baffin Bay. Often one criticism or at least a reason to doubt or be skeptical of arguments for Arctic influence on mid-latitude weather/climate is that the climate system, especially in the mid-latitudes is chaotic or noisy and therefore making it extremely challenging to detect a meaningful signal among all the noise. Where I may instinctively attribute observed mid-latitude cold to accelerated Arctic warming, many in the field would attribute the cold temperatures to large variability inherent in the system.

I raised this in the [November 30, 2020](#) blog, but by the same token the lack of spread among the models should be a red flag when trusting or relying on the models. If there is so much noise in the climate system, why are the model forecasts almost indistinguishable? This lack of model spread was the focus of my paper about the last strong El Niño/Southern Oscillation (ENSO) event in 2015/16 [Cohen et al. 2017](#). The points raised in that paper seem as relevant for this past La Niña winter.

Reflecting back on this winter I think many of the relevant themes that I can think of I already expressed in my recent paper [Cohen et al. 2018](#). In that I discuss, ENSO and Arctic influence, the polar vortex, dynamical vs. statistical models. So, if readers are interested in exploring further and have the time, the ideas shared in that paper are as relevant if not more this winter than even in 2018.

I use the NCEP/NCAR reanalysis to generate the AER forecast so I do like to compare the AER model forecast with the NCEP/NCAR reanalysis so as to compare apples with apples but in the past, I have been criticized for showing NCEP/NCAR reanalysis as observations. I will admit that there were some glaring errors in NCEP/NCAR reanalysis over the summer. So, in **Figure ii**, I show the same as Figure i, but with observations based on the GFS analysis data, which seems to me to be of better quality. The color scale is a bit different, so the observed anomalies looked more washed out in **Figure ii**.

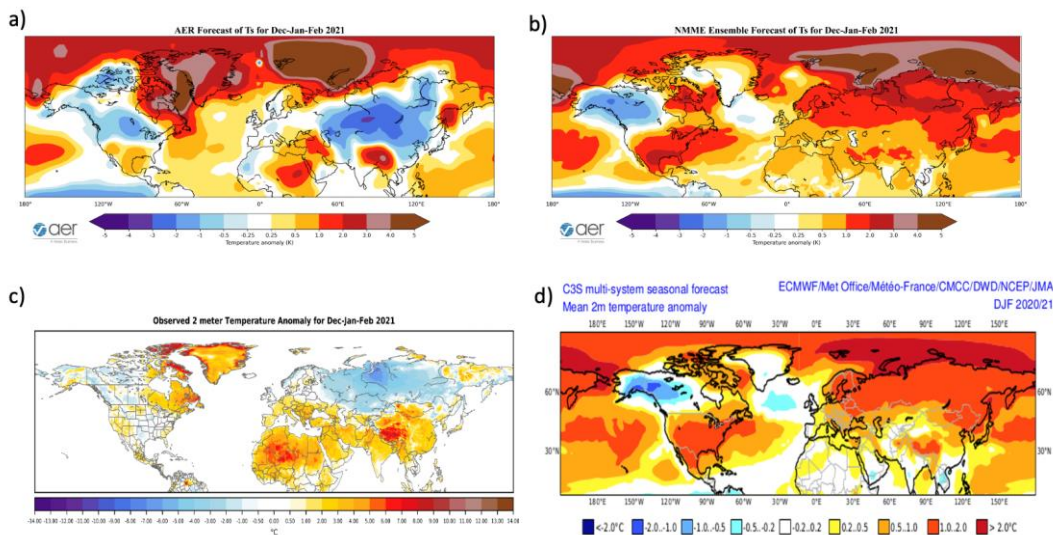


Figure ii. a) The AER winter temperature anomaly forecast b) the NMME winter temperature anomaly forecast from <https://www.cpc.ncep.noaa.gov/products/NMME/> c) The observed temperature anomalies for December, January and February 2021 from the GFS analysis. d) the C3S winter temperature anomaly forecast from <https://www.copernicus.eu/en> all for December, January and February 2021.

Winter may be over, but it looks like we are not completely done with wintry weather. It is officially spring, but it looks to me as though the stratospheric PV has one last trick up its sleeve. I mentioned about a possible minor PV disruption that could bring back the cold to eastern North America. This is a type of event that I refer to as a reflective or stretching PV event. If you need a reminder here is a recent paper - [Kretschmer et al. 2018](#). I discuss these events often in the blog and most recently was in association with the record cold and snow in the Central US back in October 2020. I thought it was an exceptional meteorological event but will from now on exist in the shadow of what

occurred in February 2021. Anyway, these events tend to favor cold temperatures in East Asia and especially Canada and the US with relatively mild temperatures in Europe similar to what is predicted in the second half of March (see **Figure 9** below). Often the models underpredict the intensity of these events with the model predicted magnitude of the cold increasing into the event. In **Figure iii**, I include the PV animation from this morning. What is depicted is far from textbook, but you can see the shifting of the coldest temperatures from Siberia to Canada and what appears to be a stretching of the PV center that would increase cross polar flow from Siberia to Canada. I admit this is still somewhat speculative, it is late March with solar strength comparable to September and snow cover across the US is actually below normal for this time of year. I don't want to oversell the event but also I don't want to undersell it as well.

Initialized 00Z 10 hPa HGT/HGTa 08-Mar-2021

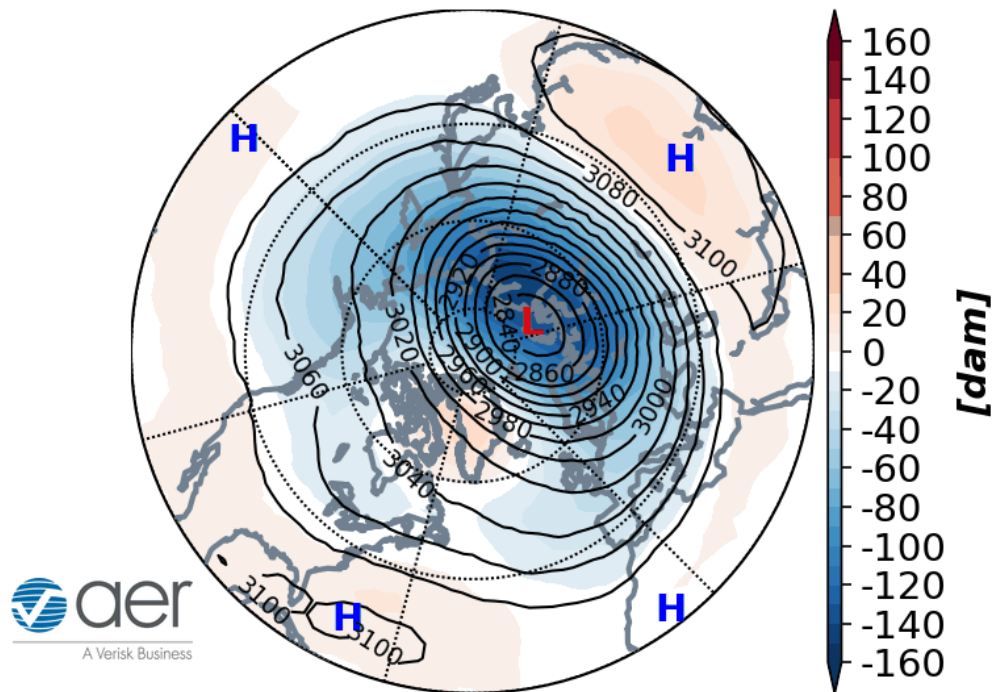


Figure iii. (a) Observed 10 hPa geopotential heights (dam; contours) and temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere for 8 March 2021 and predicted through 23 March 2021. The forecasts are from the 00Z 8 March 2021 GFS model ensemble.

1-5 day

The AO is predicted to turn strongly positive this week (**Figure 1**) as negative geopotential height anomalies dominate the Arctic with mostly positive geopotential height anomalies across the mid-latitudes of the NH (**Figure 2**). And with negative geopotential height anomalies predicted across Greenland (**Figure 2**), the NAO is predicted to remain positive as well.

