

Arctic Oscillation and Polar Vortex Analysis and Forecasts

December 30, 2019

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.

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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.
- The current positive AO is reflective of negative pressure/geopotential height anomalies in the central Arctic and Alaska with mixed pressure/geopotential height anomalies across the mid-latitudes. The North Atlantic Oscillation (NAO) is also positive with weak negative pressure/geopotential height anomalies spread across Greenland and Iceland; and the NAO is predicted to remain positive over the next two weeks as heights remain negative across Greenland.
- The general pattern across Europe the next two weeks is ridging/positive geopotential height anomalies over Europe. The general above normal geopotential heights and the lack of snow cover will result in widespread normal to above normal temperatures across Europe including the United Kingdom (UK). However, during the end of the first week and into the second week of January a trough/low pressure propagating through the Mediterranean will induce northerly flow with normal to below normal temperatures in Western and Southern Europe.
- With a positive AO the general predicted pattern for Asia the next two weeks is ridging/positive geopotential height anomalies with normal to above normal temperatures. Exceptions will be troughing/negative pressure/geopotential height anomalies and normal to below normal temperatures across the northern Indian subcontinent the entire period and Eastern Siberia week two.

- This week the predicted pattern across North America is troughing/negative pressure/geopotential height anomalies with widespread normal to below normal temperatures across Alaska and the Western United States (US) with ridging/positive geopotential height anomalies and normal to above normal temperatures widespread in Canada and the central and eastern US. Next week the troughing/negative pressure/geopotential height anomalies will slide into the Eastern US pulling some of the normal to below normal temperatures now in Alaska into Eastern Canada and the Eastern US. In week two the troughing/negative pressure/geopotential height anomalies are predicted to retrograde once more into western North America allowing cold temperatures to become widespread across Alaska and Canada and possibly the Northern US, though overall the Eastern US should be milder this period.
- In the Impacts section I focus on my expectations for the coming weeks vis-a-vis polar vortex behavior.

Impacts

I feel like it is *déjà-vu* all over again with a strong stratospheric polar vortex (PV) in December leading to a positive AO and a relatively mild pattern across the Northern Hemisphere as we head into January. Reminds me most recently of winters 2015/16 and 2016/17. In 2015/16 possibly the combination of a westerly quasi biennial oscillation (QBO) and super El Nino lead to an anomalously strong, possibly even an all-time record strong PV that I would argue contributed to an overall mild winter. January was surprisingly cold in the Eastern US given the record strong PV in large part because a cyclone penetrated unusually far north into the central Arctic bringing with it anomalous heat and humidity that triggered a tropospheric negative AO event. Eventually though in February and especially March the PV became more disrupted and contributed to at least episodic more severe winter weather.

In 2016/17, the PV started off record weak in the fall and at one point the models were predicting one of the earliest major warmings (where the zonal mean zonal wind at 10hPa and 60°N reverses from positive to negative) ever observed in November. But the major warming never materialized the PV quickly strengthened, coupled with the surface and the AO was positive in January with relatively mild temperatures across the NH. Again, the PV became more perturbed in February and contributed to more episodic severe winter weather in February and March.

This winter the PV weakened in November heading into December but the PV weakening fell well short of major warming status, despite model forecasts to the contrary. The PV has since recovered and has been on the stronger side of normal and this has coupled with the surface contributing to a positive AO to at least kick-off January accompanied by a relatively mild pattern across the NH. In the Eastern US the mild pattern will be interrupted briefly by colder temperatures early next week. I would attribute this interruption in the mild pattern to a relatively minor and short-lived reflective PV disruption. But once the forcing from the PV disruption abates by late next week, it makes sense to me that Madden Julian Oscillation forcing should dominate North American weather. MJO is predicted to be in a fairly robust phase five which favors ridging south of the Aleutians troughing in western North America and more ridging in the Eastern US. However, Canada is predicted to remain cold and storms traversing North America can tap into this reservoir of cold resulting in at least short-term cold air outbreaks. Also I do believe that the models are overly sensitive to tropical forcing and they could adjust colder with time.

But like in 2016 and again 2017 I expect the PV to become more disrupted. Increasing at least episodic severe winter weather. Our polar vortex model is predicting a weakening of the PV from the very end of the second into the third week of January. Though I am certain the predicted weakening in the model is overdone, the model at least usually matches the trend in the PV. Also based on what I see from the ECMWF stratospheric winds a much more defined reflective layer is predicted to form in the stratosphere so if nothing else I would expect more reflective PV disruptions. So, though January looks to start off relatively mild in the Eastern US or at least seasonable given the cold air from the reflective event next week, I expect an increasing risk of cold weather related to PV disruptions. The risk for cold weather is probably aided by the warm sea surface temperatures in the eastern North Pacific that favors mid-tropospheric ridging in the region.

Whatever probability of cold weather that I see for the Eastern US, I anticipate lower probabilities for Europe with the possible exception of the Mediterranean region. Outside of the higher elevations, Europe has seen little winter weather this year. And with the AO predicted to be positive into the foreseeable future, there is little reason to expect that to change. Though the GFS is predicting higher probabilities of snowfall across Central and Eastern Europe than I might have expected given the positive AO. And without a large PV disruption, I have a hard time imagining an extended period of winter weather across Europe for the remainder of the winter.

Admittedly I don't have some insightful analysis as to why I expect the PV to become more disrupted with time other than to point to other recent winters. It does seem blocking in the North Atlantic sector would go a long way to disrupting the PV and none is apparent in the short term. Also, I would say a major warming is not likely this winter given that we had a major warming each of the past two winters. Three winters in a row is not unprecedented but fairly uncommon.

