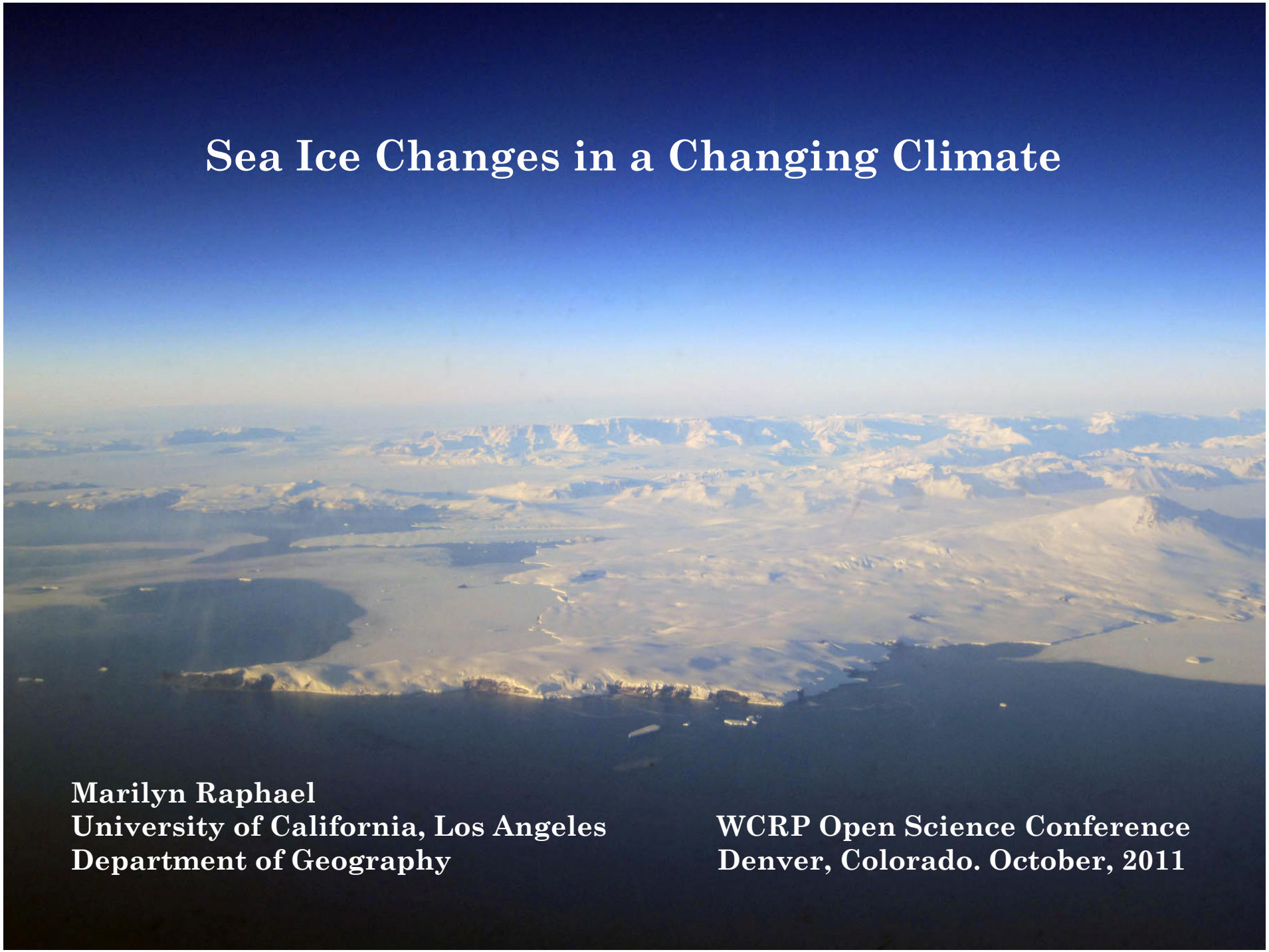
Sea Ice Changes in a Changing Climate

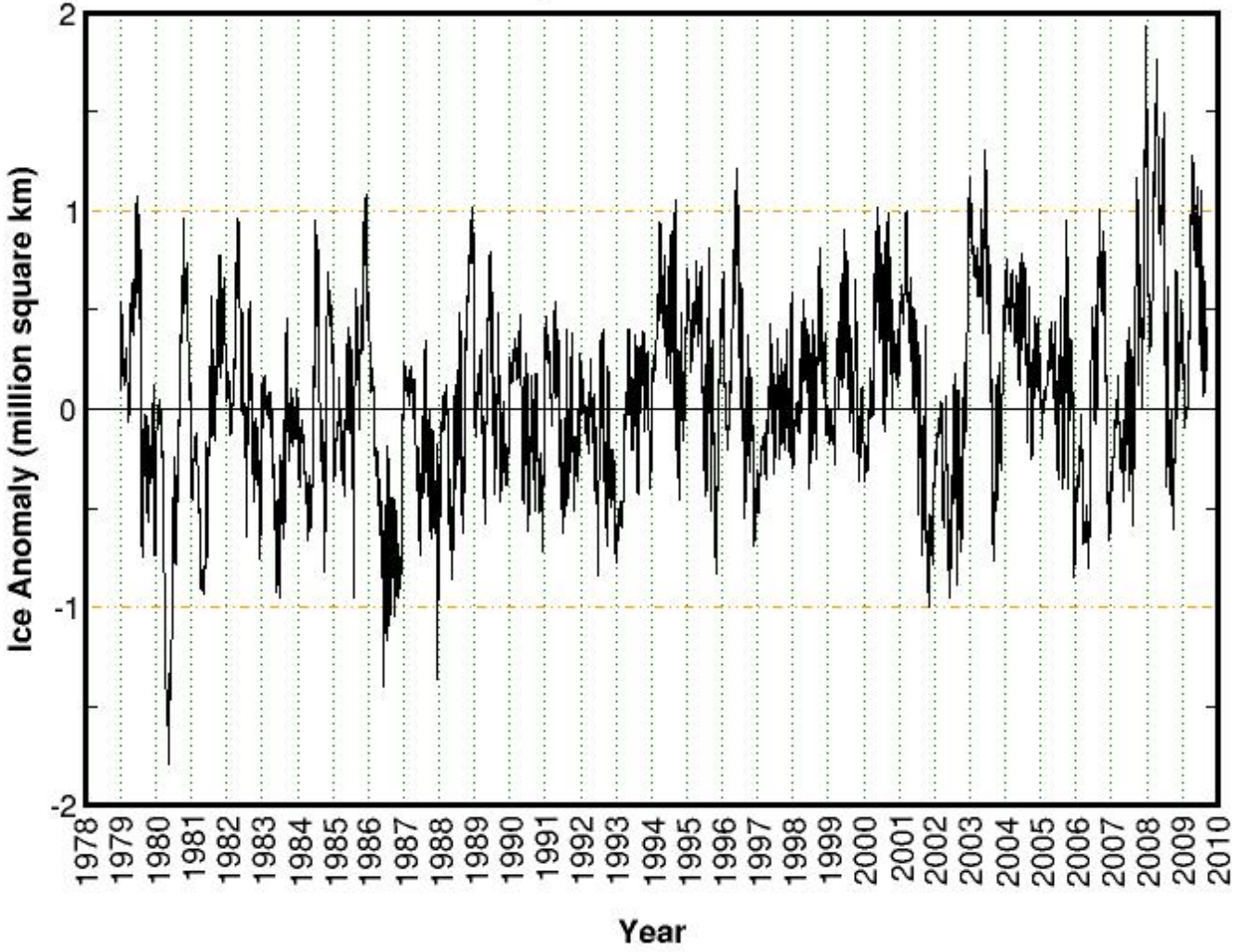


Marilyn Raphael
University of California, Los Angeles
Department of Geography

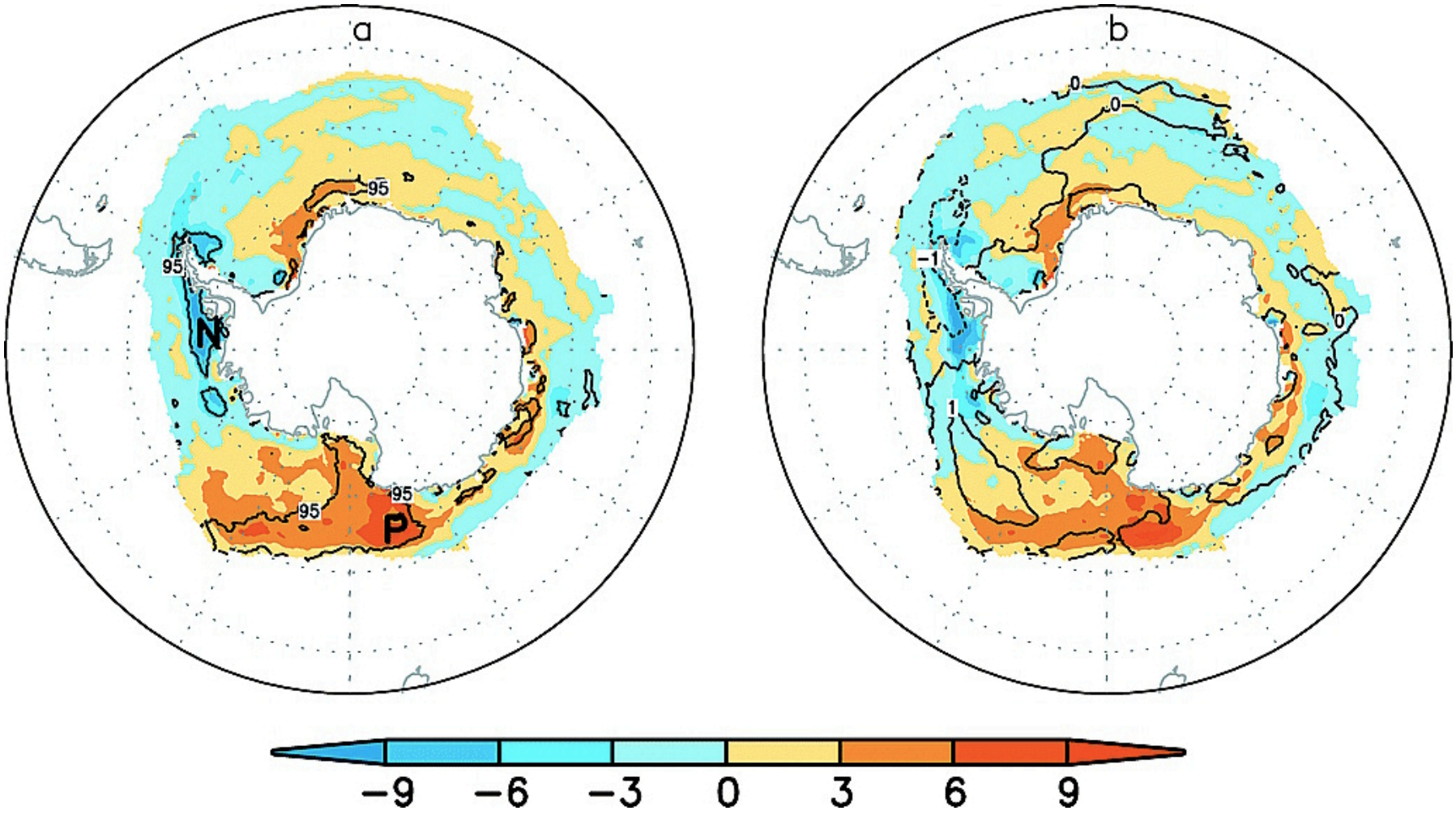
WCRP Open Science Conference
Denver, Colorado. October, 2011

