Arctic Oscillation and Polar Vortex Analysis and Forecasts

April 27, 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 positive and is predicted to remain positive this week but then is predicted to straddle neutral this weekend and next week.
- The current positive AO is reflective of negative pressure/geopotential height anomalies in the Central Arctic and North Pacific side of the Arctic and 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 slowly trend positive as height anomalies across Greenland are predicted to become negative next week.

- This week troughing/negative geopotential height anomalies and normal to below normal temperatures are predicted for Northern Europe including the United Kingdom (UK) with ridging/positive geopotential height anomalies with normal to above normal temperatures for Southern Europe. However next week ridging/positive geopotential height anomalies and warm temperatures are predicted to become more widespread across Europe as Greenland blocking disappears.
- 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 Northwestern and Southern Asia.
- The predicted general pattern for North America over the next two weeks is ridging/positive geopotential height anomalies with normal to above normal temperatures stretching across Alaska, Western Canada and the Western US forcing troughing/negative geopotential height anomalies with normal to below normal temperatures in Eastern Canada and the Eastern United States (US). One exception is this week when troughing with below normal temperatures will spread across Alaska and Northwestern Canada.
- Once again, in the Impacts section I discuss the predicted Final Warming of the polar vortex (PV) and the implications for the Northern Hemisphere (NH) circulation pattern.

Impacts

As I sit here in home, enduring a second day of cloudy, wet, relatively cold and windy weather from a storm passing to our south and had this been winter would have brought a crippling snowstorm. And this storm or pattern isn't unique. It seems that every few days here in the Northeastern US we get a rainstorm that had it been winter would have produced a snowstorm, though even these late season storms are bringing snow to the higher elevations of the Northeast. I find myself asking (and I realize that I am not unique asking this question) – where was this pattern in winter?

I reflexively look to the PV for answers. The winter was characterized by a stronger than normal stratospheric PV that was hostile to meridional (north to south), large amplitude flow and high latitude blocking that is so favorable for sustained cold air outbreaks and snowstorms. Instead the strong PV supported fast zonal flow of the Jet Stream that was displaced to the north that favored overall mild temperatures and rainfall across

the US except for higher elevations and near the Canadian border. Similarly, an even milder and snowless pattern persisted across Europe all winter.

Then once winter was over, high pressure/blocking returned to the North Atlantic sector that excited the vertical transfer of energy from the troposphere to the stratosphere and has weakened the stratospheric PV. This increase in vertical energy transfer has decelerated a hyperactive PV and it does appear that the weakening of the PV will actually overshoot the typical weakening resulting in stronger easterly winds in the polar stratosphere than the climatological average (see **Figure i**). Easterly winds in the polar stratosphere are the telltale sign of the Final Warming (where the stratospheric PV disappears until the fall).

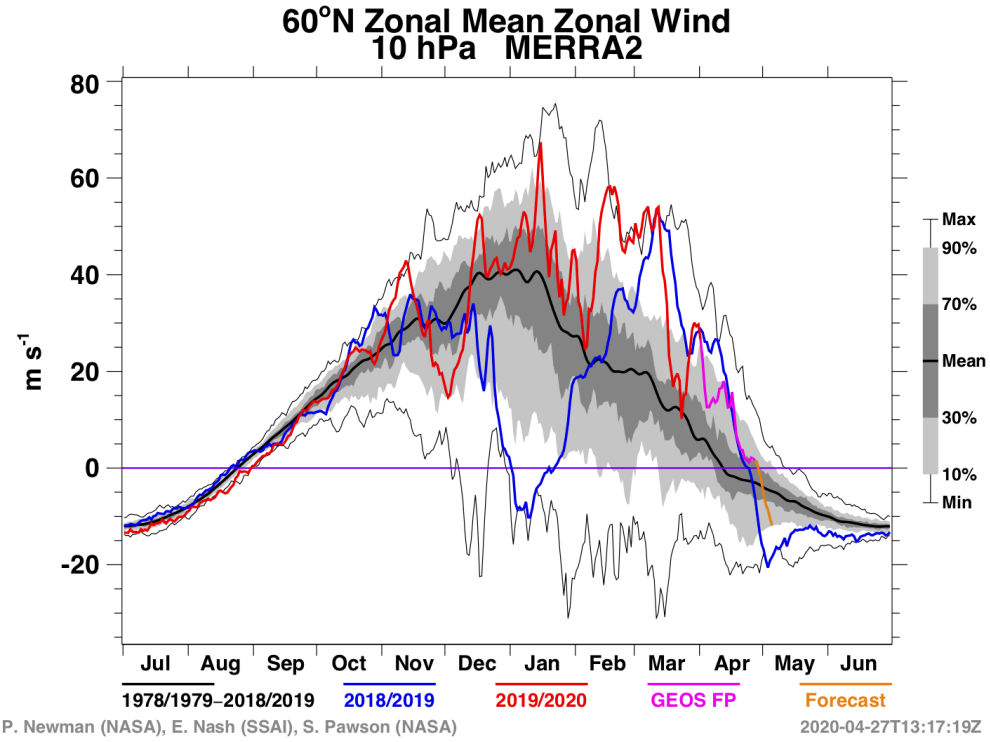

Figure i. Poleward heat transport between 45 to 75°N at 100 hPa. Plot valid for 27 April 2020. Poleward heat transport is strongly related to WAFz. Plot downloaded from https://acd-ext.gsfc.nasa.gov/Data_services/met/ann_data.html

During the weakening of the PV it even split into two separate vortices one over western Asia and the other over Central Canada. Typically, when this occurs in winter this PV split is followed by downward propagation of positive polar cap geopotential height anomalies (PCHs) from the stratosphere to the troposphere that is related to high

latitude blocking, cold air outbreaks and snowstorms. Looking at recent and today's PCH plot (**Figure 11**) there is no obvious sign of downward propagation. But I am not sure that the PCH plot is truly indicative of a downward propagation when seasonally the Final Warming should have already occurred.

Instead I include in **Figure ii**, the geopotential heights at 10, 50 and 150 hPa from the ECMWF analysis from last week. From the mid-stratosphere to the lower stratosphere we can see two distinct vortices one in Canada and the other in Western Asia. And we can see that in today's forecast from the GFS, there are predicted mid-tropospheric troughs in both Western Asia and Eastern North America (**Figures 5** and **8**) in the same locations where the two stratospheric sister vortices where situated last week. This is characteristic of a winter PV weakening/split followed by downward propagation.

