# Is regional warming natural or not?

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Climate has changed substantially throughout Earth's history. However, the observed warming of 1.4°F since 1900 has spurred interest in identifying whether such changes are part of a natural cycle or due to human factors. The answer to this scientific question lies at the heart of whether our actions both have been responsible for documented changes and can be modified to ease the pace of warming and avoid subsequent impacts to global society.

The increase in global averaged surface air temperature and sea surface temperatures over the past century has been well documented through a variety of means and has been estimated to be around 1.4°F from 1900 to 2012. This increase has not been a smooth upward glide, but rather has involved a sharp increase since the 1960s, with a widely reported slowing down (also known as the "hiatus") in surface-based warming since the record-setting El Niño year in 1998. While much has been made about this slowdown in warming, including speculations that the Earth system is not as sensitive to man-made forcing as reported, 2014 is the warmest year on record, which is remarkable given the lack of any significant El Niño event (El Niño years are generally warmer). Variations in global mean surface temperature arise primarily from three factors: (1) absorbed solar radiation, (2) strength of the atmospheric greenhouse effect, and (3) internal coupled ocean-atmosphere climate variability. The Intergovernmental Panel on Climate Change's fifth assessment report concluded that it is "extremely likely" that a majority of the increase in temperatures since the mid-20th century is due to man-made emissions of greenhouse gases and that modeled estimates of the man-made contributions were of similar magnitude to the observed warming.

**IMPACT**

Observed long-term warming of the Pacific Northwest has primarily been driven by man-made increases in greenhouse gas levels, despite recent reports to the contrary. The Pacific Northwest is thus not immune to human-driven changes in climate, historically and under future climate scenarios.

Regional variability in temperature is additionally subject to regional-to-hemispheric variations in atmospheric circulation. For example, the well-documented and repeated El Niño Southern Oscillation (ENSO) and Pacific North American (PNA) modes of variability are two of the more influential circulation patterns for much of the Pacific Northwest (PNW). While a portion of the year-to-year, decade-to-decade, and multidecadal variability in temperature can be linked to variability in these natural patterns, there is no long-term trend in these patterns that can explain the magnitude of observed 1.4°F warming in the region since 1900. Rather, in a 2014 study published in the *Journal of Climate*, we determined that accumulation of man-made greenhouse gases was the leading cause of the observed warming.

Recently, a study published in the *Proceedings of the National Academies of Science* by Johnstone and Mantua (JM) reported findings contradictory to ours, suggesting that natural changes in atmospheric circulation explain nearly all of the observed warming in WA, OR, and northern CA. They hypothesize that a long-term decline in air pressure over the northeastern Pacific Ocean has allowed for a more southerly flow and intrusion of warmer maritime air into the region.

