20th century Antarctic air temperature and snowfall simulations by IPCC climate models

David H. Bromwich[1], Andrew J. Monaghan[1,2], and David P. Schneider[3]

[1]Polar Meteorology Group, Byrd Polar Research Center, The Ohio State University

[2]Research Applications Laboratory, National Center for Atmospheric Research

[3]Climate and Global Dynamics Division, National Center for Atmospheric Research

Byrd Polar Research Center
Polar Meteorology Group
The Ohio State University

Study Goal

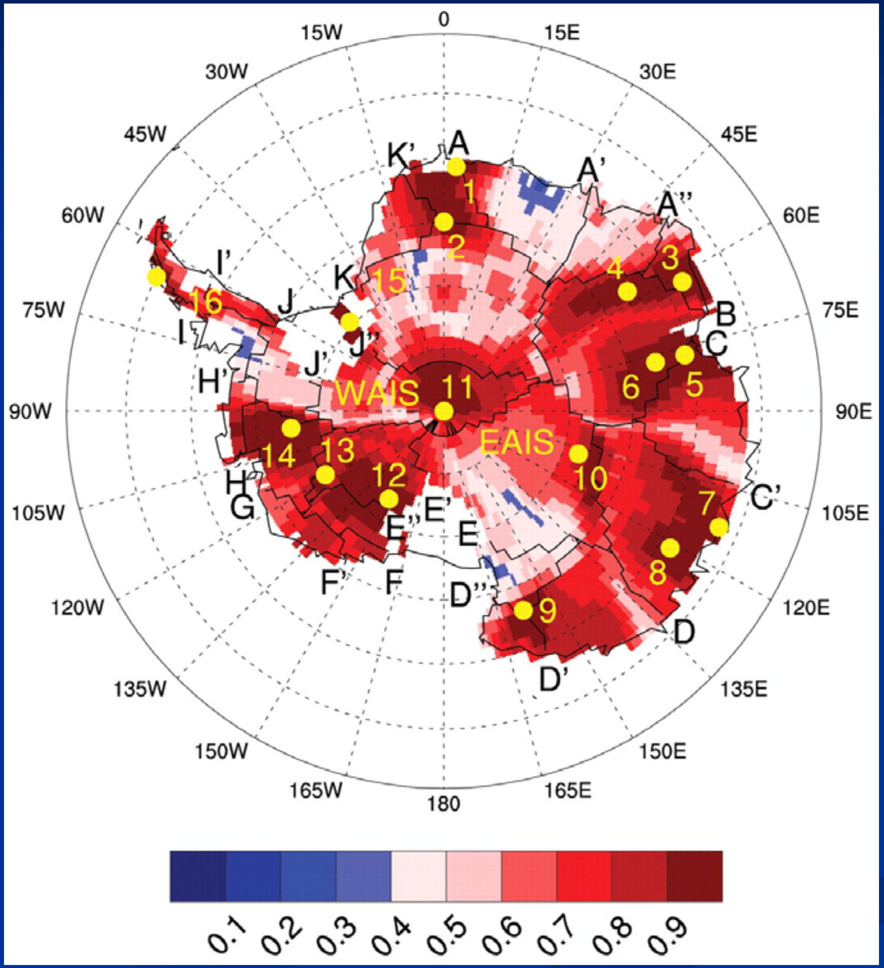
- Use recently developed Antarctic fields of 2-m temperature and snowfall over the Antarctic ice sheets to test the performance of a representative sample of IPCC AR4 climate models during the 20th century.

Outline

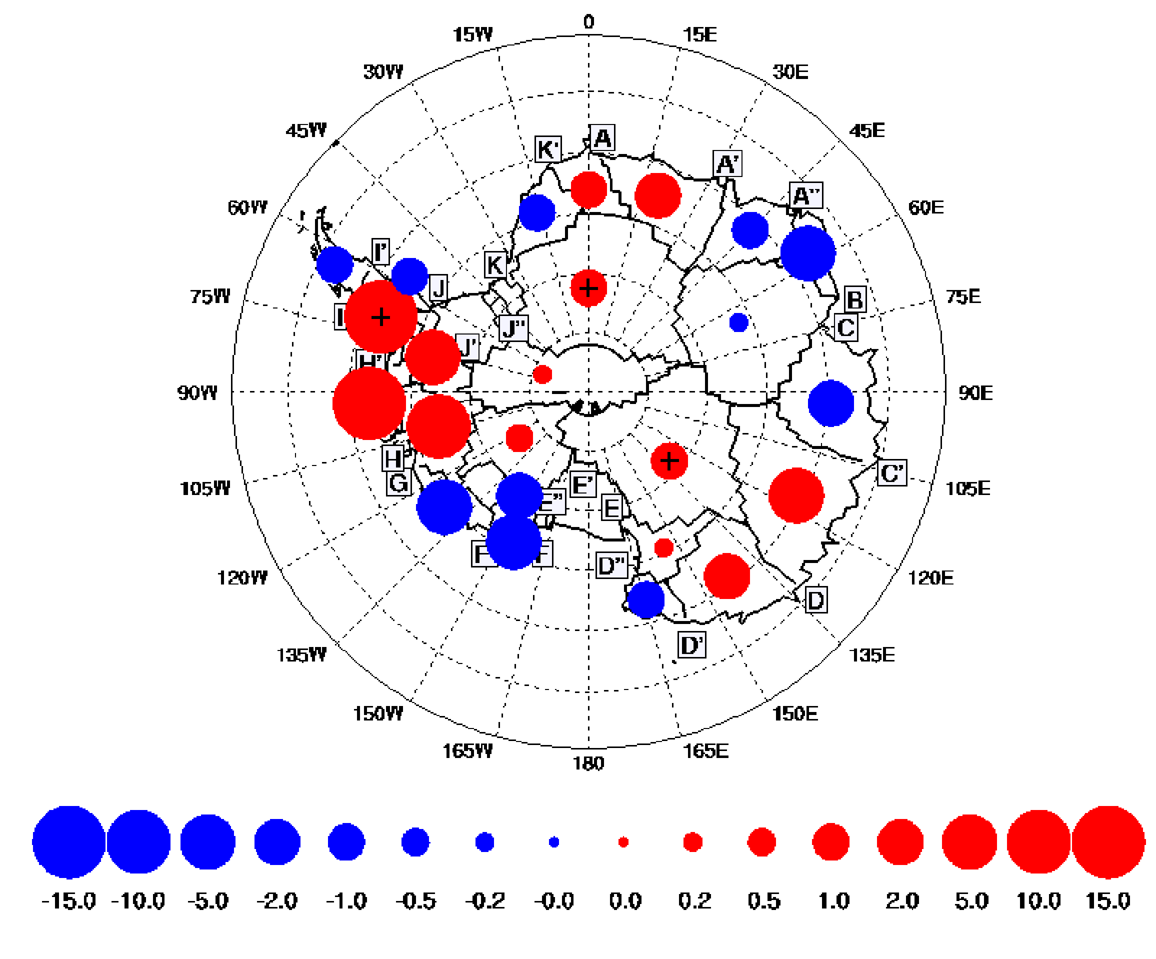
- Introduction
- Snowfall and temperature data sets
- IPCC AR4 climate model snowfall and temperature trends over the ice sheet
- Explore the reasons for the discrepancies
- Conclusions

