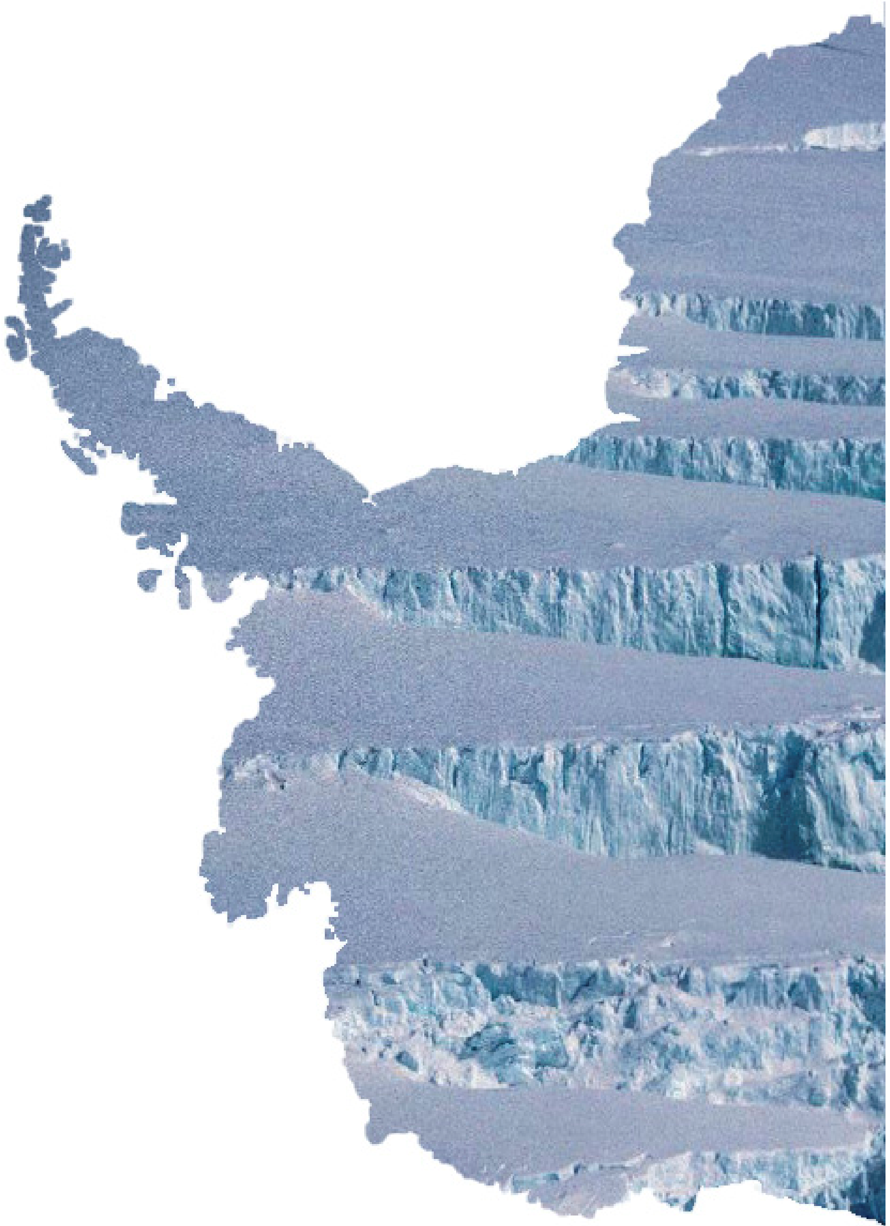
Antarctic Climate Variability and Change



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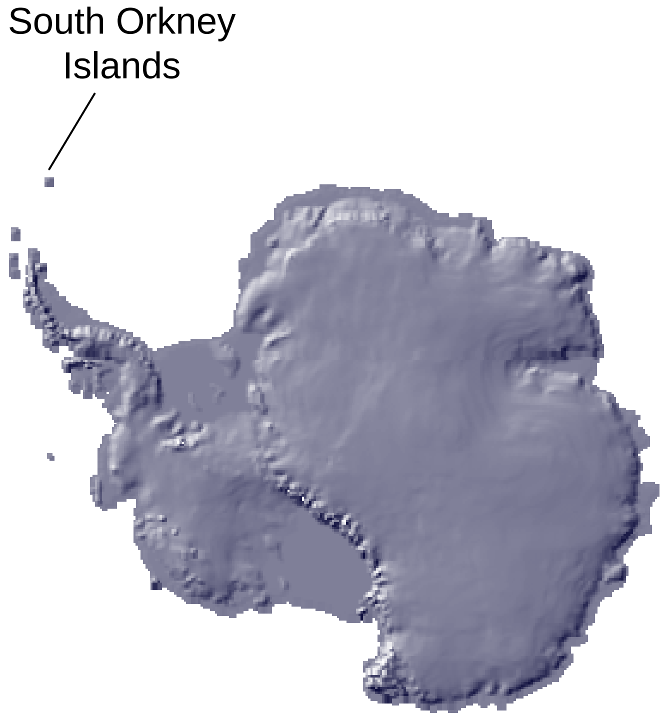
NATURAL ENVIRONMENT RESEARCH COUNCIL

Outline of presentation

- Development of the Antarctic observing network
- Quality of Antarctic atmospheric analyses/reanalyses
- Observed patterns of climate variability and change
- Large-scale modes of circulation variability and their signatures in the Antarctic
- Modelling Antarctic climate change
- Summary – Future challenges

Development of the Antarctic observing network

1903: First permanent observatory south of 60^{o}S, Orcadas, South Orkney Islands



Development of the Antarctic observing network

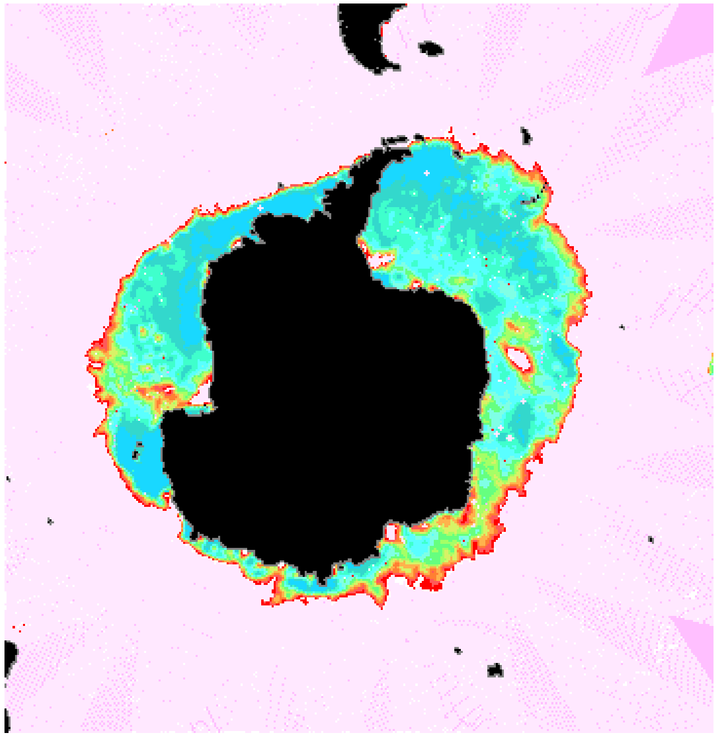
1957: International Geophysical Year, 55 stations established in the Antarctic (not all continued to operate post-IGY)

Halley Bay, 1958

Development of the Antarctic observing network

1979: First GARP Global Experiment (FGGE)

<u>Satellite observations:</u>
-Sounder data over data-sparse Southern Ocean
-Passive microwave observations of sea ice

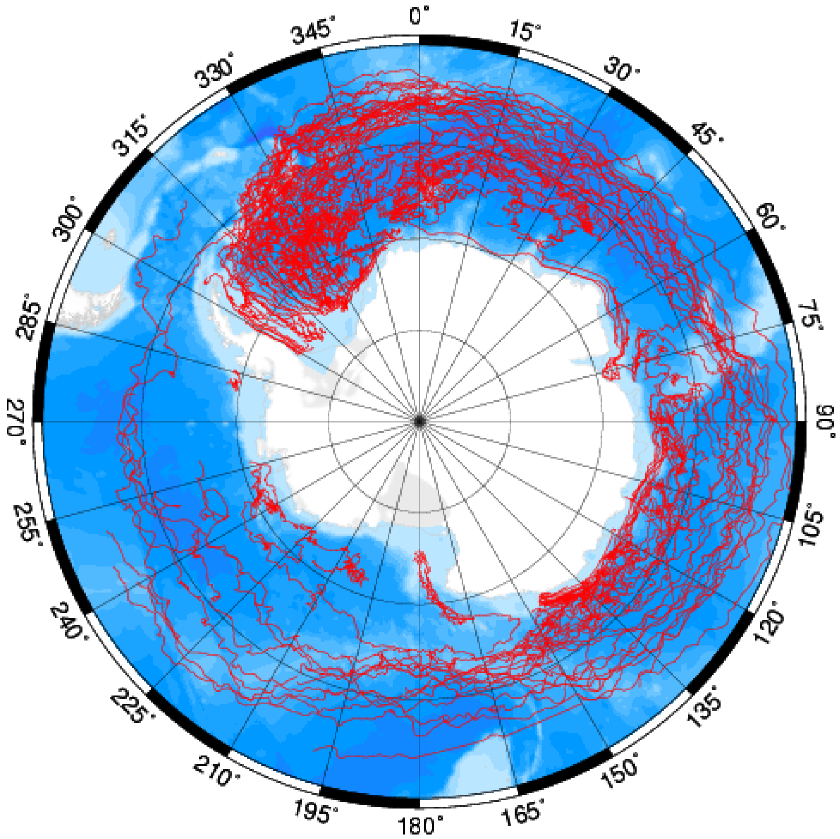


Sea ice concentration, mapped with the SSM/I sensor

Development of the Antarctic observing network

1979: First GARP Global Experiment (FGGE)

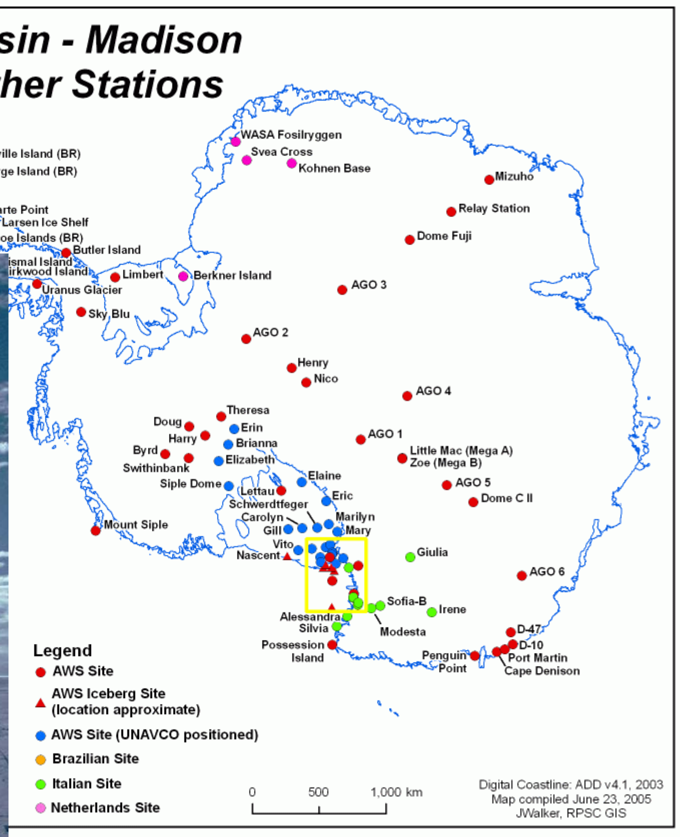
Southern Ocean drifting buoys



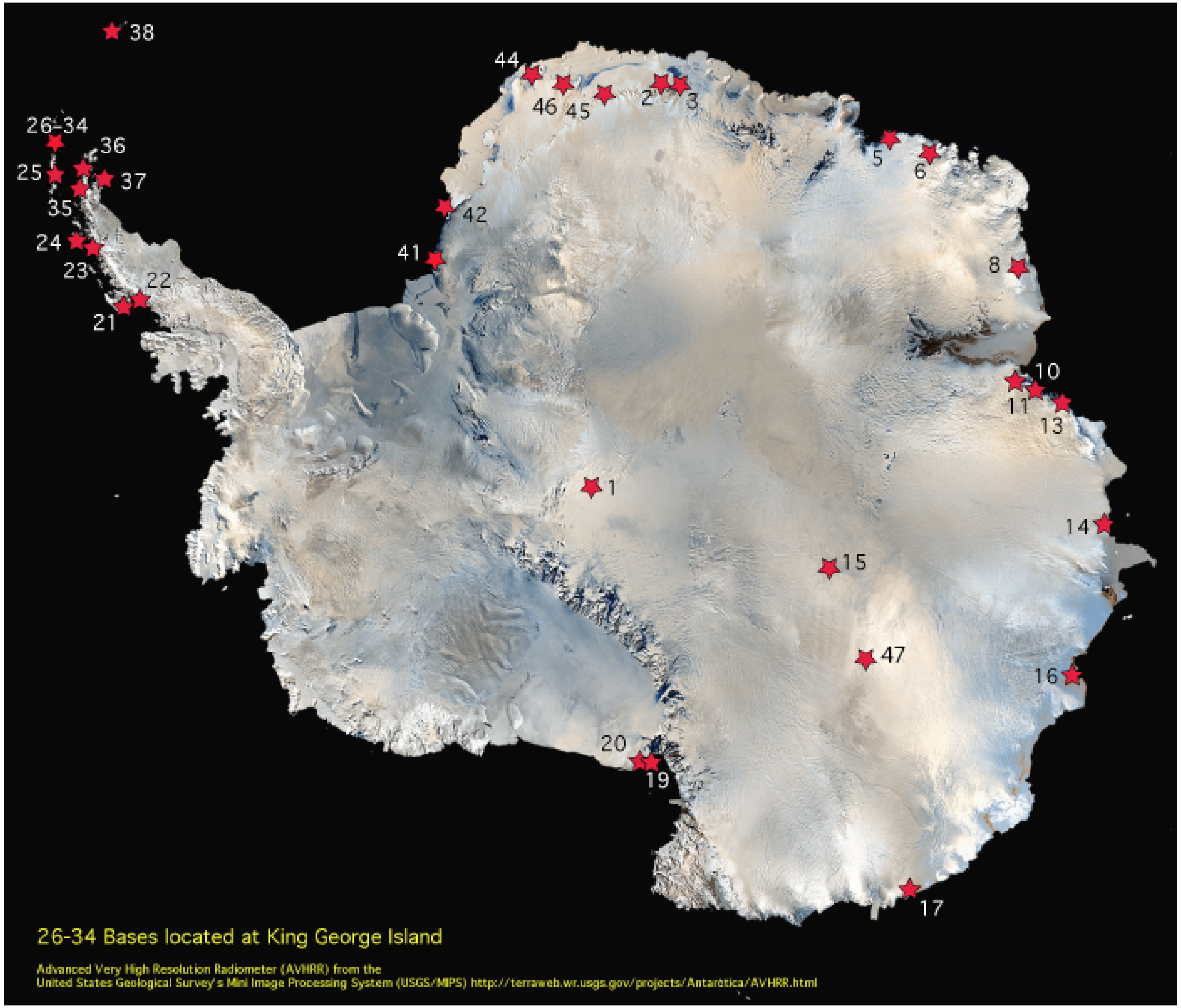
Development of the Antarctic observing network

1979: First GARP Global Experiment (FGGE)

Establishment of Antarctic AWS networks



Development of the Antarctic observing network



Quality of Antarctic analyses/reanalyses

- Manual analyses from IGY era
- Hemispheric operational analyses from 1970s
- Global operational analyses from 1980s
- Reanalyses IGY (or before) – present
  - Very reliable 1979+
  - Less reliable before 1979