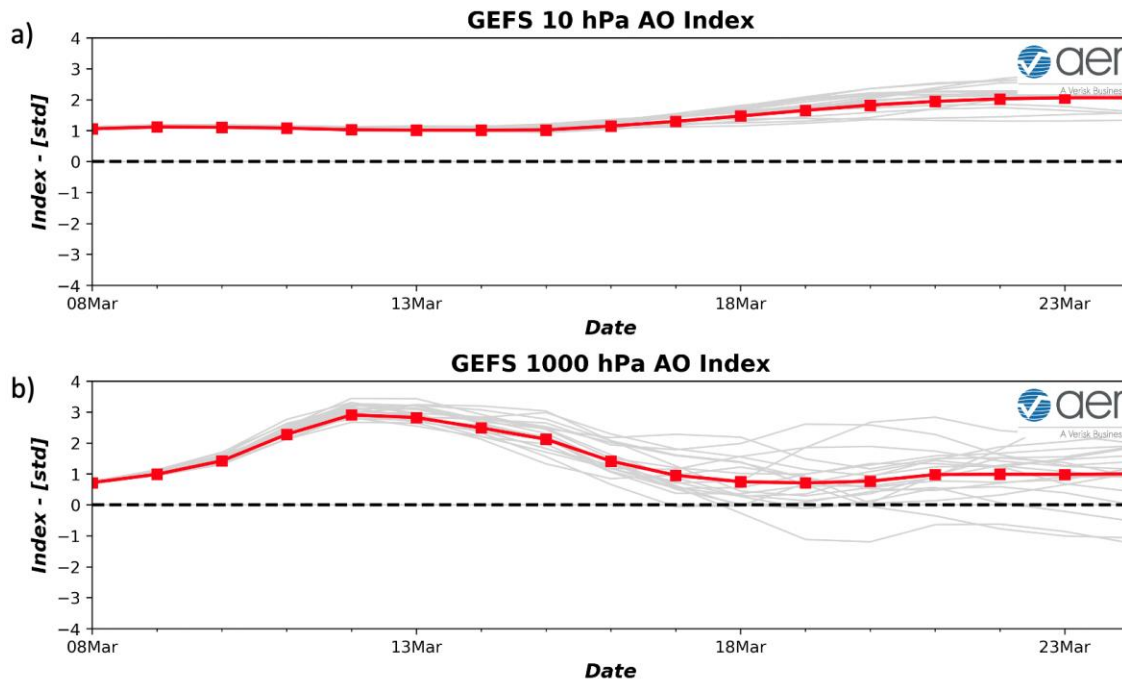


Figure 1. (a) The predicted daily-mean AO at 10 hPa from the 00Z 8 March 2021 GFS ensemble. (b) The predicted daily-mean near-surface AO from the 00Z 8 March 2021 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

Transient ridging/positive geopotential height anomalies predicted across Greenland ending today contributed to troughing/negative geopotential height anomalies across Northern Europe this week (**Figures 2**). **This will favor** normal to below normal temperatures across much of Northern Europe including the UK with normal to above normal temperatures across Southern Europe where westerly flow will persist relatively warm temperatures (**Figure 3**). Persistent troughing/negative geopotential height anomalies across Northern Asia is predicted to become more regionalized to Eastern Siberia and the Urals with ridging/positive geopotential height anomalies across Southern and Eastern Asia this period (**Figure 2**). This is predicted to favor normal to below normal temperatures across much of Western Asia and Eastern Siberia with normal to above normal temperatures becoming more widespread across the remainder of Asia (**Figure 3**).

GEFS 1-5 Day Forecast 500 mb GPH/GPH Anomaly
INIT: 00Z 03/08/2021 FCST: 03/09/2021 to 03/13/2021

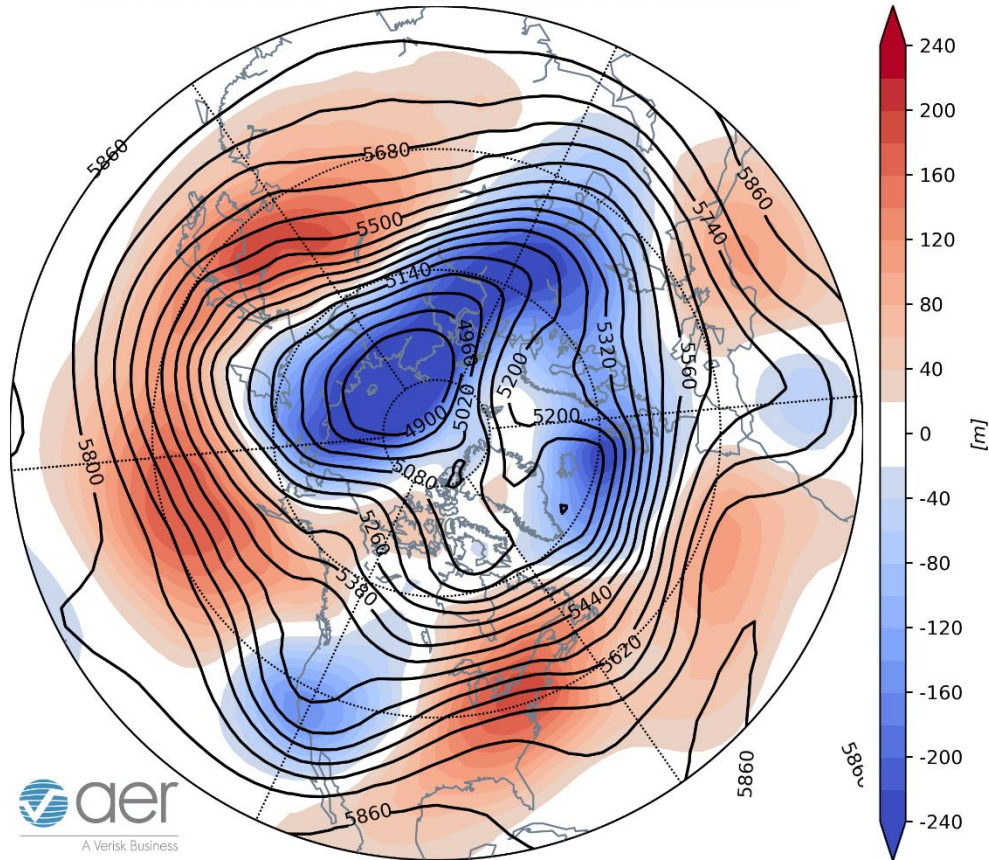


Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 9 – 13 March 2021. The forecasts are from the 00z 8 March 2021 GFS ensemble.

This week, troughing/negative geopotential height anomalies are predicted to become focused in western North America while ridging/positive geopotential height anomalies will overspread Eastern Canada and the Eastern US this period (**Figure 2**). This pattern is predicted to bring normal to below normal temperatures across Alaska, Western Canada and the Western US with normal to above normal temperatures across Eastern Canada and the Eastern US (**Figure 3**).

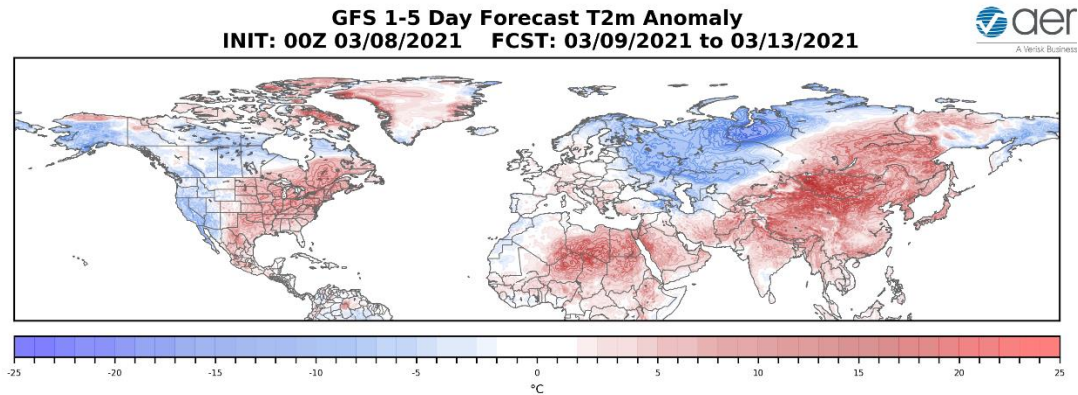


Figure 3. Forecasted surface temperature anomalies (°C; shading) from 9 – 13 March 2021. The forecast is from the 00Z 8 March 2021 GFS ensemble.

