Antarctic Climate and Sea Ice Variability – a Brief Review

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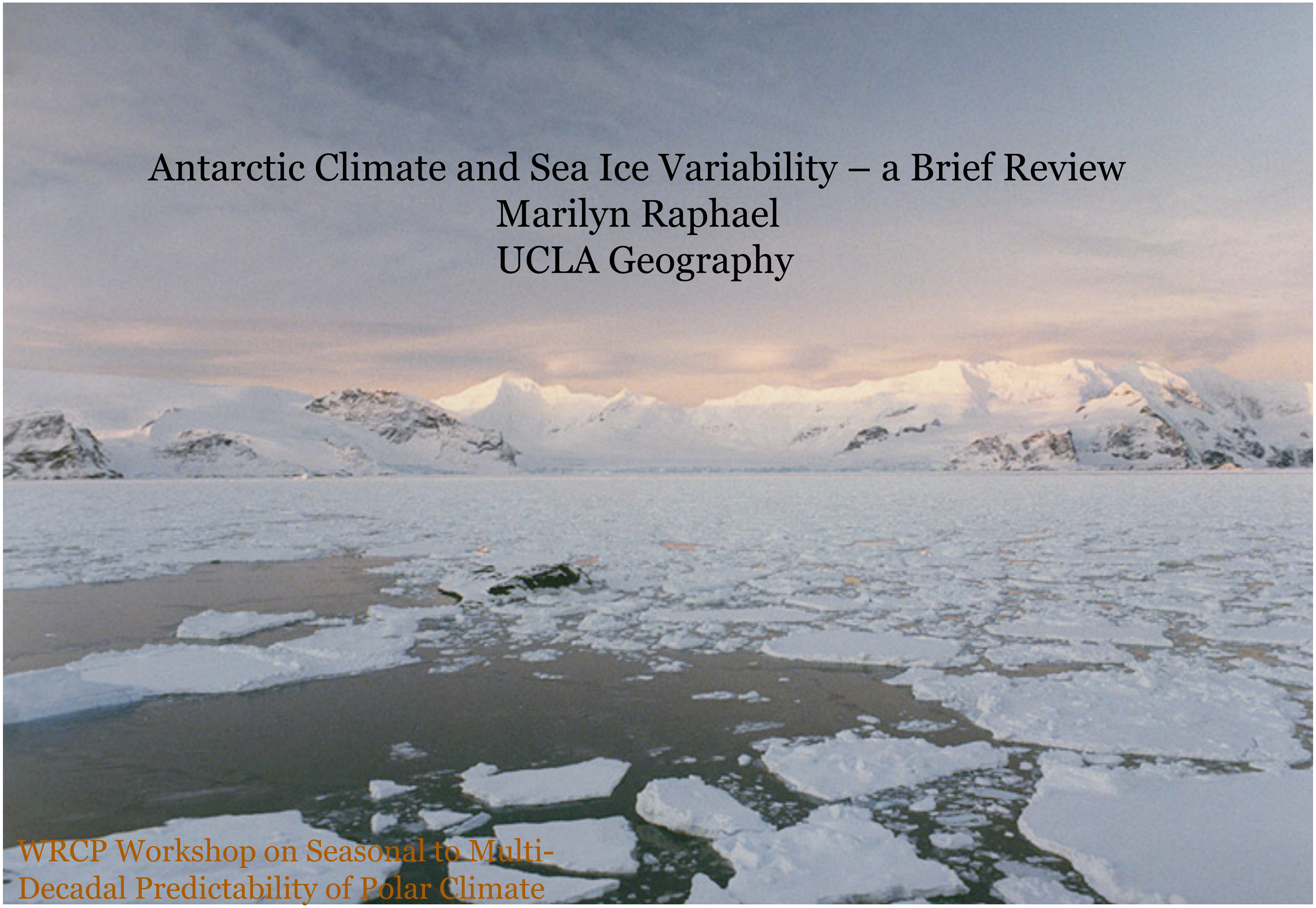
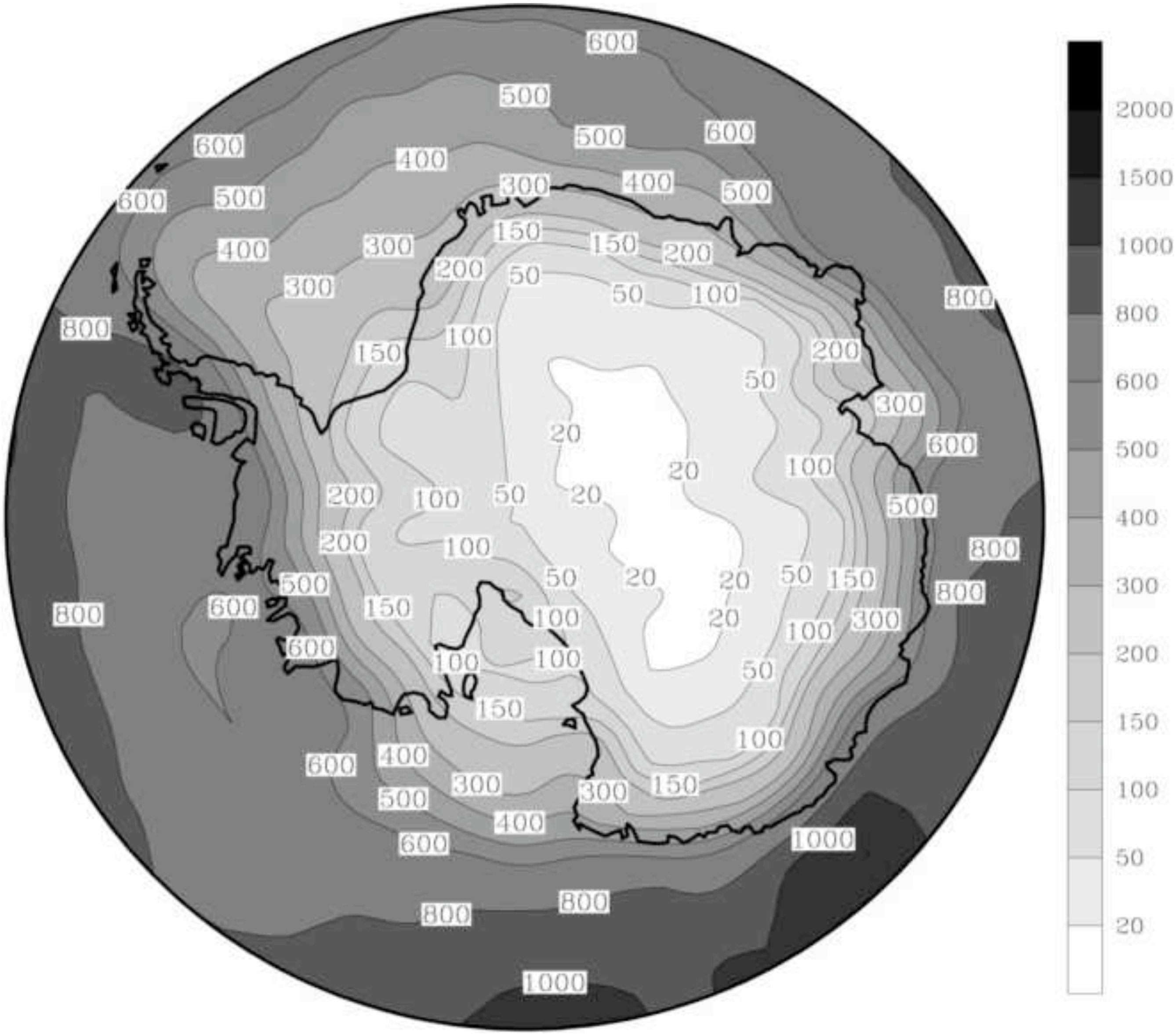
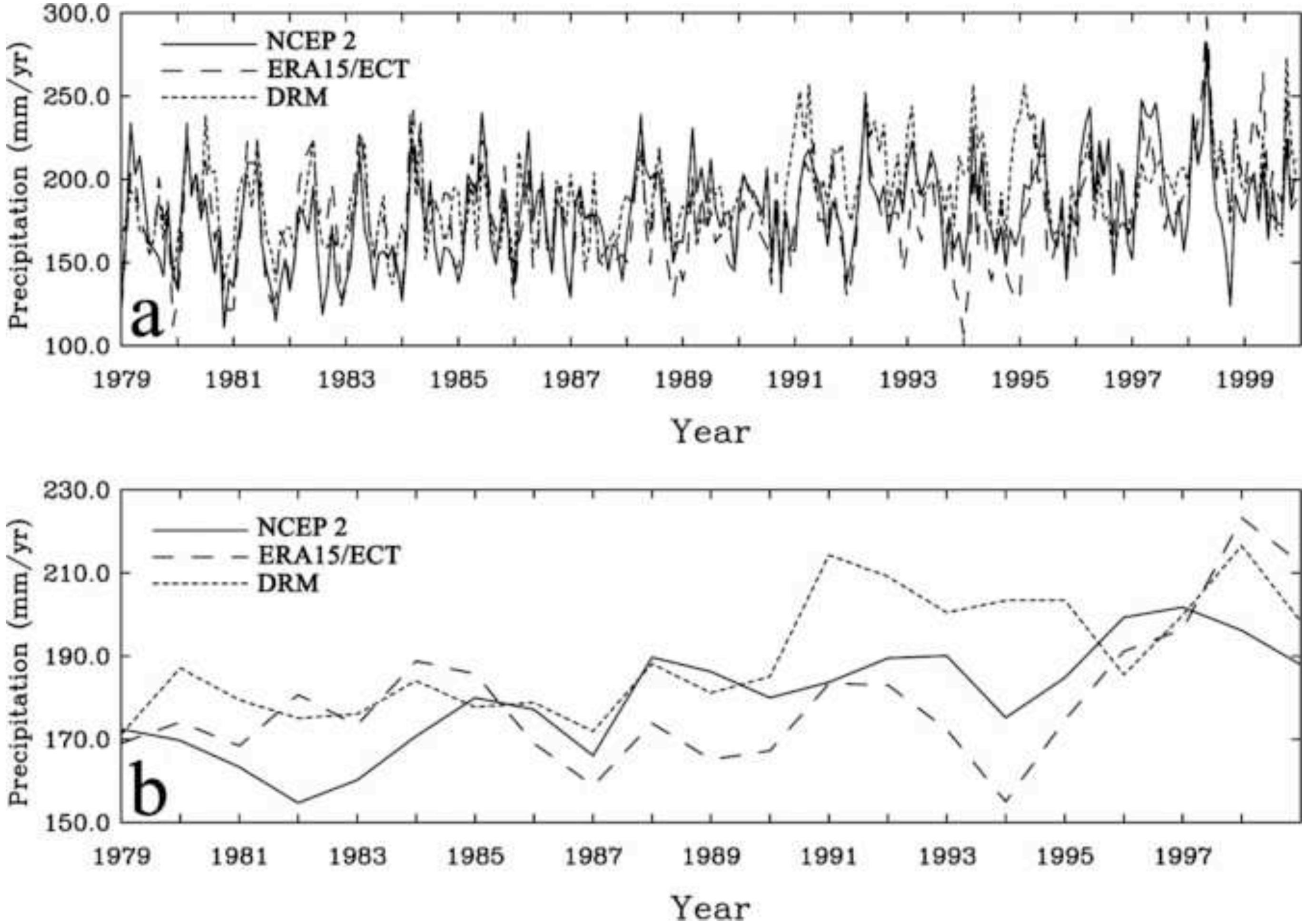


