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Brief communication: Significant cold bias in ERA5 output for McMurdo region, Antarctica

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Abstract. The ERA5 climate reanalysis dataset plays an important role in applications such as monitoring and modelling climate system changes in polar regions, so the calibration of the reanalysis to ground observations is of great relevance. Here, we compare the 2-meter air temperature time series of the ERA5 reanalysis to the near-ground air temperature measured in 17 Automatic Weather Stations in the McMurdo Sound, Antarctica. We find that the reanalysis data has a systematic cold bias of ~ 5°C. Our results show that future work should rely on secondary observations to calibrate when using the ERA5 reanalysis in polar regions.

Short Summary. By analyzing temperature time series over more than 20 years, we have found a discrepancy between the 2-meter temperature values reported by the ERA5 reanalysis and the Automatic Weather Stations in the McMurdo Sound, Antarctica. The ERA5 reanalysis temperatures are systematically colder by ~5°C.

1. Introduction

ERA5 dataset represents the fifth iteration of ECMWF (European Center for Medium-Range Weather Forecasts) global climate hindcasting derived by combination of climate data assimilation and climate simulations (Hersbach et al, 2020). With its global coverage, high temporal resolution, and relatively high spatial resolution of 31 km this dataset may prove particularly useful for research in polar regions such as

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Antarctica, where long-term climate observations are geographically sparse and often temporally discontinuous (Lazzara et al, 2012). A recent study found encouraging agreement between ERA5 output and AWS (Automatic Weather Station) data from 13 stations located in the southern section of Antarctic Peninsula (Tetzner et al., 2019).

Here, we report the results of a comparison between monthly 2-meter air and ground temperatures in the McMurdo region, Antarctica, reported in the ERA5 dataset and corresponding observations from 17 AWS locations across this region. We focus our analysis on this region because of the relatively high spatial and temporal coverage of AWS observations and due to the high multidisciplinary research interest in this region which contains the main USA and New Zealand research stations and is proximal to Italian and Korean research stations. Despite the encouraging results found by Tetzner et al. (2019) for the southern Antarctic Peninsula, we find a significant cold bias in ground temperatures and air temperatures in our study area.

2. Data and methods

We analyze the daily surface temperature (2-meter temperature) recorded at 17 AWS (Figure 1) managed by the McMurdo Dry Valleys Long Term Ecological Research Project (LTER) since 1992, although some of the stations have been reporting data only since 1986 (Doran et al., 2002;). We compare the AWS data to the monthly ECMWF ERA5 climate reanalysis surface temperature data (Muñoz Sabater, 2019) and we also we tested against the near-surface bias-corrected reanalysis dataset (Cucchi et al., 2022). For each

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LTER AWS, where daily 2-meter air temperature data was available, we ran a 30-day moving average filter with 0% overlap to obtain monthly time series. The ERA5 grid node used in comparisons to each individual AWS was selected by minimizing the haversine distance between each AWS and all the nodes in the reanalysis grid. Finally, we interpolated both time series to a regular monthly sequence. The time series for the ERA5 node data were truncated to match the periods where data was available at their corresponding AWS. We report the mean temperature for the span of each time series and the standard error of the mean for each sample.

Furthermore, we compare the two data sets by analyzing the correlograms and performing a linear regression. Figure 2.b shows an example of this comparison. We report the squared correlation coefficients (R^2) as a metric of the goodness of fit and the p-values from the F-statistic to assess the level of statistical significance.

3. Results

Table 1 summarizes the results of our comparison. Even though some of the largest differences in the mean between the AWS station and the closest ERA5 grid node are observed for stations at high altitudes (e.g., Beacon Valley and Mt. Fleming) there are other stations at relatively high altitudes that report a smaller bias (e.g., Friis Hills) and conversely, the Taylor Valley AWS station is not at a high altitude, but it does report a significant bias. The only station where the ERA5 average temperature was warmer than the corresponding AWS was located at Lake Vida, in Wright Valley.

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Table 1. List of available AWS in the McMurdo Dry Valleys region and comparison to ERA5 closest node.

