How robust is the recent cooling trend in the Antarctic Peninsula?

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Abstract

The upward evolution of temperatures in the Antarctic Peninsula has weakened and even reversed in the last two decades. Due to the long-term variability of the region it is not easy to assess whether observed recent cooling trends are consistent with the internal variability or not. For this reason, in this paper we assess the robustness of the trends by analyzing their sensitivity with respect to the choice of time period selected. Every possible temperature trend in the 1958-2016 interval has been calculated and displayed in a two-dimensional parameter diagram. Our results suggest that the warming observed in the Antarctic Peninsula since 1958 is robust, as all periods longer than 30 years exhibit statistically significant changes, especially in summer (with lower magnitude and higher significance) and autumn and winter (whit larger magnitude and lower significance). Instead, periods shorter than 30 years exhibit alternations of warming and cooling periods, and therefore do not represent robust trends even if they are statistically significant. Consequently, the recent 20-year cooling trend cannot be considered at the moment as an evidence of a shift in the overall sign of the trend.

Keywords: temperature trend, sensitivity, global warming, Antarctic Peninsula, climate change, variability

1. Introduction

The Antarctic Peninsula (AP) has shown a dramatic warming during the second half of the 20th century (Vaughan et al. 2003, Thomas et al. 2009, Ding et al. 2011, Schneider et al. 2012). This warming has been attributed to regional changes in atmospheric circulation, particularly to the enhancing of westerlies as a result of a positive trend of the Southern Annular Mode in response to stratospheric ozone depletion (Marshall 2007, Lubin et al. 2008), and an increase of northerly winds as a result of the shift in the position and the strength of Amundsen Sea Low (Hosking et al. 2013, Raphael et al. 2016).

Nonetheless, in recent years, the warming trend on the AP has reversed. In fact, since late 20th century onwards, temperatures over this region exhibited a cooling trend (Carrasco 2013, Turner et al. 2016, Oliva et al. 2016). Statistically significant trends found for the last 20-year period (Oliva et al. 2016) may suggest the influence of an external signal of cooling. Nevertheless, Turner et al. (2016) demonstrated that this cooling is a result of an increase of cyclonic conditions over the Weddell Sea, that is consistent with the long-term natural variability (Ludescher 2016). Large natural variability makes not easy to asses weather a particular significant trend is attributable to internal variability or not.

For example, in other situations, like in the case of the global surface temperature trends studied by Liebmann et al. (2010), obtaining statistically significant trends is not enough to claim that they are a response to climate change. It is necessary to assess whether they are robust, for instance by checking that the magnitude and statistical significance of the trends do not exhibit strong variations if we slightly change the time intervals for which they are estimated.

In this article, we explore the observational temperature time series in AP in order to analyze whether the recent 20-year cooling trend in the region is robust or not and if it has been an exceptional circumstance in the past 60 years. To reach this goal, we assess the sensitivity of the mentioned recent temperature trends to the choice of time interval for which they are estimated. Assessing the mechanisms that produced this cooling period is beyond of the scope of this study since it has been previously stated by Turner et al. (2016). This paper is structured as follows: We describe the datasets and the methodology in section 2. Temporal sensitivity of annual and seasonal temperature trends in Antarctica since 1958 is examined in Section 3. The final section contains some concluding remarks.

2. Datasets and methodology

a) Temperature datasets

Eleven datasets of AP stations were selected from the Reference Antarctic Data for Environmental Research (READER) project (Turner et al. 2004) [available on-line at https://legacy.bas.ac.uk/met/READER/]. These data include time series of quality controlled monthly mean temperatures; their locations are shown in Figure 1. Annual and seasonal temperatures were calculated averaging the monthly means. In order to compare among stations, we subtracted the mean temperature of each station for the baseline period 1971-2000 and averaged them to obtain temperature anomalies for AP.

b) Trends and sensitivity methods

Temperature trends have been estimated using least-squares linear regression. To evaluate the statistical significance of the linear trend we used a Student's t-distribution of the residuals using an effective sample size calculated following Santer et al. (2000). We also performed Mann-Kendall and Monte Carlo tests, obtaining similar results.

