
# Supplemental Material

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Supporting Material for

# Cloud Influence on ERA5 and AMPS Surface Downwelling Longwave Radiation Biases in West Antarctica

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## Introduction

The supporting information includes 5 figures and 2 tables:

- Figure S1 shows AMPS and ERA5 temperature, water vapor mixing ratio, and relative humidity profile biases over McMurdo Station for different atmospheric regimes.
- Figure S2 is the same as Figure S1, but for data over the WAIS Divide.
- Figure S3 depicts the coefficient of determination ($r^2$) and mean deviation of the temperature at McMurdo Station and WAIS Divide from their surrounding regions at 3 different pressure levels, based on ERA5 output data for the full year of 2016.
- Figure S4 is the same as Figure S3, but for the specific humidity.
- Figure S5 is the same as Figure S3, but for the relative humidity.
- Table S1 provides robustness test results based on the McMurdo dataset, in which the hourly thresholds for the determination of cloud occurrence and type were modified.
- Table S2 shows the $LW\downarrow$ mean error and SD calculated only based on periods when both the model and the observations agree on the atmospheric regime.

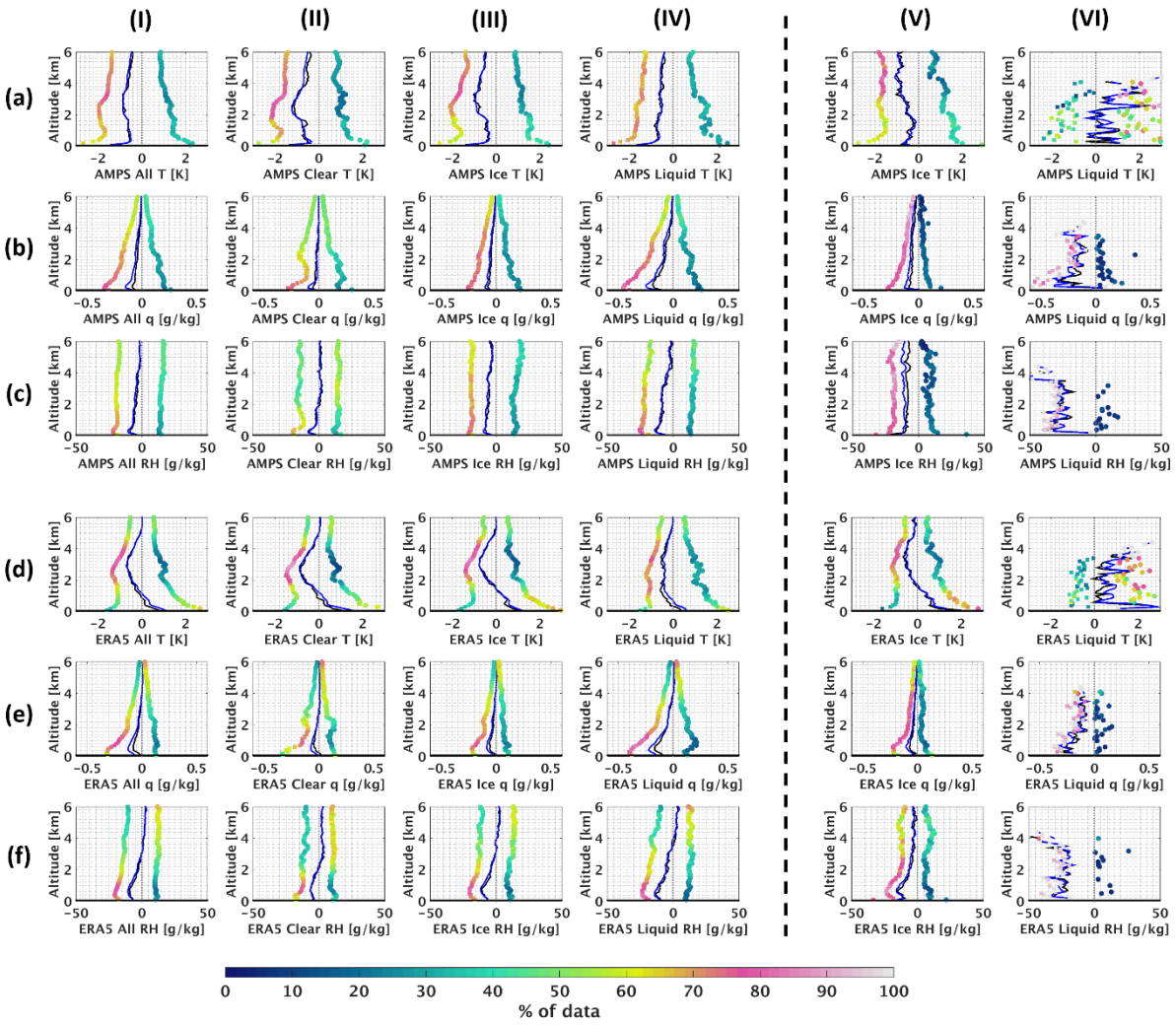


**Figure S1: AMPS (rows a-c) and ERA5 (rows d-f) temperature (*T*; rows a and d), water vapor mixing ratio (*q*; rows b and e), and relative humidity (RH) with respect to liquid (rows c and f) profile biases over McMurdo Station for a different atmospheric regime in each column. The columns represent the full datasets (I), clear-sky periods (II), ice-cloud and liquid-bearing cloud occurrences (III and IV, respectively), ice-cloud occurrences where only detected ice-bearing vertical grid cells are used (V), and liquid-bearing cloud occurrences where only detected liquid-bearing vertical grid cells are used (VI). In every profile, the black and blue curves designate the median and mean biases, respectively. The square and circle markers to the left and right of the mean curves denote the root-mean-square-error (RMSE) of the model under and overestimation cases, respectively, where the model underestimation RMSEs are multiplied by -1 to distinguish**

**them from model overestimation cases. The colors represent the percentage of the data samples that are under or overestimated, such that the percentage sum of the model under and overestimated cases at a given altitude equals to 100%. The thick horizontal black line designates the surface altitude. This comparison is only based on hours where radiosonde measurements were made. This figure shows that the model biases in the different atmospheric regimes are generally similar. However, liquid-bearing grid cells are largely warmer and drier than observed, which results in large RH biases that may explain some of the liquid deficiency in the models.**

