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An Updated Reconstruction of Antarctic Near-Surface Air Temperatures at Monthly Intervals Since 1958

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Abstract. An updated near-surface temperature reconstruction for the Antarctic continent is presented for 1958 to 2022 (65 years) as monthly anomalies relative to 1981-2010 (RECON). It is based on monthly mean 2-m temperatures at 15 fixed stations that are spatially extrapolated to the entire continent using weights derived from the European Centre for Medium-Range Weather Forecasts 5th generation reanalysis (ERA5). Infilling of the fixed station records are performed where necessary to yield complete time series for 1958-2022. Variability and trends are tested at independent stations that have much shorter periods of record. RECON is designed for Antarctic climate variability and change applications for large spatial scales and extended time scales.

1. Introduction

Near-surface air temperature is a fundamental variable for describing and understanding the climate. For those regions of Earth that are remote and sparsely populated, establishing their temperature history from direct observations can be a major challenge. For Antarctica, a substantial network of permanent research stations was established in conjunction with the International Geophysical Year (IGY) of 1957-1958 (e.g., Jones et al., 2019), although there are isolated sites in the Antarctic Peninsula region that predate the IGY. One of these is Orcadas station that has the longest continuous temperature record south of 60°S and which started in 1903. As a result, the derivation of the continental temperature regime from meteorological observations should start from the IGY. One complication is that the temperature records were collected initially for weather forecasting purposes and the quality was not always suitable for detecting small climate changes. So, care is needed in applying these data to derive Antarctica's air temperature history.

2. Methodology

One key consideration for reconstructing the continental temperature from station observations is the spatial extrapolation from these point observations to the entire continent. For this task, we depend on global reanalyses that reconstruct the weather and climate across the entire Earth from a wide variety of meteorologically related observations. For Antarctica and the Southern Ocean, such reanalyses have much lower quality prior to 1979 when

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there was very limited satellite coverage over the data sparse Southern Ocean (e.g., Bromwich et al., 2024). So, our use of global reanalyses for spatial temperature extrapolation is restricted to after 1979, and even then spurious features such as artificial trends can be present. We employ temperature anomalies that the reanalyes tend to skillfully capture and that typically have a large spatial footprint especially for interior Antarctica (e.g., Zhu et al., 2021, Fig. 3; King et al., 2003).

Nicolas and Bromwich (2014) reconstructed the air temperature over Antarctica from monthly temperature observations at 15 fixed stations across Antarctica on a 60-km polar stereographic projection. These data were spatially extrapolated to the entire continent based on the statistical linkages between the stations and all grid points covering Antarctica from the Climate Forecast System Reanalysis (CFSR) for the 30-year period 1979-2009. The reconstruction closely matched the station observations, was not impacted by anomalous temperature trends in the reanalysis and was verified against independent temperature observations. It spanned 1958-2012 at monthly intervals. We present a new version of this data set in this manuscript.

To revise and update the Nicolas and Bromwich (2014) analysis, Belgrano Station is employed instead of Halley Station. This is done because the frequent relocation of the Halley observation site on the floating Brunt Ice Shelf led to artifacts in the temperature time series resulting in weak cooling for 1957-2019 whereas weak warming likely occurred (King et al., 2021). The other 14 stations used by Nicolas and Bromwich (2014) are applied here. Figure 1 locates these sites. The European Centre for Medium-Range Weather Forecasts (ECMWF) 5th Generation Reanalysis (ERA5; Hersbach et al., 2020) is employed to provide the spatial weights that extrapolate the station observations. ERA5 is a more modern and higher resolution global reanalysis than CFSR and has fewer issues with anomalous temperature trends (Gossart et al., 2019). Testing for the 1958-2012 period using the 15 stations employed by Nicolas and Bromwich (2014) demonstrated that CFSR and ERA5 based spatial extrapolation produced very similar results (not shown). Further, Nicolas and Bromwich (2014) and Screen and Simmonds (2012) found that spatial extrapolation to the entire continent from long-term station observations was relatively insensitive to the reanalysis used for near surface air temperatures and free atmosphere temperatures, respectively.

