

Arctic Oscillation and Polar Vortex Analysis and Forecasts

May 11, 2020

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) recently embarked on an experimental process of regular research, review, and analysis of the Arctic Oscillation (AO) and Polar Vortex (PV). This analysis is intended to provide researchers and practitioners real-time insights on one of North America's and Europe's leading drivers for extreme and persistent temperature patterns.

During the winter schedule the blog is updated once every week. Snow accumulation forecasts replace precipitation forecasts. Also, there is renewed emphasis on ice and snow boundary conditions and their influence on hemispheric weather. With the start of spring we transition to a spring/summer schedule, which is once every two weeks. Snow accumulation forecasts will be replaced by precipitation forecasts. Also, there will be less emphasis on ice and snow boundary conditions and their influence on hemispheric weather.

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

Summary

- The Arctic Oscillation (AO) is currently negative and is predicted to remain negative the next two weeks.
- The current negative AO is reflective of mostly positive pressure/geopotential height anomalies in the Arctic with mixed pressure/geopotential height

anomalies across the mid-latitudes. The North Atlantic Oscillation (NAO) is currently negative with positive pressure/geopotential height anomalies spread across Greenland; and the NAO is predicted to remain mostly negative the next two weeks.

- Over the next two weeks ridging/positive geopotential height anomalies will favor troughing/negative geopotential height anomalies and normal to below normal temperatures widespread across Europe including the United Kingdom (UK) but focused in Eastern Europe except for normal to above normal temperatures in Southeastern Europe.
- The predicted general pattern for Asia over the next two weeks is ridging/positive geopotential height anomalies with normal to above normal temperatures. Some regional exceptions are troughing/negative pressure/geopotential height anomalies with normal to below normal temperatures in Western Asia upstream of the European troughing and in and around Pakistan and Afghanistan.
- Over the next two weeks ridging/positive geopotential height anomalies with normal to above normal temperatures anchored across Alaska and Western Canada will force troughing/negative geopotential height anomalies with normal to below normal temperatures in Eastern Canada. Meanwhile troughing/negative geopotential height anomalies accompanied by normal to below normal temperatures will enter the Western US flipping troughing/negative geopotential height anomalies with below normal temperatures this week to ridging/positive geopotential height anomalies with normal to above normal temperatures in the Eastern US next week.
- Once again, in the Impacts section I discuss an apparent and very curious troposphere-stratosphere-troposphere coupling event and the implications for the Northern Hemisphere (NH) circulation pattern.

Impacts

On Friday I sent out an esoteric tweet, at least for the Twitter audience that I hope the regular readers of the blog had a better understanding of. One raison d'être for the blog is to exploit recent research on troposphere-stratosphere-troposphere (T-S-T) coupling to provide improved forecasts on subseasonal to seasonal timeframes that is really not available elsewhere. For example, this past winter lack of high latitude blocking/high pressure contributed to spinning up the stratospheric polar vortex (PV), which in turn reinforced the lack of high latitude blocking/high pressure, a positive AO, a relatively cold Arctic and mild winter weather across the mid-latitudes of the NH. This positive feedback loop, pretty much spanned the entire winter. Alternatively, high latitude blocking/high pressure, especially near Scandinavia and the Urals, weakens the PV contributing to more widespread high latitude blocking/high pressure, a negative AO, a relatively warm Arctic and severe winter weather across the mid-latitudes of the NH.

However, this T-S-T coupling is supposed to be limited to the period when the PV actually exists and mostly to the months of October through March. The reason being is

once high pressure replaces the PV or low pressure centered near the North Pole, the winds reverse from westerly to easterly (flow is counterclockwise around low pressure but clockwise around high pressure). Vertical energy propagation requires westerly background flow to escape the troposphere into the stratosphere. So, once the winds go easterly upwelling energy from the troposphere to the stratosphere ceases. Also, in the absence of upwelling energy from the troposphere to the stratosphere, the stratosphere should cool relative to climatology due to increasing carbon dioxide in the atmosphere. In the troposphere, carbon dioxide warms the atmosphere because it is an efficient heat trapping gas but, in the stratosphere, carbon dioxide cools the atmosphere because it is an efficient emitter of infrared radiation resulting in energy loss.

The Final Warming (where the stratospheric PV disappears until the fall) has clearly occurred back in April. Yet looking at the polar cap geopotential height anomalies (PCHs) reveals an almost classic T-S-T coupling event (**Figure 11**) where high latitude blocking forces a PV weakening followed by an extended period of a negative AO. Based on my understanding of the physics this shouldn't be happening post a Final Warming because easterly winds in the stratosphere should be inhibiting all upwelling energy. The lack of upwelling vertical energy should promote relatively cold PCHs in the stratosphere. Therefore, I don't have a good explanation for warming stratospheric PCHs other than maybe our understanding, including my own, of wave energy propagation from the troposphere to the stratosphere is over simplified.

Regardless of expectations and understanding, we are observing warming PCHs in the stratosphere. There is also a clear model forecast of what is a real or apparent downward propagation of those relatively warm PCHs from the stratosphere to the troposphere (**Figure 11**) coupled with mid-tropospheric high pressure in the central Arctic and Greenland blocking, all consistent with a negative AO (**Figures 5, 8 and 1**). In the winter months, a negative AO is related to widespread severe winter weather across the mid-latitudes. However, in summer the extent of weather impacts related to the AO are more limited. So, though a negative AO is related to relatively cold winter weather in the Eastern US, Northern Europe and East Asia this is not necessarily true in summer. The record cold and snow experienced at the end of last week and over the weekend in the Northeastern US seems to be associated with the first stage of the ongoing T-S-T coupling event or what I like to refer to as the tropospheric precursor as seen in **Figure 11**. However so far there are no forecasts of the return of relatively cold weather in the Eastern US with the third stage of the T-S-T coupling event or what I refer to as the mature climax stage and certainly it is possible that relatively cold temperatures will not return to the Eastern US in the upcoming predicted negative AO regime. Instead the forecast is for relatively cold temperatures to be focused across Northern Europe during the third stage of the ongoing T-S-T coupling event.