Snowfall Reconstruction

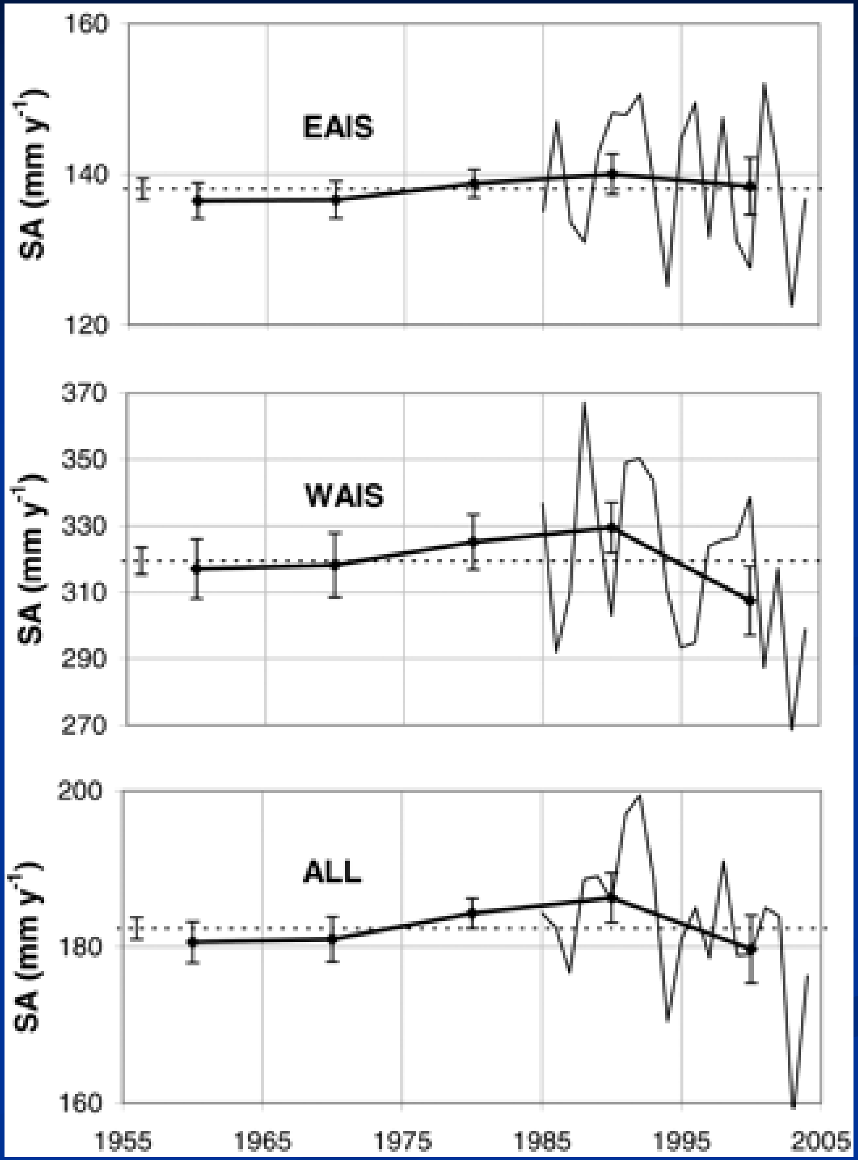
Spatial correlations of annual ERA-40 precipitation 1985-2004. Plot shows maximum absolute correlation for each ERA-40 “ice core” with all model grid points. Apply these spatial correlations to time series from the 16 ice cores prior to 1985.