Trouging and/or colder temperatures are predicted to support new snowfall regionally across Northern Eurasia and the higher elevations, while warmer temperatures will cause widespread snow melt across Europe and Asia (**Figure 4**). Trouging and/or colder temperatures are predicted to support regionally new snowfall across Alaska, parts of Canada and the Western US while warmer temperatures will cause widespread snow melt in Southeastern Canada and the Northeastern US (**Figure 4**).

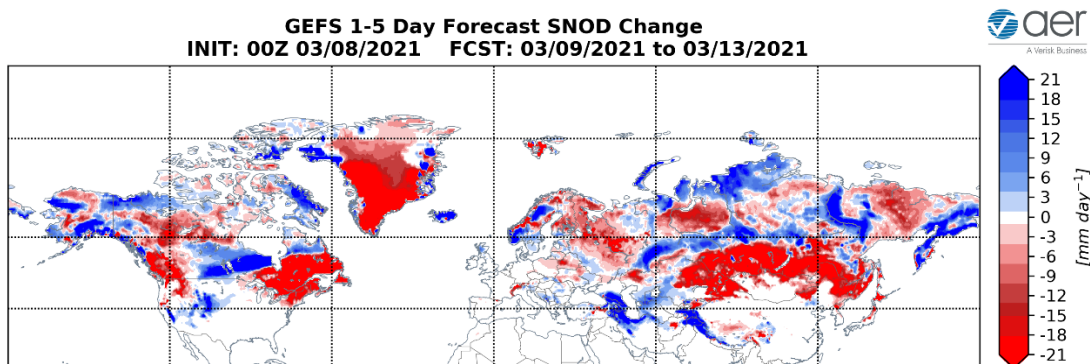


Figure 4. Forecasted snow depth changes (mm/day; shading) from 9 – 13 March 2021. The forecast is from the 00Z 8 March 2021 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to remain positive this week (**Figure 1**) as negative geopotential height anomalies continue to dominate the Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 5**). And with negative geopotential

height anomalies predicted across Greenland (**Figure 5**), the NAO is predicted to remain positive as well.

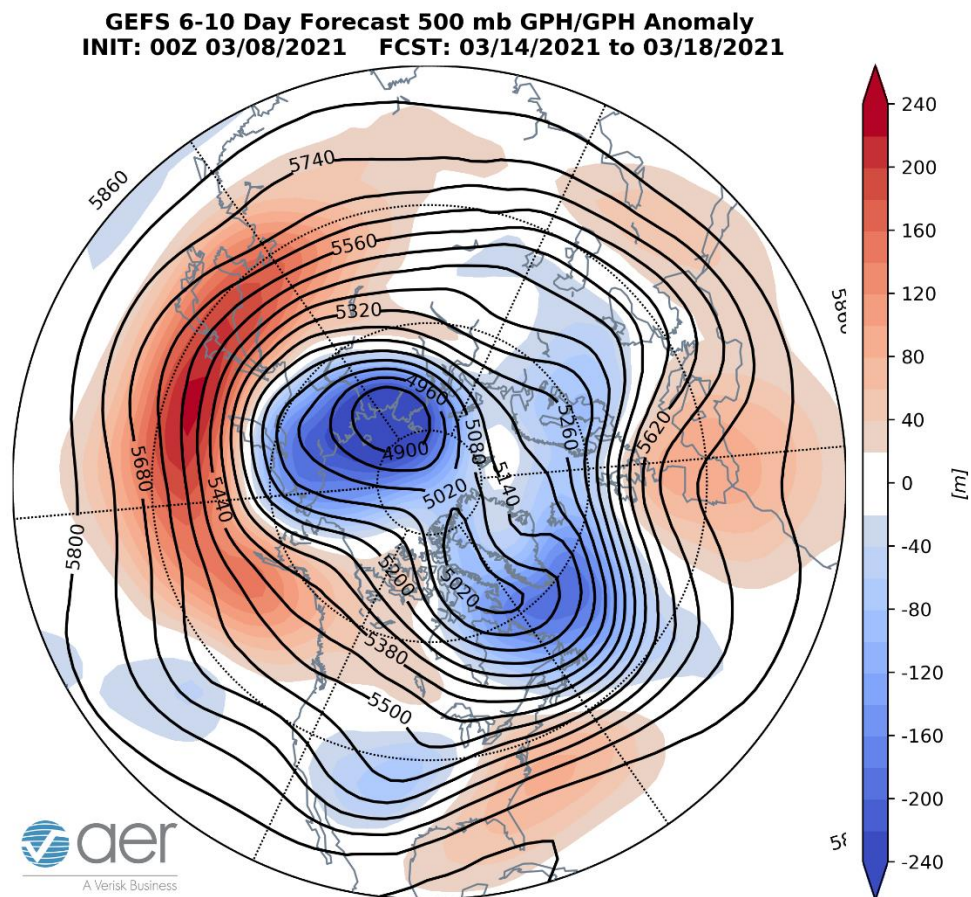


Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 14 – 18 March 2021. The forecasts are from the 00z 8 March 2021 GFS ensemble.

With the return of troughing/negative geopotential height anomalies across Greenland, ridging/positive geopotential height anomalies are predicted across Western Europe this week (**Figures 5**). **This will favor** normal to above normal temperatures across much of Europe including the UK **with the possible exception of** Scandinavia where low heights will persist normal to below normal temperatures (**Figure 6**). Persistent troughing/negative geopotential height anomalies across Northern and Western Asia with ridging/positive geopotential height anomalies across Southern and Eastern Asia are predicted to persist for one more week (**Figure 5**). This pattern favors normal to below normal temperatures across much of Western and far Northern Asia, though some colder temperatures will start to filter into Central Asia with normal to above normal temperatures remaining widespread across Southern and Eastern Asia (**Figure 6**).

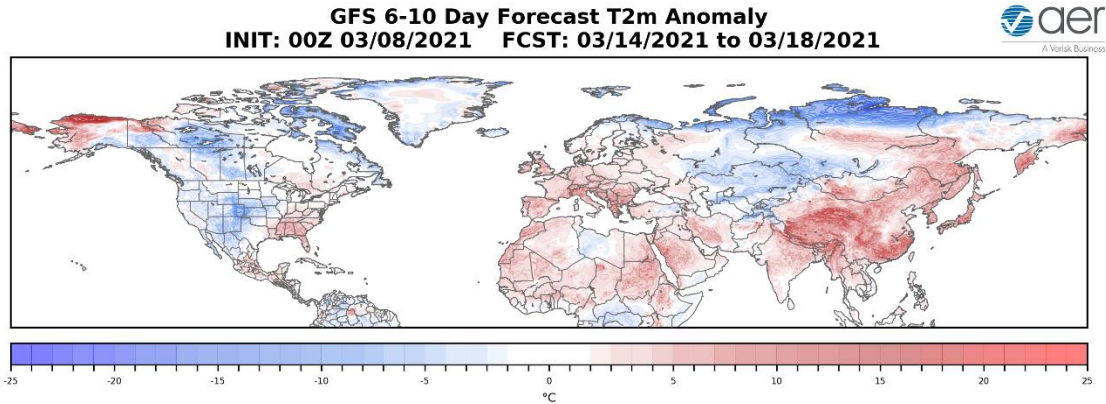


Figure 6. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 14 – 18 March 2021. The forecasts are from the 00Z 8 March 2021 GFS ensemble.

Deepening troughing/negative geopotential height anomalies in Hudson Bay, that I believe are related to a minor PV disruption will begin to focus troughing/negative geopotential height anomalies in eastern North America while ridging/positive geopotential height anomalies will begin to overspread Alaska and Western Canada this period (**Figure 5**). This pattern is predicted to bring normal to above normal temperatures across Alaska, Western Canada and the Eastern US while normal to below normal temperatures previously across western North America will begin to filter into Eastern Canada and the Central US (**Figure 6**).