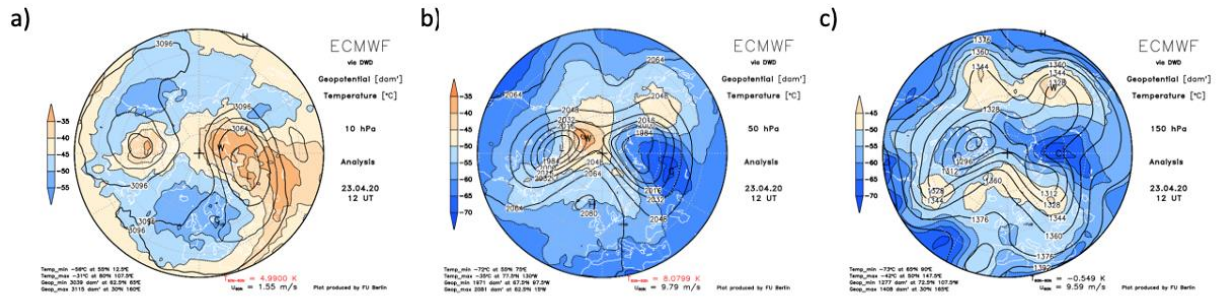

Figure ii. ECMWF analyzed geopotential heights (dam; contours) and temperatures (°C; shading) at a) 10 hPa, b) 50 hPa and c) 150 hPa from 23 April 2020 (plot taken from https://www.geo.fu-berlin.de/en/met/ag/strat/produkte/winterdiagnostics/index.html).

And the downward propagation has been coupled with Greenland blocking, helping to anchor troughs in both western Eurasia and eastern North America accompanied by cold temperatures and at least in the Eastern US a classic snowstorm track. So, I would argue that the dynamically induced PV weakening/Final Warming and the PV split has contributed to the colder than normal temperatures in eastern North America and western Eurasia. This pattern has been in place since the last blog or about two weeks ago and it is predicted to continue into the second week of May. That would put the duration of the pattern at around four weeks to a month.

I believe, though I don't have as much experience with Final Warming induced patterns, a month is about the length I would expect a pattern to last that was induced by a dynamic Final Warming (though one could argue that the dynamic Final Warming of March 2016 was of much longer duration but that was a truly exceptional event and of much greater amplitude than the current event). Therefore, I would expect a pattern change in the Eastern US around mid-May and an end to the stormy, cool pattern, at least as anomalous as the end of April has been. But in Western Asia the trough may be more persistent. As I have mentioned a few times, the dominant summer pattern has

been ridging in Europe and East Asia with troughing in between in West Asia. So, I could see the dynamical Final Warming induced trough transition to the summer induced pattern in West Asia.

So why the PV split accompanied by a winter like weather pattern in April but not in any of the winter months? I don't have a good answer. I am just grasping at straws but maybe the strong positive Indian Ocean Dipole in the fall coupled with a westerly quasi biennial oscillation protected the PV from wave excited perturbations. And now in the spring we are sufficiently removed from those forcings that protected the PV to allow more significant weakening. Perhaps but to be honest I don't really know.

1-5 day

The AO is currently positive **(Figure 1**) with negative geopotential height anomalies in the Central and North Pacific side 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.

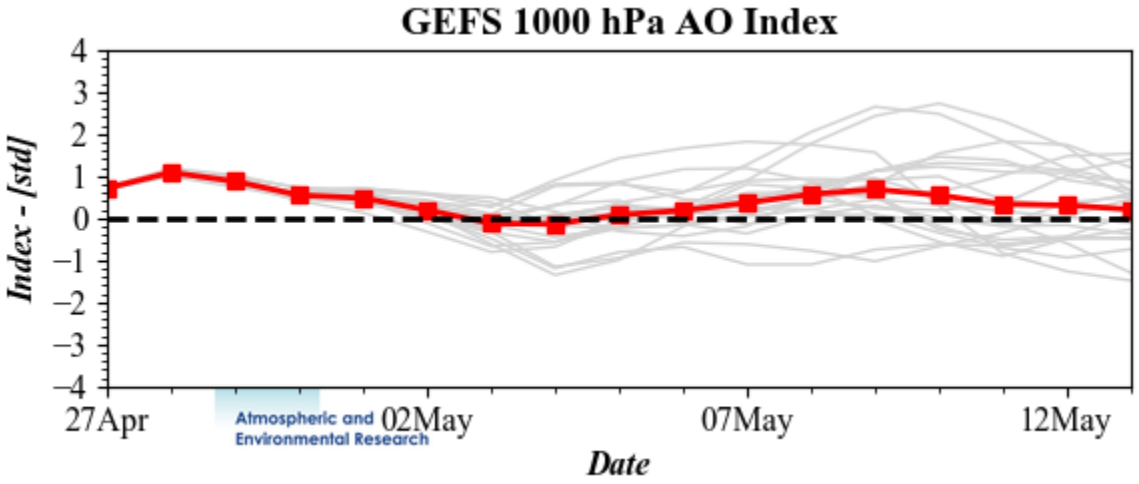

Figure 1. The predicted daily-mean AO at 10 hPa from the 00Z 27 April 2020 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

This week, ridging/positive geopotential height anomalies with normal to above normal temperatures will dominate much of Southern Europe with troughing/negative geopotential height anomalies and normal to below normal temperatures for Northern Europe including the UK (**Figures 2 and 3**). Troughing/negative geopotential height anomalies are predicted for Western Asia, Eastern Siberia and the Tibetan Plateau with 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**).