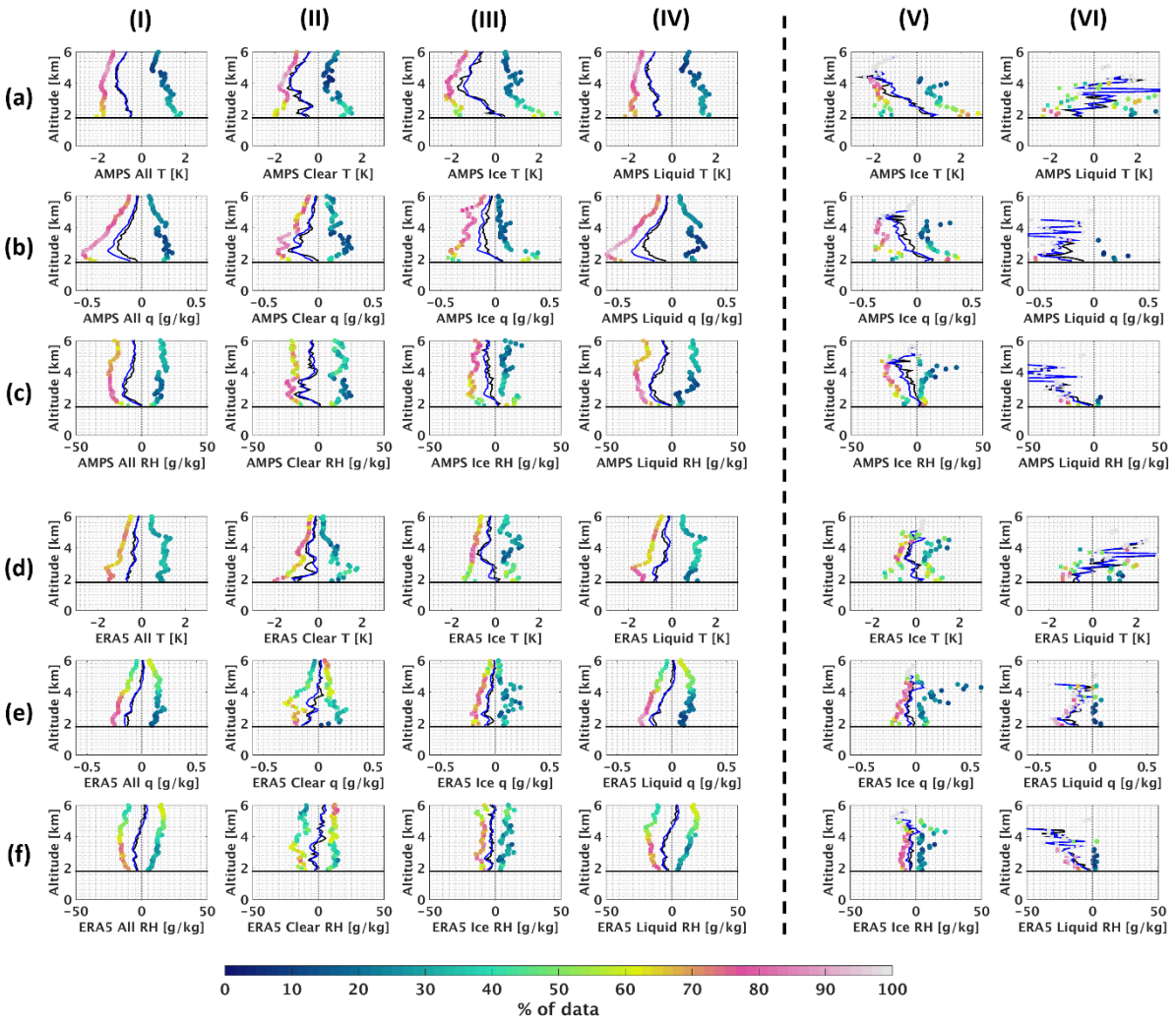


**Figure S2: Same as Figure S1 but for the West Antarctic Ice Sheet (WAIS) Divide. Similar to McMurdo, the model bias patterns in the different atmospheric regimes are generally similar, while the liquid-bearing grid cells are largely warmer and drier than observed, which results in large RH biases that increase with height, and may explain some of the liquid deficiency in the models.**

