Forced and chaotic variability of basin-scale heat budgets in the global ocean:

focus on the South Atlantic crossroads

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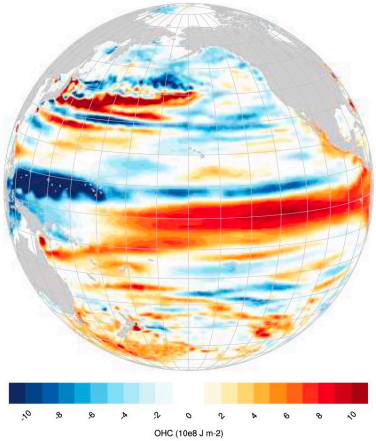
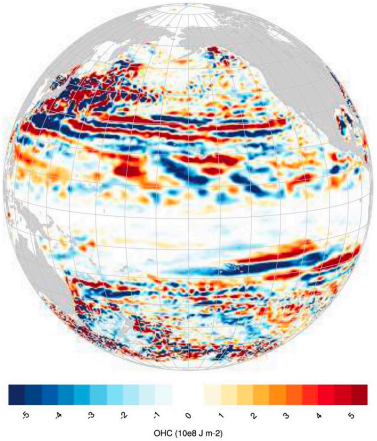
0-700m Ocean Heat Content averaged over 2002

Atmospherically-driven FORCED SIGNAL (Emean)



Ocean-driven CHAOTIC SIGNAL (member 5 — Emean)

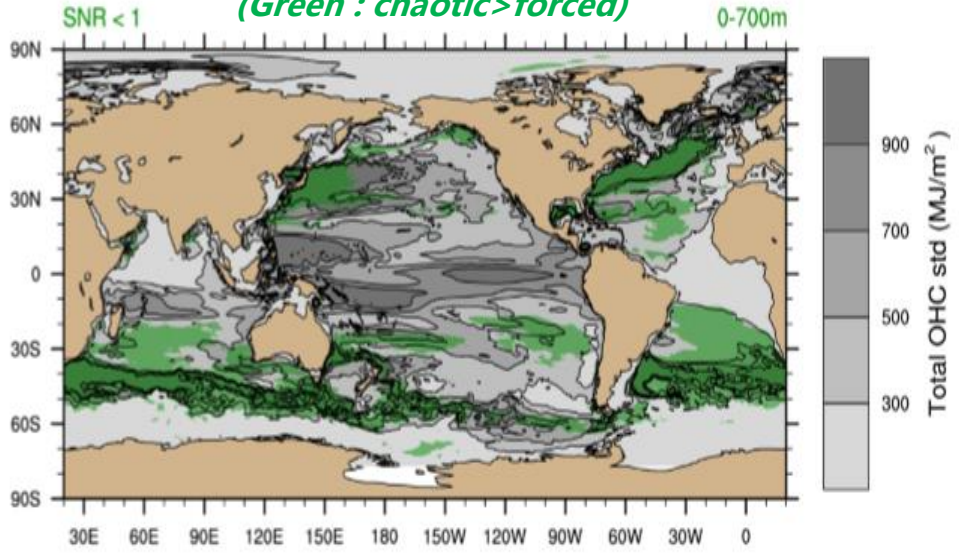


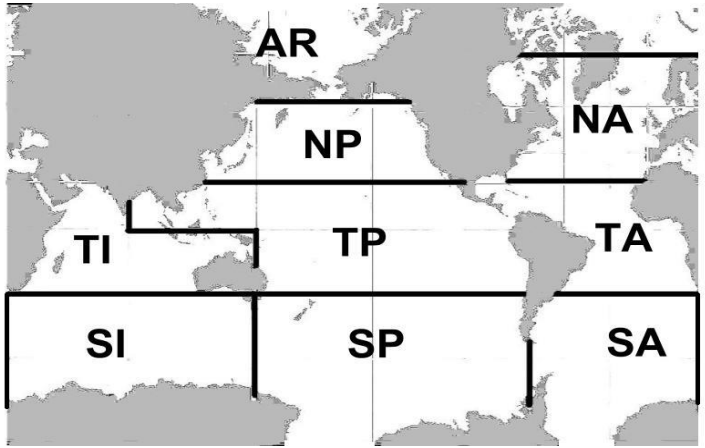
Objectives

Ocean heat content (OHC) : $OHC = \rho Cp \iiint_{-D}^{\eta} T(x,y,z)dxdydz$

Contributions of forced and chaotic variabilities on the oceanic heat budget at the scale of these basins ?