WRCP Workshop on Seasonal to Multi-Decadal Predictability of Polar Climate

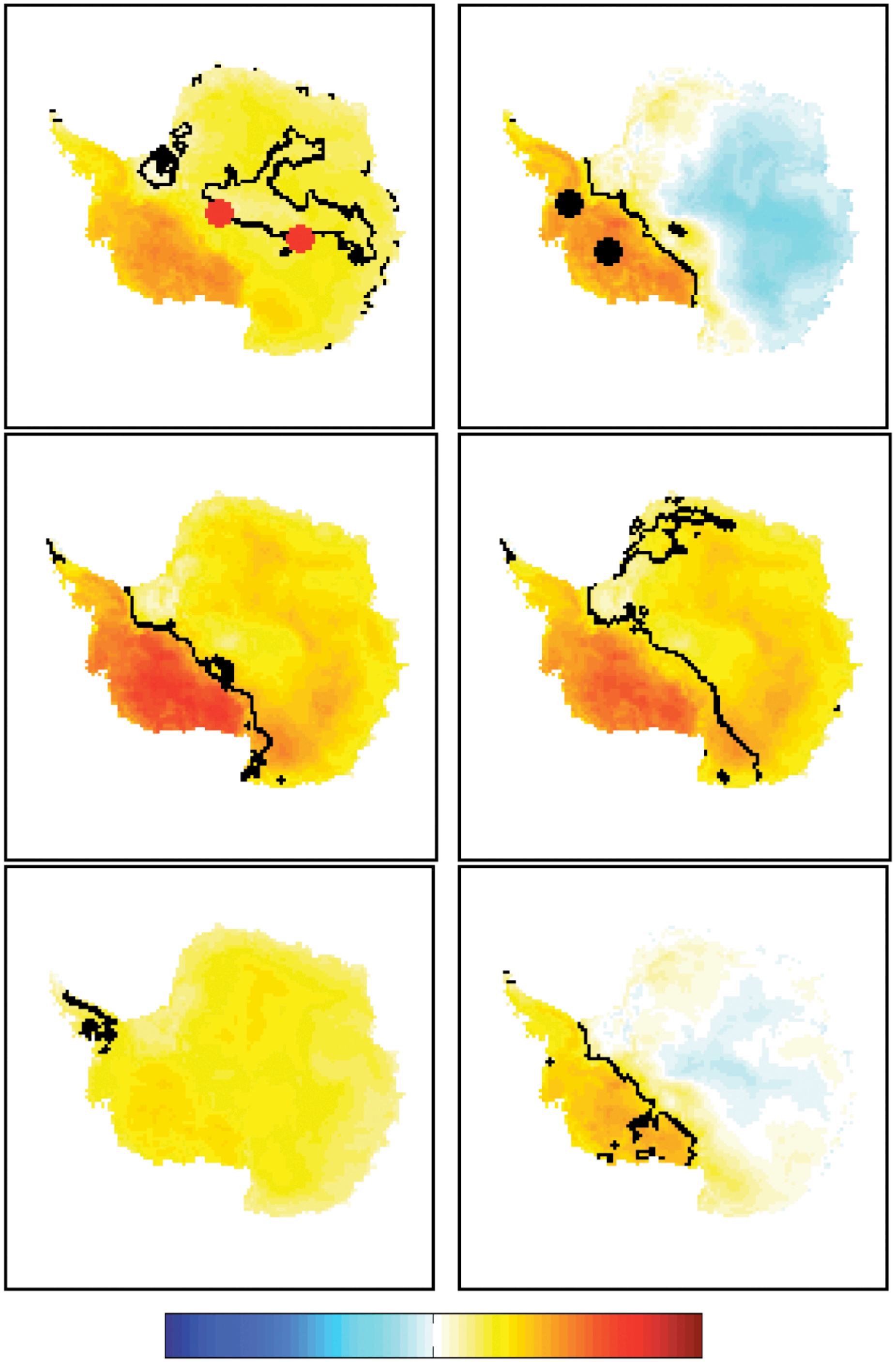


Mean annual precipitation produced by NCEP2 for the years 1979–99 (mm yr21water equivalent). Bromwich et al, 2004

A significant upward trend 11.3 to 11.7 mm yr22 for 1979–99 is found from retrieved and forecast Antarctic precipitation over the continent.



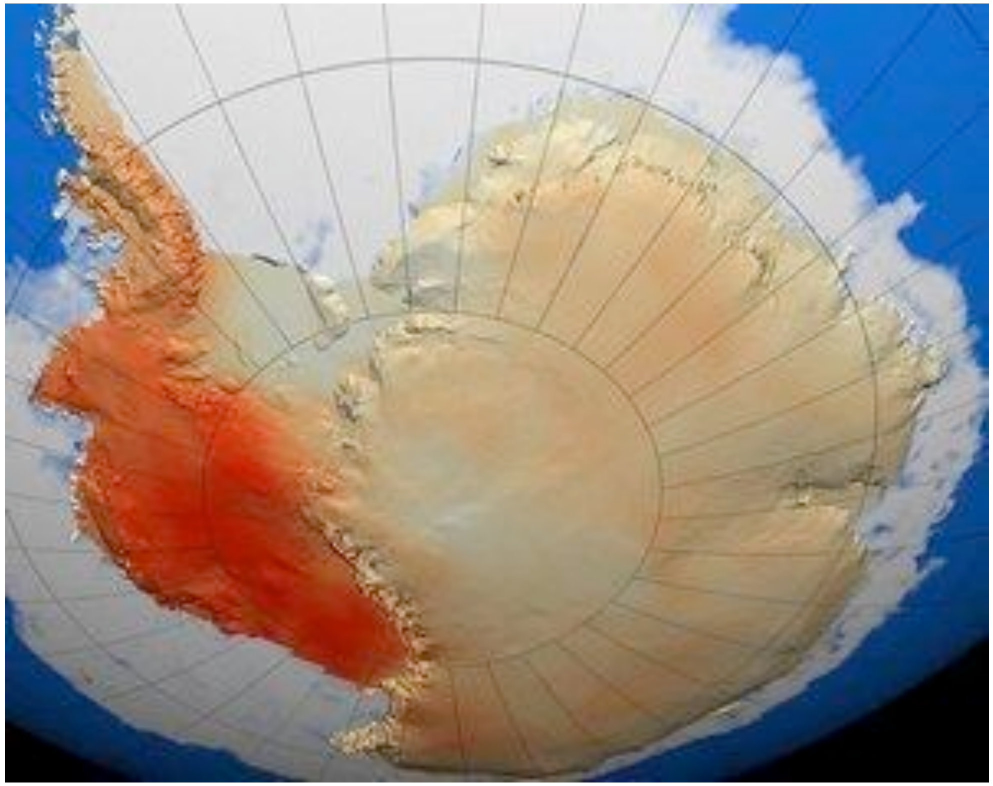
(a) Monthly and (b) annual time series for the modeled precipitation over all of Antarctica. Bromwich et al, 2004



Spatial pattern of temperature trends (degrees Celsius per decade) from reconstruction using infrared (TIR) satellite data. a, Mean annual trends for 1957–2006; b, Mean annual trends for 1969–2000, c–f, Seasonal trends for 1957–2006: winter (June, July, August; c); spring (September, October, November; d); summer (December, January, February; e); autumn (March, April, May; f).

Over the long term (150 years) Antarctica has been warming, recent cooling trends in the 1990s attributed to positive trend in the SAM offset this warming. (Schneider et al, 2006) – *ice cores*

Warming of Antarctica extends beyond the Antarctic Peninsula includes most of west Antarctica. Except in autumn, warming is apparent across most of the continent but is significant only over west Antarctica including the Peninsula (Steig et al, 2009). *1957 – 2006 reconstruction from satellite data.*



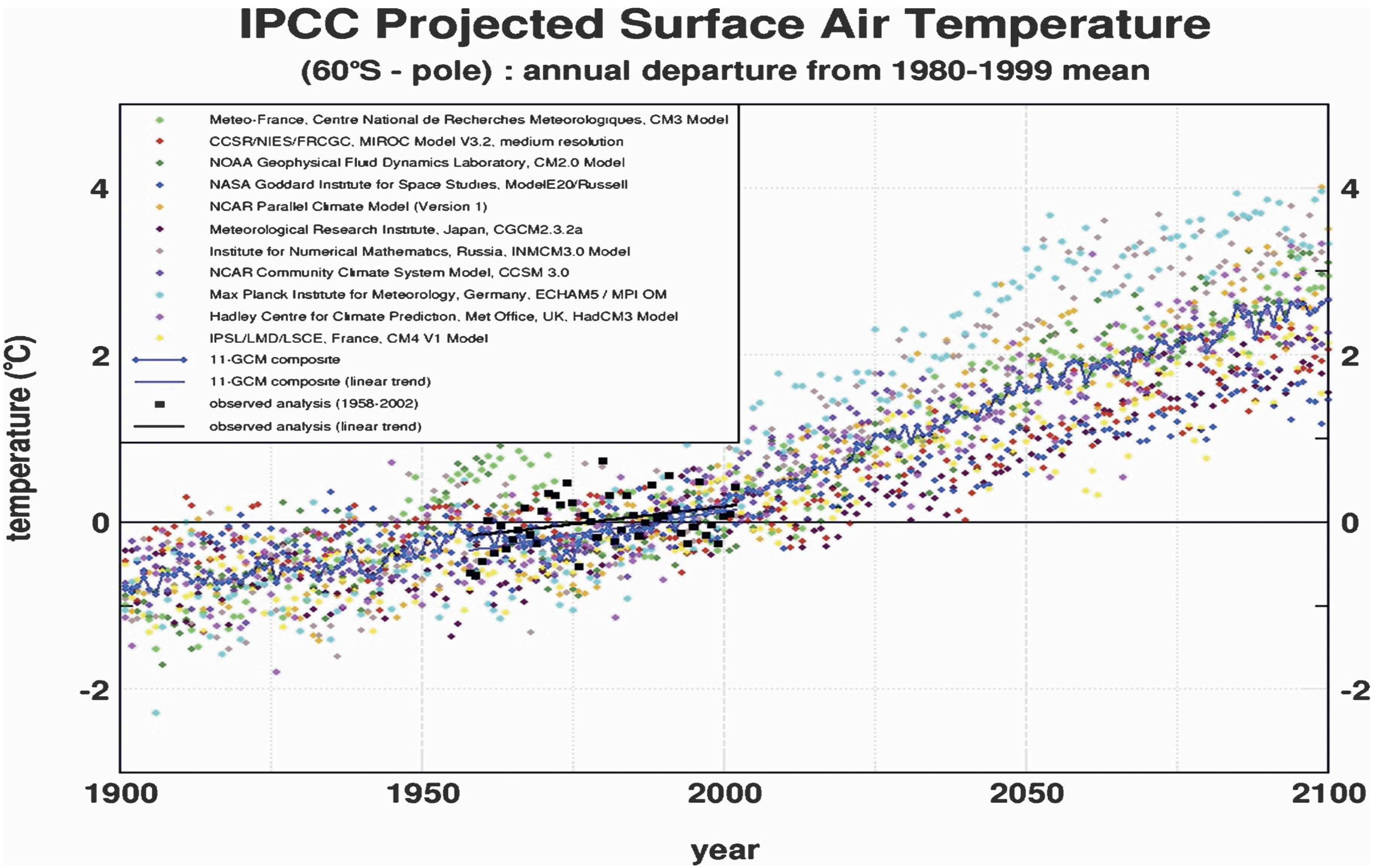
Steig et al, 2009

Steig et al, 2009 – reconstruction based on satellite and station data annual warming of 0.18C per decade for 1957 – 2006; *winter and spring leading*.

