Science and Technology Infusion Climate Bulletin
NOAA's National Weather Service
42nd NOAA Annual Climate Diagnostics and Prediction Workshop
Norman, OK, 23-26 October 2017

Diagnosing Extremes and Trends of Seasonal Temperatures in Alaska

John E. Walsh and Brian Brettschneider
Alaska Center for Climate Assessment and Policy
University of Alaska, Fairbank, AK

1. Introduction

Recent changes in the Arctic's climate have been large and widely reported (AMAP, 2011; IPCC, 2013). These changes span multiple components of the climate system: sea ice, snow cover, glaciers and the Greenland Ice Sheet, and permafrost. Changes in these various components are consistent with atmospheric warming, which has also been well documented, especially during the past few years when the Arctic has set new records for winter and annual temperatures (Richter-Menge and Mathis, 2017). The present paper represents a step towards the attribution of this warming by evaluating the contribution of changes in atmospheric circulation in a region (Alaska) for which the warming of recent decades is typical of the Arctic.

Figure 1 shows the post-1950 Arctic warming in map form for the winter season (December-February) and at the annual (January-December) time scale. Alaska's annual mean warming, which is slightly more than 2°C since 1950, is typical of most of the Arctic (Fig. 1a). The Arctic's warming is greater than most of the rest of the Northern Hemisphere, a manifestation of the well-known Arctic amplification (*e.g.,* Pithan and Mauritsen, 2014). However, the Arctic's winter warming (Fig. 1b) shows a spatially more complex pattern, with a maximum over Alaska, northwestern Canada and the Beaufort Sea. The greater spatial complexity of the winter pattern is consistent with a greater role of the atmospheric circulation in advecting into a region air that is warmer or colder than its climatological mean.

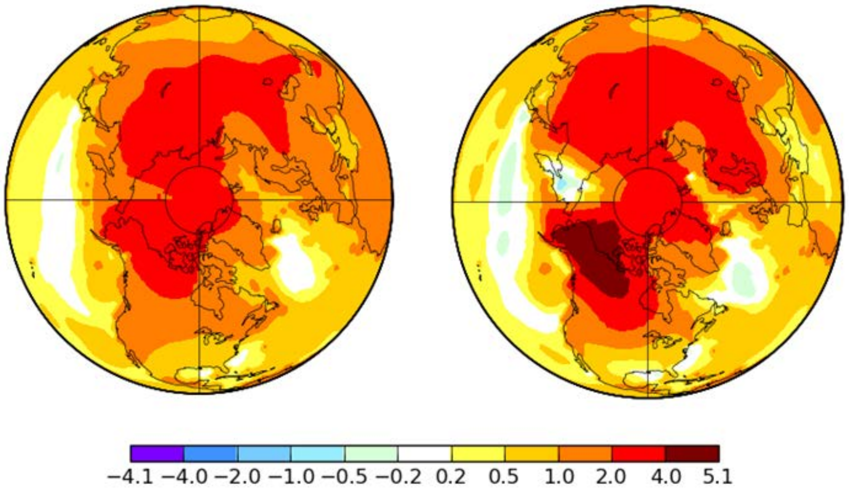


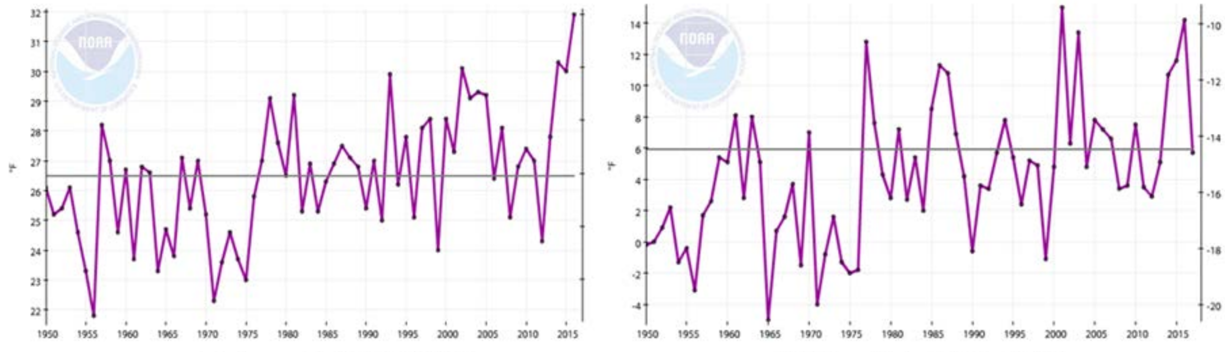
Fig. 1 Surface air temperature change (°C) from 1950 to 2017 based on least-squares linear fit to annual (left) and winter (Dec.-Feb.) (right) temperatures. Source: NASA Goddard Institute for Space Studies, https://data.giss.nasa.gov/gistemp/maps/