1-20 yr ocean heat content interannul variability
(Green : chaotic>forced)





[Sérazin et al.,2017]

contents

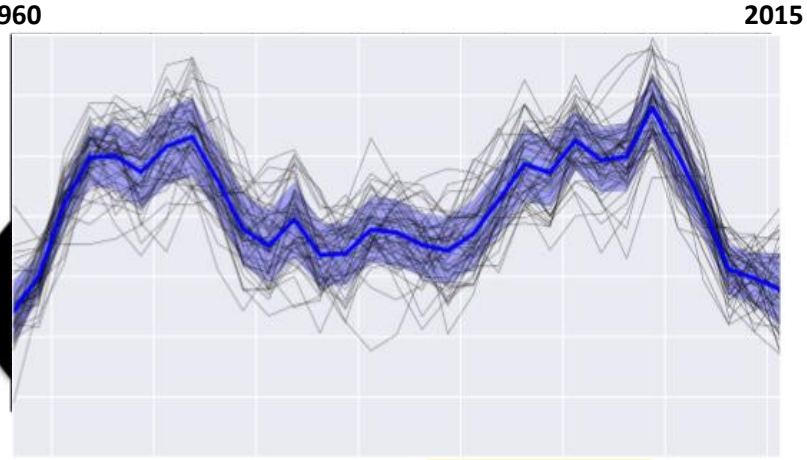
- Methodology
- Forced and chaotic heat budgets
  - Global ocean overview
  - Focus on the South Atlantic
  - Forced Antarctic Circumpolar wave
- Conclusion

2.1 Methodology

The OCCIPUT project: Forced and chaotic variability

56-year, 1/4°, 50-member ensemble simulation of the global ocean

DFS5.2 realistic forcing, 1960-2015. Same on the 50 members



$$Total = Forced + Chaotic$$

$\forall\ member\ i$:

$$f_i(t) = < f(t) > + f'_i(t)$$

50-member ensemble mean

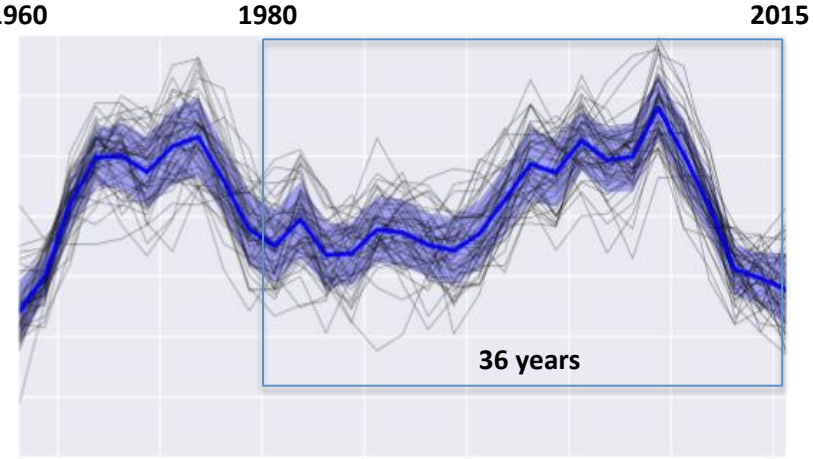
Forced standard deviation σ_F: Temporal std($< f(t) >$)

Chaotic standard deviation σ_I: Temporal mean (Ensemble std ($f'_i(t)$))

2.1 Methodology

The OCCIPUT project: Forced and chaotic variability

$$Ratio\ (R) = \frac{\sigma_I}{\sigma_T} X100\%$$



The magnitude of total variability:

$$\sigma_T = \sqrt{\sigma^2{}_F + \sigma^2{}_I}$$

Forced standard deviation σ_F: Temporal std($< f(t) >$)

Chaotic standard deviation σ_I: Temporal mean (Ensemble std (f'_i(t)))