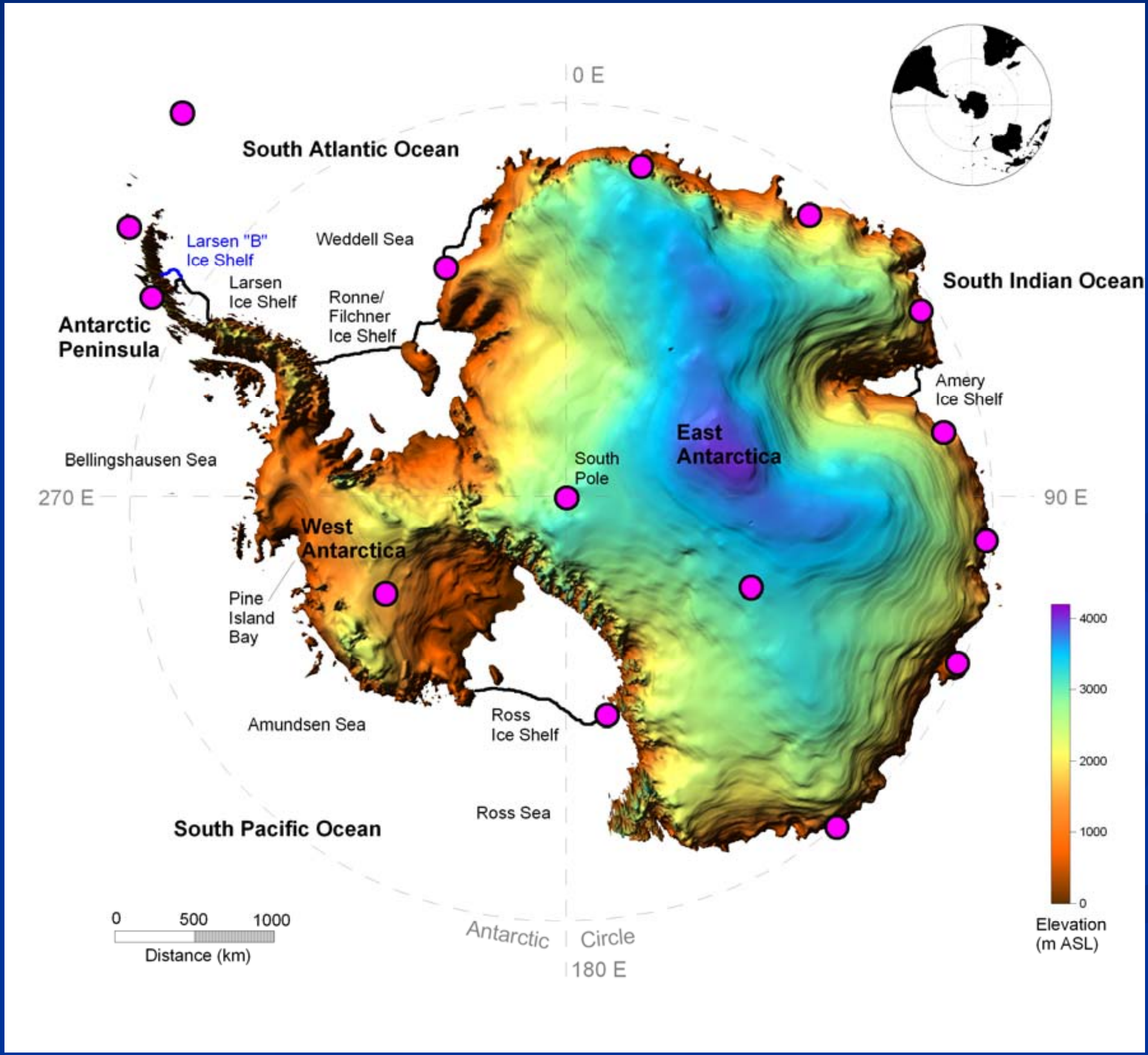
Linear trends of annual Antarctic snowfall accumulation (mm y^{-1} decade^{-1}) for 1955-2004, calculated from the area-averages in each of the glacial drainage basins.



Time series of decadal mean of annual snowfall accumulation (mm year^{-1} WEQ) for 1955–2004 for EAIS, WAIS, and the grounded ice sheet (ALL). The annual accumulation is also shown for the past 2 decades, the period for which ERA-40 is used. The dotted line represents the 50-year mean. Uncertainty bars are ±1 standard error. The uncertainty bar at the far left of each graph is for the 50-year mean.