So, what to expect during the predicted negative AO period that may be relatively prolonged? As long as Greenland remains in place Europe is at elevated risk for cooler

weather. I also think the Northeastern US is at risk of cooler weather, but this is not evident in the plots below. But the cool risk across both Europe and the Eastern US will lessen even if the negative AO persists as we progress deeper into the summer season simply because the relationship between the AO and weather in the mid-latitudes weakens as the summer progresses. Therefore, despite the ongoing unusual T-S-T coupling event and even if the negative AO response is prolonged, I still believe that overall warm temperatures across most of the NH is the most reasonable expectation.

Sunny and warm weather in the Arctic associated with a negative AO, are conducive to ice melt both sea ice in the Arctic ocean and land ice on Greenland. Over the past several summers, low pressure has developed across the Central Arctic during the warmest summer months when sea ice melt is greatest helping to retard sea ice melt and preventing new record sea ice extent minimums. And despite the current weather conditions, I still believe the development of a Central Arctic low pressure, is a reasonable but not certain expectation. If high pressure continues to dominant the Arctic in mid-summer, then sea ice extent will approach and possibly surpass the record minimum of 2012.

1-5 day

The AO is currently negative (**Figure 1**) with positive geopotential height anomalies in most of the Arctic and mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 2**). And with predicted positive geopotential height anomalies across Greenland (**Figure 2**), the NAO is predicted to be negative as well.

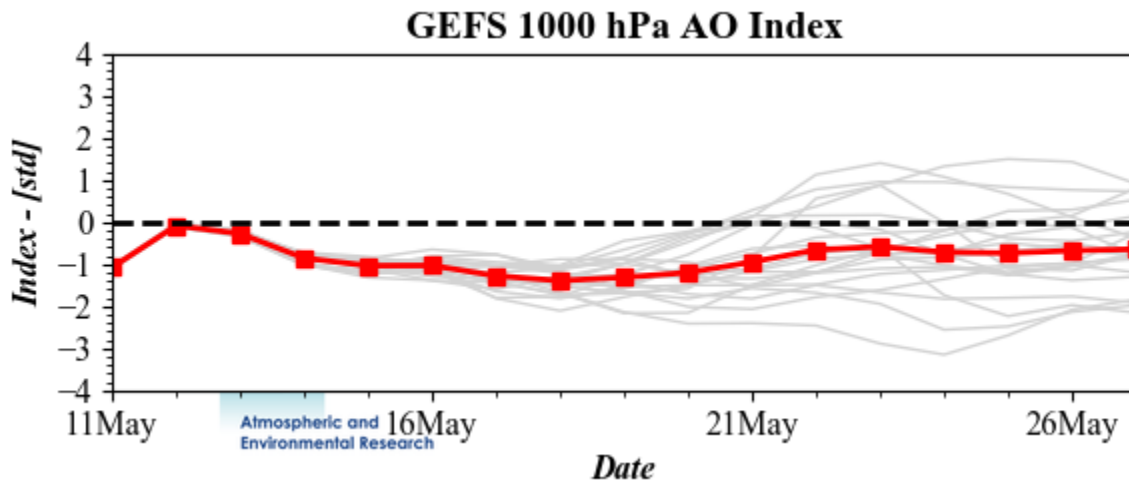


Figure 1. The predicted daily-mean AO at 10 hPa from the 00Z 11 May 2020 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

This week, ridging/positive geopotential height anomalies across Greenland will favor troughing/negative geopotential height anomalies and normal to below normal temperatures for much of Northern and Western Europe including the UK while ridging/positive geopotential height anomalies and normal to above normal temperatures will dominate Southern and Eastern Europe (Figures and 3). Troughing/negative geopotential height anomalies in Western Asia, will help to anchor ridging/positive geopotential height anomalies widespread across Central and Eastern Asia this week (Figure 2). This pattern favors normal to below normal temperatures across Western Asia and the Northern Indian subcontinent with normal to above normal temperatures in Central and Eastern Asia (Figure 3).

GEFS 1-5 Day Forecast 500 mb GPH/GPH Anomaly
INIT: 00Z 05/11/20 FCST: 05/12/20 to 05/16/20

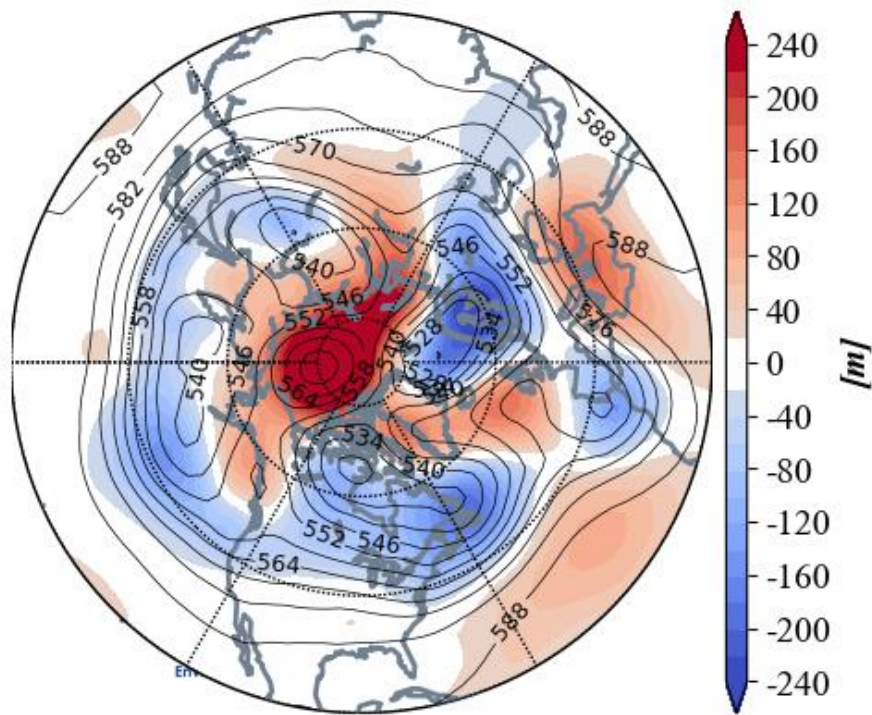


Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 12 – 16 May 2020. The forecasts are from the 00z 11 May 2020 GFS ensemble.