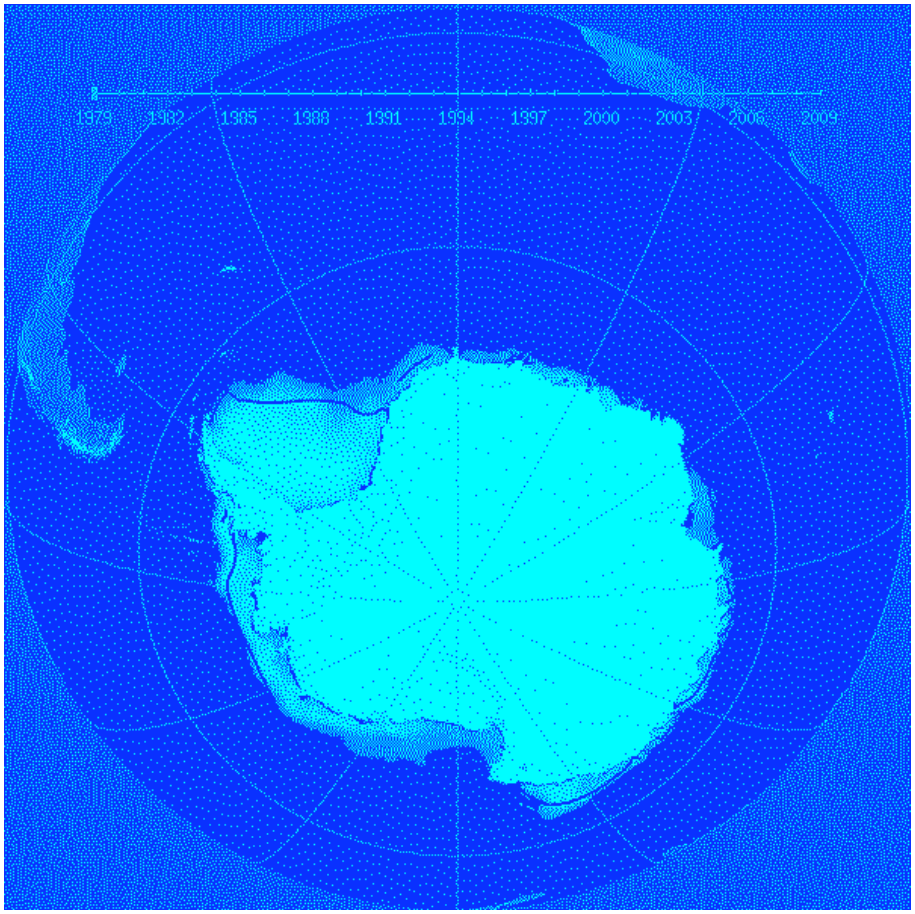
Chapman and Walsh, 2007 – reconstruction based on station data and oceanic records 1950-2002: *warming across most of West Antarctica*

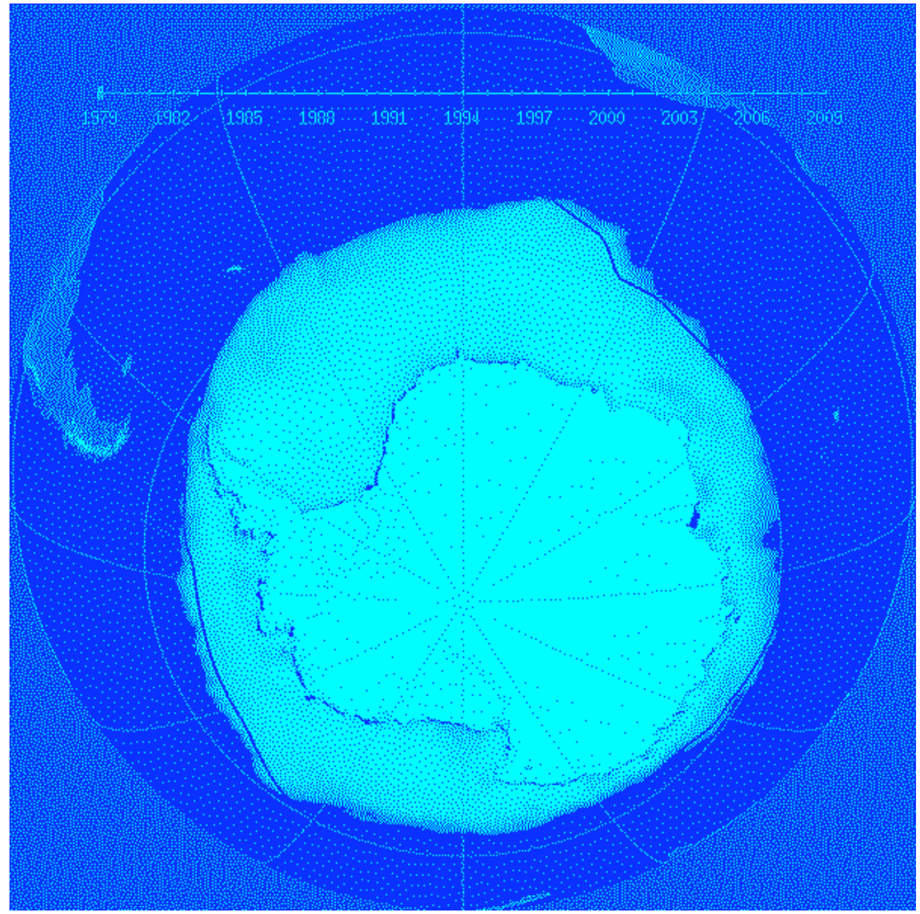
Monaghan et al, 2009 – reconstruction 190-2005: warming across West Antarctica in all seasons; *significant in spring and summer*

Trends are strongly seasonal.



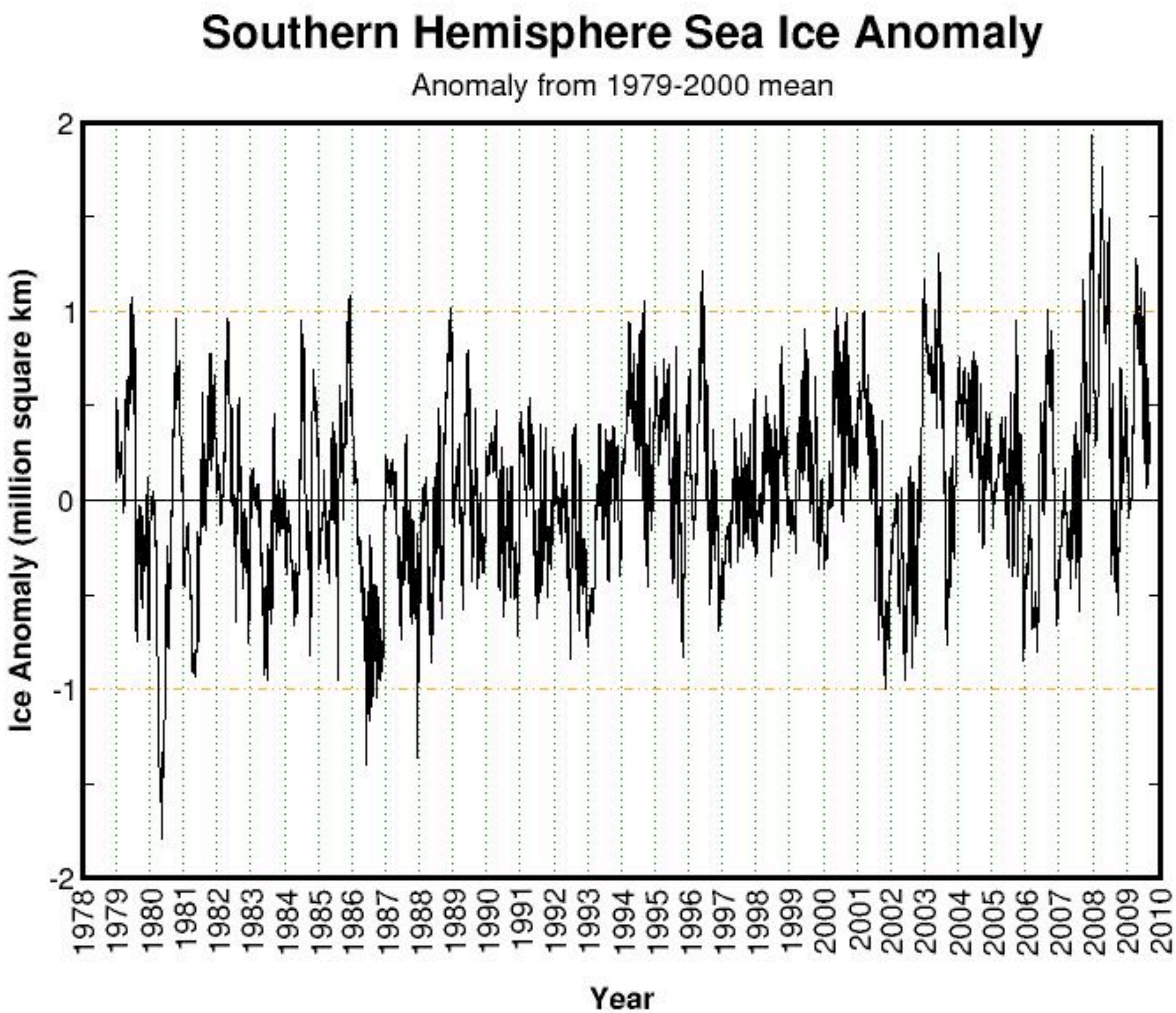
Annual mean surface air temperatures for the 60°–90°S domain, expressed as departures from 1981 to 2000 means, as projected by the 11 global climate models (and 11-model composite mean) of the IPCC AR4 (SRES A1B forcing scenario). Corresponding anomalies of annual mean surface air temperature and associated linear trend from the gridded analyses are also shown for 1958–2002 . Chapman and Walsh, 2007





Antarctic sea ice from 1979 to 2009 summer and winter maximum

Sea ice extent increasing on average.