Quality of Antarctic analyses/reanalyses

<u>**Factors influencing quality of analyses in the Antarctic**</u>

- **Data availability**

- **Biases in model background field**

- **Boundary conditions (sea ice, SSTs, land-sea mask)**

- **Model physics (stable boundary layers, ice/snow surface properties, air-sea-ice fluxes, clouds)**

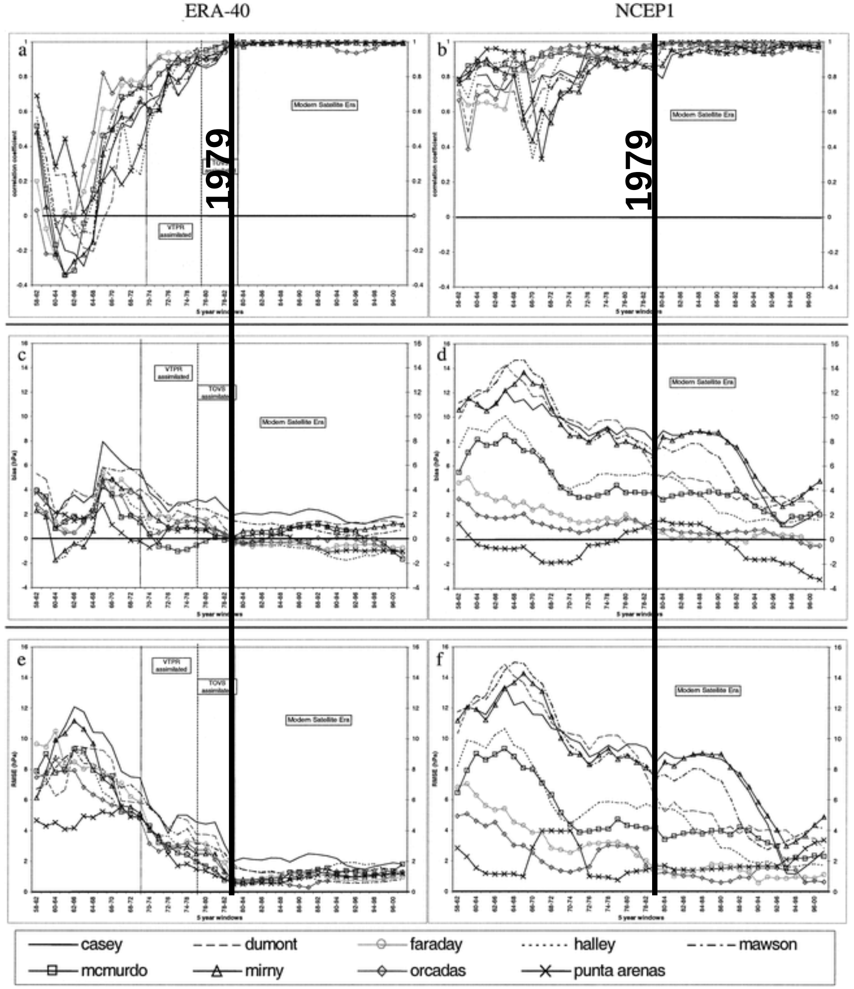
Quality of Antarctic analyses/reanalyses

ERA-40 NCEP1

Correlation

Bias

RMSE

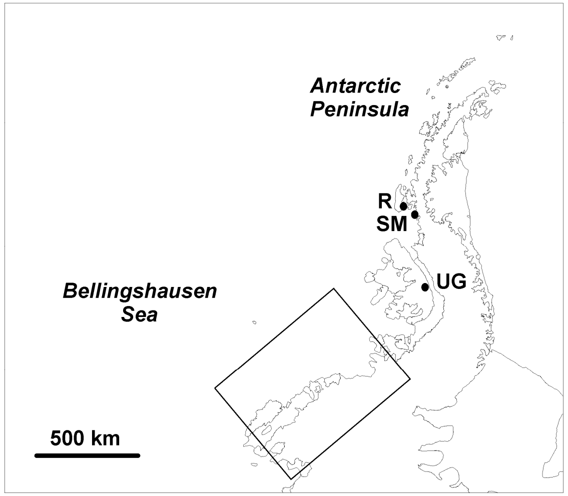


Validation of reanalyses against mslp observations from 8 Antarctic stations, 1958-2002

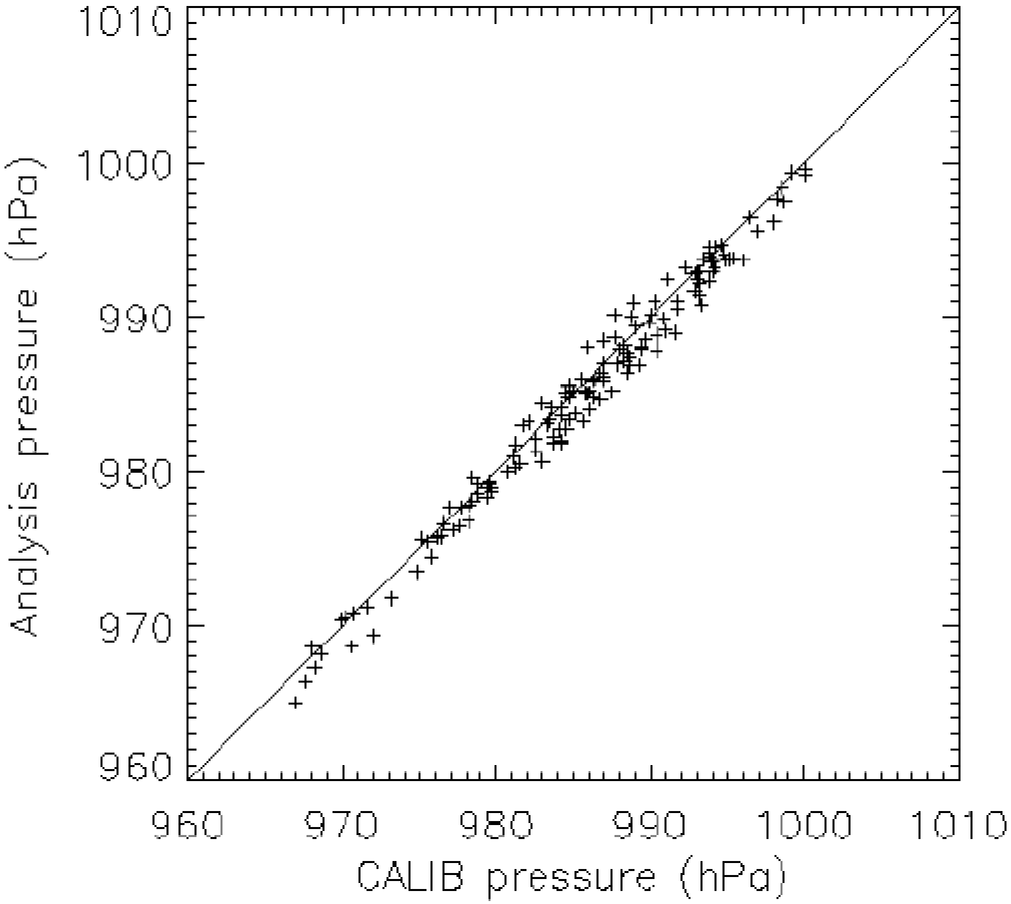
Quality of analyses improves greatly after 1979 – "modern satellite era"

Bromwich and Fogt, *J. Climate*, 2004

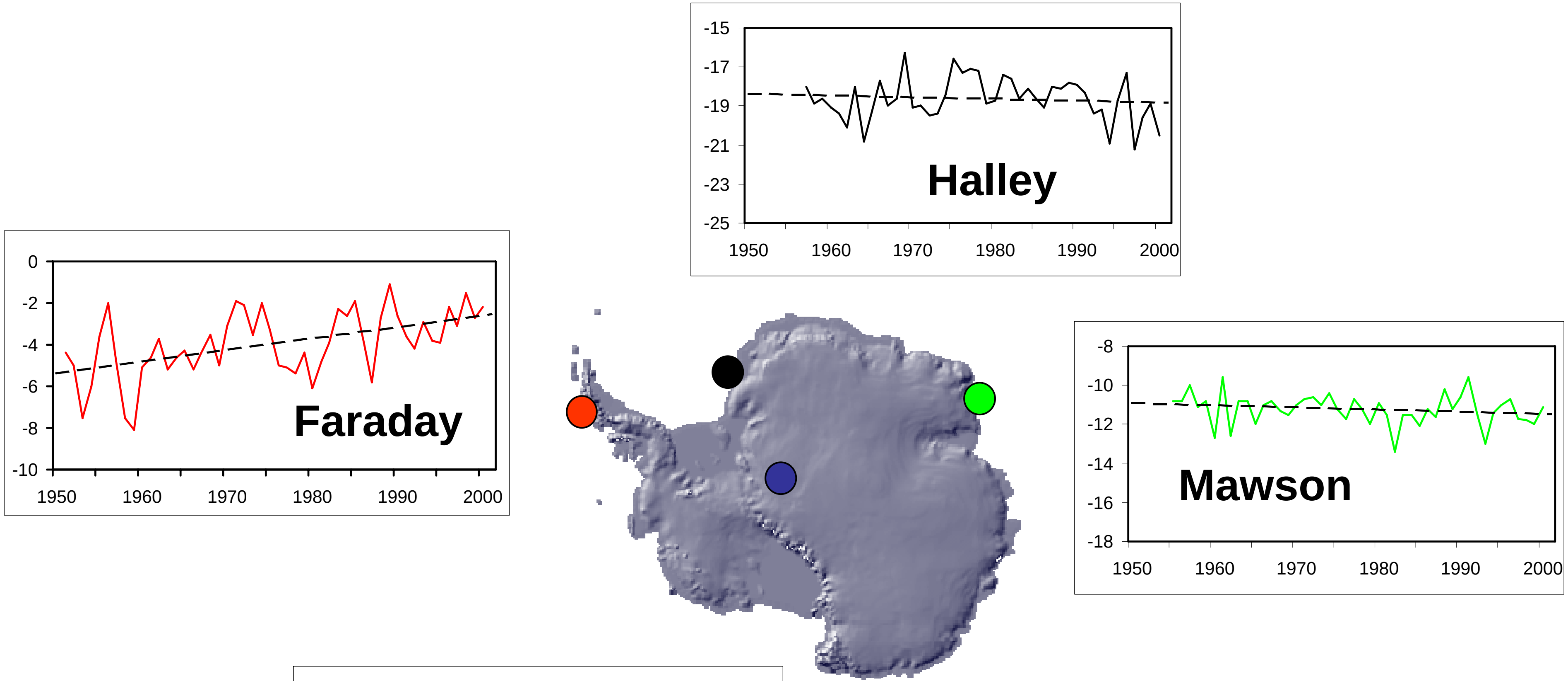
Quality of Antarctic analyses/reanalyses

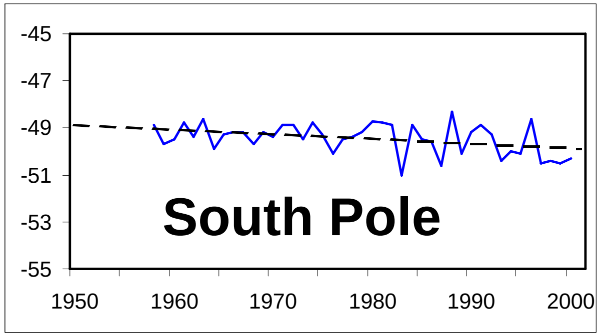


Validation of ECMWF operational analyses against drifting buoy data, Feb.-Apr. 2001
(King, *Wea. & Forecasting, 2003)*



Observed patterns of climate variability



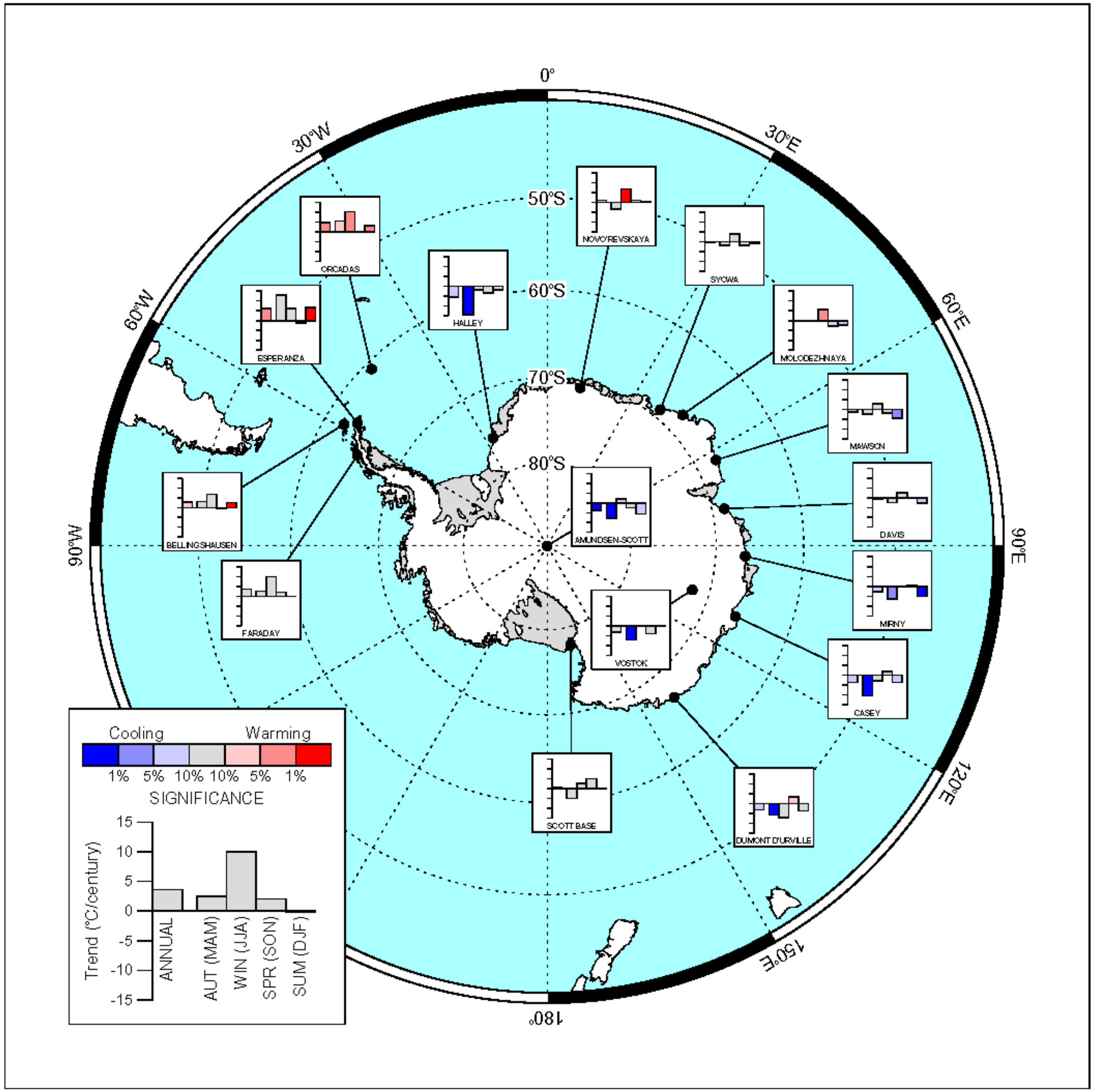


Annual mean temperatures 1951-2000 (ºC)