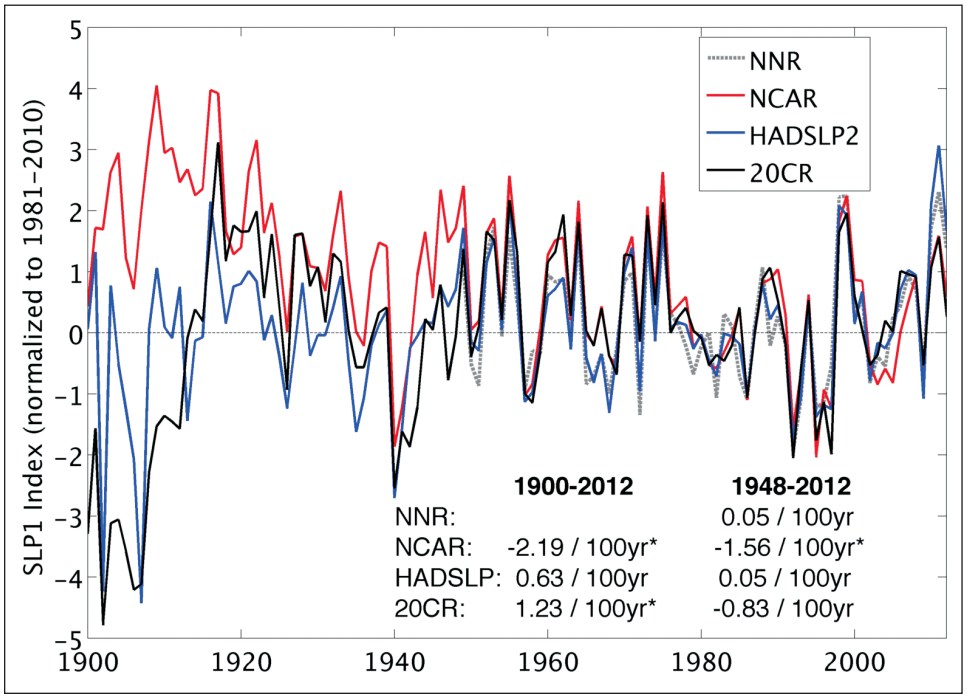


**Figure 1.** *Time series of the annual mean of monthly sea-level pressure variability described by Johnstone and Mantua (JM) from four different datasets. Note that the National Center for Atmospheric Research (NCAR) dataset used by JM to reach their conclusions shows a significant decline over the period of record relative to the other datasets. Linear trends for the different datasets are provided and statistical significance is denoted by *. (NNR: National Centers for Environmental Prediction/NCAR Reanalysis; HADSLP: Hadley Centre Sea Level Pressure dataset; 20CR: National Oceanic and Atmospheric Administration 20th Century Reanalysis)*

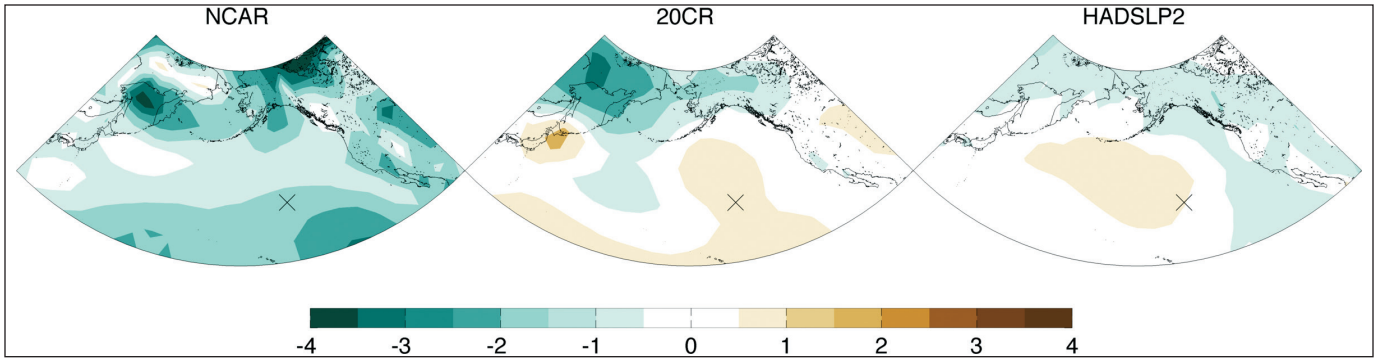


**Figure 2.** *Estimated linear least squares trends in annual mean sea-level pressure from 1900 to 2012 for three datasets: (left to right) National Center for Atmospheric Research (NCAR), National Oceanic and Atmospheric Administration 20th Century Reanalysis (20CR), and Hadley Centre Sea Level Pressure (HADSLP2). Trends are reported in units of millibars per century. For reference, an × is placed over the center of action of the mode of variability reported by Johnson and Mantua.*

The authors based their conclusions on the long-term decline in air pressure from a single dataset extending back to the beginning of the 20th century (Figure 1). However, we found that other long-term estimates of sea-level pressure over the northeastern Pacific fail to replicate the results of the dataset they chose. Moreover, the dataset JM used shows a coherent, long-term decline over nearly the entire Pacific sector that suggests a systematic problem with trends for these data over the 1900 to 2012 period (Figure 2). Since surface winds are driven by relative, rather than absolute, changes in atmospheric pressure, it is doubtful that the broader changes reflected in these data would lead to dynamic changes in the wind and movement of warmer air into the region. Curiously, even for the more recent time period from 1948 to 2012, when long-term sea-level pressure estimates show broader agreement and more sophisticated atmospheric reanalyses are available, the data used by JM show a continual decline across the northeastern Pacific. Given that JM's findings are strongly predicated on the long-term decline in sea-level pressure, we suggest that their conclusions may be premature and are very sensitive to the choice of datasets. Whereas we have fairly strong agreement on temperature records for the region, there is much larger structural uncertainty regarding sea-level pressure estimates from the northeastern Pacific.