Monthly average 2-m temperatures from the 14 stations employed by Nicolas and Bromwich (2014) as well as Belgrano (Fig. 1) were updated through 2022. Table 1 describes the sources used for the updates (primarily the READER site; Turner et al., 2004), and the steps employed fill in the gaps that were present in the data from READER. The Belgrano Station record requires special discussion. The 1958-1960 values at Belgrano II (actual observations 1980-present) were based on Belgrano I 1958-1960 READER observations estimated for Belgrano II location by employing Halley Station monthly temperature observations that were available for both 1958-1960 as well as when Belgrano II was in operation. For 1961-1979 at Belgrano II, we used estimates produced by the Global Historical Climatology Network – Monthly Mean Temperature Version 4 (Menne et al., 2018), denoted as GHCNm version 4 QFE. Menne et al. (2018, p. 9847) outlined that the estimation procedure "iterates to find a set of neighboring correlated series for each station series requiring estimates (the target) that minimizes the confidence limits for the difference between the target values and estimates of these values derived using neighboring values. The difference between the target and neighbor average is used as an offset in the interpolation to account for climatological differences between the target and neighbors." For 1980 and later, the Belgrano II record provided by READER has 75% or more of the 6 hourly observations for each month that we adopt as a sound basis for computing reliable monthly mean temperatures. GHCNm version 4 QFE values are used for 4 missing data periods in 1980, 1981, 2002, and 2003 at Belgrano II. Other notable aspects from Table 1 are that GCHNm quality-controlled values (GHCNm version 4 QCF) are employed to fill short gaps in 9 station records from READER. GHCNm QFE estimates are used to fill extended periods with no observations for Davis, Syowa, and Vostok stations based on adjacent station observations.

The details of the spatial extrapolation method using ordinary kriging is paraphrased from Nicolas and Bromwich (2014). For each month (t), the temperature anomaly $\hat{A}(x,t)$ estimated at each point of the grid (x) covering continental Antarctica is derived from a linear weighted combination of the anomalies $A(i,t)$ observed at each of the 15 stations (denoted by i), according to the following Eq. (1):

$$\hat{A}(x,t) = \sum_{i=1}^{15} \eta_i W_i(x) A(i,t). \tag{1}$$

$W_i(x)$ is the weight at point x of the temperature anomaly observed at station i relative to the 1981-2010 mean and is equal to the square of Pearson's correlation coefficient between the ERA5 2-m air temperature anomaly at the station and that at grid point x with respect to the 1981-2010 mean after linearly detrending ERA5. The weights are optimized to minimize the estimation error by accounting for the covariances between the i station records. The station anomalies $A(i,t)$ are divided by their standard deviation (1981-2010) for normalization and to account for the spatial differences in variance. η_i accounts for the positive (+1) or negative (-1) sign of temperature correlation between the normalized station anomaly $A(i,t)$ and that at location x. The equation yields an estimated normalized temperature anomaly at each grid point (x) that is then multiplied by the ERA5 temperature standard deviation (1981-2010) at that point to yield the estimated temperature anomaly.