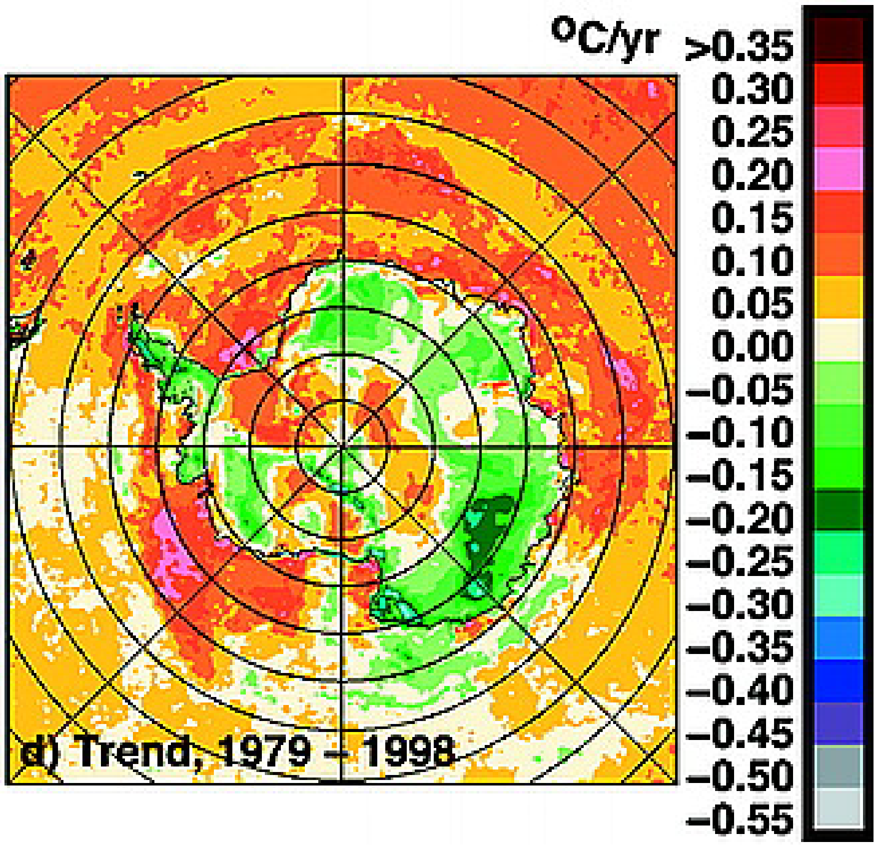
Observed patterns of climate variability

Antarctic near-surface temperature trends 1971-2000

(Minimum of 27 years' data required for inclusion)



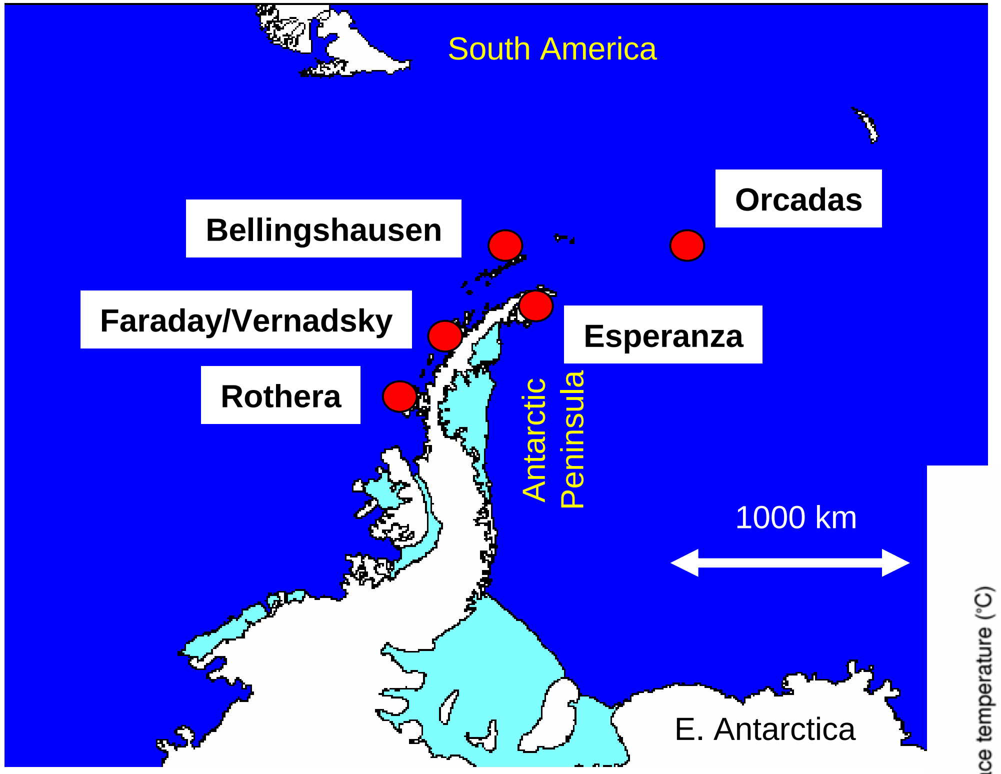
Observed patterns of climate variability

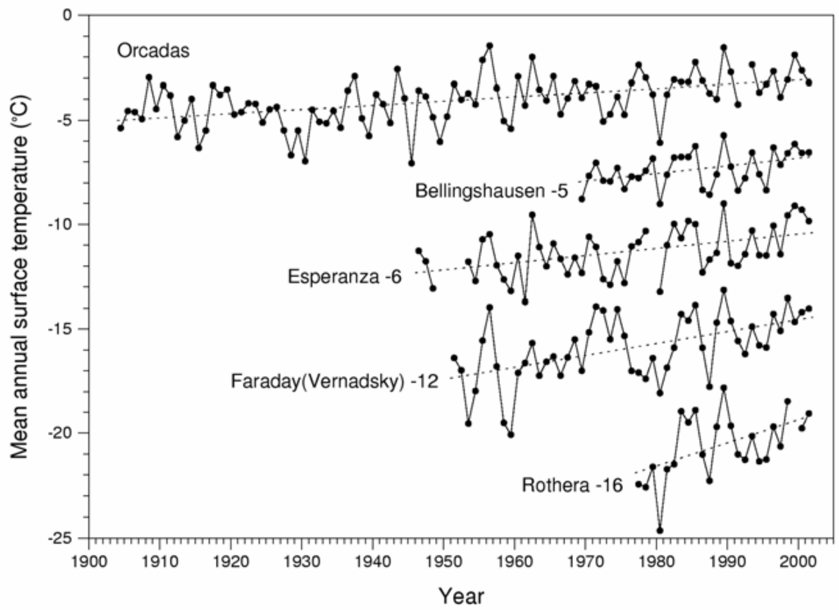


Surface temperature trend 1979-1998 from satellite infrared measurements (J. Comiso, *J. Climate*, 2000)

Observed patterns of climate variability

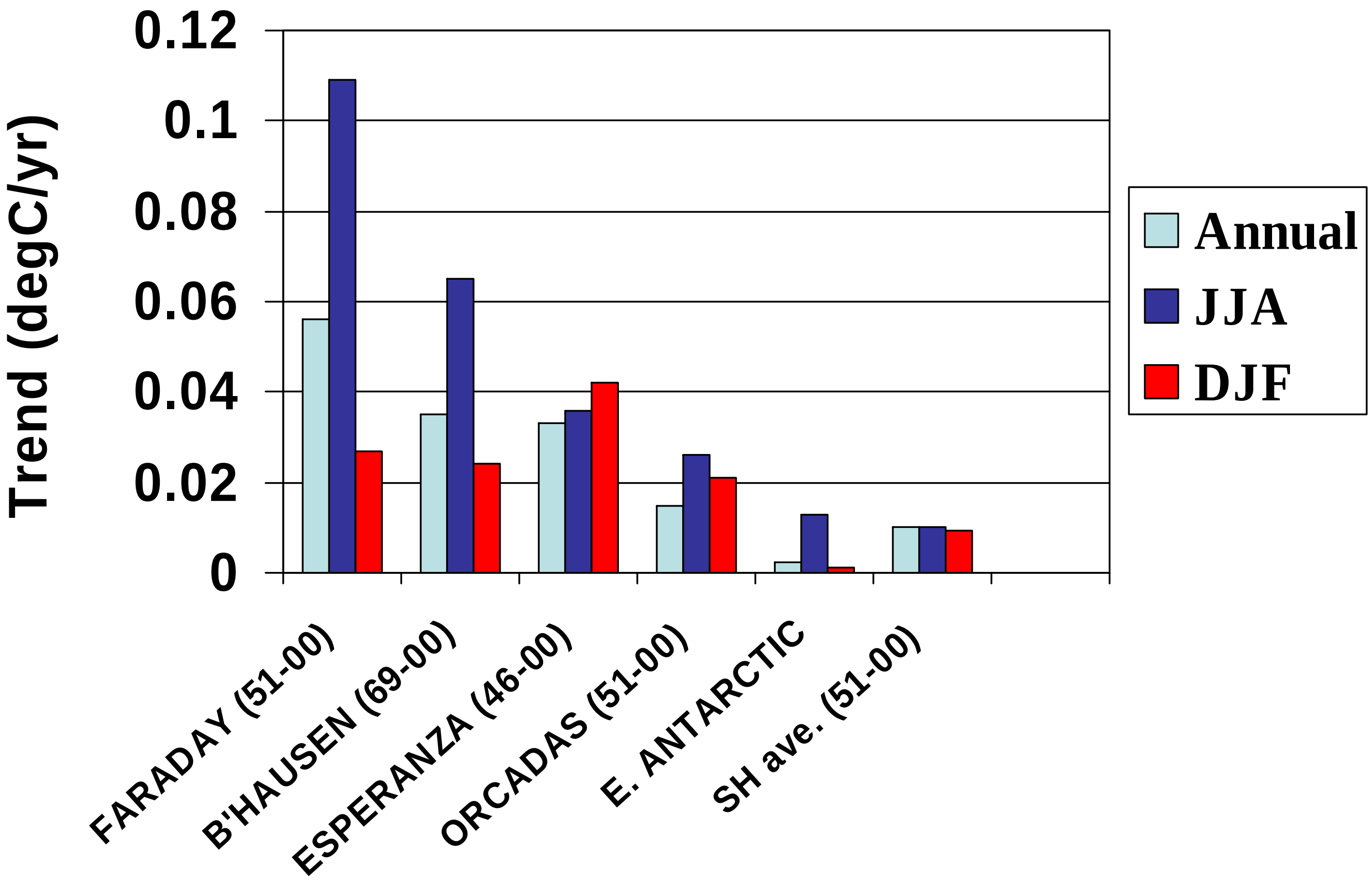
Rapid warming in the Antarctic Peninsula





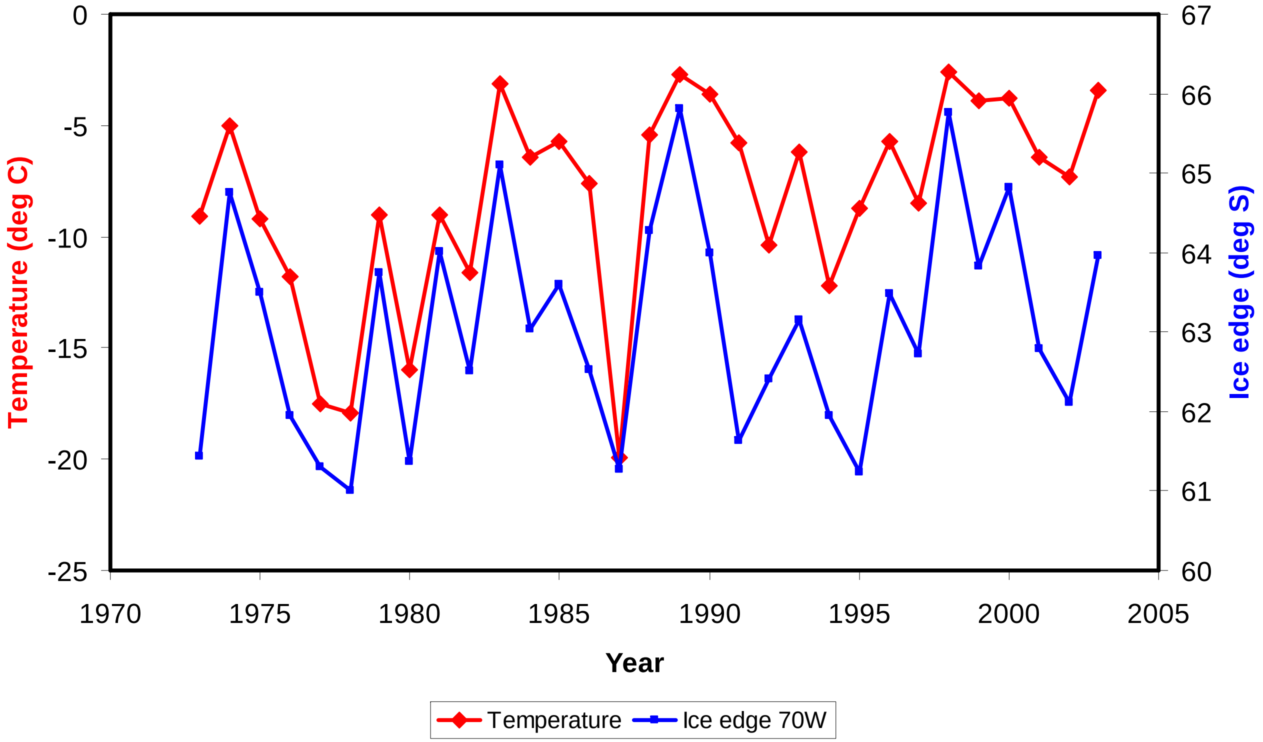
Observed patterns of climate variability

Rapid warming in the Antarctic Peninsula



Observed patterns of climate variability

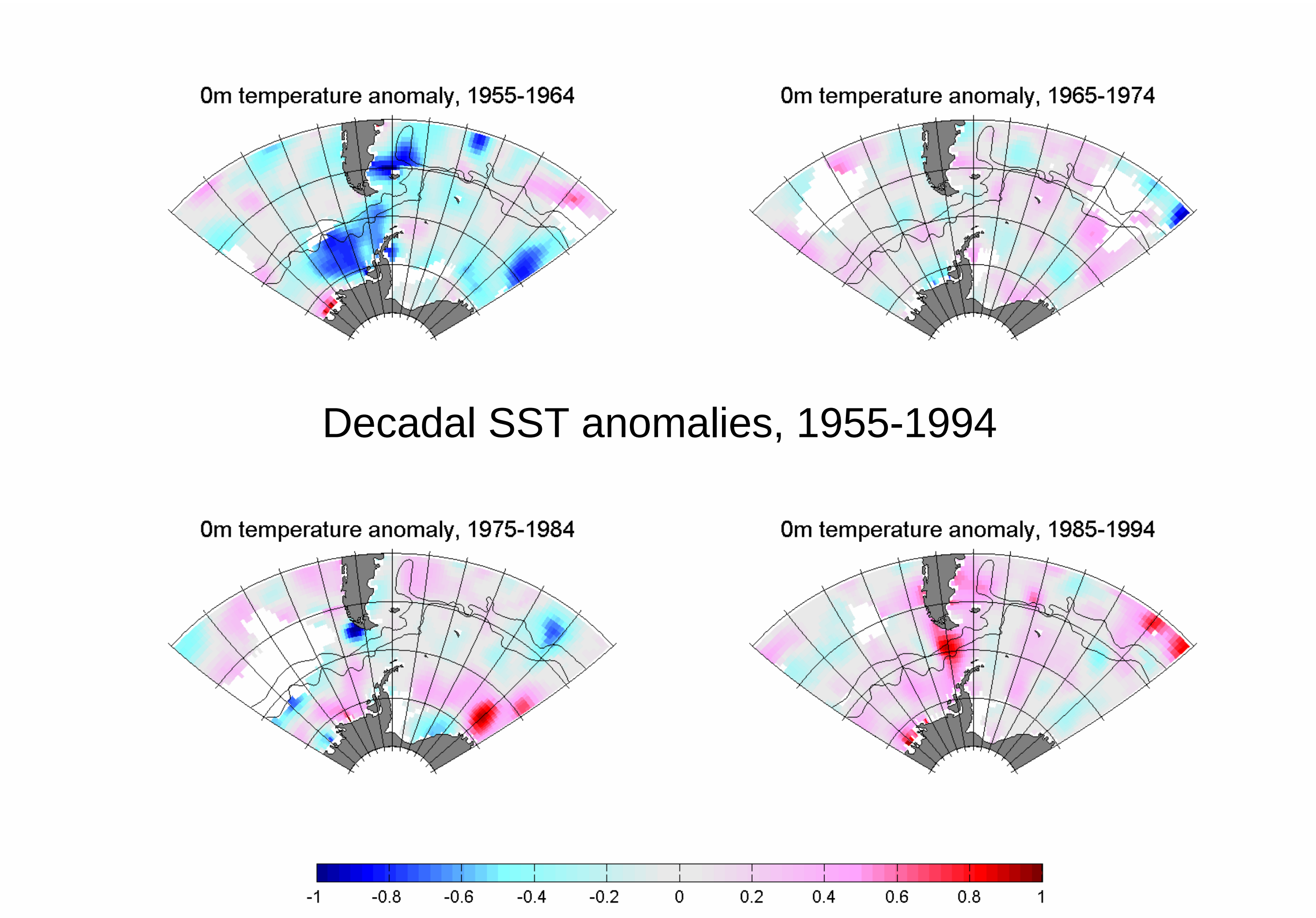
<u>Rapid warming in the Antarctic Peninsula</u>



