A Rossby Wave Bridge from the Tropical Atlantic to West Antarctica

A Physical Explanation of the Antarctic Paradox and the Rapid Peninsula Warming

Xichen Li; David Holland; Edwin Gerber; Changhyun Yoo

Acknowledgements: David Bromwich; Steve Price; Ryan Fogt

Scripps Institution of Oceanography / Courant Institute of Mathematics

OUTLINE

- Background of this Study
  - Recently observed climate changes around Antarctica
  - Potential linkages of these changes to the Tropical Oceans
- Atmospheric Bridge between Atlantic and Austral Circulation
  - Analysis and model study of the Atlantic-Antarctica teleconnection
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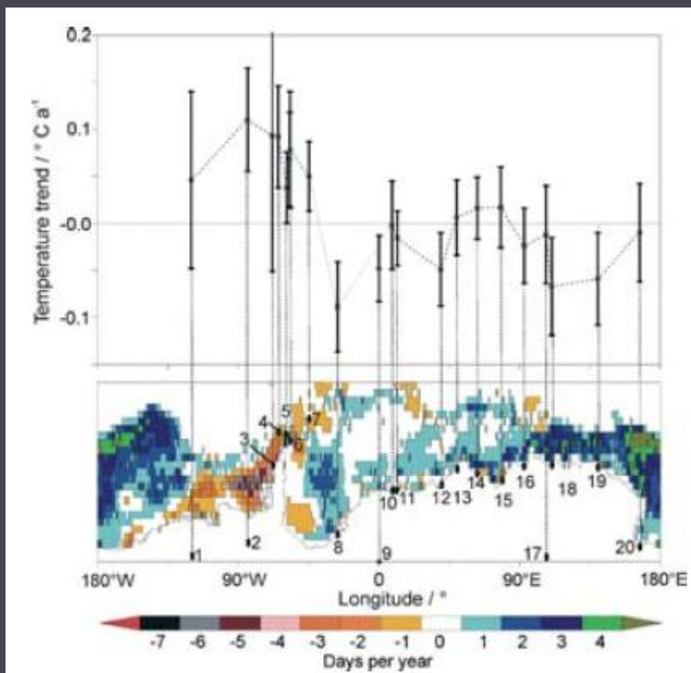
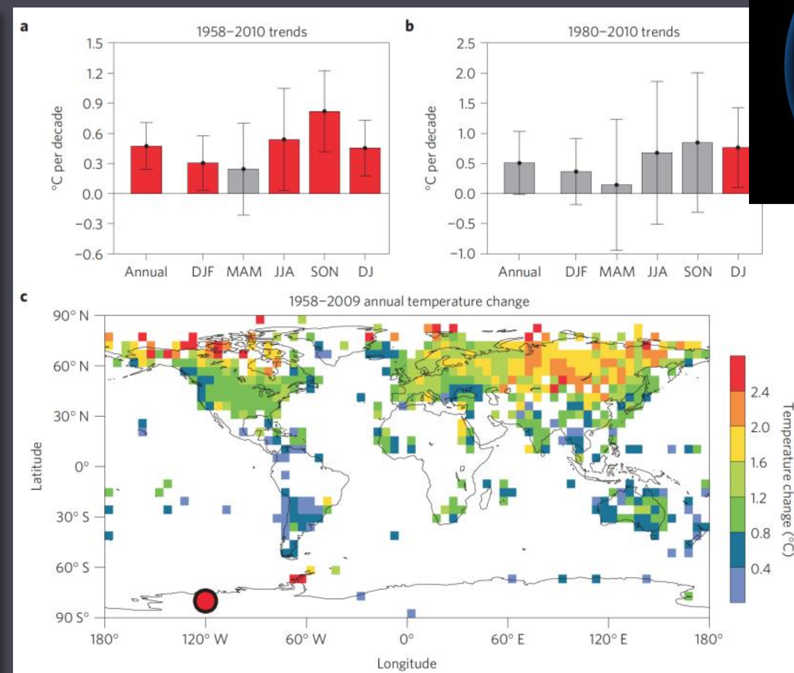
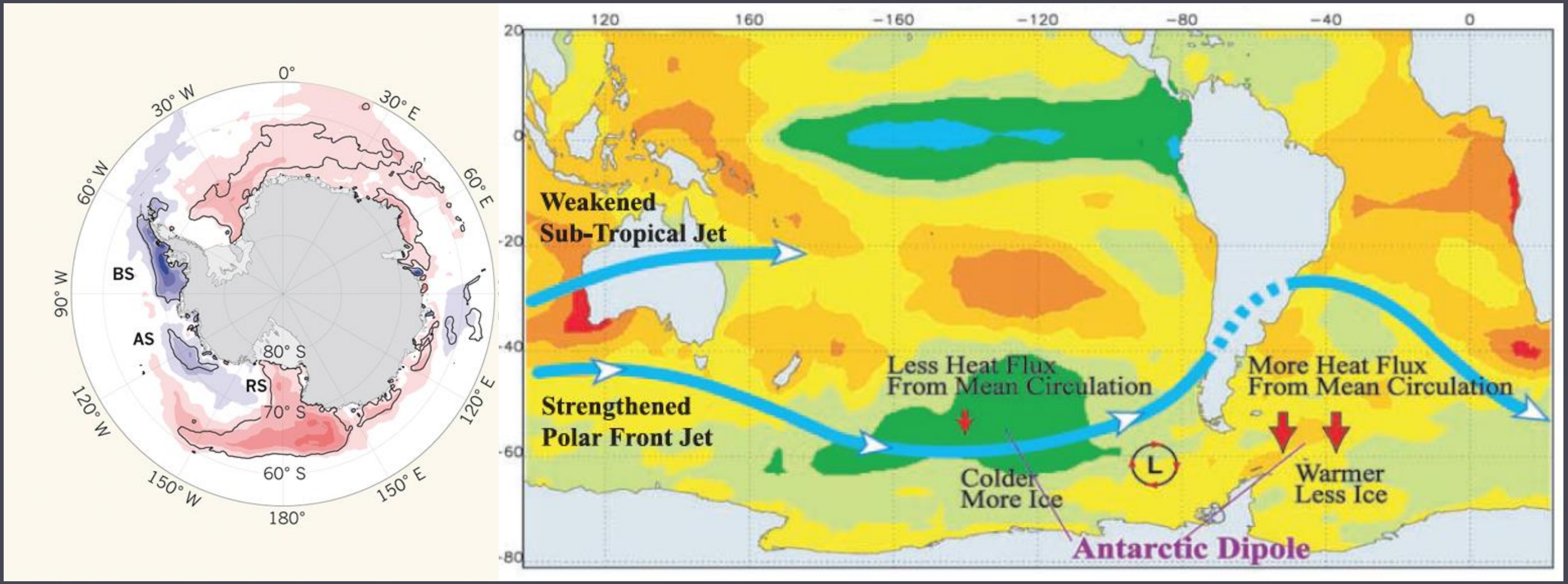
Surface Temperature Changes : Marie Byrd Land





- *Vaughan et al.* *2003* *D. Bromwich et al.* *2012*

Sea Ice Redistribution : Response to ABSL



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- *Rapid Regional Warming* *(10 times of GHG warming)*
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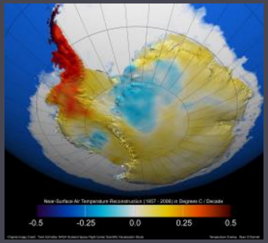

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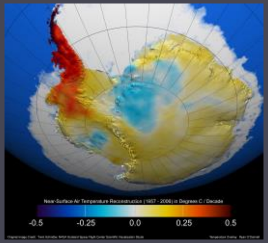

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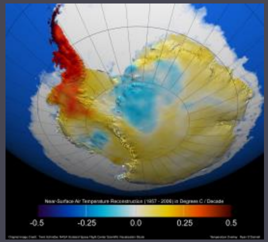

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- *Oceanic / Atmospheric Circulation Change and Variability*

Atmospheric Circulation Variability: ABSL

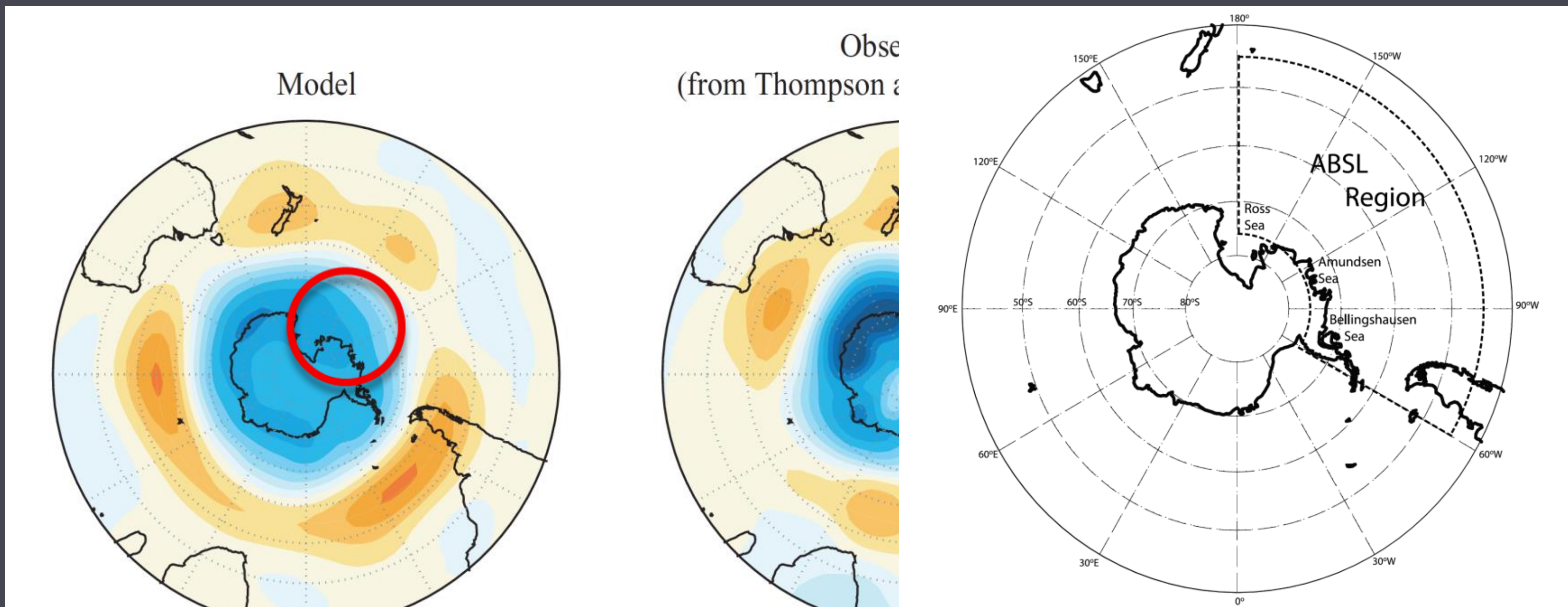

Figure 2. Map displaying the ABSL region (45°–75°S, 180°–60°W) and encompassed Ross, Amundsen, and Bellingshausen Seas.

- *Vaughan et al. 2003* — *D. Bromwich et al. 2012*
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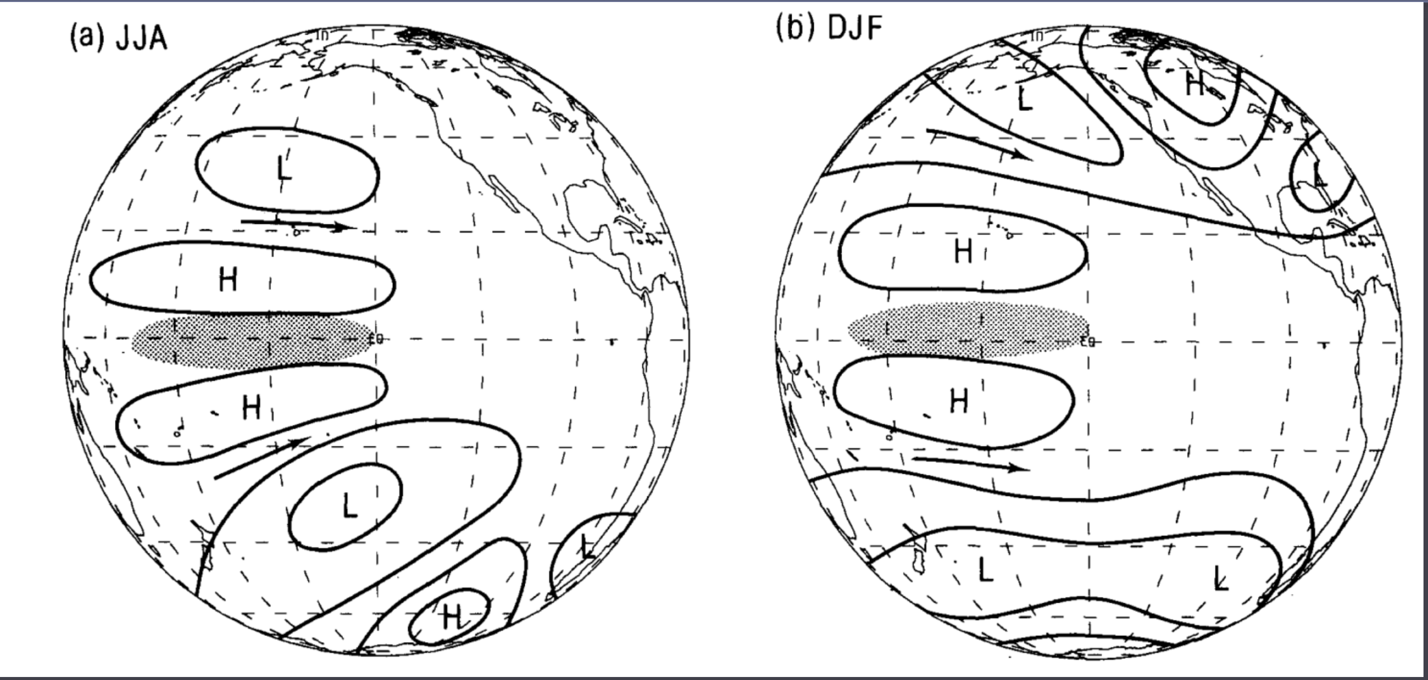
Teleconnections : Tropical Anomaly Generates Rossby Wave



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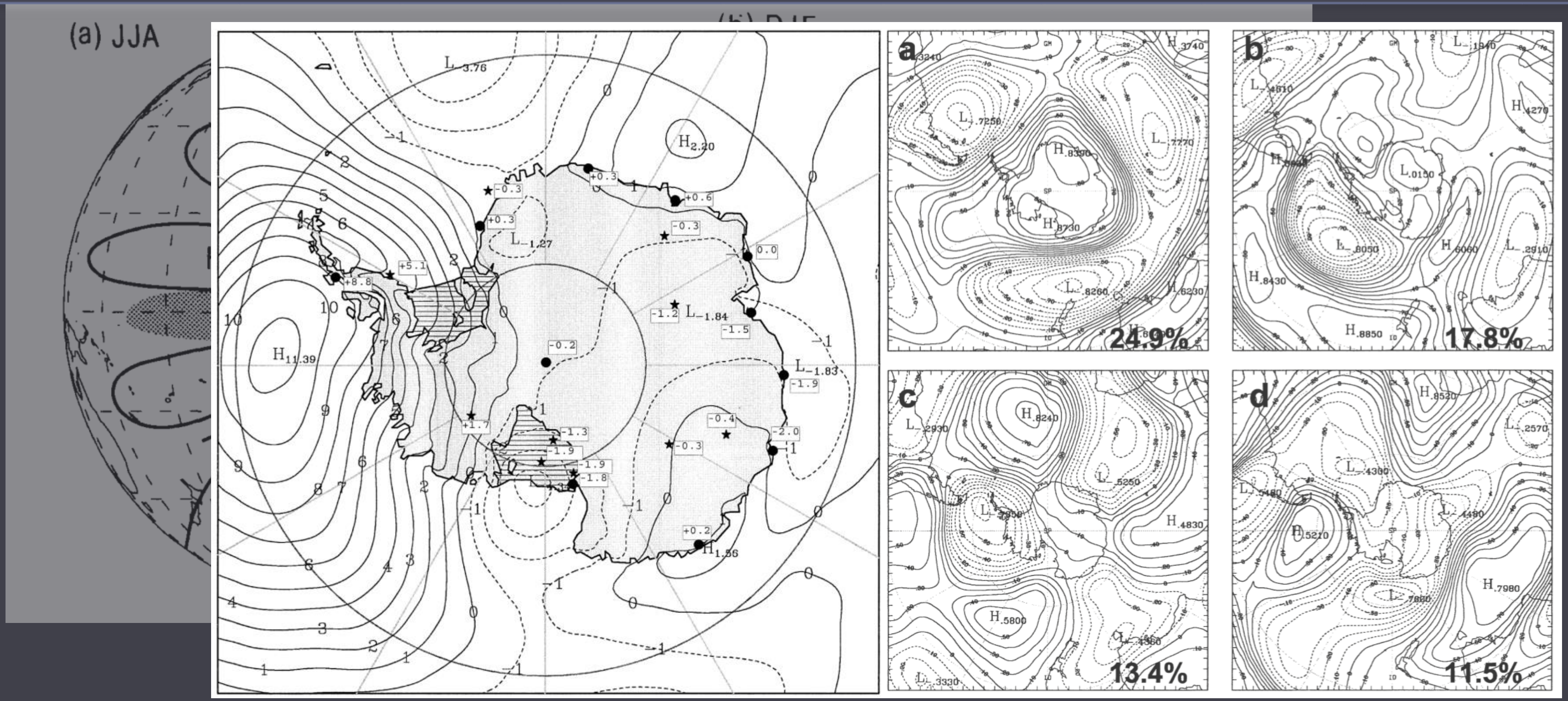
Teleconnections : ENSO Interacts with SAM and PSA