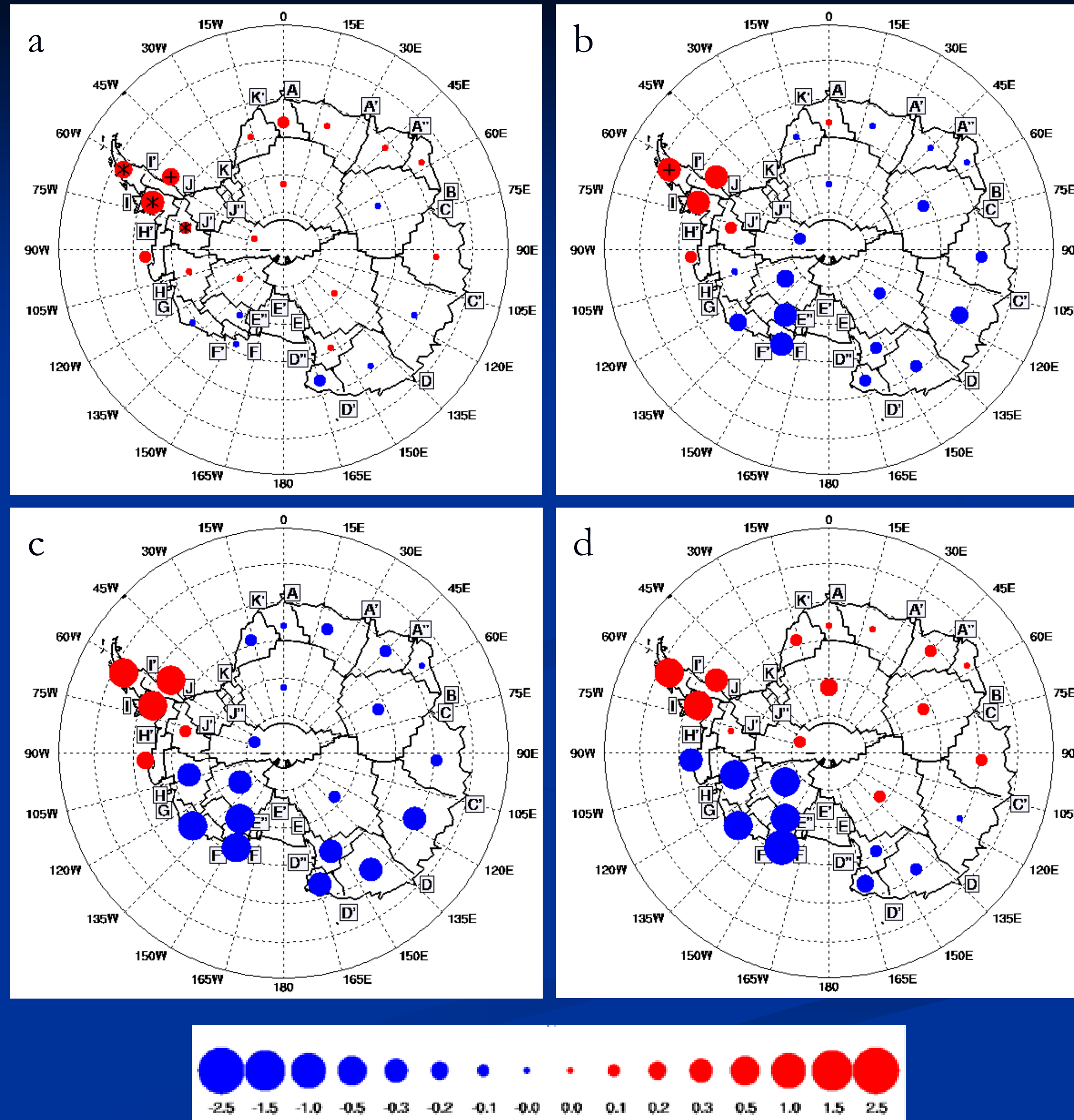


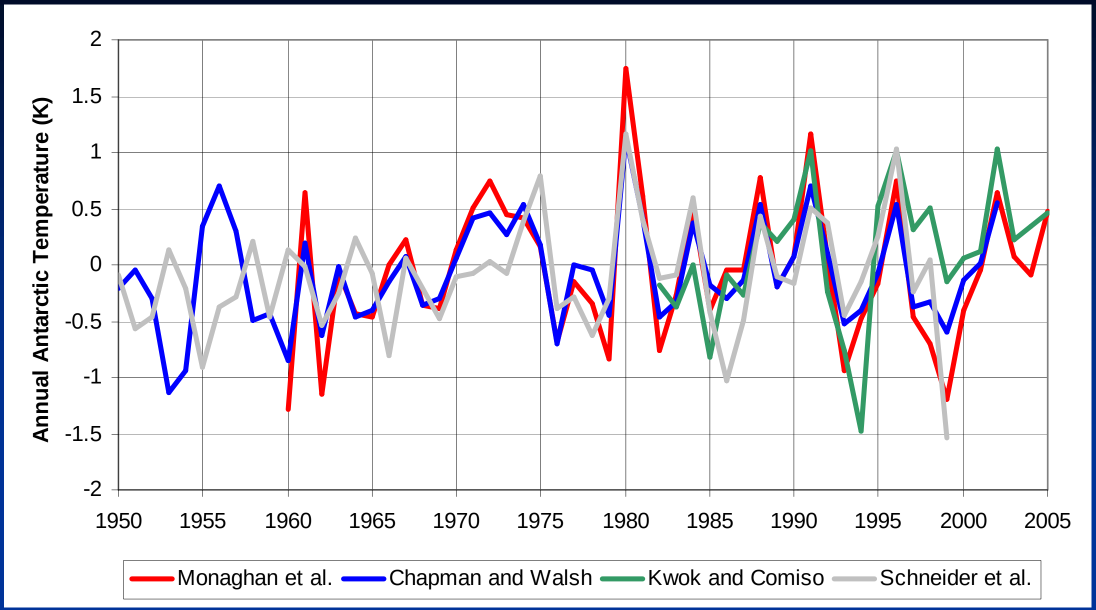
2-m temperature reconstruction. Similar methodology to snowfall reconstruction. Long-term observational sites are shown by red circles. Done by month.