Southern Hemisphere Sea Ice Anomaly
Anomaly from 1979-2000 mean
Ice Anomaly (million square km)
Year
2
1
0
-1
-2
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
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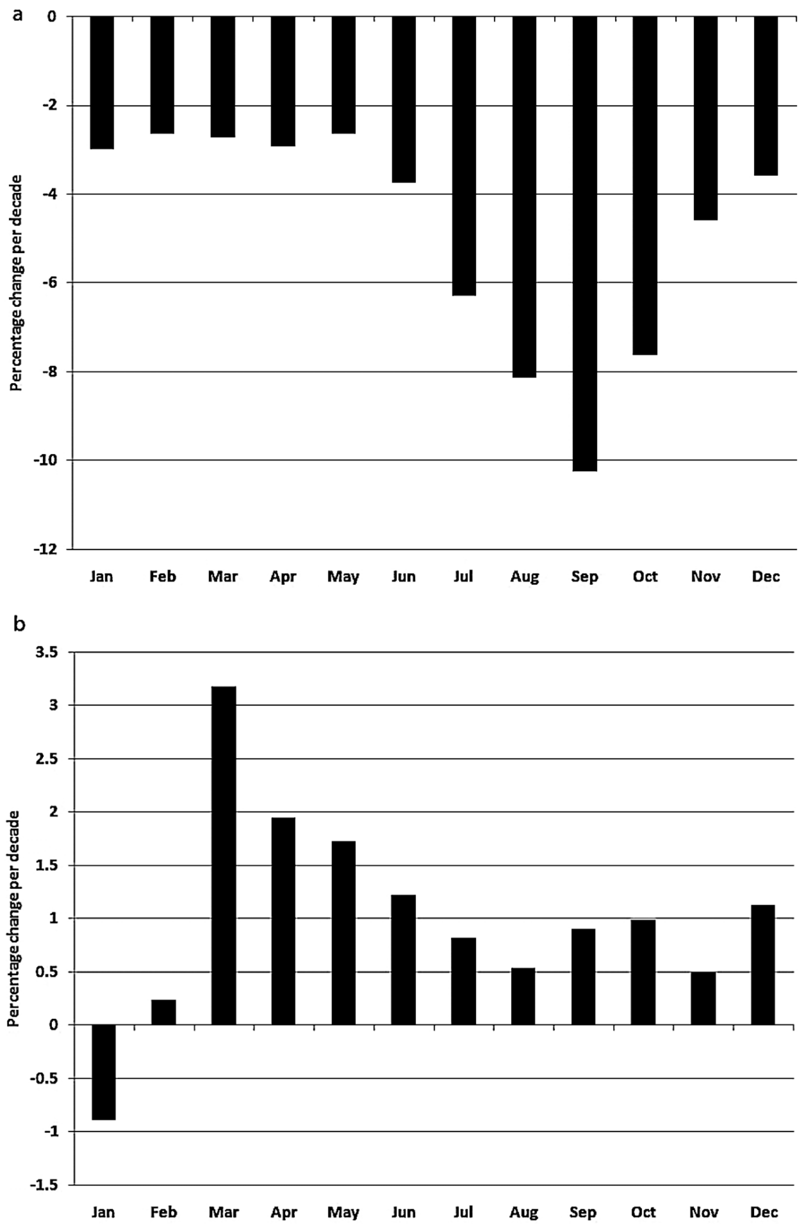
2008
2009
2010

NSIDC, 2010

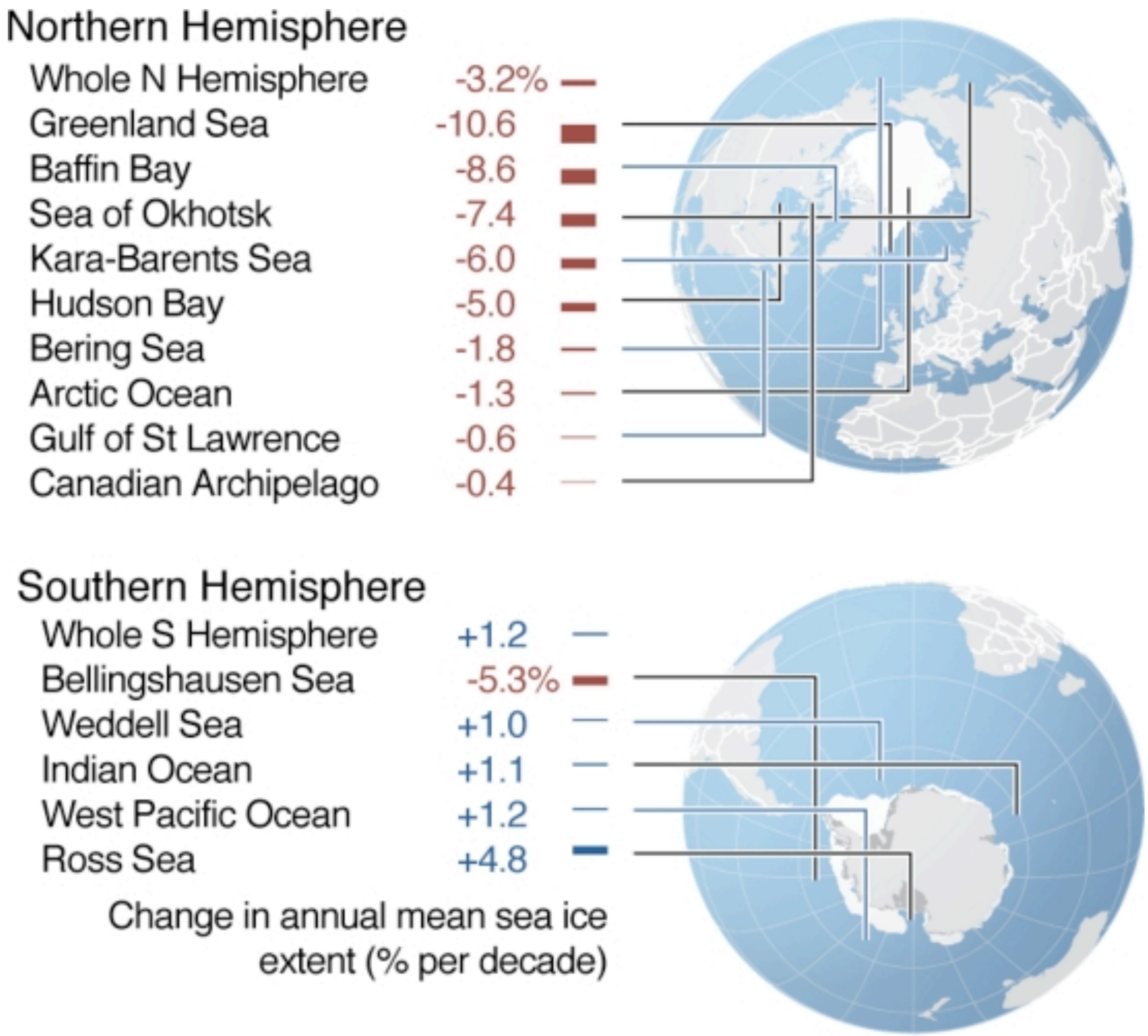


ARCTIC

Monthly trends in sea ice extent for 1979 – 2007 (% per decade)

ANTARCTIC

Turner et al, 2009


Northern Hemisphere
Whole N Hemisphere -3.2%
Greenland Sea -10.6
Baffin Bay -8.6
Sea of Okhotsk -7.4
Kara-Barents Sea -6.0
Hudson Bay -5.0
Bering Sea -1.8
Arctic Ocean -1.3
Gulf of St Lawrence -0.6
Canadian Archipelago -0.4
Southern Hemisphere
Whole S Hemisphere +1.2
Bellingshausen Sea -5.3%
Weddell Sea +1.0
Indian Ocean +1.1
West Pacific Ocean +1.2
Ross Sea +4.8
Change in annual mean sea ice extent (% per decade)

NSIDC, 2010

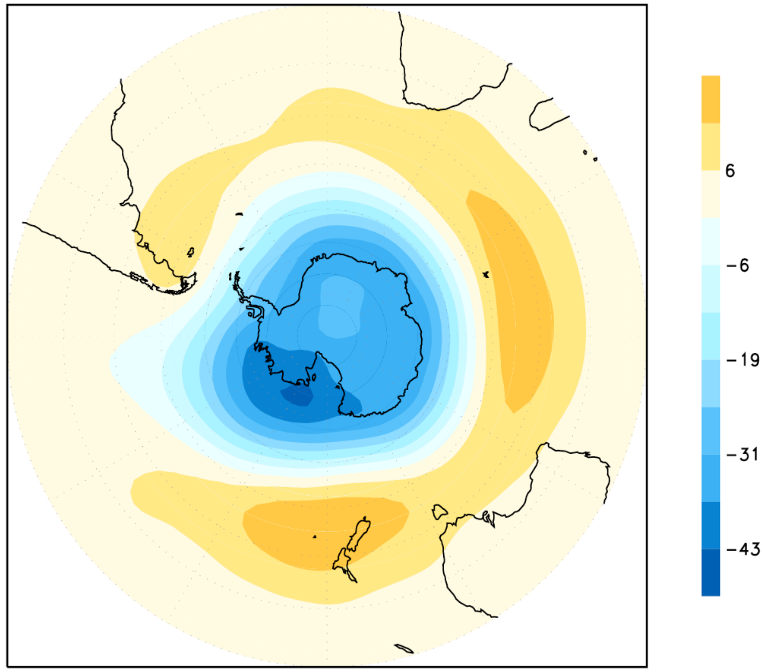
Atmospheric Mechanisms influencing Antarctic Sea ice and Climate:

Southern Hemisphere Annular Mode (SAM aka AAO)

Pacific South American Mode (PSA)

Semi-Annual Oscillation (SAO)

Zonal Wave Three (ZW3)



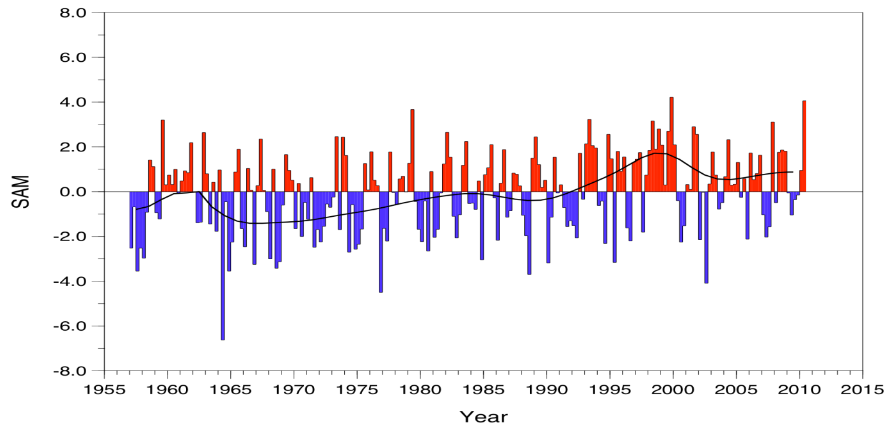
850-hPa height regressed on an index of the SAM Southern Hemisphere Annular Mode

The SAM is characterized by a largely zonally symmetric structure representing an alternation in mass between the middle and high latitudes of the SH. It describes the month-to month variability in the zonally varying geopotential height in the troposphere.