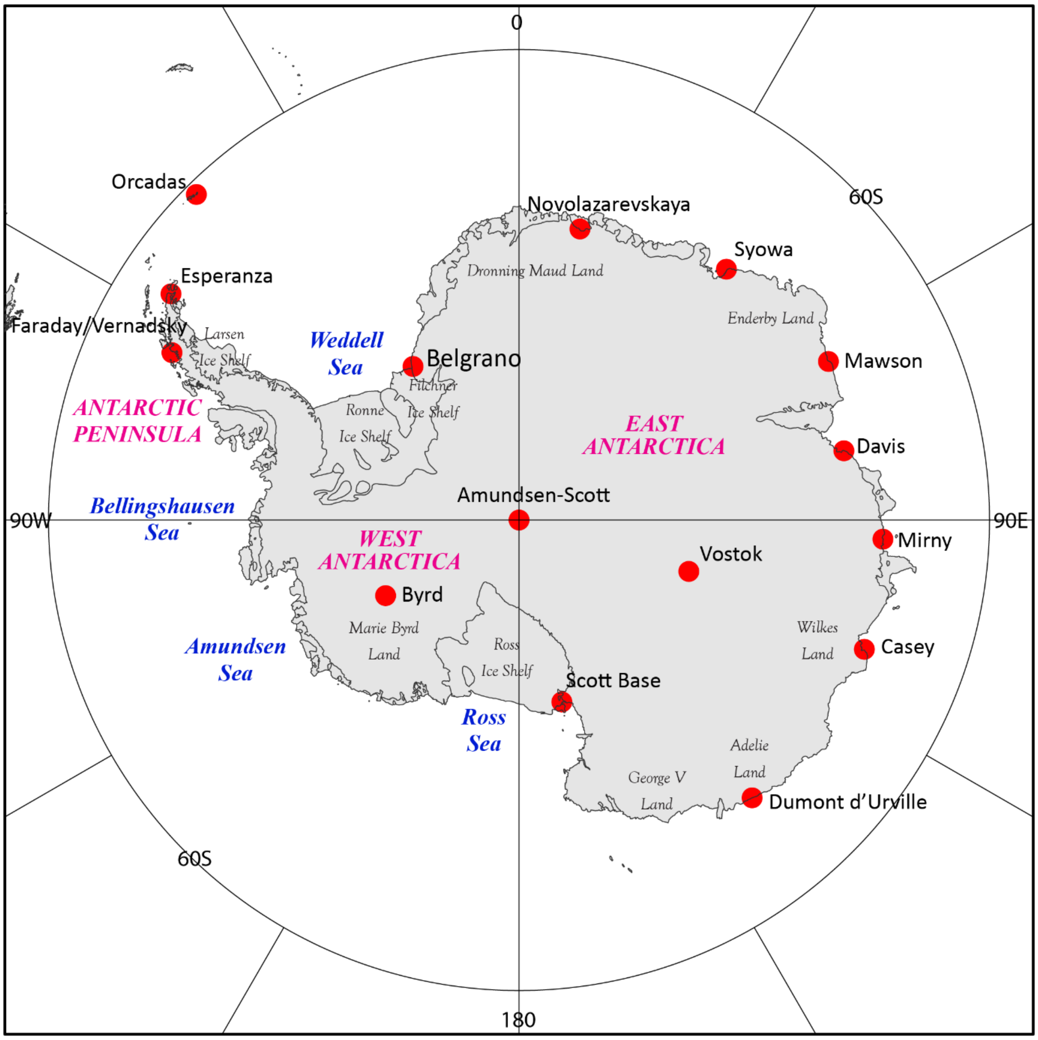

Figure 1: Antarctic stations (red dots) used to reconstruct the near surface air temperature over Antarctica at monthly intervals from 1958-2022.

ERA5 weights and the updated station records were employed to produce the updated Nicolas and Bromwich (2014) data set that now spans the 66 years from 1958-2022 at monthly intervals: it is called RECON for the remainder of this manuscript. ERA5 weights were calculated for the 13 available stations in 1958 (Syowa and Novolazarevskaya observations missing), 14 stations in 1959-1960 (Novolazarevskaya observations missing), and all 15 for 1961-2022 see Table 1.

Station	Other Observations	GHCNm QFE[2]	Missing
Belgrano II		61-79, 80(01-09), 81(01-05)	
		02(03-12), 03(01-03)	
Byrd	58-22[3]		
Casey	58(01-12)[1], 59(01)[1]		
Davis	16(05)[1]	64(11,12), 65(01-12), 66(01-12)	
		67(01-12), 68(01-12), 69(01,02)	
Dumont	14(04,11)[4], 15(01-06,09,10)[4]		
d'Urville	16(01,03-06,08-12)[4]		
	17(08)[1],19(03,04)[1], 21(05)[1]		
Esperanza	79(01,03)[1], 20(05)[1]	79(09,10,11,12)	
Faraday/	18(09)[1]		
Vernadsky			
Mawson			
Mirny	07(02,03,05,06)[1], 09(06)[1]		
Novolazareyskaya	09(10)[1]	61(01)	58(01-12)
			59(01-12)
			60(01-12)
Orcadas	02(03-12)[1], 03(01-12)[1]		
	09(02)[1], 20(05)[1], 21(04-12)[1]		
	22(01,02,06,08-11)[1]		
Scott Base	16-22[6]		94(01,02)
South Pole	58-22[5]		
Syowa		62(02-12), 63(01-12), 64(01-12)	58(02-12)
		65(01-12), 66(01)	59(01)
Vostok	07(02,03,05,06)[1], 09(06)[1]	62(01-12), 63(01), 94(02-11)	
		96(01-12), 03(02-12), 04(01,02)	

Primary Source: ***UK BAS, Met READER***	
Other Data Sources:	[1]**GHCNm v4 QCF**
	[2]**GHCNm v4 QFE**
	[3]**OSU Polar Meteorology Group**
	[4]**Meteo France**
	[5]**University of Wisconsin-Madison**
	[6]**The National Institute of Water and Atmospheric Research Ltd (NIWA), NZ**

Table 1: Data sources employed to fill gaps in the READER data sets to produce RECON. The filled months are indicated by YY(MM) or YY(MM-MM) format.

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3. Tests of the Temperature Reconstruction Against Independent Observations

To validate RECON for Antarctica, we first confirm that RECON fits closely with the observed monthly temperatures at the stations used in the reconstruction, also termed anchor stations. Table 2 demonstrates for those 15 locations (shaded) the correlation is close to 1 at nearly all sites, the bias is minimal, and the root mean square error (RMSE) is small. The significantly smaller correlation for Orcadas may be caused by its location near the edge of our grid where the atmospheric circulation is more impacted by lower latitude processes. Thus, RECON reproduces the observations at the anchor sites with high skill.

Next we compare RECON's monthly values against observed monthly temperatures from the READER site not used in the reconstruction (Table 2, unshaded). Almost all of these are from the period after 1979 and are selected so that 10 or more years of continuous observations are available. Stations immediately adjacent to the anchor sites have been excluded and regions with numerous sites, like Terra Nova Bay, are represented by one site. Spatial coverage of Antarctica was also a consideration. 28 of the 57 stations used by Nicolas and Bromwich (2014) were examined along with the addition of 6 new sites. Of the 34 independent stations employed here, only 6 are staffed with the rest being automatic weather stations On average the bias is tiny and the correlation between RECON and the observations is 0.76. Looking at the individual stations, the correlation is 0.7 or larger at 25 of the 34 independent stations, and the absolute bias is much smaller than 1°C at 31 of the 34 stations. Dome A, the highest point on the East Antarctic Ice Sheet, is a particularly challenging location where surface winds are controlled by the synoptic scale circulation and record low air temperatures can occur in winter (Scambos et al., 2018). Overall, the skill statistics for the current reconstruction dominantly for 1979-2022 using independent observations are comparable to those given by Nicolas and Bromwich (2014) for their 57 stations for 1979-2012.