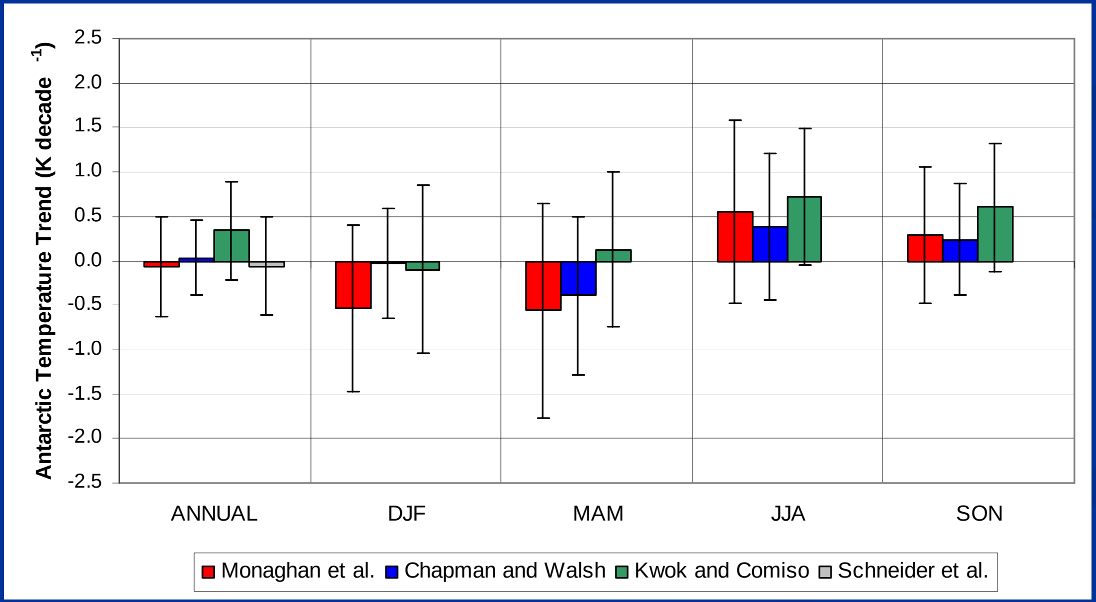


Linear trends of annual Antarctic near-surface temperature (K decade^{-1}) for (a) 1960-2005, (b)1970-2005, (c) 1980-2005, and (d) 1990-2005, calculated from the area-average in each of the glacial drainage basins.

Larger dots represent larger trends as specified by the legend. For example, the red (blue) dot in the legend labeled "1.5" ("-1.5") represents a trend that is >1.5 (<-1.5) K decade^{-1}. Statistical significance is represented by symbols: "+" is $p<0.10$; "*" is $p<0.05$; and "Δ" is $p<0.01$. The statistical uncertainty accounts for the variance, as well as that due to the methodology and measurement error.







Top: Annual Antarctic near-surface temperature (K) during 1950-2005 from four datasets. Anomalies are with respect to the 1980-1999 mean. Bottom: The annual and seasonal linear trends (K decade^{-1}) for each dataset during the common period 1982-2002.

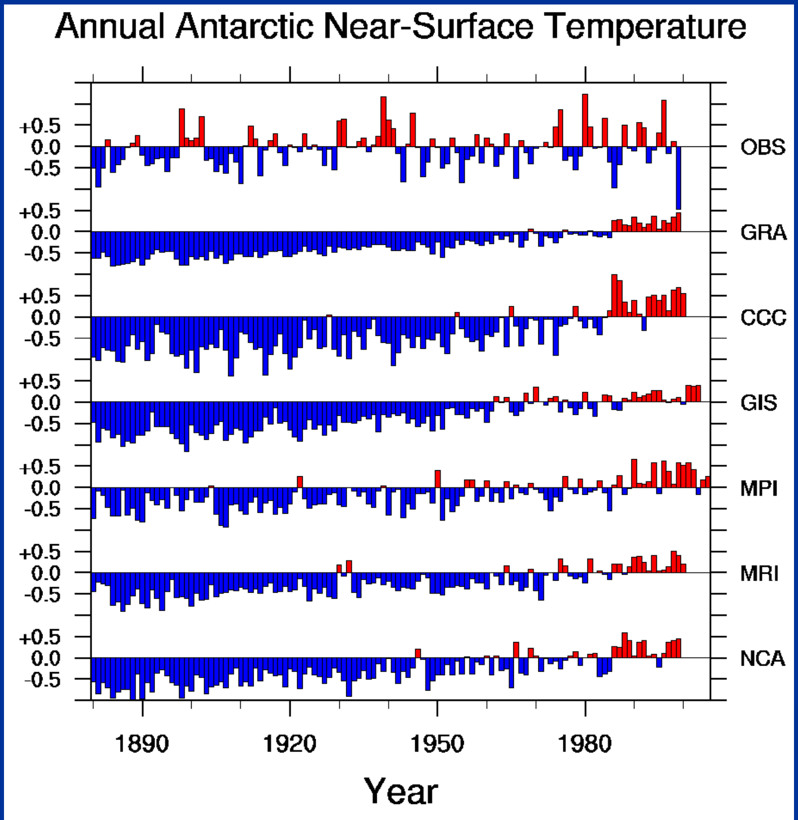
None of the trends are statistically significant from zero at the 95% confidence interval, as indicated by the error bars. For the longer datasets, none of the annual or seasonal Antarctic near-surface temperature trends are statistically significant if calculated for 1960-2002