Southern Hemisphere Sea Ice Anomaly

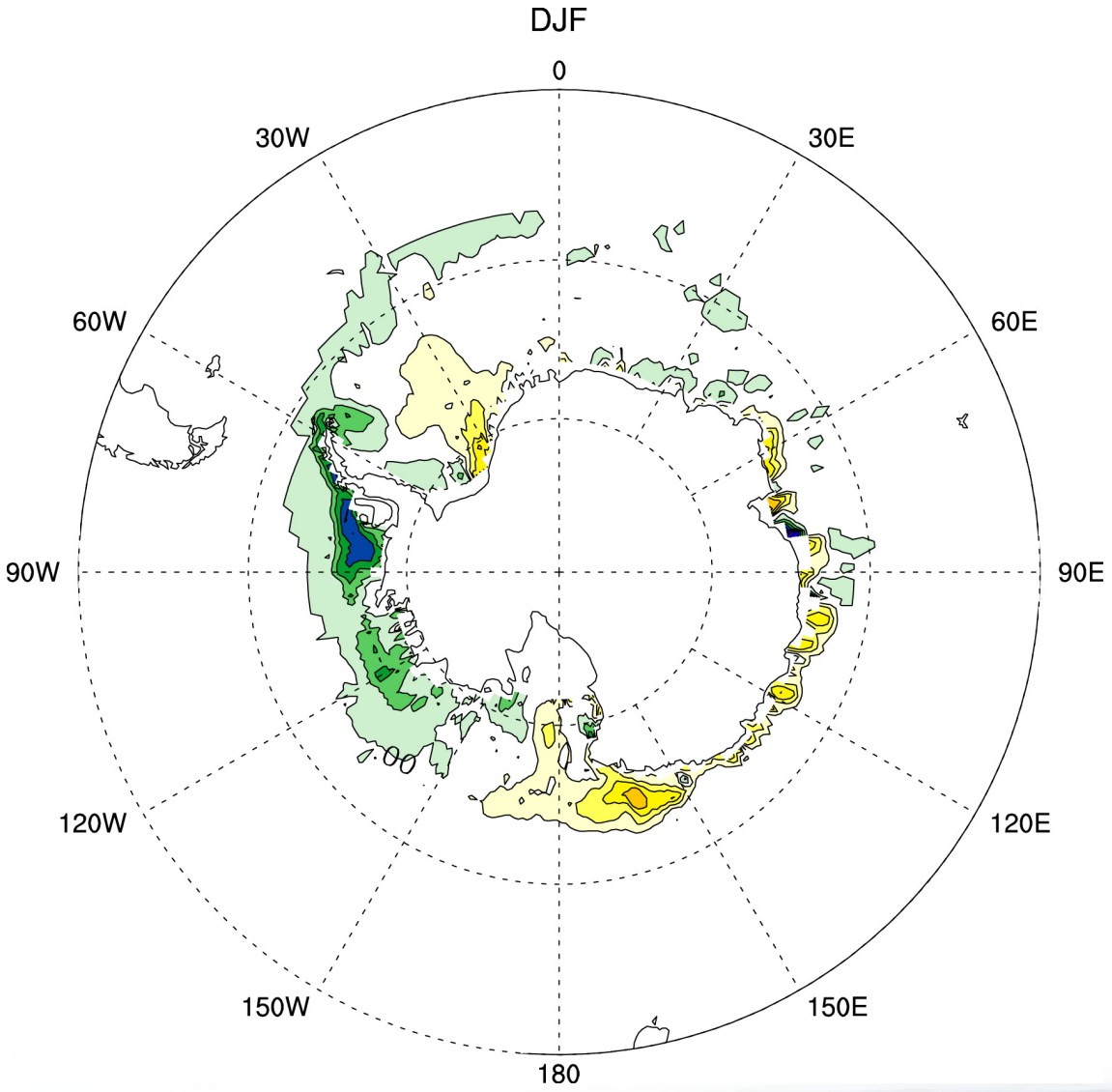
Anomaly from 1979 – 2000 Mean



NSIDC, 2010



Liu et al, 2004: Trends in Antarctic sea ice: a) total trend, b) trend with influences of SAM and ENSO removed.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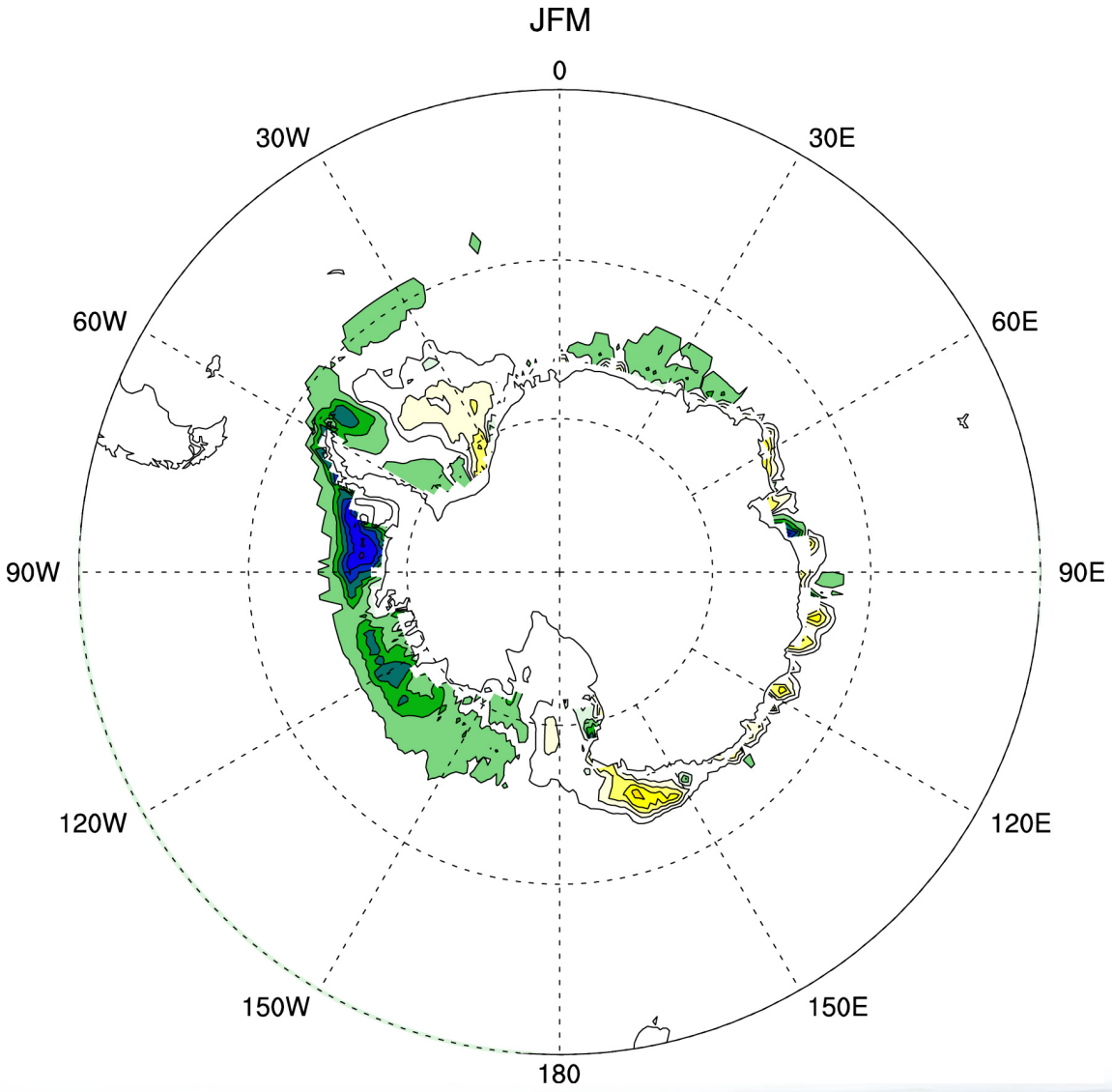
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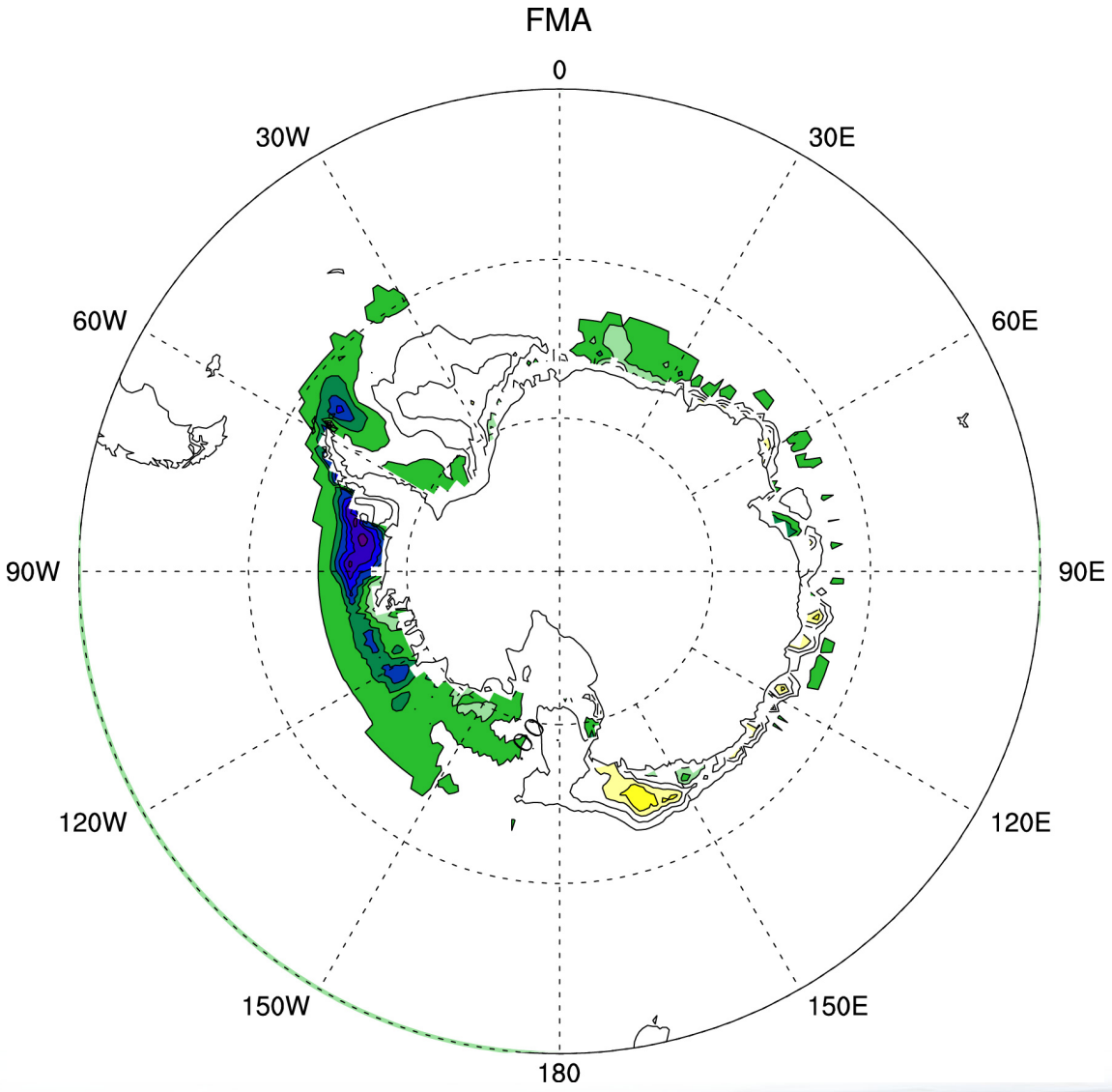
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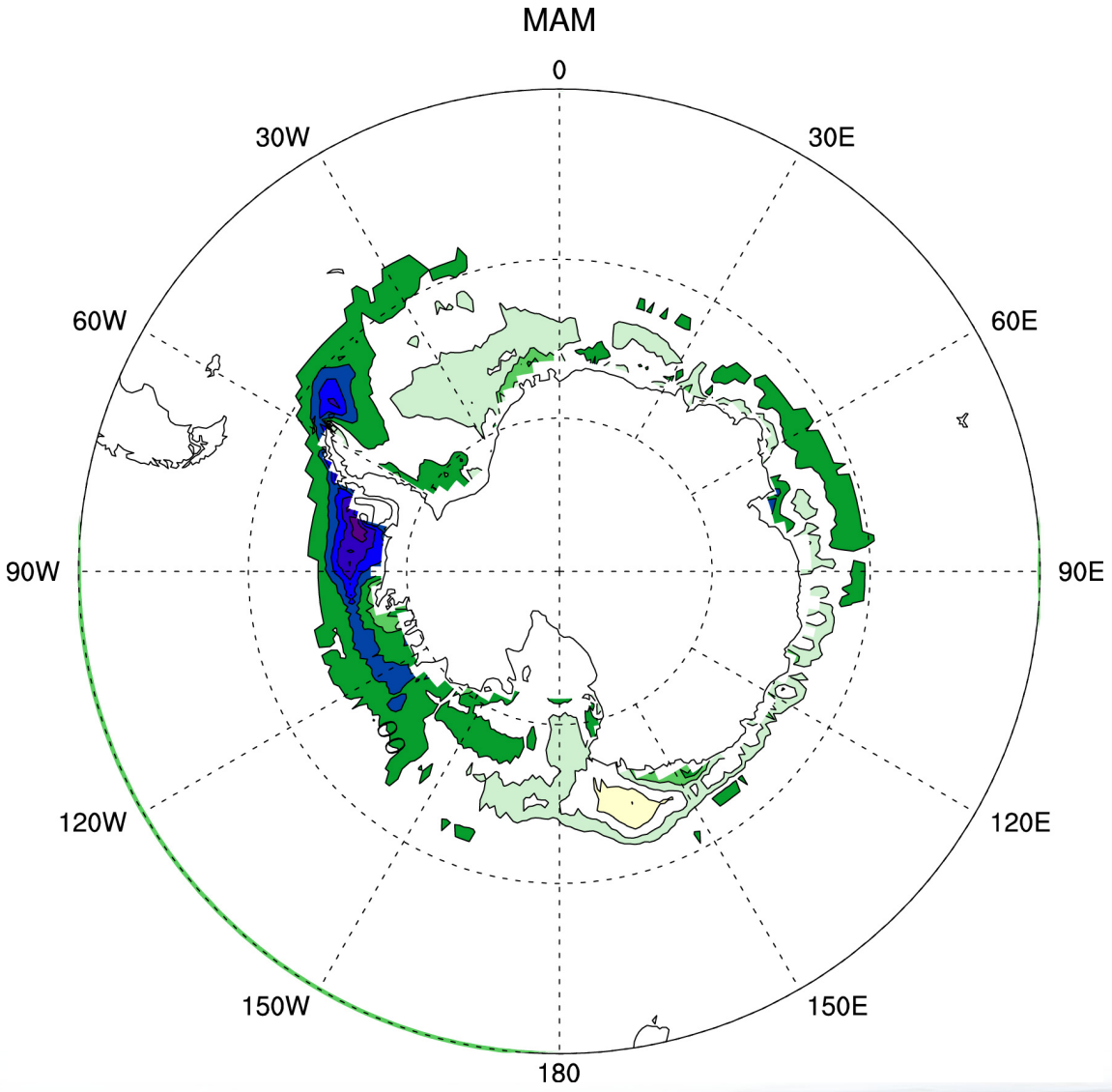
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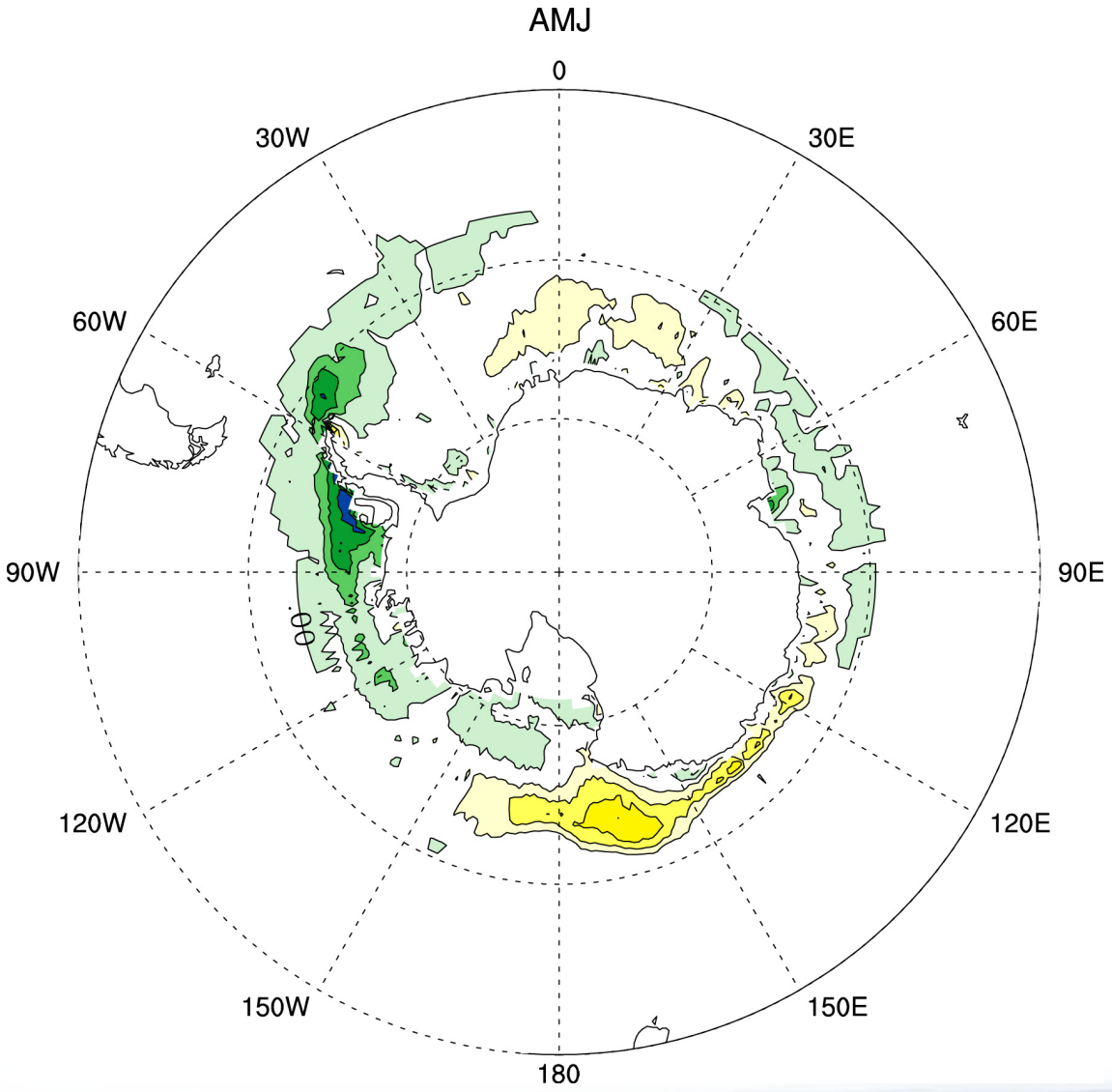
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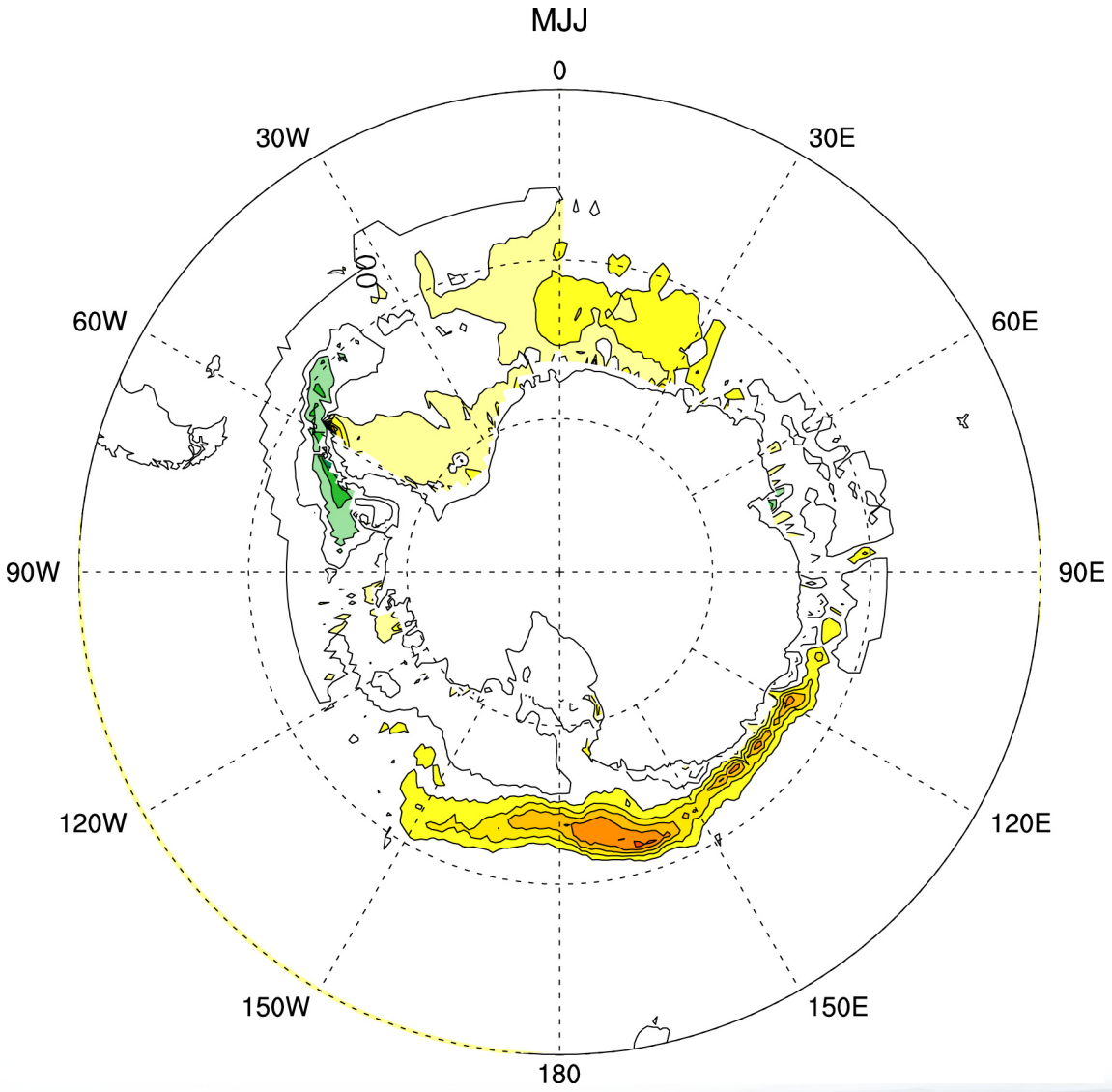
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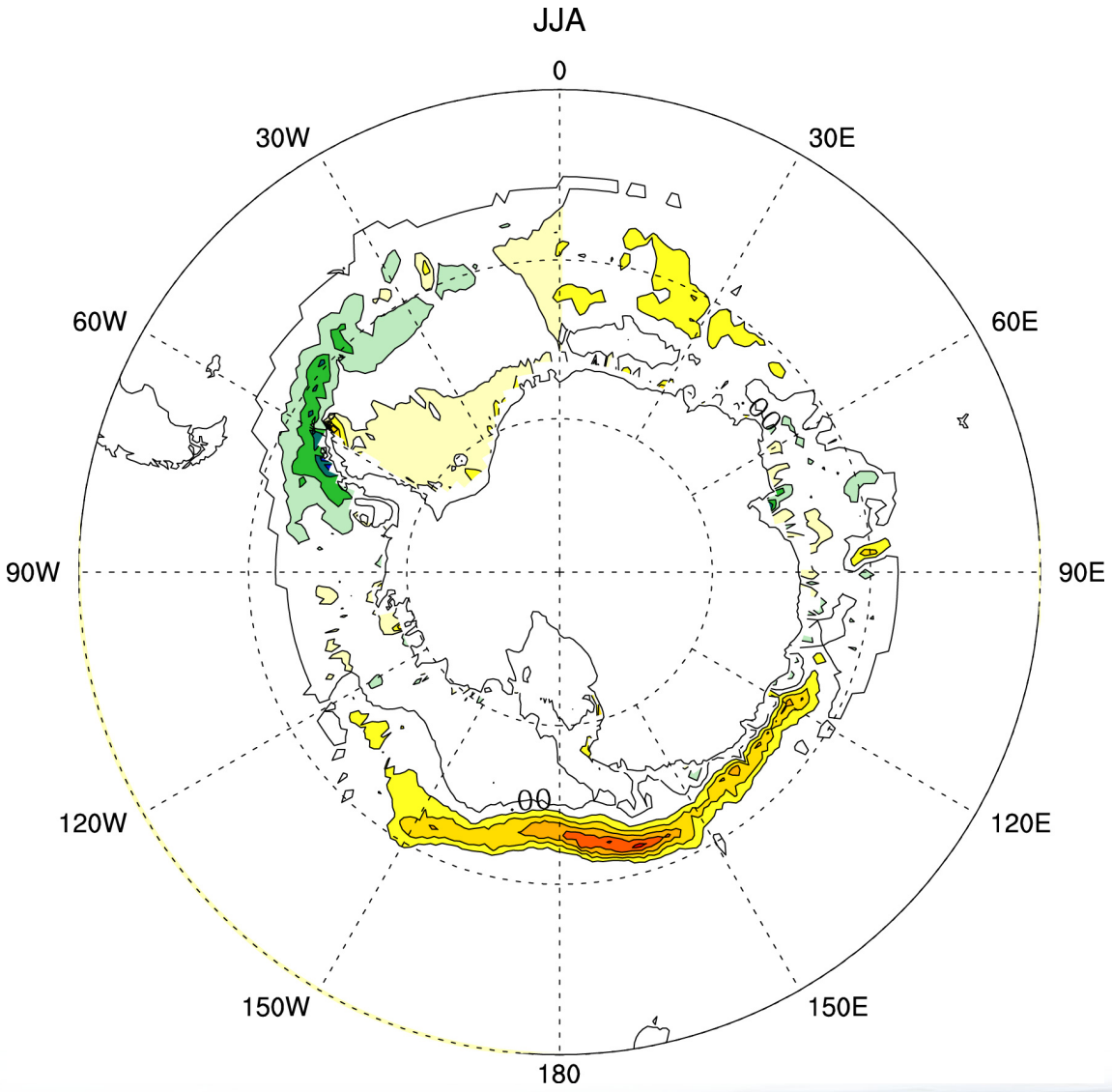
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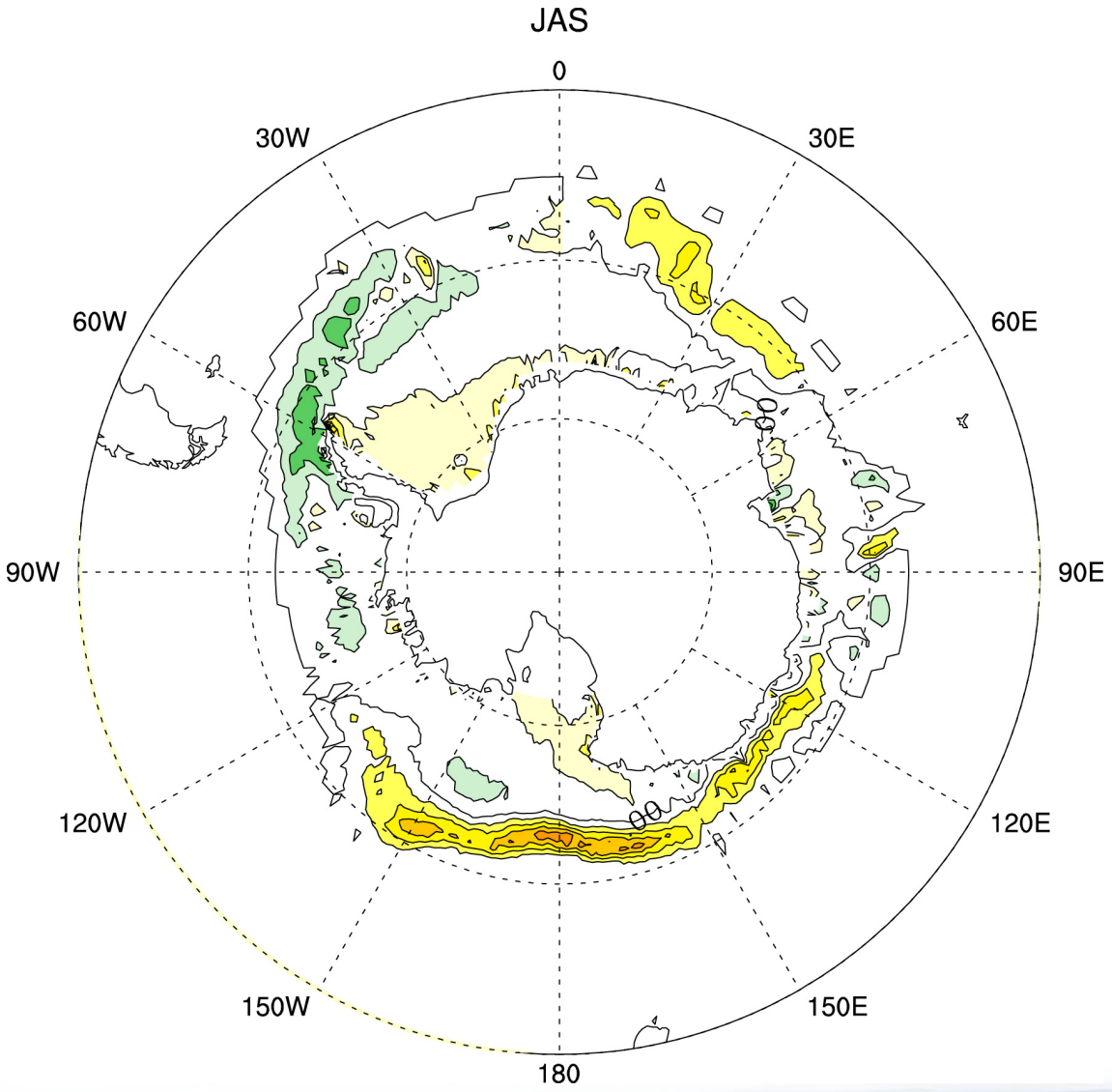
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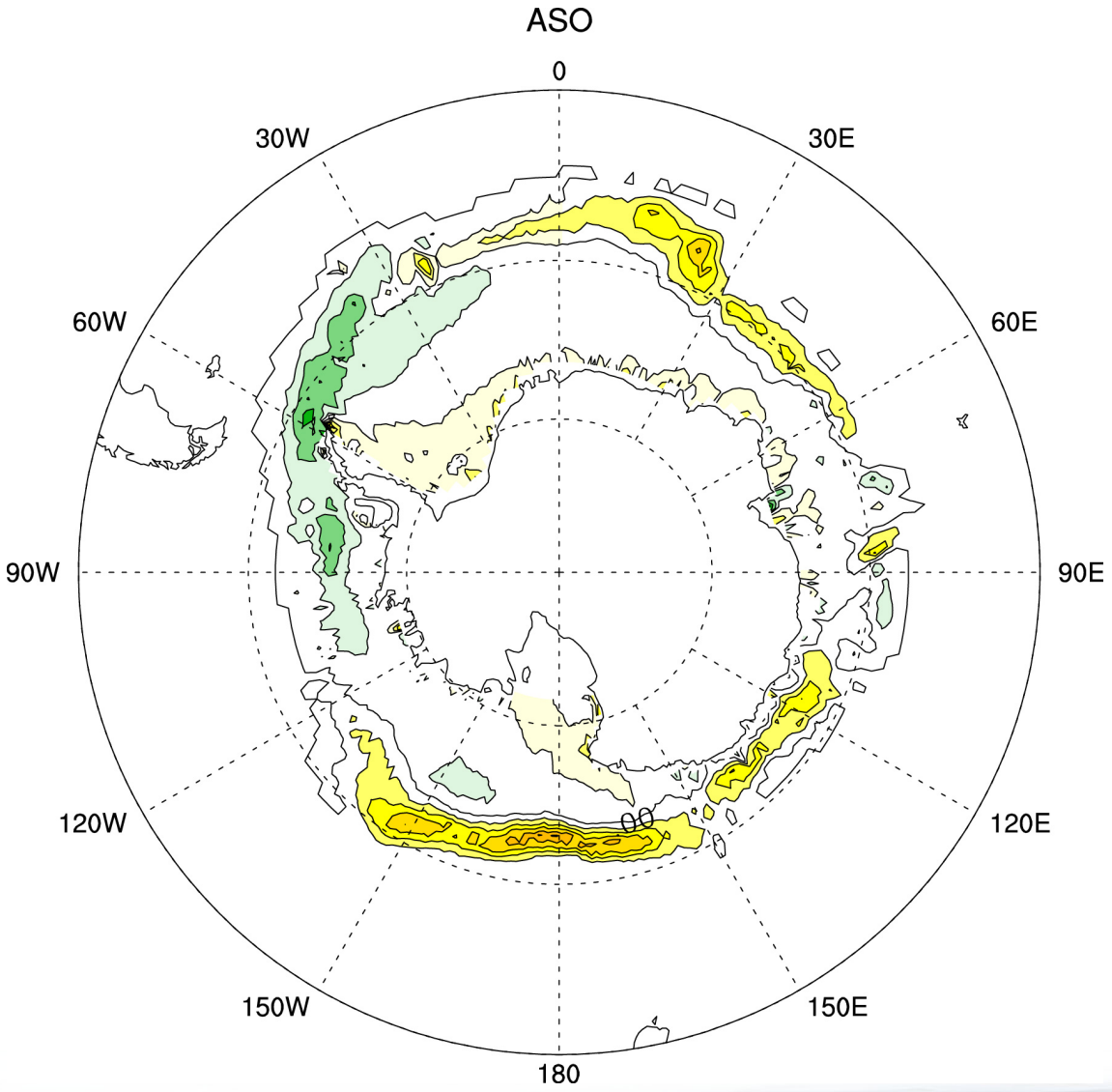
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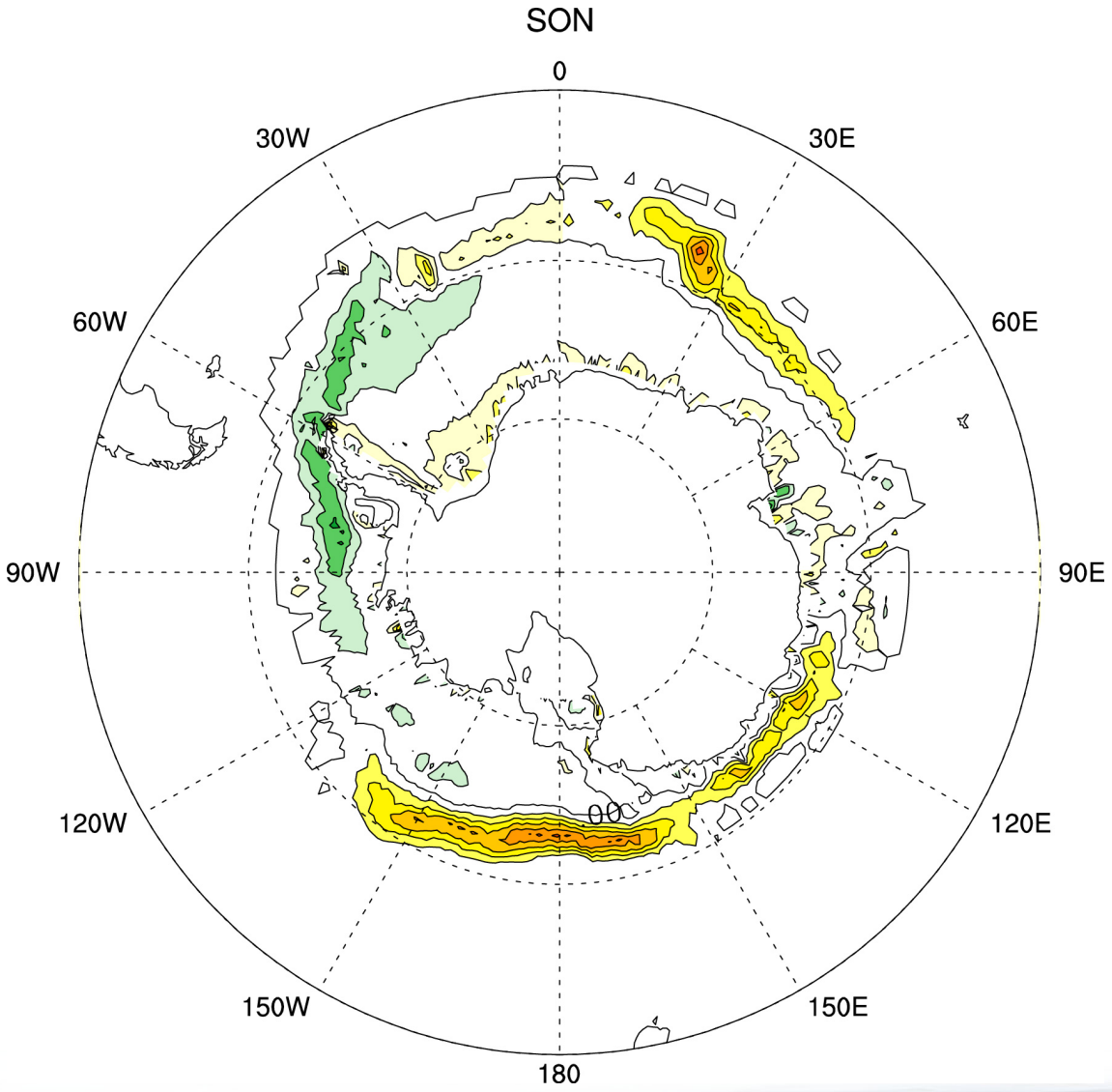
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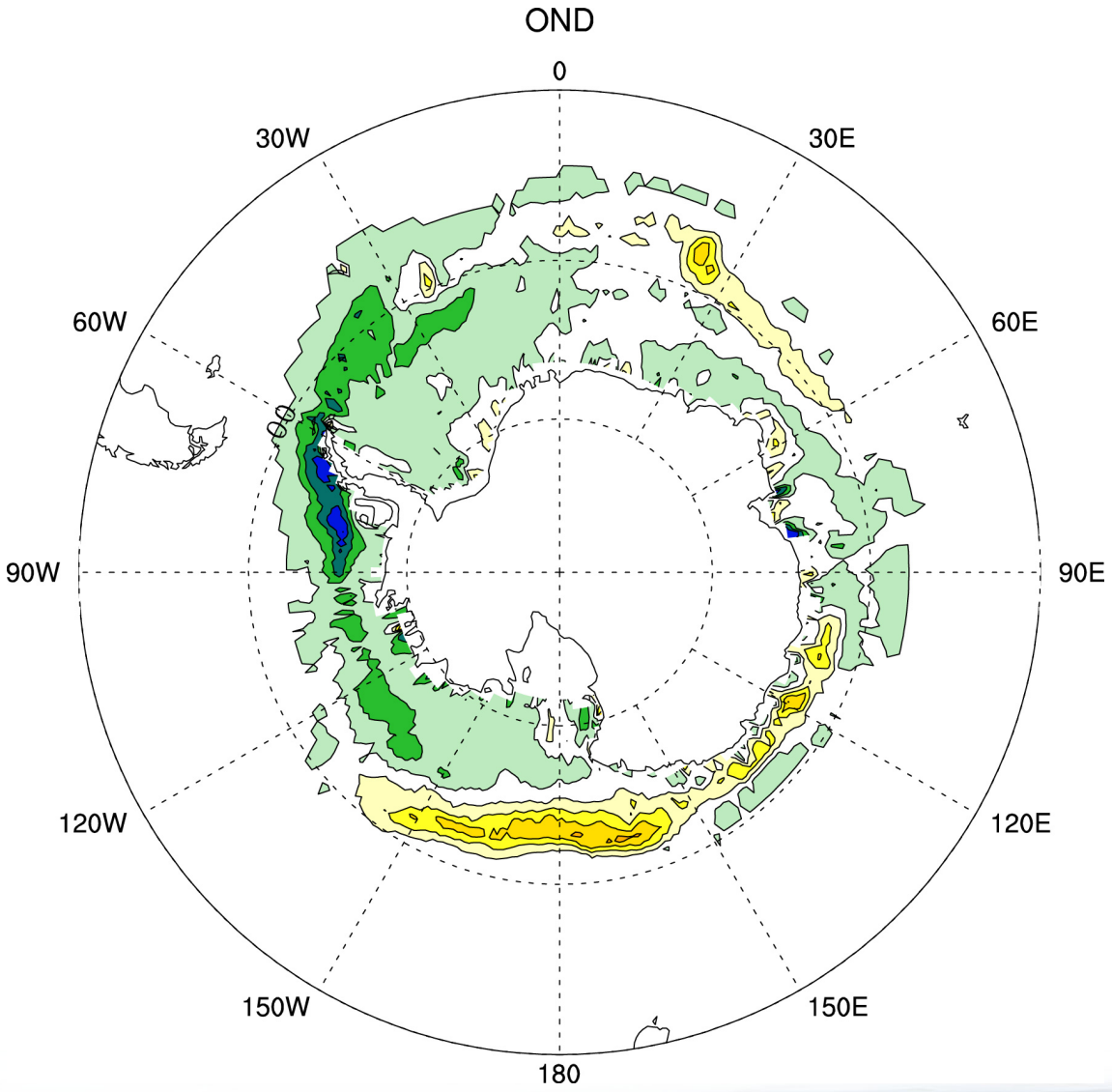
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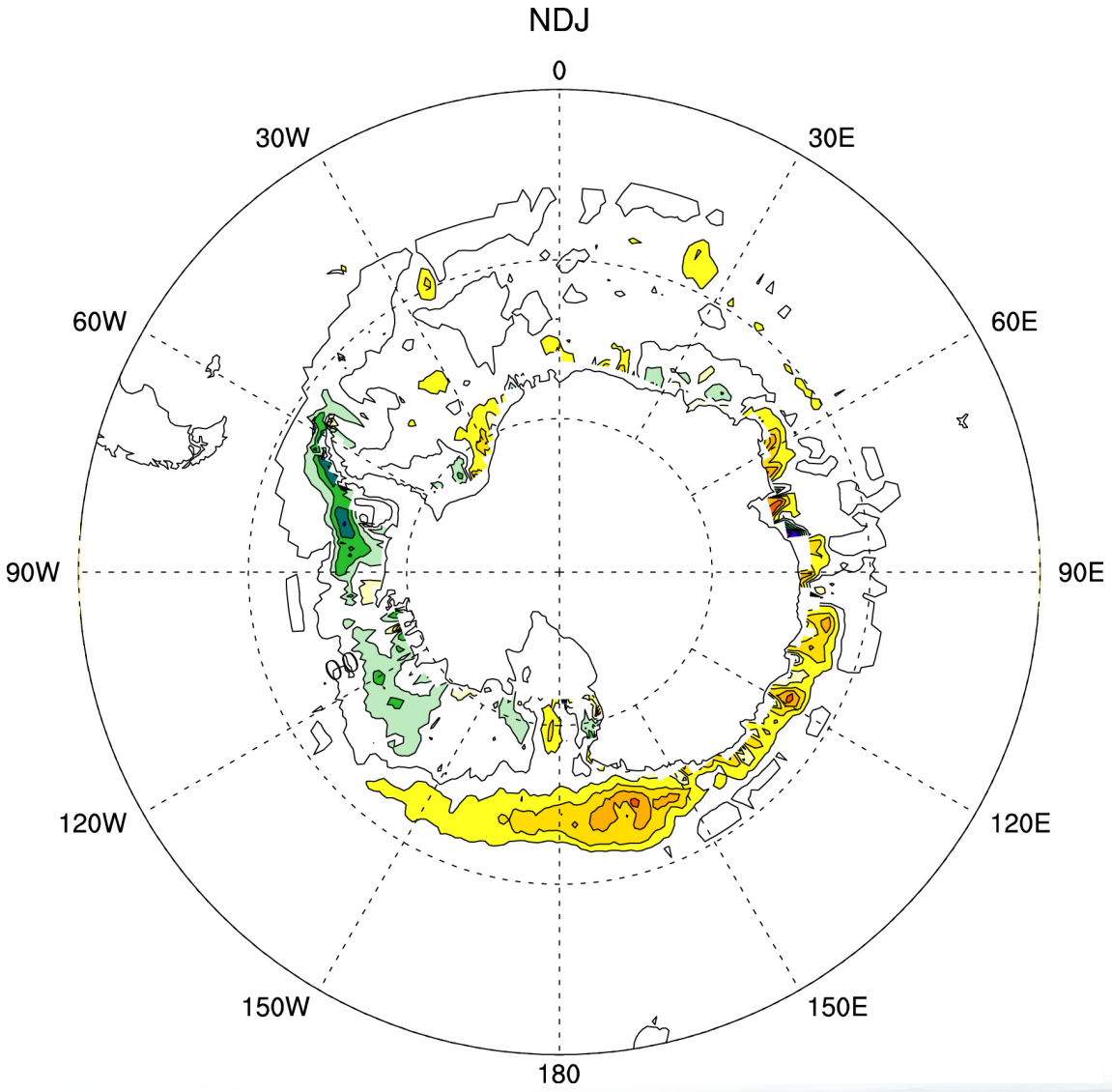
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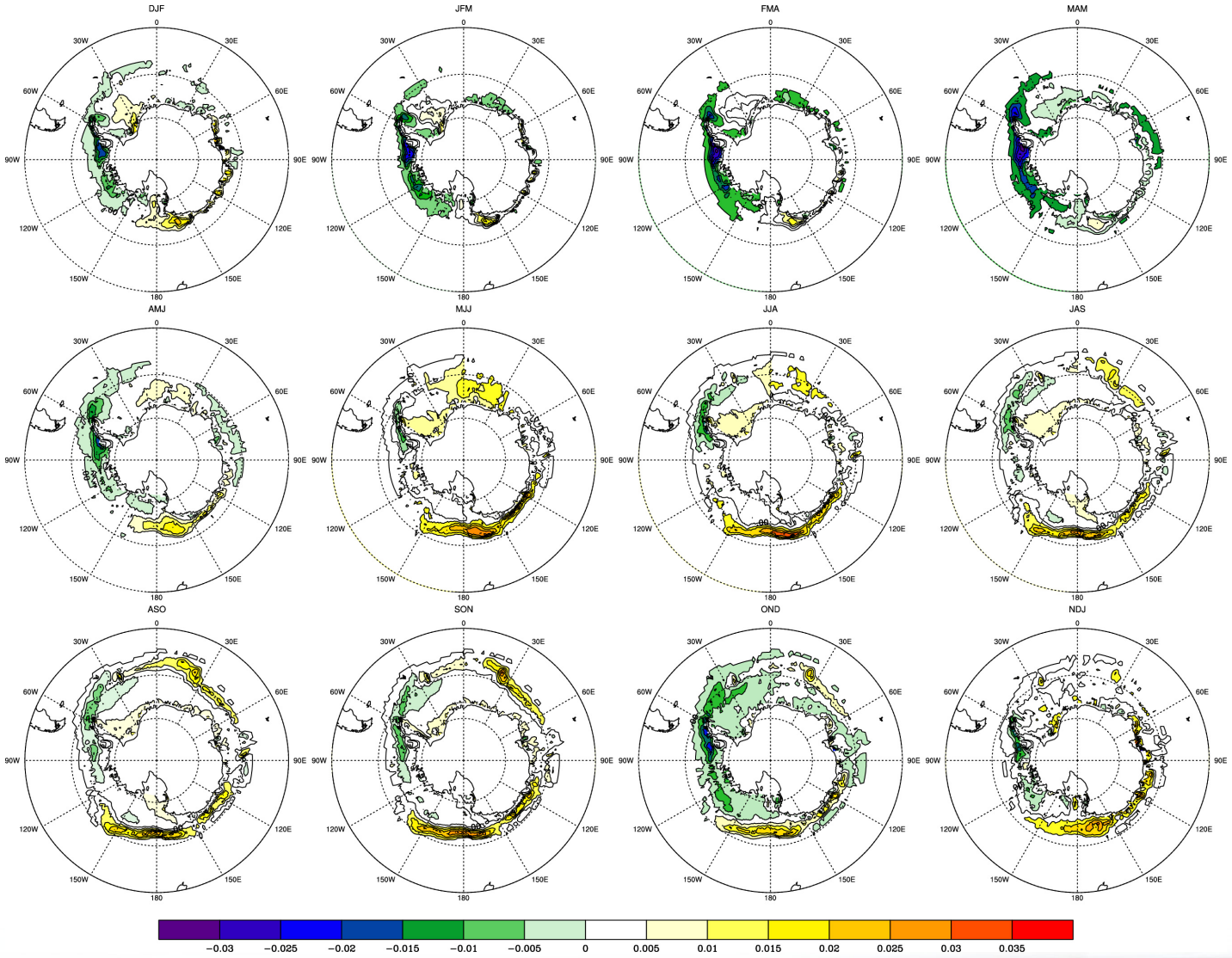
Seasonal Sea Ice Trend 1980 – 2009