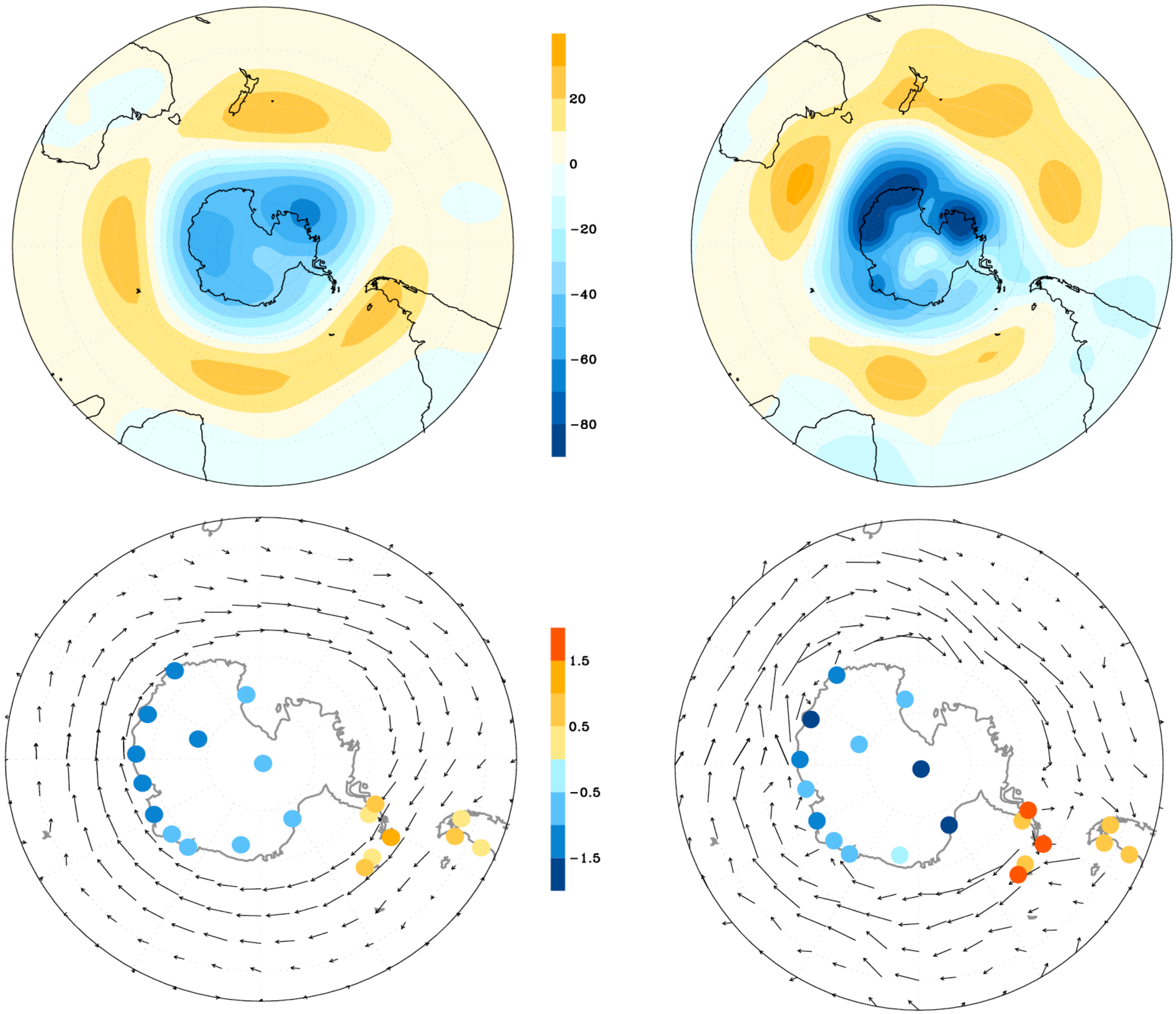
It is the leading mode of SH variability in virtually all atmospheric fields. (e.g. Rogers and van Loon, 1982; Thompson and Wallace, 2000; Marshall, 2003, 2007; Schneider et al., 2006

The SAM reflects north-south meanders in the SH eddy driven jet, and is strongly related to fluctuations in surface winds and temperatures throughout the high latitude Southern Hemisphere.

SAM Index 1957 -2010 (Marshall, 2010)

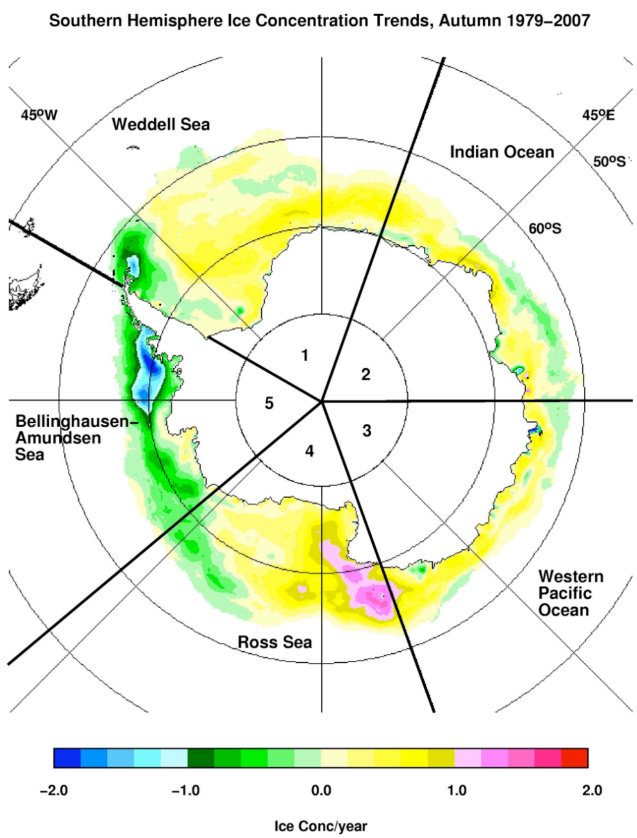


Strong seasonal and interannual variability on which is superimposed a trend towards positive phase in the late 20th and early 21st century



Recent trends in SH Z500 (top) winds and station temperature (bottom) (Dec.-May 1979-2000). Left – trend congruent with SAM; Right - total trend.
(*Thompson and Solomon, 2002*)

Positive trend in SAM attributed to Greenhouse gas loading and stratospheric ozone depletion.



Spatial pattern in Autumn sea ice changes over 1979 - 2007

Turner et al, 2009

Turner et al, 2009 indicate that the annual increase in sea ice is led by autumn increases in the Ross Sea associated with stronger Amundsen Sea low "forced" by stratospheric ozone depletion.

Future expectations for SAM and therefore for sea ice, temperature, wind

- Arblaster and Meehl (2006), Miller et al (2006) – SAM will continue positive even as stratospheric ozone recovers because of the positive radiative forcing associated with increasing GHG.

- Perlwitz et al (2009) expect a reversal of the trend in SAM in summer as stratospheric ozone recovers
  Son et al (2009) also expect reversal of current trend in SAM as expressed through deceleration of the westerly jet on the poleward side.

In these two studies different types models were used ..... Stratospheric models not coupled to ocean but forced by SSTs, CMIP models fully coupled but stratosphere not well specified. Need studies of fully coupled models with well-specified stratosphere (Arblaster et al, in press).

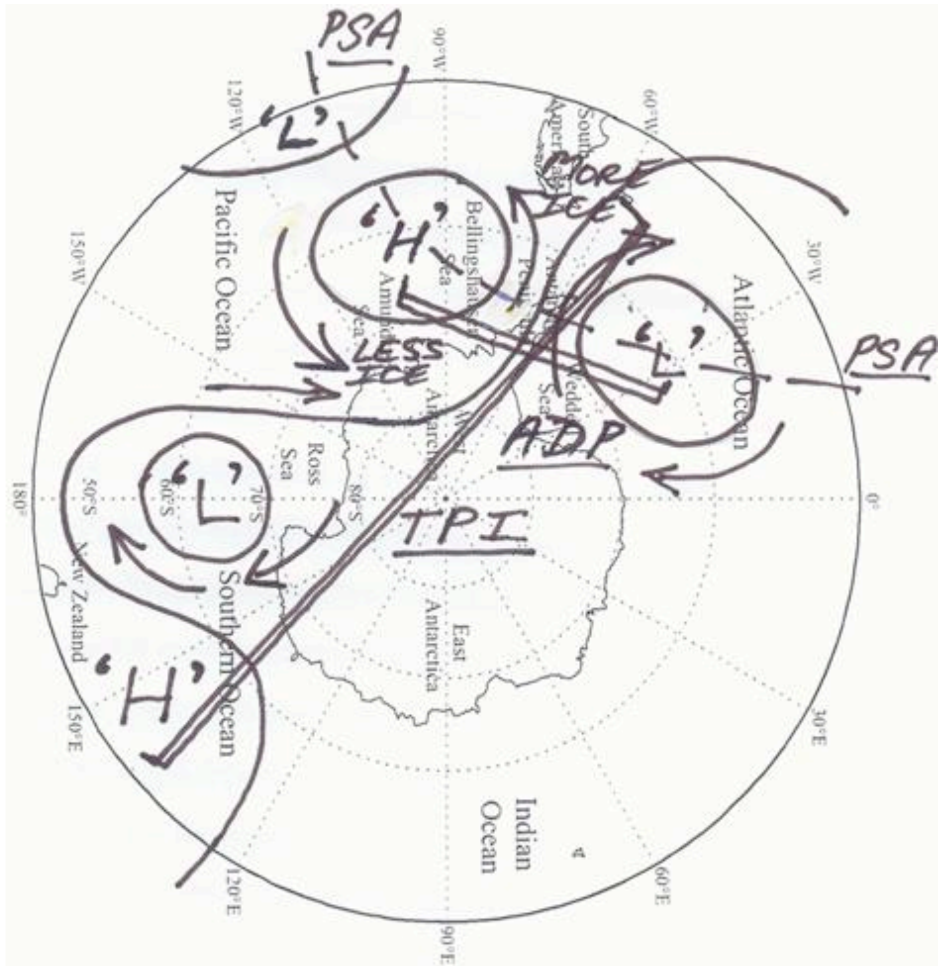
THE PACIFIC SOUTH-AMERICAN pattern (PSA)

Is the second mode of of circulation in the extra-tropical SH atmospheric circulation (Mo et al, 2000). Dominates climate variability in the high latitude south Pacific. Is part of a stationary wave train generated by Tropical convection (Mo and Higgins, 1998)