Internal variability is readily apparent in the annual temperatures at the regional scale. Figure 2 shows time series of the annual and winter (December-February) statewide average temperatures for Alaska for the 1950-2017 period. While positive trends are apparent in both time series, interannual and multiyear variations are large, and in some cases the year-to-year variations are larger than the overall trend for the 68-year period. The 68-year changes based on least-squares fits to the time series in Fig. 2 are 2.1°C for the annual values and 4.1°C for the winter values. The corresponding trend-derived changes for the other seasons (not shown) are 2.2ºC for spring, 1.3°C for summer and 0.8ºC for autumn, indicating that the warming has been largest in winter and smallest in autumn.

The final two years of the winter time series in Fig. 2b provide support for the premise that the atmospheric circulation is a key factor in interannual temperature variations over Alaska. The statewide average temperatures for December-February ending in 2016 and 2017 were -9.8ºC and -14.7°C, respectively. These temperatures

---

Correspondence to: John E. Walsh, Alaska Center for Climate Assessment and Policy, University of Alaska, Fairbank, AK; E-mail: jwalsh@mail.iarc.uaf.edu



(a) Annual, 1950-2016 **(b) Dec-Feb, 1950-2017**

Fig. 2 Time series of Alaska statewide temperature for 1950-2016/17 for (a) the full calendar year and (b) winter. Temperature scales for °F and °C are shown on the left and right ordinate axes, respectively. Source: National Centers for Environmental Information, https://www.ncdc.noaa.gov/cag/

represent departures of +4.7°C and -0.2ºC from the mean for the 1980-2010 reference period. The difference of approximately 5°C in the 3-month mean temperatures is consistent with the sea level pressure anomalies for the same three-month periods. Figure 3 shows that the 2015-2016 winter was characterized by negative pressure anomalies of more than 12 hPa in the Aleutian region, corresponding to an unusually deep Aleutian low with anomalous northward airflow and warm advection into mainland Alaska. By contrast, the winter of 2016-17 had positive sea level pressure anomalies of more than 10 hPa in the Aleutians, with even larger anomalies to the south, contributing to the eastward advection into much of Alaska. The sensitivity of Alaskan temperatures to near-surface atmospheric circulation, illustrated by the temperature and sea level pressure anomalies of these two recent winters, leads to the hypothesis that much of the trend of winter (and annual) temperatures over Alaska during recent decades is attributable to variations of the atmospheric circulation.