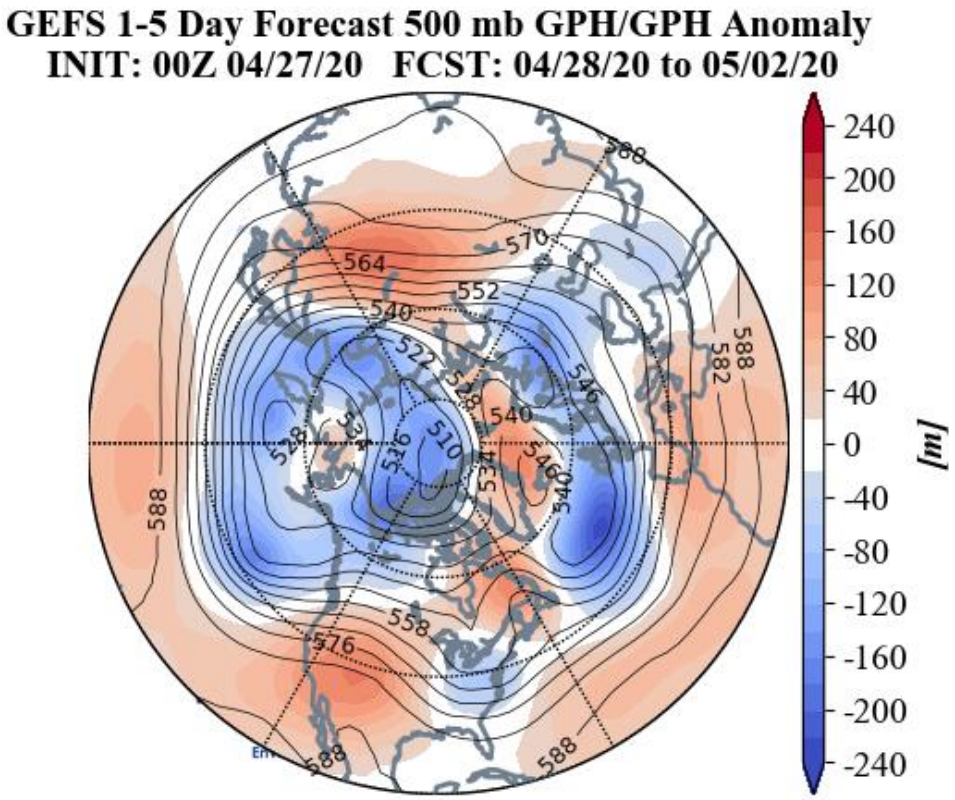

Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 28 April – 2 May 2020. The forecasts are from the 00z 27 April 2020 GFS ensemble.

This week, ridging/positive geopotential height anomalies are predicted for the Western US and Northeastern Canada with troughing/negative geopotential height anomalies for Alaska, Northwestern Canada and the Eastern US (**Figure 2**). This pattern is predicted to bring normal to below normal temperatures across Alaska, Northwest and far Southeastern Canada and the Eastern US with normal to above normal temperatures across much of Canada and the Western US **(Figure 3).**

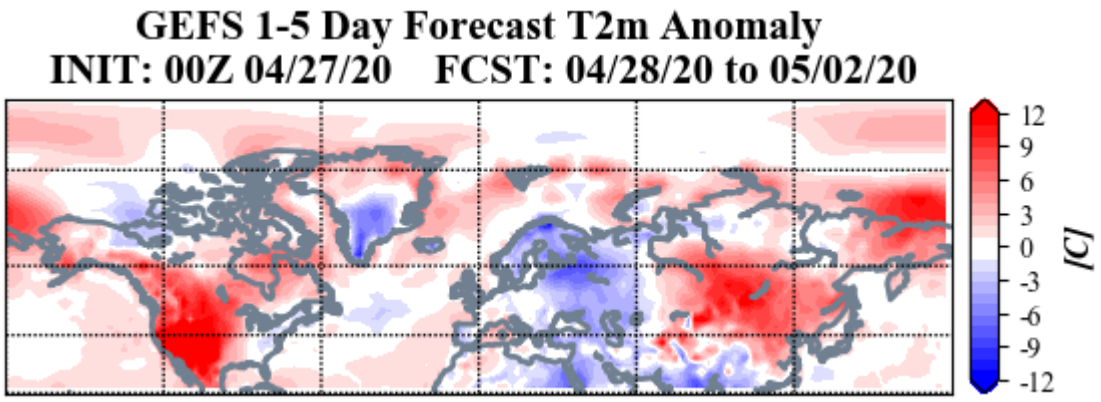

Figure 3. Forecasted surface temperature anomalies (°C; shading) from 28 April – 2 May 2020. The forecast is from the 00Z 27 April 2020 GFS ensemble.

Above normal precipitation is predicted for Western Europe and much of Northern Asia with below normal precipitation for East Asia (**Figure 4**). Near normal precipitation is predicted for North America except for above normal precipitation in Western and Southeastern Canada and the Eastern US (**Figure 4**).

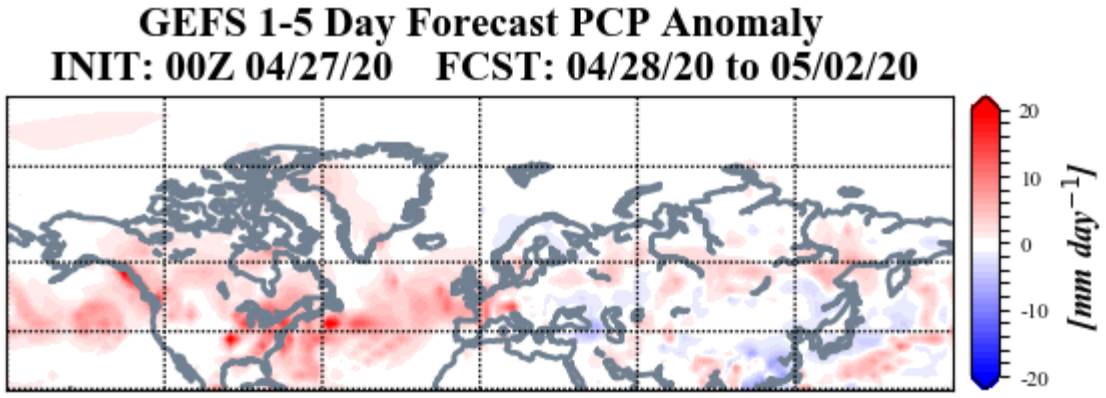

Figure 4. Forecasted precipitation anomalies (mm/day; shading) from 28 April – 2 May 2020. The forecast is from the 00Z 27 April 2020 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to turn neutral **(Figure 1**) as positive geopotential height anomalies become more widespread across the North Pacific side of the Arctic with mixed geopotential height anomalies across the mid-latitudes of the NH (**Figure 5**). And with

weak geopotential height anomalies predicted across Greenland (**Figure 2**), the NAO is predicted to turn neutral as well.