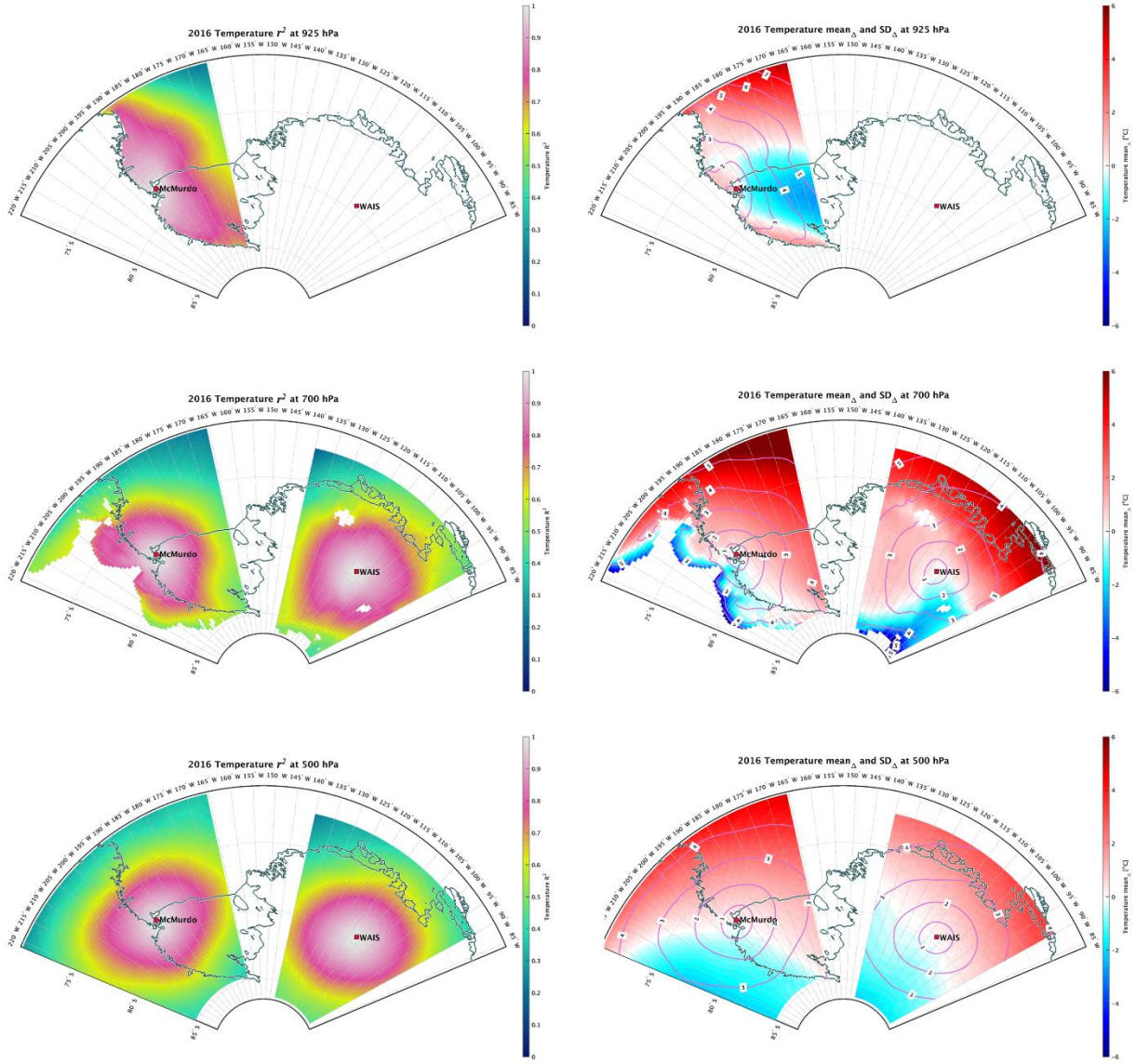


**Figure S3: Coefficient of determination ($r^2$; left panels) and mean deviation (right panels) of the 925 hPa (top), 700 hPa (middle), and 500 hPa (bottom) *T* at McMurdo Station and the WAIS Divide from their surrounding regions, distant by up to 7° in latitude (~650 km) and 28° in longitude (up to ~650 km), based on ERA5 output data for the full year of 2016. The magenta contours, drawn in 1 K increments, designate the standard deviation (SD) of the *T* differences from the corresponding site. Regions where the minimum surface pressure during the full-year dataset is lower than the examined pressure level are excluded from the analysis. The high SDs at large distances from both sites indicates that the excellent correlation in these regions is highly**

**influenced by the annual cycle. The significantly sharper slope in the SD around McMurdo at 700 hPa implies that this site may be representative of a relatively smaller surrounding region, while the mean *T* difference magnitudes below 2 K and the relatively milder increase in SD suggests that the WAIS Divide *T* might be representative of a large fraction of the WAIS.**