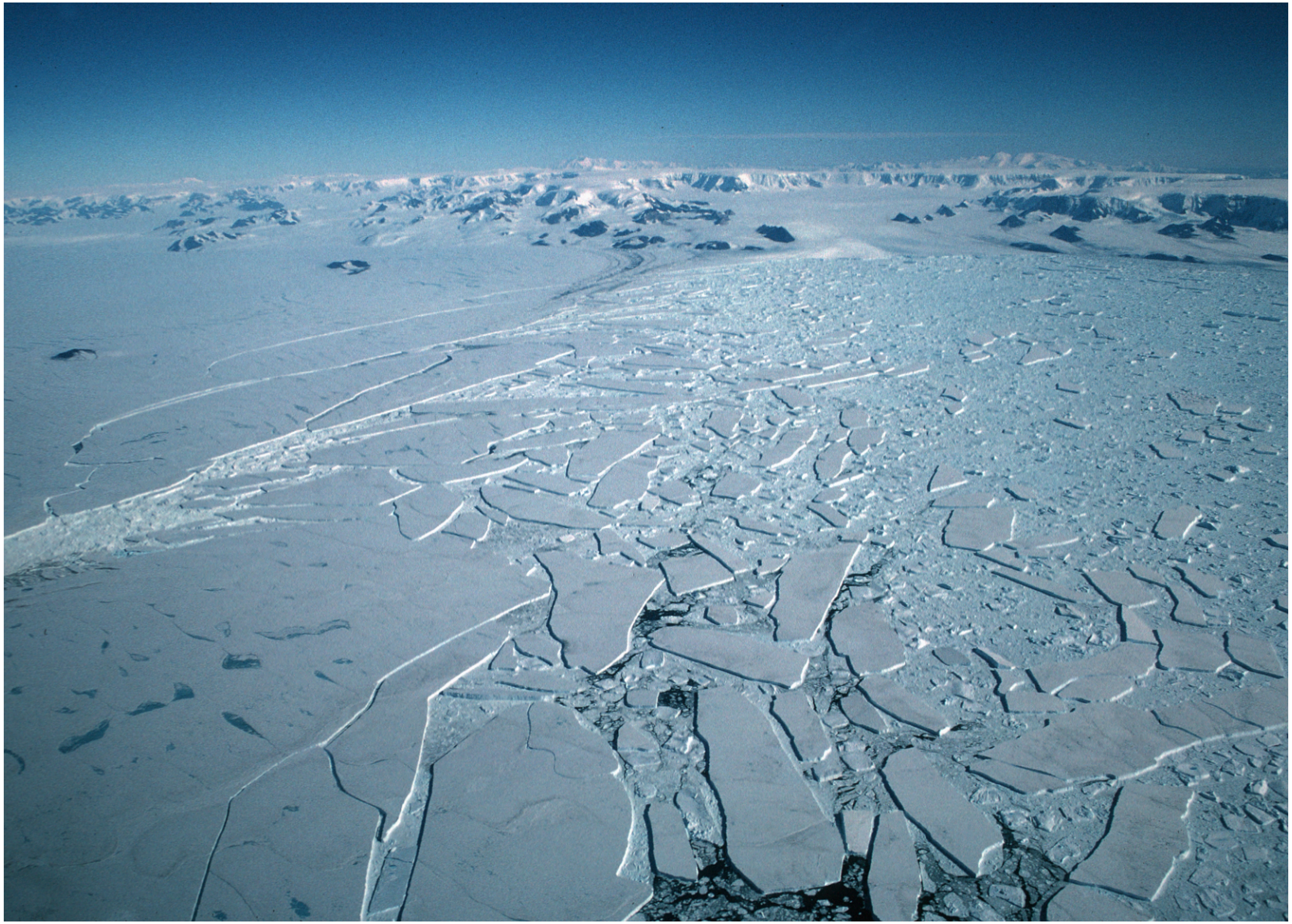
Winter temperature at Faraday and sea ice edge at 70W (inverted)

Observed patterns of climate variability

Rapid warming in the Antarctic Peninsula



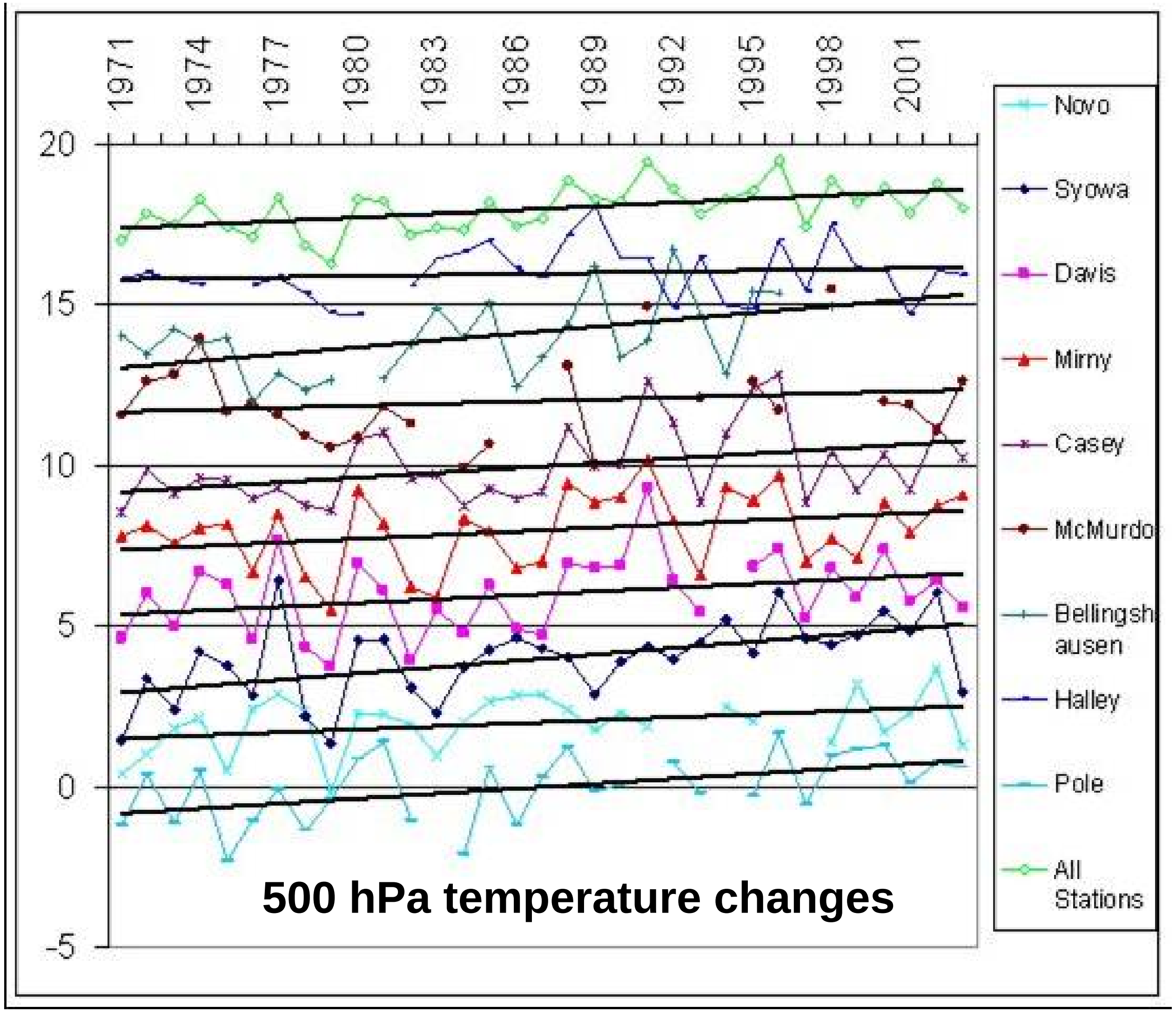
Meredith and King, *Geophys. Res. Lett.*,2005



Collapse of the Larsen A ice shelf, NE Antarctic Peninsula, February 1995

Observed patterns of climate variability

Rapid mid-tropospheric warming

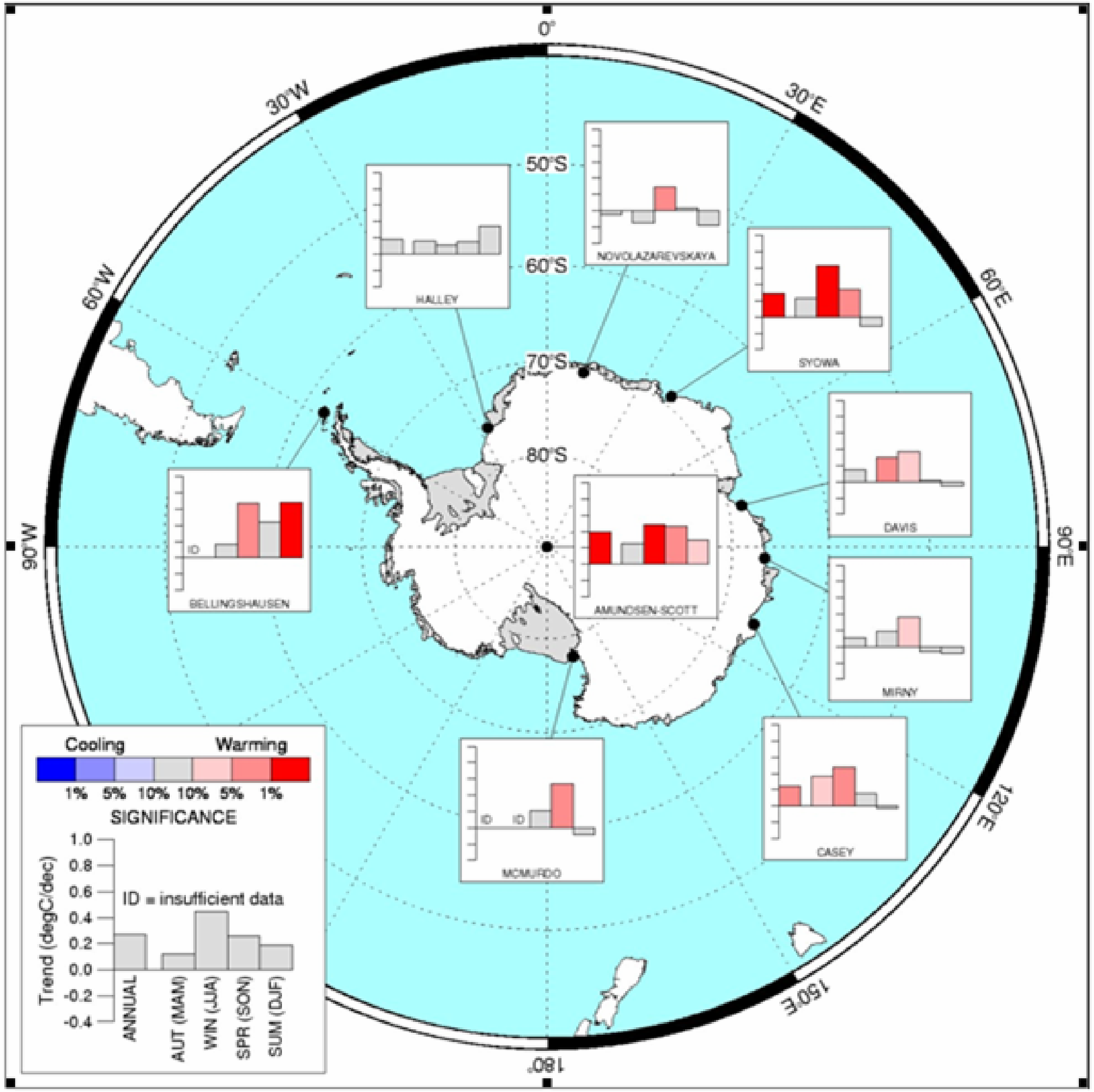


Between 1971 and 2000, 500 hPa temperatures have risen more rapidly (0.6 degC/decade) over Antarctica than anywhere else on Earth

(Turner et al, *Science*, 2006)

Observed patterns of climate variability

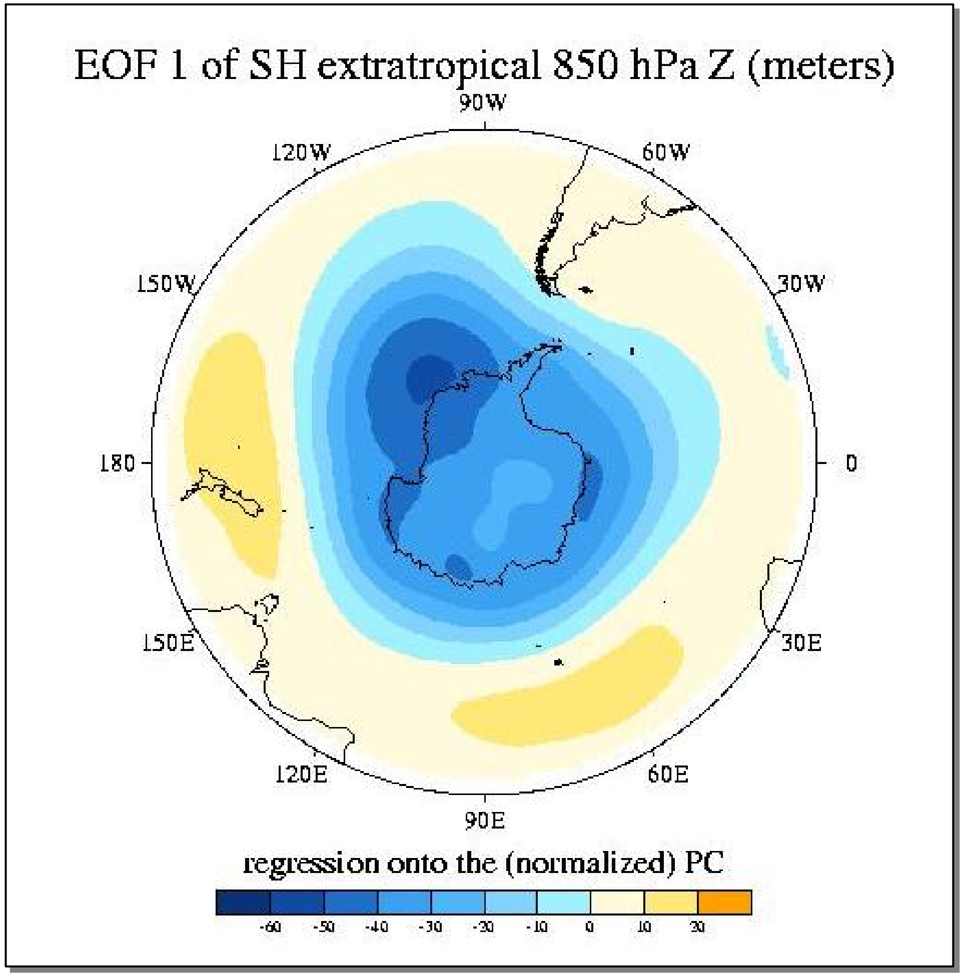
Rapid mid-tropospheric warming



500 hPa temperature trends, 1971-2000

- **Warming trend largest in winter (JJA)**
- **Tropospheric warming seen in 20th century climate simulations with GCMs, but *not* amplified in the Antarctic**