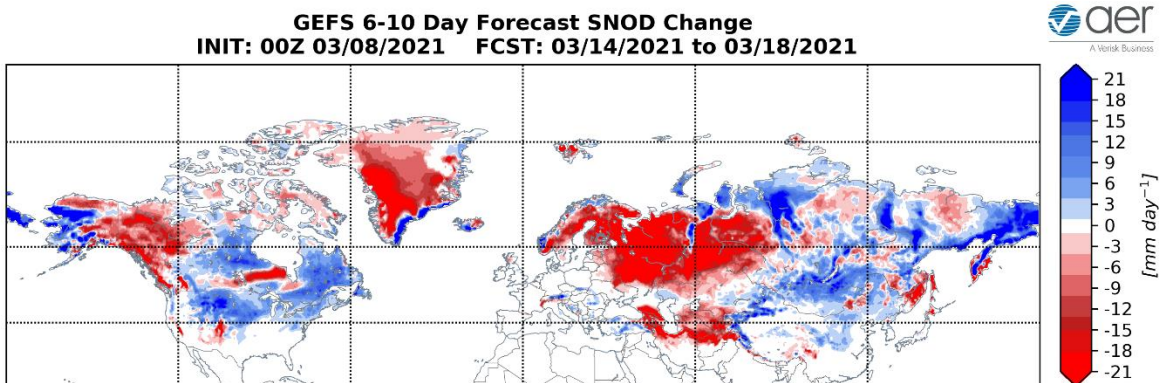


Figure 7. Forecasted snow depth changes (mm/day ; shading) from 14 – 18 March 2021. The forecasts are from the 00Z 8 March 2021 GFS ensemble.

Troughing and/or colder temperatures are predicted to potentially support new snowfall across Eastern Asia and Siberia while warmer temperatures will cause widespread snow melt in western Eurasia (**Figure 7**). Troughing and/or colder temperatures are predicted to support the potential for new snowfall across Central and Eastern Canada

and the Northern US while warmer temperatures will cause snow melt in Western Canada and the Southwestern US (**Figure 7**).

11-15 day

As geopotential height anomalies are predicted to remain negative for much of the Arctic with mixed positive geopotential height anomalies across the mid-latitudes of the NH (**Figure 8**), the AO should remain positive this period (**Figure 1**). With negative pressure/geopotential height anomalies spread across Greenland (**Figure 8**), the NAO is predicted to remain positive this period as well.

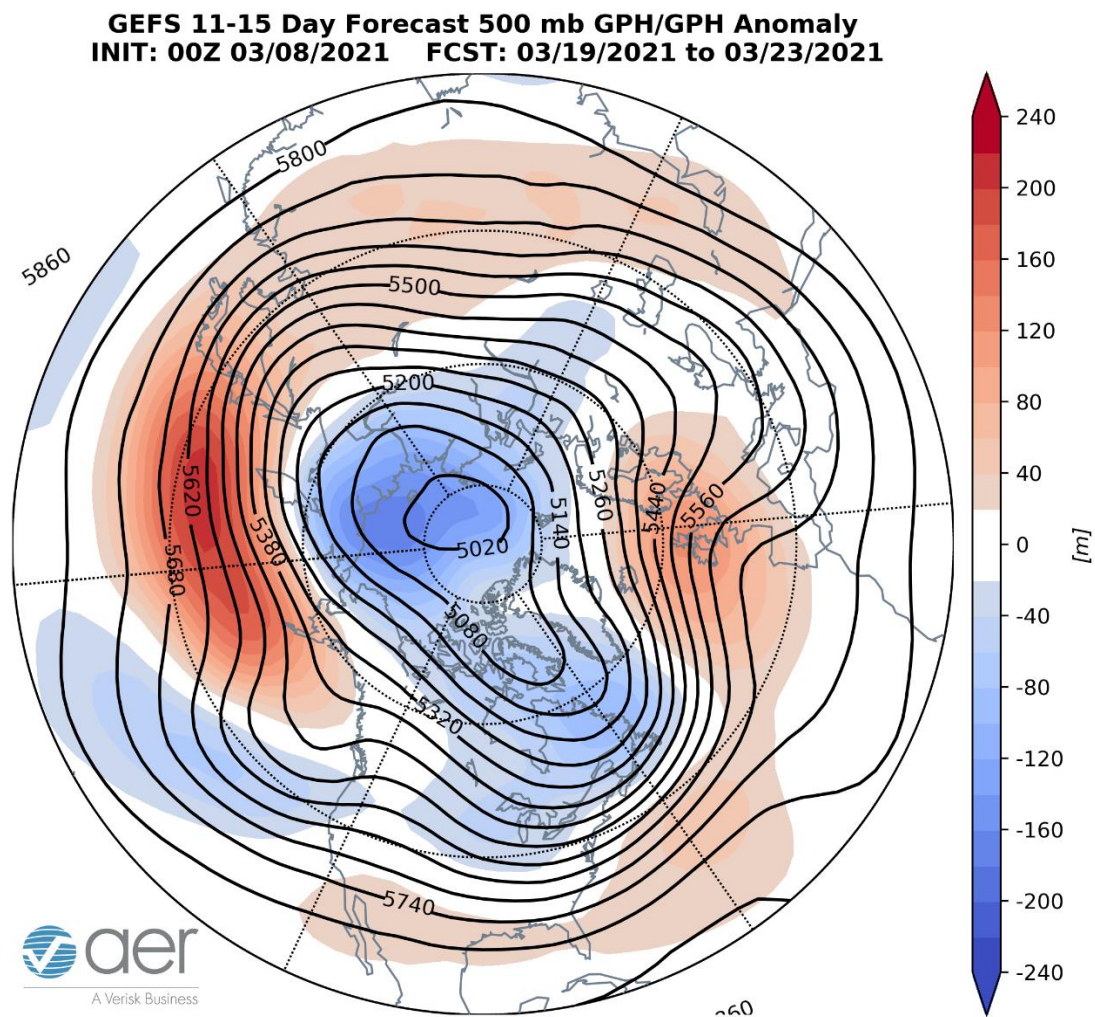


Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 19 – 23 March 2021. The forecasts are from the 00z 8 March 2021 GFS ensemble.

Ridging/positive geopotential height anomalies are predicted to still dominate Europe this period (**Figure 8**). This favors widespread normal to above normal temperatures across Europe including the UK this period, though some colder temperatures could begin to filter west from Siberia towards Eastern Europe (**Figures 9**). European ridging/positive geopotential height anomalies will help deepen troughing/negative geopotential height anomalies across Northern Asia while ridging/positive geopotential height anomalies persist across Southern Asia (**Figure 8**). This pattern favors normal to below normal temperatures becoming more widespread across Northern Asia with normal to above normal temperatures across Southern and Eastern Asia (**Figure 9**).

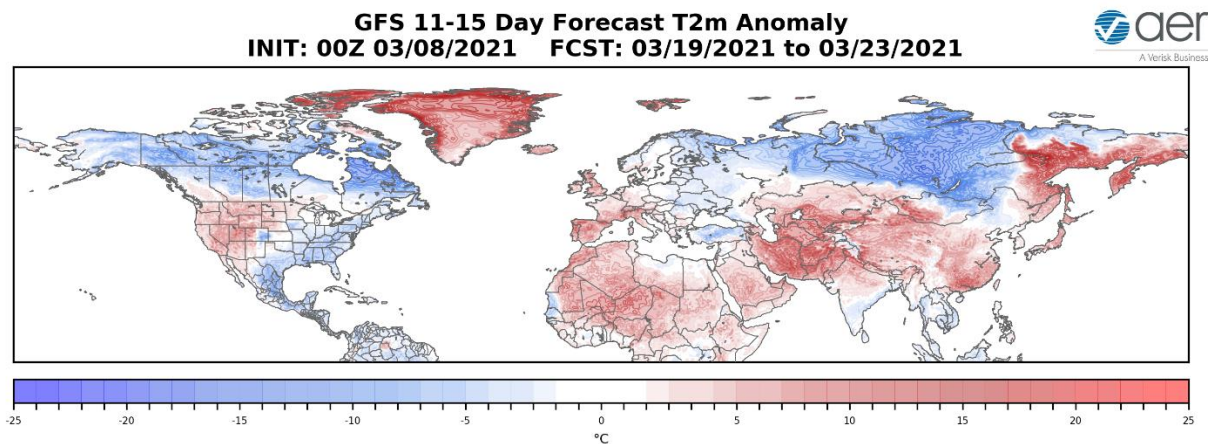


Figure 9. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 19 – 23 March 2021. The forecasts are from the 00z 8 March 2021 GFS ensemble.

Troughing/negative geopotential height anomalies in eastern North America are predicted to deepen with weak ridging/positive geopotential height anomalies in western North America this period (**Figure 8**). This pattern favors widespread normal to below normal temperatures for Alaska, much of Canada and the Eastern US with normal to above normal temperatures across the Western US (**Figure 9**).