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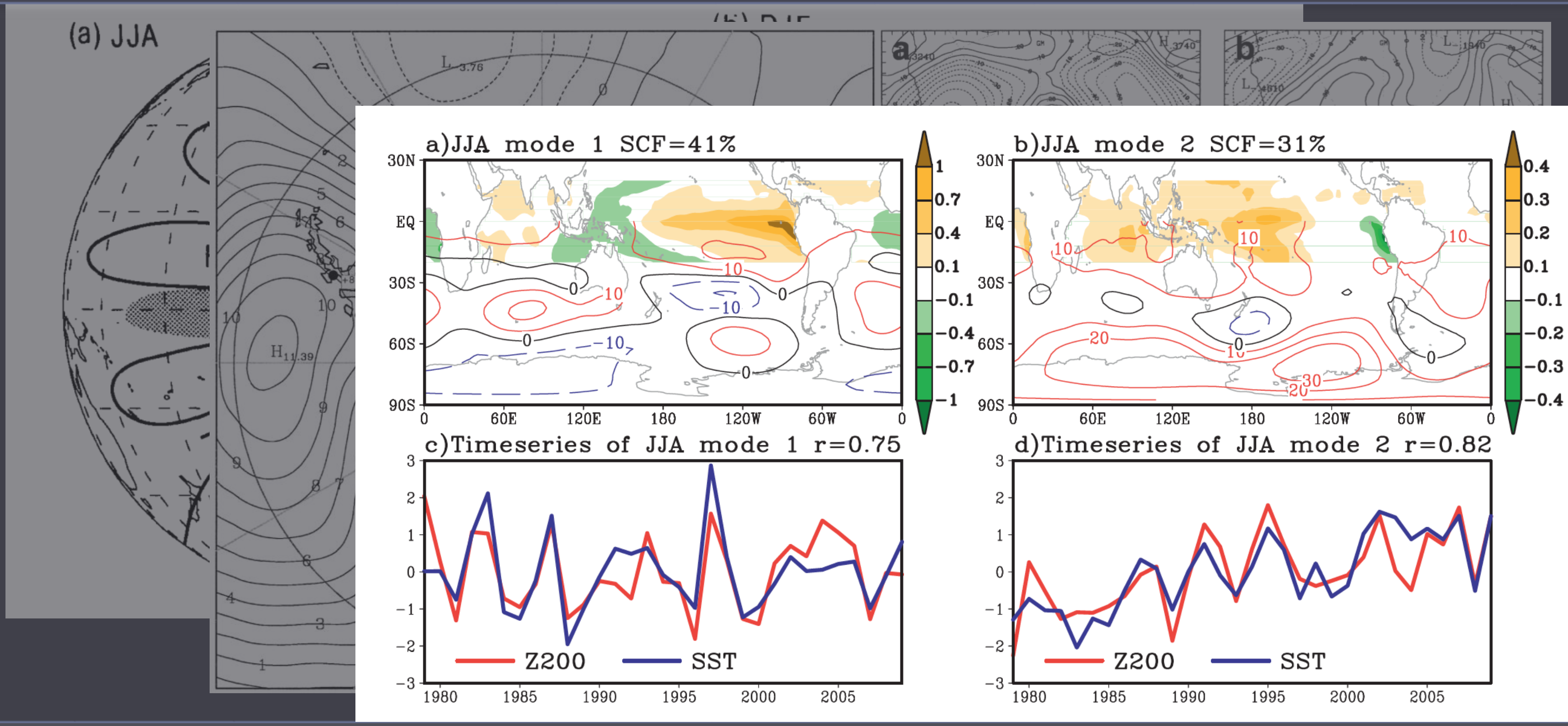
Teleconnections : Potential Effect from Central Pacific Warming



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The Role of Atlantic Ocean

In the Tropical – Antarctic Teleconnection.

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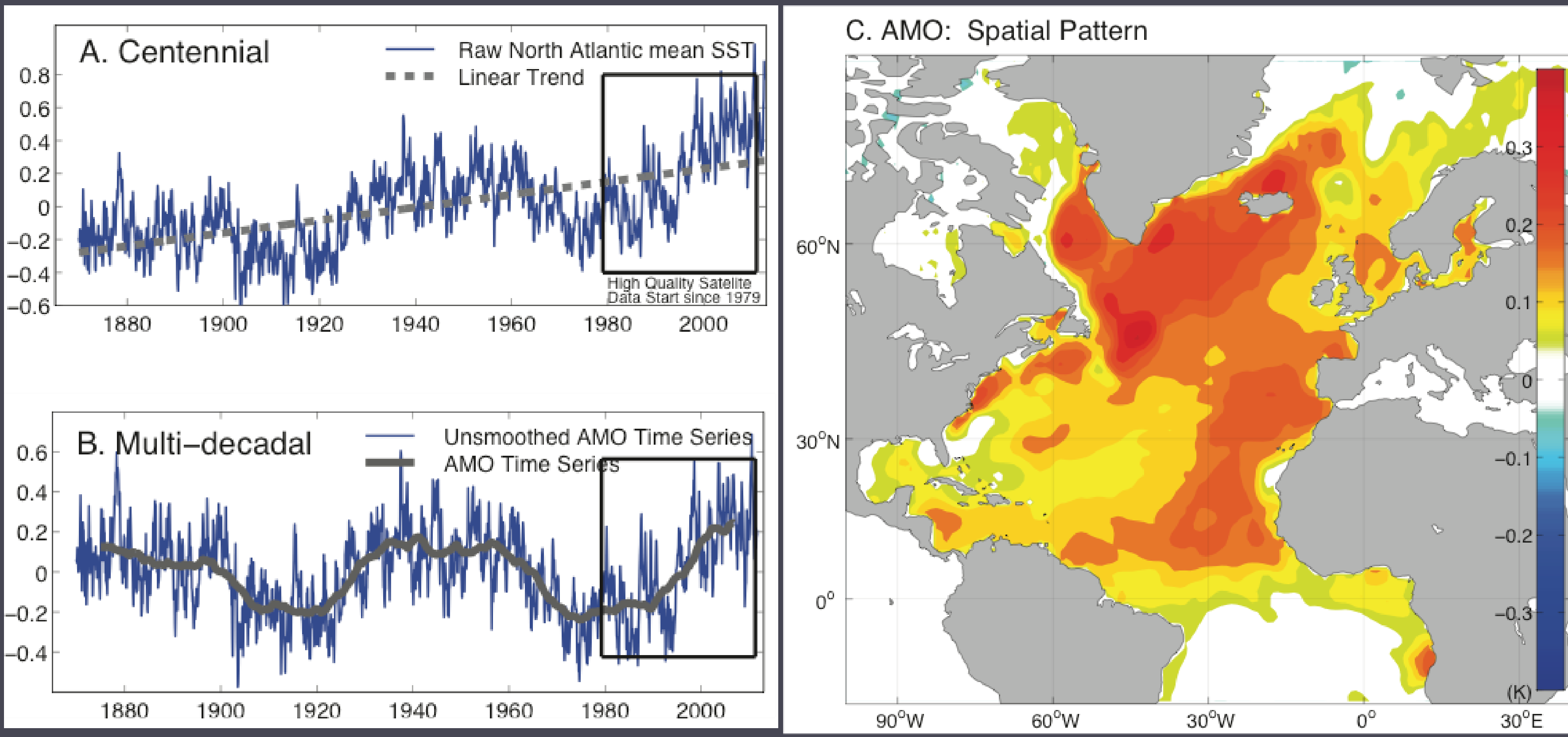
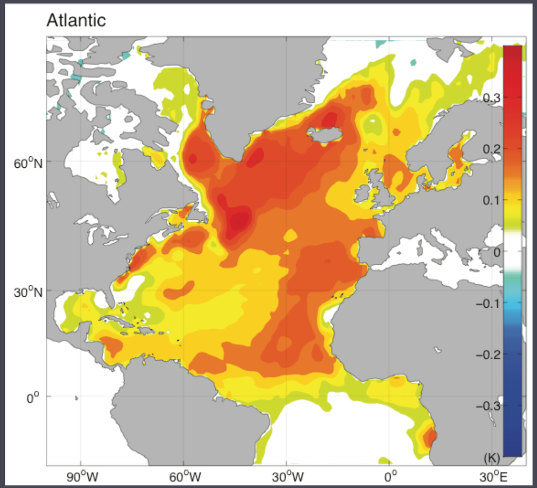
Atlantic Multidecadal Oscillation (AMO)



Overview of Part II



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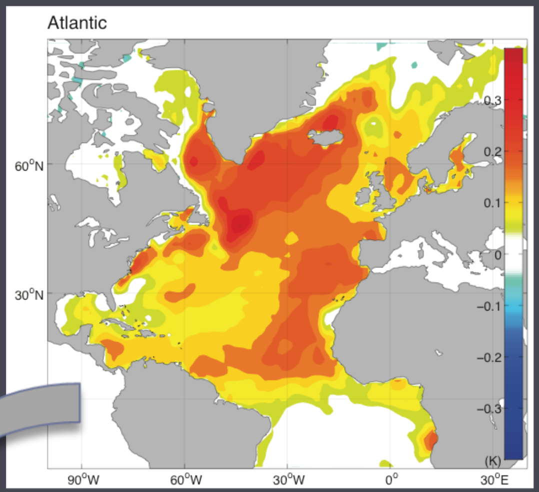

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  - *Regression*
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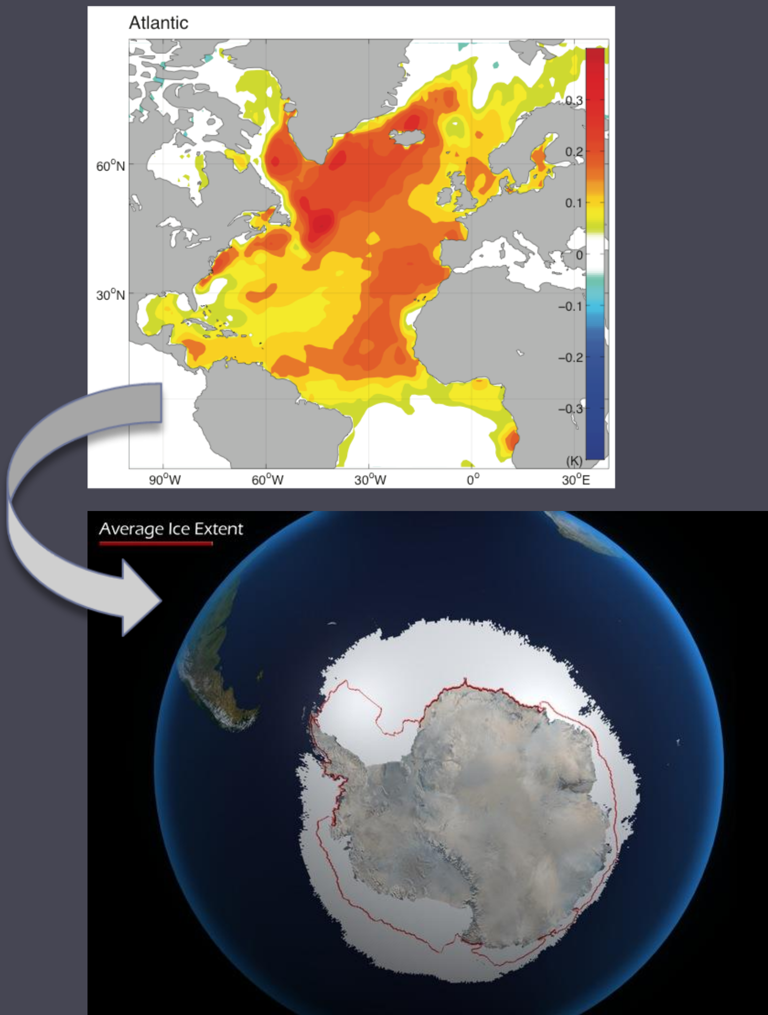

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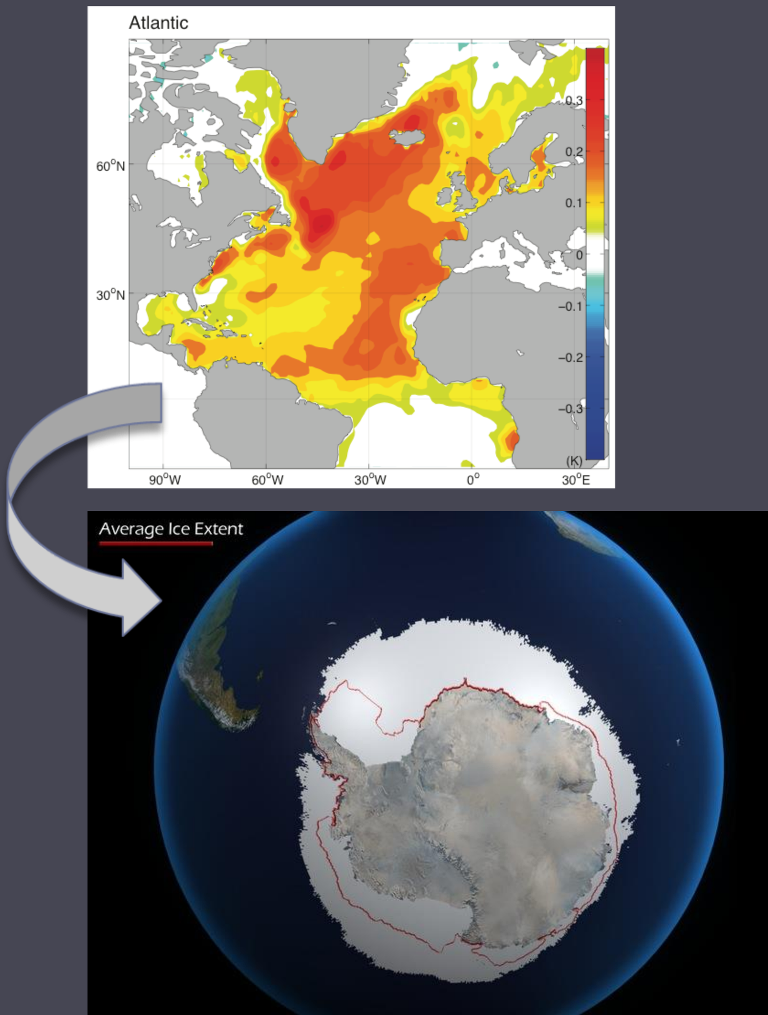

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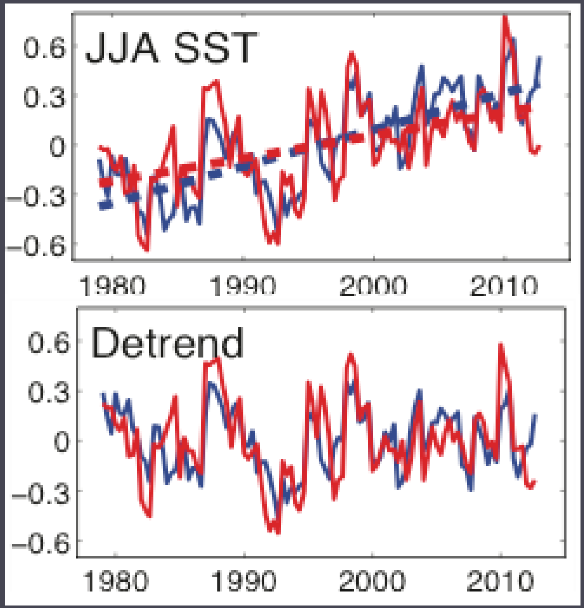
- *Physical Dynamics*
  - *Theoretical Rossby Wave Model (Karoly Rossby Wave Model)*

Regression Analysis

Against Atlantic SST



- *Austral Winter*

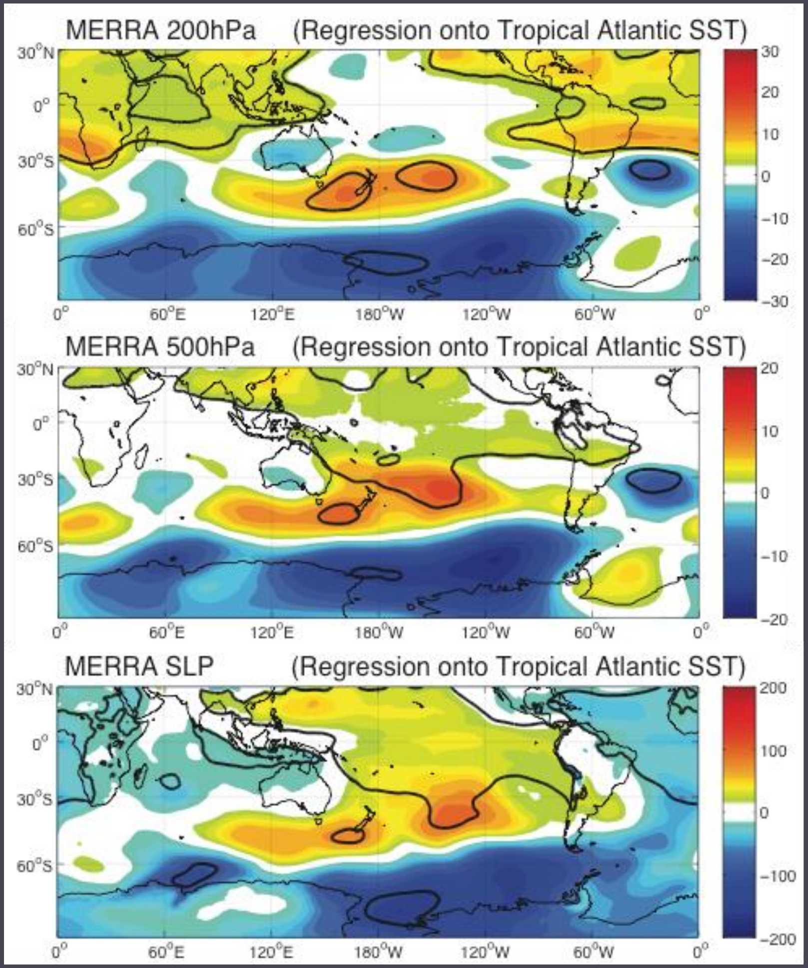
  (June – July – August)