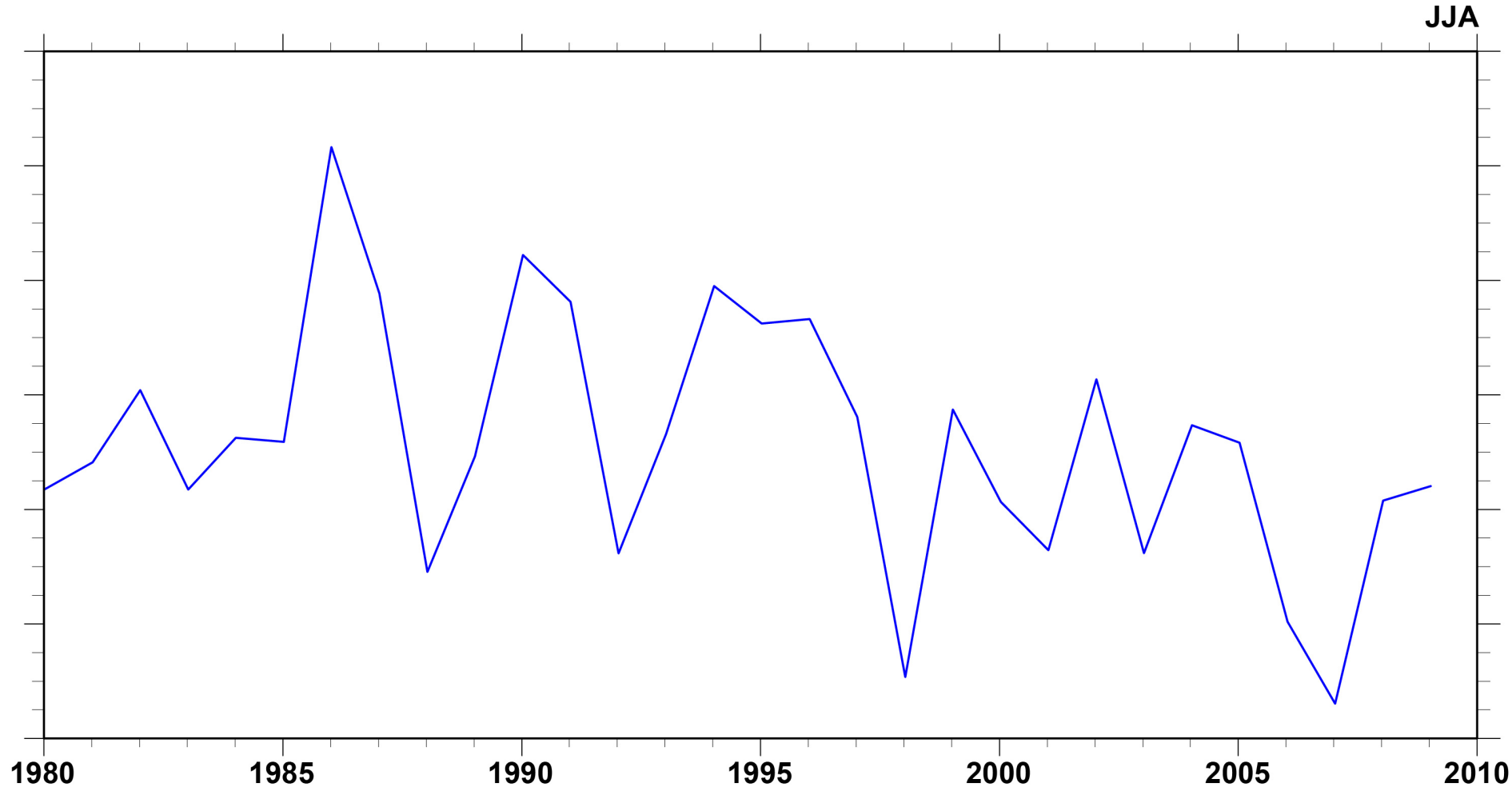
There are strong seasonal differences in sea ice trends.