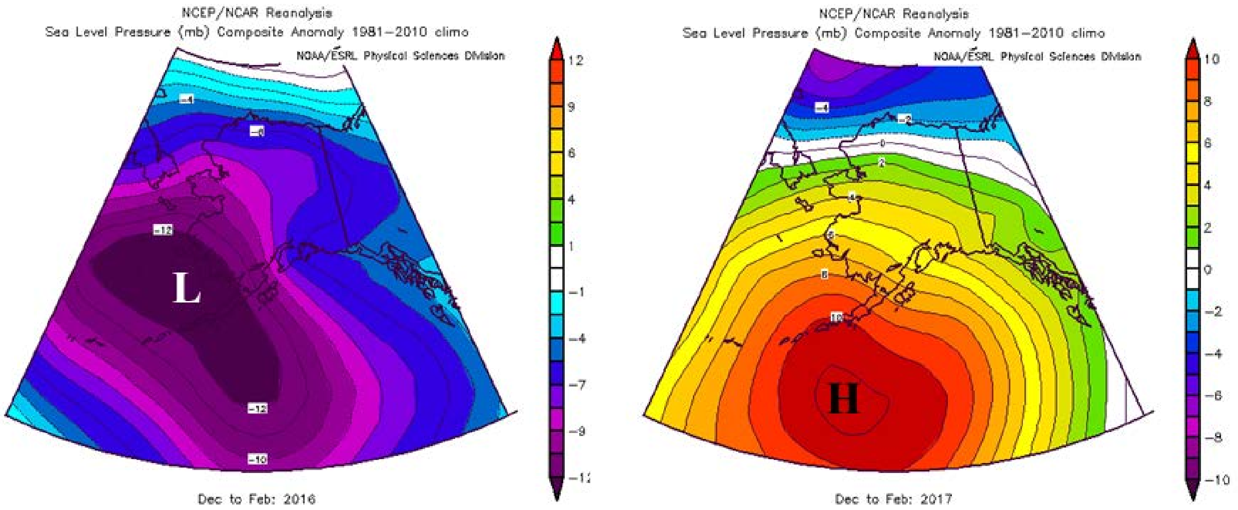


Fig. 3 Departures from climatological mean (1981-2010) mean sea level pressure (hPa) for December-February of 2015-16 (left) and 2016-17 (right). Contour interval (2 hPa) and color bar are the same for both panels.

2. Methodology

Our diagnostic evaluation of the contribution of the atmospheric circulation to the recent warming of Alaska is based on an analog methodology. The analog methodology was illustrated for a single year by Walsh *et al.* (2017), who showed that winds accounted for a substantial portion of the anomalous warmth of the 2015-16 winter and spring (October-April). The approach consists of a comparison of a particular year's sea level pressure (SLP) field over the Alaska region with the SLP fields of all other years in the 1949-2017 period, the selection of the five years with the closes match of SLP fields, and the construction of an analog-derived temperature by averaging the temperatures of the five best analog years. Guided by the results in the previous study, we base our analog-year selection on the spatial pattern correlation over the Alaska domain bounded by 50ºN, 75°N, 180°W and 130°W, SLP as the analog selection variable, and the five best analogs for each year. We perform the analog selection for the statewide temperatures of each season (winter, Dec-Feb; spring, Mar-May; summer, Jun-Aug; autumn, Sep-Nov), although our emphasis will be on the winter season.

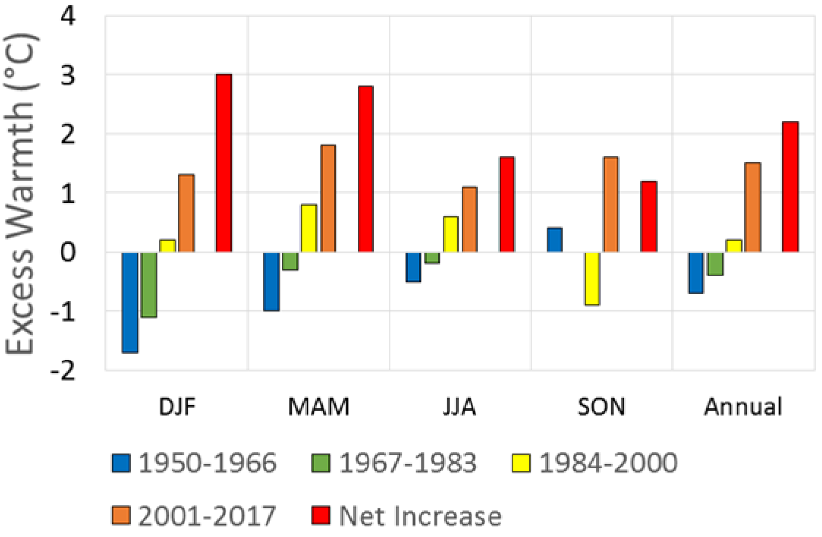


Fig. 4 Excess warmth (°C) by season and quartile (17-year period), from earliest (blue) to most recent (orange). Negative values indicate that actual temperature was cooler than the analog-derived, positive values indicate actual temperature was warmer than analog-derived. Also shown (red bars) are the total changes in excess warmth from the first to the last quartile.