Near Term Conditions

1-5 day

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

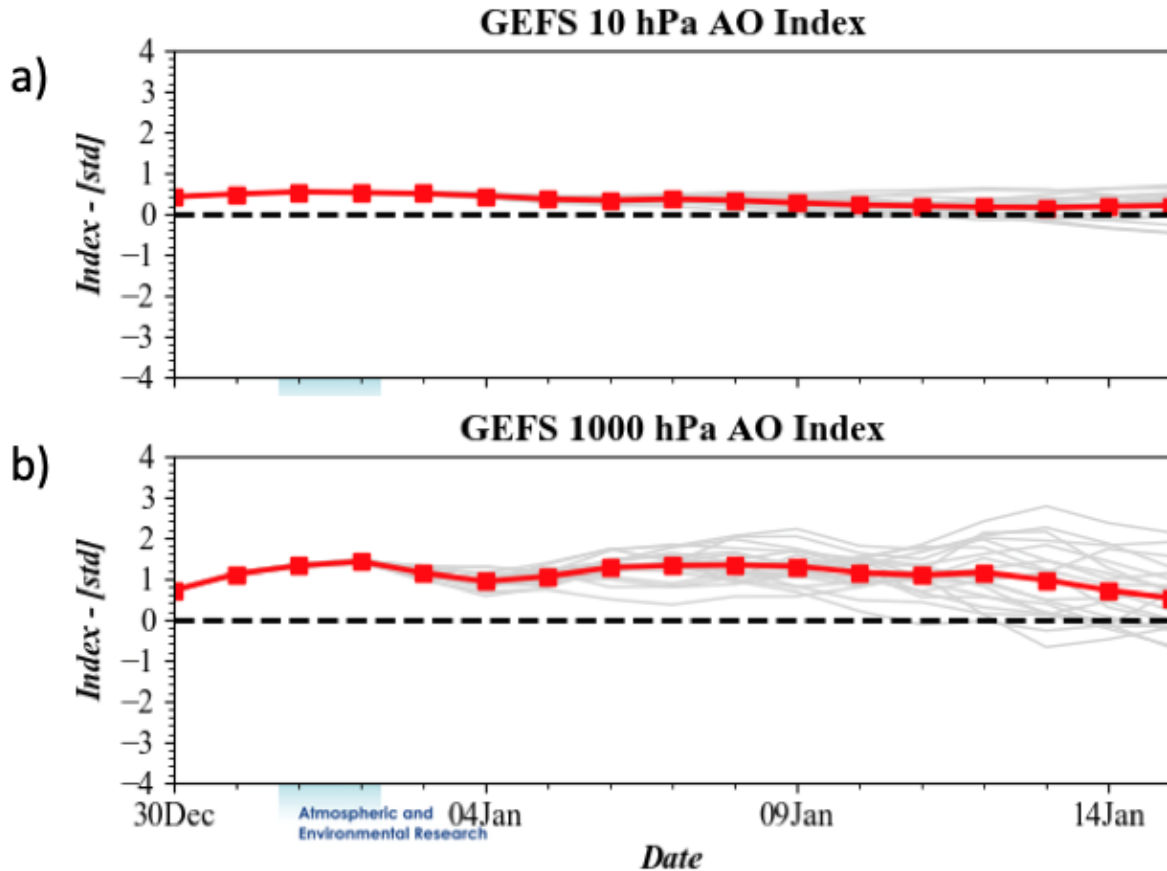


Figure 1. (a) The predicted daily-mean AO at 10 hPa from the 00Z 30 December 2019 GFS ensemble. (b) The predicted daily-mean near-surface AO from the 00Z 30 December 2019 GFS ensemble. Gray lines indicate the AO index from each individual ensemble member, with the ensemble-mean AO index given by the red line with squares.

This week ridging/positive geopotential height anomalies are predicted to dominate Western and Northern Europe with troughing/negative geopotential height anomalies mostly confined to Southeastern Europe (**Figure 2**). General high heights and lack of snow cover will result in normal to above normal temperatures across much of Europe including the UK with the possible exception of normal to below normal temperatures across the Balkan States and Turkey (**Figure 3**). This week, ridging/positive geopotential height anomalies are predicted to dominate much of Asia (**Figure 2**) favoring widespread normal to above normal temperatures across much of Asia (**Figure 3**). Exceptions are the northern India subcontinent and Northeastern Asia where regional troughing/negative geopotential height anomalies (**Figure 2**) are predicted to result in normal to below normal temperatures (**Figure 3**).

GEFS 1-5 Day Forecast 500 mb GPH/GPH Anomaly
INIT: 00Z 12/30/19 FCST: 12/31/19 to 01/04/20

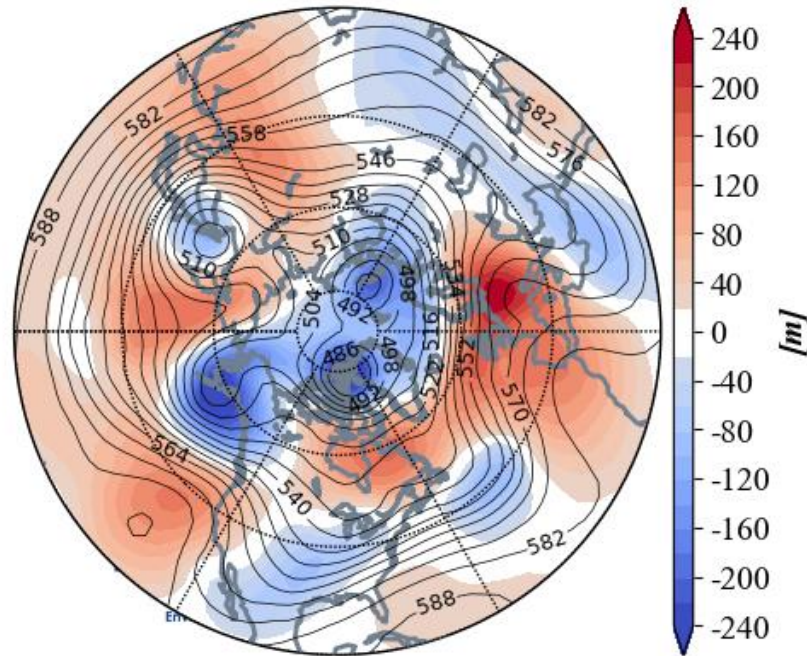


Figure 2. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 31 December 2019 – 4 January 2020. The forecasts are from the 30 December 00z GFS ensemble.

This week, troughing/negative geopotential height anomalies in Alaska and the Western US will force downstream ridging/positive geopotential height anomalies across central and eastern North America (**Figure 2**). This is predicted to result in normal to below normal temperatures in Alaska and the Western US with normal to above normal temperatures across much of Canada and the Central and Eastern US (**Figure 3**).

GEFS 1-5 Day Forecast T2m Anomaly
INIT: 00Z 12/30/19 FCST: 12/31/19 to 01/04/20

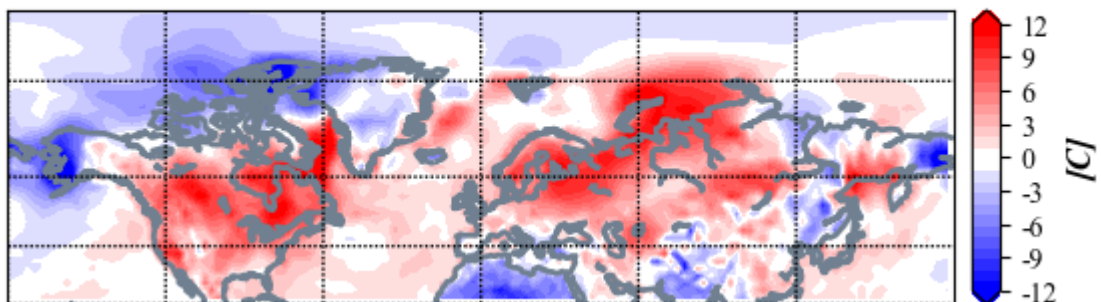


Figure 3. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 31 December 2019 – 4 January 2020. The forecast is from the 00Z 30 December 2019 GFS ensemble.