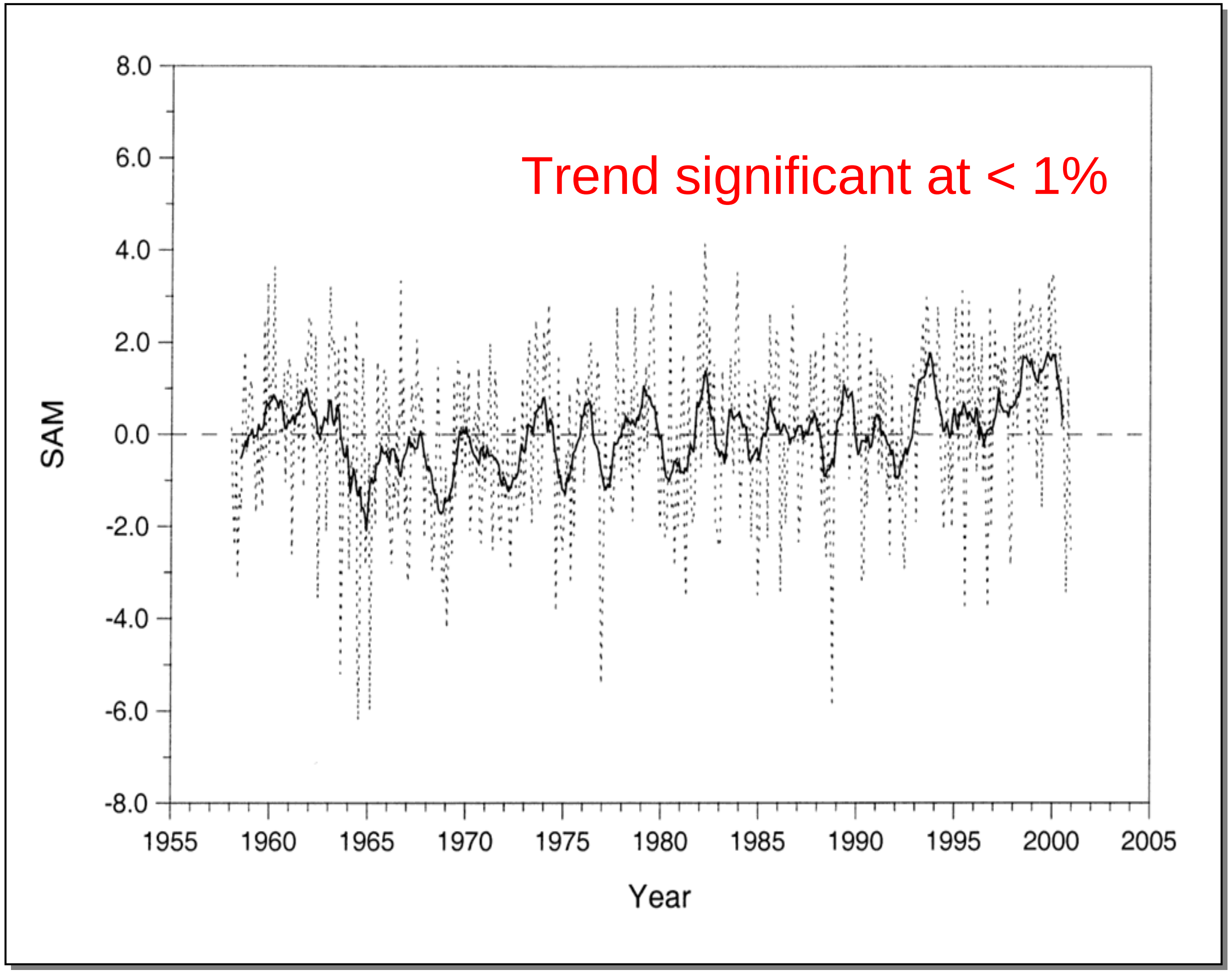
Large-scale modes of variability – the SAM



Source: http://www.jisao.atmos.washington.edu/data/aao/

- The Southern Hemisphere Annular Mode (SAM, aka Antarctic Oscillation (AAO), High Latitude Mode) is the leading mode of variability in the atmospheric circulation of the Southern Hemisphere.
- Synchronous sea-level pressure/geopotential height anomalies of opposite sign in Antarctica and the mid-latitudes, causing strengthening and weakening of the circumpolar westerlies. **High SAM index = strong westerlies and *vice-versa***.
- Contributes a significant proportion (~30%) of SH atmospheric circulation variability from intraseasonal to inter-decadal timescales.

Large-scale modes of variability – the SAM



Monthly indices of the SAM as calculated from observations normalized to 1958-2000. The full line is a running 12-month filter. (G. Marshall, *J. Climate*, 2003)

Large-scale modes of variability – the SAM

Possible causes of the observed SAM trend:

• Natural variability – unlikely, as 30-year trends of this magnitude are not seen in a 1000-year control run of a coupled GCM (Marshall et al., 2004)

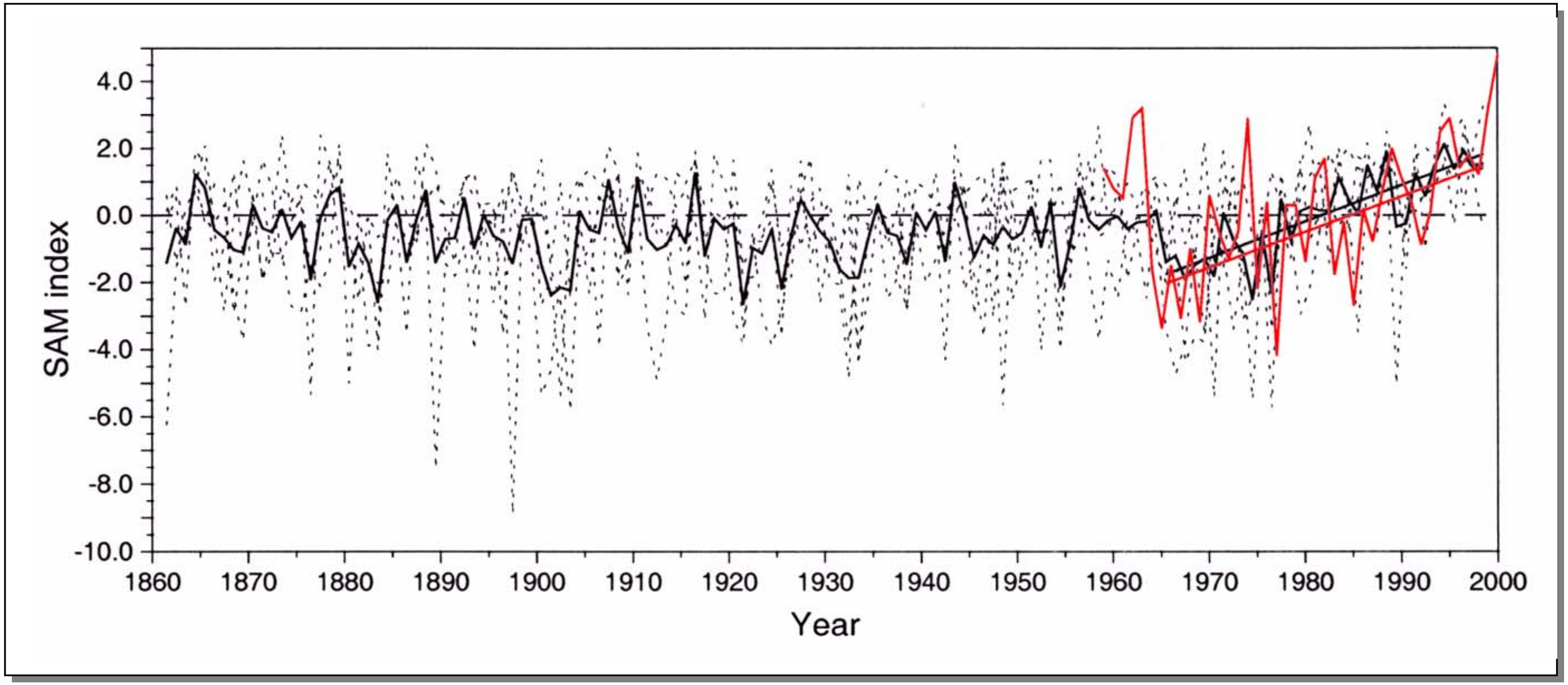
• Stratospheric ozone depletion (Sexton, 2001; Thompson and Solomon, 2002 Gillet and Thompson, 2003)

• Greenhouse gasses (Kushner et al., 2001; Cai et al., 2003)

• Anthropogenic + natural forcings (Marshall et al., 2004; Arblaster and Meehl, 2006)

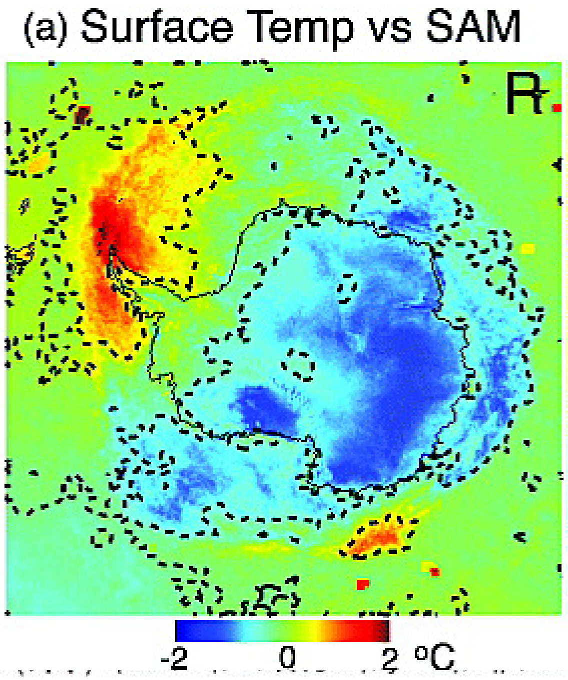
• Mid- and low-latitude SST variations (Grassi et al., 2005; L'Heureux and Thompson, 2006; work in progress at BAS)

Large-scale modes of variability – the SAM

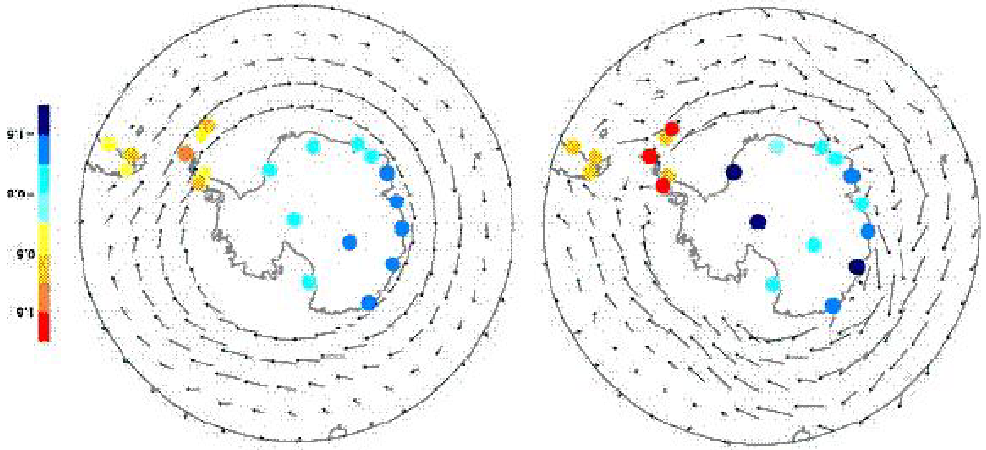


SAM index variations from observations (red) and from a run of the HadCM3 model with all major anthropogenic and natural forcings included (Marshall et. al, *GRL*, 2004)

Large-scale modes of variability – the SAM



Regression of satellite IR surface temperature on SAM index (Kwok and Comiso, *GRL*, 2002)

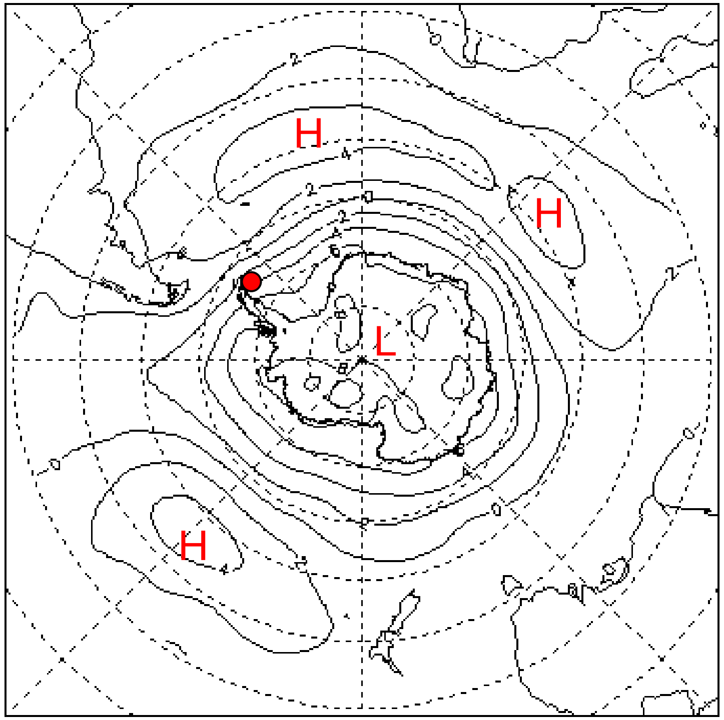


Trend associated with SAM

Total trend

Thompson and Solomon *Science*, 2002

Large-scale modes of variability – the SAM



Sea-level pressure anomalies associated with warm summers at Esperanza (●)

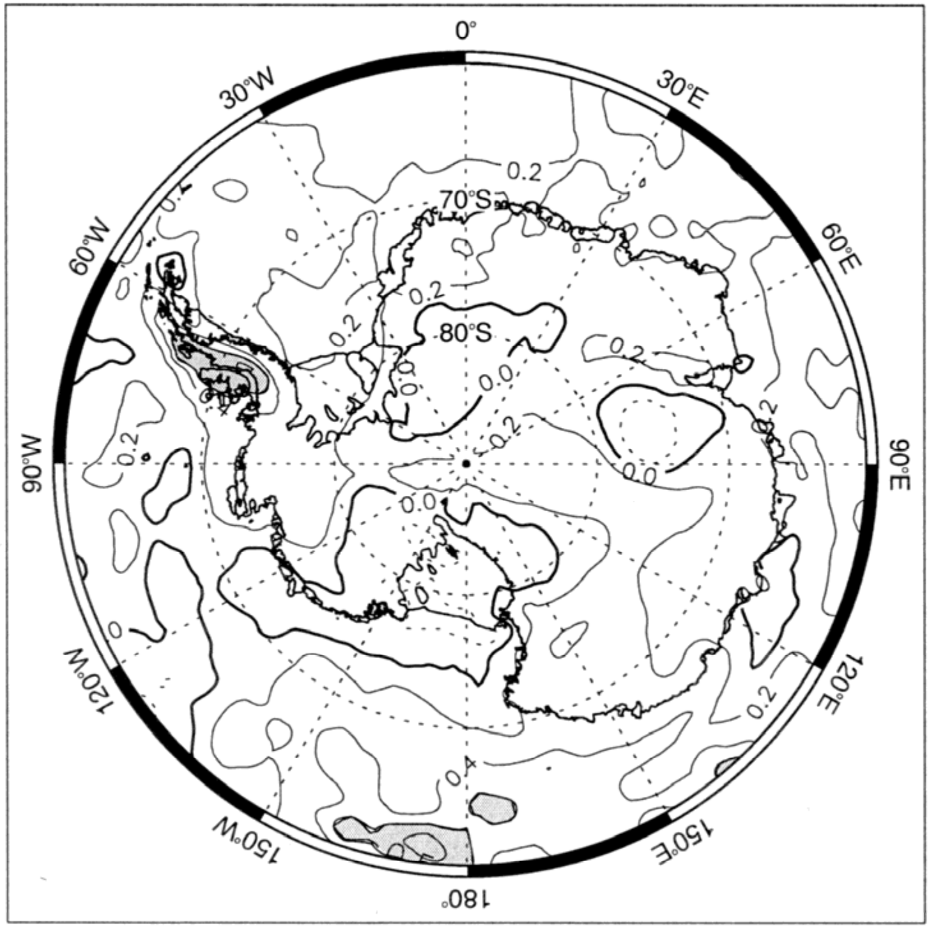
• Variations in SAM index explain over 30% of variability in summer temperature at Esperanza