Regression Analysis

~10,000m GPH

~5,000m GPH

Surface SLP



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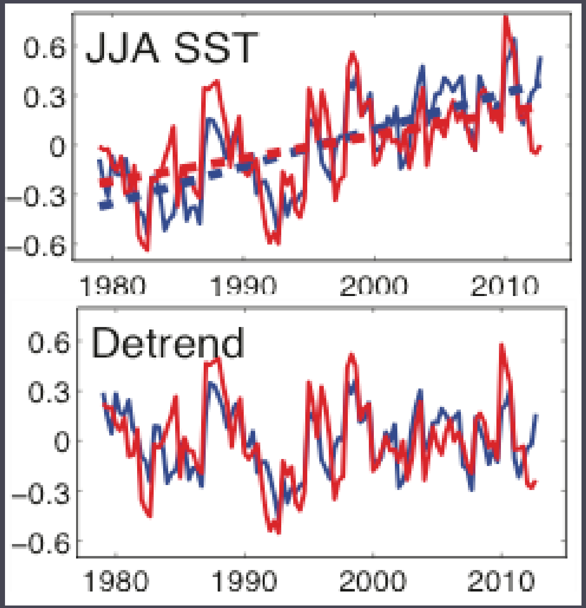

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Regression Analysis : Verification using ERA-interim data

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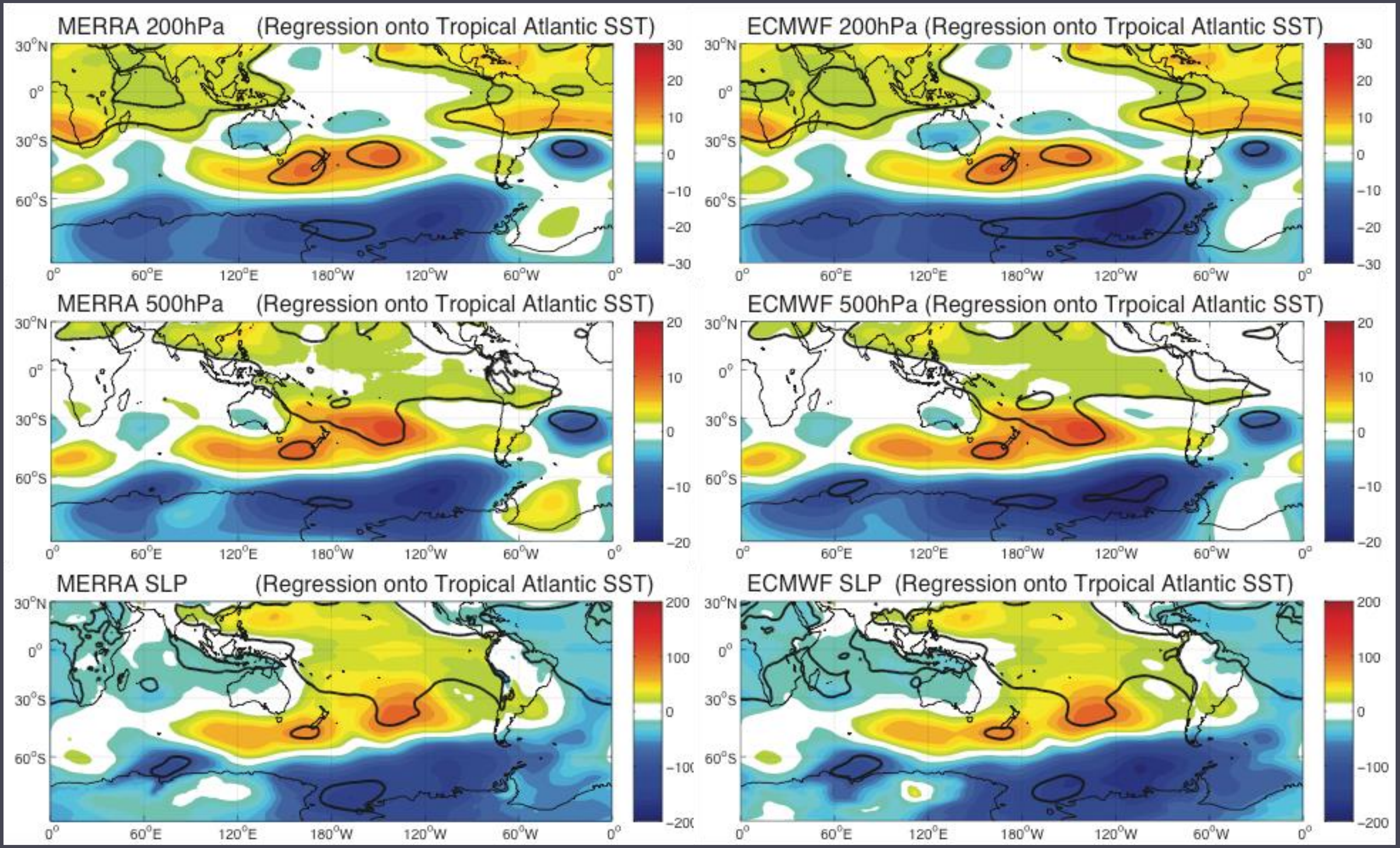
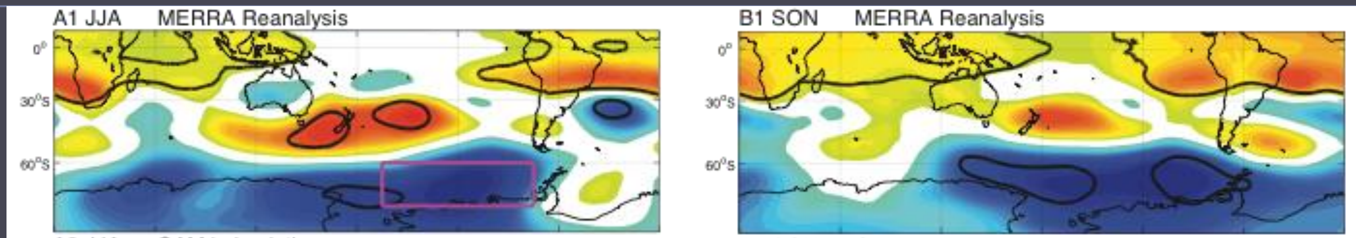
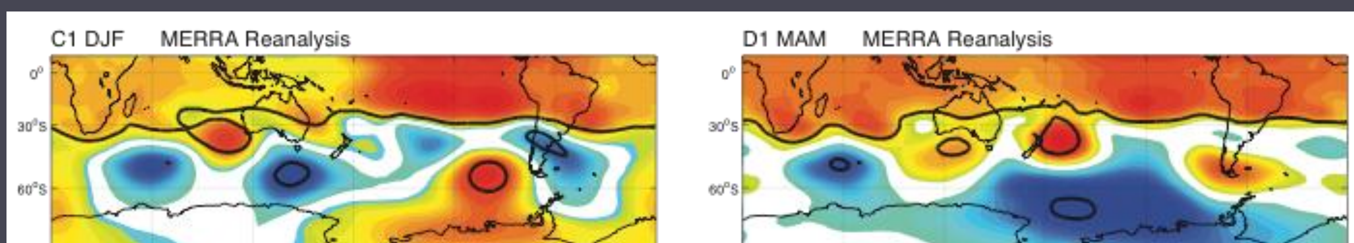


CAM4 Simulation & Regression for All Seasons



- JJA
- SON



- DJF
- MAM

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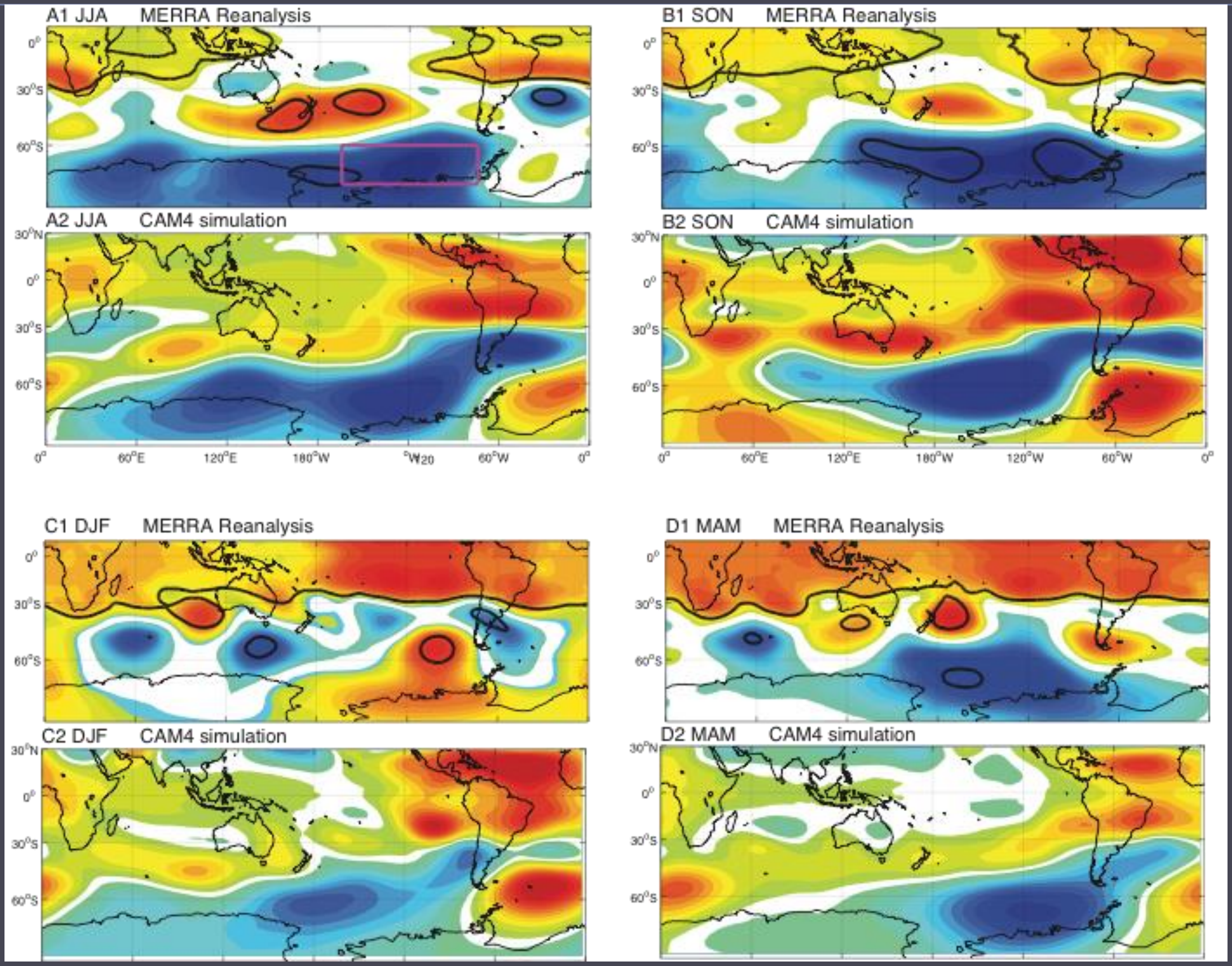

- A Teleconnection between Atlantic and Antarctica

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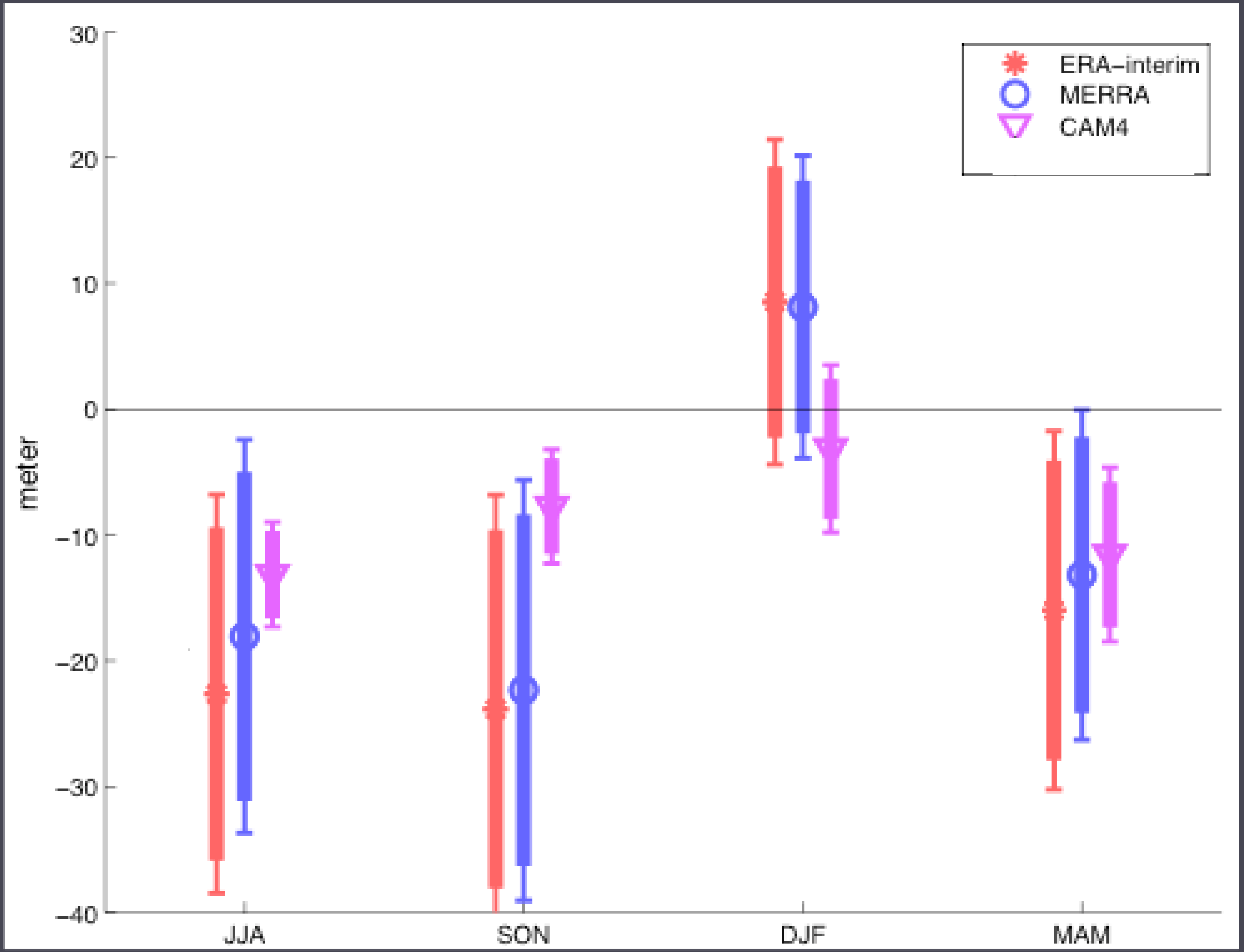


GFDL Dry-Dynamical-Core : An Idealized Model

- Numerical Solver of the Primitive Equation
  - **Isolated** from any parameterization processes
  - **Spectral** dynamical core
  - With a horizontal resolution of ~3 degree

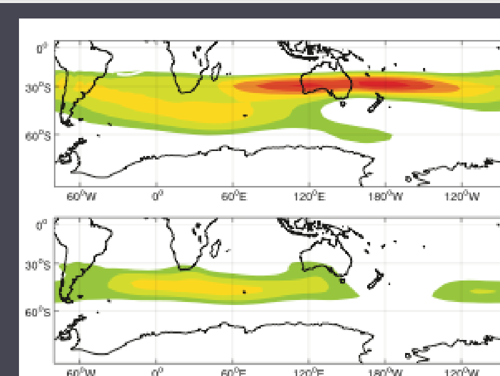
$$\begin{aligned}
\frac{du}{dt} - \left(f + u\frac{\tan\phi}{a}\right)v &= -\frac{1}{a\cos\phi}\frac{1}{\rho}\frac{\partial p}{\partial \lambda} + F_\lambda \\
\frac{dv}{dt} + \left(f + u\frac{\tan\phi}{a}\right)u &= -\frac{1}{\rho a}\frac{\partial p}{\partial \phi} + F_\phi \qquad \textit{momentum} \\
g &= -\frac{1}{\rho}\frac{\partial p}{\partial z}
\end{aligned}$$

$$\frac{\partial \rho}{\partial t} = -\frac{1}{a\cos\phi}\left[\frac{\partial}{\partial \lambda}(\rho u) + \frac{\partial}{\partial \phi}(\rho v\cos\phi)\right] - \frac{\partial}{\partial z}(\rho w) \qquad \textit{mass}$$