Trouthing and/or cold temperatures are predicted to bring new snowfall across Western Russia, Siberia, the Tibetan Plateau, and Turkey (**Figure 4**). Trouthing and cold temperatures are predicted to bring new snowfall to Alaska, much of Canada and northern New England (**Figure 4**). Warmer temperatures are predicted to result in snowmelt for Northern and Eastern Europe, south of Hudson's Bay, the Intermountain West in the US and the US Northern Plains (**Figure 4**).

GEFS 1-5 Day Forecast Mean 24-hour Snow Depth Change
INIT: 00Z 12/30/19 FCST: 12/31/19 to 01/04/20

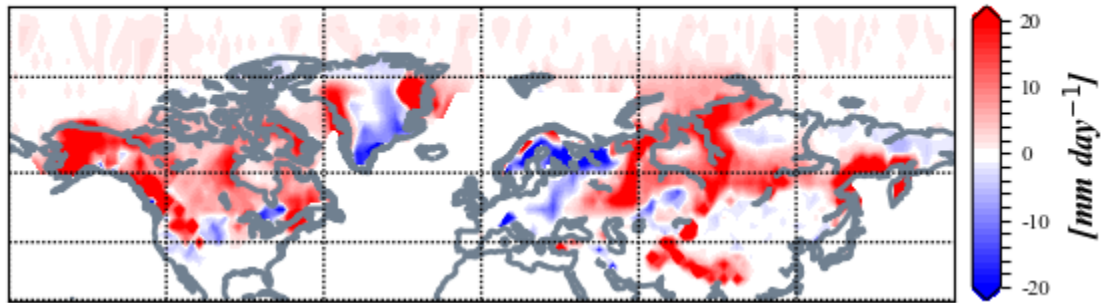


Figure 4. Forecasted snowdepth anomalies (mm/day; shading) from 31 December 2019 – 4 January 2020. The forecast is from the 00Z 30 December 2019 GFS ensemble.

Mid-Term

6-10 day

The AO is predicted to remain positive this period (**Figure 1**) as negative geopotential height anomalies persist across the Central Arctic and North Atlantic side of 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 2**), the NAO is predicted to turn more positive.

GEFS 6-10 Day Forecast 500 mb GPH/GPH Anomaly
INIT: 00Z 12/30/19 FCST: 01/05/20 to 01/09/20

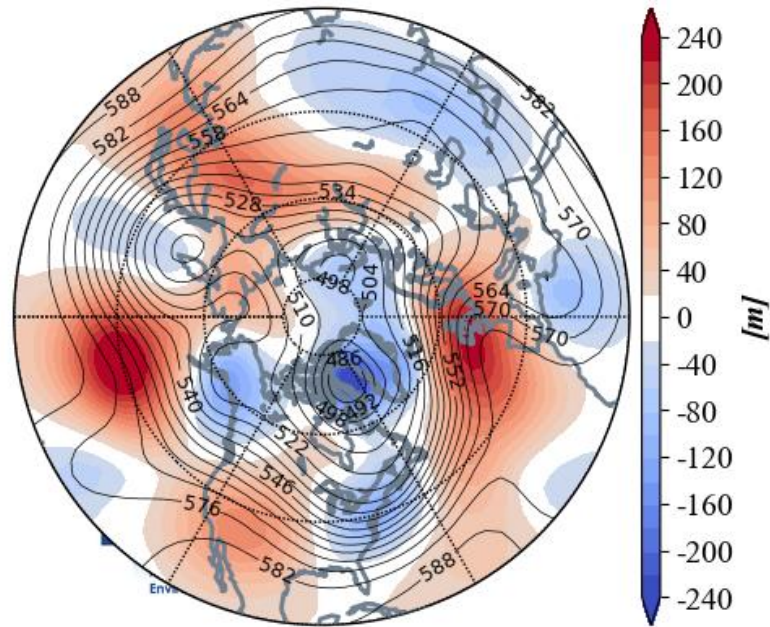


Figure 5. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 5 – 9 January 2020. The forecasts are from the 30 December 00z GFS ensemble.

The general pattern of ridging/positive geopotential height anomalies across much of Europe with troughing/negative geopotential height anomalies predicted for the western Mediterranean region (**Figures 5**). Once again generally high geopotential heights and lack of snow cover will favor widespread normal to above normal temperatures for much of Europe including the UK. with the exception of Western Europe where northerly flow on the backside of the Mediterranean low pressure will support cold temperatures (**Figure 6**). Ridging/positive geopotential height anomalies will dominate Asia with exception of troughing/negative geopotential height anomalies across Southwestern and Southcentral Asia (**Figure 5**). This is predicted to yield normal to above normal temperatures for much of Asia with normal to below temperatures confined to parts of the Middle East and the north Indian subcontinent (**Figure 6**).

GEFS 6-10 Day Forecast T2m Anomaly
INIT: 00Z 12/30/19 FCST: 01/05/20 to 01/09/20

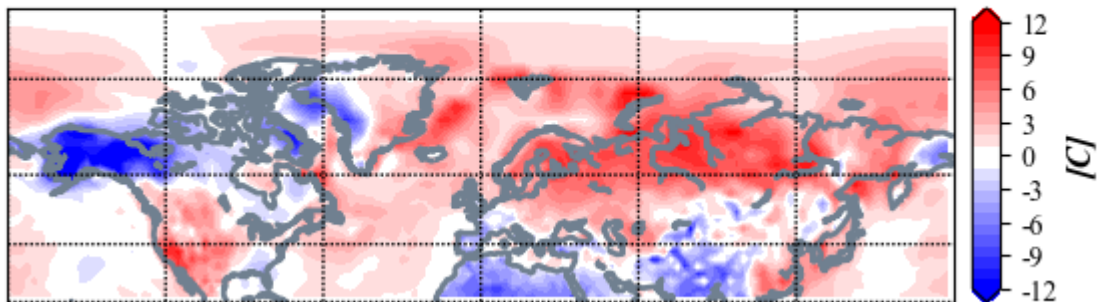


Figure 6. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 5 – 9 January 2020. The forecasts are from the 00Z 30 December 2019 GFS ensemble.

Trouthing/negative geopotential height anomalies will extend from Alaska southeastwards into the Eastern US with ridging/positive geopotential height anomalies across the Western US (**Figure 5**). This pattern is predicted to bring normal to below normal temperatures across Alaska, Northern and Central Canada and much of the Eastern US with normal to above normal temperatures in Southwestern and far Eastern Canada, the Western US and New England (**Figure 6**).