This week, ridging/positive geopotential height anomalies predicted for Alaska and Western Canada will force troughing/negative geopotential height anomalies for Eastern Canada and the Eastern US (Figure 2). This pattern is predicted to bring normal to above 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).

GEFS 1-5 Day Forecast T2m Anomaly
INIT: 00Z 05/11/20 FCST: 05/12/20 to 05/16/20

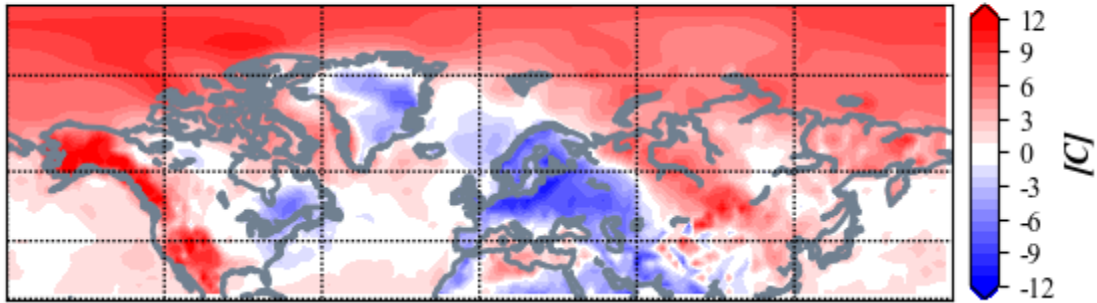


Figure 3. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 12 – 16 May 2020. The forecast is from the 00Z 11 May 2020 GFS ensemble.

Above normal precipitation is predicted for Southwestern and Northeastern Europe with below normal precipitation for Southeastern Europe with near normal precipitation across Asia (**Figure 4**). Near normal precipitation is predicted for North America except for above normal precipitation across the Northern US (**Figure 4**).

GEFS 1-5 Day Forecast PCP Anomaly
INIT: 00Z 05/11/20 FCST: 05/12/20 to 05/16/20

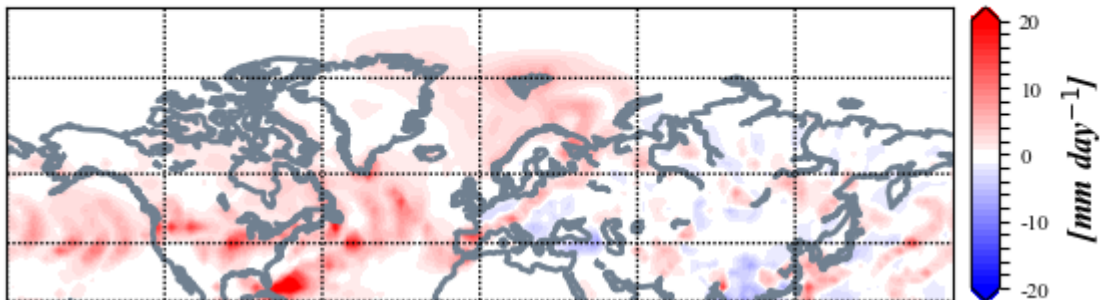


Figure 4. Forecasted precipitation anomalies (mm/day; shading) from 12 – 16 May 2020. The forecast is from the 00Z 11 May 2020 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to remain (**Figure 1**) positive geopotential height anomalies remain widespread Arctic but focused in the Central Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 5**). And with positive geopotential

height anomalies predicted across Greenland (**Figure 2**), the NAO is predicted to remain negative as well.

GEFS 6-10 Day Forecast 500 mb GPH/GPH Anomaly
INIT: 00Z 05/11/20 FCST: 05/17/20 to 05/21/20

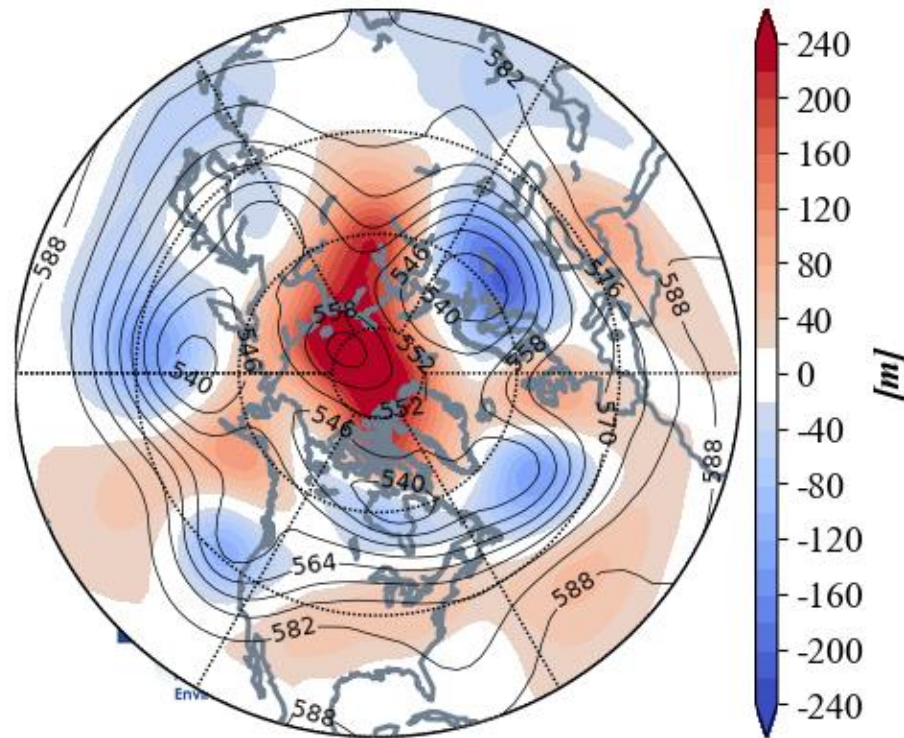


Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 17 – 21 May 2020. The forecasts are from the 00z 11 May 2020 GFS ensemble.