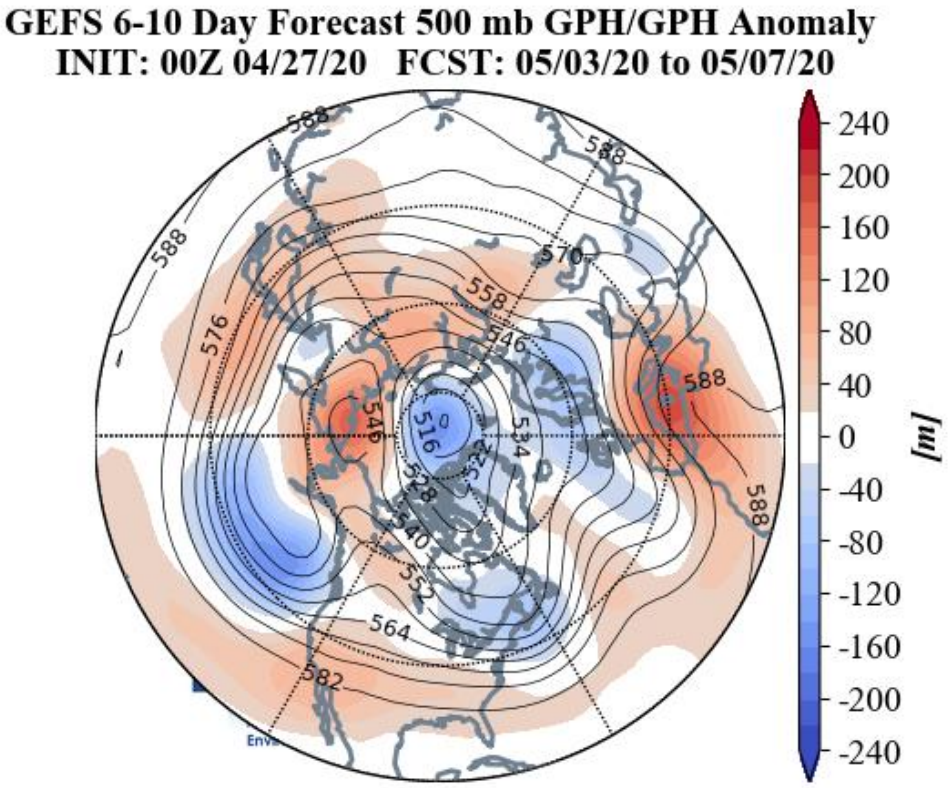

Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 3 – 7 May 2020. The forecasts are from the 00z 27 April 2020 GFS ensemble.

Ridging/positive geopotential height anomalies are predicted to strengthen and become more widespread across Southern and into Central Europe with troughing/negative geopotential height anomalies across Northern Europe, especially Scandinavia this period (**Figures 5).** This pattern will favor normal to above normal temperatures across Southern and Central Europe including the UK with normal to below normal temperatures mostly confined to Scandinavia and the Baltic States (**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 except for troughing/negative geopotential height anomalies in Southeastern Siberia (**Figure 5**). This is predicted to yield normal to below normal temperatures in far Western Asia and Southeastern Siberia with normal to above temperatures In Central and Eastern Asia **(Figure 6**). Some weak troughing/negative geopotential height anomalies across Southern Asia will favor normal to below normal temperatures in the Tibetan Plateau (**Figures 5 and 6**).

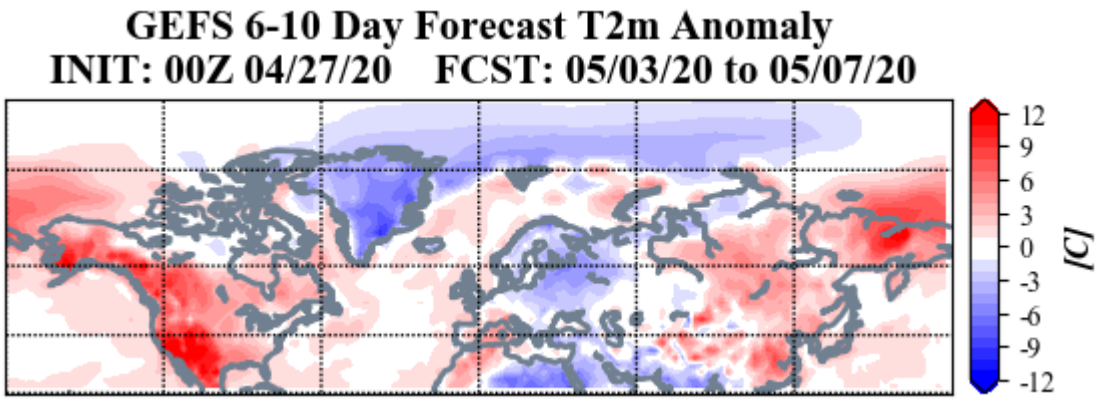

Figure 6. Forecasted surface temperature anomalies (°C; shading) from 3 – 7 May 2020. The forecasts are from the 00Z 27 April 2020 GFS ensemble.

Ridging/positive geopotential height anomalies will stretch across Alaska, Western Canada, the Western and Southern US with troughing/negative geopotential height anomalies downstream across Eastern Canada and the Northeastern US this period (**Figure 5**). This pattern is predicted to bring normal to above normal temperatures across Alaska, Western Canada and the Western and Southern US with normal to below normal temperatures for Northeastern Canada and the Northeastern US **(Figure 6).**

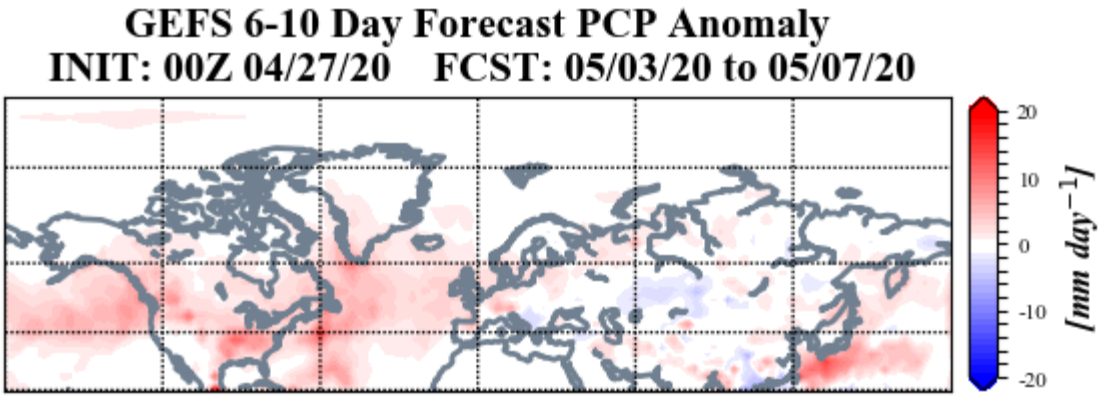

Figure 7. Forecasted precipitation anomalies (mm/day; shading) from 3 – 7 May 2020. The forecasts are from the 00Z 13 April 2020 GFS ensemble.

Normal to above normal precipitation is predicted for Western and Central Europe with normal to below normal precipitation in interior Asia (**Figure 7**). Near normal precipitation is predicted for much of North America with above normal precipitation in the Eastern US, Western Canada and US Northern Rockies (**Figure 7**).

11-15 day

With predicted positive geopotential height anomalies predicted for the North Pacific side of the Arctic and negative geopotential height anomalies on the North Atlantic side of the Arctic (**Figure 8**) and mixed geopotential height anomalies across the mid-latitudes of the NH, the AO is predicted to straddle neutral this period (**Figure 1**). With predicted negative pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO is likely to be neutral to positive.