AWS Location name	AWS ID	Latitude	Longitude	Elevation (m.a.s.l.)	Distance to ERA5 node (km)	AWS data date range	Avg 2m air temperature @ AWS	Avg 2m air temperature @ ERA5 node	AWS_{mean_temp}-$ERA5_{mean\_temp}$
Beacon Valley	BENM	-77.828	160.6569	1176.0	3.27	2000-12-11 - 2012-11-19	-21.48 ± 0.7	-33.39 ± 0.69	11.91 ± 1.39
Lake Bonney	BOYM	-77.7147	162.4646	64.0	1.84	1993-12-08 - 2018-10-09	-17.26 ± 0.61	-23.85 ± 0.43	6.59 ± 1.04
Lake Brownworth	BRHM	-77.4344	162.7036	279.0	3.83	1995-01-23 - 2018-11-10	-19.94 ± 0.66	-25.28 ± 0.52	5.34 ± 1.18
Canada Glacier	CAAM	-77.6133	162.9644	264.0	1.71	1994-12-18 - 2011-01-05	-16.36 ± 0.72	-22.93 ± 0.61	6.57 ± 1.33
Commonwealth Glacier	COHM	-77.5646	163.2823	290.0	3.96	1993-12-06 - 2018-10-30	-17.69± 0.47	-21.94 ± 0.51	4.25 ± 0.98
Explorer's Cove	EXEM	-77.5887	163.4175	25.0	1.32	1997-12-05 - 2018-11-23	-18.97 ± 0.7	-21.51 ± 0.55	2.54 ± 1.25
Mt. Fleming	FLMM	-77.5327	160.2714	1870.0	3.7	2011-01-22 - 2018-11-11	-24.2 ± 0.58	-33.84 ± 0.76	9.65 ± 1.34
Lake Fryxell	FRLM	-77.6113	163.1701	19.0	1.45	1994-12-12 - 2018-11-19	-19.78 ± 0.7	-22.22 ± 0.51	2.44 ± 1.21
Friis Hills	FRSM	-77.7474	161.5162	1591.0	5.28	2011-01-04 - 2018-11-06	-22.56 ± 0.63	-26.69 ± 0.75	4.13 ± 1.38
Garwood Ice Cliff	GAFM	-78.0259	164.1315	51.0	2.97	2012-01-24 - 2012-12-19	-16.66 ± 2.79	-23.49 ± 2.28	6.84 ± 5.07
Howard Glacier	HODM	-77.6712	163.0773	472.0	3.25	1993-12-04- 2018-10-31	-17.18 ± 0.44	-20.6 ± 0.47	3.42 ± 0.91
Lake Hoare	HOEM	-77.6254	162.9005	77.0	2.82	1987-11-25 - 2018-11-29	-17.61 ± 0.51	-23.53± 0.42	5.92 ± 0.93
Miers Valley	MISM	-78.1011	163.7877	51.0	0.31	2012-02-11 - 2018-11-06	-16.69 ± 0.97	-23.1 ± 0.91	6.41 ± 1.88
Taylor Glacier	TARM	-77.74	162.1314	334.0	4.51	1994-12-05 - 2018-11-05	-16.9 ± 0.5	-25.23 ± 0.43	8.34 ± 0.93
Upper Howard	UHDM	-77.686	163.145	N/A	1.89	2001-11-28 - 2003-12-24	-16.56 ± 1.49	-20.15 ± 1.73	3.59 ± 3.22

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Lake Vanda	VAAM	-77.5257	161.6913	296.0	2.87	1994-12-08 - 2018-12-07	-19.58 ± 0.75	-24.96 ± 0.44	5.38 ± 1.19
Lake Vida	VIAM	-77.3778	161.8007	351.0	2.47	1995-12-08 - 2018-11-14	-26.68 ± 0.96	-23.93 ± 0.48	-2.74 ± 1.44

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Figure 2.a illustrates the comparison of AWS and ERA5 monthly temperature time series for one of 17 locations used in this study (Lake Hoare) over the time span of two decades. The cold bias is clearly visible and persistent throughout the period covered by the AWS data. The monthly temperature mismatch is particularly large during the summer months, when observations indicate actual temperatures were up to +10°C higher than ERA5 temperatures (e.g., Figure 2b). Over the rest of the year the mismatch shrank to the range of 2-6°C. Figure 2.b suggests that there is a strong seasonality in the relationship between the data sets. During the austral Winter and Summer seasons the temperatures are generally closely clustered together, systematically being closer correlated during the Winter and more dispersed during the Summer. The Spring and Fall seasons show a hysteresis that is repeated over all the comparisons. As the environment warms up during the Spring months the ERA5 temperatures are above the best-fit line and drop below it during the Fall. These seasonal biases may ultimately be helpful in revealing what climate processes must be better represented in the ERA5 reanalysis to eliminate the strong observed temperature bias.