Ongoing ridging/positive geopotential height anomalies across Greenland and the Central Arctic will help to anchor troughing/negative geopotential height anomalies across Northern and Eastern Europe while ridging/positive geopotential height anomalies with normal to above normal temperatures persist across Southeastern Europe (**Figures 5**). This pattern will favor normal to below normal temperatures across much of Europe including the UK with normal to above normal temperatures mostly confined to Southeastern Europe (**Figure 6**). Persistent troughing/negative geopotential height anomalies in Western Asia will help to anchor ridging/positive geopotential height anomalies in Central and Eastern Asia (**Figure 5**). This is predicted to yield normal to below normal temperatures in far Western Asia with normal to above temperatures in Central and Eastern Asia (**Figure 6**). Some weak troughing/negative geopotential height anomalies across the Northern Indian subcontinent will favor normal to below normal temperatures across Pakistan and Afghanistan (**Figures 5 and 6**).

GEFS 6-10 Day Forecast T2m Anomaly
INIT: 00Z 05/11/20 FCST: 05/17/20 to 05/21/20

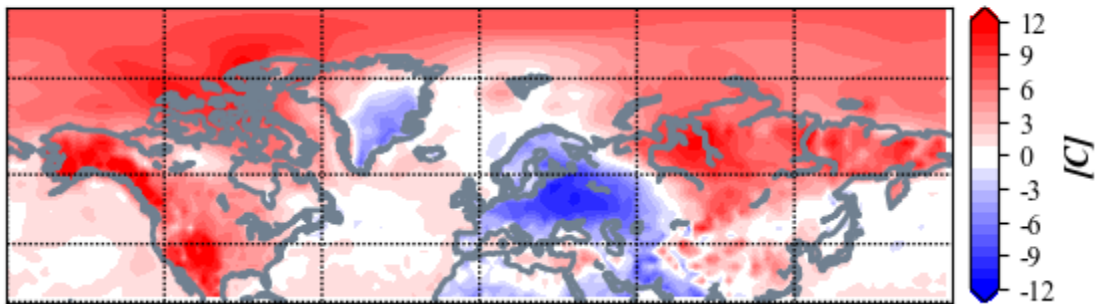


Figure 6. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 17 – 21 May 2020. The forecasts are from the 00Z 11 May 2020 GFS ensemble.

Persistent ridging/positive geopotential height anomalies will stretch across Alaska and Western Canada, will continue to favor troughing/negative geopotential height anomalies downstream across Eastern Canada this period (**Figure 5**). However, to the south troughing/negative geopotential height anomalies will enter the Western US from the North Pacific helping to build ridging/positive geopotential height anomalies in the Eastern US (**Figure 5**). This pattern is predicted to bring normal to above normal temperatures across Alaska, Western Canada and the Eastern US with normal to below normal temperatures for Eastern Canada and the Western US (**Figure 6**).

GEFS 6-10 Day Forecast PCP Anomaly
INIT: 00Z 05/11/20 FCST: 05/17/20 to 05/21/20

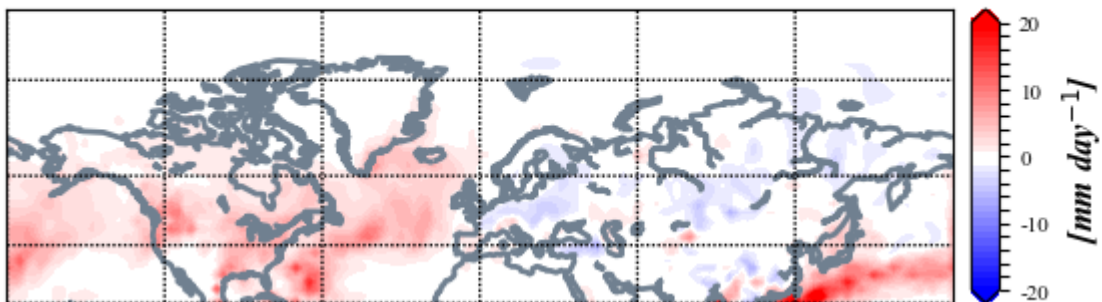


Figure 7. Forecasted precipitation anomalies (mm/day; shading) from 17 – 21 May 2020. The forecasts are from the 00Z 11 May 2020 GFS ensemble.

Normal to below normal precipitation is predicted for much of Eurasia (**Figure 7**). Near normal precipitation is predicted for much of North America with above normal precipitation in the Northwestern and Eastern US (**Figure 7**).

11-15 day

With predicted continued widespread positive geopotential height anomalies across the Arctic and mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 8**), the AO is predicted to remain negative this period (**Figure 1**). With predicted positive pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO is likely to be negative as well.