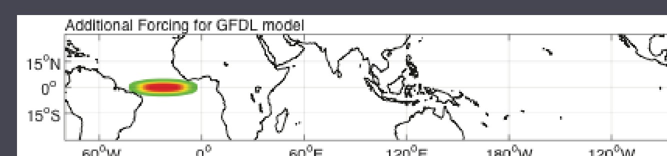
$$C_p\frac{dT}{dt} - \frac{1}{\rho}\frac{dp}{dt} = Q \qquad \textit{energy}$$

$$p = \rho RT \qquad \textit{equation of state}$$

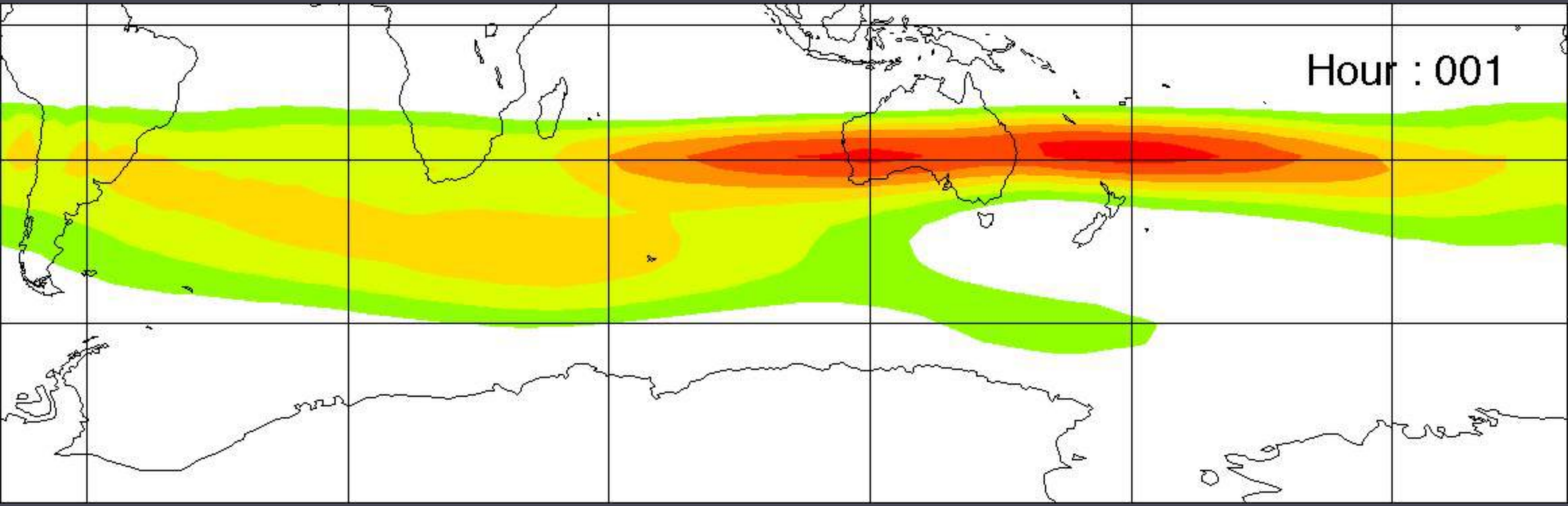
- Driven by Climatological Background State
  - From the **ERA-interim** Reanalysis



- Initial Condition Simulation
  - The model is **Neutralized** with an external forcing
  - An external perturbation is introduced in the **Initial condition**
  - Model response is considered as the **Evolution** of the impact of this initial perturbation

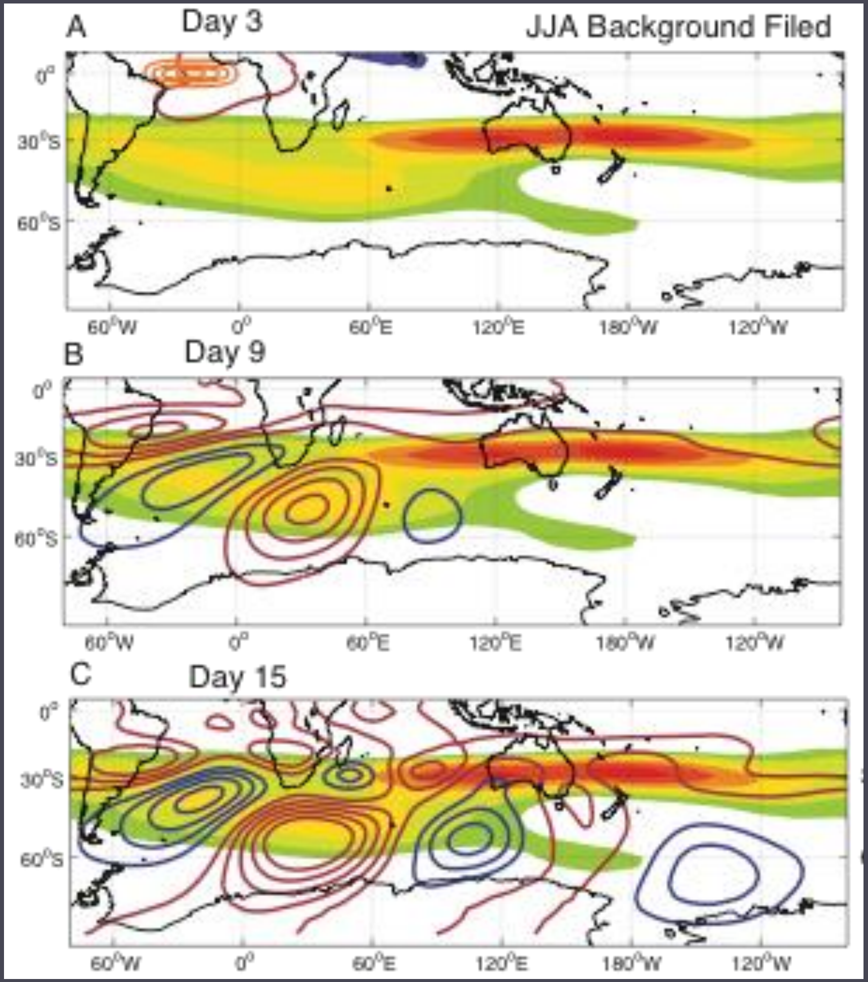


Rossby wave trains simulated by GFDL dynamical core : JJA



- GFDL initial condition simulations show clear Rossby Wave Trains
- Transport to Amundsen Sea within two weeks

Rossby wave trains simulated by GFDL dynamical core : Seasonality



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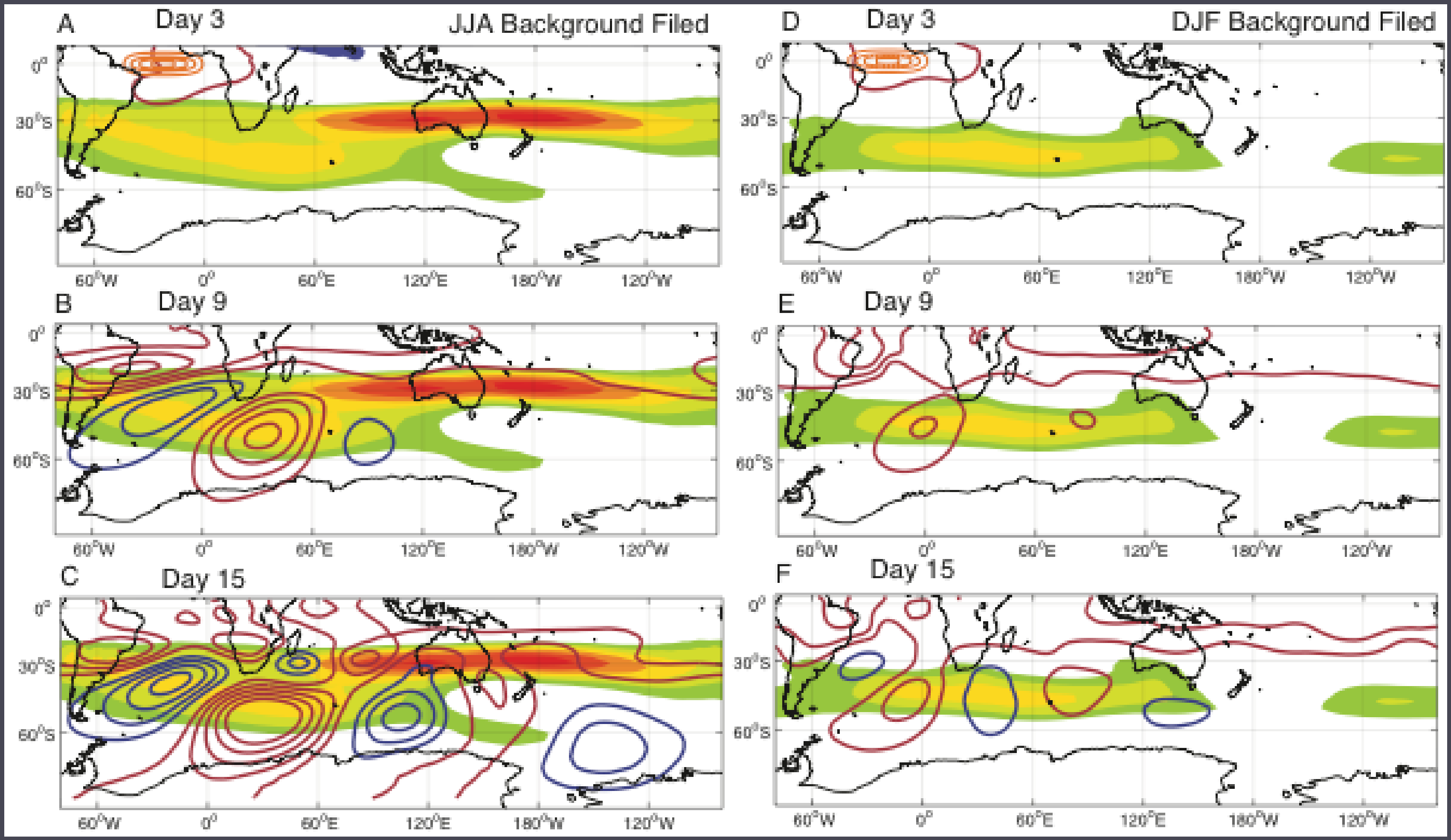

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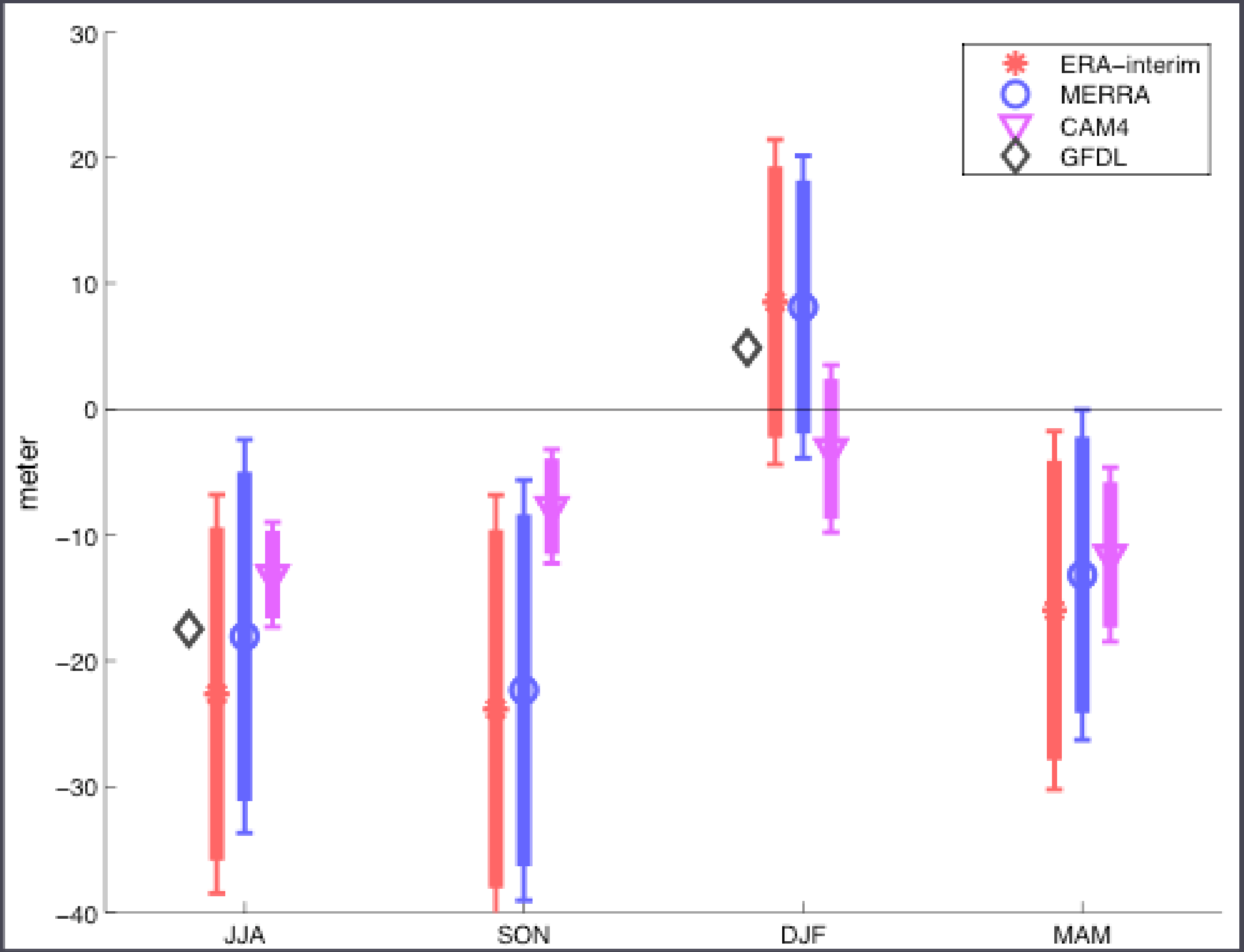

Theoretical Stationary Rossby Wave Model

- Dispersion relation of Rossby wave

$$\omega = Uk - \frac{\beta_* k}{K^2}$$

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$$K^2 = l^2 + k^2 = \frac{\beta_*}{U}$$

- Where

$$\beta_* = \beta - U_{yy}$$

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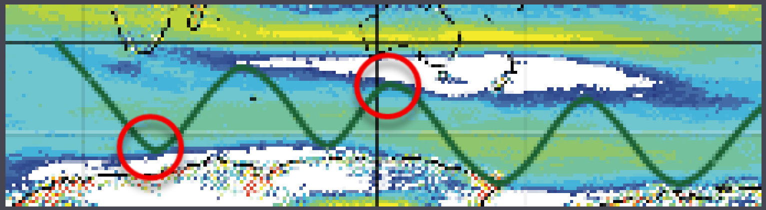
- We can derive the group velocity at each location

$$c_{gx} = \frac{2\beta_* k^2}{K^4} \qquad c_{gy} = \frac{2\beta_* kl}{K^4} \qquad \frac{c_{gy}}{c_{gx}} = \frac{l}{k}$$

Reflection and Blocking of Rossby Wave Trains

- When β is too small or U_{yy} is too large, $\beta_* = \beta - U_{yy}$ becomes small,

$$K = \sqrt{\frac{\beta_*}{U}} \sim k \qquad \frac{c_{gy}}{c_{gx}} = \frac{l}{k} \sim 0$$



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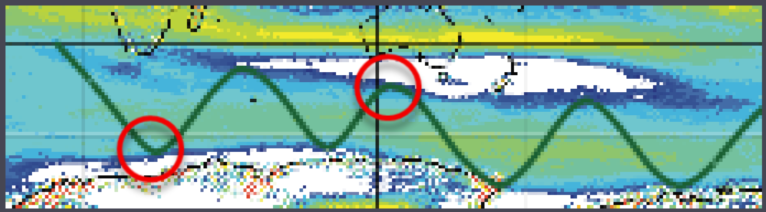
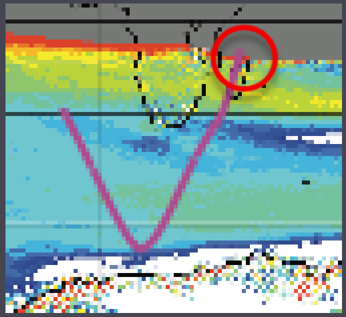


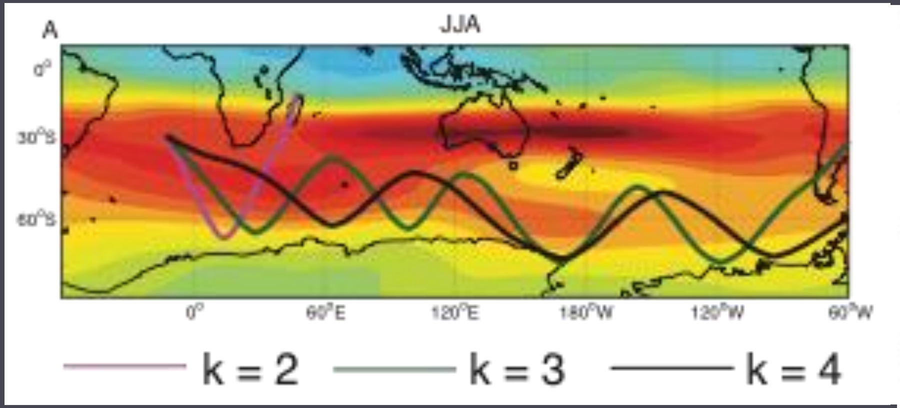
Rossby Wave will be reflected

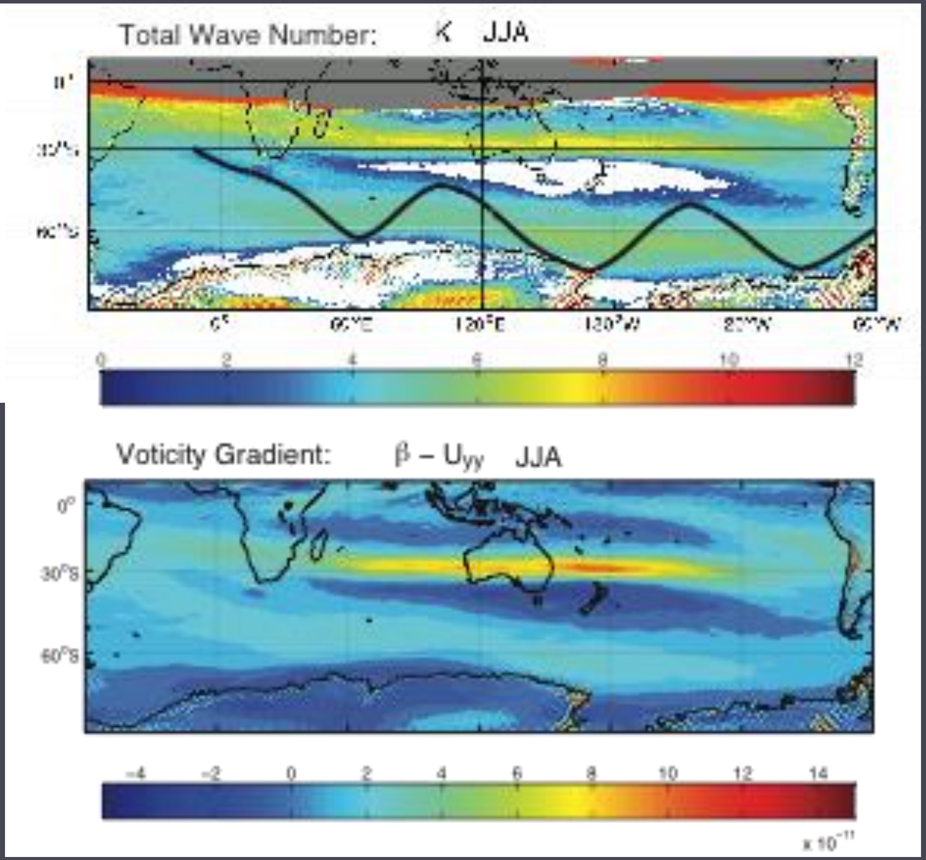
- When U is negative, $K = \sqrt{\frac{\beta_*}{U}}$ becomes imaginary