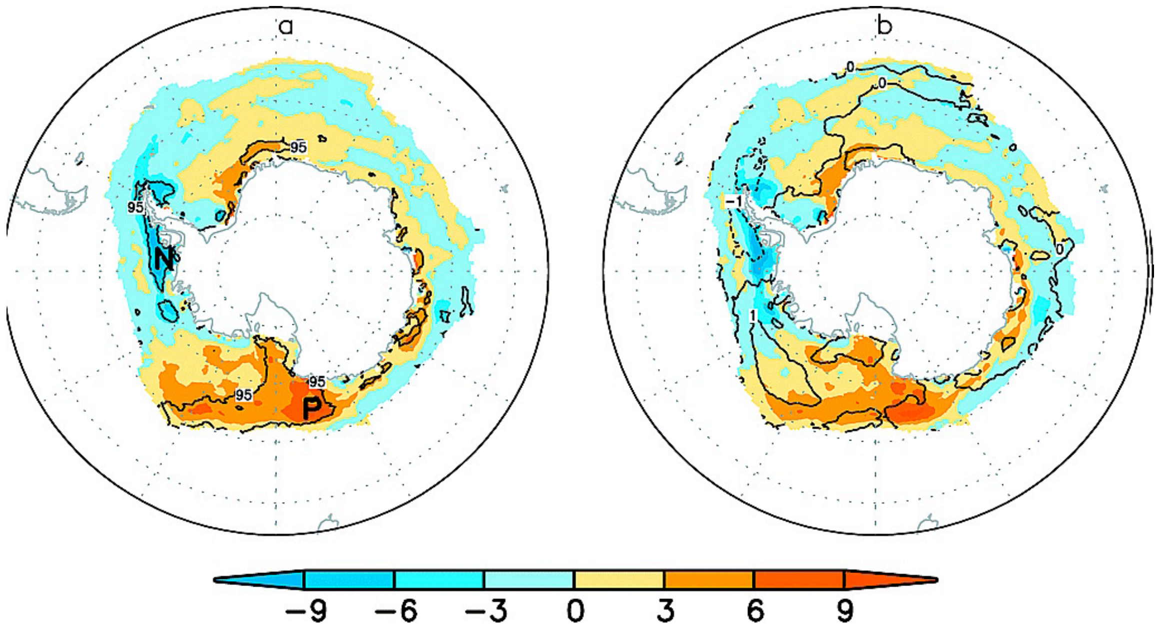
It correlates well with the SOI (Mo, et al, 2000) and responds strongly to ENSO forcing (Turner, 2004).

Is associated with variability in ENSO – In response to Warm events the PSA pattern is high pressure in the Amundsen Sea, low pressure in the south Atlantic and east of New Zealand. The response to Cold events is the reverse.

The net effect on sea ice is opposing sea ice anomalies east of the Ross Sea and in the Weddell Gyre (Yuan, 2004, Yuan and Li, 2008).



PSA, warm event Carleton, 2008



Spatial trends in Antarctic sea ice concentration 1979-2002.
a) Trend before removing the influence of AAO and ENSO;
b) Trend after removing the influence of ENSO and the AAO.
(Liu et al, 2004).

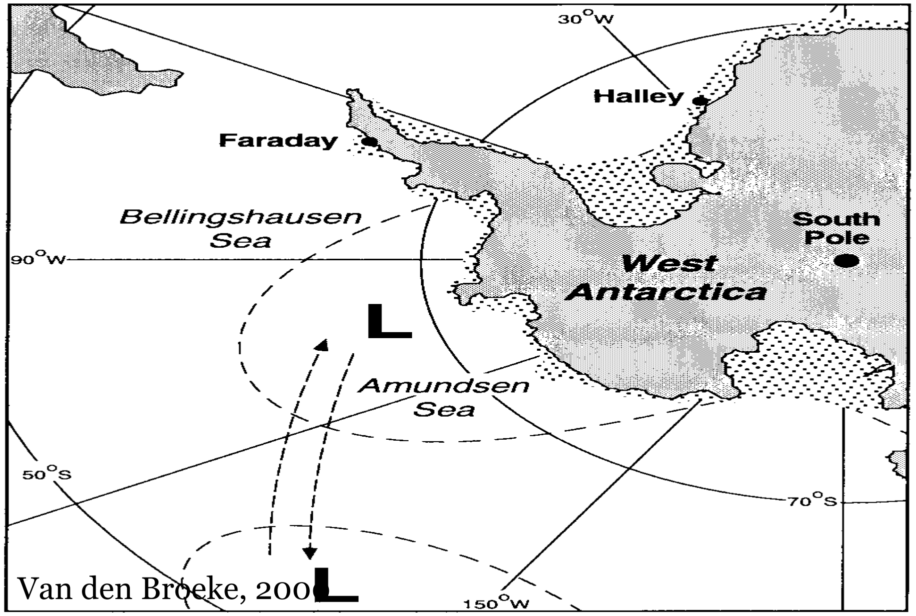
SEMI-ANNUAL OSCILLATION (SAO)

The SAO is an important characteristic of the SH circulation explaining more than 50% of the variability in the SLP.

It is apparent through the depth of the southern extra-tropical atmosphere, it is manifested by the variation in intensity and position of the Antarctic circumpolar trough (CPT).

The CPT contracts, deepens and moves south in March and September and expands, weakens and moves north in June and December. These twice-yearly fluctuations in the CPT are accompanied by similar fluctuations of the tropospheric temperature gradients, geopotential heights, SLP and winds at middle and high latitudes in the SH.

The net result is a semiannual exchange of mass between the Antarctic and midlatitudes so that air moves from north to south twice a year and back (van Loon 1991).



Van den Broeke, 2000

The movement of the CPT in the Pacific Ocean sector of Antarctica. At the time of maximum contraction of the CPT (March and September) low pressure areas migrate southeastwards over the Amundsen Sea to end up close to the coastline of West Antarctica (bold southern--most **L in Figure 1). In the expansion phases (April–July and October–January),** this area migrates to the north and west, resulting in a pronounced semi-annual cycle in surface pressure, windspeed and cloudiness.

A positive coupling exists between the amplitude of the SAO and wintertime ABS sea ice extent. In years with a weakly-developed SAO, the failure of the circumpolar pressure trough to move northwestward from April to July suppresses sea ice growth.

The amplitude of the SAO shows considerable decadal oscillations (Van Loon *et al., 1993; Hurrell and* Van Loon, 1994). This variability influences temperature trends in Antarctica (Van den Broeke, 1998a,b), either directly through changes in warm air advection, or indirectly through changes in local wind speed and cloudiness (Van den Broeke, 2000).

Note: SAO is not well-simulated by AR4 models – e.g. the SAO is too strong and too far north over the Pacific.

ZONAL WAVE THREE (ZW3)

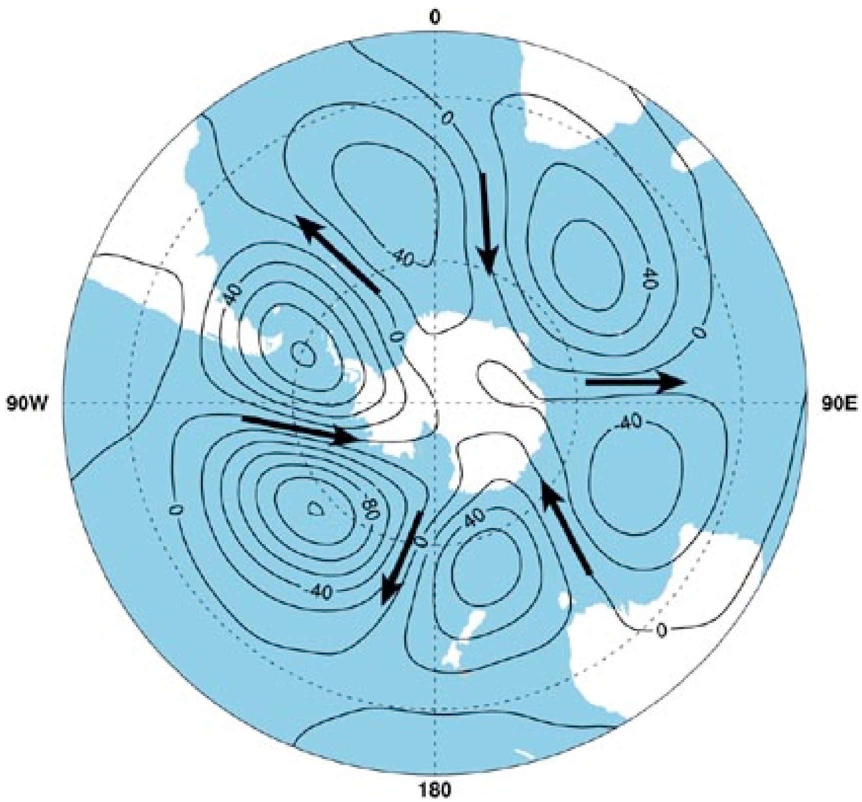
Zonal wave 3 is the asymmetric part of the large-scale atmospheric circulation associated with meridional flow in the extra-tropical SH.

It is quasi-stationary and it contributes to 8% of the spatial variance in the field reaching a maximum near 50S. Its ridges generally lie downstream of the southern continents (van Loon and Jenne 1972).

ZW3 is a dominant feature of the circulation on daily (e.g. Kidson 1988), seasonal (e.g. Mo and White 1985) and interannual (e.g. Karoly 1989) timescales at latitudes 45–55S.

Trenberth (1980) shows that it contributes significantly to monthly and interannual circulation variability and it has been associated with blocking in the SH (e.g. Trenberth and Mo 1985).

Influence of zonal wave three on the circulation

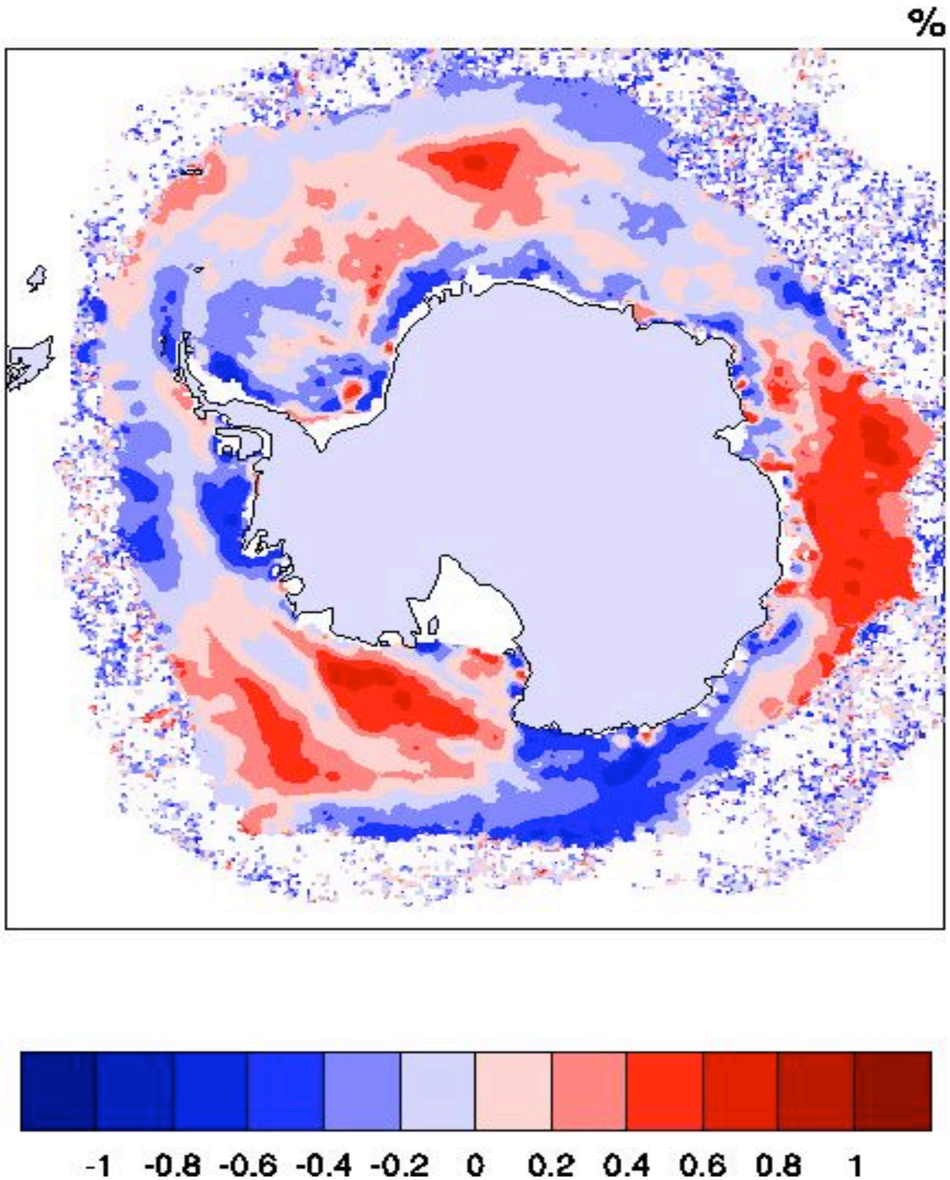


•Preferred regions of equatorward and poleward flow. Equatorward flow would bring colder air and poleward flow, warmer.