GEFS 6-10 Day Forecast Mean 24-hour Snow Depth Change INIT: 00Z 12/30/19 FCST: 01/05/20 to 01/09/20

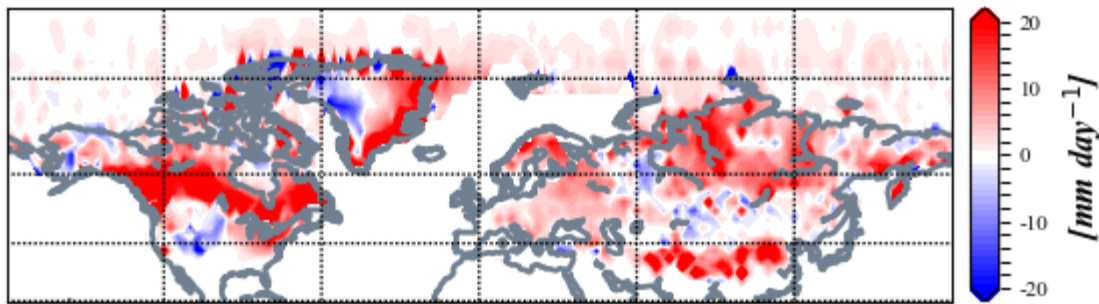


Figure 7. Forecasted snowdepth changes (mm/day; shading) from 5 – 9 January 2020. The forecasts are from the 00Z 30 December 2019 GFS ensemble.

Trouthing and/or cold temperatures will support the potential for new snowfall across much of Northern Asia, possibly Western Russia, Scandinavia, Central and Eastern Europe parts of the Middle East, the Tibetan Plateau, Northeast Asia, much of Northern and Eastern Canada and possibly the Midwestern and Northeastern US (**Figure 7**). Some snowmelt is predicted in Central Asia and the US Rockies (**Figure 7**).

11-15 day

With persistent negative geopotential height anomalies predicted for the Arctic (**Figure 8**), the AO is predicted to remain positive this period (**Figure 1**). With predicted negative pressure/geopotential height anomalies across Greenland (**Figure 8**), the NAO is likely to remain positive this period as well.

GEFS 11-15 Day Forecast 500 mb GPH/GPH Anomaly
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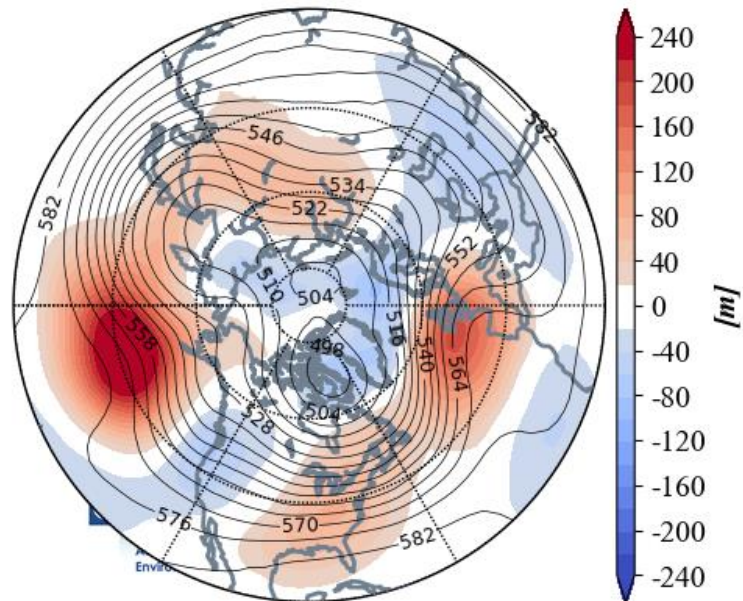


Figure 8. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere from 10 – 14 January 2020. The forecasts are from the 30 December 00z GFS ensemble.

Ridging/positive geopotential height anomalies will continue to dominate much of Europe with troughing/negative geopotential height anomalies confined to the eastern Mediterranean (**Figures 8**). Above normal heights dominating the region will continue to favor widespread normal to above normal temperatures across much of Europe including the UK this period, however northerly flow on the backside of the Mediterranean low pressure could support normal to below temperatures in France Spain and parts of Southern Europe (**Figures 9**). Widespread ridging/positive geopotential height anomalies are predicted to persist across Asia with some regional troughing/negative geopotential height anomalies over Western Asia, Eastern Siberia and Northeast Asia (**Figure 8**). This pattern favors normal to above normal temperatures across much of Asia with normal to below normal temperatures mostly confined to parts of Southern and Northeastern Asia (**Figure 9**).

GEFS 11-15 Day Forecast T2m Anomaly
INIT: 00Z 12/30/19 FCST: 01/10/20 to 01/14/20

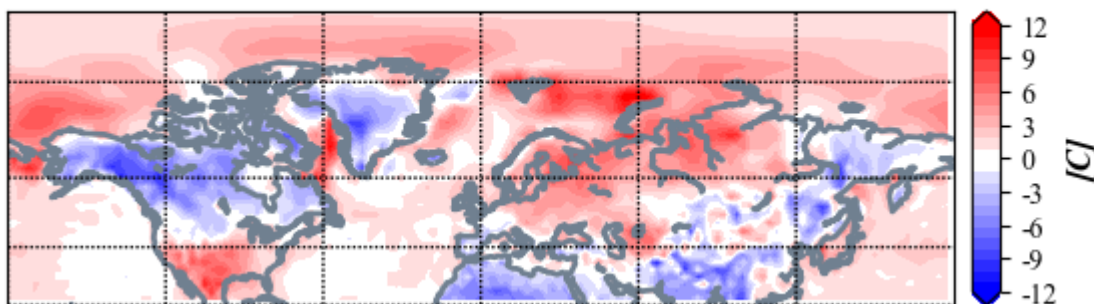


Figure 9. Forecasted surface temperature anomalies ($^{\circ}\text{C}$; shading) from 10 – 14 January 2020. The forecasts are from the 30 December 00z GFS ensemble.

Strong predicted ridging/positive geopotential height anomalies south of the Aleutians will support downstream troughing/negative geopotential height anomalies across western North America while ridging/positive geopotential height anomalies return to Eastern Canada and the Eastern US (**Figure 8**). This pattern is predicted to favor normal to below normal temperatures across Alaska, much of Canada and the US along the Canadian border with normal to above normal temperatures for much of the Southern and Central US (**Figure 9**).

GEFS 11-15 Day Forecast Mean 24-hour Snow Depth Change INIT: 00Z 12/30/19 FCST: 01/10/20 to 01/14/20

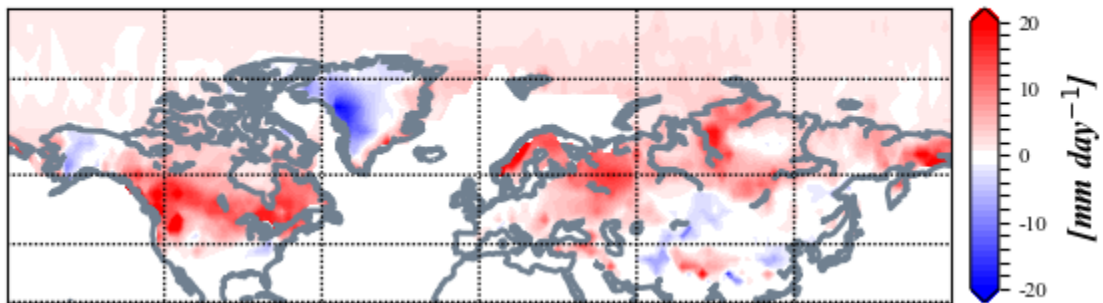


Figure 10. Forecasted snow depth changes (mm/day ; shading) from 10 – 14 January 2020. The forecasts are from the 00z 30 December GFS ensemble.