Sea ice is always decreasing in the B/A Seas and around the Peninsula.

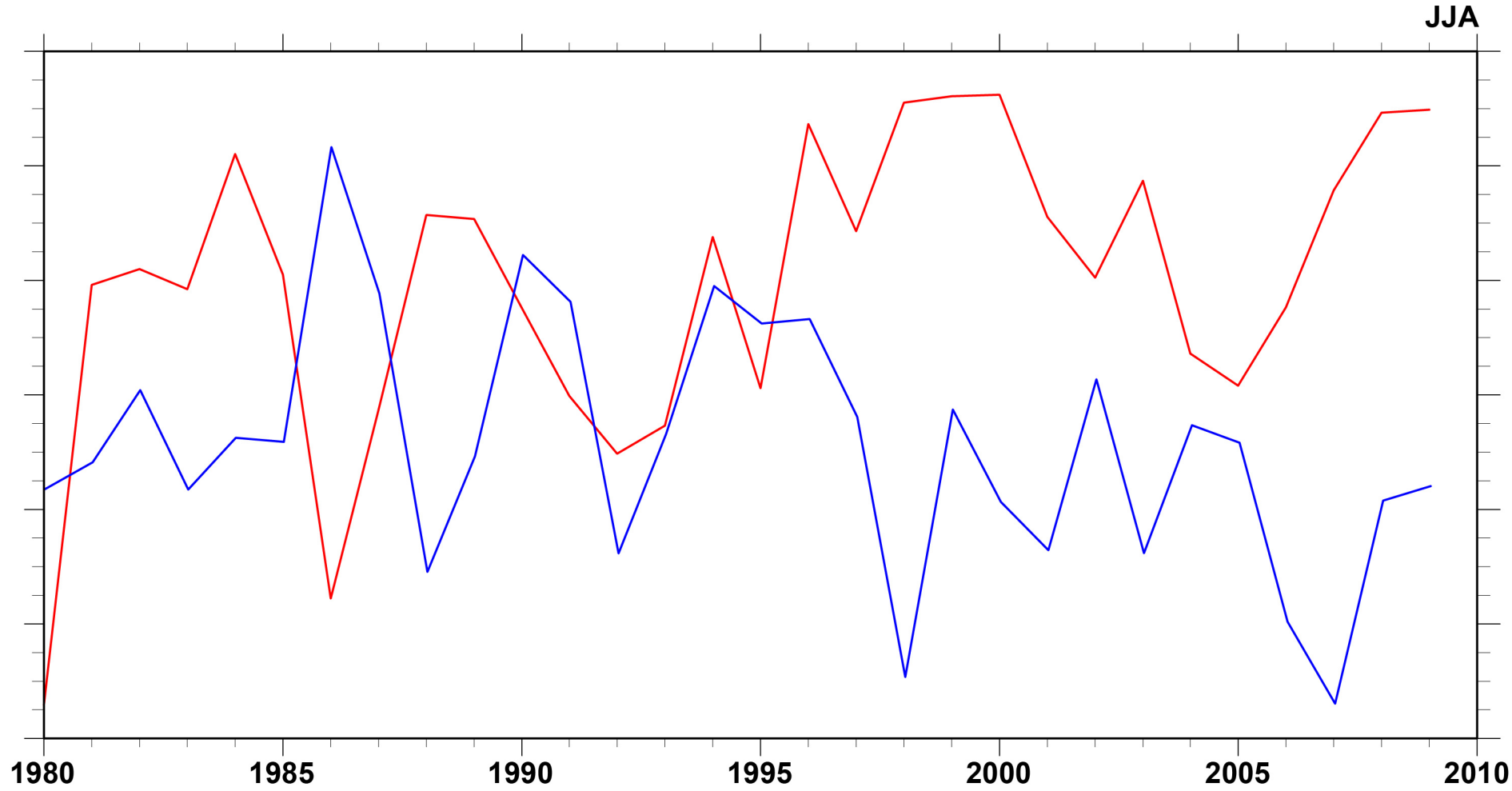
From January to May sea ice decrease dominates the sea ice field.

From May to September sea ice increase dominates the sea ice field.

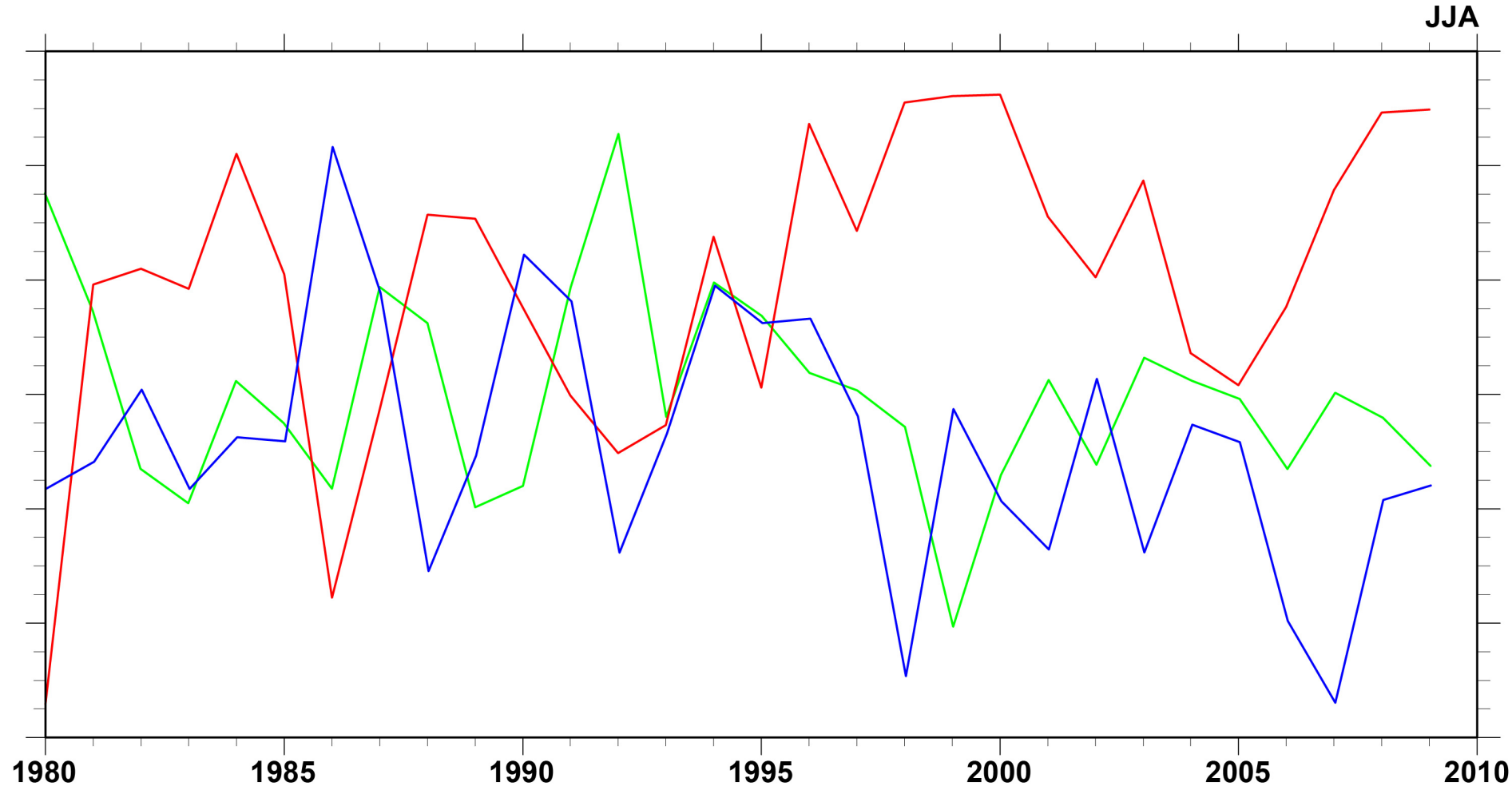
Average Observed B/A Sea



Average Observed Ross Sea



Average Observed Weddell Sea



Large scale Atmospheric Mechanisms Influencing Antarctic Sea Ice and Climate:

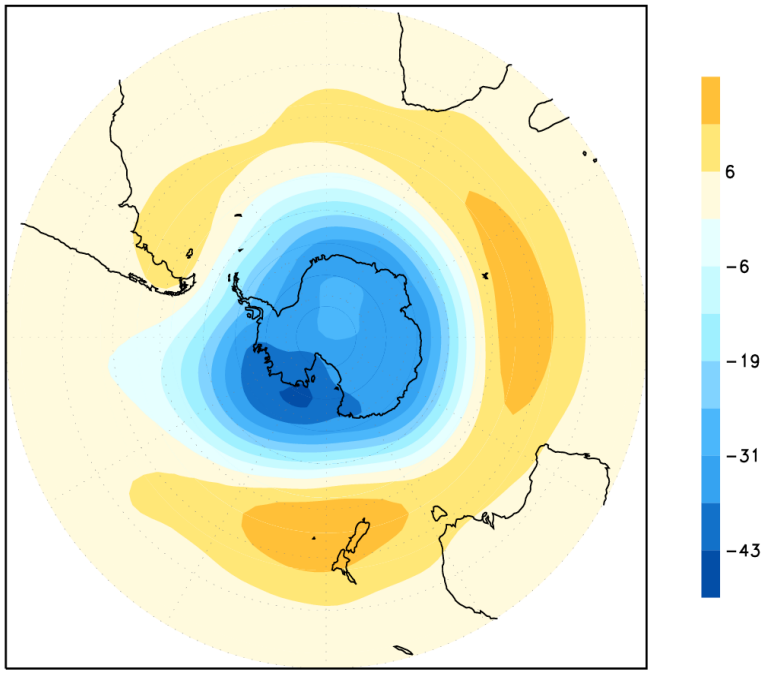
- **Southern Hemisphere Annular Mode (SAM aka AAO)**
- **Pacific South American Mode (PSA)**
- **Semi-Annual Oscillation (SAO)**
- **Zonal Wave Three (ZW3)**

How do these mechanisms influence sea ice?

They exert control on windspeed and direction which in turn controls advection of energy and mechanical motion of ice.

- Poleward movement of relatively warmer air will have a direct impact on ice leading to melt and indirect impact by influencing the sensible heat flux exchange between the atmosphere and the ocean/sea ice surface.

- Wind direction forces the movement of ice towards the continent (restricting sea ice extent) or away from the continent (expanding sea ice extent).

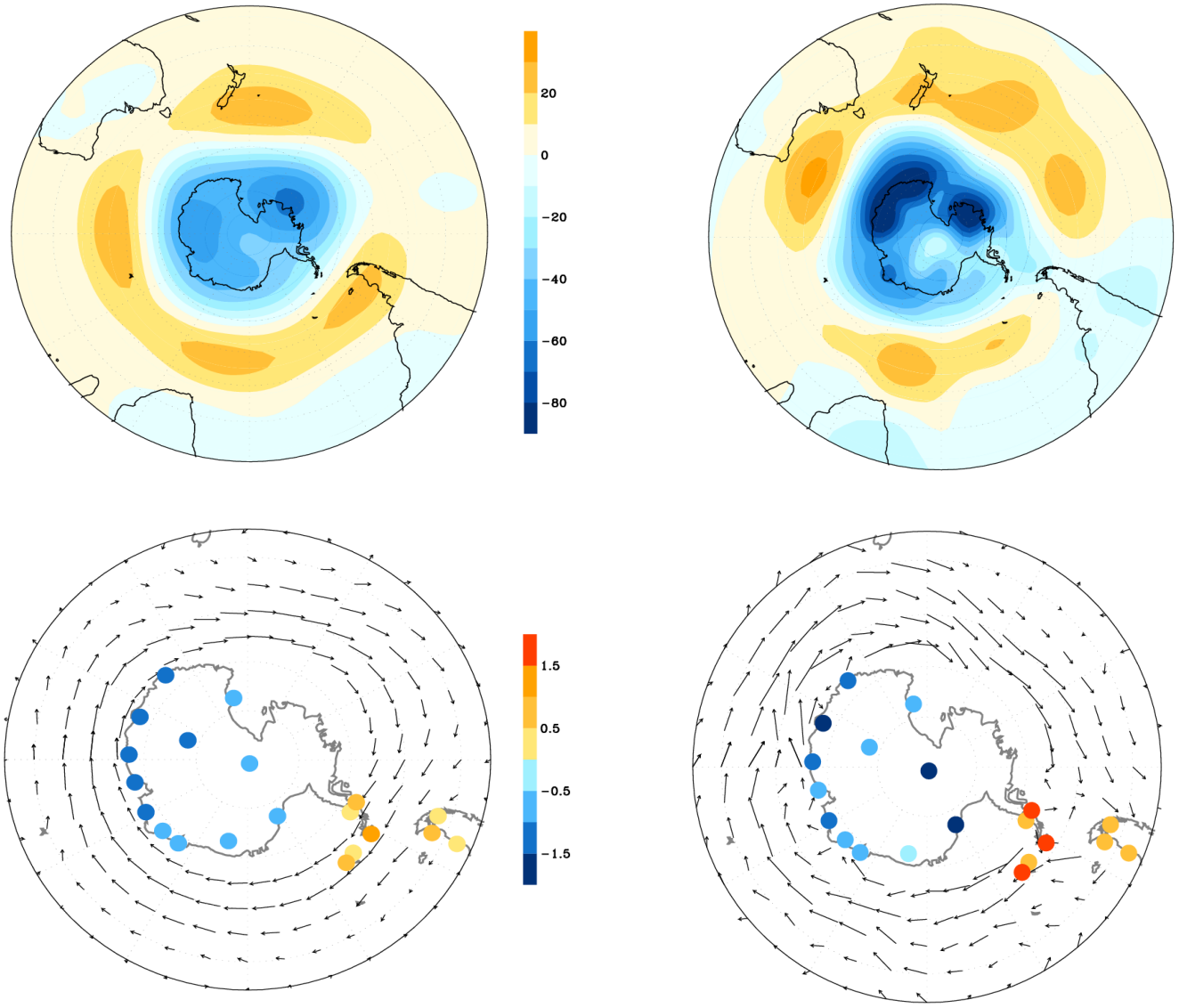


850-hPa height regressed on an index of the SAM (Southern Hemisphere Annular Mode)

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.

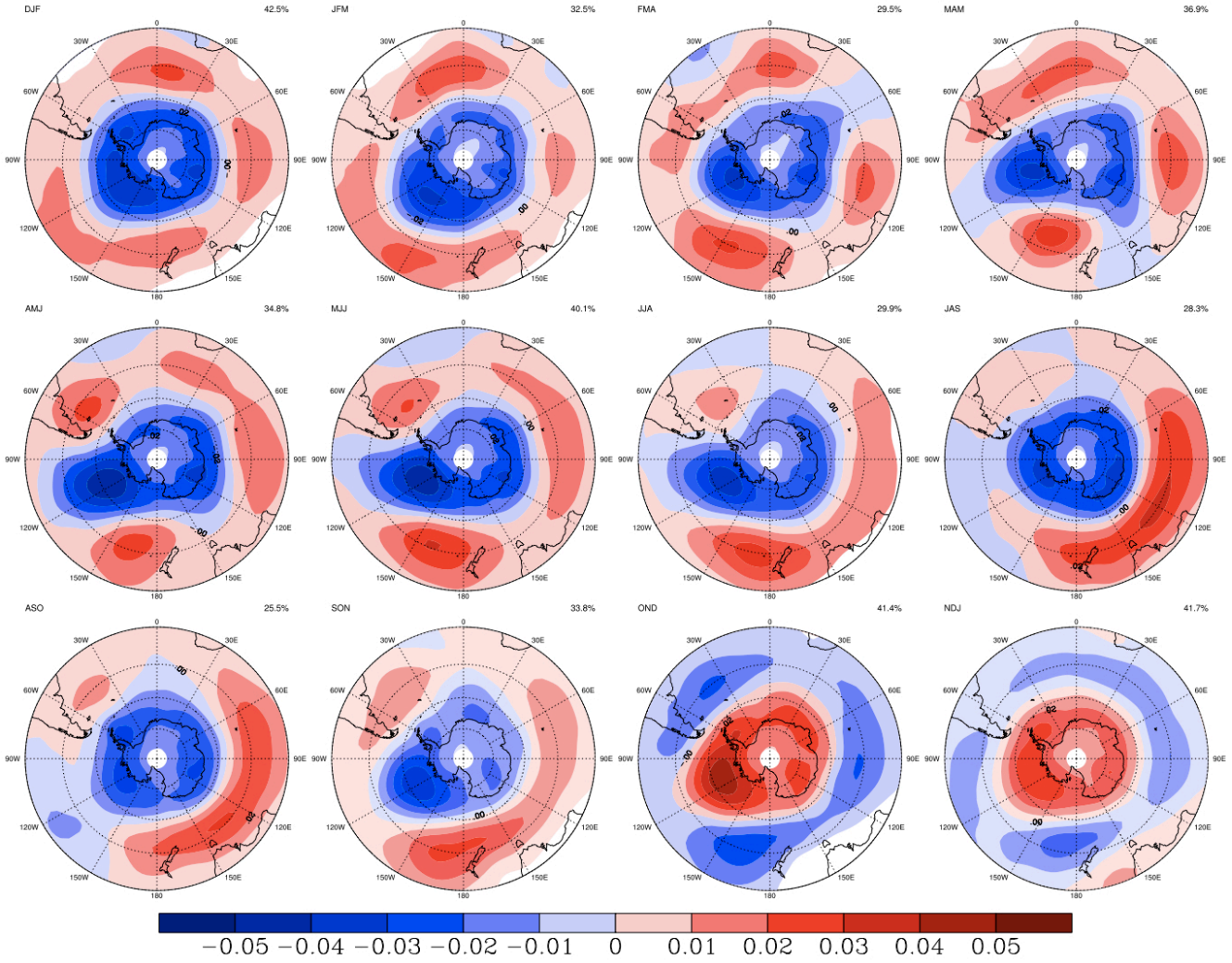
It is the leading mode of SH variability in virtually all atmospheric fields. (e.g. Rogers and van Loon, 1982; Thompson and Wallace, 2000; Marshall, 2003, 2007; Schneider et al., 2006

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.