•Has the potential to influence the Antarctic sea-ice region by influencing the meridional transport of heat in the atmosphere and ocean.

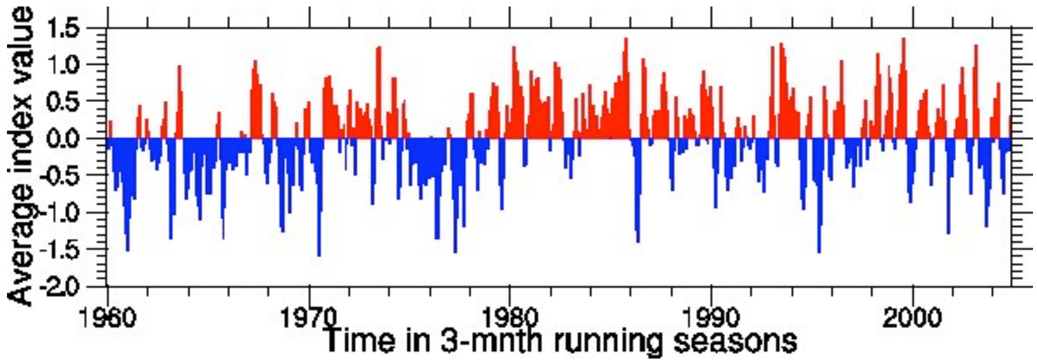
Raphael, 2004

Correlation of ZW3 index and sea-ice concentration



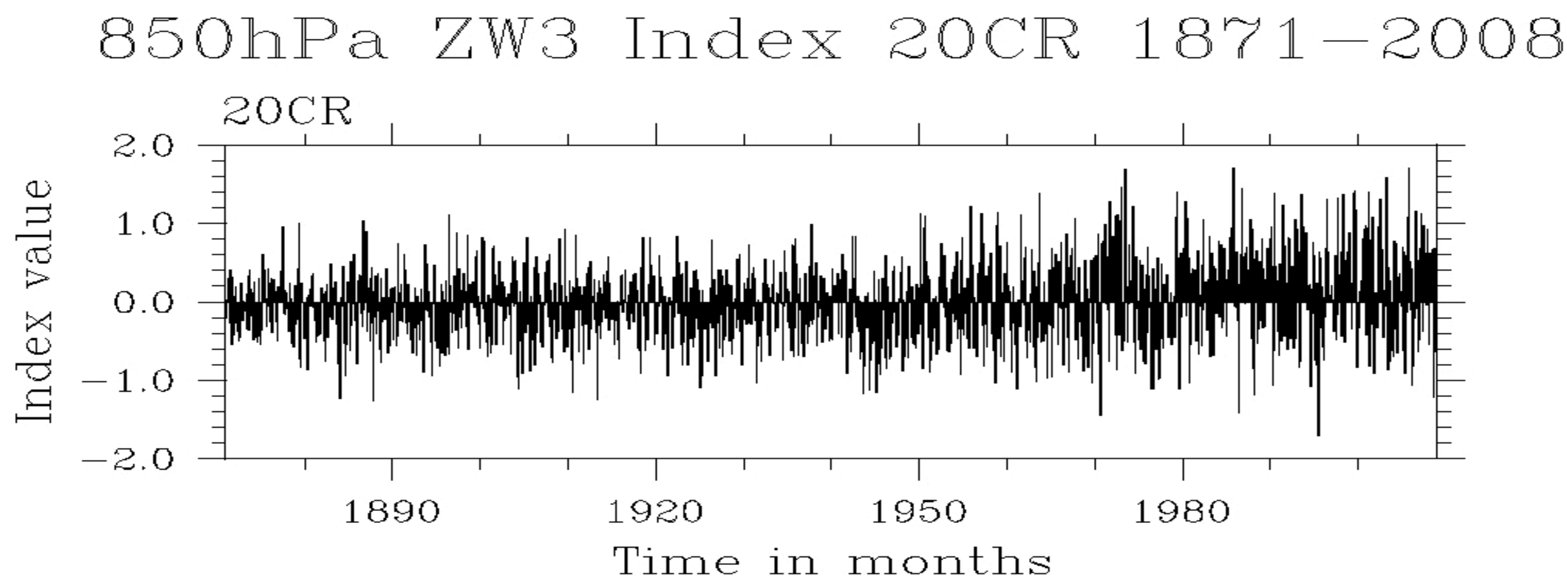
- Wave 3 pattern of correlation of up to 0.6.
- Positive ZW3 index is associated with larger SIC in Ross Sea, Eastern Weddell Sea and in Eastern Antarctica.
- Positive ZW3 index is associated with smaller SIC in Bellingshausen and Amundsen Seas and around the Antarctic peninsula.
- SIC – sea ice concentration

Time series of zonal wave three index 1960-2004 (Raphael 2004)

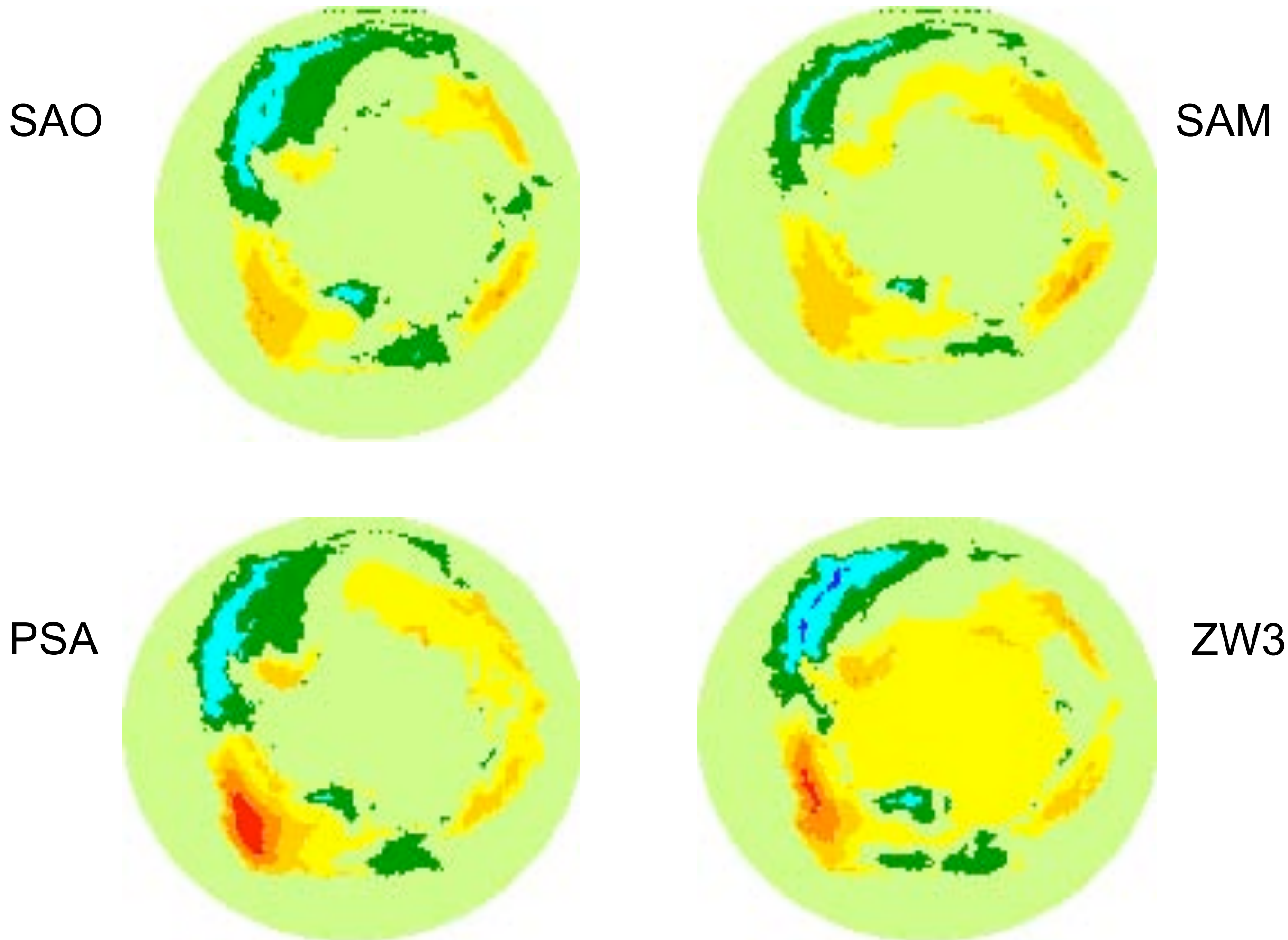


Note the strong interannual variation that is characteristic of zonal wave three.

Note also the shift towards more positive values from around 1979. This increase in strength of ZW3 (movement towards more meridional flow) has also been noted in station data by van Loon et al (1993).