Stationary Rossby Wave can no longer propagate and is blocked by the trade wind

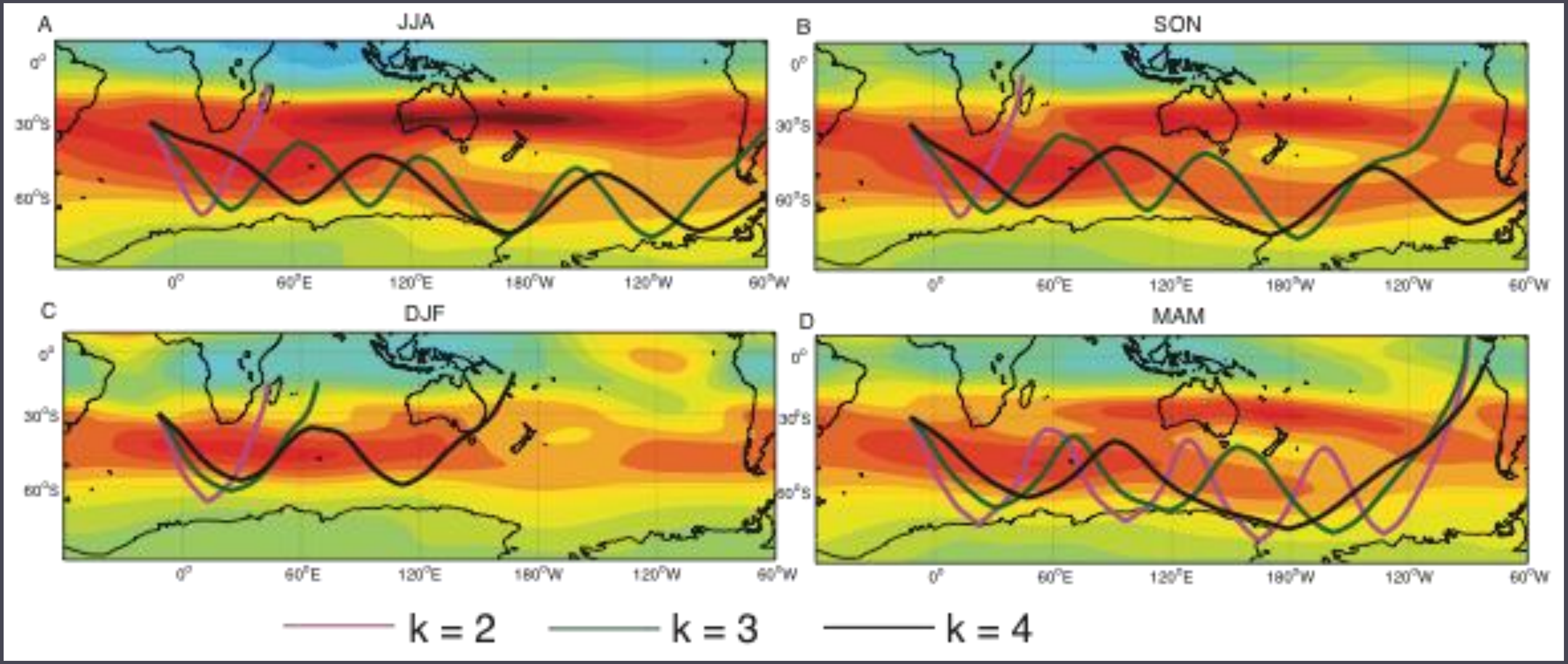
Stationary Wave in Hoskins – Karoly Model





Rossby Wave is reflected several times and propagates along the southern edge of the Sub-tropical Jet

Seasonality of the Stationary Wave Trains



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  Critically Depends on the Background Flow, in Particular, the Sub-Tropical Jet

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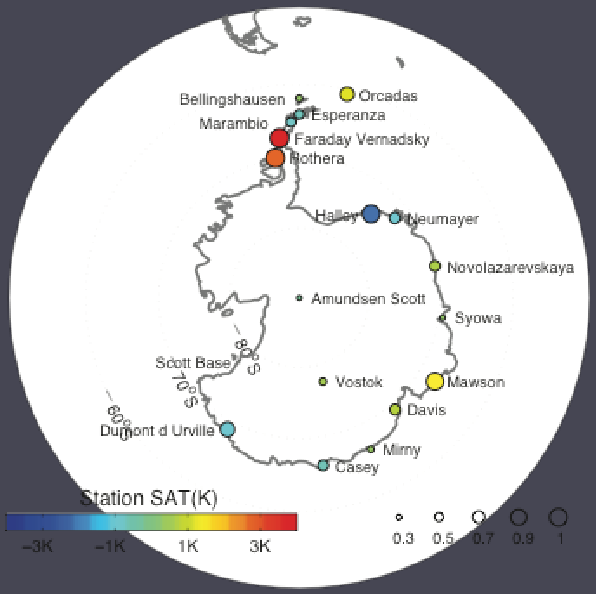
Air Temperature Response to Tropical Atlantic Warming



Linear Regression

Observed Trend

Numerical Simulation

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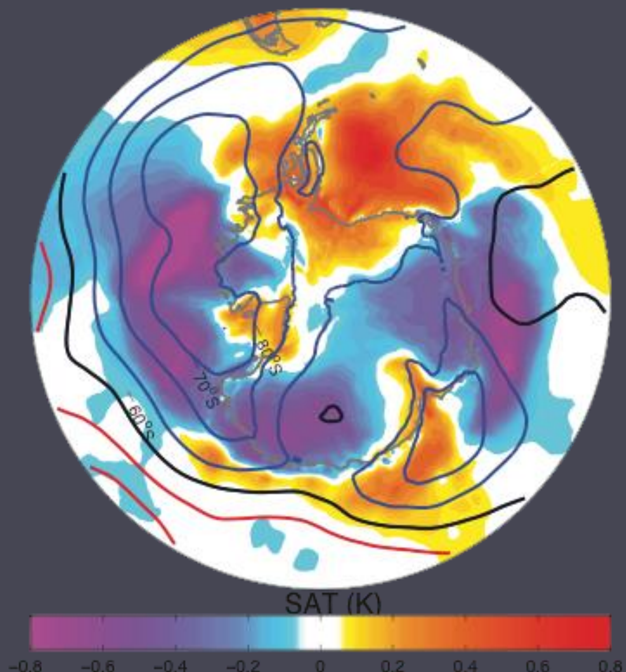

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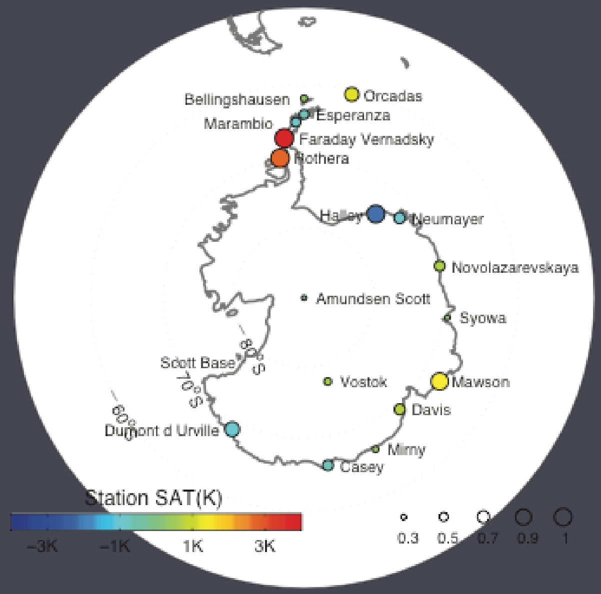

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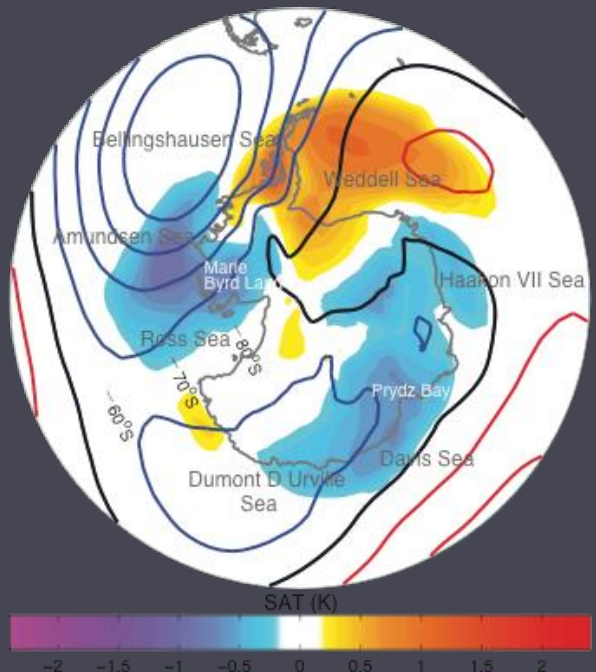

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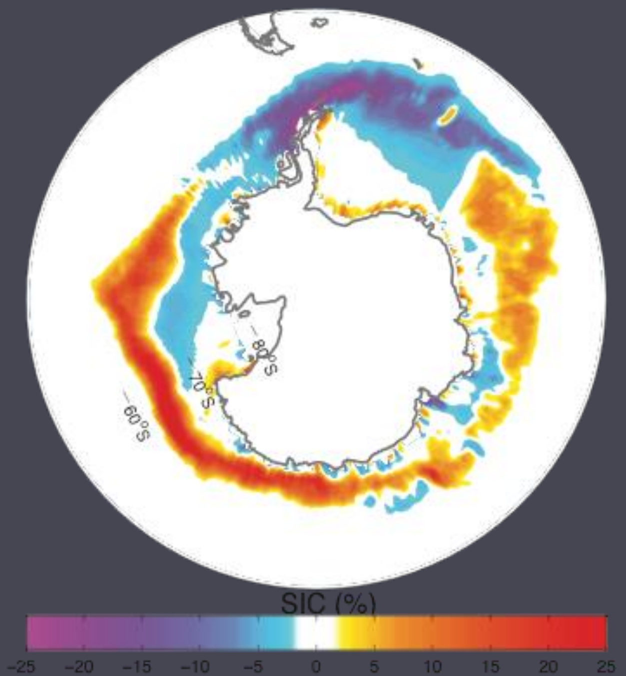

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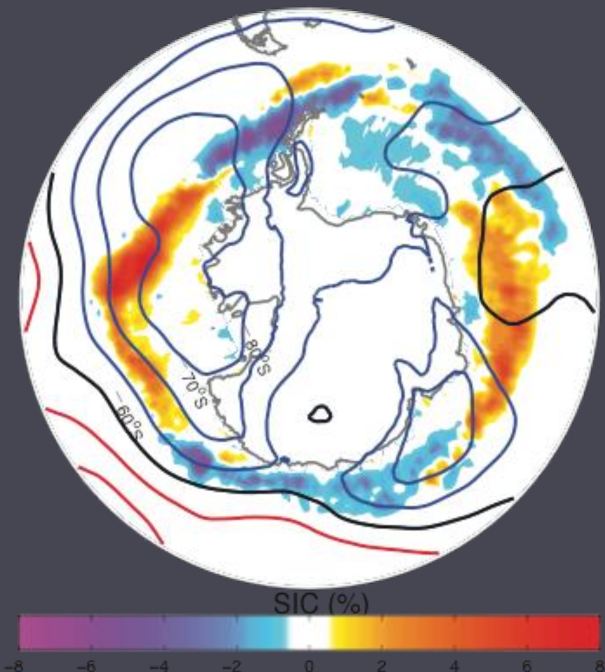

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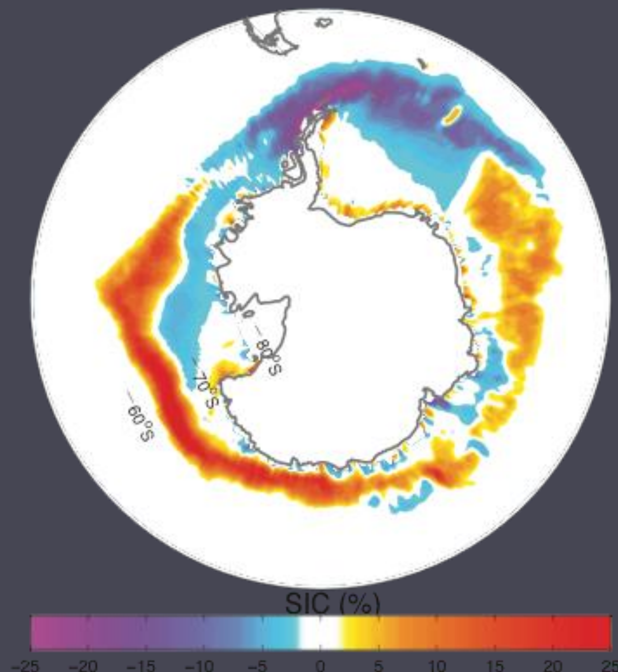

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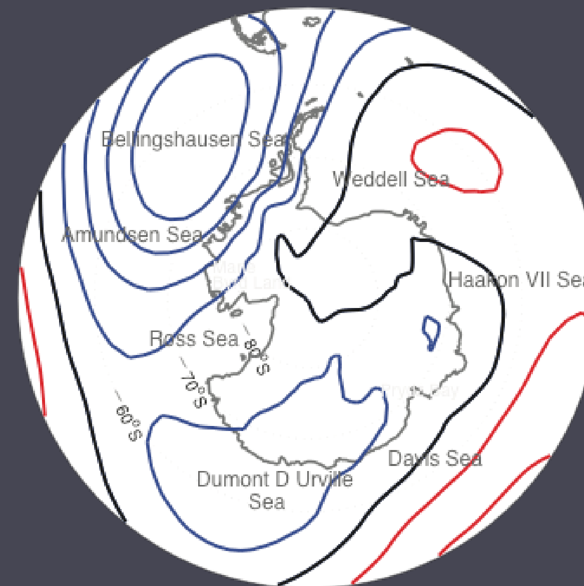

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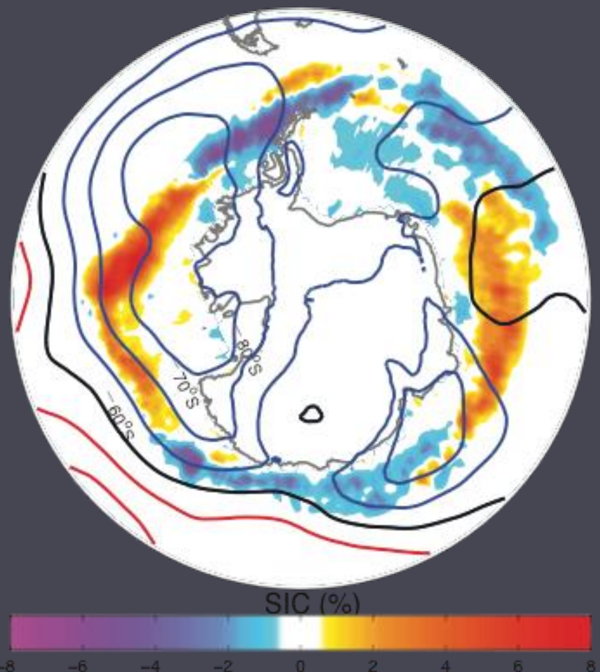

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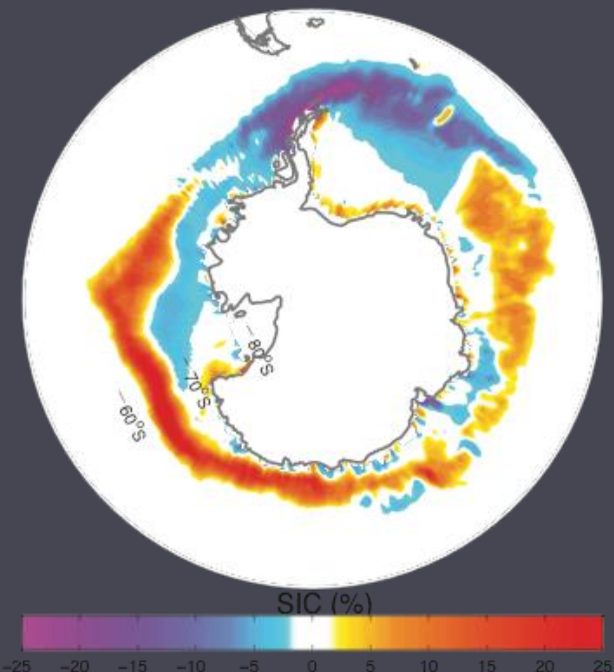