4. Discussion

Our results differ significantly from the findings reported by Tetzner et al. (2019) for the Southern Antarctic Peninsula - Ellsworth Land region. For that region there is a slight cold bias of the ERA5 surface temperatures close to the coast (-0.51°C ± 0.74) and a slight warm bias in the mountain range escarpment

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(+0.14°C ± 0.72) which has encouraging implications for using the reanalysis data where there is no AWS coverage, which represents most of Antarctica. In contrast, we find no clear topographic dependence on the temperature differences between AWS and ERA5 data, even though the largest differences are indeed in two high altitude areas, Beacon Valley and Mount Fleming. The magnitude of the overall cold bias (average of all differences) is more than an order of magnitude larger (5.33 ± 0.76 °C) as compared to the study of Tetzner et al. (2019) and seems to be systematic. TheERA5 temperatures show a large overshoot during the summer, with an average difference of 6.7 ± 0.8 °C (e.g., Figure 2). This may be a particularly significant problem given the fact that warm summer temperatures determine the annual melt rate of snow, glaciers, and permafrost in Antarctica. The bias presented here is also present when using the near-surface bias-corrected reanalysis dataset (Cucchi et al., 2022). Modelling of snow or ice melting driven by ERA5 temperatures (e.g., Costi et al., 2018) with a strong cold bias, as observed in our study region, will result in a significant underestimate of summer melt production. Although the ERA5 reanalysis is an outstanding source of global climate variables, the discrepancy between our results and those obtained by Tetzner et al. (2019) suggests that secondary observations should be used to test the reliability of the ERA5 dataset in polar regions.

5. Conclusions

We have compared the surface temperature (2-meter temperature) recorded at 17 AWS in the McMurdo Dry Valleys, Antarctica with temperatures from the ERA5 reanalysis dataset. We found that the temperatures reported by the global climate reanalysis are, on average, 5.34 ± 0.76 °C colder than the temperatures recorded at the permanent weather stations. The cold temperature bias appears to be the largest during the warm summer months (6.7 ± 0.8 °C), when loss of snow and ice to melting is the largest. We advise using secondary observations to assess the accuracy of parameters included in ERA5 reanalysis for polar regions.

Data availability. The AWS data were provided by the NSF-supported McMurdo Dry Valleys Long Term Ecological Research program (OPP-1637708) and can be accessed at: https://mcm.lternet.edu/meteorological-stations-location-map. The "ERA5-Land hourly data from 1950 to present" (DOI: 10.24381/cds.e2161bac) and the "Near surface meteorological variables from 1979 to 2019 derived from bias-corrected reanalysis" (DOI: 10.24381/cds.20d54e34) were downloaded from the Copernicus Climate Change Service (C3S) Climate Data Store.

Author contributions. ST conceived the study. RGG performed the analysis. RGG and ST prepared the manuscript with equal contributions.

Competing interests. The authors declare that they have no conflict of interest.

References

Costi, J., Arigony-Neto, J., Braun, M., Mavlyudov, B., Barrand, N.E., Da Silva, A.B., Marques, W.C. and Simoes, J.C., 2018. Estimating surface melt and runoff on the Antarctic Peninsula using ERA-Interim reanalysis data. Antarctic Science, 30(6), pp.379-393.

Cucchi M., Weedon G. P., Amici A., Bellouin N., Lange S., Müller Schmied H., Hersbach H., Cagnazzo, C. and Buontempo C., 2022. Near surface meteorological variables from 1979 to 2019 derived from bias-corrected reanalysis, version 2.1. Copernicus Climate Change Service (C3S) Climate Data Store (CDS), (Accessed on DD-MMM-YYYY), 10.24381/cds.20d54e34

Doran PT, McKay CP, Clow GD, Dana GL, Fountain AG, Nylen T, Lyons WB. Valley floor climate observations from the McMurdo Dry Valleys, Antarctica, 1986–2000. Journal of Geophysical Research: Atmospheres. 2002 Dec 27;107(D24):ACL-13. https://doi.org/10.1029/2001JD002045