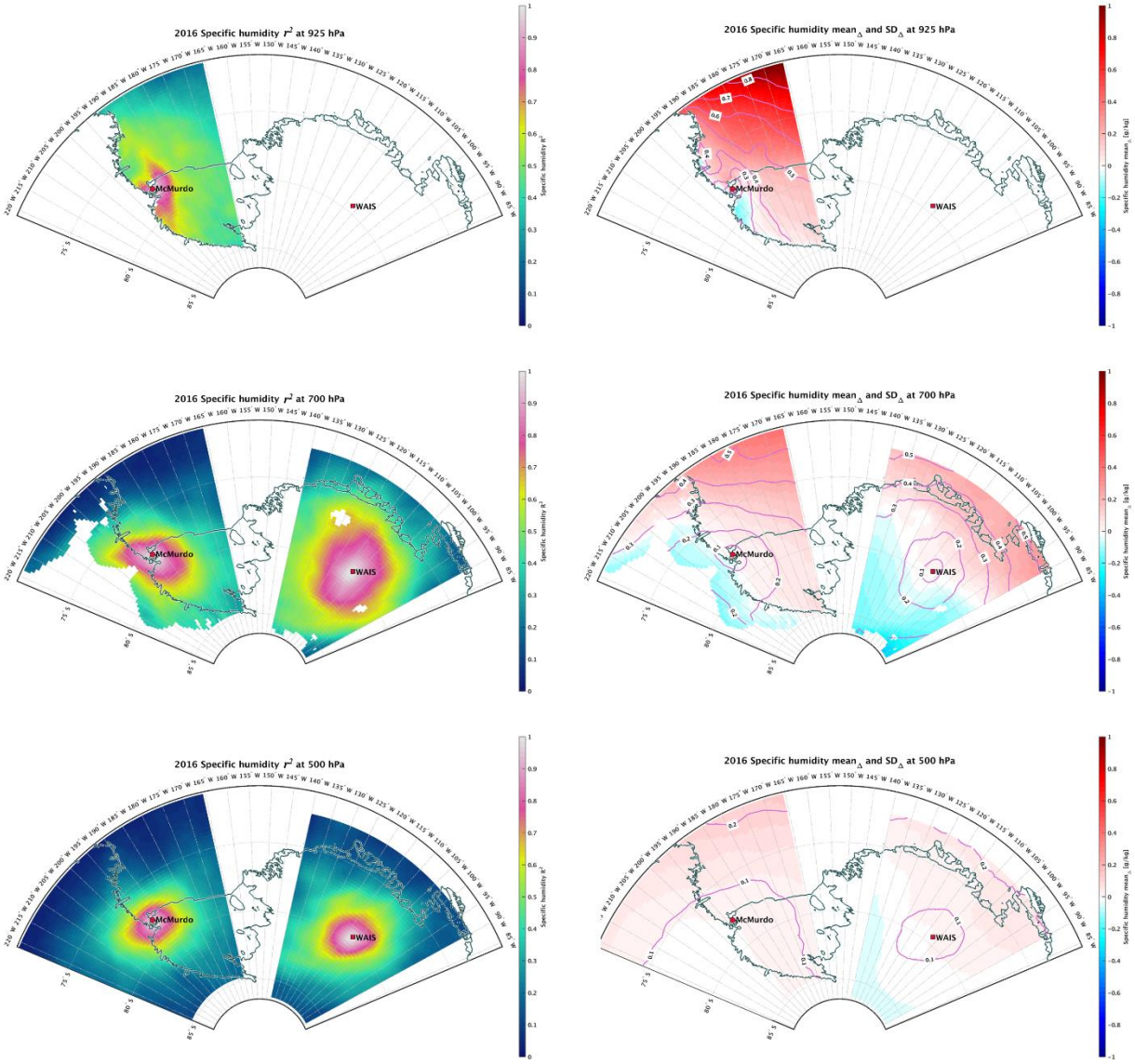


**Figure S4: Same as Figure S3 but for *q* with contour increments (in the right panels) of 0.1 g/kg. Similar to the temperature plots, McMurdo seems to represent only a limited region of the north-western Ross Ice Shelf, while the WAIS Divide is more representative of the WAIS.**