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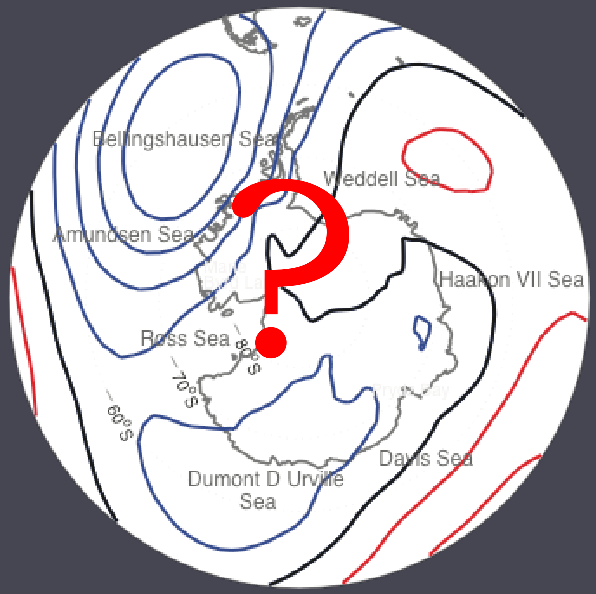
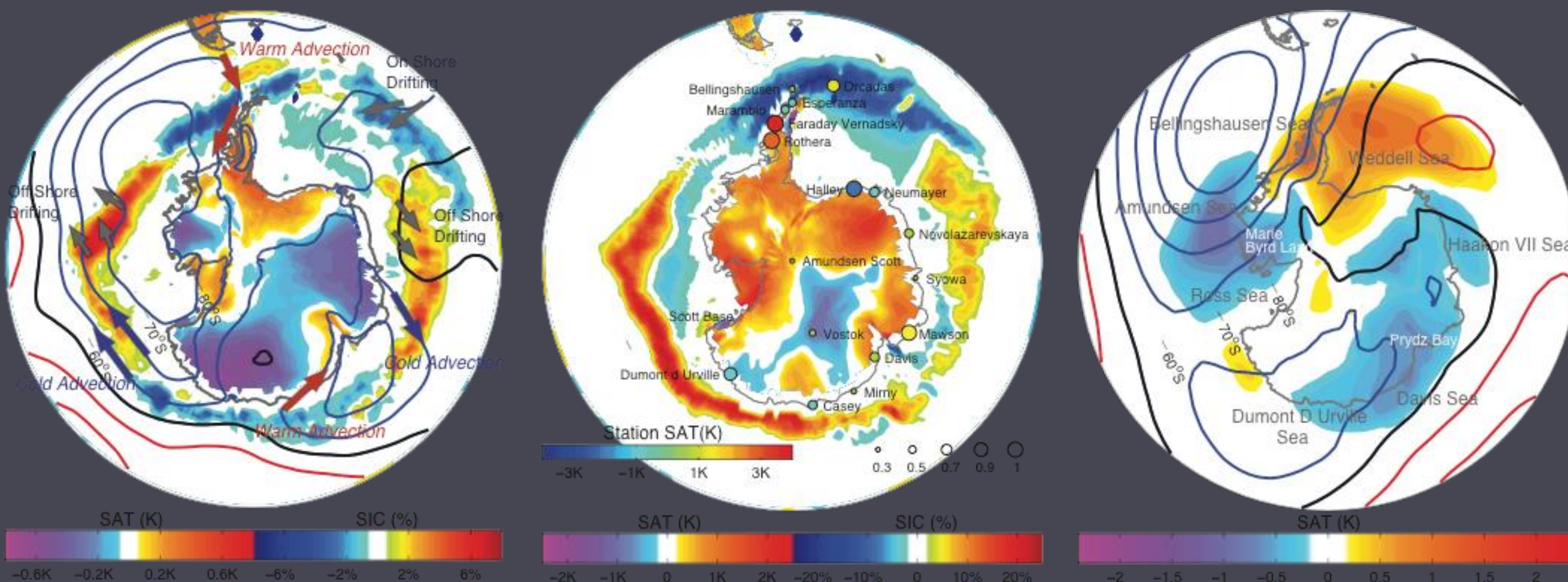


Numerical Simulation

Mechanism



- Regression and simulation well reproduce the trend of SIC and SAT

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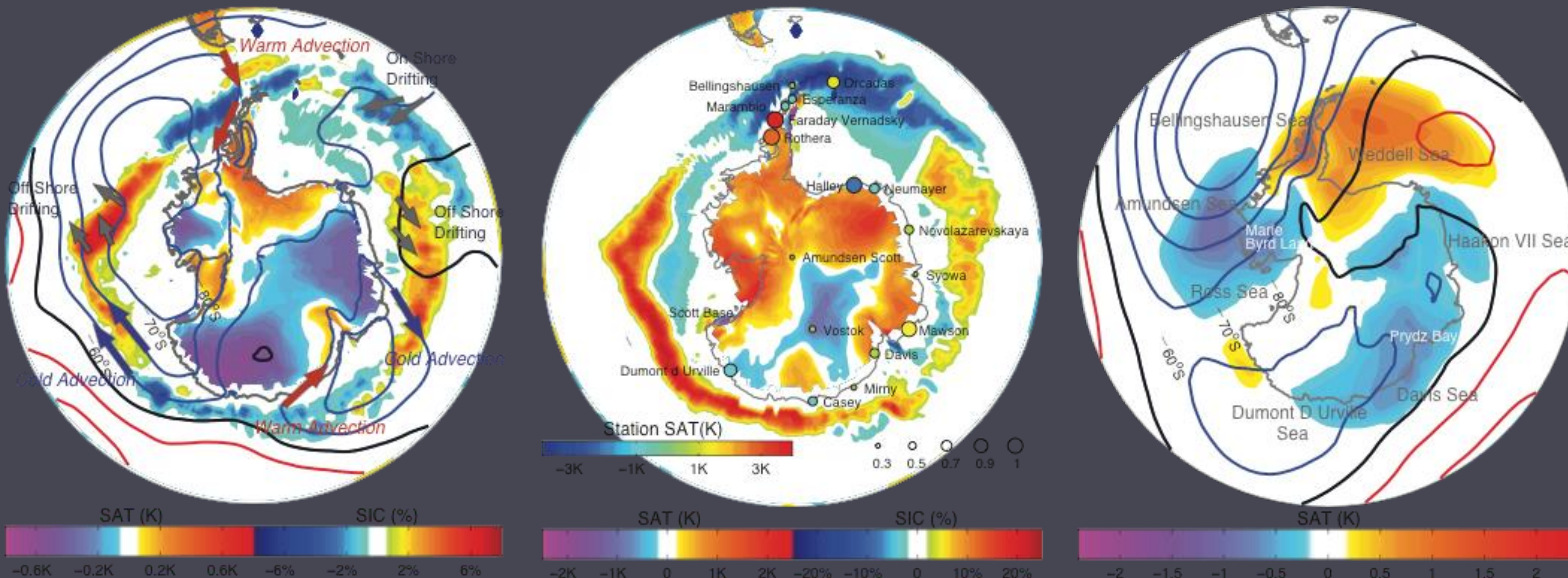

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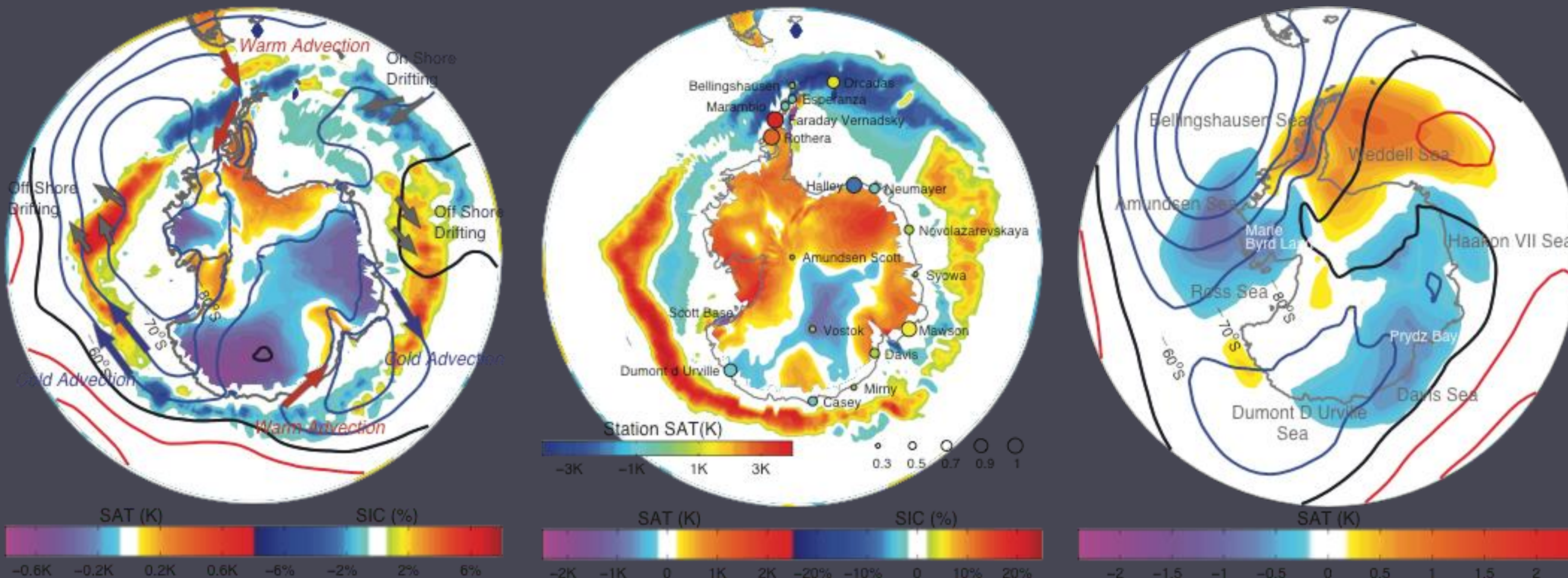

- Regression and simulation well reproduce the trend of SIC and SAT
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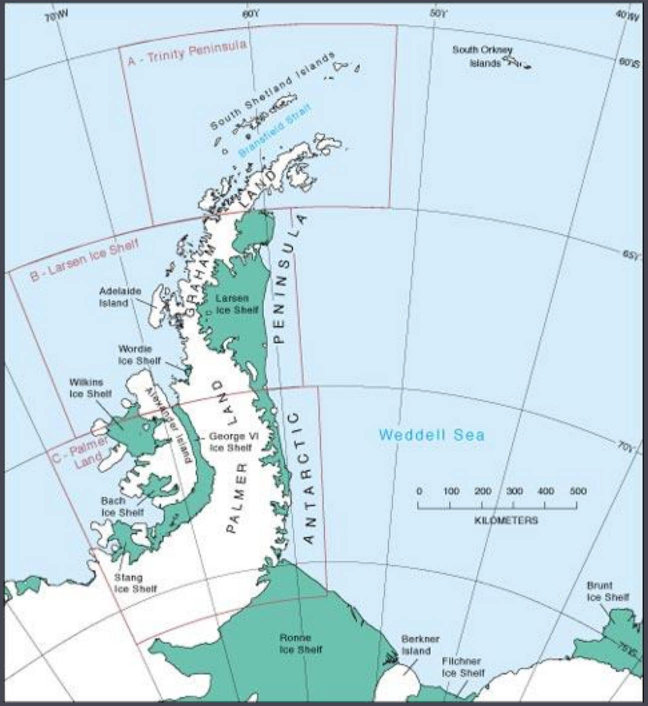
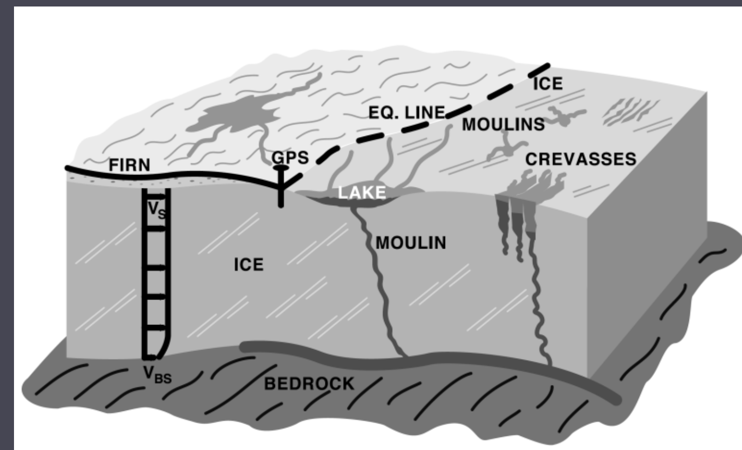
- Marie Byrd Land warming is not well explained by this mechanism

Potential Impact on Land Ice



Potential Impact on Land Ice



- Zwally *et.al* 2002
-

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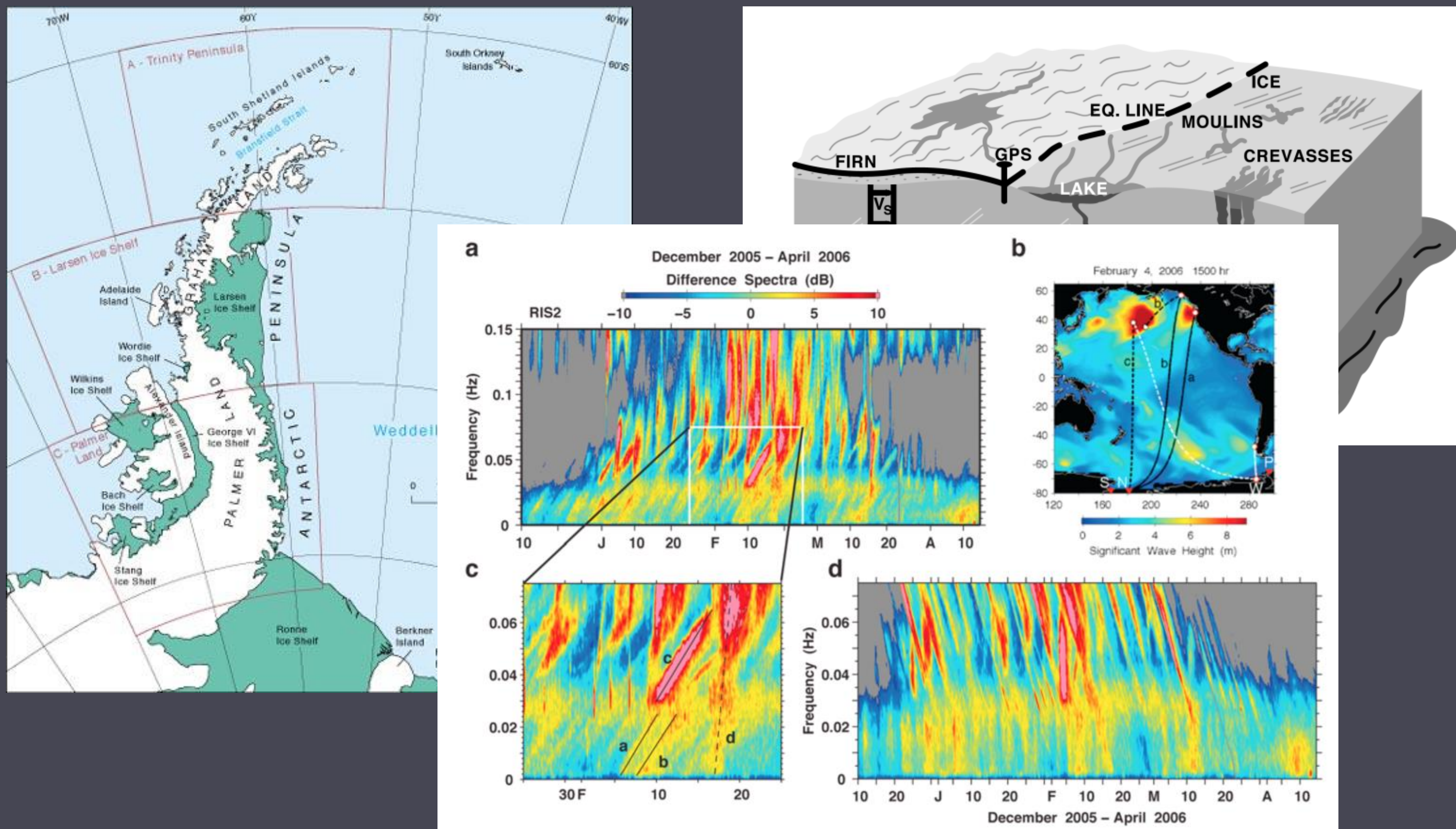

- Zwally *et.al* 2002
- Bromirski *et al* 2010

Summary : Atlantic Impacts on Antarctic Climate

- *Atlantic – Antarctic Teleconnection Helps to Explain:*

The Antarctic Ice Paradox

The Sea Ice Redistribution

The Rapid Peninsula Warming

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- *Further Contribute to*

  Land Ice Melting

  Sea Level Rise

  Deep Ocean Circulation

OUTLINE

- Background of this Study
  - Recently observed climate changes around Antarctica
  - Potential linkages of these changes to the Tropical Oceans
- Atmospheric Bridge between Atlantic and Austral Circulation
  - Analysis and model study of the Atlantic-Antarctica teleconnection
  - Physical Mechanisms and Rossby Wave Dynamics
- The Impacts on the Sea Ice and the Surface Temperature
  - Atlantic warming helps to explain Antarctic Paradox and Peninsula warming
- Conclusions and Future Research Plan

Recent Climate Changes over Antarctica

- *Atlantic – Antarctic Teleconnection : SAM and ABSL*
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Discussion and Future Research Plan