We denote the portion of a seasonal temperature anomaly unexplained by the atmospheric circulation as the “excess warmth”, which is also referred to in the literature as the “dynamically adjusted temperature anomaly” (*e.g.*, Deser *et al.* 2014). The “excess warmth” can be attributable to (1) local effects that aggregate systematically in a statewide average, (2) anomalous surface states (anomalies of ocean temperature, sea ice, snow cover), or (3) external forcing such as the effects of increasing greenhouse gas concentrations. A clean separation of the second and third potential attribution sources is not possible from the observational data because increasing greenhouse gas forcing can result in changes in ocean temperature, sea ice and/or snow cover, thereby augmenting direct radiative effects on air temperature. The direct radiative effects of increasing greenhouse gas concentrations may be further partitioned into increased downwelling radiation from anthropogenic sources (CO2, CH4, *etc.*) and from water vapor, as atmospheric warming is expected to be accompanied by an increase of specific humidity (Serreze *et al.*, 2012; Cullather *et al.*, 2016). However, if the temperature anomaly unexplained by the atmospheric circulation shows a systematic warming over time, then one can point to a trend of “excess warmth” that is consistent with the direct and indirect effects of increasing greenhouse gas concentrations.

3. Results

The “excess warmth” will be negative if the actual temperature is colder than the mean value of the five best circulation analog years, and it will be positive if the actual temperature is warmer than the analog-derived value. Figure 4 shows the excess warmth as a function of season and subperiod (quartile) of the 68-year period of record. In all seasons except autumn, the excess warmth increases monotonically from the earliest to the most recent 17-year quartile. In all seasons except autumn, it is negative in the first two quartiles and positive in the two most recent quartiles. Even in autumn, the most recent quartile has the most positive value of excess warmth. The increase from the first to the final quartile ranges from 1.2°C in autumn to 3.0ºC in winter, with an annual mean increase of 1.5°C. As an indication of the sensitivity to the metric used in analog selection, we note that the winter-season increase of excess warmth is 3.0°C when analogs selection is based on the spatial pattern correlation, while it is 4.1ºC when based on the root-mean-square difference of the gridded pressures.

Least-squares linear fits to the time series of excess warmth for each season enable estimates of changes from 1949/50 to 2016/17. These changes are shown in Fig. 5, together with the corresponding total changes in temperature (trends including the circulation-driven component) and the percentages of the total trend that the excess warmth represents in each season. During winter the linear-trend increase of excess warmth is approximately 2.1°C, which is 51% of the total linear-trend-derived change of 4.2ºC. During autumn, the 0.5°C increase of excess warmth represents 64% of the total warming. During spring and summer, essentially all the total increase of temperature is "excess warmth", as there is essentially no trend in the circulation-derived component of the temperatures. Alternatively, one may say that the atmospheric circulation has not made a detectable contribution to changes of temperature over Alaska during spring and summer, while it has made a substantial contribution in winter and autumn. If the values for the four seasons are averaged into annual values, the increase of excess warmth is 1.5ºC, which is approximately 75% of the overall 2.1ºC increase of annual mean temperature from 1949 to 2017. However, it should be emphasized that this percentage has a strong seasonal variation, with winter and autumn being the seasons in which the atmospheric circulation has been a major contributor (49% in winter, 36% in autumn) to the overall temperature trend.

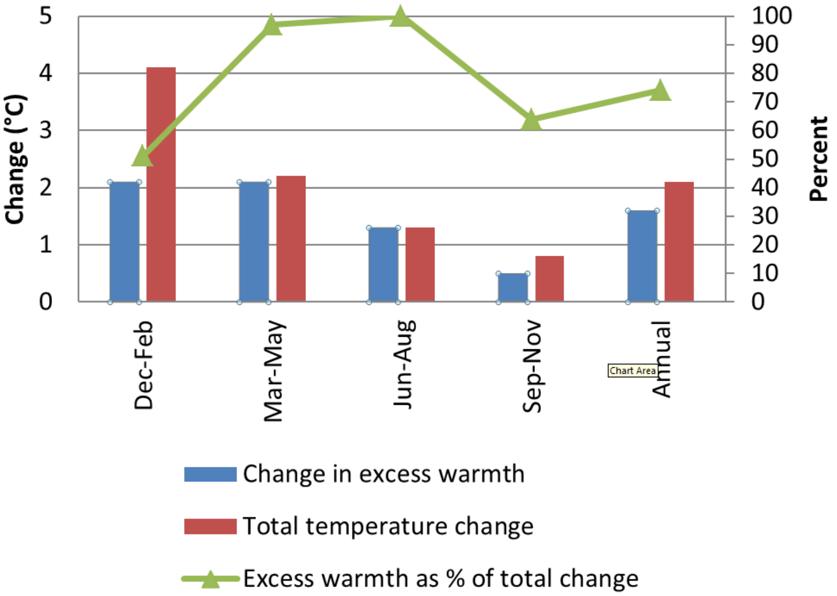


Fig. 5 Change in excess warmth by season based on least-squares linear fit to yearly values, 1949/50 through 2016/17 (blue bars). Also shown are total changes of temperature (red bars) and change in excess warmth as a percentage of the total change of temperature (green line). The latter is the same as the ratio of the trends.