An additional test of RECON skill at the observation sites is provided in Table 2 by the R^2 metric employed by Nicolas and Bromwich (2014) and defined in their Appendix. This quantity measures the fraction of observational variance explained by RECON and the entire reconstruction period is considered. It is a more conservative estimate than $1 - r^2$. Table 2 shows that R^2 averages 0.98 for the anchor sites and 0.52 for the independent sites. That is, RECON explains on average 52% of the observational anomaly variance at the independent sites. Individual problematic sites where R^2 is low are Dome A especially, Relay Station, and Troll. The average R^2 for independent stations obtained here is slightly smaller than those given by Nicolas and Bromwich (2014) for 1979-2012 in their Table 3.

Station	Data Coverage	Lat	Lon	Elevation (m)	Bias	RMSE	r	R^2
Byrd	1958-2022	-80.10	-119.32	1530.0	0.01	0.26	1.00	0.99
Faraday	1958-2022	-65.10	-65.15	11.0	0.07	0.51	0.98	0.98
Orcadas	1958-2022	-60.40	-44.44	6.0	-0.02	1.60	0.68	0.99
Casey	1958-2022	-66.30	110.50	42.0	-0.01	0.34	0.99	0.97
Scott Base	1958-2022	-77.50	166.45	16.0	0.01	0.31	1.00	1.00
Davis	1958-2022	-68.60	78.00	13.0	0.02	0.39	0.98	0.97
Mawson	1958-2022	-67.60	62.90	16.0	0.01	0.32	0.99	0.97
South Pole	1958-2022	-90.00	0.00	2835.0	-0.02	0.21	1.00	1.00
Dumont d'Urville	1958-2022	-67.00	140.00	43.0	-0.01	0.27	0.99	0.99
Mirny	1958-2022	-66.50	93.00	30.0	-0.02	0.51	0.97	0.93
Syowa	1959-2022	-69.00	39.35	21.0	0.03	0.37	0.99	0.99
Esperanza	1958-2022	-63.20	-56.59	13.0	0.00	0.30	0.99	0.99
Novolazarevskaya	1961-2022	-70.50	11.49	119.0	0.01	0.12	1.00	1.00
Vostok	1958-2022	-78.50	106.90	3490.0	-0.01	0.17	1.00	1.00
Belgrano II	1958-2022	-77.90	-34.60	256.0	0.01	0.52	0.98	0.91
Elaine	1993-2022	-83.10	174.20	60.0	-0.22	2.45	0.83	0.50
Lettau	1986-2022	-82.50	-174.40	55.0	-0.12	2.41	0.85	0.55
Bellingshausen	1968-2022	-62.20	-58.90	16.0	0.03	0.99	0.86	0.58
Fossil Bluff	2005-2022	-71.30	-68.50	66.0	-0.02	2.14	0.70	0.39
Leningradskaya	1972-1991	-69.50	159.40	304.0	0.22	1.34	0.65	0.44
Molodezhnaya	1963-1999	-67.70	45.90	40.0	-0.12	0.84	0.86	0.72
Neumayer	1981–2022	-70.70	-8.40	50.0	0.08	1.88	0.61	0.35
Rothera	1976–2022	-67.50	-68.10	32.0	0.06	1.18	0.89	0.75
Russkaya	1980–1990	-74.80	-136.90	124.0	-0.36	1.69	0.85	0.68
Butler Island	1980–2022	-72.20	-60.20	91.0	0.18	2.13	0.59	0.30
Cape Philips	1980–2022	-73.10	169.60	310.0	-0.02	1.26	0.69	0.47
D-47	2009-2022	-67.40	138.70	1560.0	-0.05	1.48	0.77	0.58
Dome A	2005-2022	-80.40	77.40	4048.0	3.60	5.27	0.44	0.01
Dome C II	1996-2022	-75.10	123.40	3280.0	-0.03	1.84	0.74	0.44
Drescher	1992–2003	-72.87	-19.03	34.0	-0.13	1.99	0.53	0.25
Elizabeth	1996–2012	-82.60	-137.10	549.0	-0.12	1.97	0.84	0.64
GC41	1984–2005	-71.60	111.30	2763.0	-0.06	2.74	0.67	0.36
GF08	1986–2007	-68.50	102.10	2125.0	0.06	2.35	0.75	0.49
Gill	1985-2022	-80.00	-178.60	30.0	-0.09	2.22	0.87	0.60
Harry	1994–2022	-83.00	-121.40	954.0	-0.16	1.26	0.89	0.79
Larsen Ice Shelf	1995–2022	-66.90	-60.90	17.0	0.28	2.16	0.68	0.44
LG10	1993-2004	-71.30	59.20	2619.0	-0.11	1.20	0.80	0.62
LG20	1991-2004	-73.80	55.70	2743.0	-0.08	1.16	0.83	0.67
LG35	1994-2007	-76.00	65.00	2345.0	0.07	1.10	0.85	0.71
LG59	1994-2003	-73.50	76.78	2565.0	0.02	1.09	0.83	0.68
Law Dome Summit	1987-1997 2003-2010	-66.70	112.70	1368.0	-0.09	1.18	0.79	0.62
Limbert	1995–2022	-75.40	-59.90	40.0	0.32	2.18	0.77	0.37
Manuela	1984–2022	-74.90	163.70	80.0	-0.26	1.12	0.77	0.55
Marble Point	1980–2022	-77.40	163.70	120.0	-0.10	0.71	0.96	0.89
Marilyn	1987–2022	-80.00	165.10	75.0	0.11	1.25	0.89	0.77
Mount Siple	1992-2005	-73.20	-127.10	30.0	0.22	1.36	0.75	0.54
Relay Station	1995–2022	-74.00	43.10	3353.0	-1.57	2.73	0.71	0.13
Theresa	1994–2022	-84.60	-115.80	1463.0	-0.25	1.35	0.78	0.57
Troll	2010-2019	-72.00	2.50	1284.0	-0.84	1.94	0.58	0.17
Avg. (15 stations)					**0.01**	**0.41**	**0.97**	**0.98**
Avg. (34 ind. stations)					**0.01**	**1.76**	**0.76**	**0.52**