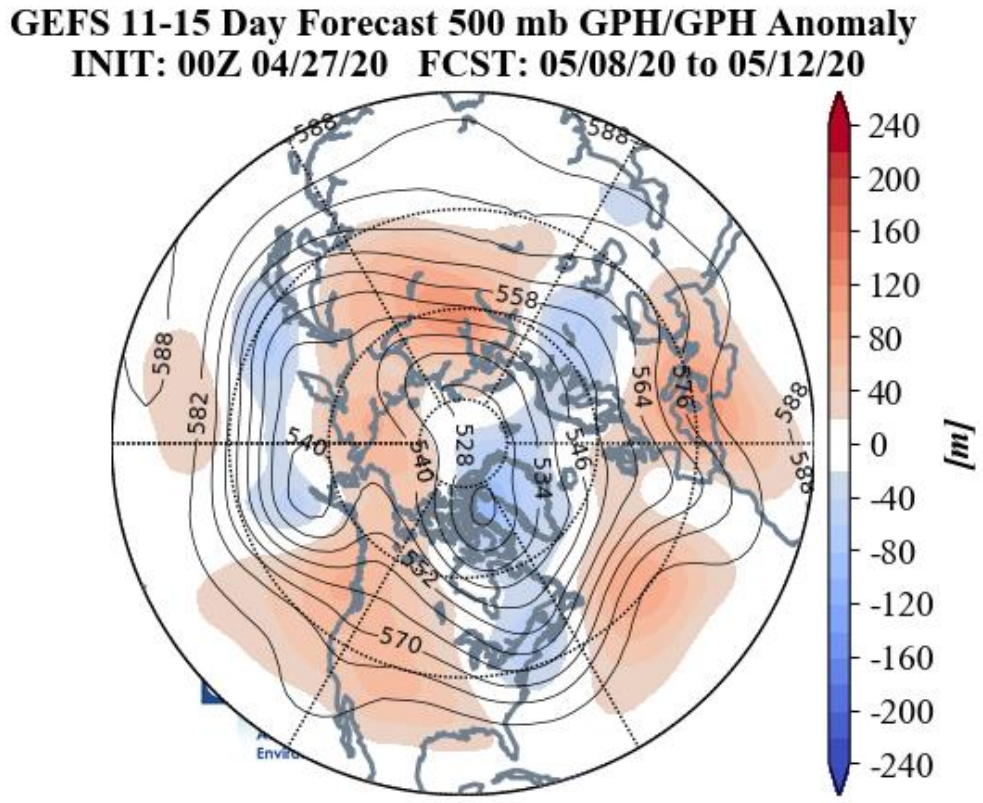

Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 8 – 12 May 2020. The forecasts are from the 00z 27 April 2020 GFS ensemble.

With troughing/negative geopotential height anomalies returning to Greenland will favor widespread ridging/positive geopotential height anomalies across Europe including the UK this period except for troughing/negative geopotential height anomalies in countries surrounding the Baltic Sea (**Figures 8**). The forecast is for widespread normal to above normal temperatures across Europe including the UK this period except for the countries surrounding the Baltic Sea (**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 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 (**Figure 9**). Some weak

troughing/negative geopotential height anomalies across Southern Asia will favor normal to below normal temperatures in the region (**Figures 8 and 9**).

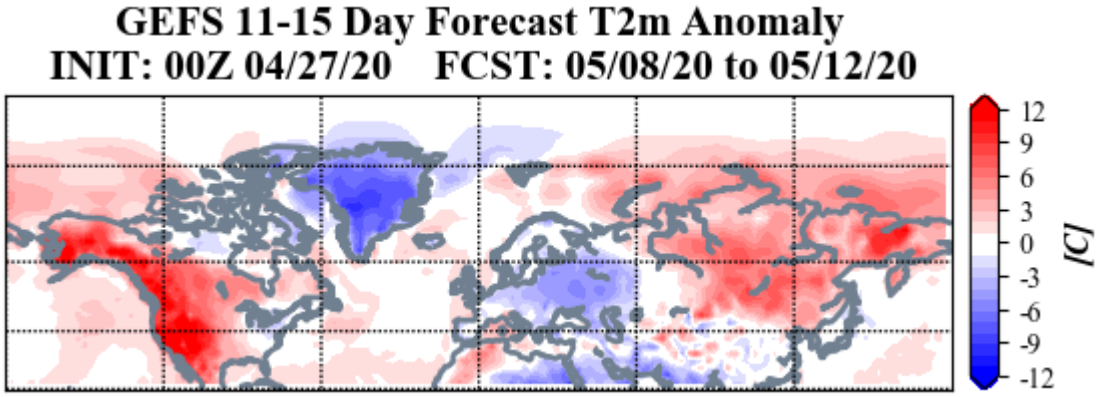

Figure 9. Forecasted surface temperature anomalies (°C; shading) from 8 – 12 May 2020. The forecasts are from the 00z 27 April 2020 GFS ensemble.

Ridging/positive geopotential height anomalies in Alaska, the Gulf of Alaska, Western Canada and the Western US will force downstream troughing/negative geopotential height anomalies in Eastern Canada and the Eastern US this period (**Figure 8**). This pattern favors normal to above normal temperatures across Alaska, Western Canada and the Western US with normal to below normal temperatures for Eastern Canada and the Eastern US (**Figure 9**).

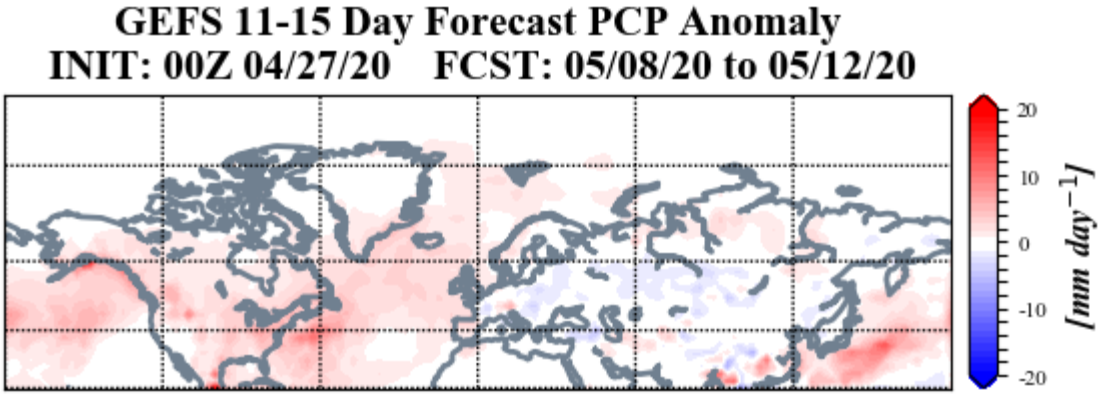

Figure 10. Forecasted precipitation anomalies (mm/day; shading) from 8 – 12 May 2020. The forecasts are from the 00z 27 April 2020 GFS ensemble.