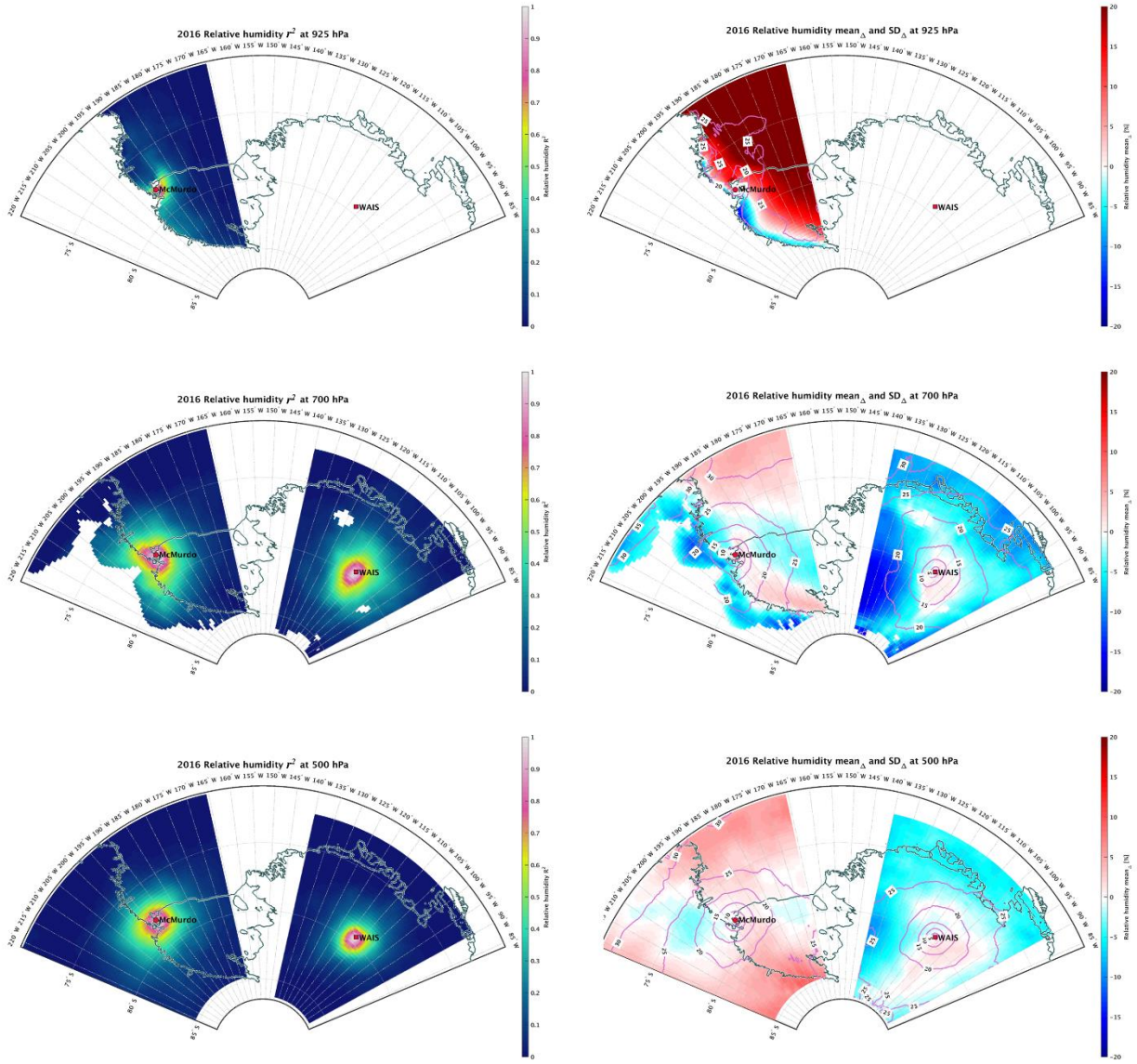


**Figure S5: Same as Figure S3 but for RH with contour increments (in the right panels) of 5%. The combination of the *T* and *q* deviations from McMurdo and the WAIS Divide results in a significantly smaller surrounding regions with high correspondence (relative to Figure S3 andFigure S4) and large mean biases, both of which are emphasized at 925 hPa, close to the minimum surface pressure at McMurdo Station. Yet, the high correlation – low deviation regions are large enough to make both sites representative for a typical climate model's horizontal mesh of 2.0°-2.5° in latitude/longitude.**

**Table S1: Robustness test results based on the McMurdo dataset, in which the hourly thresholds for the determination of cloud occurrence and type were modified. The WAIS dataset was not tested in this analysis because more data are omitted from the statistic calculations when higher thresholds are used, and hence, that dataset was not sufficiently large for this type of analysis.**