• High sensitivity to SAM due to its location – just downwind of the Peninsula mountain barrier

• Disintegration of ice shelves on E. side of Peninsula linked to SAM trend and hence to anthropogenic forcing (Marshall *et al. J.Climate*, in press)

• Large winter warming trend on W. side of Peninsula is NOT associated with SAM changes

Large-scale modes of variability – the SAM

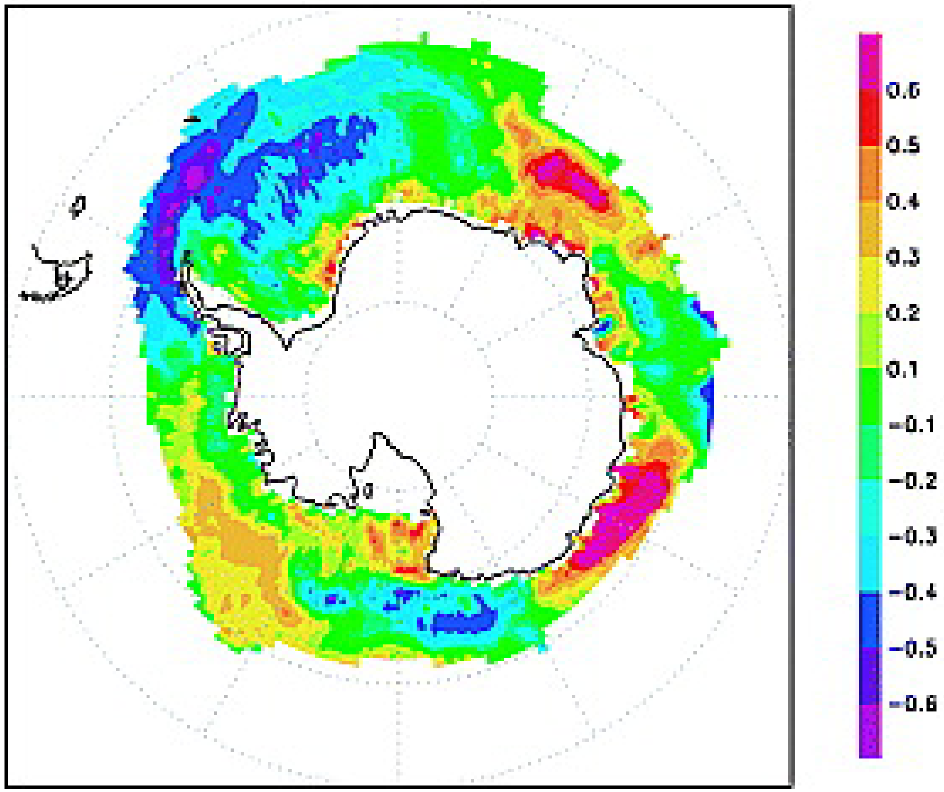


Correlation of ERA-40 annual precipitation with the SAM index

R > 0.5 shaded

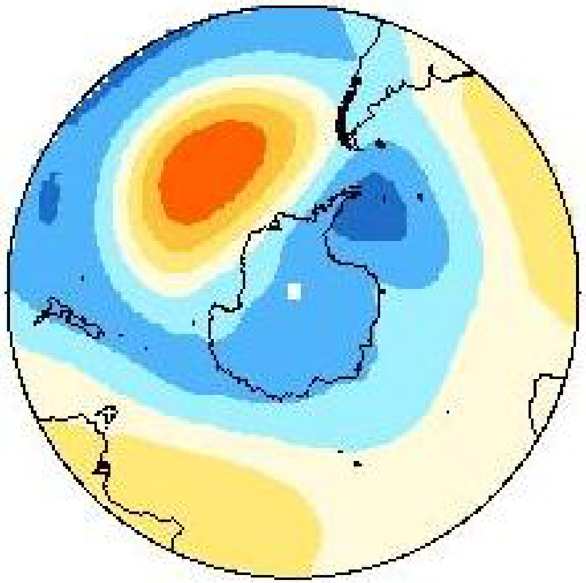
(G.J. Marshall, unpublished)

Large-scale modes of variability – the SAM



Correlation of winter sea ice concentration with SAM index (Lefebvre et al., *JGR*, 2004)

Large-scale modes of variability – the PSA mode



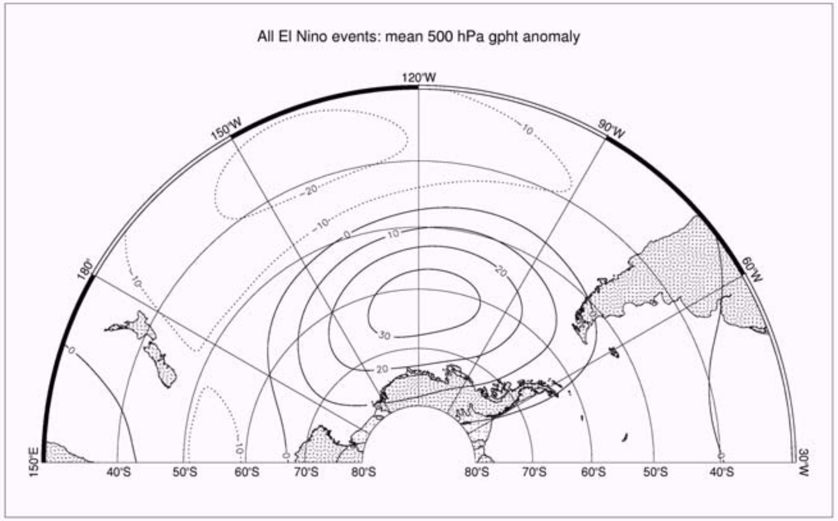
- 2^{nd} EOF of 850 hPa height explains ~11% of variance of extratropical circulation

- Takes the form of a wave train from the tropical Pacific through to the Antarctic Peninsula

- Known as the “Pacific – South American (PSA) mode”

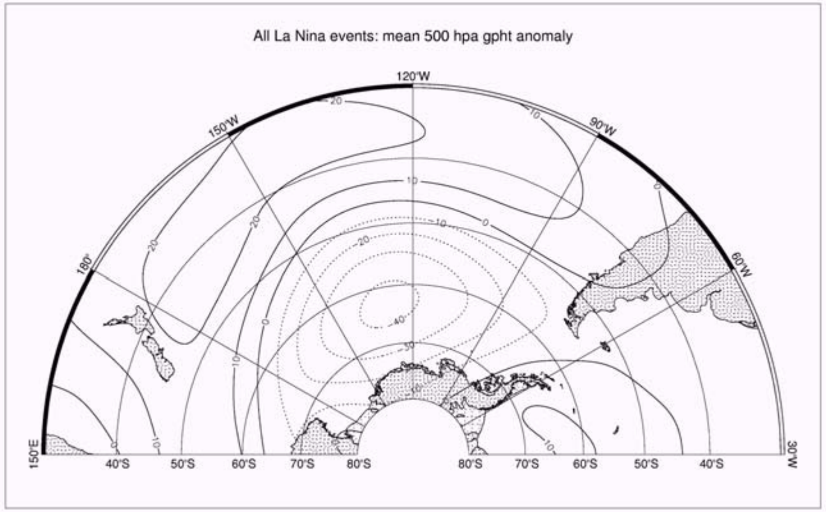
- Often associated with ENSO

Large-scale modes of variability – the PSA mode



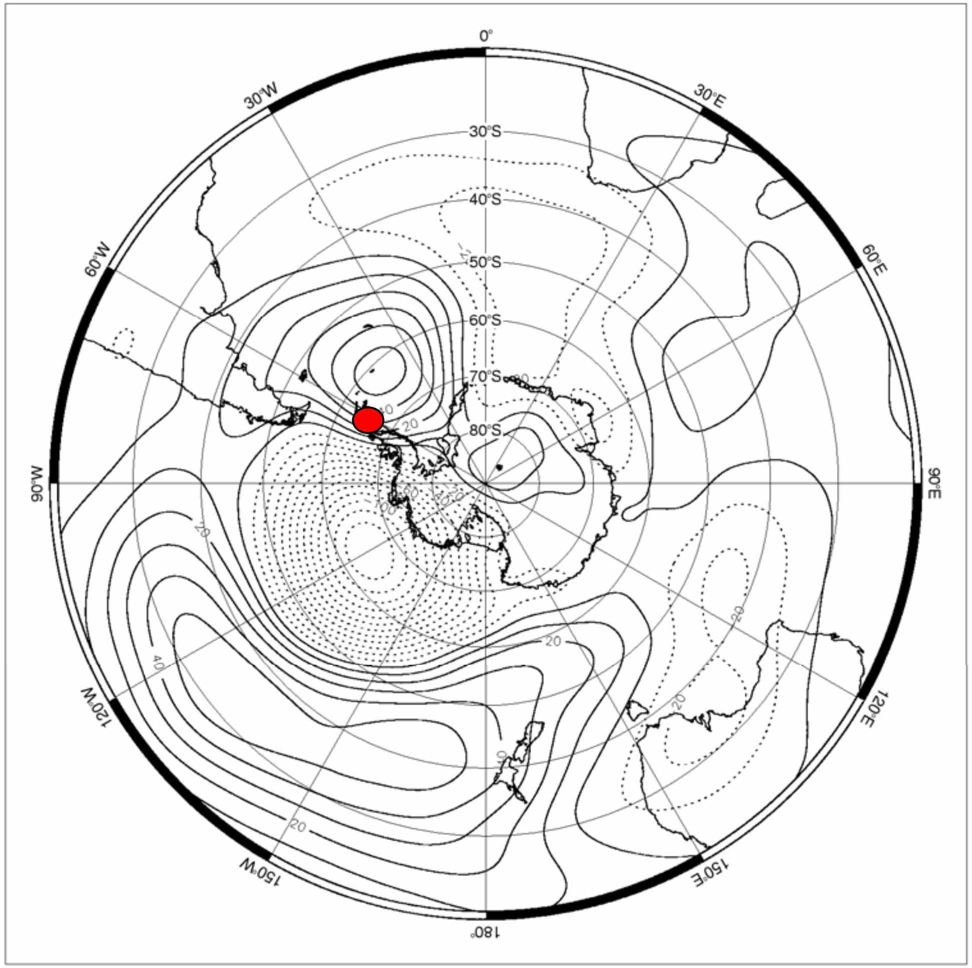
El Niño 500 hPa composite anomaly

Note: large variations are seen in the high-latitude response to individual ENSO warm/cold events



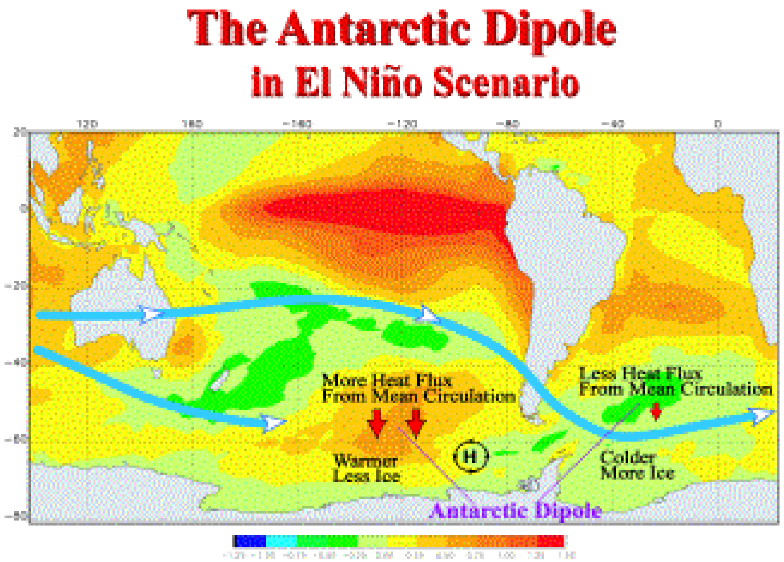
La Niña 500 hPa composite anomaly

Large-scale modes of variability – the PSA mode

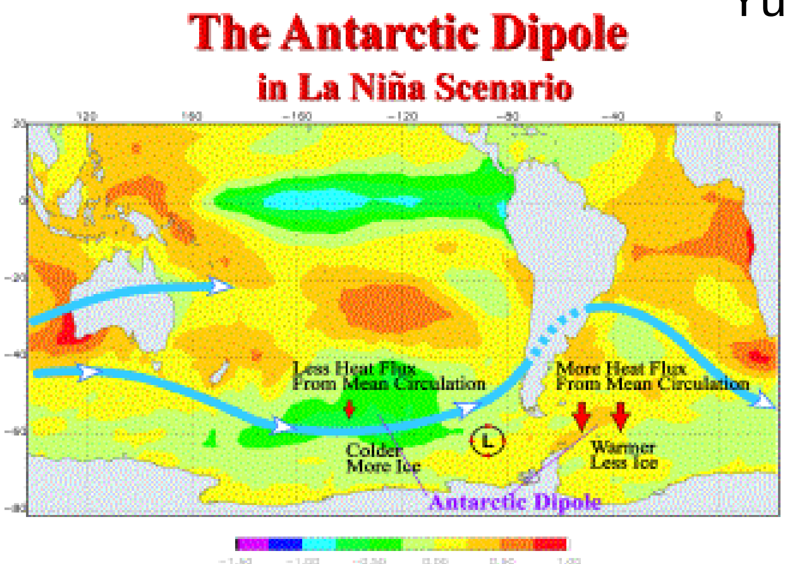


500 hPa height anomalies associated with warm winters at Faraday (●)