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*)

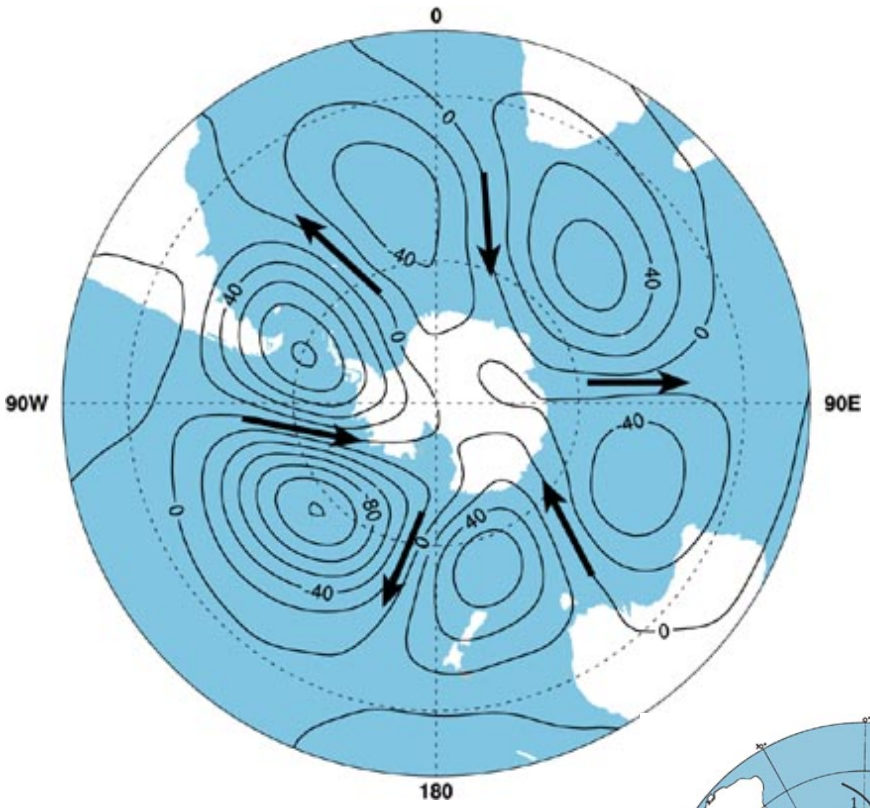
SAM: three-month running means (1980 – 2009)

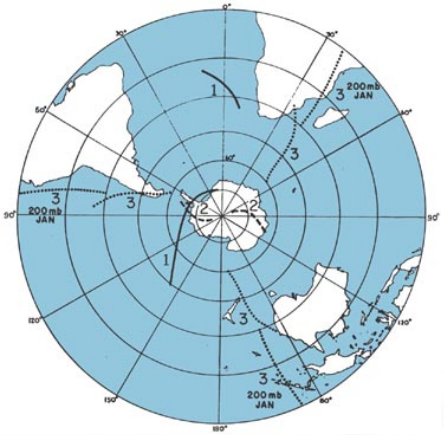


Zonal Wave Three (ZW3)

- 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

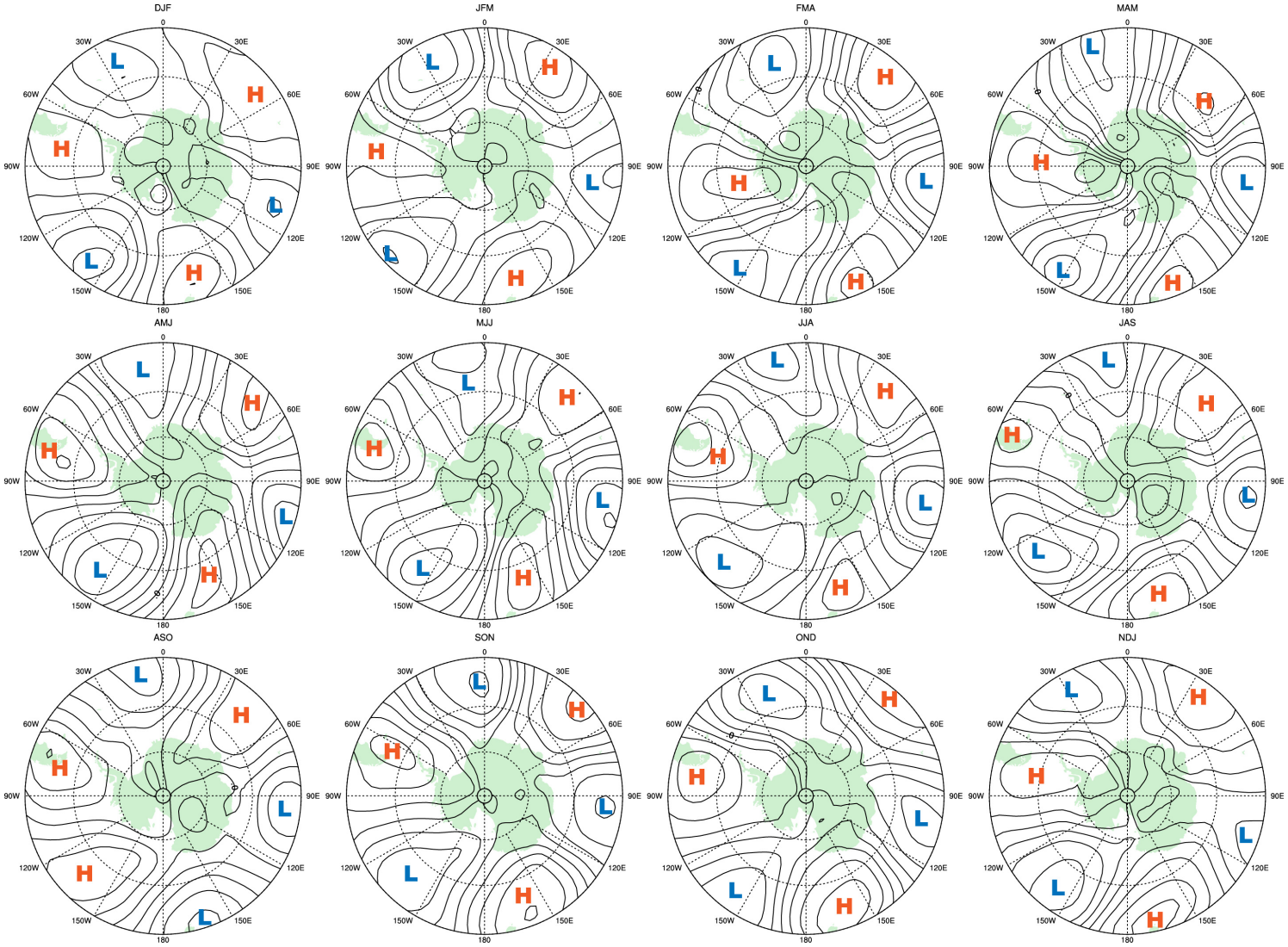




- Preferred regions of equatorward and poleward flow. Equatorward flow would bring colder air and poleward flow, warmer.
- Has the potential to influence the Antarctic sea-ice region by influencing the meridional transport of heat in the atmosphere and ocean.

Raphael, 2004

Zonal Wave Three: three-month running means (1980-2009)

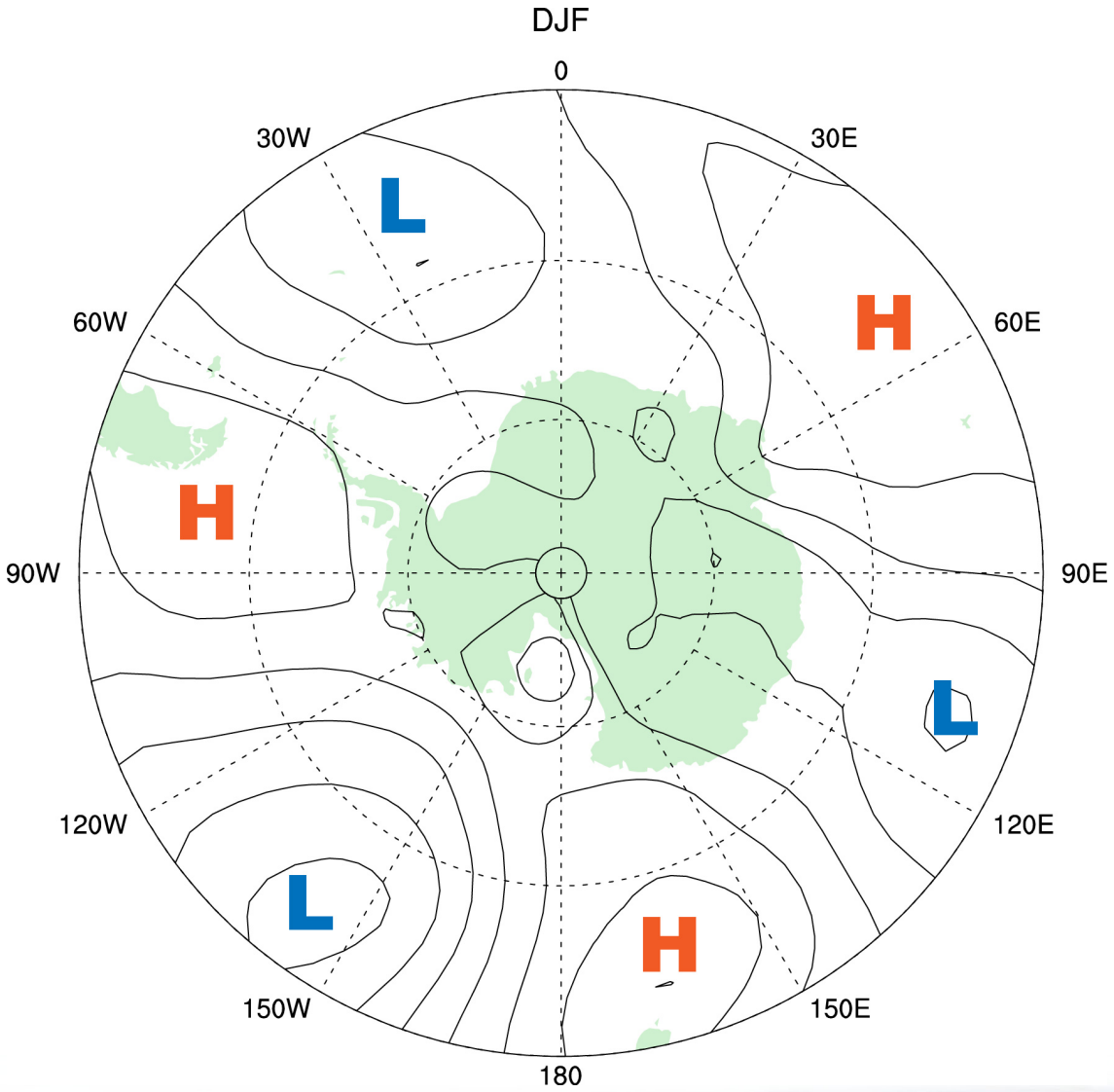


ZW3 is not stationary.

It progresses ("sloshes") from east to west and back.

Its E/W movement is limited by the continents to which it is tied.