Near normal precipitation is predicted across much of Eurasia except for normal to above normal precipitation in Spain and Southeast Asia (**Figure 10**). Near normal

precipitation is predicted for North America except for above normal precipitation in the Eastern 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 and the troposphere with the largest negative departures in the lower stratosphere (**Figure 11**). However, PCHs in the troposphere are predicted to reverse to normal to above normal next week (**Figure 11**) consistent with the predicted near neutral AO (**Figure 1**).

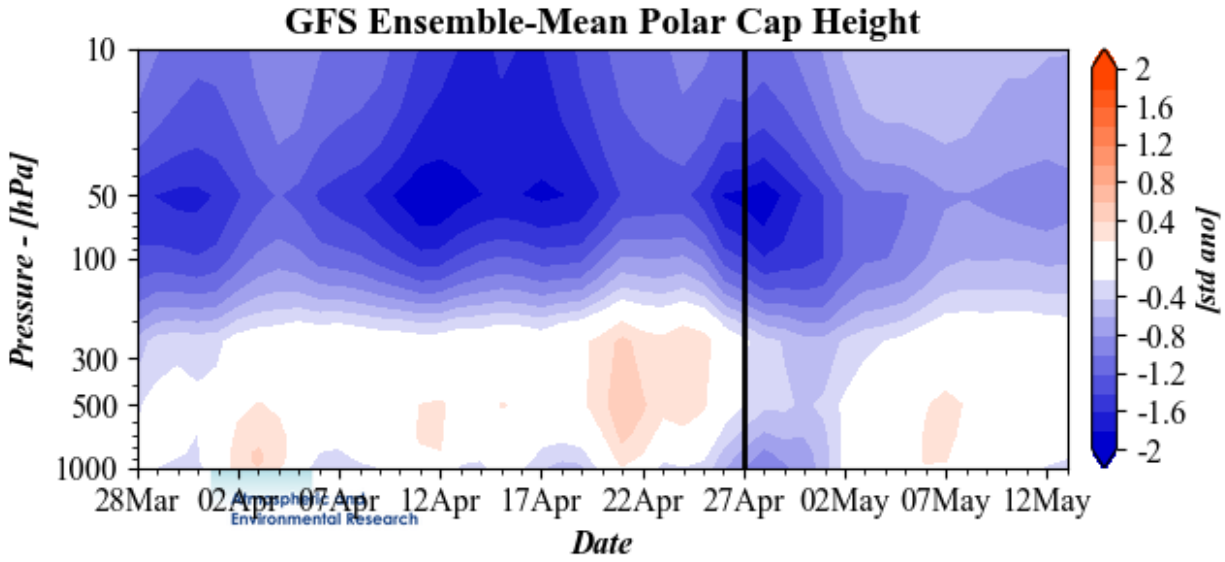

Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecasts are from the 00Z 27 April 2020 GFS ensemble.

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 strong pulse for next week (**Figure 12**). The recent and near future active positive WAFz anomalies are likely related to positive height anomalies predicted this month stretching from Northern Europe to Greenland (**Figure 2**).

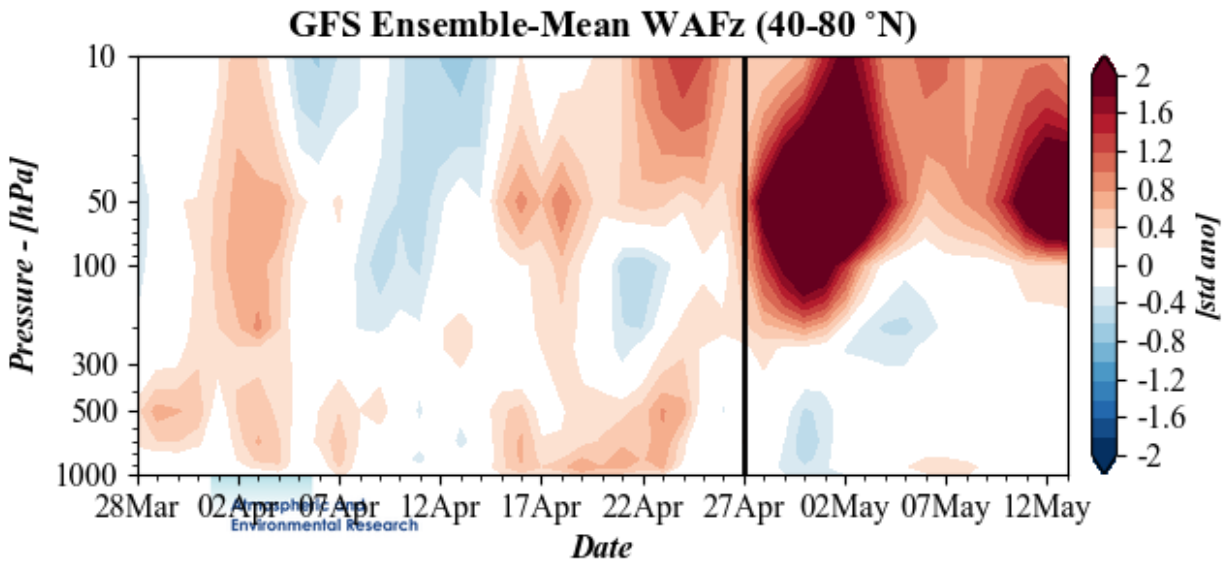

Figure 12. Observed and predicted daily vertical component of the wave activity flux (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 27 April 2020 GFS ensemble.

The positive WAFz anomalies are predicted to finally force the Final Warming (where the stratospheric PV disappears until the fall). The strong pulses of WAFz just prior to the Final Warming 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.

Currently the stratospheric PV center is centered over Western Siberia (**Figure 13**) with the largest positive temperature departures in the polar stratosphere located in the center of the PV (**Figure 13**). The PV is also elongated along an axis from the North Pole to Western Asia/Eastern Europe. This is likely related to the predicted troughing in the mid-troposphere in the same region (**Figure 2**).