Hersbach H, Bell B, Berrisford P, Hirahara S, Horányi A, Muñoz-Sabater J, Nicolas J, Peubey C, Radu R, Schepers D, Simmons A. The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society. 2020 Jul;146(730):1999-2049. https://doi.org/10.1002/qj.3803

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Lazzara MA, Weidner GA, Keller LM, Thom JE, Cassano JJ. Antarctic automatic weather station program: 30 years of polar observation. Bulletin of the American Meteorological Society. 2012 Oct;93(10):1519-37. https://doi.org/10.1175/BAMS-D-11-00015.1

Muñoz Sabater, J., 2019. ERA5-Land hourly data from 1981 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). (Accessed on &lt DD-MMM-YYYY &gt), 10.24381/cds.e2161bac.

Tetzner D, Thomas E, Allen C. A Validation of ERA5 Reanalysis Data in the Southern Antarctic Peninsula—Ellsworth Land Region, and Its Implications for Ice Core Studies. *Geosciences*. 2019; 9(7):289. https://doi.org/10.3390/geosciences9070289

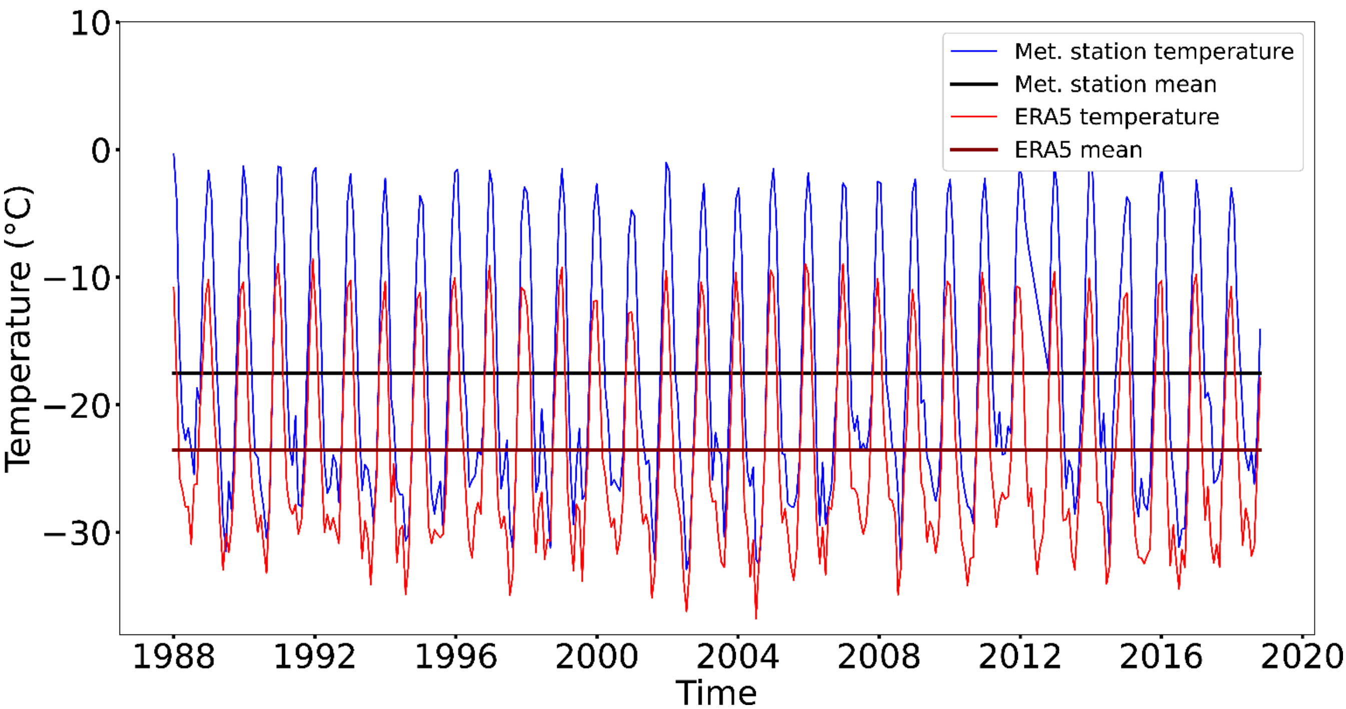

Figure 1. Map of the McMurdo Dry Valleys region showing the location of the automatic weather stations (AWS) managed by LTER and their corresponding closest ERA5 grid node.