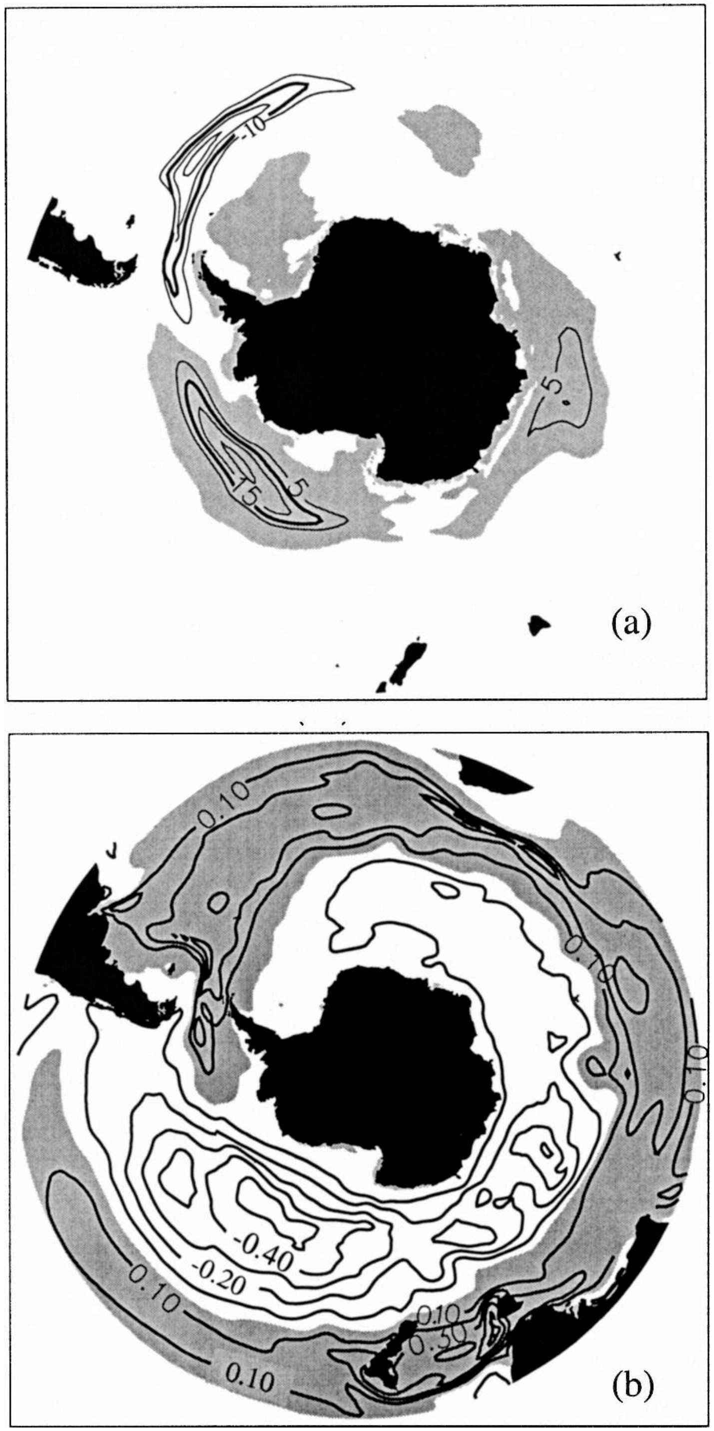


“Update” of ZW3 using 20CR Reconstruction (Compo et al, 2007



Yuan and Li, 2008

Correlation of modes of circulation with sea ice, ice lags by two months



The Antarctic Dipole: The first EOF of simulated (a) winter (JJAS) ice concentration and (b) annual averaged SST for the Southern Ocean south of 30°S. The non dimensional EOFs have been scaled by the standard deviation of the corresponding principal component time series to show the dimensional standard deviation at each grid point associated with the EOF. The contour interval is 5% for sea ice and 0.1°C for SST. The zero contour has been omitted and positive values are shaded.
Holland et al (2006)

Relative importance of climate modes for sea ice:

PSA is the dominant mode in the South Pacific where the largest trends in ice are found.

ZW3 is also strong in the south Pacific but has a more global reach.

The SAO is strong in the southwest Pacific and Indian Ocean and the western Antarctic continent.

The SAM's region of influence is similar to the SAO but is relatively weaker.

Yuan and Li (2008)

Much of the focus of research has been on the variability of the SAM and its representation in models and not on the other, apparently more important for sea ice variability, modes of circulation.

OTHER THINGS TO THINK ABOUT

a. Lefevbre and Goosse (2008) find ***that the classical modes of atmospheric variability do not explain a large part of the winter sea ice extent variability integrated over the entire Southern Ocean.***

They show that a regression of sea ice extent on SLP produces another pattern which does not replicate that of the other modes of atmospheric variability but induces change in sea ice extent by influencing temperature, ice production and ice velocity.

Their conclusion is that sea ice extent in the Southern Ocean does not behave as a single entity: *Its variability is the result of the combination of regional sea ice changes.*

b). ***By far, most studies look at the influence of the large scale circulation mechanisms and the ocean on sea ice variability. But there are feedbacks between the sea ice and the atmosphere to consider.***

One study (Raphael et al, 2010) using a fully coupled model forced with observed sea ice extremes suggests that in summer when sea ice is at an extreme minimum, surface temperature and pressure in the circumAntarctic region are higher, the polar easterlies are stronger and extend further north than average.

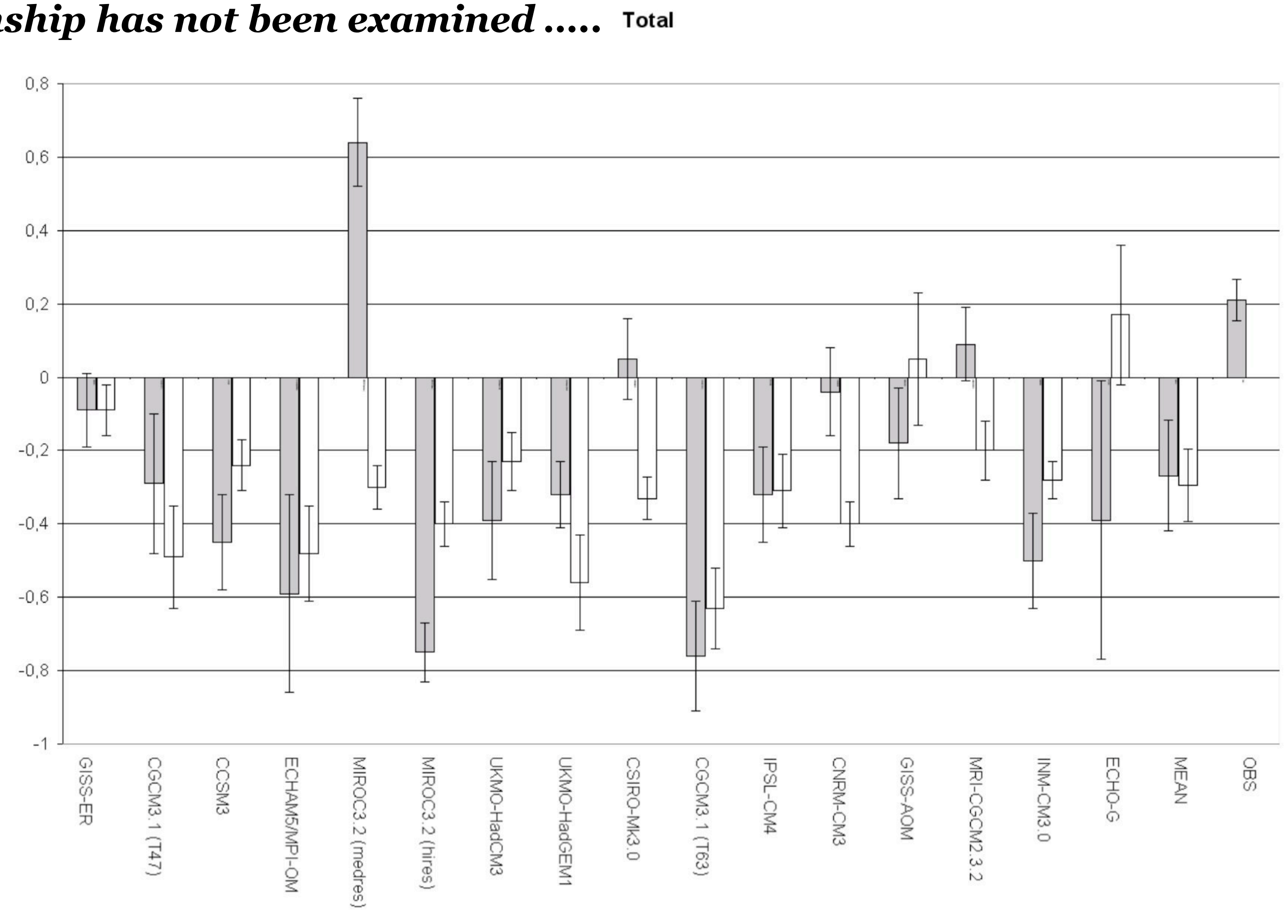
These responses are associated with an expanded polar cell expands and an equatorward shift of the midlatitude cell. The polarity of the SAM tends to be negative.

This is all related to the effect that the lack of sea ice has on temperature and pressure at the surface and is possible, we think, because Antarctic sea ice lies in the margin of the Polar and Ferrell Cells.

c) The Southern Ocean and Antarctic Sea Ice

The observed sea surface temperature in the Southern Ocean shows a substantial warming trend for the second half of the 20th century. Associated with the warming, there has been an enhanced atmospheric hydrological cycle in the Southern Ocean that results in an increase of the Antarctic sea ice for the past three decades through the reduced upward ocean heat transport and increased snowfall. (*Liu and Curry, 2010*)

d) AR4 models do not simulate the observed increase in sea ice, this has been attributed the fact that they do not do an explicit treatment of the chemistry of the stratosphere. However, we also know that they do not simulate the SAO well and the PSA/ENSO relationship has not been examined .....



The trend of the annual mean sea ice extent (bars) in the Southern Hemisphere in the different GCMs). The mean has been taken over the period 1979-2004 (20C3M-SRES A1B, gray) and over 2071-2100 (SRES A1B, white). *Lefebvre et Goosse, 2007*

SUMMARY

Climate variables in the Antarctic vary on scales ranging from seasonal to decadal.

Atmospheric circulation mechanisms that influence these climate variables include
– PSA, SAO, SAM, ZW3.

Indices of circulation mechanisms influencing these variables also vary on similar timescales and they are important in different seasons.

Prediction of change/variability in the Antarctic depend on how reliably our models reproduce these circulation mechanisms – their mean as well as their variability.

All of the variability in Antarctic sea ice has not been explained by the circulation mechanisms above – feedbacks of ice (surface temperature) to atmosphere needs further study.

There is a focus on SAM *wrt* to Antarctic sea ice but the other climate modes appear to have a stronger influence than SAM. How are these modes predicted to change as the climate changes?

ABSTRACT

Antarctica's remoteness, the difficulty of conducting research there and the paucity of observations, are some reasons why the Antarctic climate and sea ice variability are not as well understood as in the Arctic. However, research has shown that the climate of Antarctica including its sea ice is dictated by numerous influences with origins ranging from the Tropics to local atmosphere/surface interactions. Over the period of record indications are that much of Antarctica is warming, led by the Antarctic Peninsula. Regional changes in atmospheric circulation, sea surface temperatures and sea ice may explain this warming. Overall, sea ice extent is increasing, contrary to climate model predictions for the 21st century, and this increase has strong regional and seasonal signatures. Sea ice variability is strongly influenced by ENSO, Southern Hemisphere Annular Mode (SAM) and by zonal wave three (ZW3) among other large scale atmospheric circulation mechanisms. The Antarctic climate and sea ice variability are reviewed with respect to the atmospheric and oceanic mechanisms that influence them.