- *Ocean – Ice – Air Interaction is not involved in Present Study, which require more observation and coupled model simulation*
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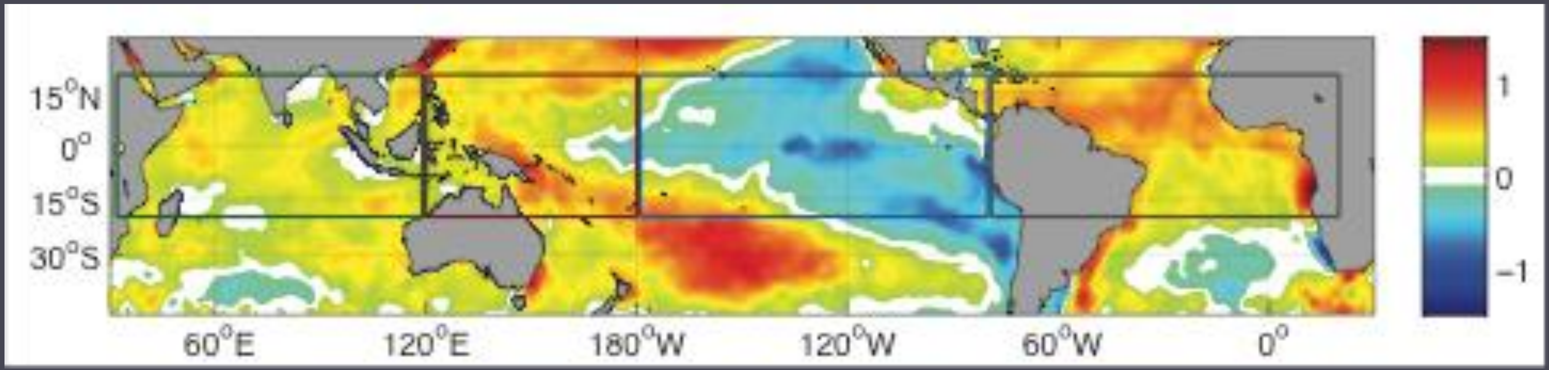
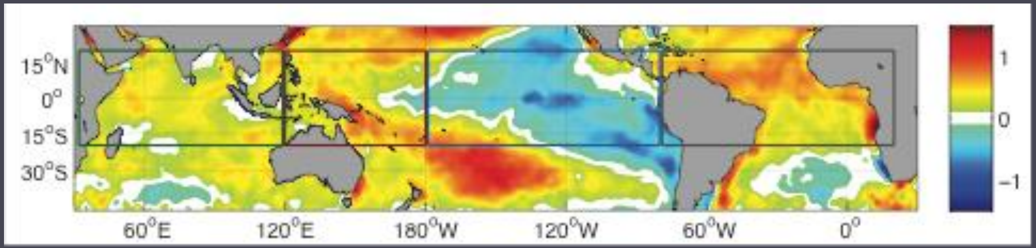
Thanks ☺

SST Trend

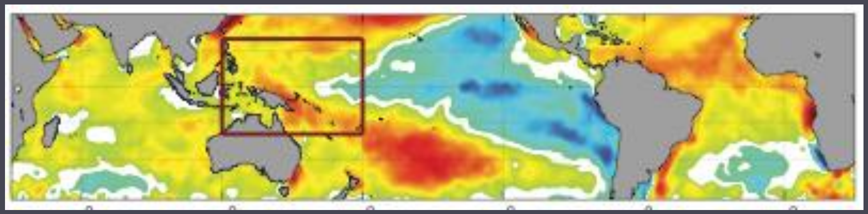


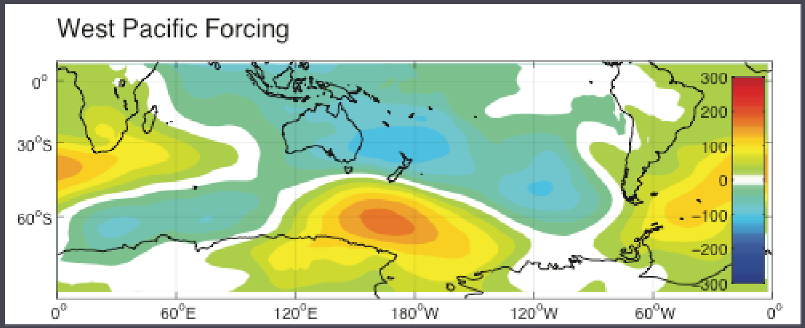
Separate the Ocean Basins based on Observed SST Trend

SST Trend as Model Forcing



Linearity & Additive Property





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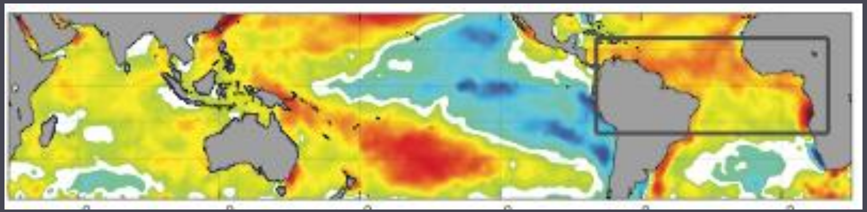

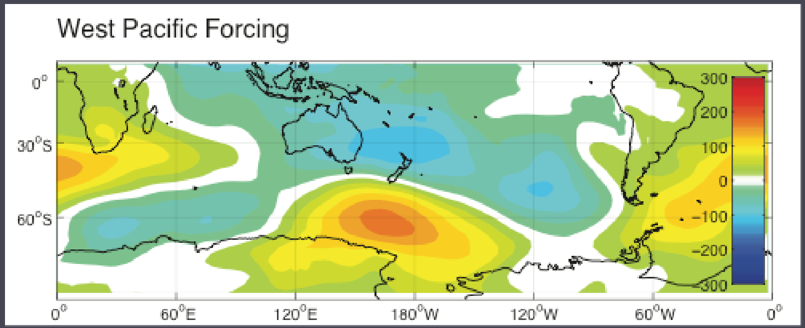

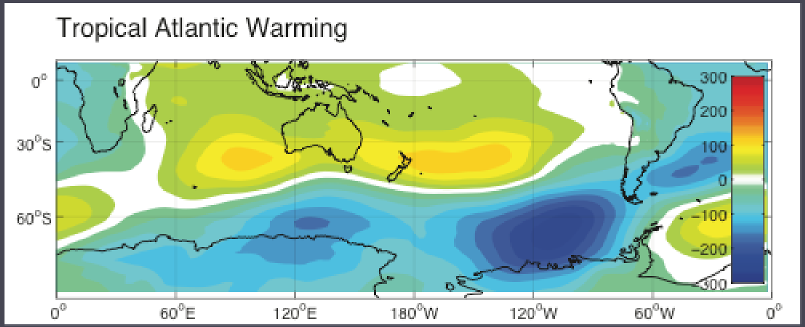

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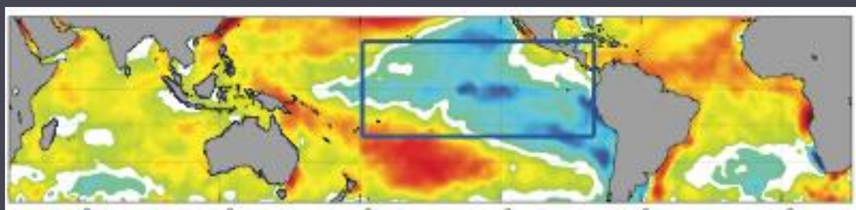

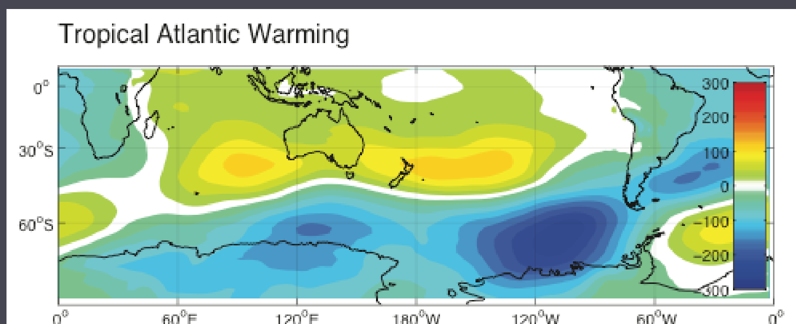

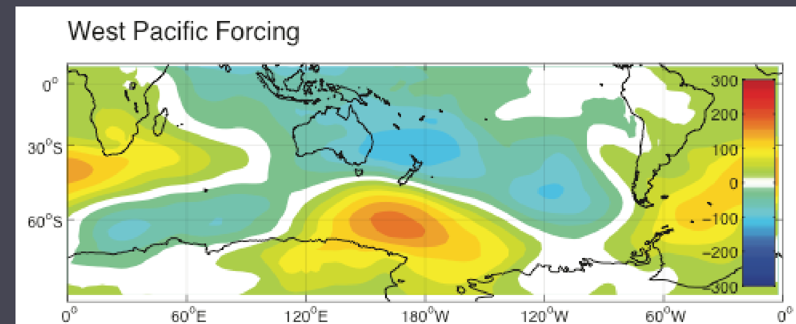

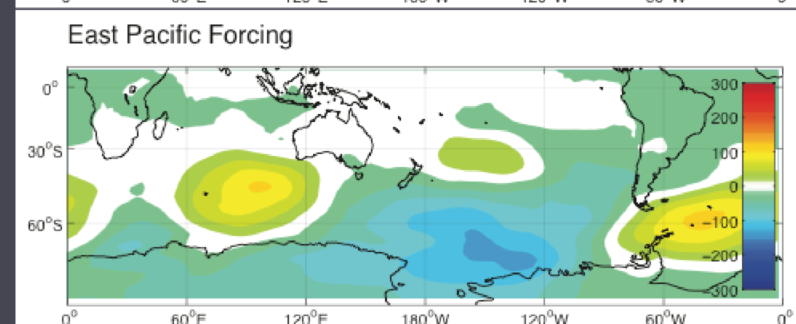

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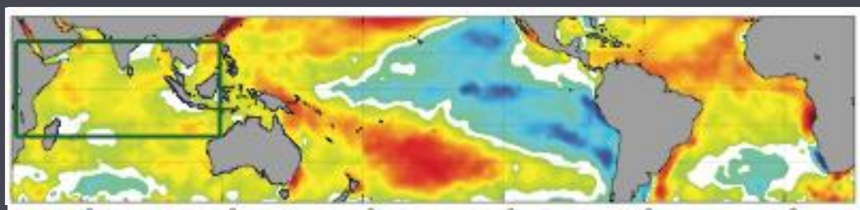

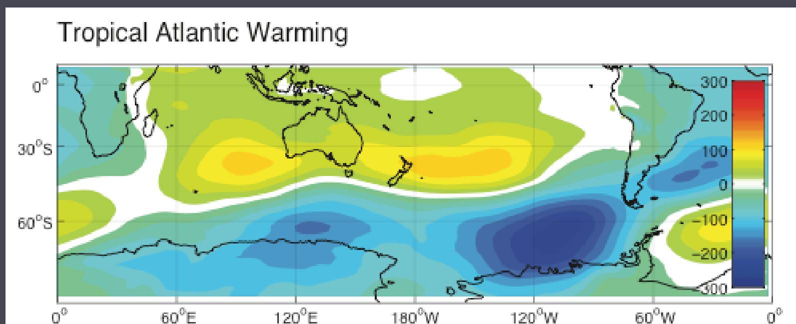

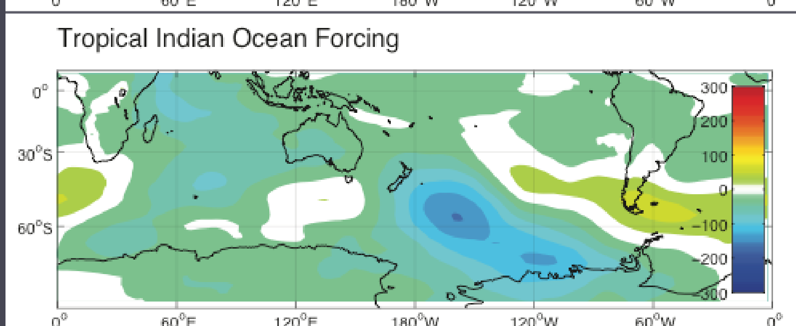

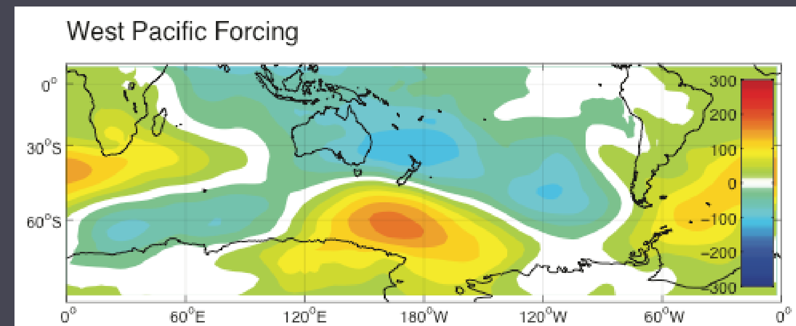

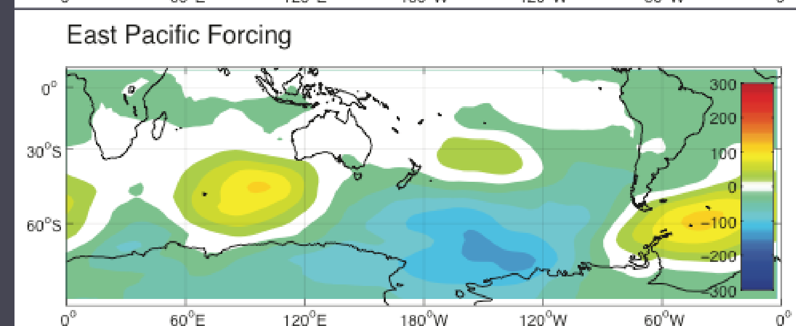

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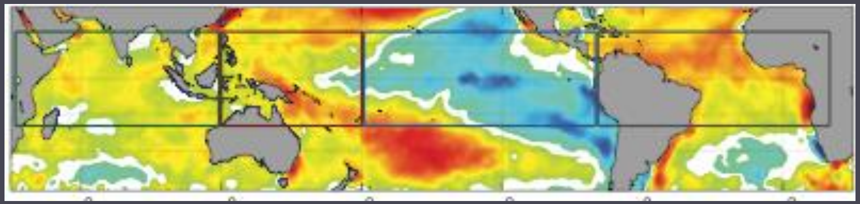