We calculated every possible trend and displayed them as a two-dimensional parameter diagram, as Liebmann et al. (2010) did to evaluate the sensitivity of global temperature trends to the choice of time interval. This tool allows us to study a broad range of variability (from interanual to interdecadal) of temperatures and assess their robustness. We choose the visualization used by Fortuny (2015), which plots linear changes (defined as product of the linear trend and the length of the considered time interval) and their statistical significance (calculated as the statistical significance of the associated trend) as a function of the initial and the final year of the period. Using cumulative temperature changes instead of temperature trends, we emphasize possible sustained long-term trends and remove weight to the short strong trends that are associated with internal variability alone. From now on, we will refer this plot as two-dimensional linear change (LC) diagram. Furthermore, LC diagrams allow us to estimate the sensitivity of the observed changes to the choice of time interval and assess whether a trend for a particular interval is a unique case or if has been previously observed. This methodology has been previously used in other locations, i.e. Spain (Gonzalez-Hidalgo et al. 2016) or France (Dieppois et al. 2016).

3. Sensitivity of the temperature trends

a) Annual Trends

Figure 2a shows the time series of annual mean surface temperature anomalies for the AP. For each year, the shading indicates the one standard deviation around the mean temperature of all stations of the region. We have superimposed the trend estimated for different time intervals: between 1958 and 2016 (in green), between 1990 and 2016 (in yellow), and between 1970 and 2000 and between 2000 and 2016 (in dark red).

The time-series shows the observed warming in the AP, and the magnitude of the linear trend is +0.32 °C/decade when estimated using the entire record. The rate of warming is stronger during the last 30 years of the 20th century, with a trend of +0.40 °C/decade. Since late 20th century the linear trend reversed. As an example, the linear trend for the 2000-2016 interval was –0.67 °C/decade. However, if we extend back this last segment few years, since 1990, we obtain again a slight warming trend of +0.12 °C/decade. These examples illustrate that short-term variability may produce large differences in trend estimations if we change the initial or the final year of the segment, as pointed out by Liebmann *et al.* (2010).

We used the annual temperature two-dimensional LC diagrams for AP (Figure 2b and c) to analyze how the warming and cooling periods has changed over the time. Both plots allow us to compare the behavior exhibited by two regions that present important differences in the evolution of their temperature time series.

As we previously observed, on AP there is a clear and significant warming during the 58-year period 1958-2016 with a temperature linear change of +1.86 °C (green circle in Figure 2b). Notice that this magnitude is the result of multiplying the +0.32 ºC/decade and the 5.8 decades of the interval. Of all the possible linear changes estimated in the 1958-2016 interval, regardless of the initial and final year, the maximum change is +2.15 °C (blue cross in Figure 2b), observed between 1958 and 2010. It is also observed that almost every time period starting before than 1980 and ending after 2000 exhibits a significant warming. Notice that almost all these periods are longer than 30 years; while lengths of 20 to 30 years still show warming periods, but they are generally non-statistically significant. Decadal variability dominates in segments shorter than 20 years, with warming and cooling periods alternating. These results suggest that only trends evaluated for at least 30-year segments may be considered robust.

In recent years, it has been a cooling of –1.12 °C for 1998-2016 or –1.43 °C for 2008-2015 (yellow circle and yellow cross in Figure 2b respectively). However, similar cooling periods has occurred previously with a slightly lower magnitude –for example, the period 1970-1980 with a change of –1.13 °C (yellow triangle in Figure 2b)– inside the overall warming trend. Therefore, even though recent cooling trend for a 20-year segment has the largest magnitude since 1958, it may not be considered robust until we do not have significant cooling trends for at least 30 years. Our results support then those of Turner et al. (2016) who shows that recent cooling is consistent with the internal variability of the region. This cooling period is still short and may be a 20-year persistent period (Ludescher 2016) inside the overall warming trend.

b) Seasonal Trends

In order to see how annual-mean temperature changes in the AP are distributed within the year we have examined the seasonal time-series. The evolution of temperature anomalies in the AP is shown in figure 3a and the associated two-dimensional LC diagrams are shown in figure 3b.