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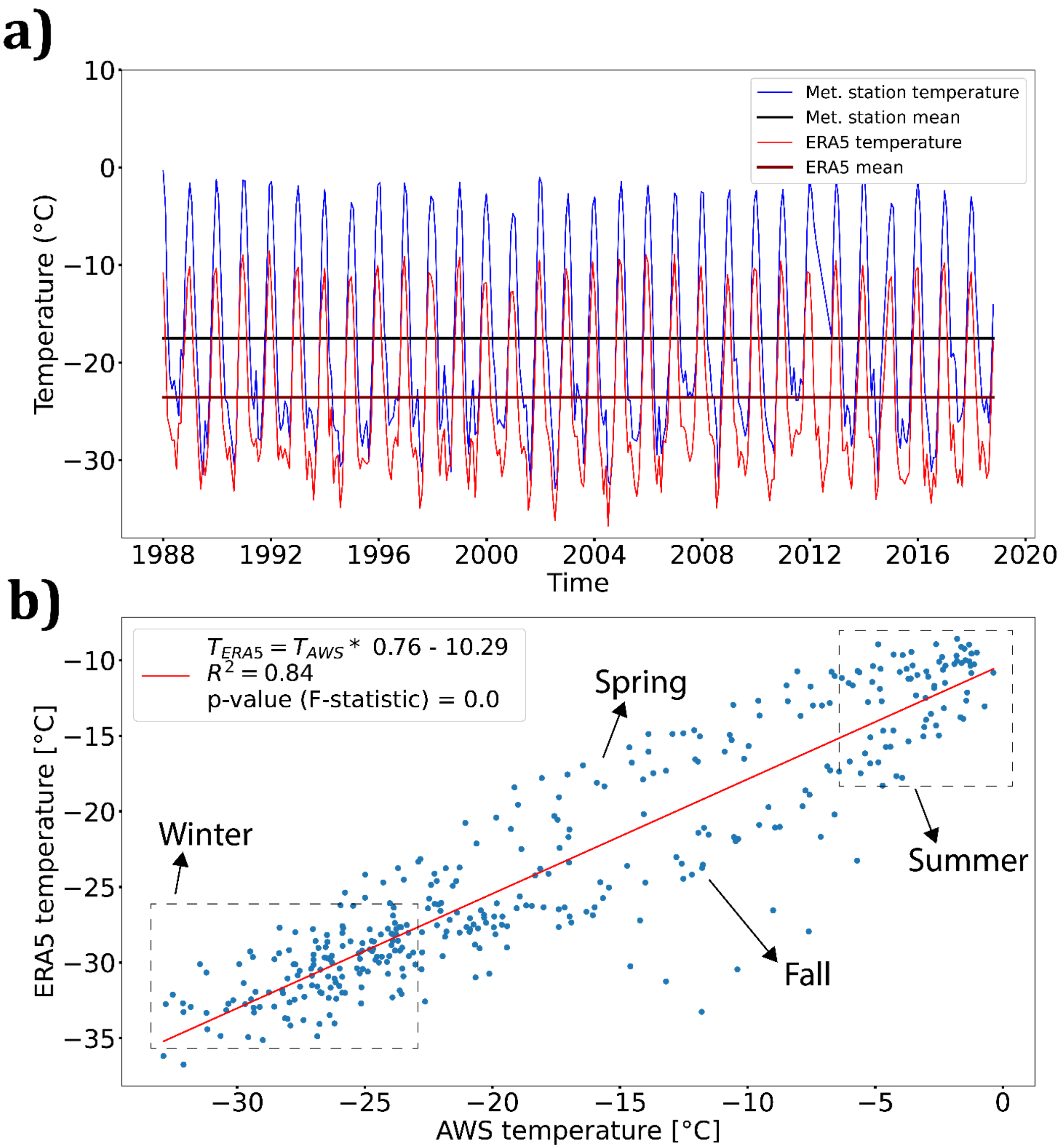

Figure. 2 a) Comparison of the monthly averaged surface temperature time series recorded at station Lake Hoare (HOEM) (blue) and the values from the closest grid node of the ERA5 reanalysis (red). b) Correlogram showing the best fit line to the relationship between the AWS temperatures and the reanalysis temperatures. Note the seasonal variation in the relationship.