Large-scale modes of variability – the PSA mode



Yuan, Ant Sci 2004



Large-scale modes of variability – the PSA mode

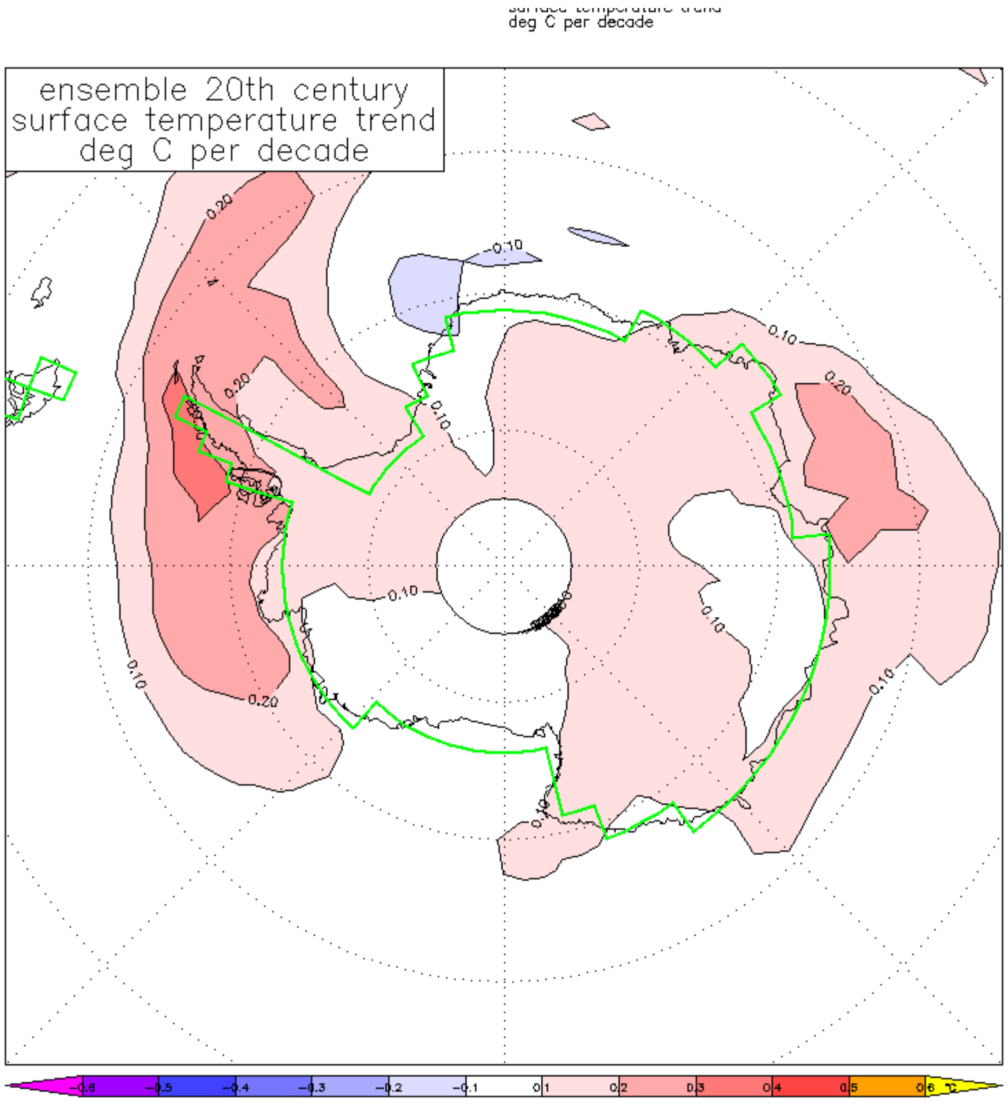
Trends in the PSA pattern

• Nodes of the PSA pattern are in data-sparse regions – cannot develop an index based on station data alone

• Reanalyses only sufficiently reliable post-1979 – variability obscures any underlying trend

• Rapid warming in Antarctic Peninsula is suggestive of a trend towards lower pressure/reduced blocking to W. of the Peninsula. Some indirect evidence for this, e.g. increase in frequency of precipitation events (Turner et al., JGR, 1997). Increased blocking to W of Peninsula suggests a trend towards more La Niña – like conditions.

Modelling Antarctic climate change

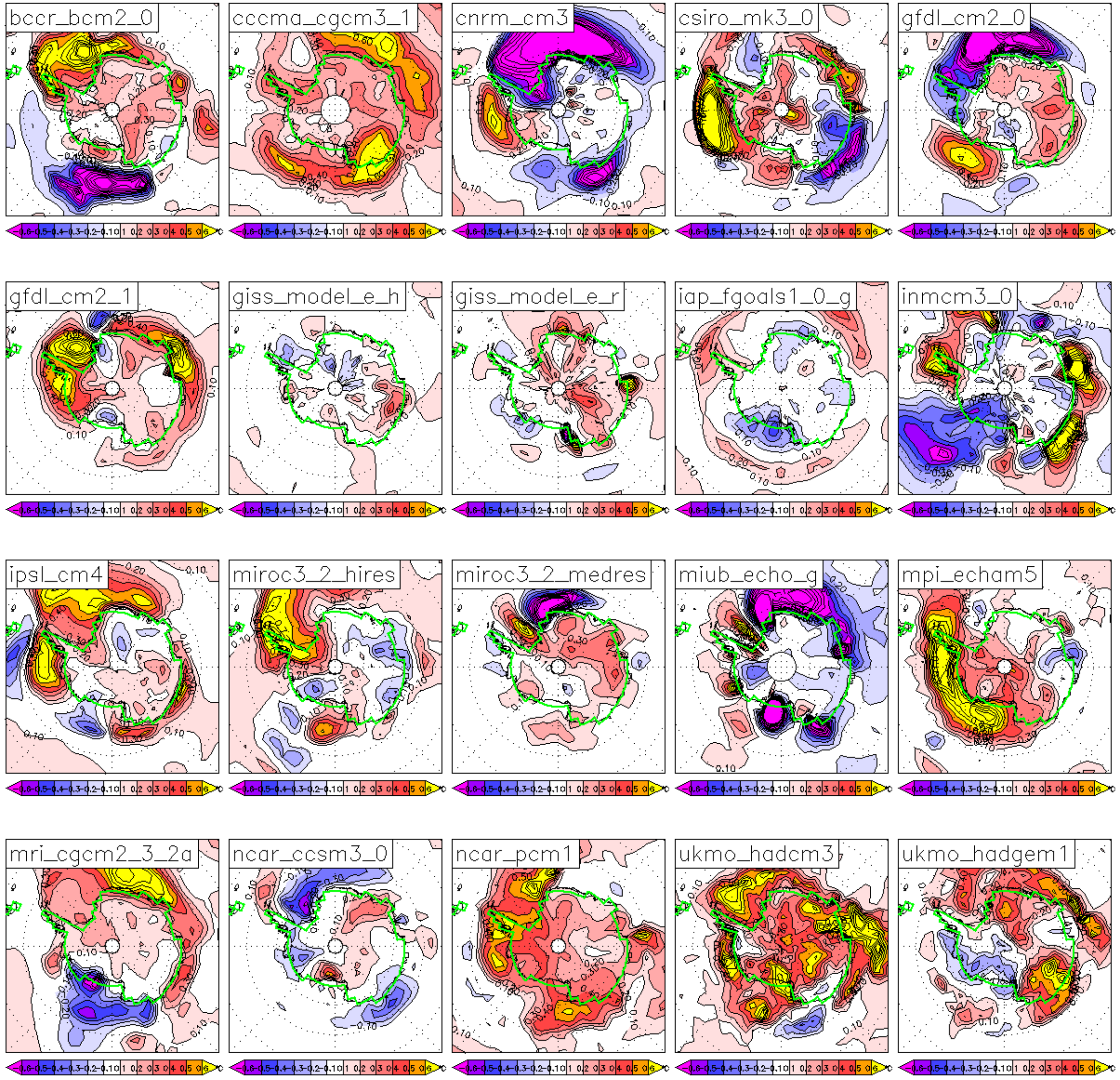


IPCC AR4 20th Century climate experiment (20c3m)

Trends in JJA surface temperature, 1950-99, average of 20 models

- Largest warming in Antarctic Peninsula (but only one-third of that observed)
- Lack of cooling over E. Antarctica

Modelling Antarctic climate change

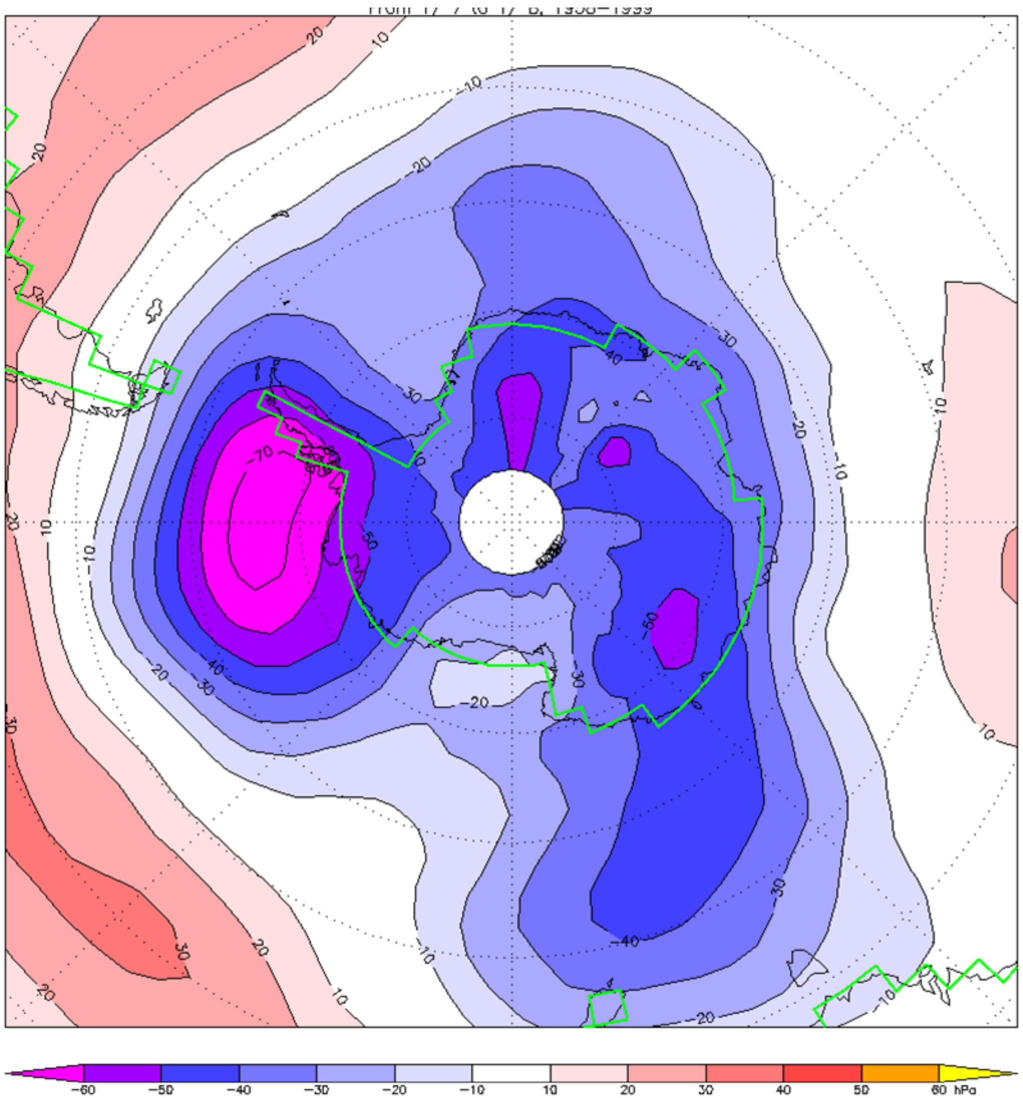


<u>IPCC AR4 20th Century climate experiment (20c3m)</u>

Trends in JJA surface temperature, 1950-99. Results from 20 models.

Note the large spread!