We found statistically significant positive temperature changes for the longest segments in all seasons, particularly large in MAM and JJA, as other studies suggest (Monaghan et al. 2008; Nicolas and Bromwich 2014). In DJF, the range of segments that exhibit statistically significant changes is wider than in the other seasons, and includes most periods over 20 years, even though the magnitude of the warming is lower and almost all periods beginning after the 1988 exhibit negative linear changes. In contrast with the results obtained for the other seasons, in SON we only find statistically significant warming in those periods ending around 2010 in which temperature anomalies were particularly large.

It is worth to notice that in summer, in addition to the lower magnitude of the warming, we observe weaker decadal variability. This behavior is probably related to the absence of the seasonal sea ice, in such a way that open sea damps the strong annual temperature changes (Franzke 2013). Therefore, decadal variability and long term signal of the annual temperatures on the AP is mainly produced by variability and signal in autumn and winter, with some contribution of summer warming for long periods.

4. Concluding remarks

Two-dimensional LC diagrams are used to contextualize the negative temperature trend observed in the AP since the beginning of the 21st century. This tool allows to inspect the robustness of significant trends in a region with strong variability as the AP. Our results indicate that the warming observed in the AP since the 1950s is robust, as most time intervals longer than 30 years exhibit strong and statistically significant linear changes. Instead, temperature trends for segments shorter than 30 years, as the recent cooling, are consistent with internal variability, as linear changes are generally non-significant and do not have a dominant sign.

We have also analysed the seasonal distribution of the observed warming in the AP showing that even though it is present in all seasons, it is particularly strong in MAM and JJA, and particularly robust in DJF (as most periods over 20 years exhibit a statistically significant linear change). In contrast, linear changes observed in SON are less robust.

We conclude that the significant negative change observed in the 1995-2015 interval is highly sensitive to the choice of time interval and, therefore, cannot be treated as a robust evidence of a change of sign in the evolution of the temperature in the AP. This study also highlights the importance of using tools like two-dimensional LC diagrams to monitor the temperature trends of a region with large variability as AP. Future work will focus on extending this approach to analyse the regional variability and forcing mechanisms at different scales inside AP.

Details of data deposit

Original data was obtained from the Reference Antarctic Data for Environmental Research (READER) project (Turner et al. 2004) [available on-line at https://legacy.bas.ac.uk/met/READER/]. Annual and seasonal anomalies of temperature used to calculate trends are stored in AEMET public repository [http://hdl.handle.net/20.500.11765/7913].

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Author contributions

Sergi Gonzalez designed the study and carry out the data analysis and wrote the first draft of the manuscript. Sergi Gonzalez and Didac Fortuny contributed to the interpretation and edit and wrote the final manuscript.

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Figure 1. Location of the Antarctic stations used to calculate temperature anomalies.

Figure 2. a) Time series of surface temperature anomalies on the Antarctic Peninsula. Blue line indicates the mean annual temperature annomaly and grey shaded area represent the one standard desviation between the time series of the different stations. The green, the yellow and the two red lines show the linear-fit for the periods 1958-2015, 1990-2015, 1970-2000 and 2000-2015 respectively. b) Two-dimensional LC diagram of annual temperatures in the Antarctic Peninsula. The vertical axis corresponds to the beginning year and the horizontal axis to the ending year of each segment. Diagonals (in green) correspond to segments with the same length (in years) and, therefore, values in the same diagonal should be interpreted as the running temperature changes. Red values indicate positive temperature changes (in °C) and blue values indicate negative changes. The contour includes statistically-significant changes at a 95% of confidence level.

Figure 3. a) Time series of surface temperature anomalies in the Antarctic Peninsula for each season. b) as in Fig 2b, but for seasonal linear changes.