| Site | Model | Atmospheric Regime | Hourly occurrence percentage threshold | Percentiles [W/m^2] | | | | | Mean [W/m^2] | SD [W/m^2] | *r* | *r* (no annual) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 5 | 25 | 50 | 75 | 95 | | | | |
| McMurdo Station | AMPS | Clear sky | 75% (paper) | -14.5 | -9.0 | -5.0 | -1.1 | 8.2 | -3.6 | 15.9 | 0.86 | 0.66 |
| | | | 100% clear sky | -14.2 | -8.6 | -4.9 | -1.1 | 7.0 | -3.4 | 16.5 | 0.84 | 0.64 |
| | | | **Change from paper:** | **-1.71%** | **-4.47%** | **-3.33%** | **2.71%** | **-13.91%** | **-6.07%** | **4.15%** | **-1.79%** | **-2.10%** |
| | | Ice cloud | 25% ice, <25% liq (paper) | -65.5 | -36.0 | -16.2 | -5.7 | 12.3 | -21.0 | 24.0 | 0.76 | 0.70 |
| | | | 25% ice, 0% liq | -62.7 | -34.4 | -16.1 | -5.1 | 12.5 | -19.9 | 23.2 | 0.76 | 0.70 |
| | | | **Change from paper:** | **-4.29%** | **-4.42%** | **-0.78%** | **-11.49%** | **1.28%** | **-5.39%** | **-3.40%** | **0.00%** | **0.00%** |
| | | | 100% ice, 0% liq | -66.7 | -41.9 | -23.9 | -8.5 | 10.6 | -25.4 | 23.5 | 0.75 | 0.65 |
| | | | **Change from paper:** | **1.78%** | **16.54%** | **47.33%** | **47.57%** | **-14.08%** | **21.06%** | **-1.76%** | **-1.67%** | **-6.89%** |
| | | Tenuous LBCL | 25% (paper) | -75.7 | -56.8 | -40.3 | -21.2 | 3.6 | -37.7 | 27.7 | 0.68 | 0.55 |
| | | | 50% | -77.0 | -60.0 | -45.0 | -28.5 | -2.7 | -42.5 | 26.2 | 0.67 | 0.52 |
| | | | **Change from paper:** | **1.76%** | **5.56%** | **11.51%** | **34.47%** | **-175.15%** | **12.74%** | **-5.30%** | **-1.31%** | **-4.95%** |
| | | | 100% | -78.9 | -67.0 | -57.6 | -46.8 | -21.2 | -54.4 | 25.9 | 0.57 | 0.43 |
| | | | **Change from paper:** | **4.26%** | **17.89%** | **42.80%** | **120.71%** | **-684.74%** | **44.34%** | **-6.23%** | **-15.88%** | **-22.13%** |
| | | Opaque LBCL | 25% (paper) | -86.0 | -75.6 | -61.1 | -31.9 | 1.5 | -51.8 | 30.6 | 0.65 | 0.62 |
| | | | 50% | -86.0 | -75.8 | -61.1 | -32.5 | 1.2 | -52.0 | 30.5 | 0.65 | 0.63 |
| | | | **Change from paper:** | **0.04%** | **0.18%** | **0.05%** | **1.71%** | **-21.95%** | **0.32%** | **-0.19%** | **0.20%** | **0.32%** |
| | | | 100% | -86.5 | -76.5 | -62.2 | -32.5 | 1.6 | -52.3 | 31.3 | 0.64 | 0.62 |
| | | | **Change from paper:** | **0.55%** | **1.17%** | **1.91%** | **1.73%** | **7.16%** | **0.89%** | **2.40%** | **-1.19%** | **-0.52%** |