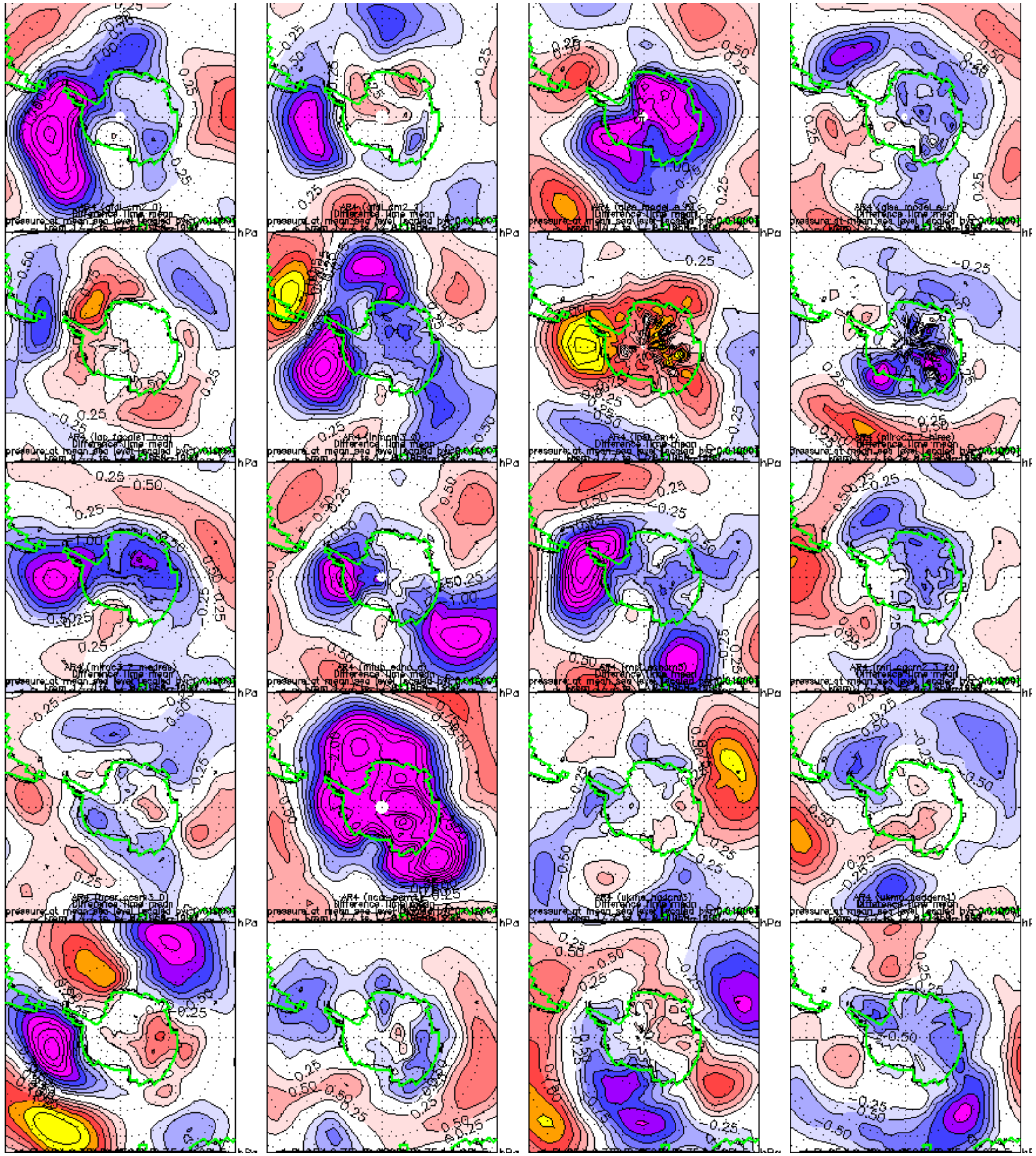
Modelling Antarctic climate change



<u>IPCC AR4 20th Century climate experiment (20c3m)</u>

Trends in July mslp, 1955-99, average of 20 models

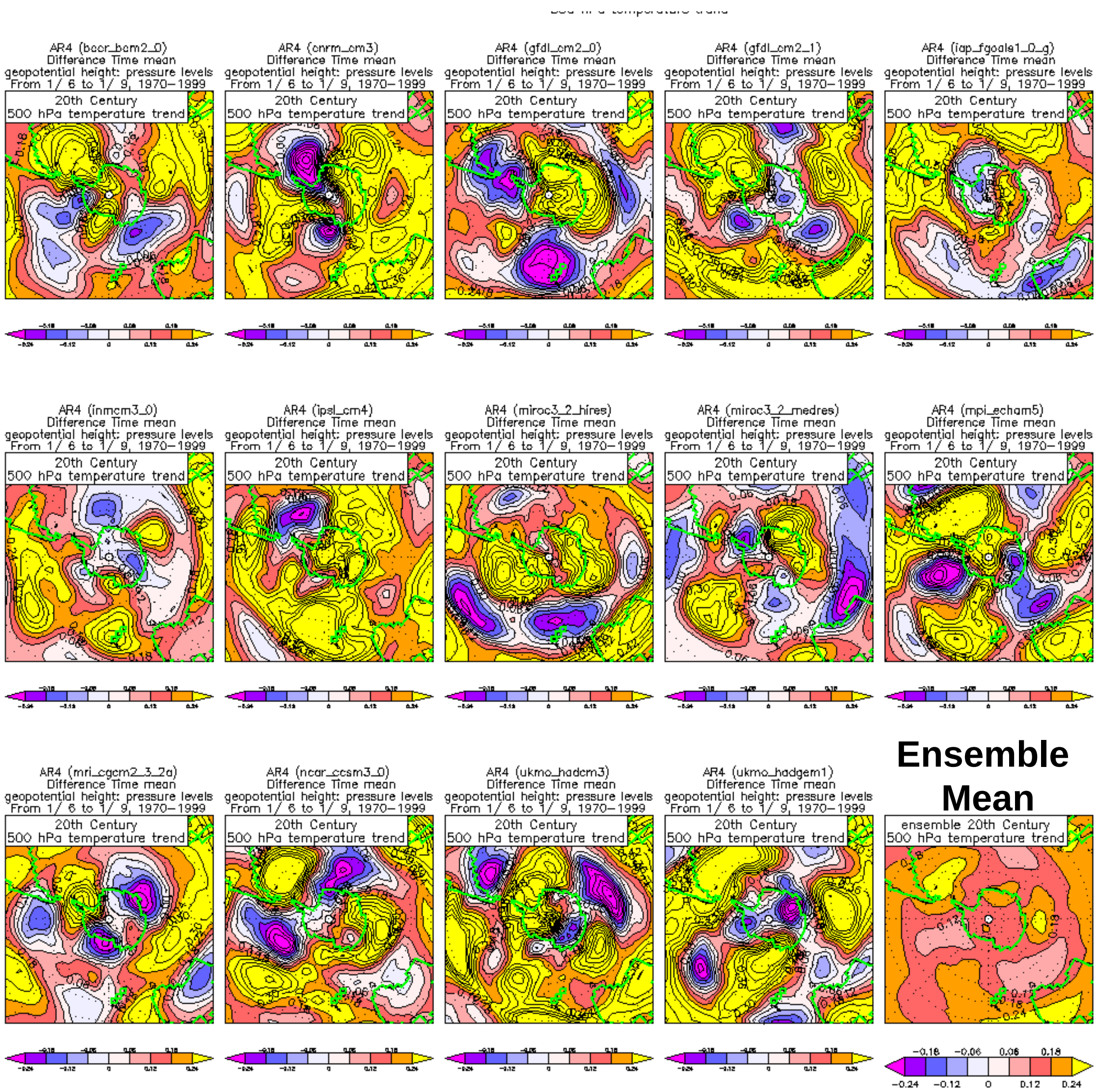
Modelling Antarctic climate change



IPCC AR4 20th Century climate experiment (20c3m)

Trends in July mslp, 1955-99. Results from 20 models

Modelling Antarctic climate change



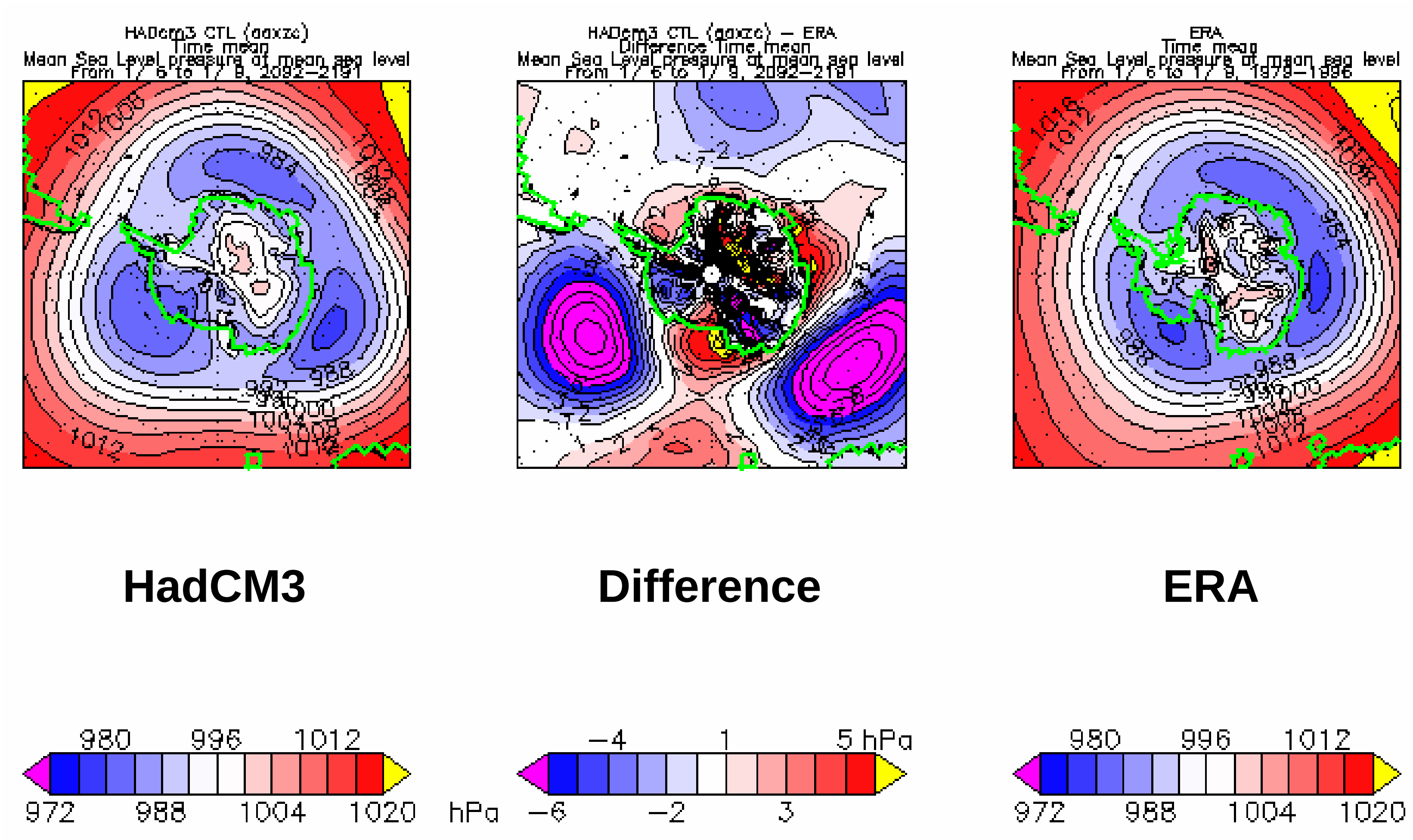
<u>IPCC AR4 20th Century climate experiment (20c3m)</u>

Trends in winter (**JJA) 500 hPa temperature**, 1970-99. Results from 19 models, plus ensemble mean

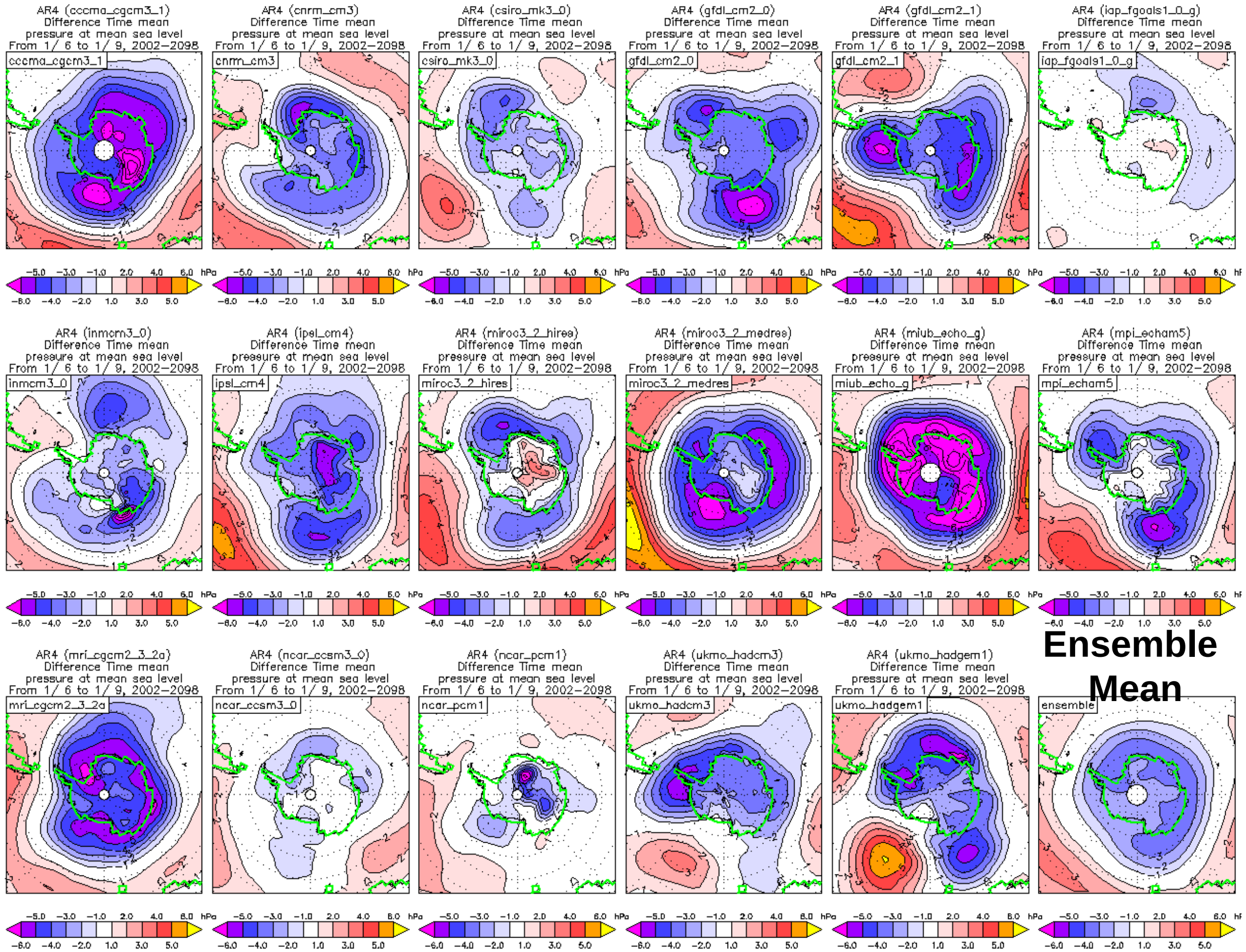
- No amplification over Antarctica
- Modelled trends less than one-third of observed trend (0.6 degC/decade)

Modelling Antarctic climate change

Modelled and observed mslp, Antarctic winter (JJA)



Modelling Antarctic climate change

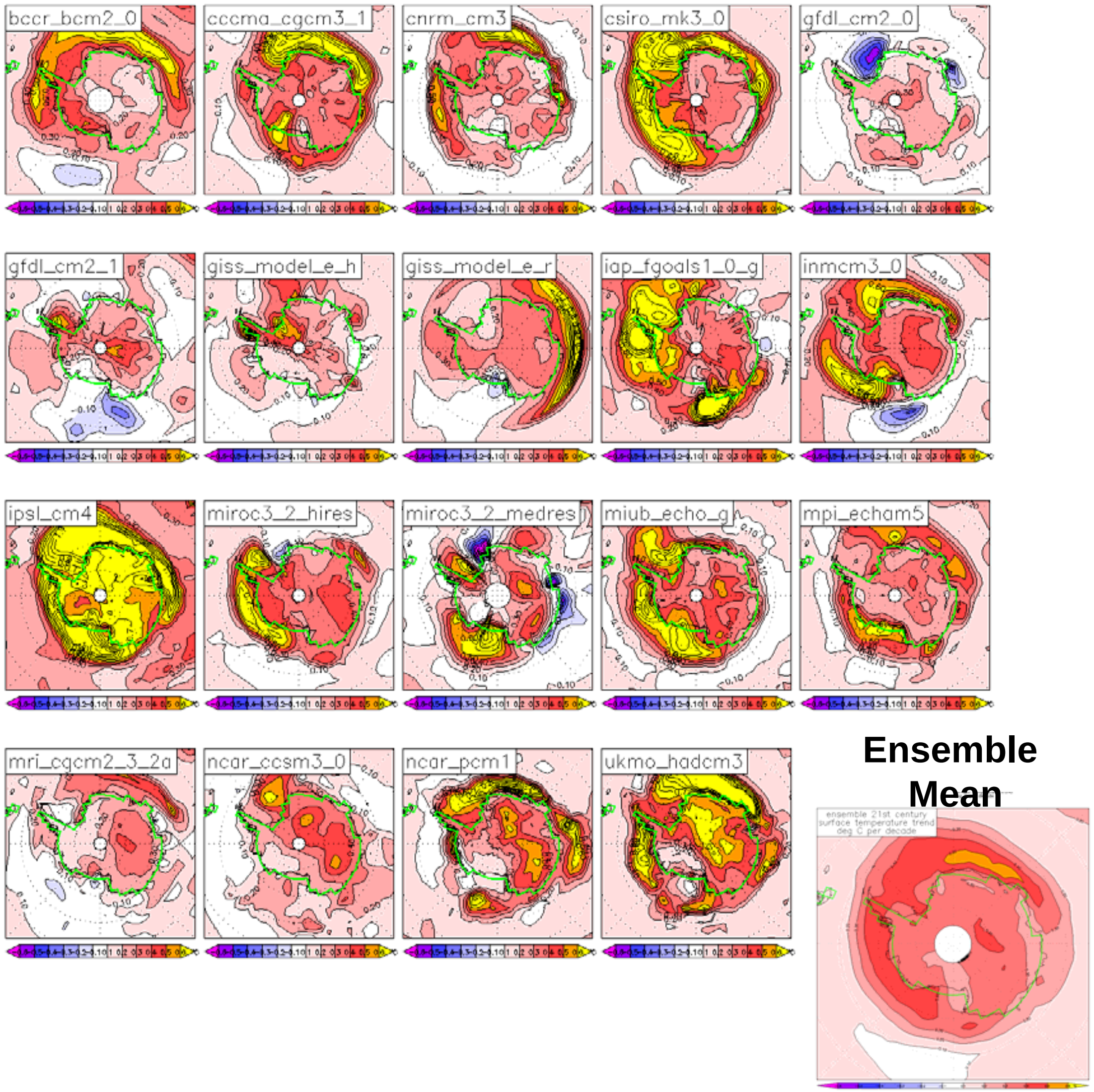


<u>IPCC AR4 future climate experiment (sresa1b)</u>

Trends in JJA mslp, 2000-2099. Results from 19 models plus ensemble mean

With greater forcing, response projects more clearly onto the annular mode

Modelling Antarctic climate change



<u>IPCC AR4 future climate experiment (sresa1b)</u>

Trends in JJA surface temperature, 2000-2099. Results from 19 models plus ensemble mean.

- Considerable variability across models
- Warming of 4-5 degC around coast – reduced sea ice?
- Peninsula no longer stands out as zone of rapid warming

Summary

- Our understanding of Antarctic climate variability is based on records that mostly start in the IGY or later

- Atmospheric analyses are unreliable in the Antarctic region prior to the modern satellite era but are of excellent quality (for large-scale circulation, at least) after 1979

- Much (but not all) recent climate variability in the Antarctic can be related to large-scale modes of atmospheric circulation variability (SAM, PSA)

- Simulations of 20th-century Antarctic climate change show a great degree of variability between models. Signals of projected 21st- century change are more robust

Challenges for IPY and beyond

• What are the causes of the exceptional winter warming in the west Antarctic Peninsula and the Antarctic mid-troposphere ?

• How does observed and projected climate change impact on the Antarctic ice sheets, the Southern Ocean and its ecosystems? What are the implications for global change (sea level rise, bottom water formation, CO_2 uptake) ?

• Given the large spread in model predictions/hindcasts, how confident can we be in making projections of environmental change in the Antarctic? How important are model systematic errors and can we reduce these?

• Can we improve Antarctic atmospheric analyses for the pre-satellite era, thus giving us longer useful records to work with?

Acknowledgements

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