Troughing and/or cold temperatures will support new snowfall across much of northern Asia, the Tibetan Plateau and possibly Eastern and Central Europe (**Figure 10**). New snowfall is possible across much of Canada, the Northern US but especially the Northwestern US (**Figure 10**). Some snowmelt is possible in Central Asia the US Ohio Valley (**Figure 10**).

Longer Term

30-day

The latest plot of the polar cap geopotential height anomalies (PCHs) currently shows only weak anomalies with normal to below normal PCHs in the troposphere and stratosphere (**Figure 11**). The one exception is strong negative/cold PCHs in the lower troposphere predicted for this week consistent with a predicted positive AO this week (**Figure 1**). The predicted cold PCHs in the lower troposphere this week appear to be coupled with and in response to downward propagation of cold PCHs in the middle stratosphere due to a normal to strong PV since mid-December (**Figure 11**).

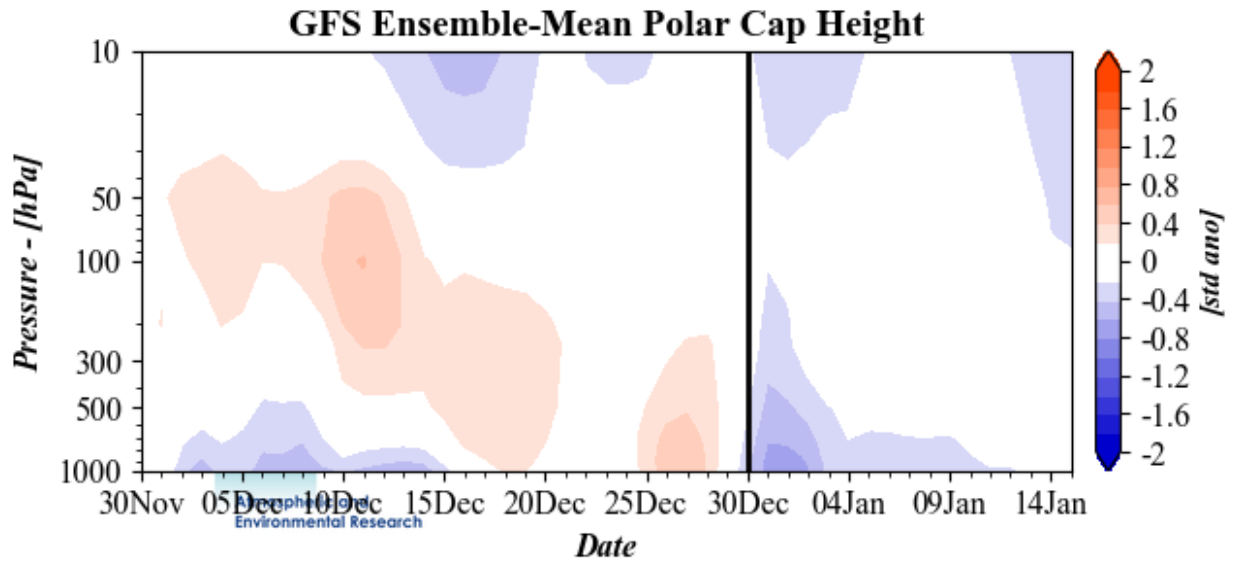


Figure 11. Observed and predicted daily polar cap height (i.e., area-averaged geopotential heights poleward of 60°N) standardized anomalies. The forecasts are from the 00Z 30 December 2019 GFS ensemble.

The plot of Wave Activity Flux (WAFz) or poleward heat transport shows a relatively quiet two-week period week with only weak positive anomalies predicted (**Figure 12**). The predicted positive WAFz for the upcoming week are predicted to be followed by weak negative anomalies over the weekend and into early next week. Positive followed by negative WAFz anomalies is characteristic of a reflective PV disruption that tends to favor cold temperatures in central and eastern North America. I would attribute the shot of cold temperatures predicted for early next week in the Eastern US to this reflective event. But the event looks relatively minor and the impacts should be transitory.

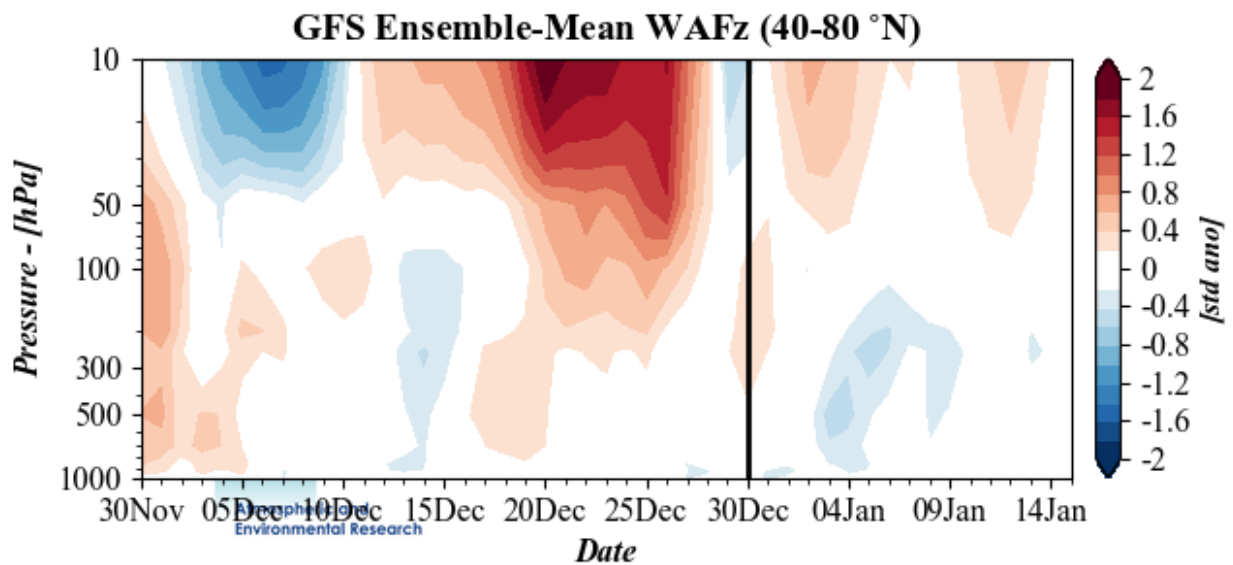


Figure 12. Observed and predicted daily vertical component of the wave activity W_{uv} (WAFz) standardized anomalies, averaged poleward of 40-80°N. The forecast is from the 00Z 30 December 2019 GFS ensemble.