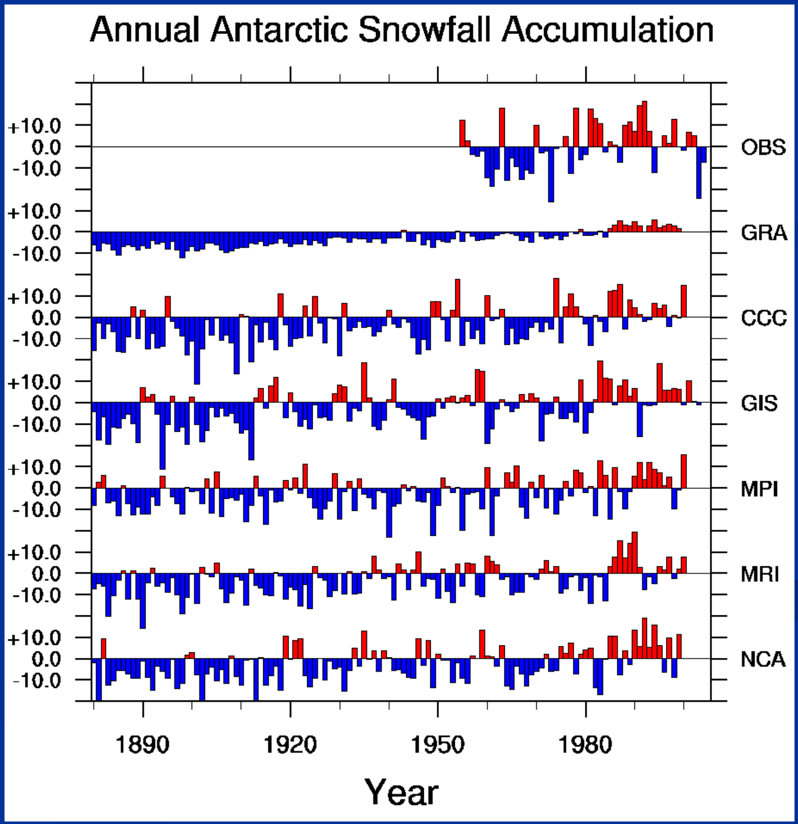
Description of the IPCC AR4 Climate Models used in this study. The "20c3m Ozone?" column lists models that include time-variable stratospheric ozone forcing in the 20th century simulations.

GCM	Abbreviation used in this study	Sponsor/Country	Horiz Resolution*	Vertical Levels*	20c3m Ozone?	Runs used
CGCM3.1(T47)	CCC	Canadian Centre for Climate Modelling and Analysis, Canada	T47 (~2.8x2.8 deg)**	31	N***	1,2,3,4
GISS-ER	GIS	NASA Goddard Institute for Space Studies, USA	5x4 deg	20	Y	1,2,3,4
ECHAM5/MPI-OM	MPI	Max Planck Institute for Meteorology, Germany	T65 (~1.9 x1.9 deg)	31	Y	1,2,3,4
MRI-CGCM2.3.2	MRI	Meteorological Research Institute, Japan	T42 (~2.8 x2.8 deg)	30	N	1,2,3,4
CCSM3	NCA	National Center for Atmospheric Research, USA	T85 (~1.4 x1.4 deg)	26	Y	1,2,3,4

*resolution of atmospheric component
**Output resolution of CGCM3.1 data is ~3.75x3.75 deg
***IPCC Documentation lists that CGCM3.1 has ozone forcing but *Codero and Forster* [*2006*] suggest it does not

Time series of annual Antarctic near-surface temperature anomalies (K; left side) and annual Antarctic snowfall anomalies (mm y^{-1}; right side) for 1880-2005 for the observations ("OBS"), the grand ensemble of the 5 model ensemble means ("GRA"), and the 5 GCM ensembles ("CCC", "GIS", "MPI", "MRI", and "NCA"). The observations are from Schneider for near-surface temperature and Monaghan for snowfall. The anomalies are with respect to the 1960-1999 mean.