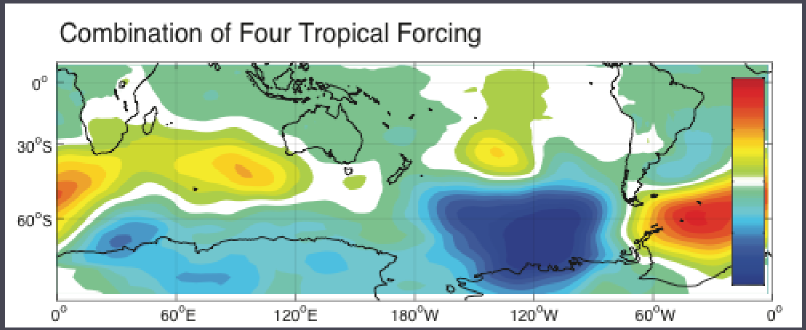

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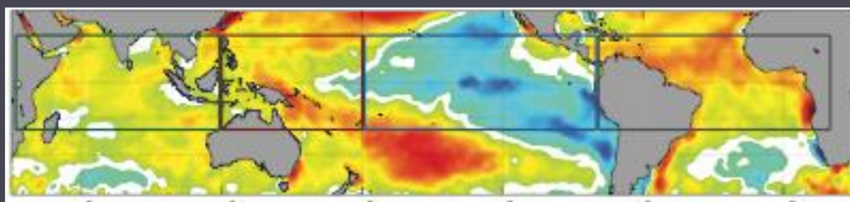
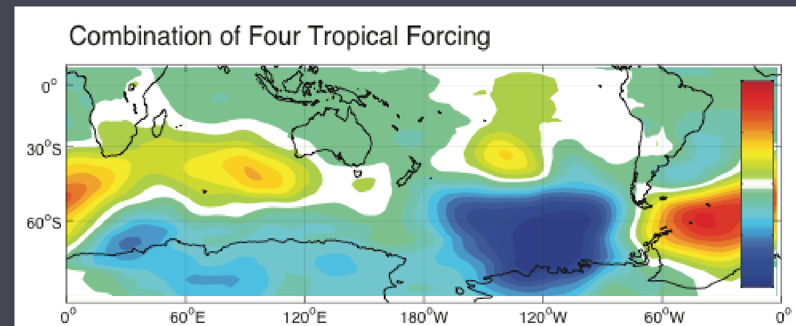
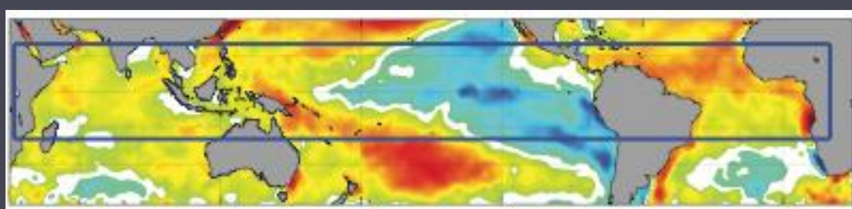
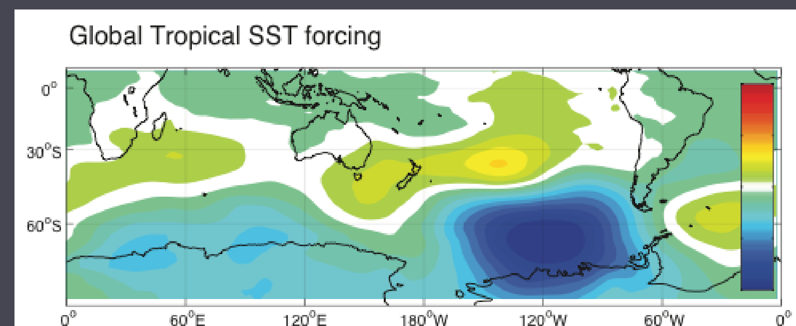
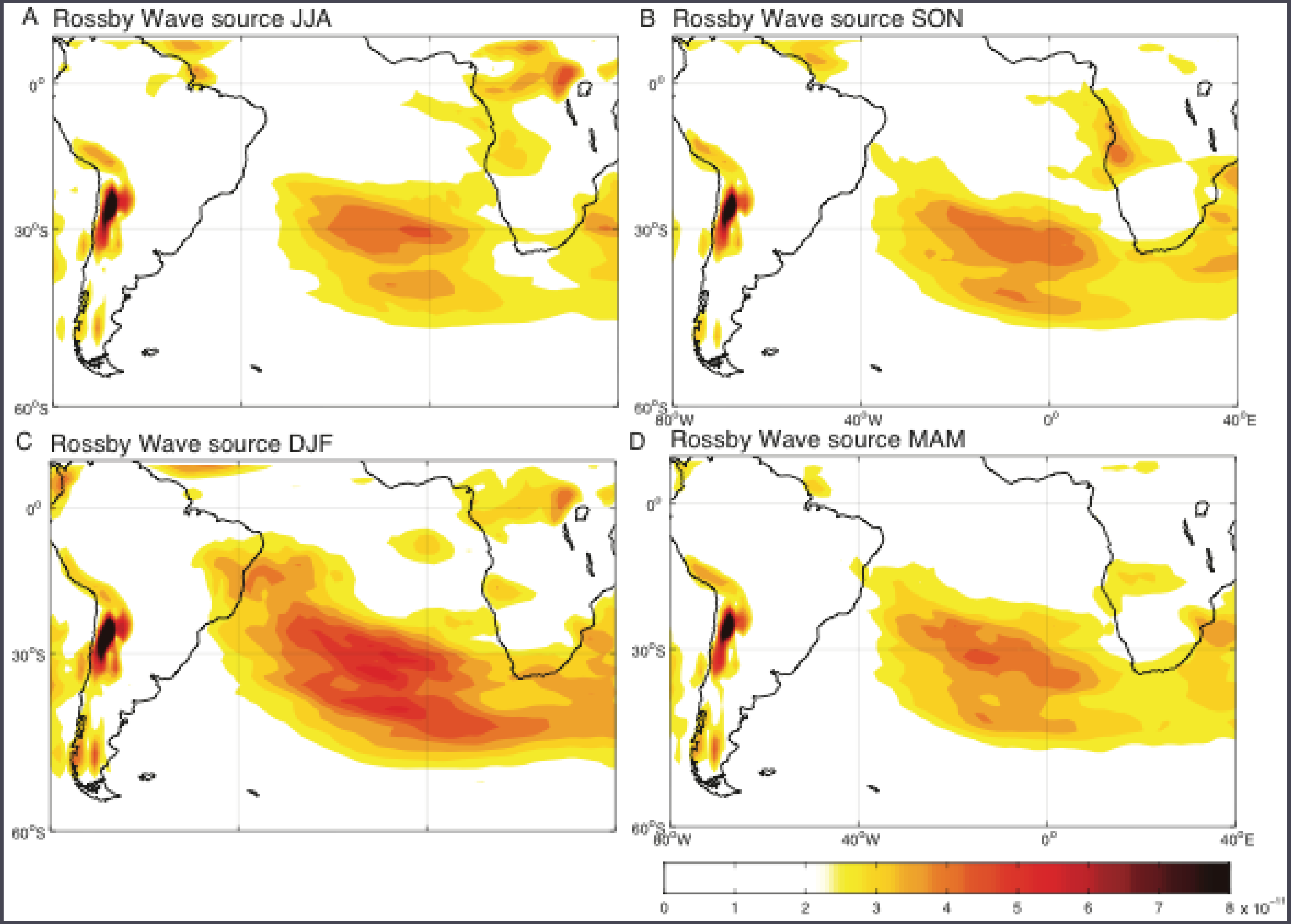




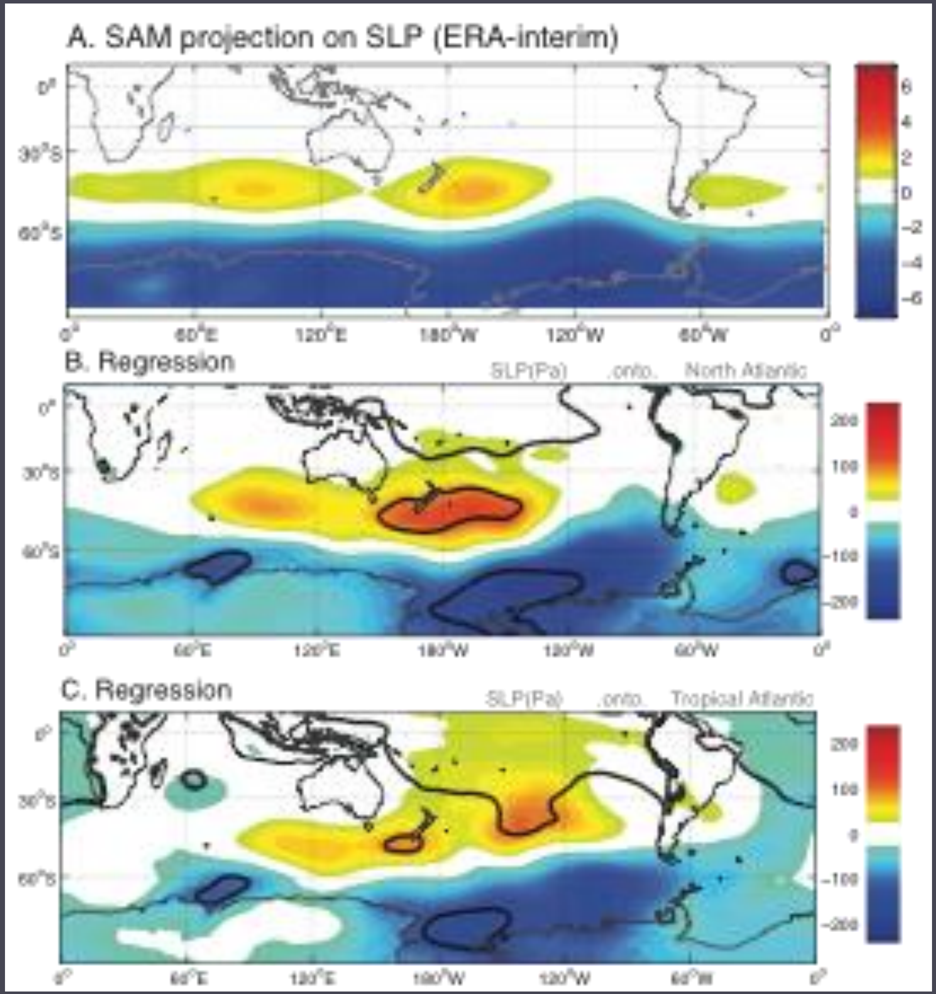




Rossby Wave Source

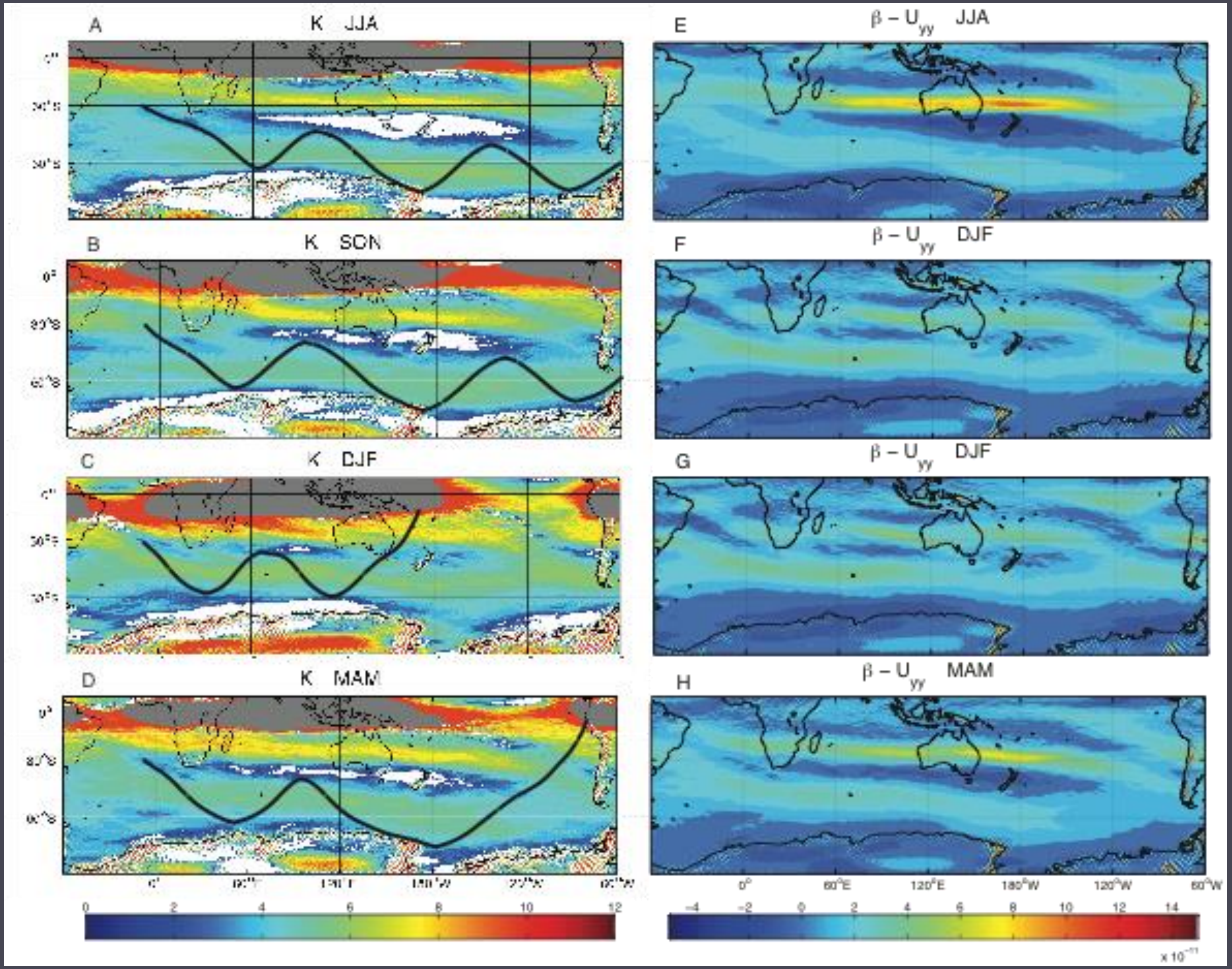


Spatial Pattern Strongly Project on Southern Annular Mode (SAM)

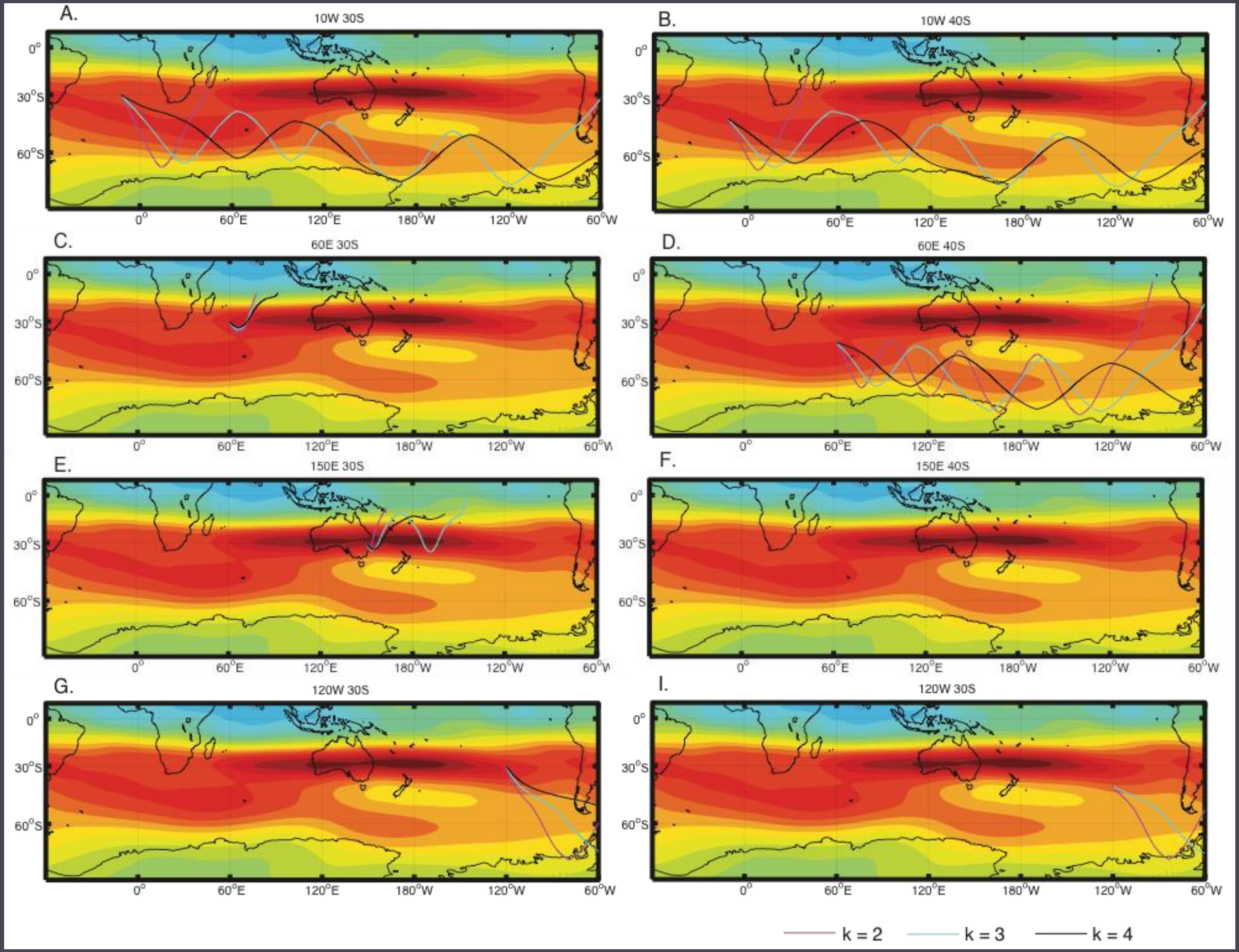


- with spatial pattern correlation > 0.8

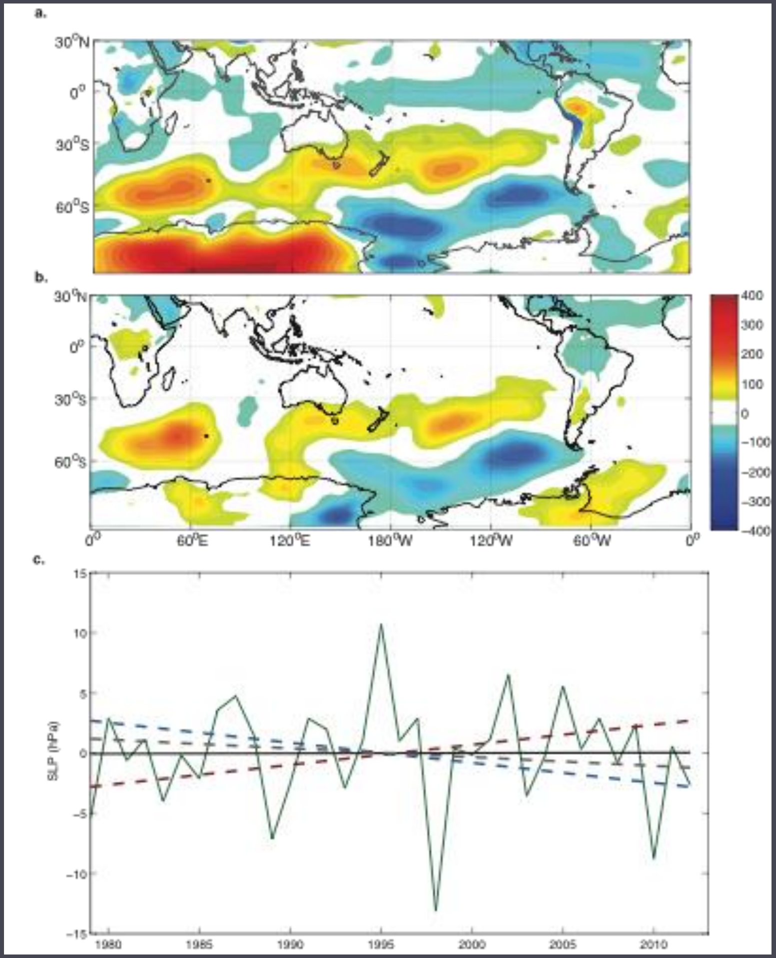
Stationary Wave in Hoskins – Karoly model



Rossby Wave Trains



ABSL trend


a.
30°N
0°
30°S
60°S
b.
30°N
0°
30°S
60°S
0°
60°E
120°E
180°W
120°W
60°W
0°
400
300
200
100
0
−100
−200
−300
−400
c.
SLP (hPa)
15
10
5
0
−5
−10
−15
1980
1985
1990
1995
2000
2005
2010