GEFS 11-15 Day Forecast 500 mb GPH/GPH Anomaly
INIT: 00Z 05/11/20 FCST: 05/22/20 to 05/26/20

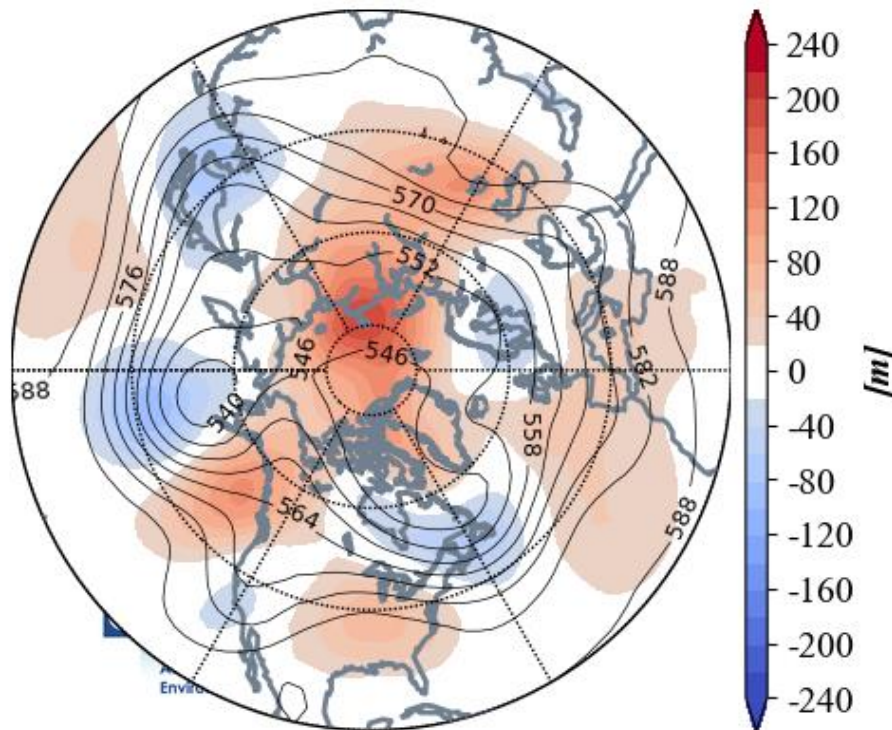


Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 22 – 26 May 2020. The forecasts are from the 00z 11 May 2020 GFS ensemble.

Persistent ridging/positive geopotential height anomalies over Greenland are predicted once again to favor downstream troughing/negative geopotential height anomalies across Northern Europe including the UK this period with mostly ridging/positive geopotential height anomalies across Southern Europe (**Figures 8**). The forecast is for widespread normal to below normal temperatures across Northern Europe including the UK with normal to above normal temperatures mostly confined to Southeastern Europe this period (**Figures 9**). Once again, ridging/positive geopotential height anomalies are predicted to dominate Asia with troughing/negative pressure/geopotential height anomalies limited to far Western and far Eastern Asia this period (**Figure 8**). This

pattern favors widespread normal to above normal temperatures across Asia with normal to below normal temperatures for far Western Asia and the Far East (**Figure 9**). Some weak troughing/negative geopotential height anomalies across the Northern India subcontinent will favor normal to below normal temperatures in the region (**Figures 8 and 9**).

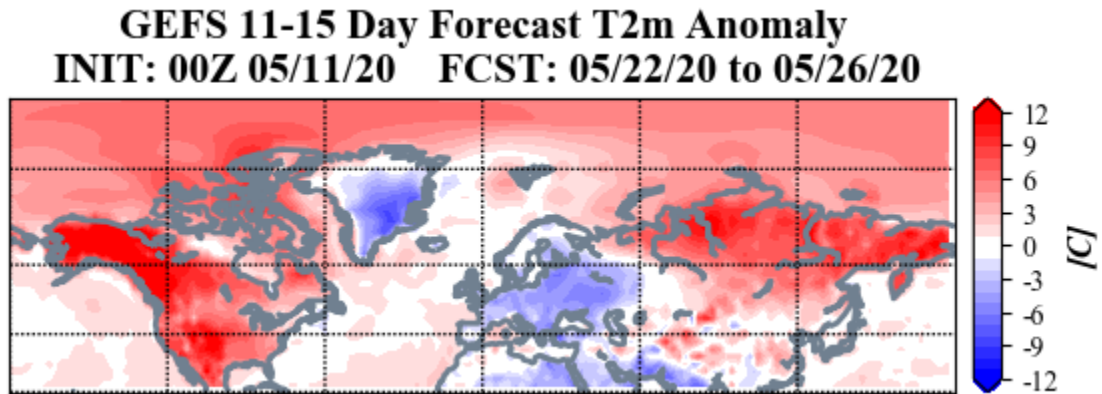


Figure 9. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 22 – 26 May 2020. The forecasts are from the 00z 11 May 2020 GFS ensemble.

Ridging/positive geopotential height anomalies in Alaska, and Western Canada are predicted to continue to force downstream troughing/negative geopotential height anomalies in Eastern Canada while troughing/negative geopotential height anomalies in the Western US force ridging/positive geopotential height anomalies in the Eastern US (**Figure 8**). This pattern favors normal to above normal temperatures across Alaska, Western Canada and the Eastern US with normal to below normal temperatures for Eastern Canada and the Western US (**Figure 9**).

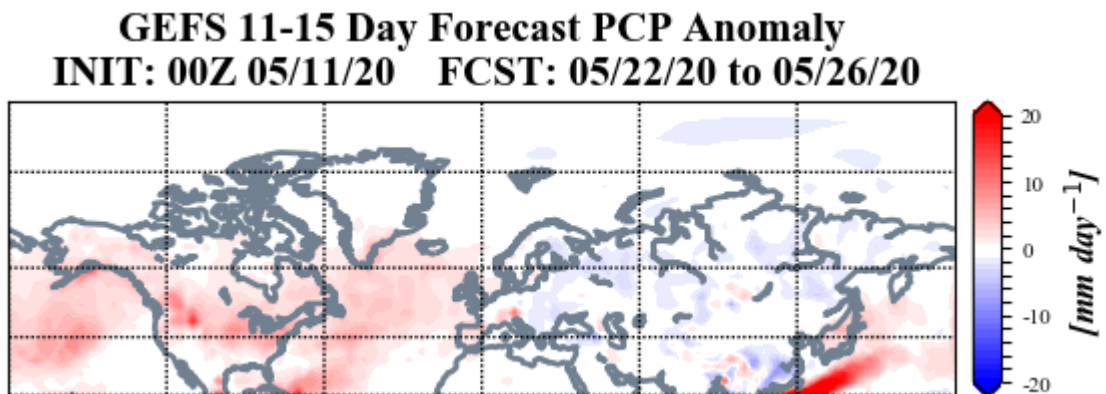


Figure 10. Forecasted precipitation anomalies (mm/day ; shading) from 22 – 26 May 2020. The forecasts are from the 00z 11 May 2020 GFS ensemble.