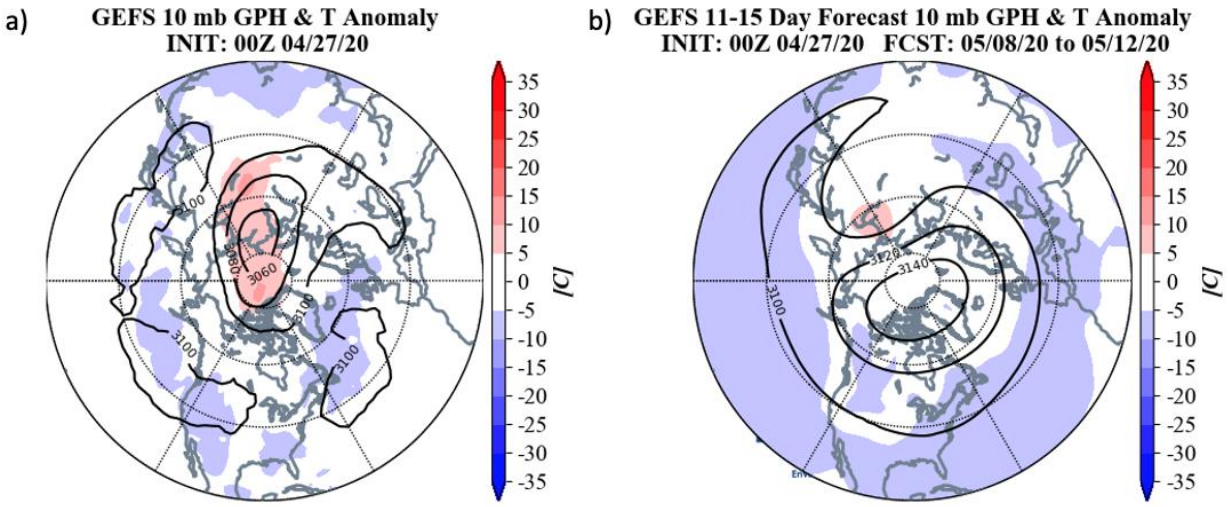

Figure 13. (**a**) Analyzed 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere at 00Z 27 April 2020 . (**b**) Same as (a) except forecasted averaged from 8 – 12 May 2020. The forecasts are from the 00Z 27 April 2020 GFS operational model.

Over the next two weeks, the PV center is predicted to be displaced into East Asia and weaken as ridging spreads across the Central Arctic (**Figure 13).** The displacement and weakening of the PV are related to the strong WAFz pulses of the next two weeks and based on the GFS forecast will result in the Final Warming with only a weak remnant visible in Siberia by the second week of May (**Figure 13)**.

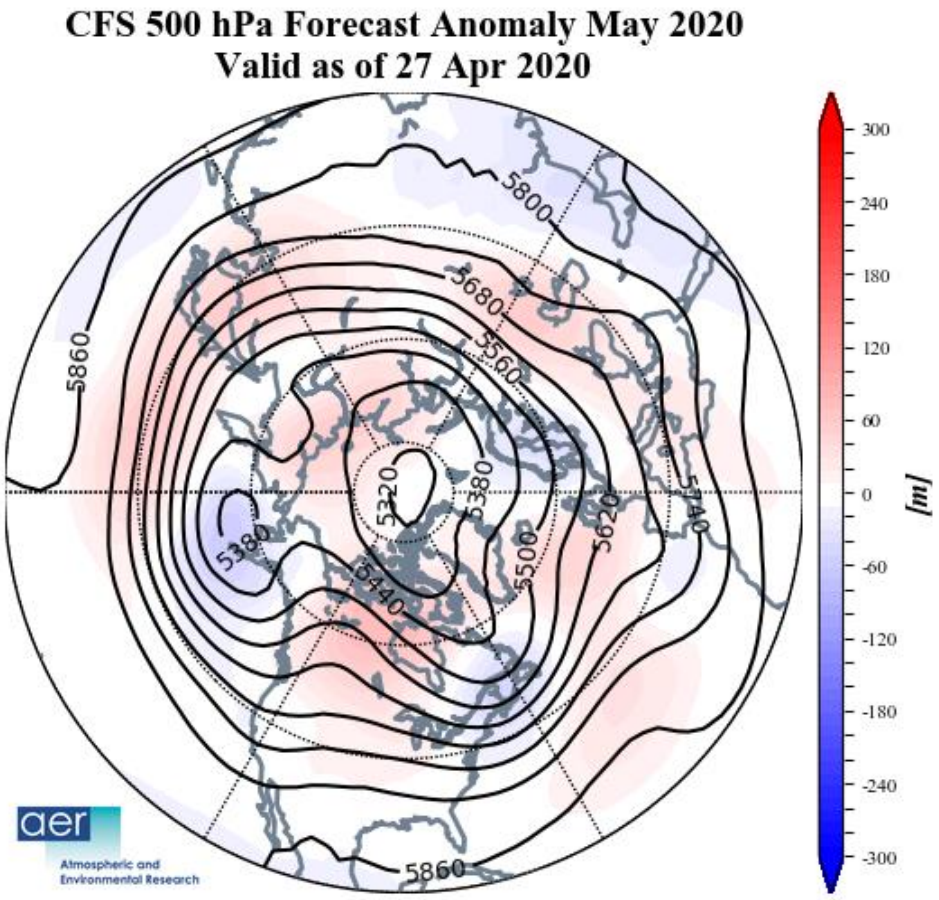

Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for May 2020. The forecasts are from the 00Z 27 April 2020 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and the surface temperatures (**Figure 15**) forecast for May 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 including Greenland, Western Asia, Eastern Siberia, Alaska and Western and Central Canada with troughing in Eastern Europe into the Middle East, East Asia, Eastern Canada and the Southwestern and Eastern US (**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 Central Europe, Western and Southern Asia, Southeastern Canada and the Northeastern US **(Figure 15).**

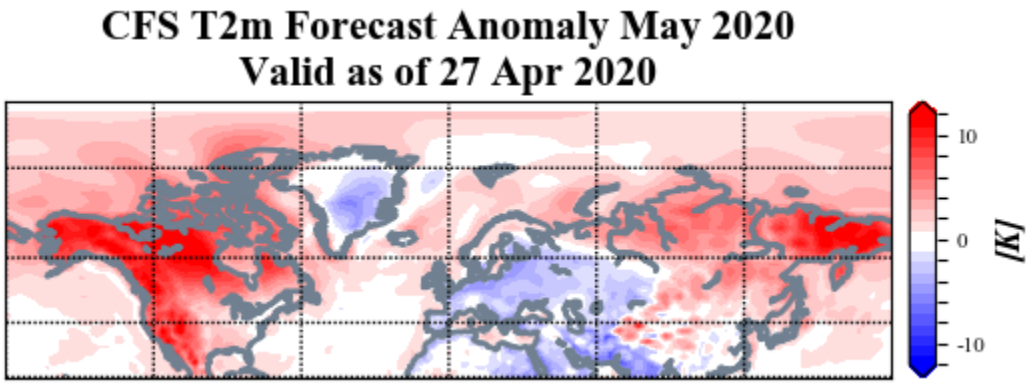

Figure 15. Forecasted average surface temperature anomalies (°C; shading) across the Northern Hemisphere for May 2020. The forecasts are from the 00Z 27 April 2020 CFS.