Shading indicates stations that are used to develop the temperature reconstruction RECON. Several independent stations have missing data longer than 12 months.

Table 2: Bias, Root-mean-square deviation (RMSE), Pearson's correlation coefficient (r), and fractional observational variance explained by the reconstruction (R^2) between temperature reconstruction dataset and station observations with longer-term records, including 34 independent stations. Monthly anomalies are employed.

To confirm that RECON reproduces the observed long-term 2-m air temperature trends at independent stations that are not used to generate it, a selection of 10 sites with records mostly exceeding 35 years has been made. All are coastal or near sea level locations apart from the interior Dome C II record that spans 27 years. Almost all locations started after 1979. Modest infilling of the AWS monthly data has been done to produce complete time series. The 4 staffed stations at the top of the table have nearly complete records. Extended periods of comparison are used so that any trends are less likely to be totally swamped by the variability. Table 3 presents the annual temperature trends at the selected stations as well as those from RECON and ERA5. ERA5 is included because it is used next in an example application. It is seen that RECON reasonably captures the trends at all selected sites, and on average does better than ERA5, although variability challenges all these comparisons. The comparison for Neumayer confirms the erroneous ERA5 warming in that region (Bromwich et al., 2024). We therefore conclude that RECON on average captures long-term temperature trends across Antarctica, implying the RECON is appropriate for large-scale analyses. The large spacing between the anchor stations also indicates that localized features would not be resolved. The spatial averaging of RECON is also consistent with the decreased temporal variability that leads to an improved focus on temporal trends.

Station	Data Coverage	OBS		RECON		ERA5	
		Trend	CI (95%)	Trend	CI (95%)	Trend	CI (95%)
Molodezhnaya	1963-1999 (37)	-0.02	0.18	0.02	0.19	0.11	0.21
Rothera	1977-2022 (46)	0.49	0.26	0.34	0.16	0.42	0.20
Neumayer	1981-2022 (42)	-0.11	0.16	0.01	0.09	0.54	0.18
Bellingshausen	1968-2022 (55)	0.20	0.12	0.29	0.14	0.26	0.12
Lettau	1986-2022 (37)	0.10	0.35	0.15	0.17	0.49	0.37
Marble Point	1980-2022 (43)	0.30	0.21	0.17	0.19	-0.04	0.23
Manuela	1985-2022 (38)	0.35	0.18	0.15	0.13	0.62	0.19
Gill	1985-2022 (38)	0.23	0.33	0.10	0.16	0.44	0.34
Dome C II	1996-2022 (27)	0.20	0.40	0.12	0.20	0.17	0.42
Butler Island	1990-2022 (33)	-0.12	0.35	0.18	0.11	-0.16	0.37
Average		0.16	0.14*	0.15	0.07*	0.29	0.19*

Table 3: 2-m air temperature trend comparison (°C/decade) between observations, RECON, and ERA5 at stations with records mostly exceeding 35 years. Number of years entered in parentheses next to record duration. Asterisk values are 95% confidence intervals for average trends. Locations listed in Table 2.