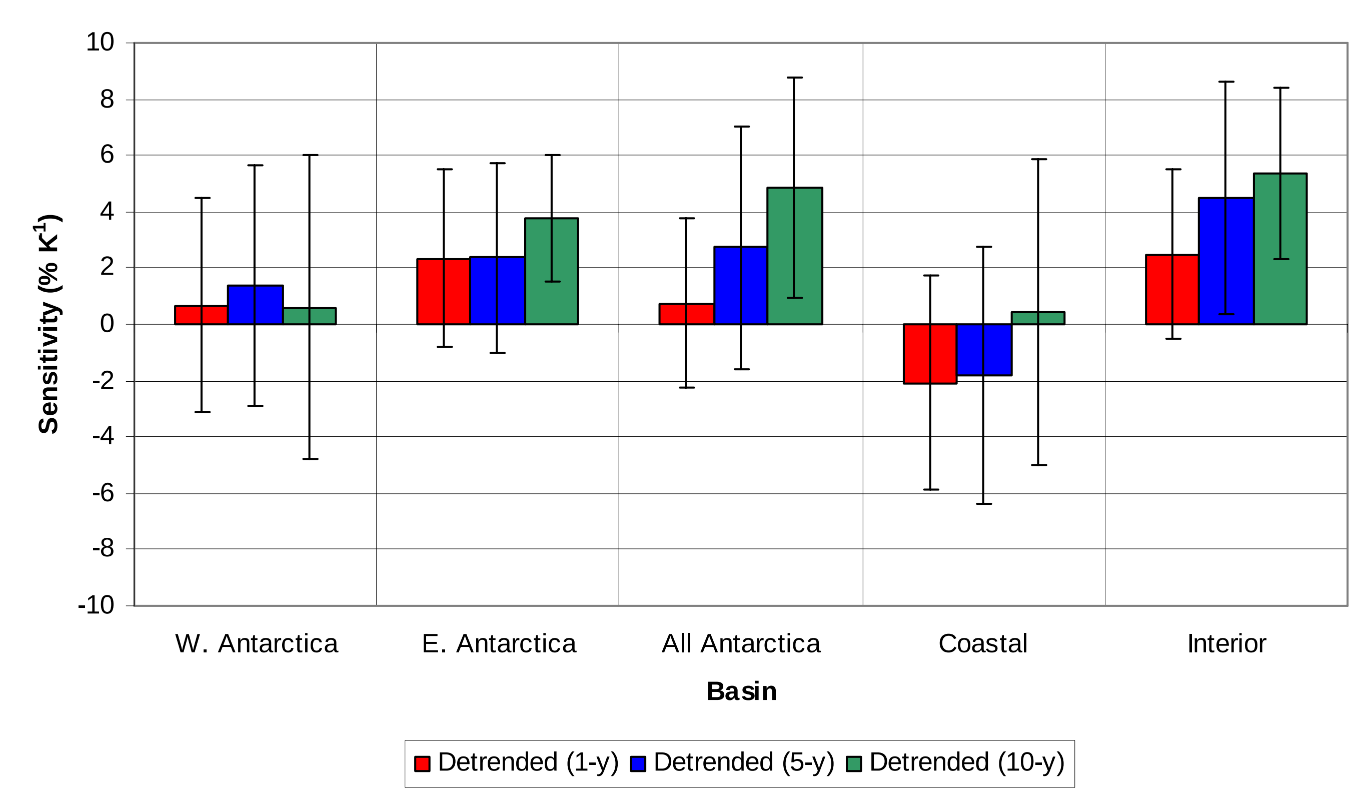


Antarctic near-surface temperature and snowfall trends and confidence intervals ($p<0.05$) for observations and GCMs for various periods and seasons. Values statistically significant from zero ($p<0.05$) are underlined. The observations are in the "Schneider" and "Monaghan" columns. The final row ("S/T Sensitivity") gives the sensitivity of annual snowfall to annual near-surface temperature fluctuations, expressed as a percentage of the long-term mean annual snowfall for a given GCM or observation.

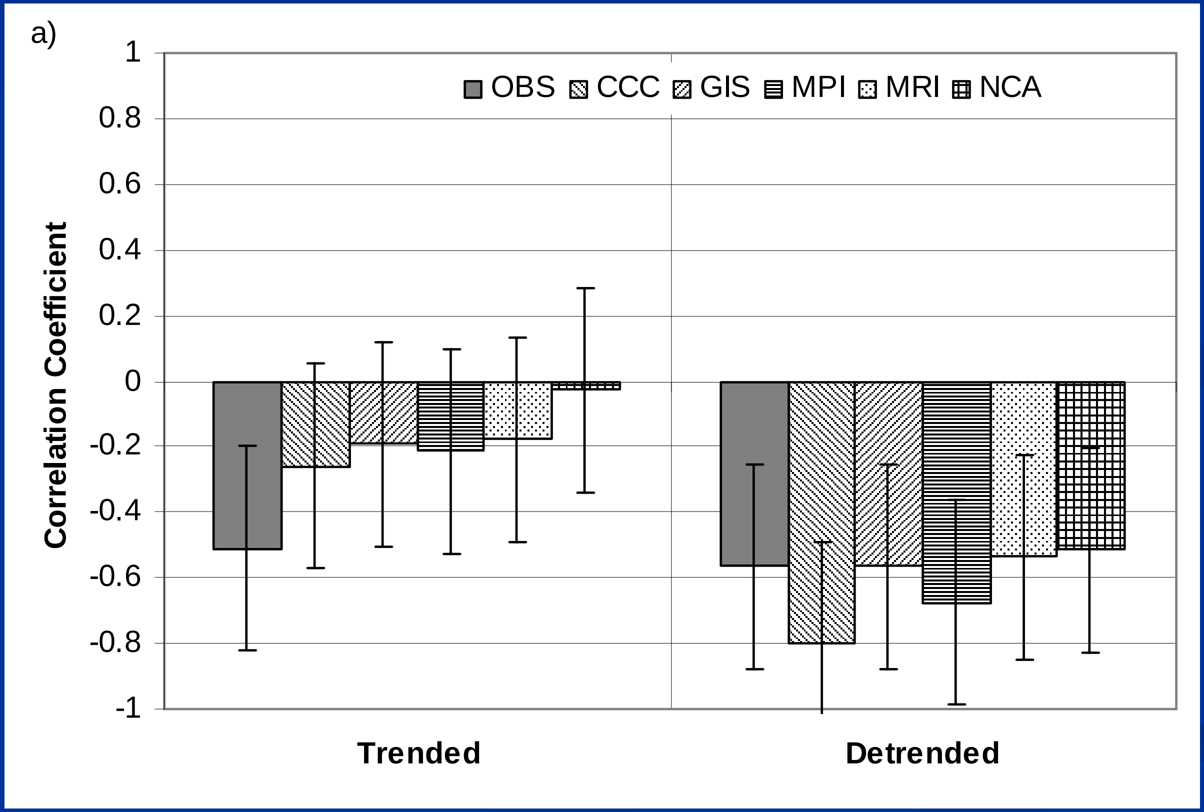
Variable	Units	Period	Season	Schneider	Monaghan	GCM 'GRA'	Min GCM	Max GCM
Temperature Trend	K century^{-1}	1880-1999	Annual	0.20 ± 0.32	- ± -	0.75 ± 0.07	0.52 (mpi)	0.97 (ccc)
Temperature Trend	K century^{-1}	1960-1999	Annual	0.13 ± 1.95	0.06 ± 2.03	1.44 ± 0.34	0.68 (gis)	2.45 (ccc)
Temperature Trend	K century^{-1}	1960-1999	DJF	- ± -	1.09 ± 3.06	1.11 ± 0.37	0.06 (gis)	2.51 (ccc)
Temperature Trend	K century^{-1}	1960-1999	MAM	- ± -	-0.61 ± 3.95	1.48 ± 0.57	0.77 (gis)	2.80 (ccc)
Temperature Trend	K century^{-1}	1960-1999	JJA	- ± -	1.56 ± 4.32	1.88 ± 0.67	1.06 (gis)	2.73 (ccc)
Temperature Trend	K century^{-1}	1960-1999	SON	- ± -	0.96 ± 2.92	1.28 ± 0.59	0.71 (gis)	1.78 (ccc)
Snowfall Trend	mm century^{-1}	1955-1999	Annual	- ± -	32 ± 31	17 ± 4	5 (gis)	26 (ccc)
S/T Sensitivity	% K^{-1}	Varies*	Annual	- ± -	4.9 ± 4.9	5.5 ± 0.8	2.4 (mri)	7.1 (mpi)