Above normal precipitation is predicted for Southwestern Europe otherwise normal to below normal precipitation is predicted across much of Eurasia (**Figure 10**). Near normal precipitation is predicted for North America except for above normal precipitation along the Northern US (**Figure 10**).

Longer Term

30-day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows normal to below normal PCHs in the stratosphere with normal to above normal PCHs in the troposphere (**Figure 11**). However, PCHs in the stratosphere are predicted to reverse to normal to above normal later this week (**Figure 11**). The above normal PCHs in the troposphere consistent with the predicted negative AO (**Figure 1**).

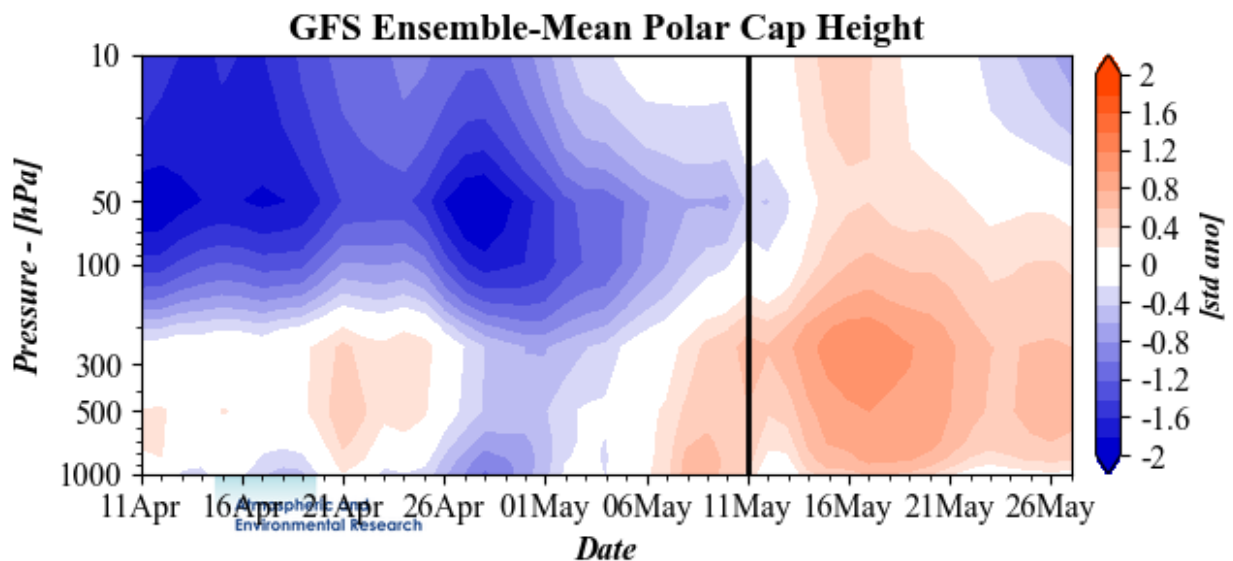


Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecasts are from the 00Z 11 May 2020 GFS ensemble.

The plot of vertical Wave Activity Flux (WAFz) or poleward heat transport forecast shows a strong positive anomaly pulse for this week followed by another pulse limited to the lower stratosphere for next week (**Figure 12**). The recent and near future active positive WAFz anomalies are responsible for reversing the negative/cold PCHs in the stratosphere to positive/warm (**Figure 2**).

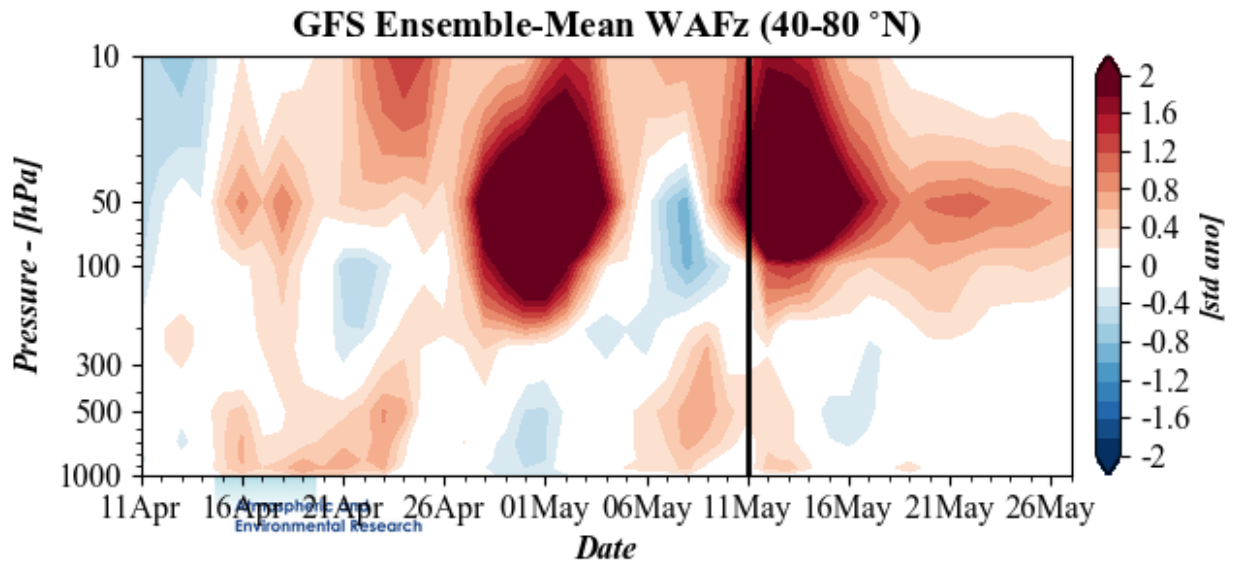


Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 11 May 2020 GFS ensemble.