It also expands and contracts with the seasons.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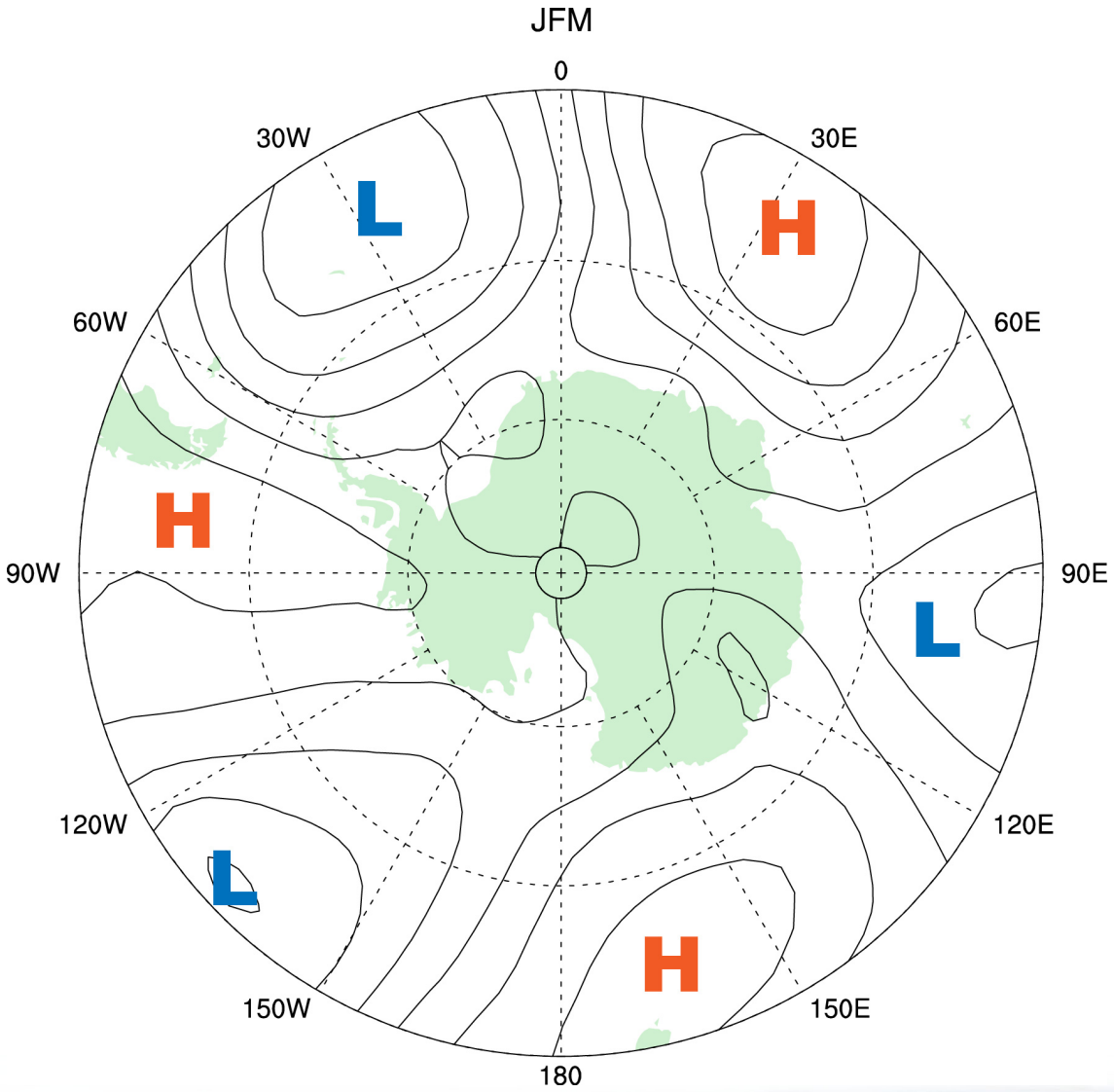
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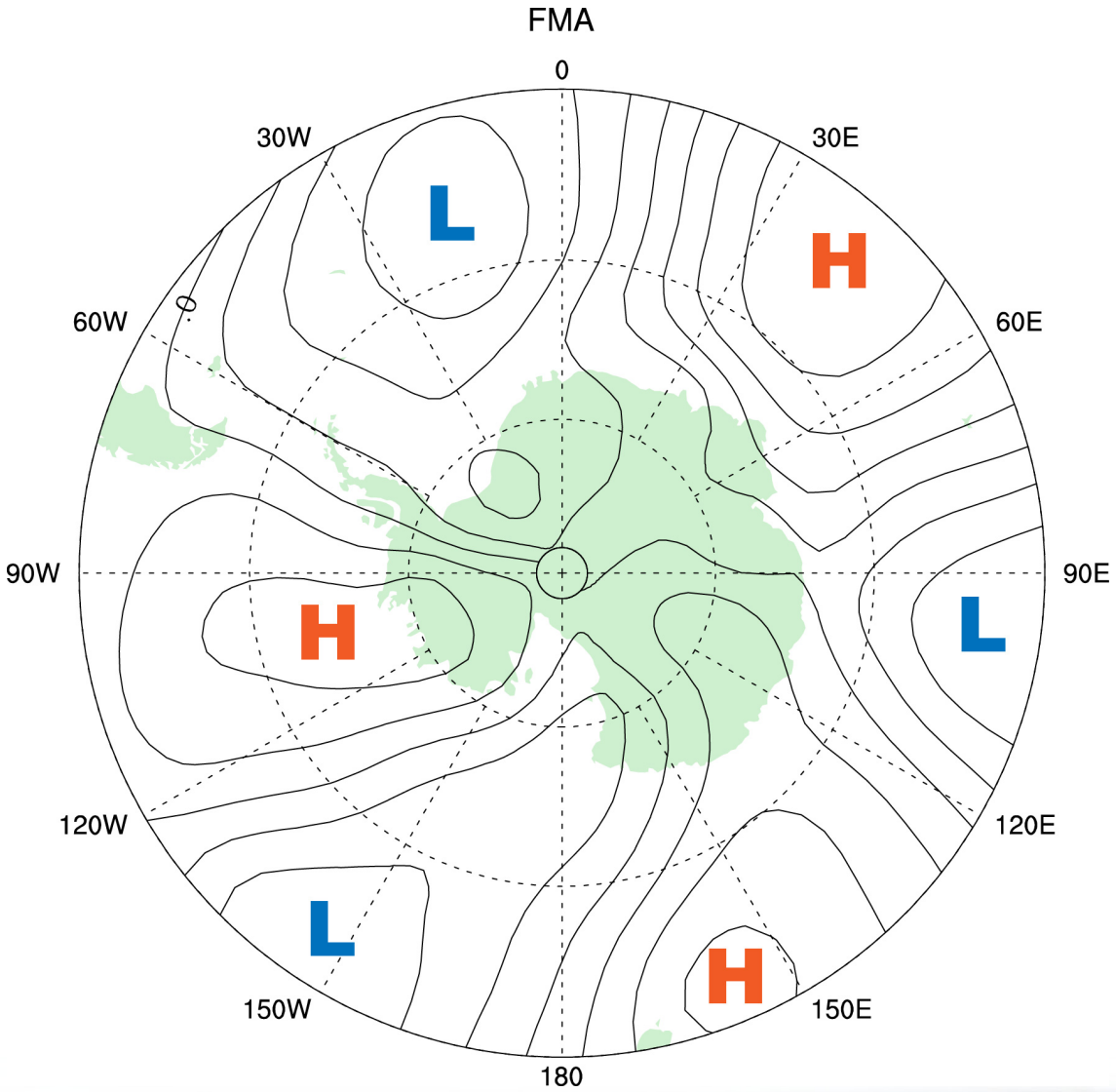
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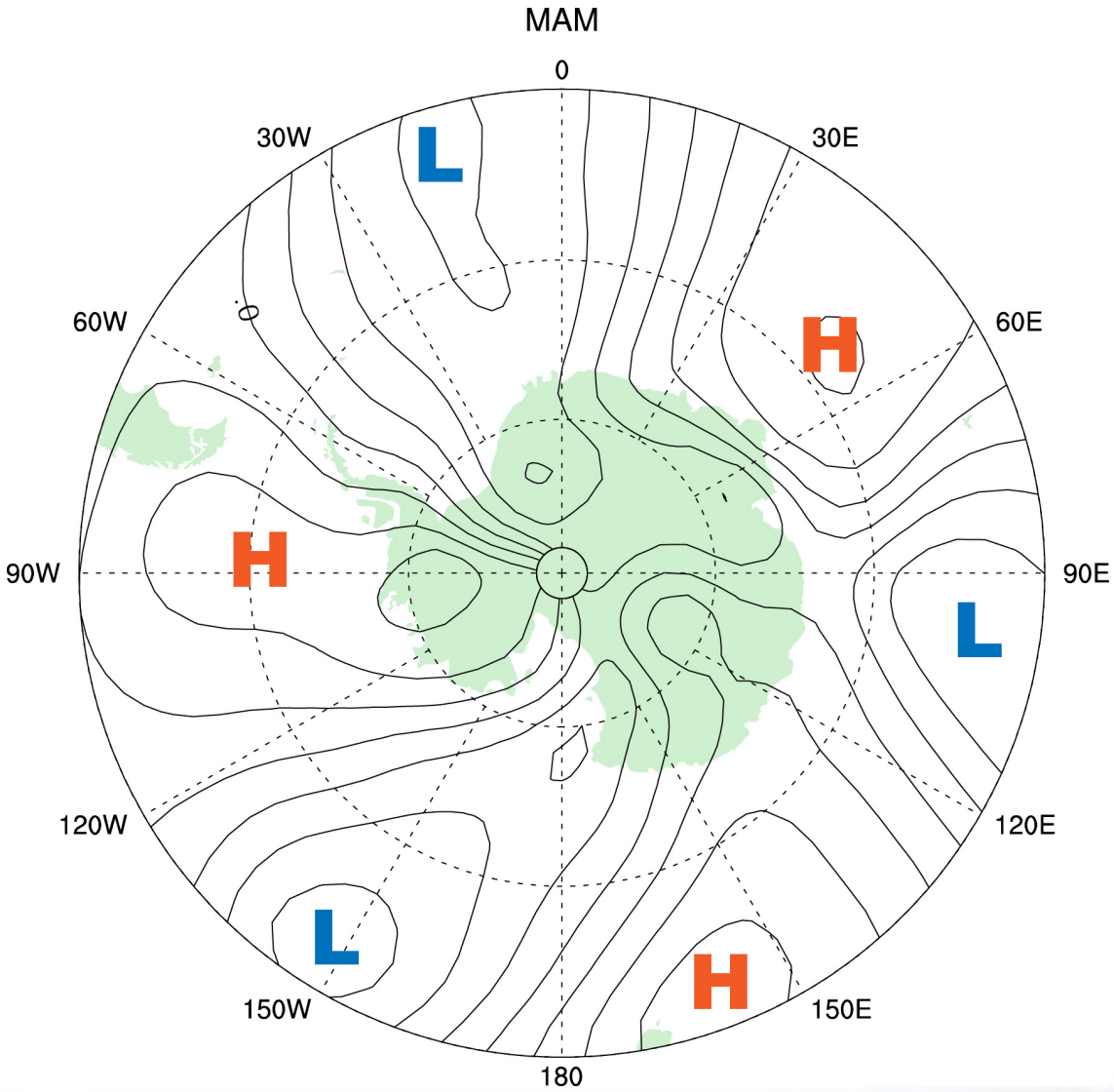
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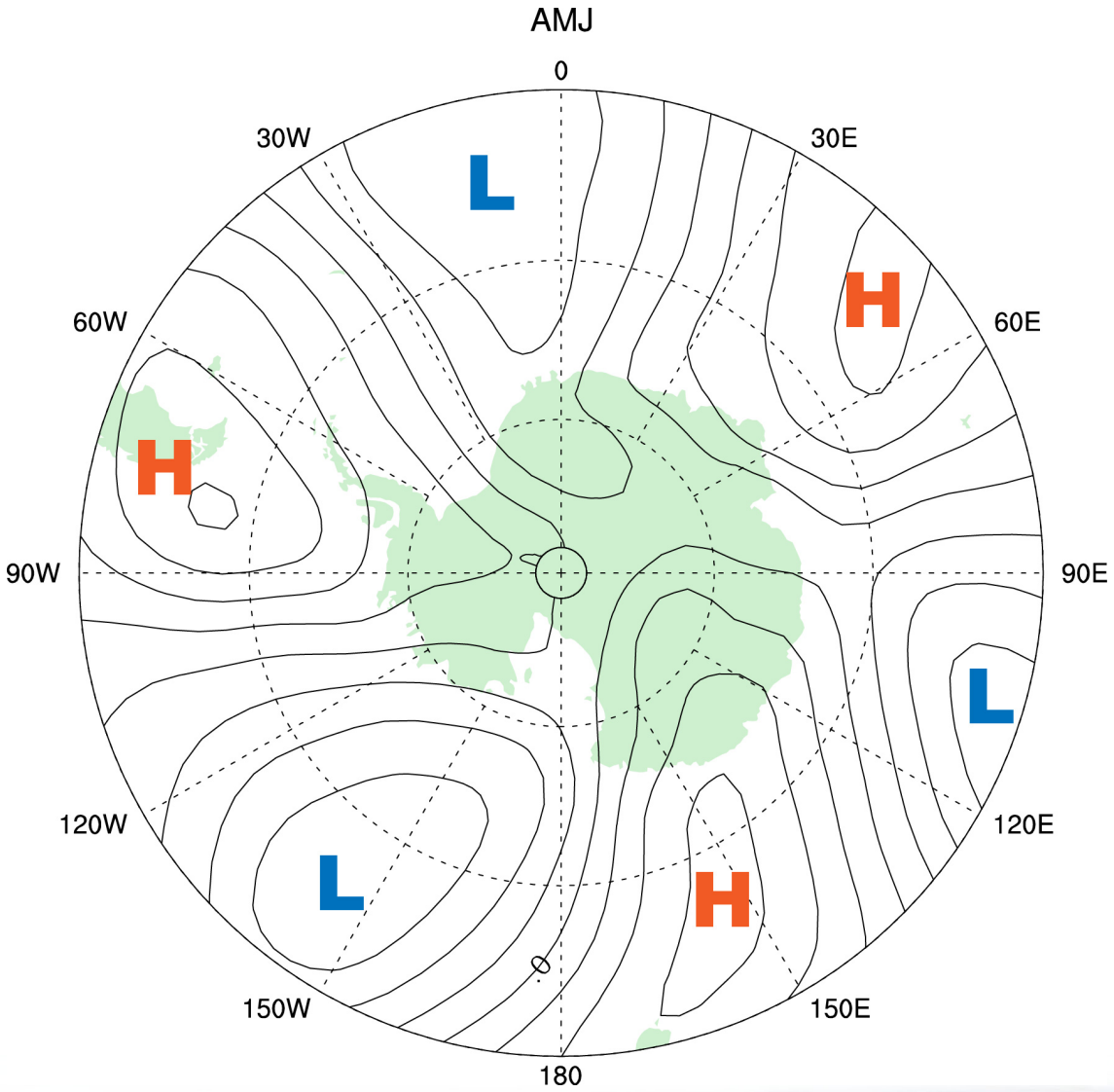
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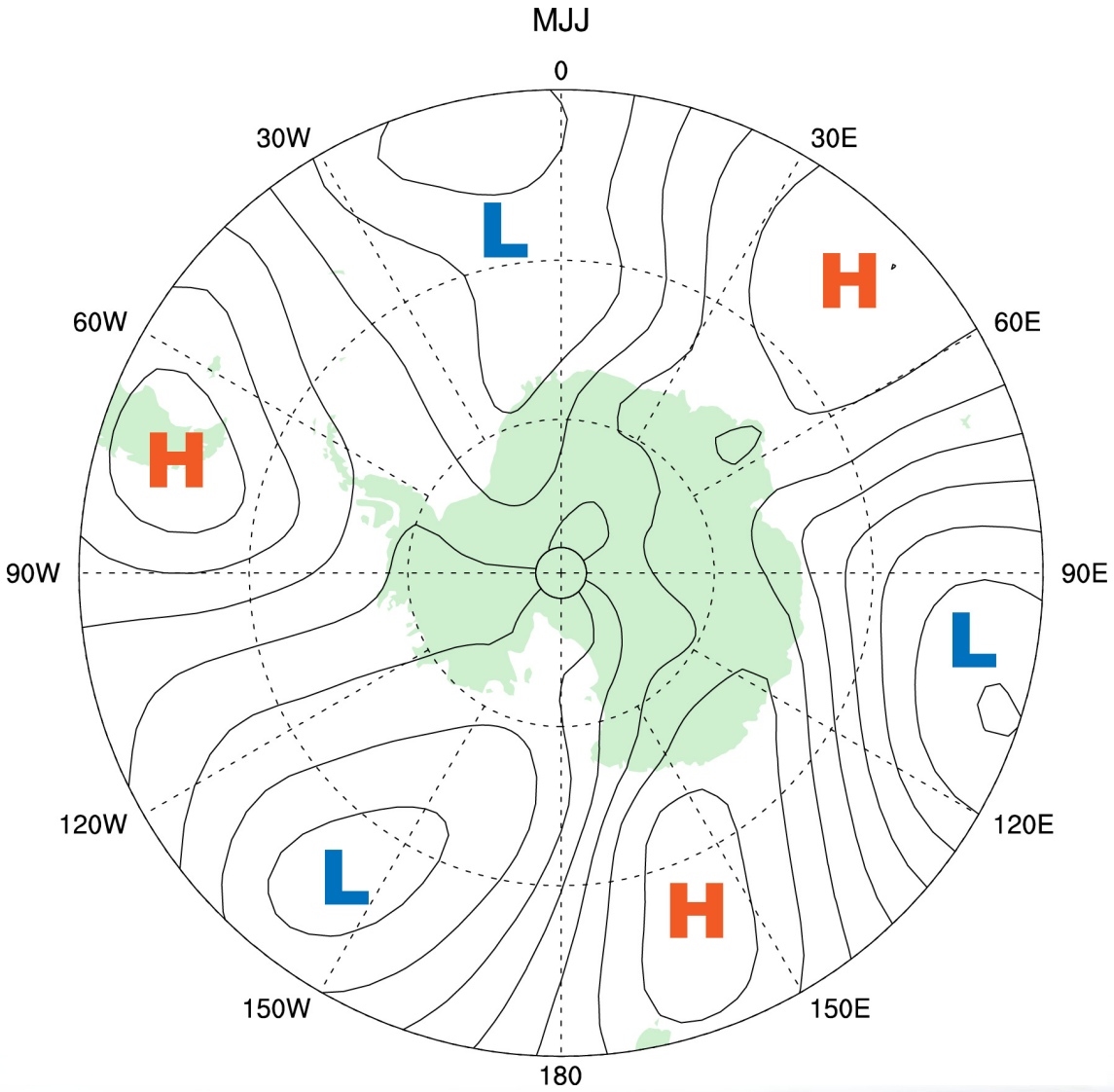
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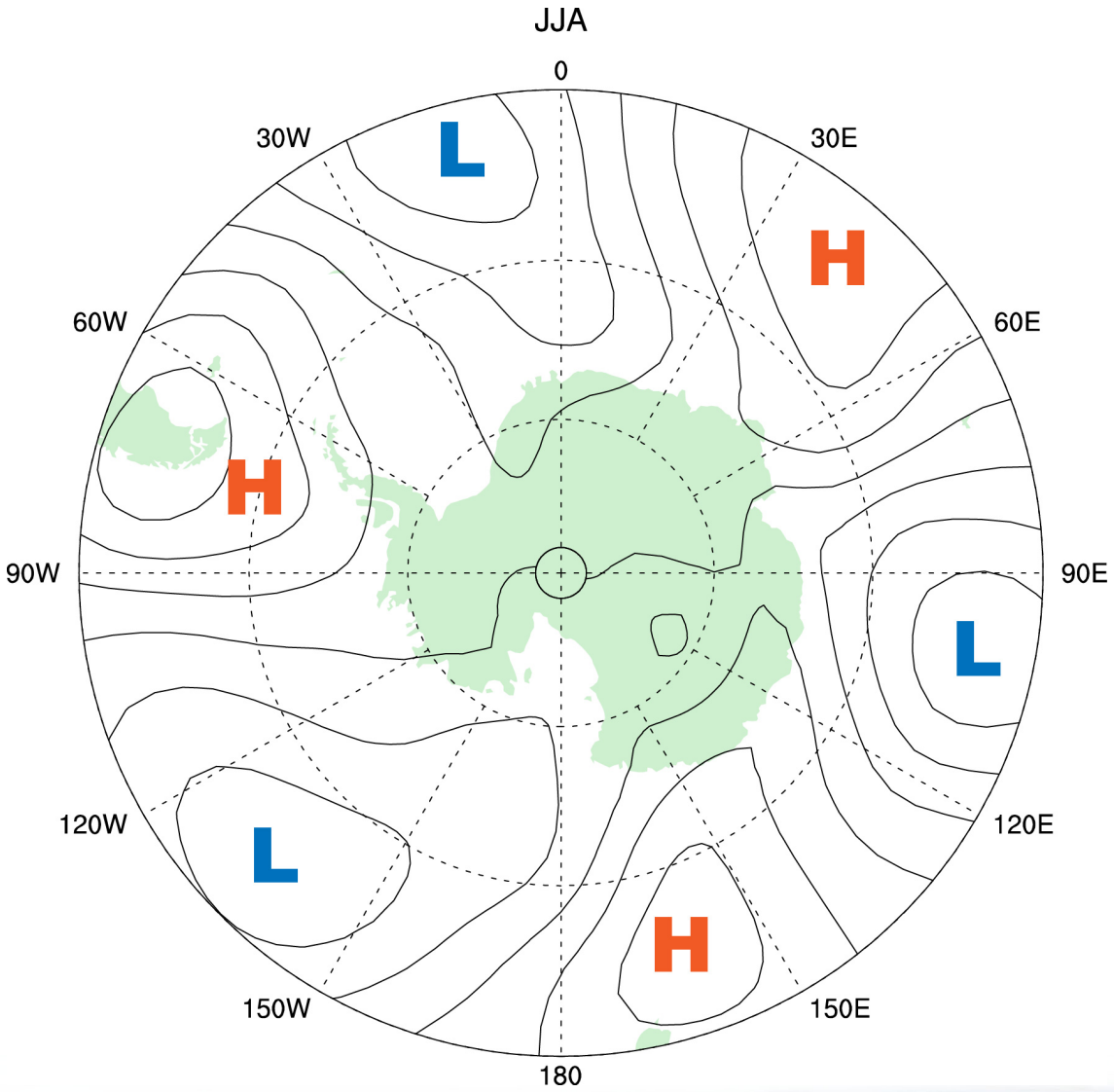
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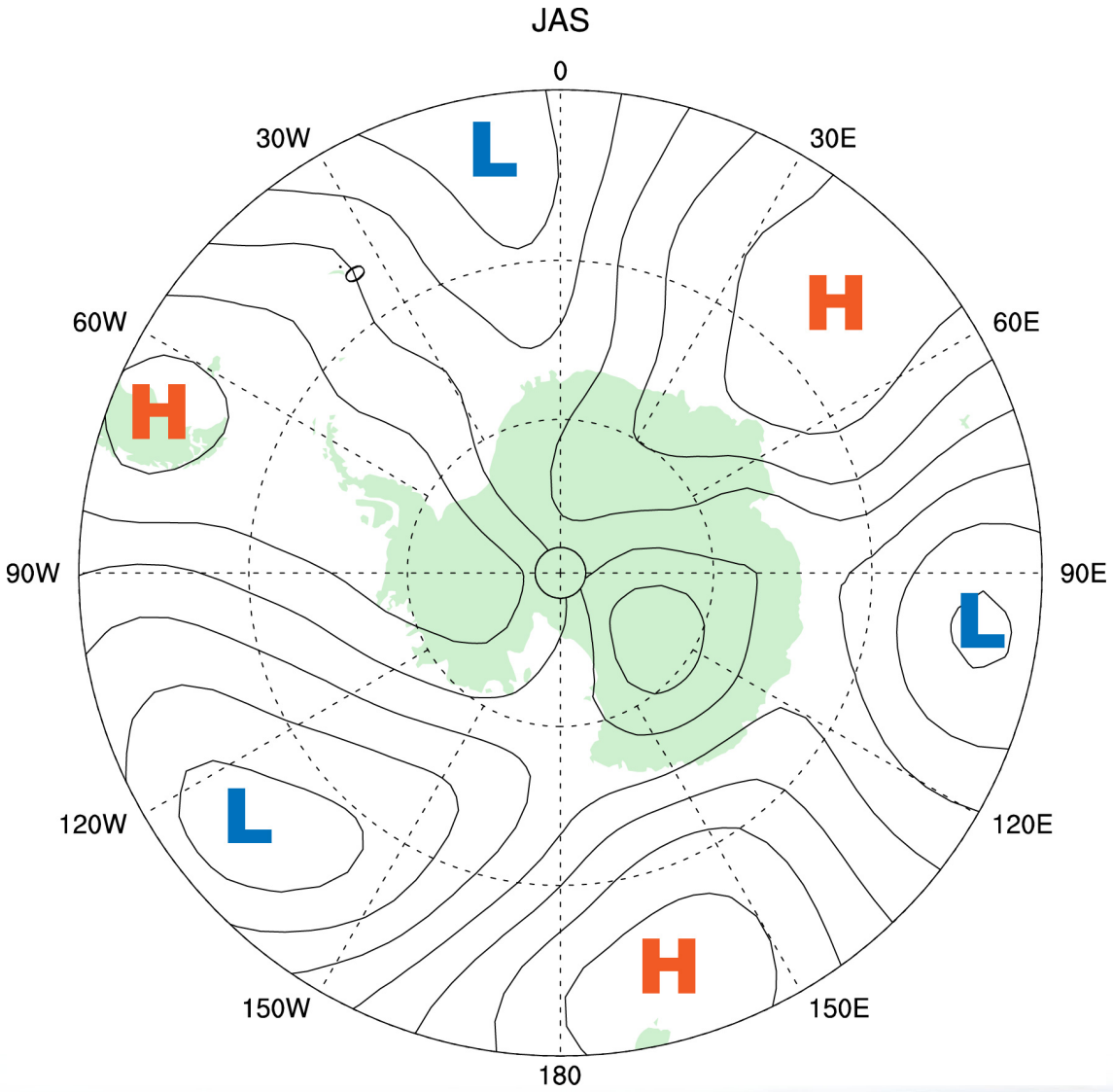
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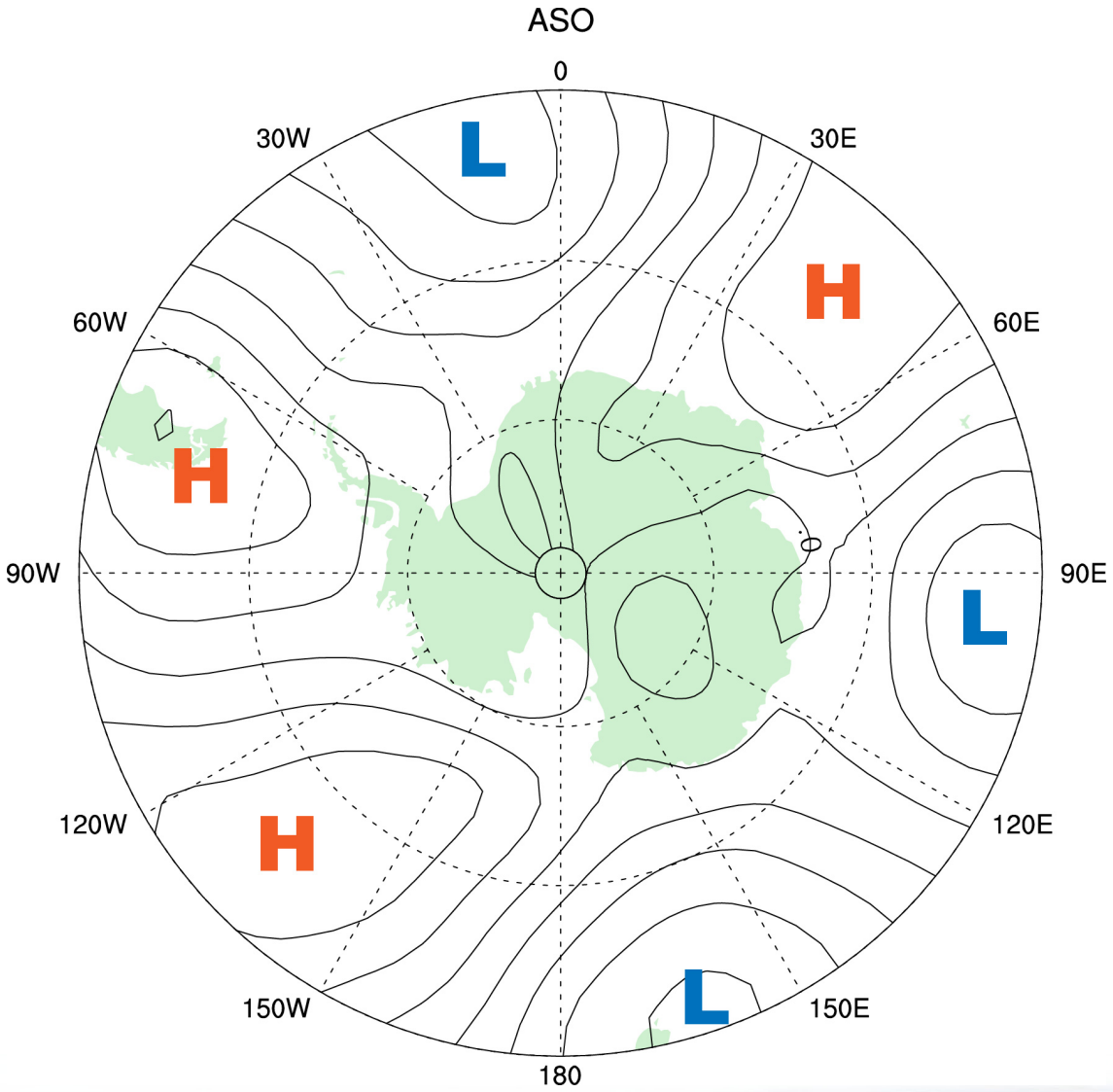
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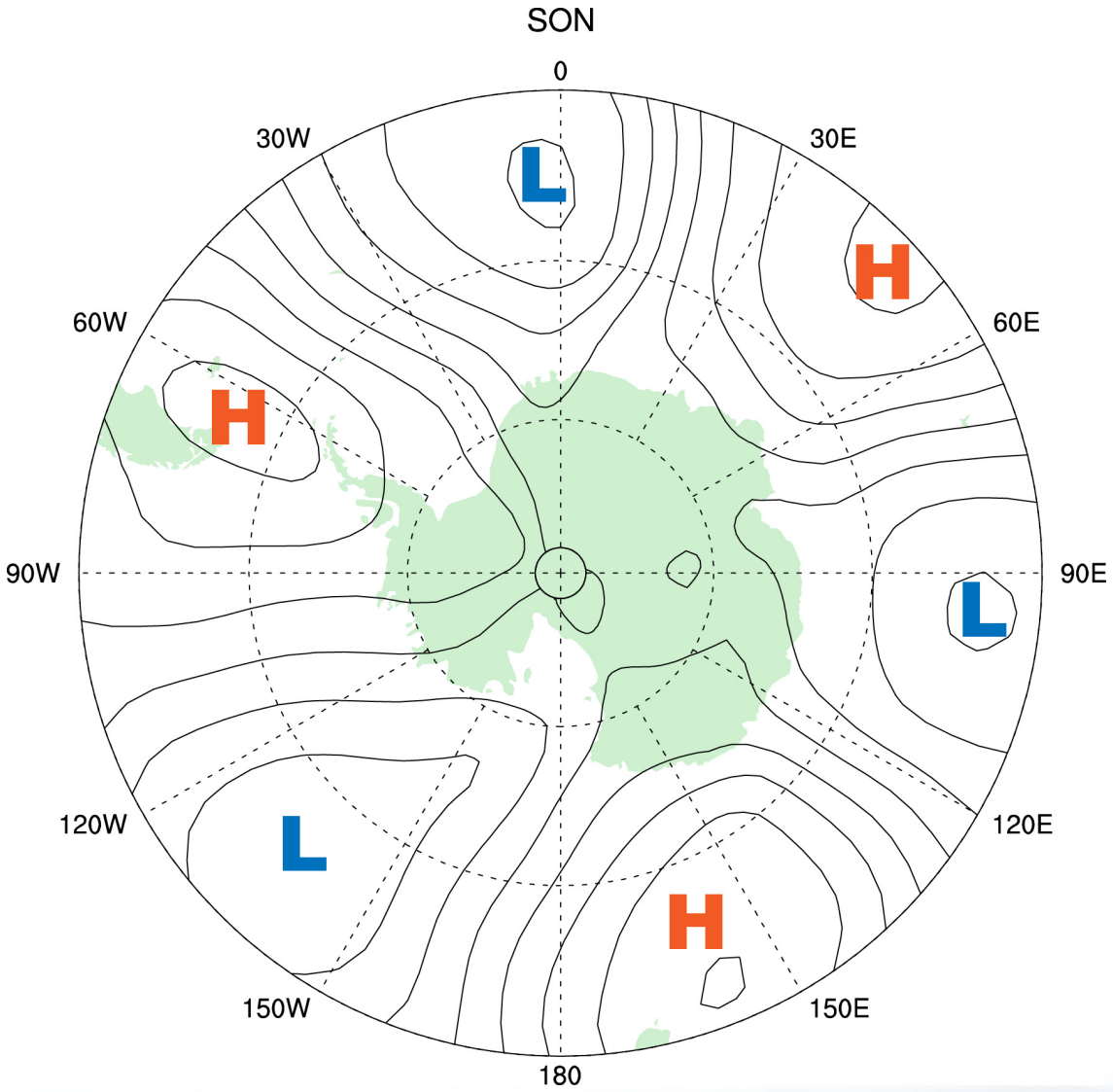
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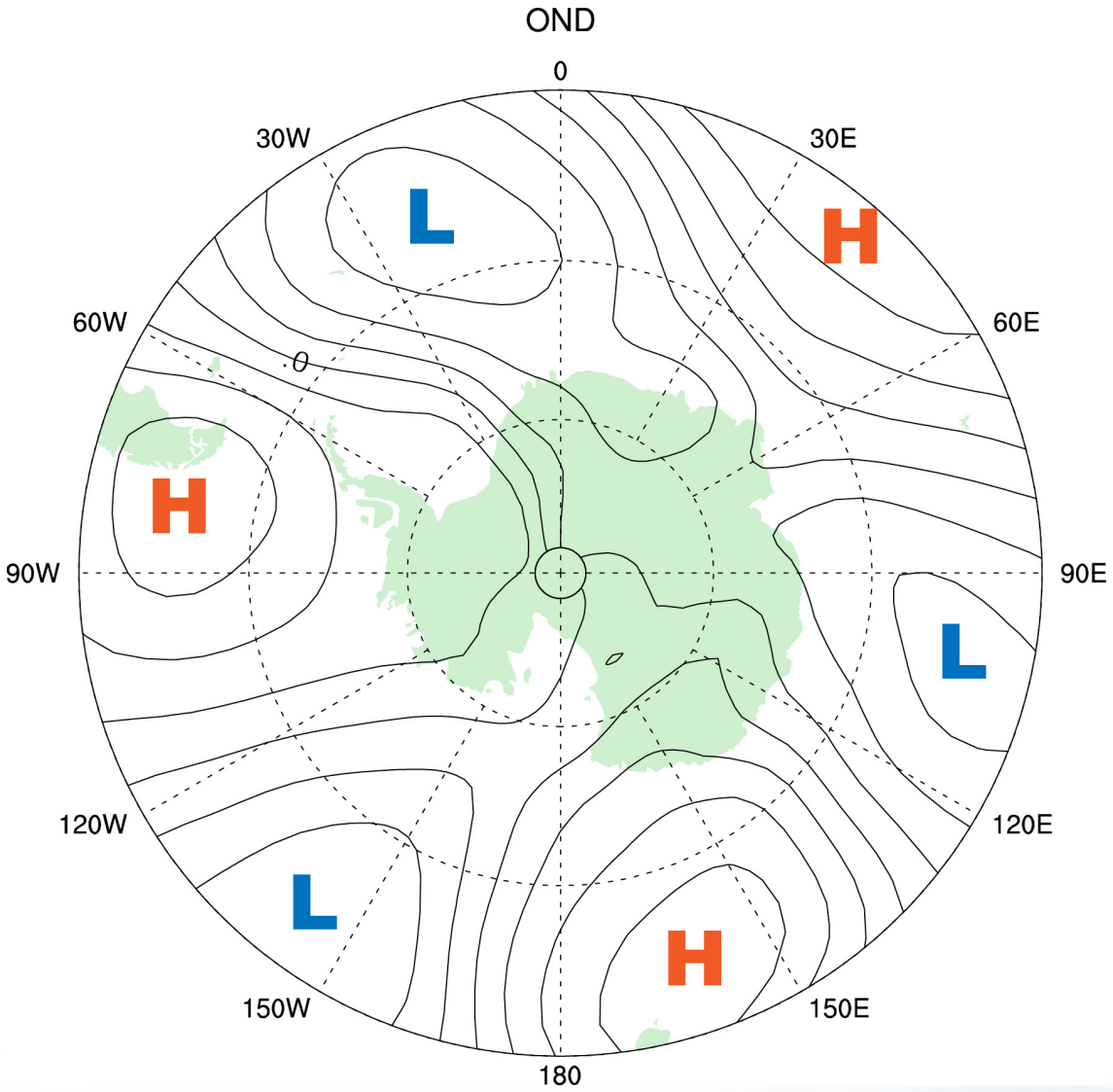