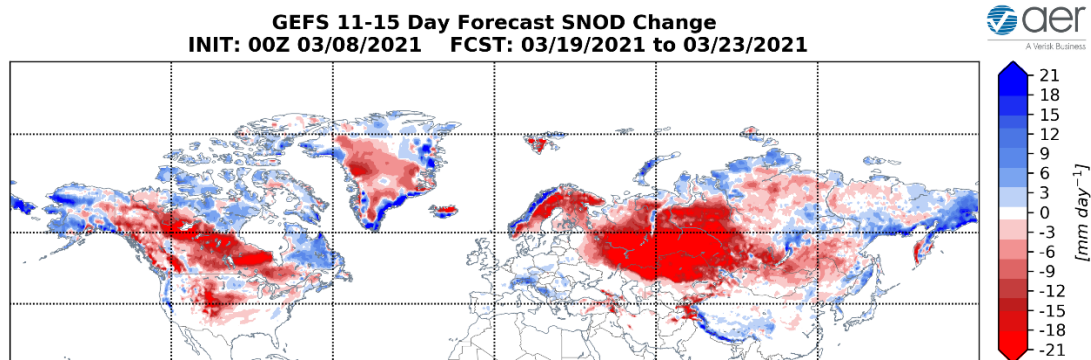


Figure 10. Forecasted snow depth changes (mm/day; shading) from 19 – 23 March 2021. The forecasts are from the 00z 8 March 2021 GFS ensemble.

Trouching and/or colder temperatures are predicted to support regionally new snowfall across Norway, the Alps, Siberia, East Asia and the Himalayas while warmer temperatures will cause snowmelt in Northeastern Europe and Northwestern Asia (**Figure 10**). Trouching and/or colder temperatures are predicted to support new snowfall across Alaska, much of Northern and Eastern Canada and the US West Coast while warmer temperatures will result in snowmelt in western and central North America (**Figure 10**).

Longer Term

30-day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows normal to cold/negative PCHs throughout the troposphere and stratosphere for the next two weeks (**Figure 11**). The deeper cold/negative PCHs currently in the upper stratosphere are predicted to descend through the stratosphere and troposphere all the way to the surface this week (**Figure 11**).

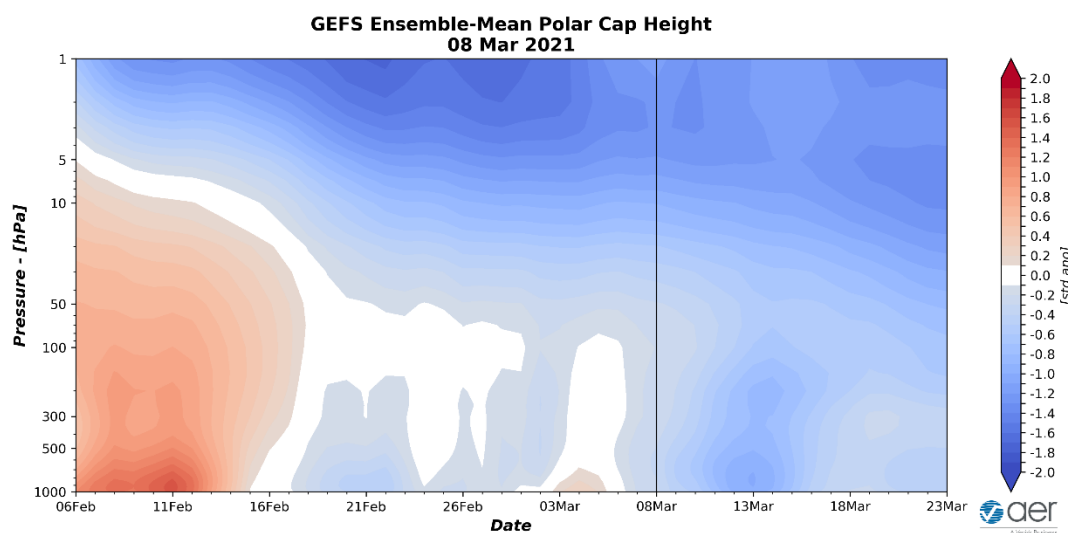


Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecast is from the 00Z 8 March 2021 GFS ensemble.

The overall cold/negative PCHs in the lower troposphere are consistent with the predicted positive surface AO the next two weeks (**Figure 1**). Similarly, the cold/negative PCHs in the mid-stratosphere are consistent with the positive stratospheric AO (at 10 hPa) the next two weeks (**Figure 1**). The imminent descent of

the more negative/cold PCHs in the stratosphere into the troposphere will force a spike of strongly positive surface AO this week (**Figure 1**).

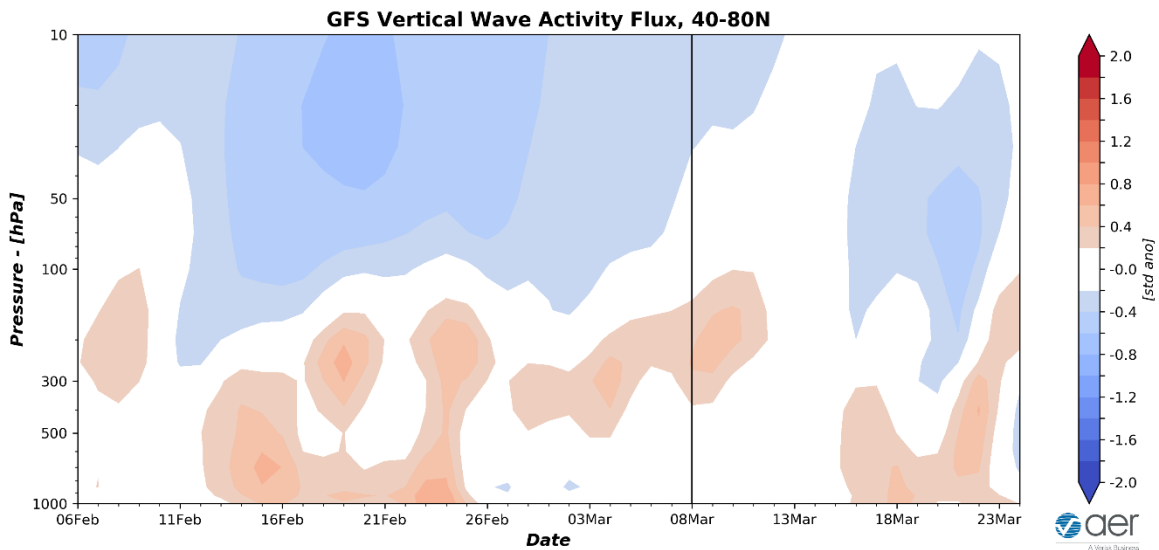


Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 8 March 2021 GFS ensemble.

The plot of the Wave Activity Flux (WAFz and is proportional to poleward heat transport) forecast is showing currently below normal WAFz in the stratosphere but slightly above normal WAFz in the troposphere (**Figure 12**). Admittedly it is not obvious from the plot, but I do believe that the WAFz forecast is suggestive of a reflective event with positive WAFz anomalies quickly followed by negative WAFz anomalies.

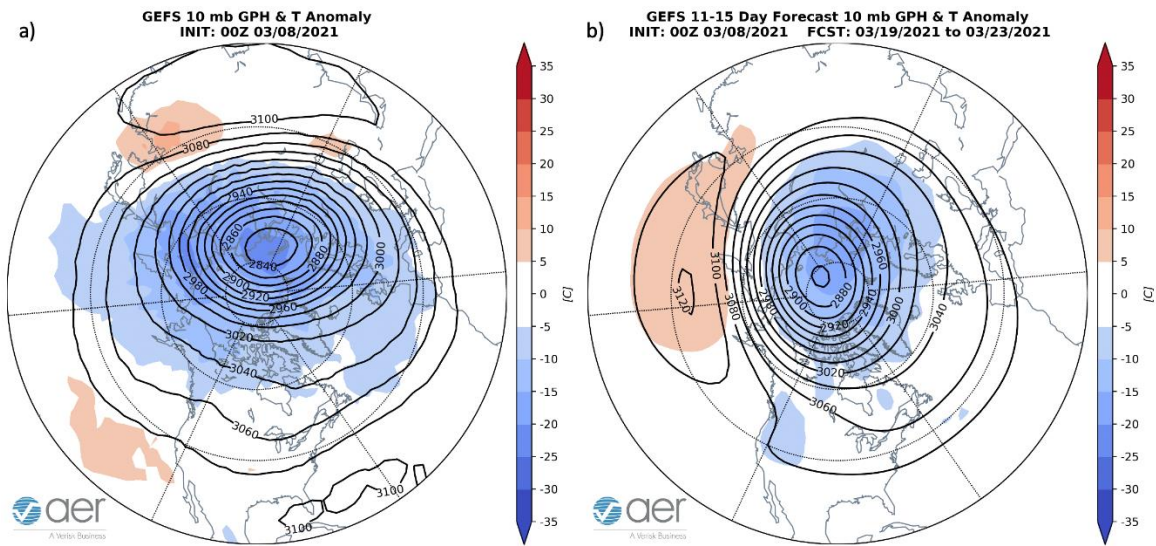


Figure 13. (a) Observed 10 mb geopotential heights (dam; contours) and temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere for 8 March 2021. (b) Same as (a) except forecasted averaged from 19 – 23 March 2021. The forecasts are from the 00Z 8 March 2021 GFS model ensemble.