The Final Warming has taken place (where the stratospheric PV disappears until the fall). But the recent and ongoing he strong pulses of WAFz suggest to me that this is a dynamically induced Final Warming rather than a passive or radiatively forced Final Warming. The implications of a dynamically forced Final Warming relative to a radiatively-only forced Final Warming is that it is more likely to have an impact on the weather. I believe that the dynamic Final Warming has contributed to the negative AO, high latitude blocking and recent unseasonable cold and snow across eastern North America and Europe.

**CFS 500 hPa Forecast Anomaly Jun 2020
Valid as of 11 May 2020**

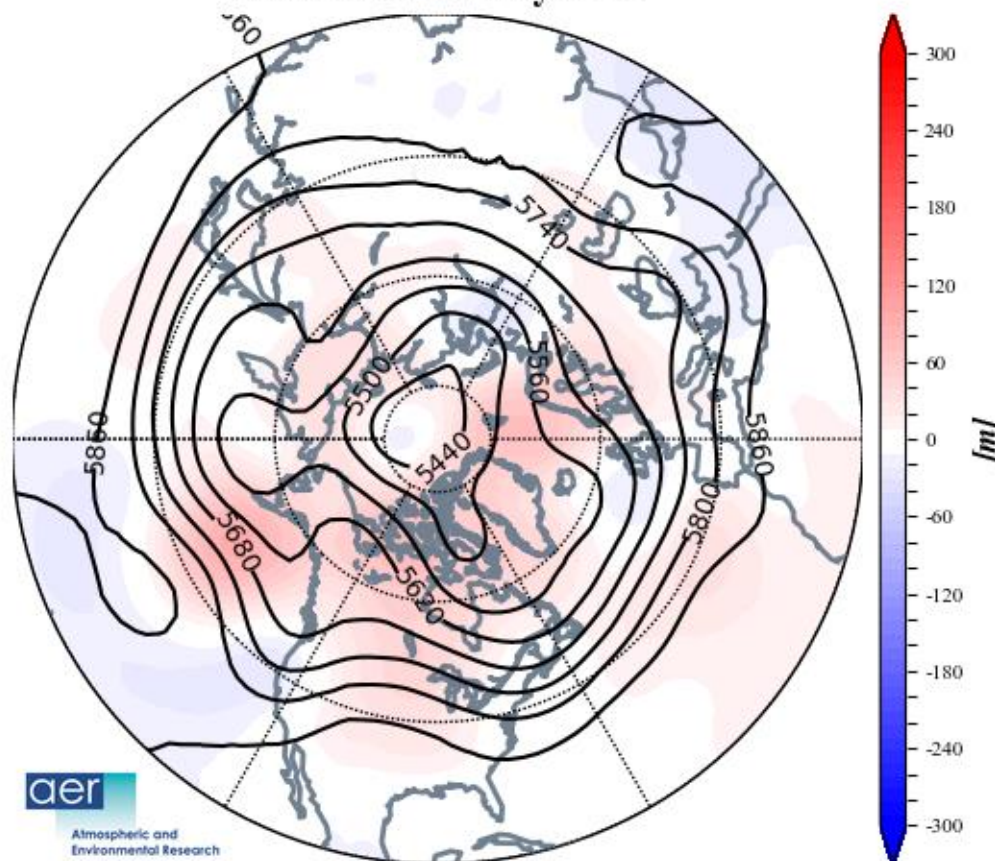


Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for May 2020. The forecasts are from the 00Z 11 May 2020 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and the surface temperatures (**Figure 15**) forecast for June from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging in the northern North Atlantic stretching from Greenland to Northern Europe, East Asia, Alaska and the interior of North America with troughing in Western Asia, the Middle East, the Dateline, Eastern Canada and the US West and East Coasts (**Figure 14**). This pattern favors relatively mild temperatures for Northern Europe, much of Northern and Eastern Asia, western North America and Northern Canada with seasonable to relatively cool temperatures for Southern and Western Europe, Western and Southern Asia, Southeastern Canada and the Northeastern US (**Figure 15**).

CFS T2m Forecast Anomaly Jun 2020 Valid as of 11 May 2020

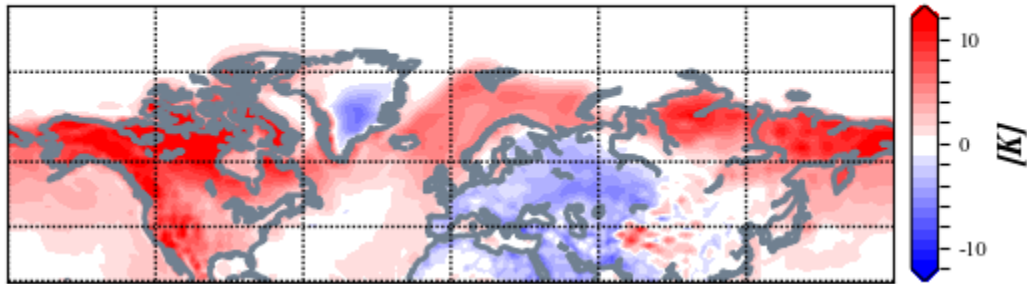


Figure 15. Forecasted average surface temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere for May 2020. The forecasts are from the 00Z 11 May 2020 CFS.

Surface Boundary Conditions

SSTs/El Niño/Southern Oscillation

Equatorial Pacific sea surface temperatures (SSTs) anomalies continue to cool slowly but neutral El Niño/Southern Oscillation (ENSO) conditions seem most likely this summer (**Figure 17**). Observed SSTs across the NH remain well above normal especially near Alaska and in the Gulf of Alaska and the western North Pacific though below normal SSTs exist regionally especially west of South America and south of Iceland. Warm SSTs in the Gulf of Alaska may favor mid-tropospheric ridging in the region.