| | | Total | *Independent of threshold* | -74.8 | -41.5 | -13.5 | -4.4 | 8.6 | -22.6 | 28.4 | 0.76 | 0.67 |
| | ERA5 | Clear-sky | 75% (paper) | -18.9 | -11.0 | -3.9 | 3.2 | 19.4 | -2.1 | 18.1 | 0.81 | 0.61 |
| | | | 100% clear sky | -18.6 | -10.5 | -3.8 | 2.8 | 17.7 | -2.0 | 18.6 | 0.79 | 0.59 |
| | | | **Change from paper:** | **-1.33%** | **-4.55%** | **-4.57%** | **-11.44%** | **-8.85%** | **-4.81%** | **2.52%** | **-1.82%** | **-2.21%** |
| | | Ice cloud | 25% ice, <25% liq (paper) | -43.4 | -18.7 | -6.9 | 6.1 | 27.7 | -6.9 | 21.0 | 0.82 | 0.80 |
| | | | 25% ice, 0% liq | -41.4 | -17.9 | -5.4 | 6.9 | 28.2 | -5.8 | 20.8 | 0.82 | 0.80 |
| | | | **Change from paper:** | **-4.65%** | **-4.30%** | **-21.82%** | **12.11%** | **1.69%** | **-15.23%** | **-1.19%** | **0.00%** | **0.00%** |
| | | | 100% ice, 0% liq | -44.8 | -20.4 | -6.9 | 6.0 | 26.9 | -7.8 | 21.4 | 0.78 | 0.74 |
| | | | **Change from paper:** | **3.19%** | **9.00%** | **-0.07%** | **-1.30%** | **-2.90%** | **12.92%** | **1.56%** | **-5.37%** | **-7.42%** |
| | | Tenuous LBCL | 25% (paper) | -70.3 | -49.3 | -29.9 | -12.0 | 10.9 | -29.4 | 27.7 | 0.69 | 0.62 |
| | | | 50% | -73.1 | -54.0 | -36.0 | -17.3 | 6.4 | -34.6 | 27.2 | 0.66 | 0.58 |
| | | | **Change from paper:** | **3.90%** | **9.54%** | **20.57%** | **44.32%** | **-40.99%** | **17.71%** | **-1.83%** | **-4.49%** | **-5.91%** |
| | | | 100% | -77.0 | -63.4 | -52.7 | -37.0 | -13.5 | -48.2 | 26.9 | 0.56 | 0.45 |
| | | | **Change from paper:** | **9.45%** | **28.62%** | **76.50%** | **208.58%** | **-223.77%** | **63.74%** | **-2.97%** | **-18.80%** | **-27.16%** |
| | | Opaque LBCL | 25% (paper) | -85.5 | -66.4 | -43.6 | -21.8 | -8.0 | -43.7 | 27.0 | 0.68 | 0.69 |
| | | | 50% | -85.5 | -66.4 | -43.7 | -22.2 | -8.0 | -43.9 | 26.9 | 0.69 | 0.69 |
| | | | **Change from paper:** | **0.00%** | **0.06%** | **0.14%** | **1.71%** | **0.35%** | **0.30%** | **-0.09%** | **0.12%** | **0.01%** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 100% | -85.6 | -67.6 | -46.0 | -23.3 | -8.4 | -45.0 | 27.4 | 0.67 | 0.68 |
| | | | **Change from paper:** | **0.18%** | **1.83%** | **5.56%** | **6.75%** | **5.33%** | **2.85%** | **1.84%** | **-1.43%** | **-0.93%** |
| | | Total | *Independent of threshold* | -65.9 | -25.6 | -10.5 | 0.8 | 21.0 | -14.1 | 26.8 | 0.79 | 0.74 |