4. Example Application

Turner et al. (2016) reported that the Antarctic Peninsula region started to cool in 1998 especially during austral summer after decades of warming. Tropically forced decadal variability was inferred to be the cause. The warming apparently resumed in the late 2010s (Carrasco et al., 2021). Similarly, the long-term warming over West Antarctica (Bromwich et al., 2013, 2014) was interrupted around the same time (Zhang et al., 2023). Xin et al. (2023) extracted the primary modes of Antarctic temperature change from 6 reanalyses and 26 observations and noted a marked change in the temperature regime took place around 2000. Figure 2 presents the annual and seasonal continental temperature trends for 1998-2022 according to RECON and ERA5. The annual depictions are broadly similar with some notable differences. The northern Antarctic Peninsula is warming strongly in ERA5 while RECON has trends near zero. ERA5 has marked cooling over the Filchner-Ronne Ice Shelf while RECON finds modest warming, both of which are statistically significant in some regions. As a result of Byrd Station observations and less RECON variability, the annual cooling over West Antarctica is much more marked (and statistically significant) in RECON than ERA5. ERA5's annual warming in Enderby Land is double that of RECON with both being statistically significant. The seasonal trends have a similar pattern but the ERA5 amplitudes are much larger. To ensure the reliability of these results, seasonal and annual trends at the 15 anchor stations were computed for ERA5, RECON, and the observations (not shown). In general, RECON trends were much closer to the observational ones than ERA5 and ERA5 often had significantly larger trends. In addition, ERA5 contains three warming hotspots that continue to 2022 and are artifacts (Bromwich et al., 2024). The results from Table 3 and the findings outlined in this paragraph indicate that the real world more closely follows the RECON depiction than that provided by ERA5.