The stratospheric AO is currently slightly positive (**Figure 1**) reflective of a relatively normal PV. However, despite the two positive WAFz pulses predicted for the next two weeks, the stratospheric AO is predicted to remain near neutral (**Figure 1**). The ridging near Alaska with an elongated PV center in the mid-stratosphere are also consistent with a reflective disruption of the stratospheric PV that result in short-lived, cold air outbreaks in central and eastern North America. The impacts on North American weather look to peak early next week.

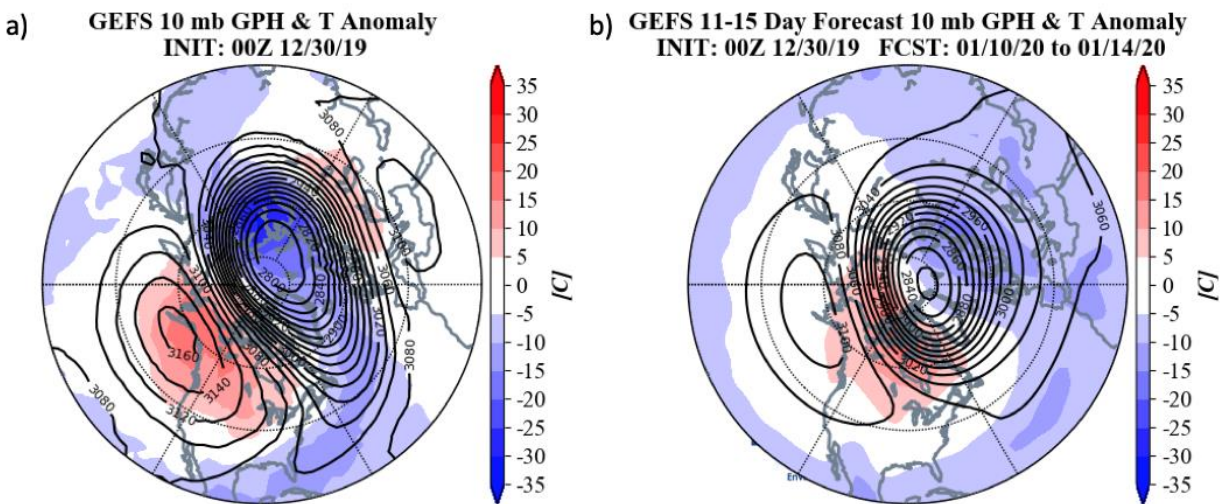


Figure 13. (a) Analyzed 10 mb geopotential heights (dam; contours) and temperature anomalies (°C; shading) across the Northern Hemisphere for 30 December 2019. (b) Same as (a) except forecasted averaged from 10 – 14 January 2020. The forecasts are from the 00Z 30 December 2019 GFS operational model.

Currently the stratospheric PV remains elongated and centered over the Laptev Sea (**Figure 13**). The largest negative temperature departures in the polar stratosphere are over the Laptev Sea and Northwest Eurasia, likely supporting the predicted low tropospheric heights in that region (see **Figures 2, 5 and 8**).

The main warming and ridging in the polar stratosphere is centered near Alaska with more minor warming over the Black and Caspian Seas (**Figure 13**). Over time the new WAFz pulses are predicted to advect this warming into the North Pacific sector of the Arctic and eventually reinforcing the ridging centered over Alaska while the PV center is predicted to remain displaced towards the North Atlantic side of the Arctic (**Figure 13**). Again, ridging near Alaska with PV center displaced towards Greenland and elongated resembles a “reflection” PV disruption that favors cold temperatures in central and eastern North America. However, the PV disruption looks relatively minor and short lived as the PV becomes more circular in shape and no longer extends into the Eastern US by the second week of January only supportive of a relatively quick shot of cold air into the Eastern US.

**CFS 500 hPa Forecast Anomaly Jan 2020
Valid as of 30 Dec 2019**

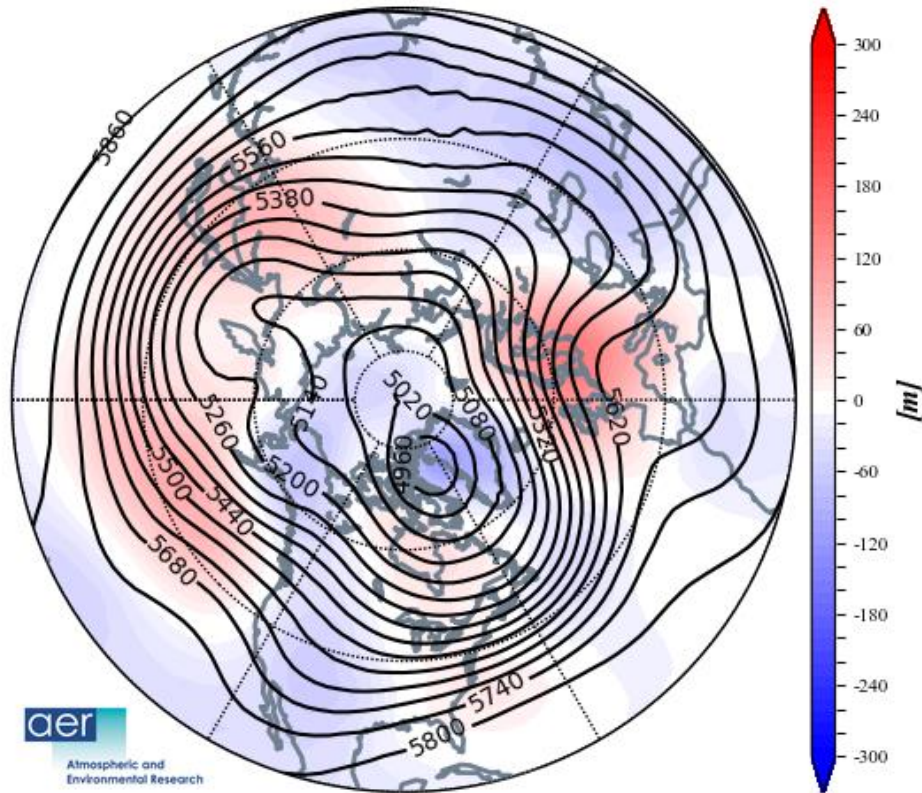


Figure 14. Forecasted average 500 mb geopotential heights (dam; contours) and geopotential height anomalies (m; shading) across the Northern Hemisphere for January 2020. The forecasts are from the 30 December 2019 CFS.