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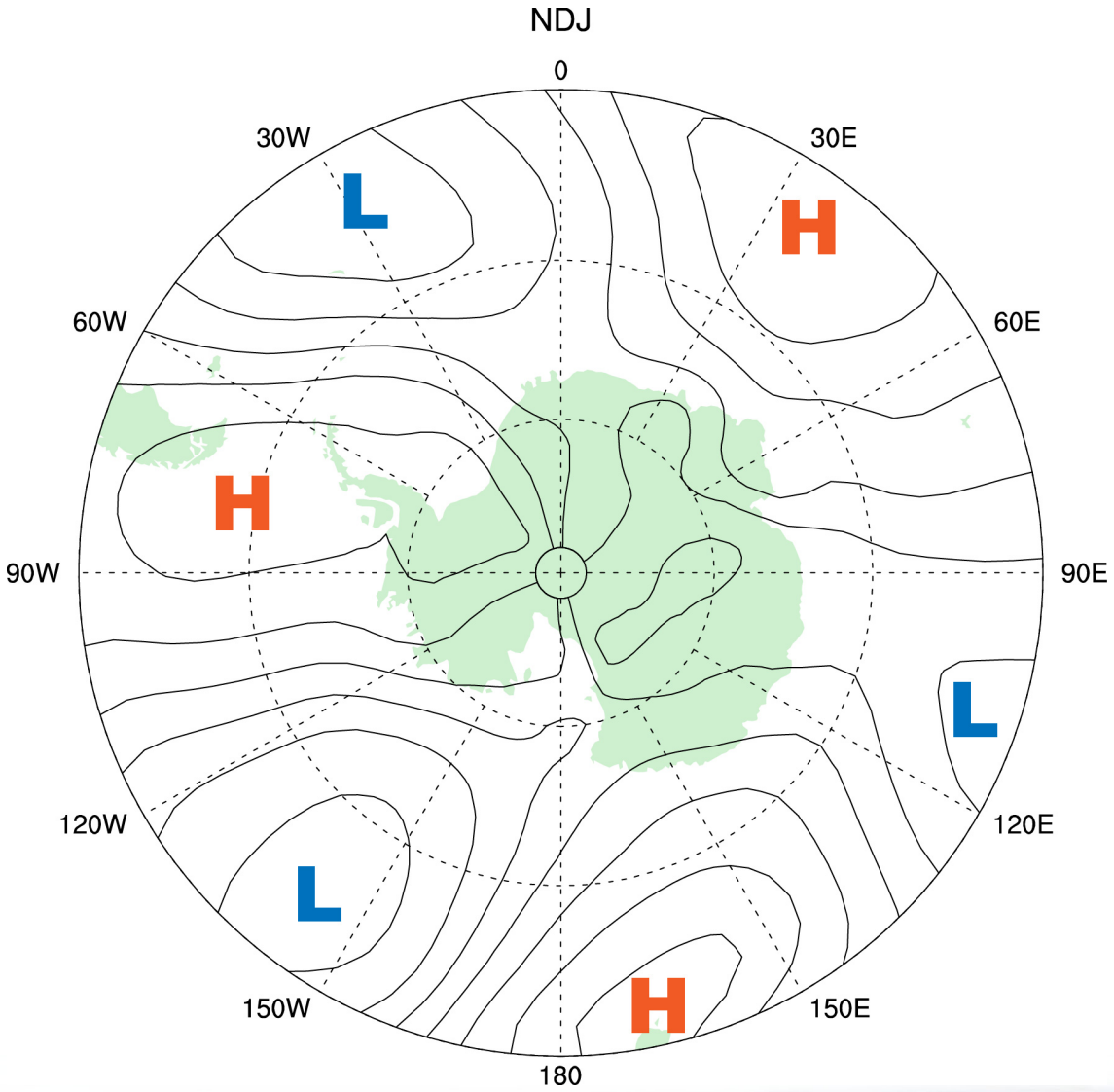

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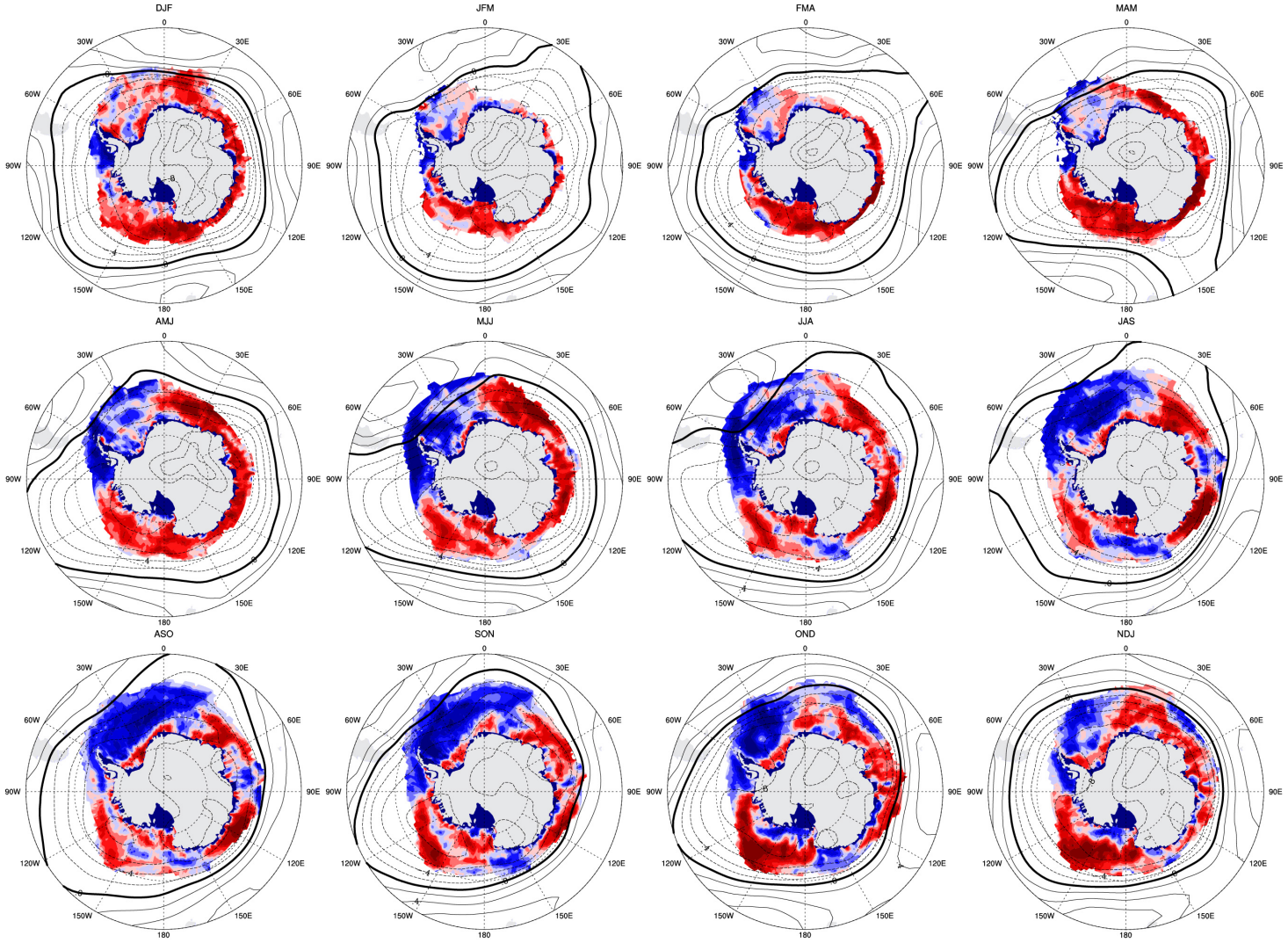
SAM and ZW3 Correlations with Sea ice. Data sets: HadISST2 and NCAR/NCEP geopotential heights at 500mb.

SAM Correlated with Sea-Ice 1980 – 2009

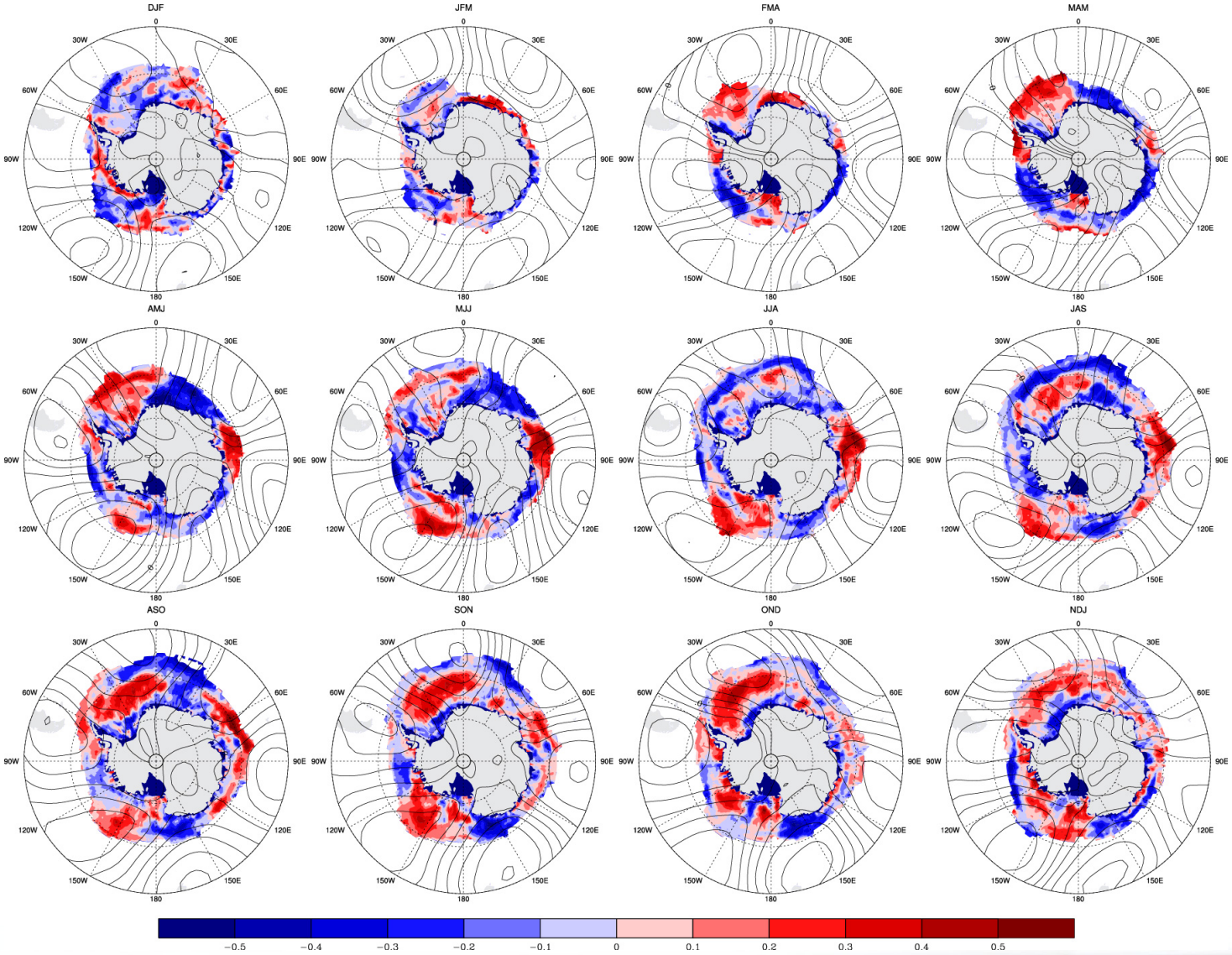


Seasonal differences in the strength of the relationship between SAM and sea ice but consistent, strong influence of SAM in the western Hemisphere Seas.

Antarctic Dipole in appears clearly in correlations from B/A Seas to Weddell Seas.

Strongest negative correlations occur where poleward flow is most pronounced.

Zonal Wave Three Index Correlated with Sea Ice: 1980 – 2009



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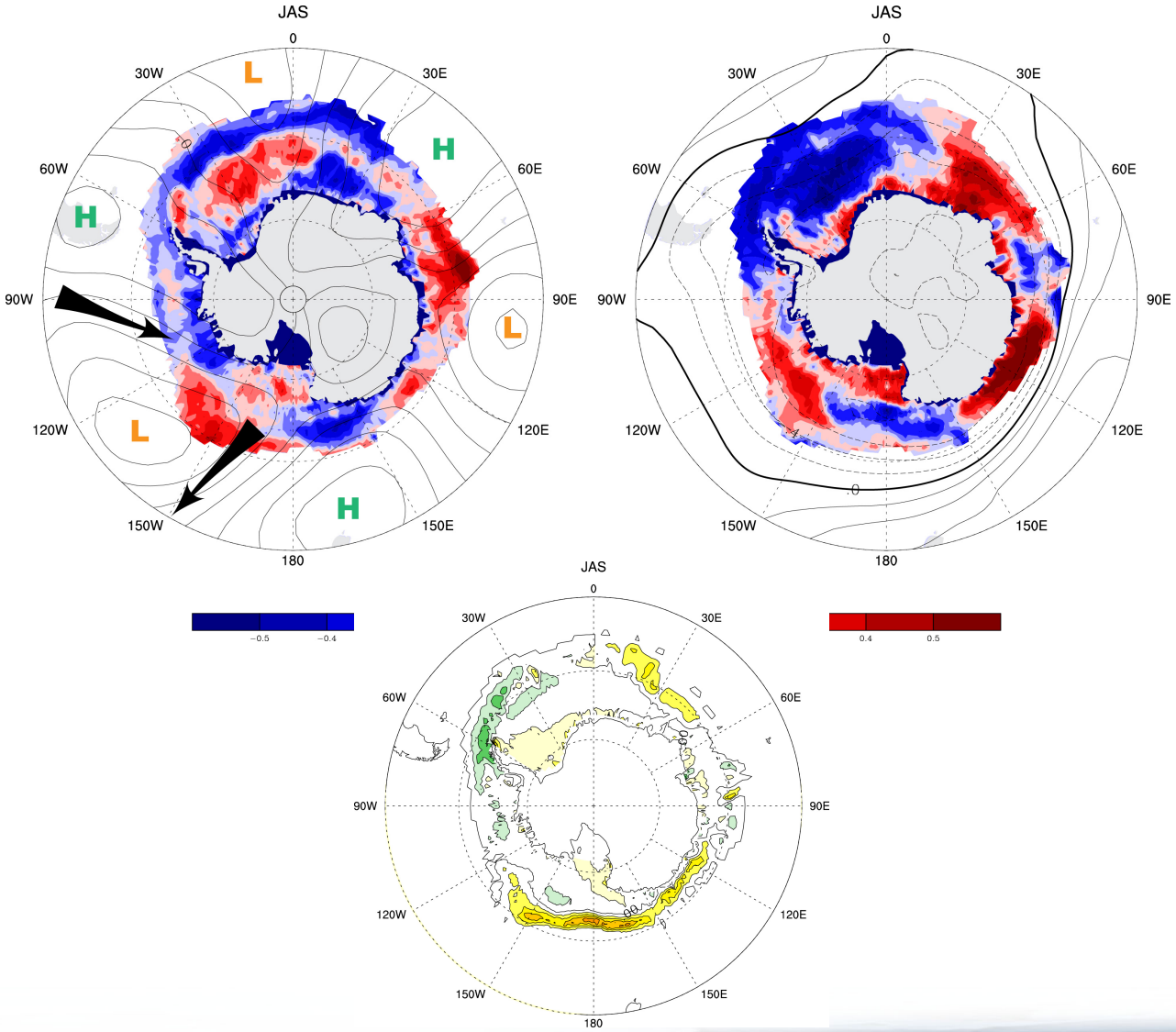
ZW3 leaves a clear imprint on the sea ice field.