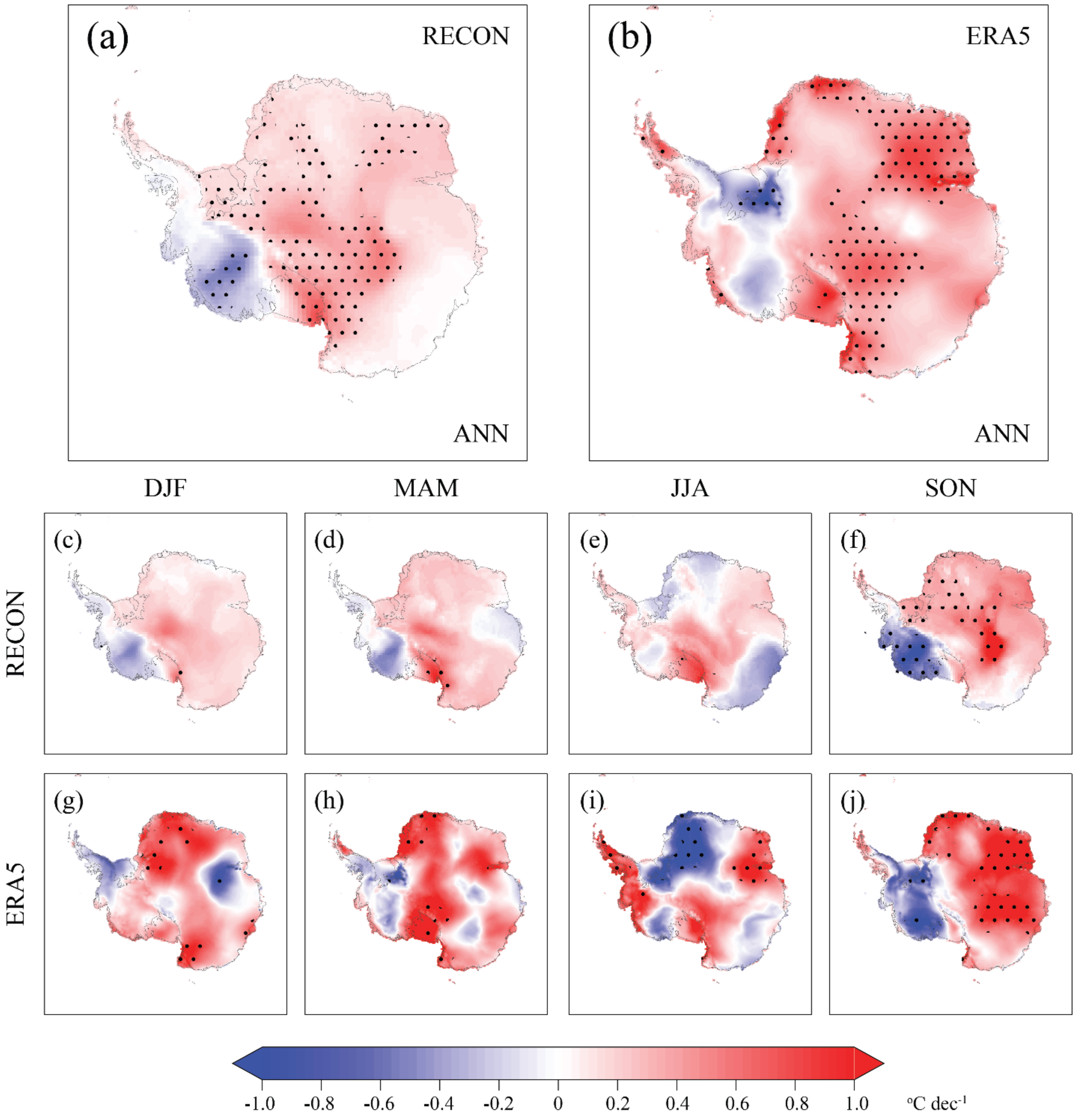

Figure 2: Annual linear temperature trends from ERA5 (left) and RECON (right) for 1998-2022. The dots indicate statistical significance of the linear trends at the 0.01 level after considering the lag-1 autocorrelation after Santer et al. (2000).

5. Data Availability

READER: https://legacy.bas.ac.uk/met/READER/
Global Historical Climate Network: https://www.ncei.noaa.gov/products/land-based-station/global-historical-climatology-network-monthly
OSU Polar Meteorology Group: Byrd Station: https://polarmet.osu.edu/datasets/Byrd_recon/
Meteo France: https://meteofrance.com/
University of Wisconsin-Madison: South Pole: https://amrdcdata.ssec.wisc.edu/dataset/amundsen-scott-south-pole-station-climatology-data-1957-present-ongoing
National Institute for Water and Atmospheric Research: Scott Base: https://cliflo.niwa.co.nz
RECON data described in this manuscript can be accessed at the Antarctic Meteorological Research and Data Center under https://doi.org/10.48567/efwt-jw56 (Bromwich and Wang, 2024)

6. Conclusions

A reconstruction of Antarctic near-surface air temperatures at monthly intervals for 1958-2022 is presented. It is an update of an earlier data set produced by Nicolas and Bromwich (2014) and shows skill in reproducing temperature trends at independent stations. The reconstruction is intended for Antarctic temperature trend analysis for large space and longtime scales.

Some desirable improvements can be identified. The southeast Weddell Sea needs a more robust record than presented here for Belgrano II that has significant infilling. Perhaps the best solution is to homogenize the presently inhomogeneous Halley temperature record. As shown by King et al. (2021) this will require removing the impact of the spatial temperature gradients on the Brunt Ice Shelf from the Halley temperature record that comes from varying station locations and will take significant effort to achieve. Xin et al. (2023) concluded that summer warming over interior Antarctica may be related to radiative effects of stratospheric ozone and thus be a special environment. Also, Xie et al. (2023) found from ERA5 for 1958-2020 that Antarctic surface warming amplifies with elevation; this result is uncertain because of major artifacts in ERA5 especially prior to 1979 (Bromwich et al. 2024). These two findings suggest that further testing of the RECON trends is desirable for those parts of the East Antarctic plateau remote from South Pole and Vostok stations to see whether the issues at Dome A and to a lesser extent at Relay Station (Table 2) are localized.

Author contributions

DHB designed the project, wrote the manuscript, and oversaw the analysis. SHW produced RECON data and performed the analysis with important contributions from XZ and AE.

Competing interests

The authors declare that they have no conflict of interest.

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References:

Bromwich, D. H., Nicolas, J. P., Monaghan, A. J., Lazzara, M. A., Keller, L. M., Weidner, G. A., and Wilson, A. B.: Central West Antarctica among the most rapidly warming regions on Earth, Nat. Geosci., 6, 139–145, https://doi.org/10.1038/ngeo1671, 2013.

Bromwich, D. H., Nicolas, J. P. Monaghan, A. J., Lazzara, M. A., Keller, L. M., Weidner, G. A., and Wilson, A. B.: Corrigendum: Central West Antarctica among the most rapidly warming regions on Earth, Nat. Geosci., 7, 76, https://doi.org/10.1038/ngeo2016, 2014.

Bromwich, D. H., Ensign, A., Wang, S.-H., and Zou, X.: Major artifacts in ERA5 temperature trends over Antarctica prior to and during the modern satellite era. Geophys. Res. Letts., in press, 2024.

Bromwich, D. H., and Wang, S.-H.: Reconstruction of Antarctic Near-Surface Air Temperatures at Monthly Intervals Since 1958. AMRDC Data Repository, https://doi.org/10.48567/efwt-jw56, 2024.

Carrasco, J. F., D. Bozkurt, D., and Codero, R. R.: A review of the observed air temperature in the Antarctic Peninsula. Did the warming trend come back after the early 21st hiatus? Polar Science, 28, https://doi.org/10.1016/j.polar.2021.100653, 2021.

Gossart, A., Helsen, S., Lenaerts, J. T. M., Vanden Broucke, S., van Lipzig, N. P. M., and Souverijns, N.: An evaluation of surface climatology in state-of-the-art reanalyses over the Antarctic Ice Sheet, J. Climate, 32, 6899-6915, https://doi.org/10.1175/JCLI-D-19-0030.1, 2019.