To reconcile our study with the novel circulation index (SLP1) identified by JM, we performed a multiple linear regression, as we did in our 2014 *Journal of Climate* study, that equally considered influences from (1) solar variability, (2) volcanic aerosols, (3) man-made greenhouse enhancements, and (4) natural circulation patterns. The latter included ENSO, PNA, and SLP1. We used the monthly average SLP1 averaged over three independent datasets, given the disparity in SLP1 trends. The modified analysis failed to change our fundamental conclusions (Figure 3). We maintain that man-made accumulations of greenhouse gases were the leading driver of long-term changes in seasonal temperature for the PNW. The inclusion of SLP1 resulted in slightly more interannual variability in spring and winter temperatures but was not linked to summer or autumn temperatures in any notable way, thus being far less important than ENSO or PNA for regional temperature.

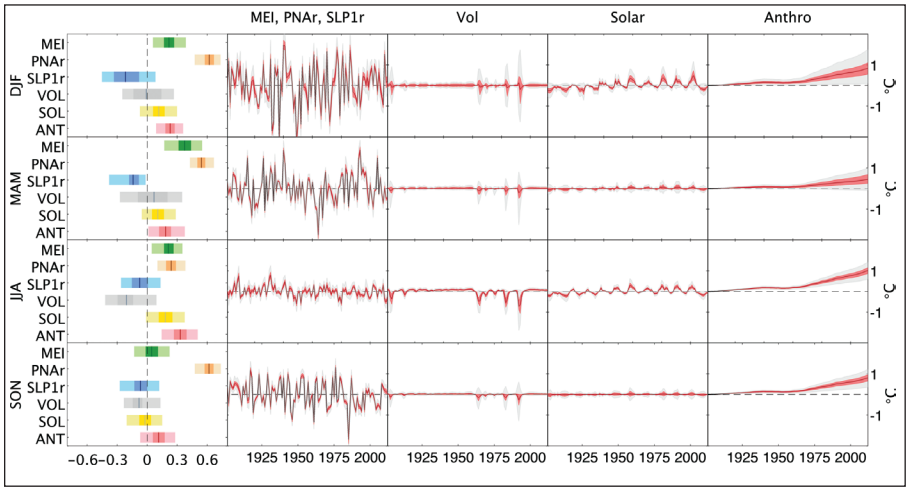


**Figure 3.** *(left column) Pearson's correlation coefficient between seasonal temperature and (1) Multivariate El Niño Southern Oscillation (ENSO) Index (MEI), (2) Pacific North American (PNA) index after removing the linear contribution (PNAr), (3) SLP1 index after removing the linear contribution from MEI and PNA (SLP1r), (4) volcanic aerosols (Vol), (5) solar variability (Sol), and (6) man-man factors (Ant). The box plots (right four columns) show the contribution to seasonal temperature due to (1) natural climate variability, (2) volcanic aerosols, (3) solar variability, and (4) man-made factors. The 95% confidence interval, interquartile range, and median of estimates are denoted by the light gray shading, red shading, and black line, respectively.*

We are not aware of any process that would allow human-driven warming in the PNW to vary substantially from human-driven warming in similar latitudes; this is fairly well simulated by climate model experiments. Furthermore, we find that decadal variability in regional temperature is very strongly correlated to global mean temperature, including most of the warming since 1960, whereas the mechanism described by JM would result in most of the warming prior to 1940. While natural climate variability has a demonstrated impact on modifying the pace of warming in the region, we believe that it has played a far lesser role in the long-term warming of the region than man-made factors.