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**Table S2: Differences in the mean error and SD when both the models and the observations exhibit the same atmospheric regime relative to when the regime occurrence is determined only based on the observations (as in Table 1 in the text).**

| Site | Model | Atmospheric Regime | Mean error [W/m^2] | | | SD [W/m^2] | | |
|---|---|---|---|---|---|---|---|---|
| | | | Regime occurrence in observations | Regime occurrence in both model and observations | % change | Regime occurrence in observations | Regime occurrence in both model and observations | % change |
| McMurdo Station | AMPS | Clear sky | -3.6 | -7.1 | 96.16% | 15.9 | 6.5 | -59.30% |
| | | Ice cloud | -21.0 | -21.2 | 1.16% | 24.0 | 24.6 | 2.78% |
| | | Tenuous LBCL | -37.7 | - | - | 27.7 | - | - |
| | | Opaque LBCL | -51.8 | 2.5 | -104.87% | 30.6 | 5.2 | -83.03% |
| | ERA5 | Clear sky | -2.1 | -12.1 | 489.53% | 18.1 | 6.0 | -67.00% |
| | | Ice cloud | -6.9 | -6.9 | 0.63% | 21.0 | 21.1 | 0.41% |
| | | Tenuous LBCL | -29.4 | -27.1 | -7.81% | 27.7 | 24.8 | -10.68% |
| | | Opaque LBCL | -43.7 | -21.6 | -50.58% | 27.0 | 13.7 | -49.35% |
| WAIS Divide | AMPS | Clear sky | -6.4 | -7.5 | 16.21% | 5.2 | 4.5 | -12.88% |
| | | Ice cloud | -23.7 | -13.4 | -43.33% | 28.1 | 29.0 | 3.12% |
| | | Tenuous LBCL | -41.2 | -12.3 | -70.04% | 34.0 | 39.3 | 15.78% |
| | | Opaque LBCL | -87.7 | - | - | 20.1 | - | - |
| | ERA5 | Clear sky | 3.1 | -4.8 | -256.65% | 14.3 | 2.1 | -85.06% |
| | | Ice cloud | 7.3 | 12.2 | 68.23% | 21.7 | 21.6 | -0.34% |
| | | Tenuous LBCL | -15.1 | -20.7 | 36.97% | 29.5 | 25.4 | -14.10% |
| | | Opaque LBCL | -65.2 | - | - | 22.4 | - | - |