There are seasonal differences in the relationship between ZW3 and sea ice.

Influence of ZW3 is not as spatially dominant as that of the SAM but the strength of the relationship is similar.

SAM ZW3 Correlation Observed



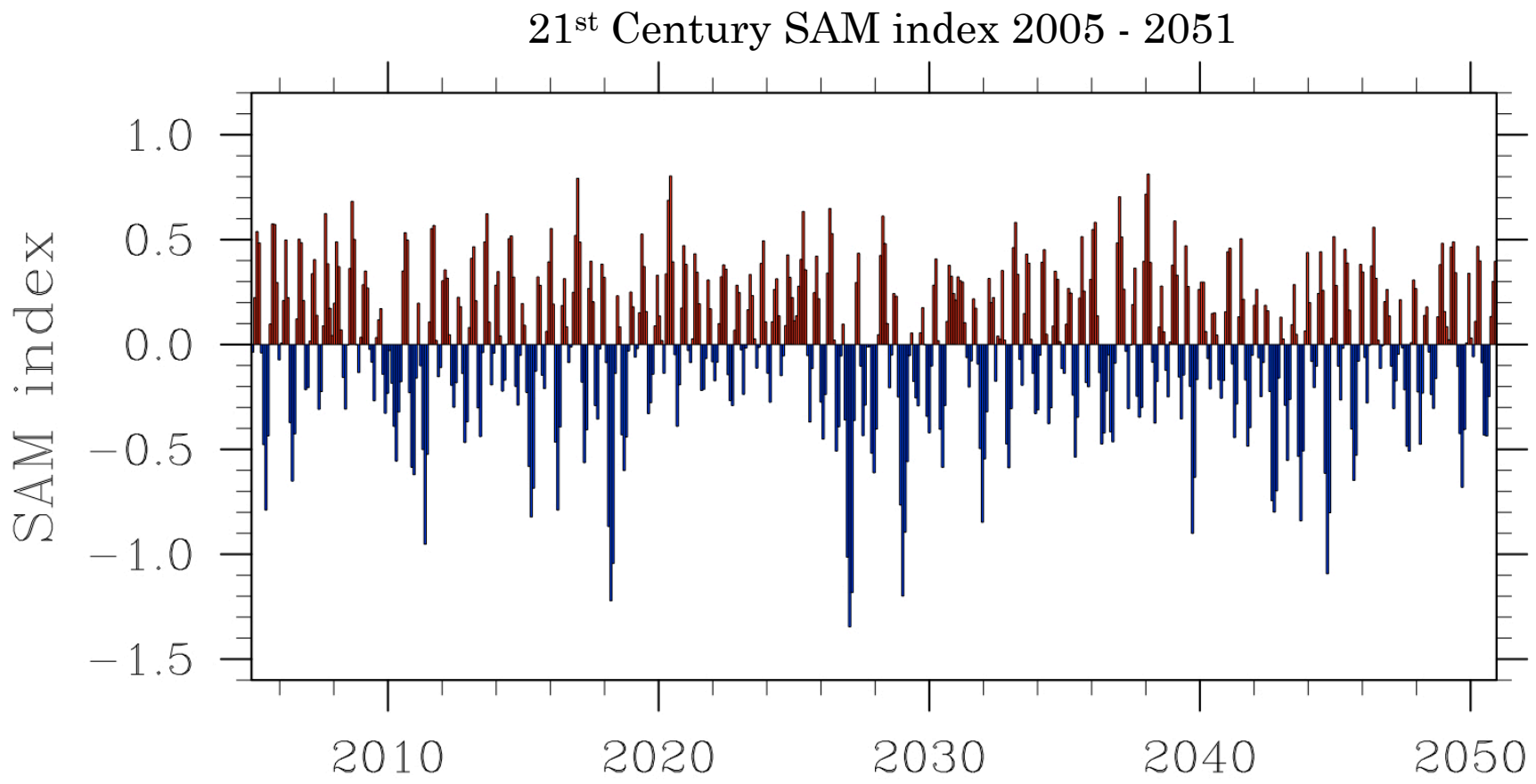
Changes in Sea Ice from 2005 - 2051

Climate model used: *Whole Atmosphere Community Climate Model (WACCM)* – a comprehensive numerical model, spanning the range of altitude from the Earth's surface to the thermosphere.
http://www.cesm.ucar.edu/working_groups/WACCM/
- a 3-member ensemble.

Caveats:

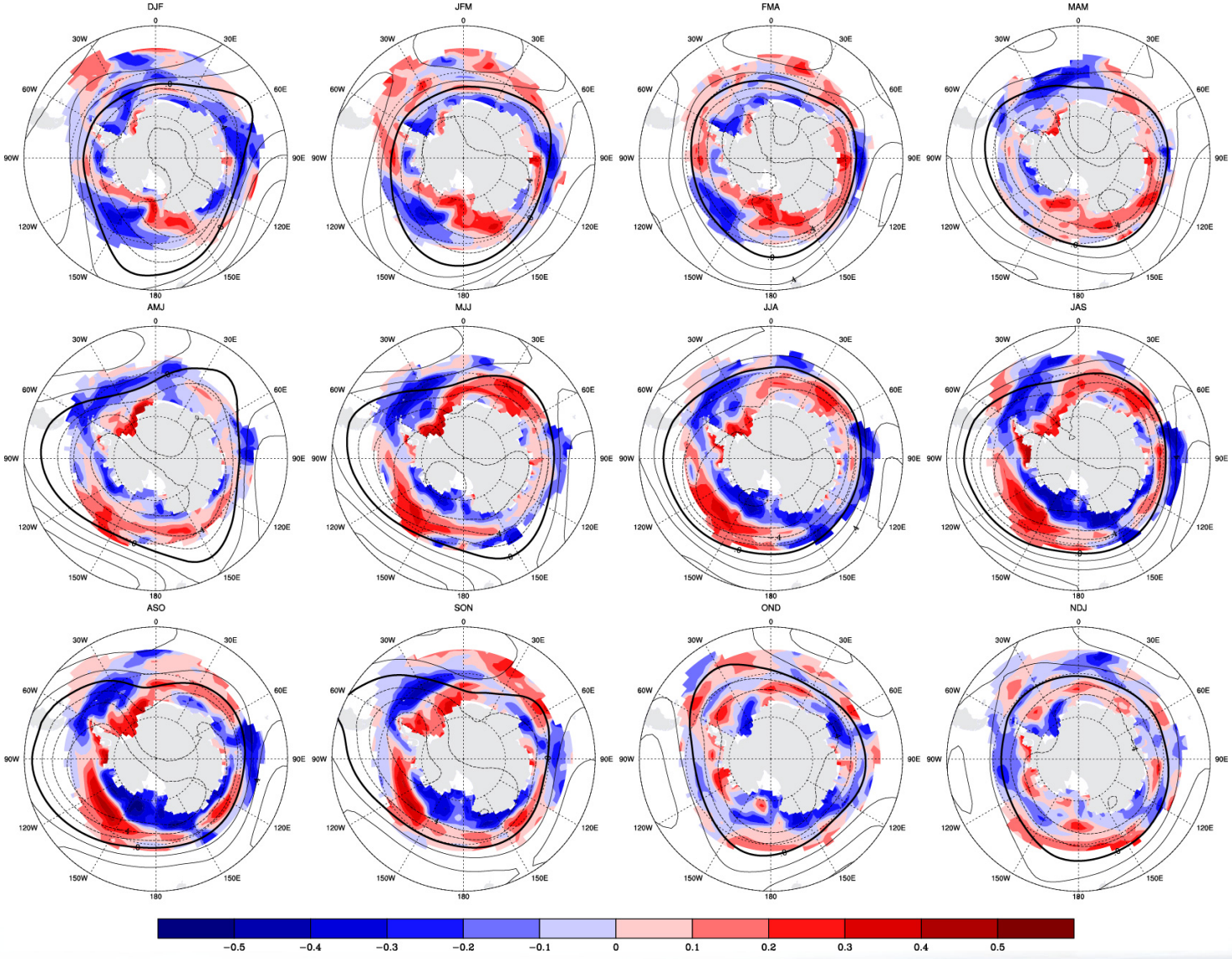
The model represents the large scale circulation well enough to allow estimations of how the circulation might change over the Antarctic region as the climate changes.

In common with other like models WACCM overestimates sea ice extent, but the relationships between sea ice and the large scale circulation are preserved.

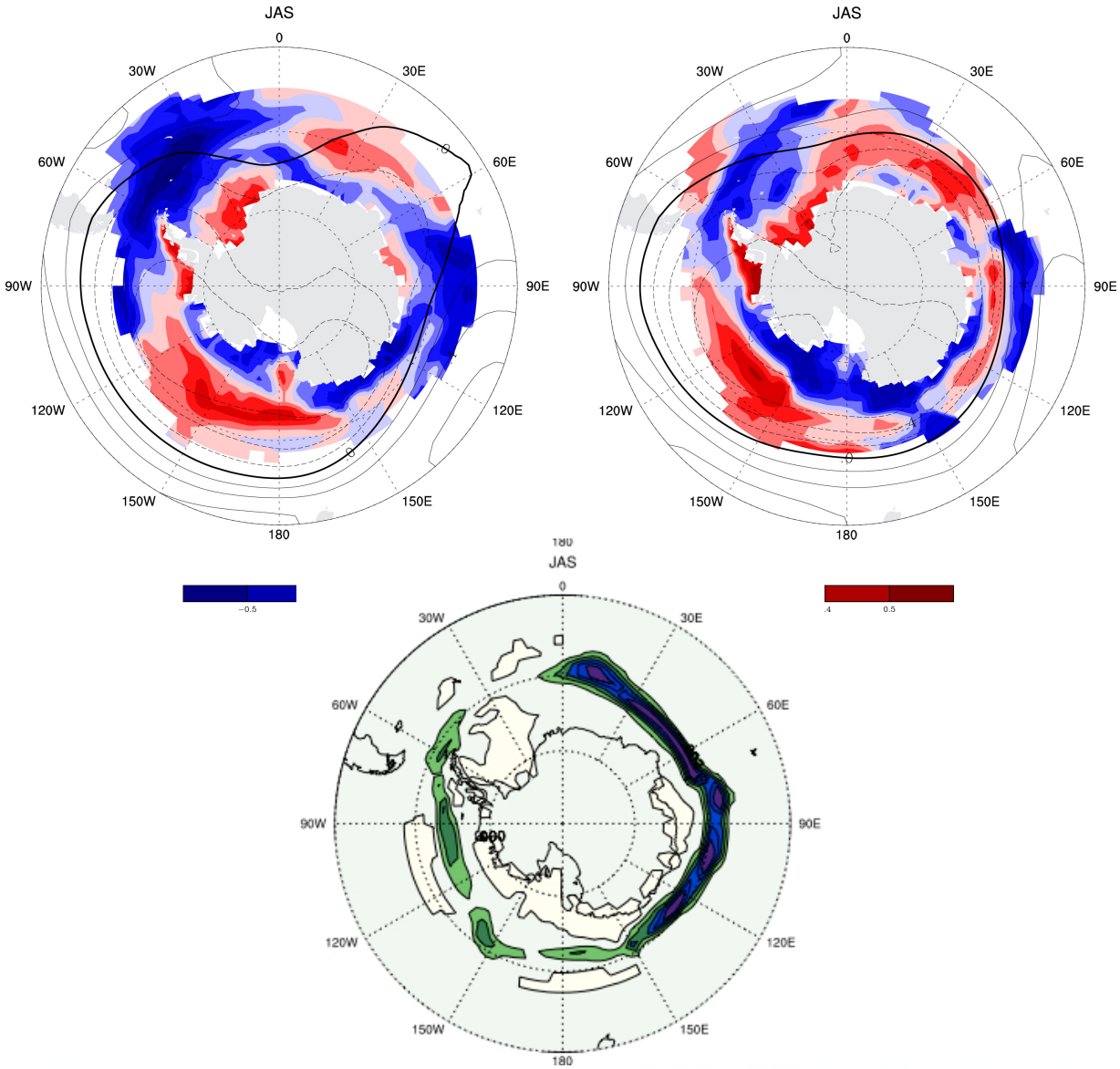


Strong variability on timescales up to decadal

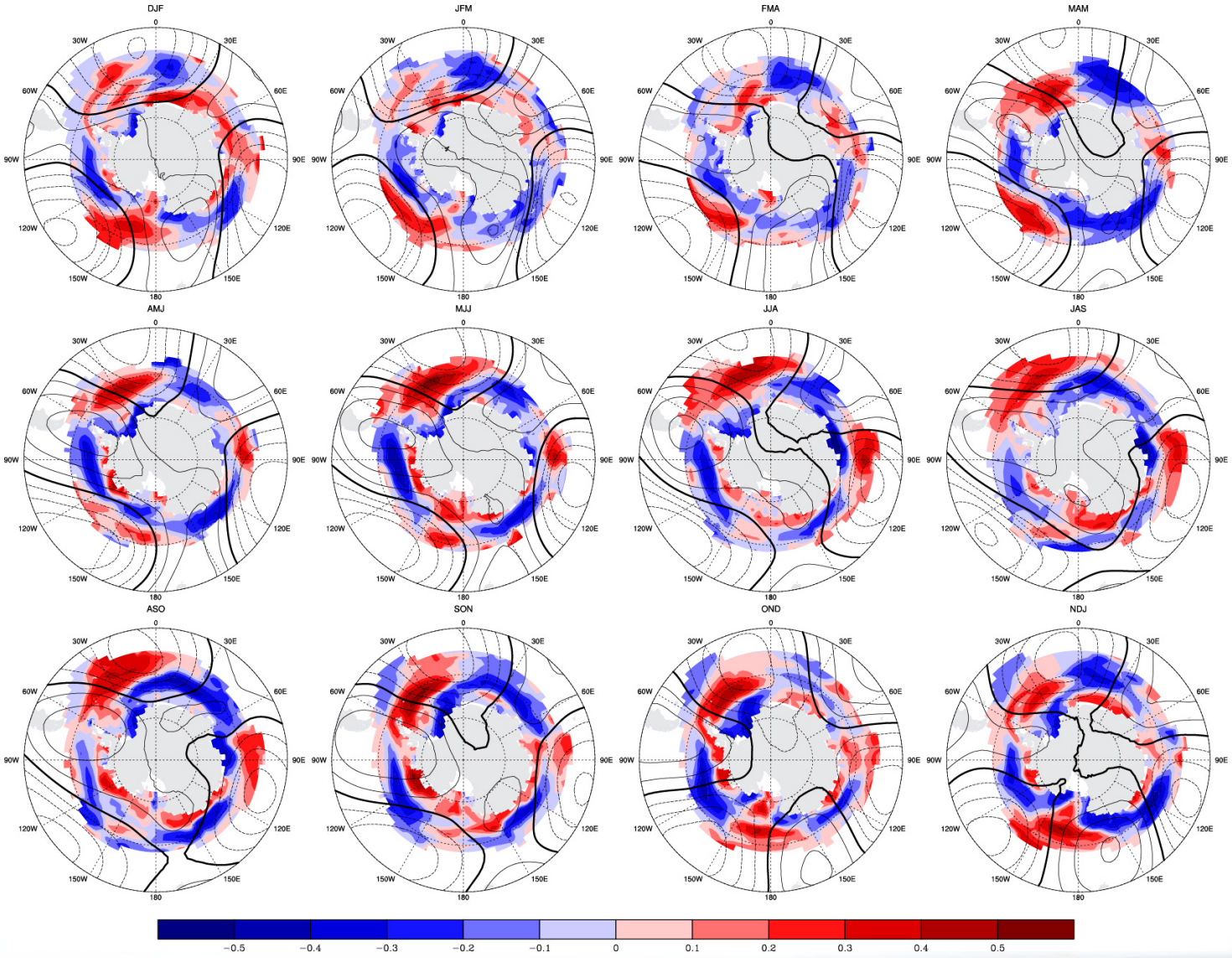
21st Century SAM over SAM Index Correlated with Sea Ice



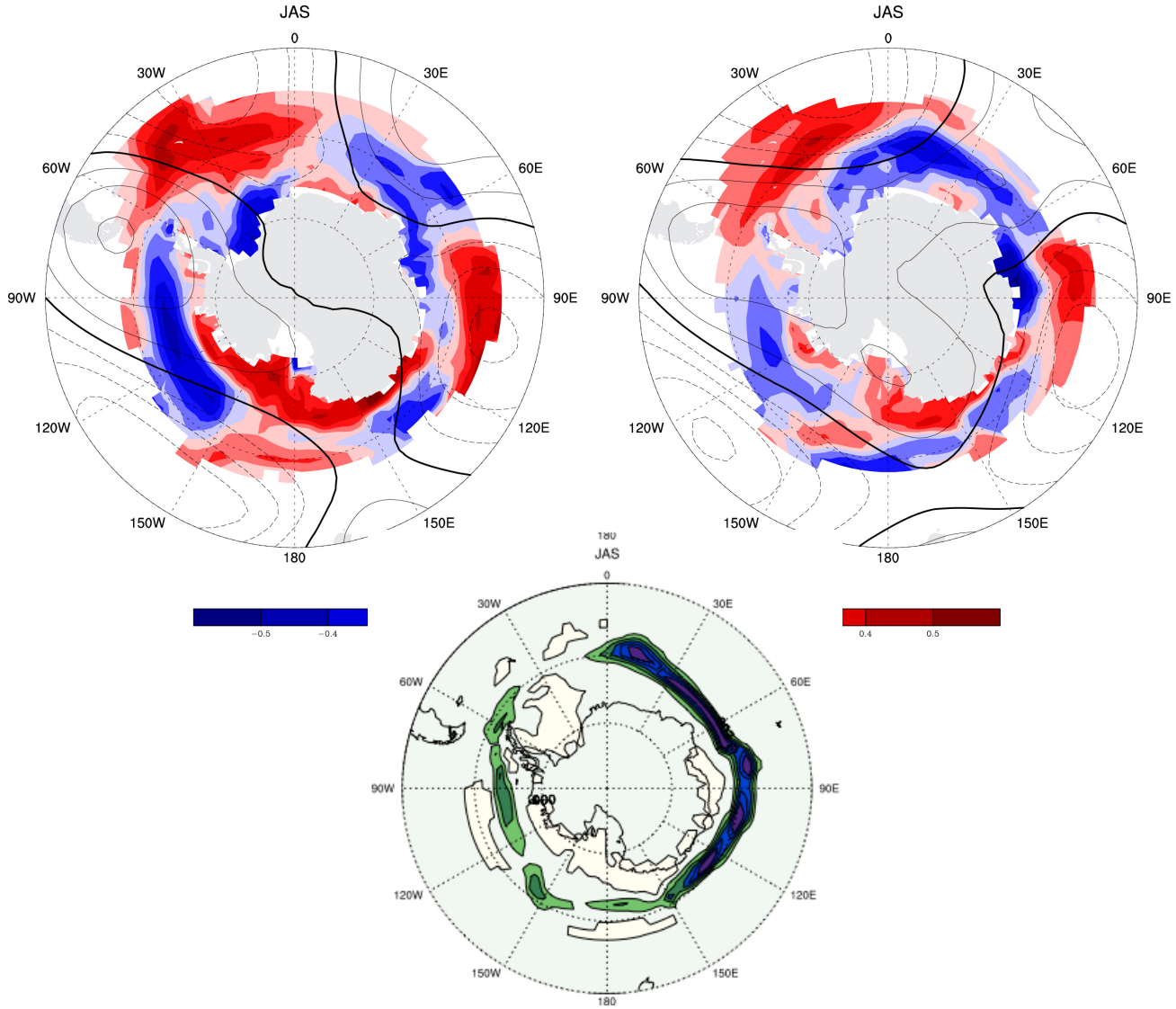
20th and 21st Century SAM



21st Century ZW3 over ZW3 Index Correlated with Sea Ice



20th and 21st Century ZW3



Summary

To get a better understanding of present day and future changes in sea ice in the Antarctic region it is necessary to do seasonal analyses

As the climate warms the atmospheric circulation mechanisms might change in response. These will involve changes in seasonality and structure as well as in amplitude. All will have to be examined in to understand/predict their impact on the trends in sea ice.

There is a lot more to do.

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