*The S/T sensitivity is calculated for the longest time period available for each data set (1960-2004 for "Monaghan" and 1880-1999 for the GCMs)

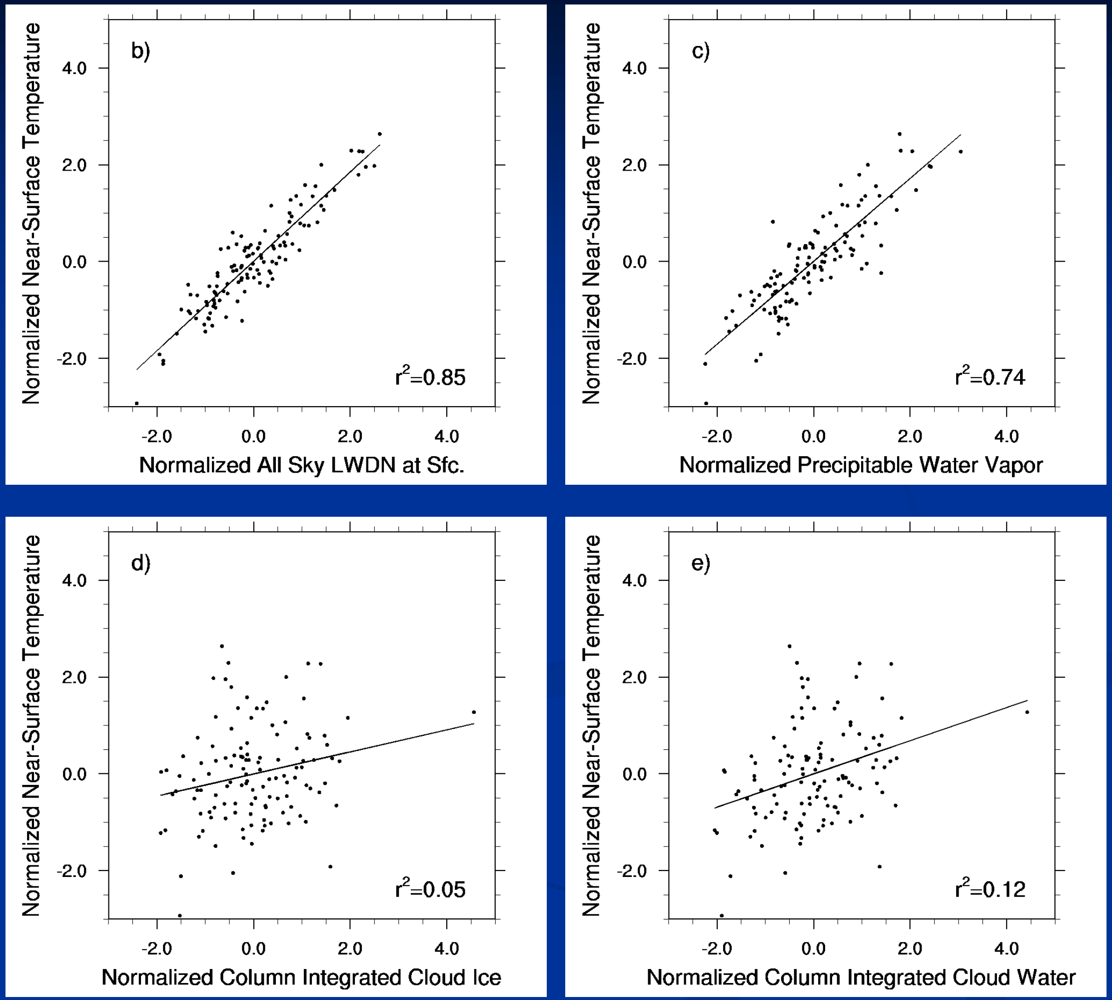
Observed sensitivity of Antarctic snowfall to near-surface temperature fluctuations (% K^{-1}) for the period 1960-2004. The 95% confidence intervals are indicated by the error bars. "Coastal" ("Interior") regions are defined by elevations <1000 m (>1000 m).



Observed and modeled correlation coefficient between annual near-surface temperature and the SAM index for trended (left) and detrended (right) time series for the period 1960-1999. The observed data ("OBS") are from Monaghan (near-surface temperature) and Marshall et al. [2003] (SAM). The error bars indicate confidence intervals (p=0.05).



(b-e) Scatter-plots of the detrended and normalized 1880-1999 GCM grand ensemble ("GRA") time series of near-surface temperature (y-axis) and b) long-wave downward, c) column integrated precipitable water vapor, d) column integrated cloud ice, e) column integrated cloud water. The black line in each plot is the slope of the linear regression and the r^2 value indicates the goodness-of fit. For a 120-year time series, the fit is statistically significant from zero ($p<0.05$) if $r^2>0.03$.



Conclusions

- Observed temperature and precipitation for Antarctica show no statistically significant trends overall.
- IPCC AR4 models have approx. the right snowfall sensitivity to temperature, but warm way too strongly in relation to observations.
- The cause is not related to the leading model of atmospheric variability, the Southern Hemisphere Annular Mode. An anomalously strong coupling between water vapor and temperature is implicated that overwhelms the actual dynamical effect.

Conclusions (cont.)

- Obviously a lot more research is needed to isolate the precise cause among the models.
- Does raise flags regarding the reliability of future projections of climate change over Antarctica.