The PV continues to remain relatively strong with the vortex centered over the Laptev Sea (**Figure 13**). The PV is also a bit elongated across Northern Eurasia allowing for troughing and colder temperatures in the troposphere (**Figure 13**). The PV center is predicted to migrate closer to the North Pole and become elongated in shape with an axis from Siberia to Western Canada (**Figure 13**). I believe that the elongated or stretched PV center may be a sign of a minor PV disruption that favors cold temperatures in East Asia and North America east of the Rockies.

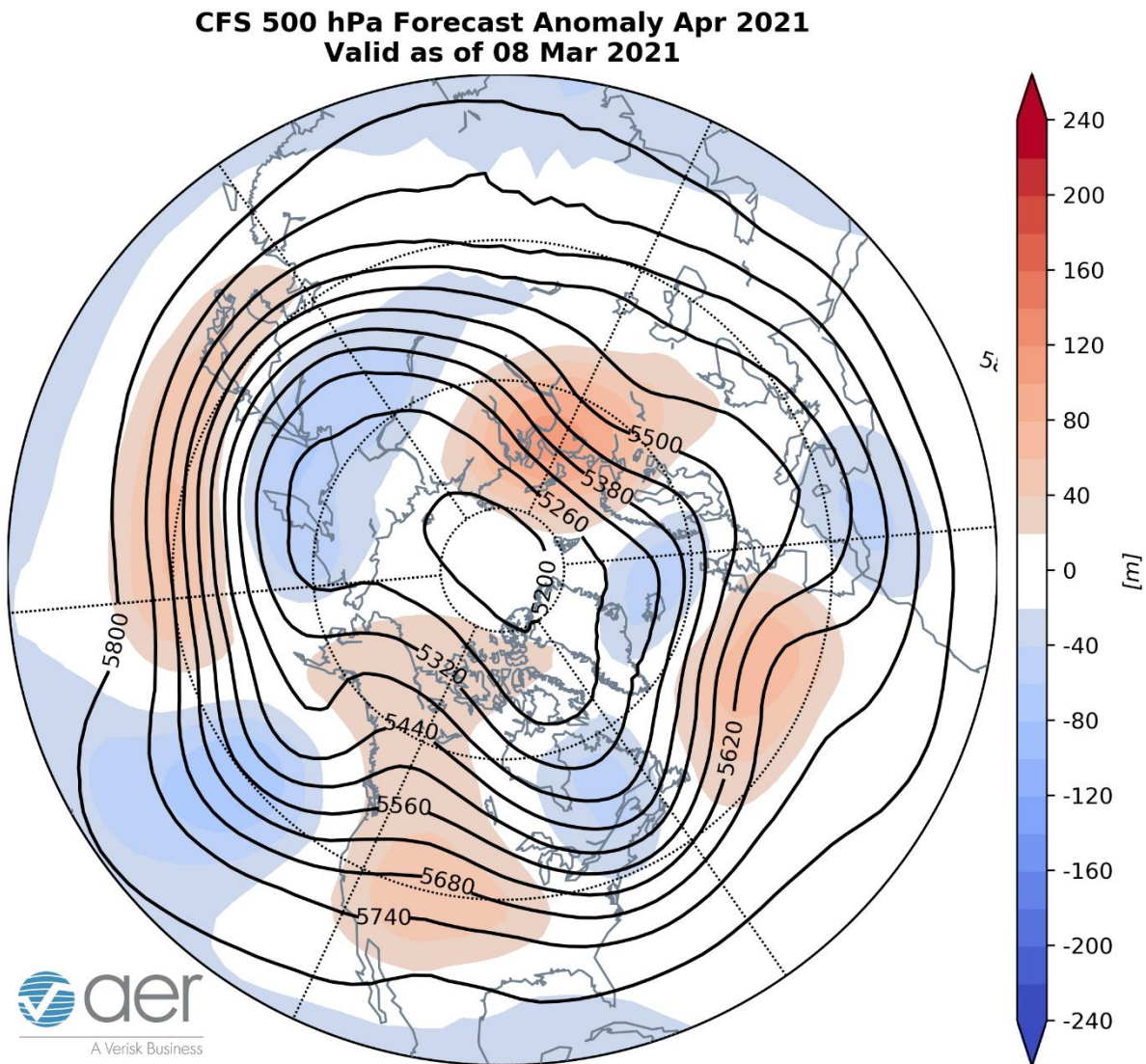


Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for April 2021. The forecasts are from the 00Z 8 March 2021 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and the surface temperatures (**Figure 15**) forecast for April from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging south of Iceland across the Urals, near the Dateline and western North America with troughing in Western Europe, East Asia, south of the Aleutians and eastern North America (**Figure 14**). This pattern favors relatively cold temperatures for Western and Southern Europe, East Asia, Eastern Canada and the Eastern US with seasonable to relatively warm temperatures for Northern Europe, Western Asia and much of Western Canada and especially the Western US (**Figure 15**).