SST Anomaly - Week Ending 10 May 2020

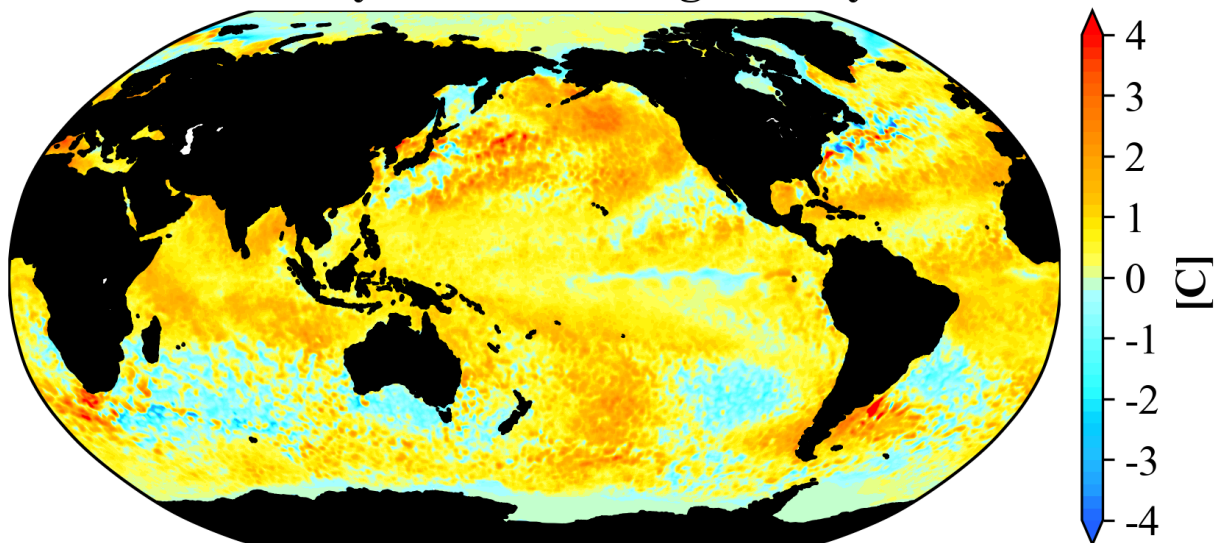


Figure 17. The latest weekly-mean global SST anomalies (ending 26 April 2020). Data from NOAA OI High-Resolution dataset.

Currently no phase of the Madden Julian Oscillation (MJO) is favored (**Figure 18**). The forecasts are for the MJO to remain weak where no phase is favored. The MJO is likely not contributing to the weather patterns across North America in the short term.

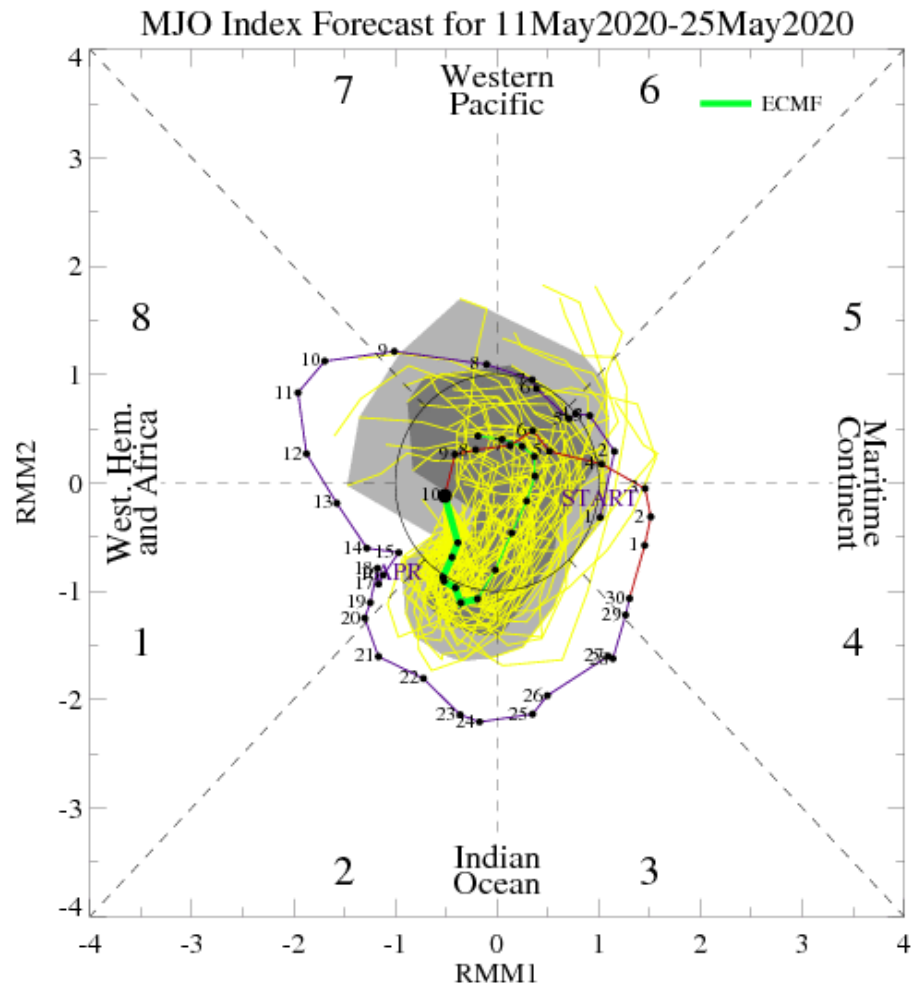


Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 11 May 2020 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model “spread” is denoted by the gray shading. Sector numbers indicate 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>