4. Conclusion

The results show that (1) the atmospheric circulation explains a substantial portion of the winter and autumn variability and trends of temperature over Alaska, and (2) the portion of the temperature variations unexplained by the atmospheric circulation exhibits a systematic trend in all seasons over the 1949-2017 period. The "excess warmth" (the portion of the temperature variations unexplained by the circulation) accounts for about 1.5ºC of the total 2.1ºC warming of the annual mean temperature since 1949. This contribution is largest (2.1ºC) in winter and spring, the two seasons in which the observed warming has been largest, and it compares favorably with the model-simulated warming attributable to increased greenhouse gas forcing.

As noted in Section 2, the approach used in this study cannot distinguish the direct radiative effect of increasing GHG concentrations from the effects of varying surface conditions (ocean temperatures, sea ice, snow cover), for which changes may be driven at least in part by increasing GHG concentrations. Nor can the analog methodology address the possibility that GHG forcing may be contributing to changes in the atmospheric circulation, although there is an emerging consensus that systematic changes of the atmospheric circulation in middle and high latitudes are presently obscured by internal variability (Shepherd, 2014; Screen *et al.*, 2014; Overland, 2016). Variations in the atmospheric circulation, in turn, play a role in the cloud cover, which can affect surface air temperatures in all seasons. Controlled model experiments are required to sort out the effects of these various components of anthropogenic forcing. However, the results reported here do point to the importance of the atmospheric circulation in explaining the recent warming of Alaska during winter and autumn.

Acknowledgements. This study was funded by NOAA's Climate Program Office, Grant NA15OAR4310169.

References

AMAP, 2011: Snow, Water, Ice and Permafrost in the Arctic: Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway, xii+538 pp.

Cullather, R. L., Y.-K. Lim, L. N. Boisvert, L. Brucker, J. N. Lee, and S. M. J. Nowicki, 2016: Analysis of the warmest Arctic winter, 2015-2016. *Geophys. Res. Lett.*, **43**, 10,808-10,816, DOI: 10.1002/2016GL071228.

Deser, C., A. S. Phillips, M. A. Alexander and B. V. Smoliak, 2014: Projecting North American climate over the next 50 years: uncertainty due to internal variability. *J. Climate*, **27**, 2271–2296.

IPCC, 2013: *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (eds.), Cambridge University Press, Cambridge, U. K. 1535 pp.

Overland, J. E., 2016: A difficult Arctic science issue: Midlatitude weather linkages. *Polar Science*, **10**, 210-216.

Pithan, F., and T. Mauritsen, 2014: Arctic amplification dominated by temperature feedbacks in contemporary climate models. *Nature Geoscience*, **7**, 181-184.

Richter-Menge, J., and J. T. Mathis, 2017: The Arctic. In State of the Climate in 2016, *Bull. Amer. Meteor. Soc.*, **98**, Special Suppl., S129-S154.

Screen, J. A., C. Deser, I. Simmonds, and R. Tomas, 2014: Atmospheric impacts of Arctic sea ice loss, 1979-2009: separating forced change from internal variability. *Clim. Dyn.*, **43**, 333-344.

Serreze, M. C., A. P. Barrett, and J. Stroeve, 2012: Recent changes in tropospheric water vapor over the Arctic as assessed from radiosondes and atmospheric reanalyses. *J. Geophys. Res.*, **117**, D10104, doi:10.1029/2011JD017421.

Shepherd, T. G., 2014: Atmospheric circulation as a source of uncertainty in climate change projections. *Nature Geoscience*, **7**, 703-708, doi: 10.1038/ngeo2253.

Walsh, J. E., P. A. Bieniek, B. Brettschneider, E. S. Euskirchen, R. Lader and R. L. Thoman, 2017: The exceptionally warm winter of 2015-16 in Alaska. *J. Climate*, **30**, 2069-2088.