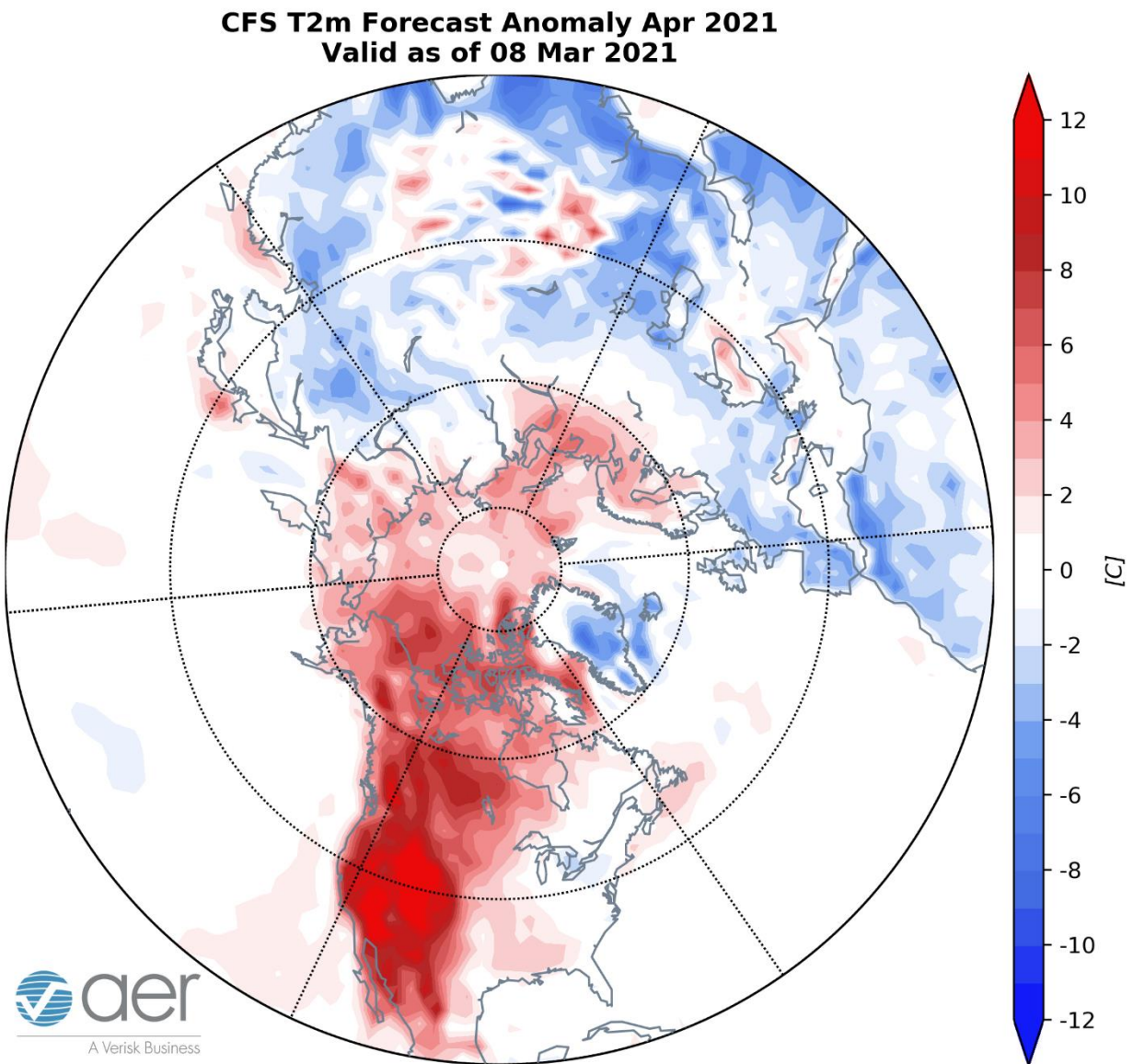


Figure 15. Forecasted average surface temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere for April 2021. The forecasts are from the 00Z 8 March 2021 CFS.

Surface Boundary Conditions

Arctic sea ice extent

Arctic sea ice is likely near its seasonal maximum and remains below normal but more extensive than recent winters. Negative sea ice anomalies exist mostly in Baffin Bay and the Bering Sea (**Figure 16**).. Below normal sea ice in the Barents-Kara seas favor Ural blocking and cold temperatures in Central and East Asia, however this topic remains controversial. Recent research has shown that the regional anomalies that are most highly correlated with the strength of the stratospheric PV are across the Barents-Kara seas region where low Arctic sea ice favors a weaker winter PV. Low sea ice in the Chukchi and Bering seas may favor colder temperatures across North America but have not been shown to weaken the PV.

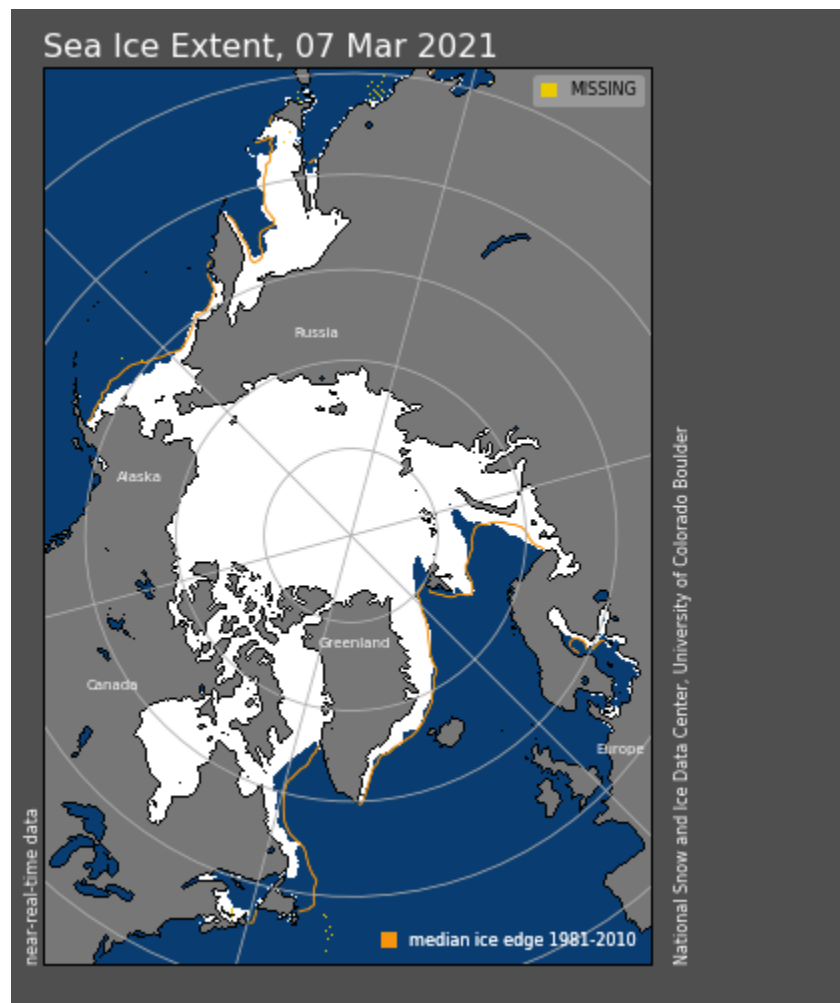


Figure 16. Observed Arctic sea ice extent on 7 March 2021 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010. Image courtesy of National Snow and Ice Data Center (NSIDC).

SSTs/El Niño/Southern Oscillation

Equatorial Pacific sea surface temperatures (SSTs) anomalies remain negative and we continue to observe a weak La Niña conditions (**Figure 17**) and La Niña is expected to persist and remain weak through the spring. Observed SSTs across the NH remain well above normal especially near Alaska and in the Gulf of Alaska, the western North Pacific and offshore of eastern North America though below normal SSTs exist regionally especially in the Southern Hemisphere and south of Iceland. Warm SSTs in the Gulf of Alaska may favor mid-tropospheric ridging in the region.

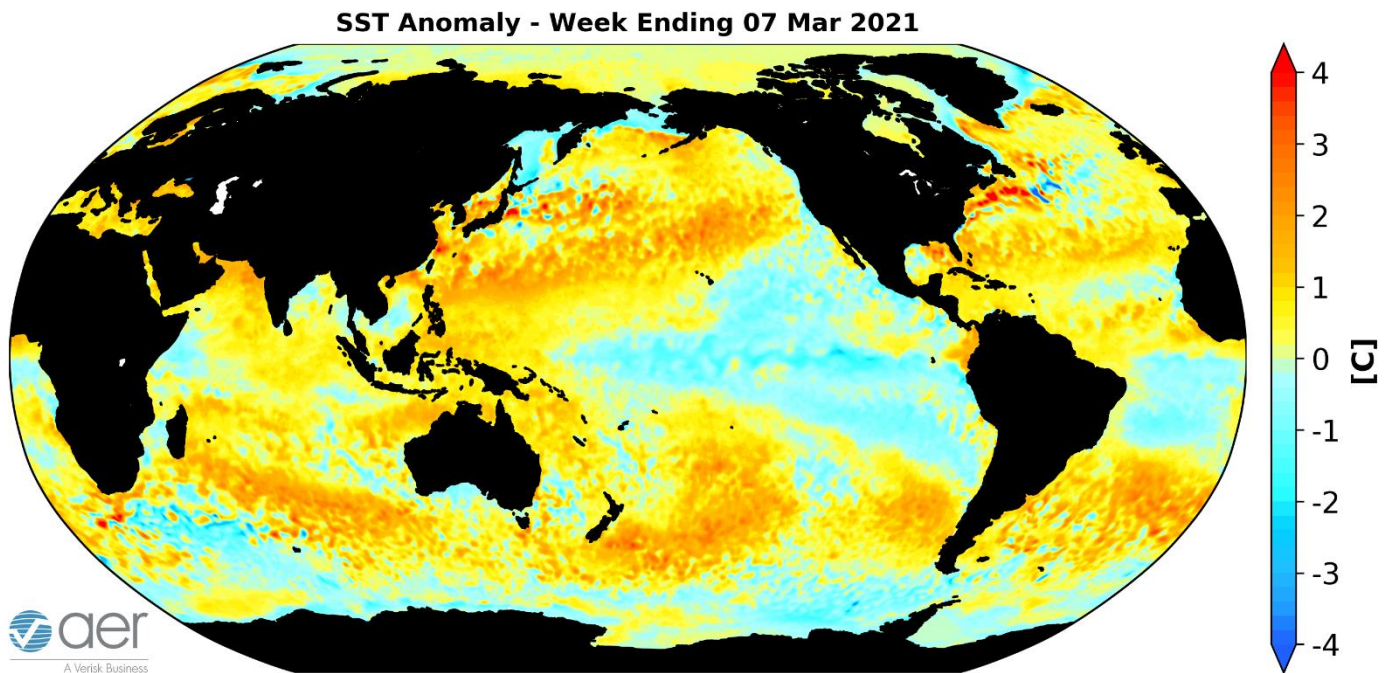


Figure 17. The latest weekly-mean global SST anomalies (ending 7 March 2021). Data from NOAA OI High-Resolution dataset.