I include in this week's blog the monthly 500 hPa geopotential heights (**Figure 14**) and the surface temperatures (**Figure 15**) forecast for January from the Climate Forecast System (CFS; the plots represent yesterday's four ensemble members). The forecast for the troposphere is ridging across Europe, Central Siberia, south of the Aleutians and the Eastern US with troughs over the eastern Mediterranean, Central Asia, Eastern Siberia/the western North Pacific and western North America (**Figure 14**). This pattern favors relatively mild temperatures for Europe, Western Asia Western and Central Siberia, Southern Canada and the US with seasonable to relatively cold temperatures for Southern Asia, Eastern Siberia, Northeast Asia, Alaska, and Northern Canada (**Figure 15**). The CFS forecast for January has returned to predicting a circulation pattern that projects on to the pattern of variability associated with a positive AO.

CFS T2m Forecast Anomaly Jan 2020 Valid as of 30 Dec 2019

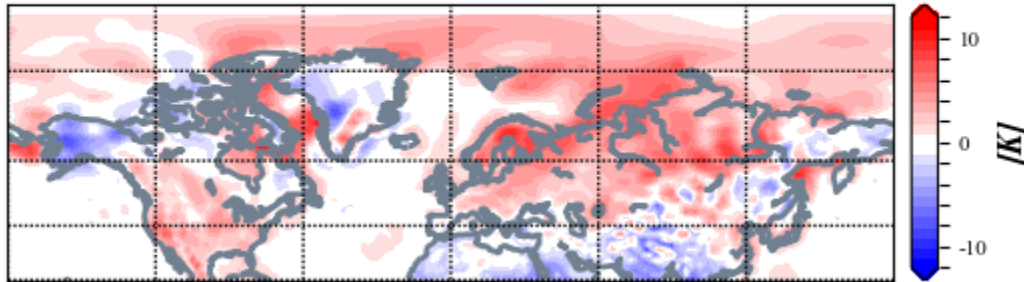


Figure 15. Forecasted average surface temperature anomalies ($^{\circ}\text{C}$; shading) across the Northern Hemisphere for January 2020. The forecasts are from the 30 December 2019 CFS.

Surface Boundary Conditions

Arctic sea ice extent

Arctic sea ice growth rate continues to grow slowly and remains well below normal. Negative sea ice anomalies exist in three regions: the Bering Sea, around Greenland-Canadian Archipelagos and Barents-Kara Seas. The anomalies in the North Pacific sector have shrunk (**Figure 16**) and based on model forecasts negative sea ice anomalies in the Bering Sea can shrink further in the next two weeks. Below normal sea ice in and around Greenland and the Canadian Archipelagos may favor a negative 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.

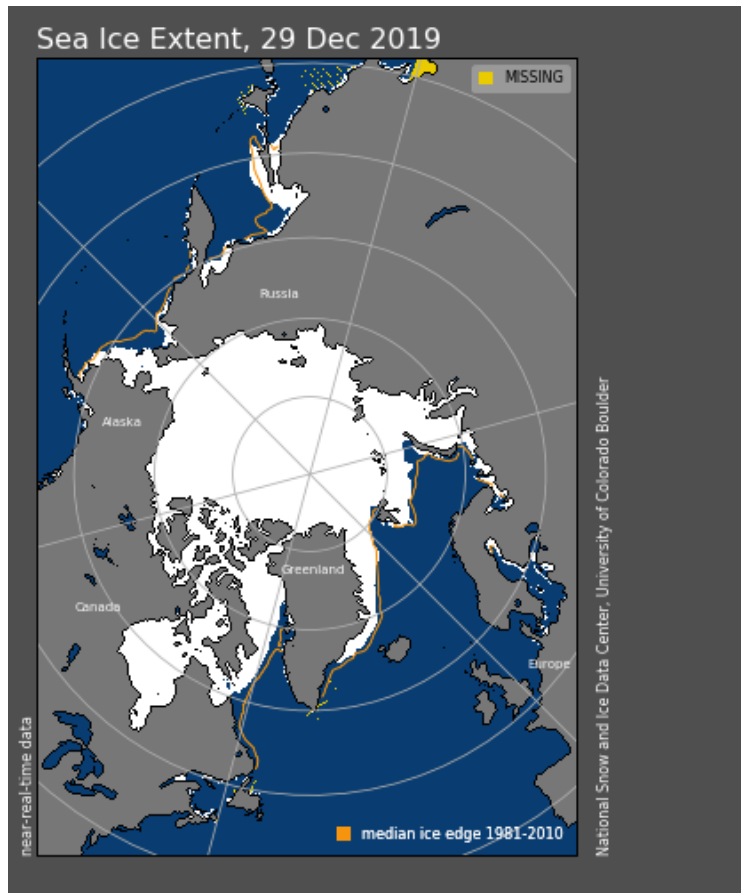


Figure 16. a) Observed Arctic sea ice extent on 29 December 2019 (white). Orange line shows climatological extent of sea ice based on the years 1981-2010.

SSTs/El Niño/Southern Oscillation

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

SST Anomaly - Week Ending 29 Dec 2019

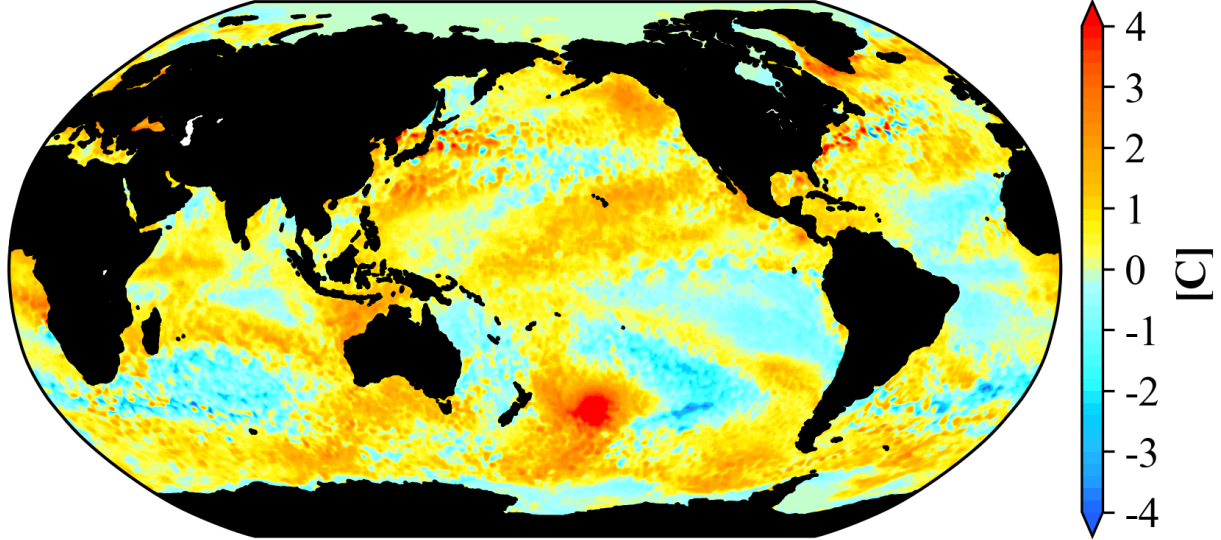


Figure 17. The latest weekly-mean global SST anomalies (ending 29 December 2019). Data from NOAA OI High-Resolution dataset.