Surface Boundary Conditions

SSTs/El Niño/Southern Oscillation

Equatorial Pacific sea surface temperatures (SSTs) anomalies are cooling slightly but neutral El Niño/Southern Oscillation (ENSO) conditions seem most likely this spring (**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.

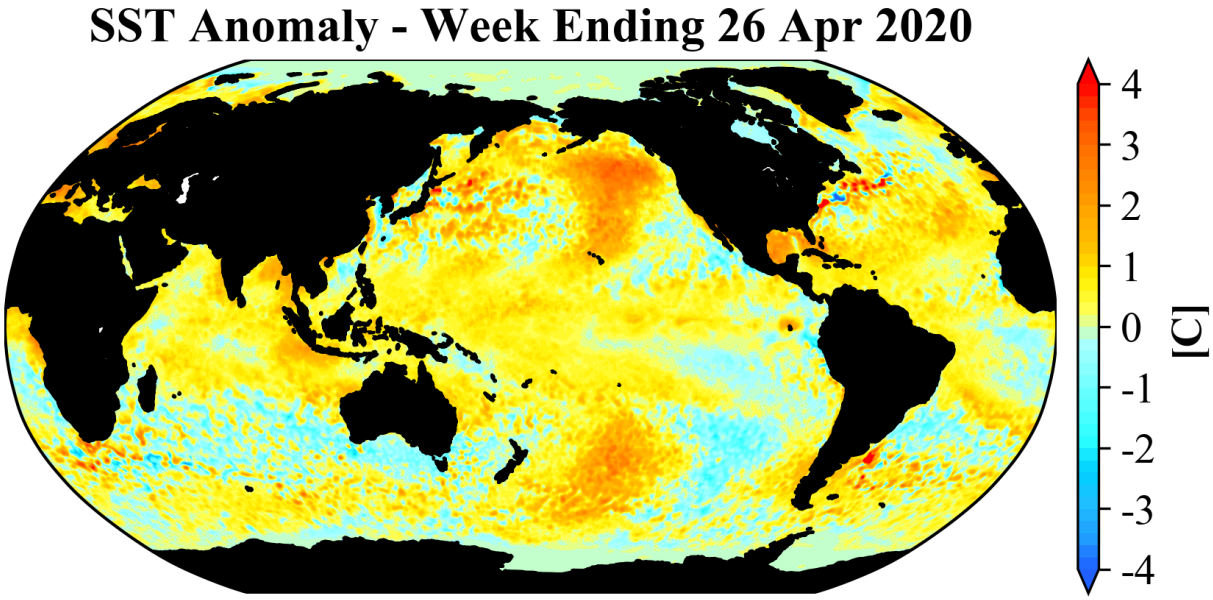

Figure 17. The latest weekly-mean global SST anomalies (ending 26 April 2020). Data from NOAA OI High-Resolution dataset.

Currently the Madden Julian Oscillation (MJO) is in phase three (**Figure 18**). The forecasts are for the MJO to weaken to where no pahse is favored. MJO phase three favors ridging centered on Alaska with troughing in eastern North America. The MJO could be partially contributing to the weather patterns across North America in the short term.

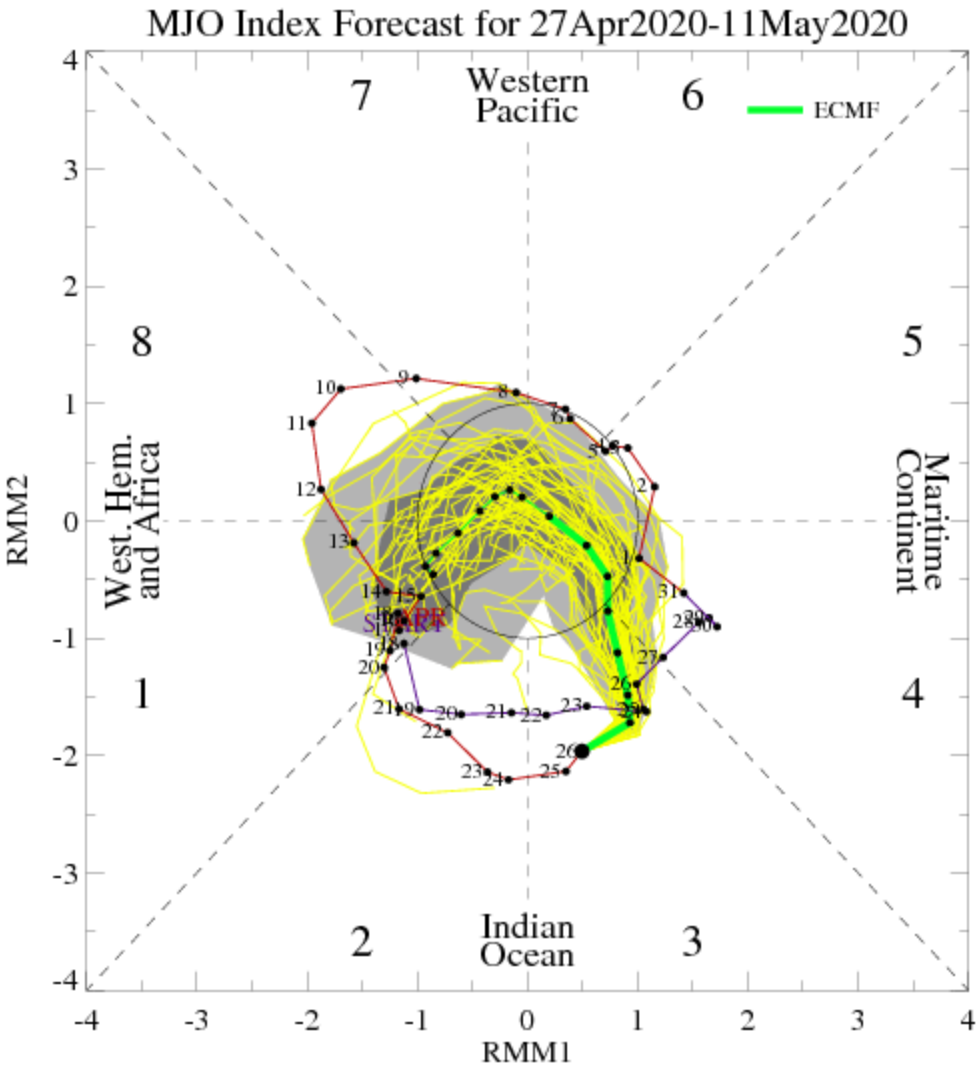

Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 27 April 2020 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model "spread" is denoted by the gray shading. Sector numbers indicate 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