Currently no phase of the Madden Julian Oscillation (MJO) is favored (**Figure 18**). The forecasts are for the MJO to emerge into phase eight and then phase one. MJO phases eight and one favor blocking across Northern Canada and troughing in the Eastern US. The MJO does not seem to be contributing much to the predicted weather pattern across North America but admittedly this is outside of my expertise.

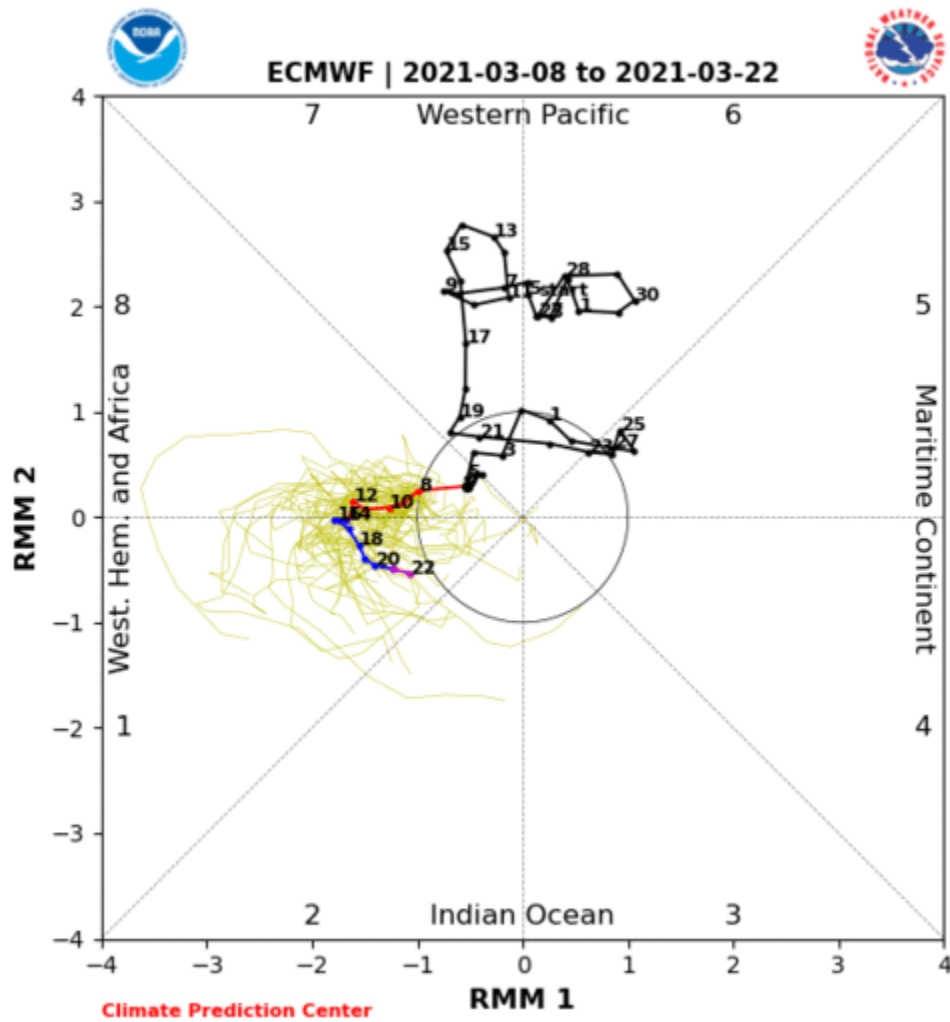


Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 8 March 2021 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model “spread” is denoted by the gray shading. Sector numbers indicate 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 extent declined over the past week across Eurasia and remains near decadal lows. Snow cover advance is likely in its seasonal decline. Above normal snow cover extent in 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.

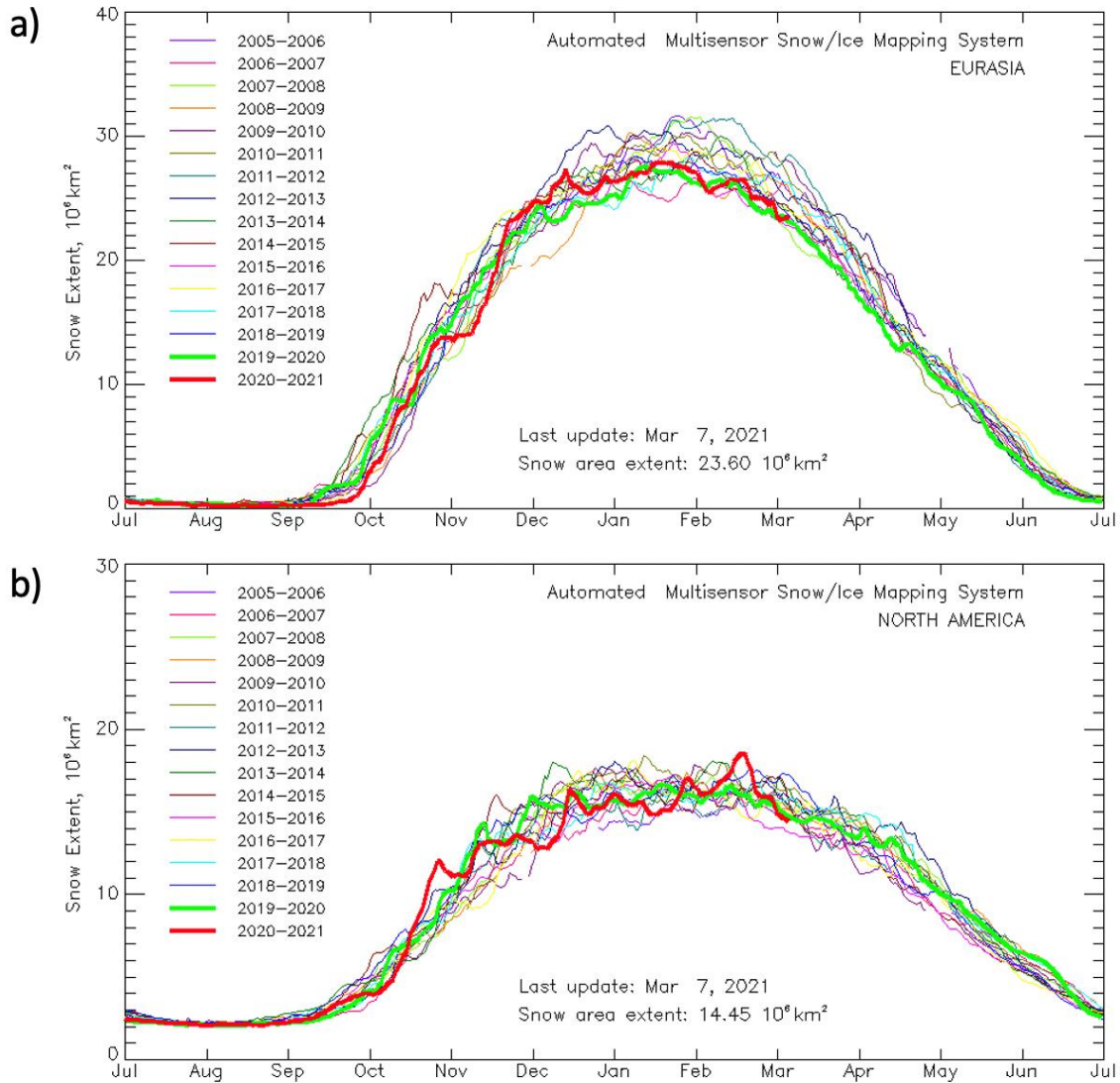


Figure 19. Observed Eurasian (top) and North American (bottom) snow cover extent through 7 March 2021. Image source:

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

North American snow cover declined from its record extent over the past week and is now at decadal means. Snow cover is now likely in its seasonal decline.