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., et al..: The ERA5 global reanalysis, Quart. J. Royal Meteor. Soc., 146, 1999-2049, https://doi.org/10.1002/qj.3803, 2020.

Jones, M. E., Bromwich, D. H., Nicolas, J. P., Carrasco, J., Plavcová, E., Zou, X., and Wang, S.-H.: Sixty years of widespread warming in the southern mid- and high-latitudes (1957-2016), J. Climate, 32, 6875-6898, https://doi.org/10.1175/JCLI-D-18-0565.1, 2019.

King, J. C., van Lipzig, N. P. M., Connolley, W. M., and Comiso, J. C.: Are temperature variations at Antarctic ice core sites representative of broad-scale climate variations? Seventh Conference on Polar Meteorology and Oceanography and Joint Symposium on High-Latitude Climate Variations, American Meteorological Society, Boston, Massachusetts, https://ams.confex.com/ams/7POLAR/webprogram/Paper61095.html, 2003.

King, J. C., Turner, J., Colwell, S., Lu, H., Orr, A., Phillips, T., Hosking, J. S., and Marshall, G. J.: Inhomogeneity of the surface air temperature record from Halley, Antarctica. J. Climate, 34, 4771-478, https://doi.org/10.1175/JCLI-D-20-0748.1, 2021.

Menne, M. J., Williams, C. N., Gleason, B. E., Rennie, J. J., and Lawrimore, J. H.: The Global Historical Climatology Network Monthly Temperature Dataset, Version 4, J. Climate, 31, 9835-9854, https://doi.org/10.1175/JCLI-D-18-0094.1, 2018.

Nicolas, J. P., and Bromwich, D. H.: New reconstruction of Antarctic near-surface temperatures: Multidecadal trends and reliability of global reanalyses, J. Climate, 27, 8070-8093, doi: 10.1175/JCLI-D-13-00733.1, 2014.

Santer, B. D., Wigley, T. M. L., Boyle, J. S., Gaffen, D. J., Hnilo, J. J., Nychka, D., Parker, D. E., and Taylor, K. E.: Statistical significance of trends and trend differences in layer-average atmospheric temperature time series, J. Geophys. Res., 105, 7337–7356, https://doi.org/10.1029/1999JD901105, 2000.

Scambos, T. A., Campbell, G. G., Pope, A., Haran, T., Muto, A., Lazzara, M., Reijmer, C. H., and van den Broeke, M. R.: Ultralow surface temperatures in East Antarctica from satellite thermal infrared mapping: The coldest places on Earth, Geophys. Res. Letts., 45, 6124–6133, https://doi.org/10.1029/ 2018GL078133, 2018.

Screen, J. A., and Simmonds, I.: Half-century air temperature change above Antarctica: Observed trends and spatial reconstructions, Journal of Geophysical Research, 117, D16108, doi:10.1029/2012JD017885, 2012.

Turner, J., Colwell, S. R., Marshall, G. J., Lachlan-Cope, T. A., Carleton, A. M., Jones, P. D., et al.: The SCAR READER project: Toward a high-quality database of mean Antarctic meteorological observations, J. Climate, 17, 2890–2898, https://doi.org/10.1175/1520-0442(2004)017<2890:TSRPTA>2.0.CO;2, 2004

Turner, J., Lu, H., White, I., King, J. C., Phillips, T., Hosking, J. S., Bracegirdle, T. J., Marshall, G. J., Mulvaney, R., and Deb, P.: Absence of 21st century warming on Antarctic Peninsula consistent with natural variability, Nature, 535, 411–415, https://doi.org/10.1038/nature18645, 2016.

Xie, A., Zhu, J. Qin, X. Wang. S. Xu, B., and Wang Y.: Surface warming from altitudinal and latitudinal amplification over Antarctica since the International Geophysical Year, Scientific Reports,13, 9536, https://doi.org/10.1038/s41598-023-35521-w, 2023.

Xin, M., Li, X., Stammerjohn, S. E., Cai, W., Zhu, J., Turner, J., Clem, K. R., Song, C., Wang, W., and Hou, Y.: A broadscale shift in antarctic temperature trends, Clim. Dyn., 61, 4623–4641, https://doi.org/10.1007/s00382-023-06825-4, 2023.

Zhang, X., Wang, Y., Hou, S., and Heil, P.: Significant West Antarctic cooling in the past two decades driven by tropical Pacific forcing, Bull. Amer. Meteor. Soc., 104, E1154-E1165, https://doi.org/10.1175/BAMS-D-22-0153.1, 2023.

Zhu., J., Xie, A., Qin, X., Wang, Y., Xu, B., and Wang, Y.: An assessment of ERA5 reanalysis for Antarctic near-surface air temperature, Atmosphere, 12, 217, https://doi.org/10.3390/atmos12020217, 2021.