Currently no phase of the Madden Julian Oscillation (MJO) is favored (**Figure 18**). The forecasts are for the MJO to remain relatively weak this week and then emerge into phase five next week. MJO phase five favors ridging south of the Aleutians, troughing in western North America with more ridging in the Eastern US. Based on the weather model forecasts, MJO is likely to have a strong influence on North American weather next week.

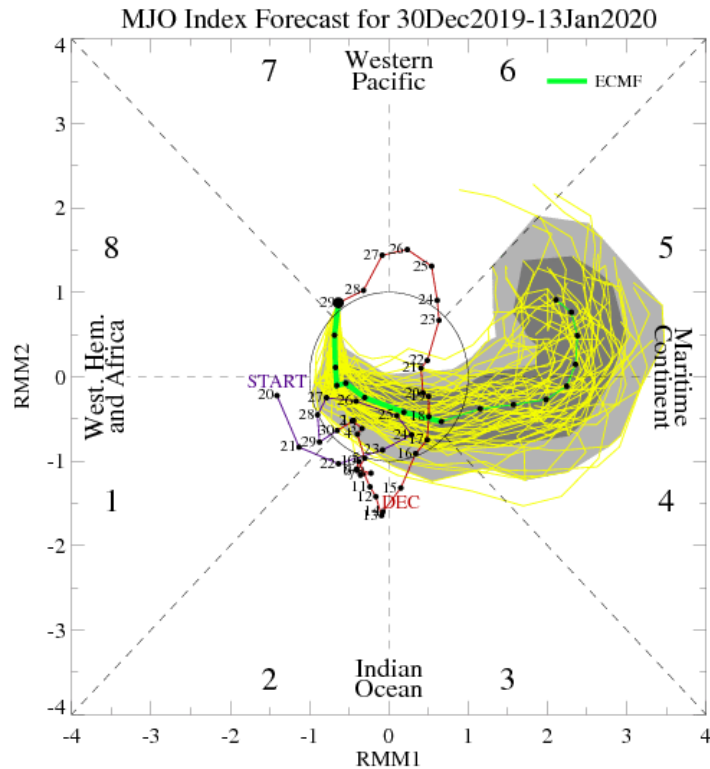


Figure 18. Past and forecast values of the MJO index. Forecast values from the 00Z 30 December 2019 ECMWF model. Yellow lines indicate individual ensemble-member forecasts, with the green line showing the ensemble-mean. A measure of the model “spread” is denoted by the gray shading. Sector numbers indicate 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 has remained steady across Eurasia but remains near decadal lows. Snow cover is predicted to advance especially across Western Asia next week though for now I don't see any major advance. 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.

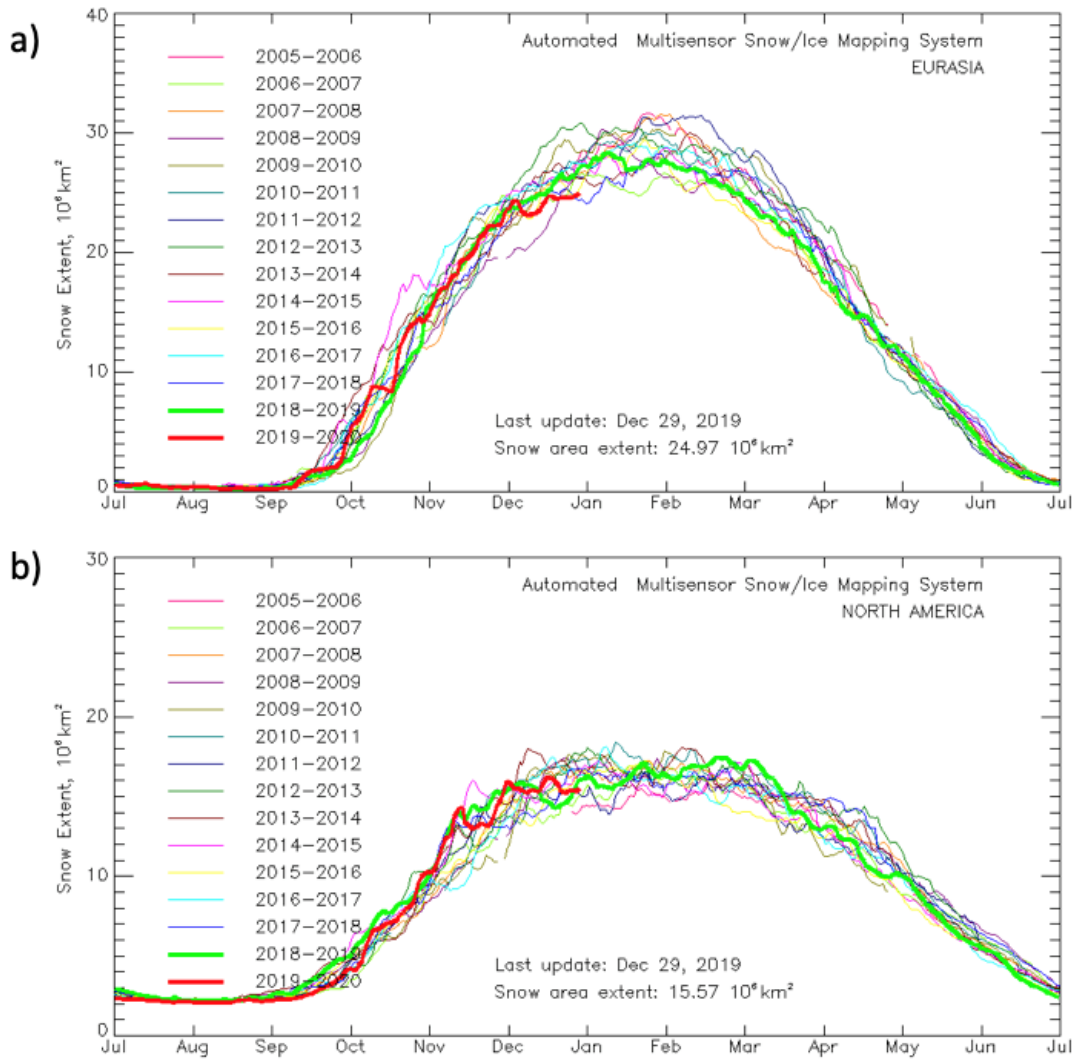


Figure 19. Observed Eurasian (top) and North American (bottom) snow cover extent through 29 December 2019. Image source:

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

North American snow cover has melted back this past week with warmer temperatures and is now near decadal lows. I don't foresee any major advance for the upcoming week. The early advance of snow cover across Canada this fall, has likely contributed to an early start of cold temperatures across the Western US and now the Eastern US.