Ocean heat tendency ∂tOHC

$$OHC = \rho Cp \iiint_{-D}^{\eta} T(x,y,z)dxdydz$$

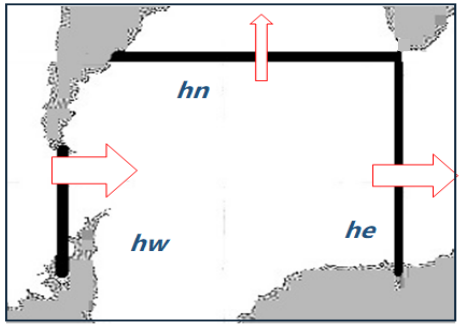
$$\partial tOHC = Conv + Qnet + \cancel{Residual}$$

Advective heat transport convergence

Air-sea heat fluxes

Discretization error + Diffusive heat transport convergence

$$Conv = hw - he + hs - hn$$



$$\frac{Var(Residual)}{Var(\partial tOHC)} < 10\%$$

2.3 Methodology

Time scales

$$\partial tOHC = Conv + Qnet$$

$$Total = Forced + Chaotic$$

36-year monthly time series:

$$x(t) = \overline{x(t)} + x^{trend}(t) + x^{S}(t) + x^{HF}(t) + x^{LF}(t) + x^{VLF}(t)$$

Lanczos filter

- **Subannual: HF < 1.5 years**
- **Interannual :1.5 < LF < 10 years**
- **Decadal: VLF >10 years**

Climate relevant

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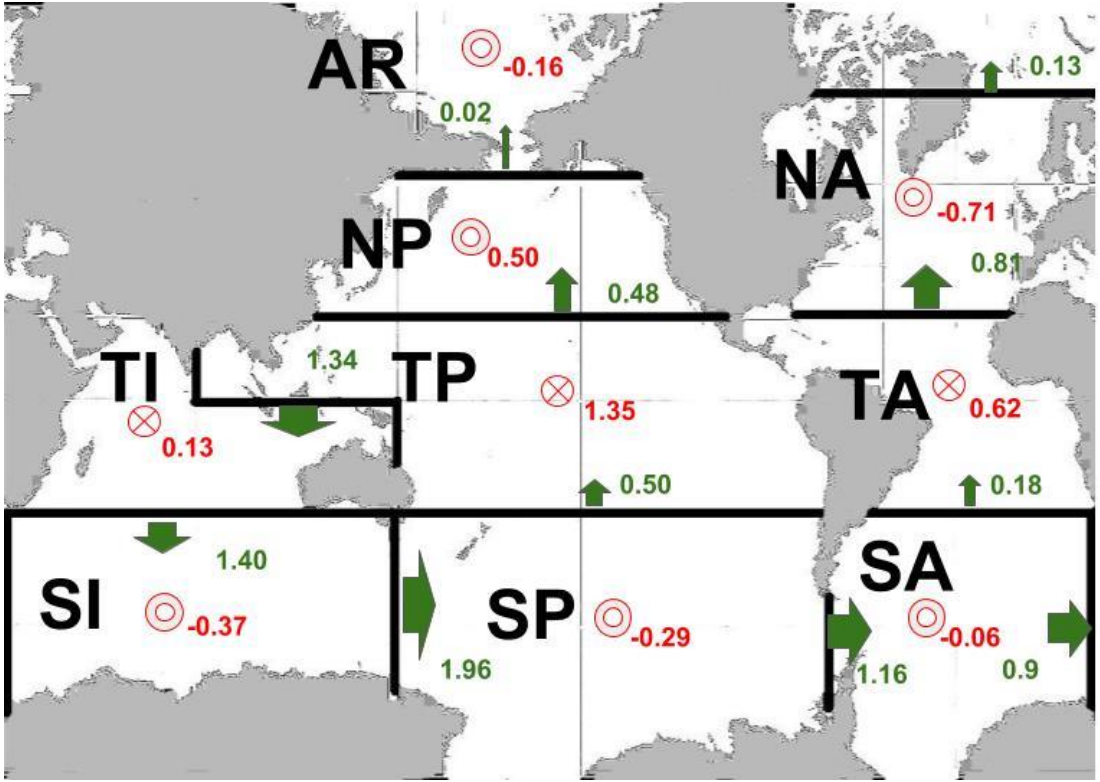
Time- and Ensemble-mean air-sea heat fluxes and advective heat transports



Mean air-sea heat fluxes

2.1 PW : atmosphere → low-latitude ocean

2.1 PW : mid/high-lat ocean → atmosphere

Mean advective heat transports

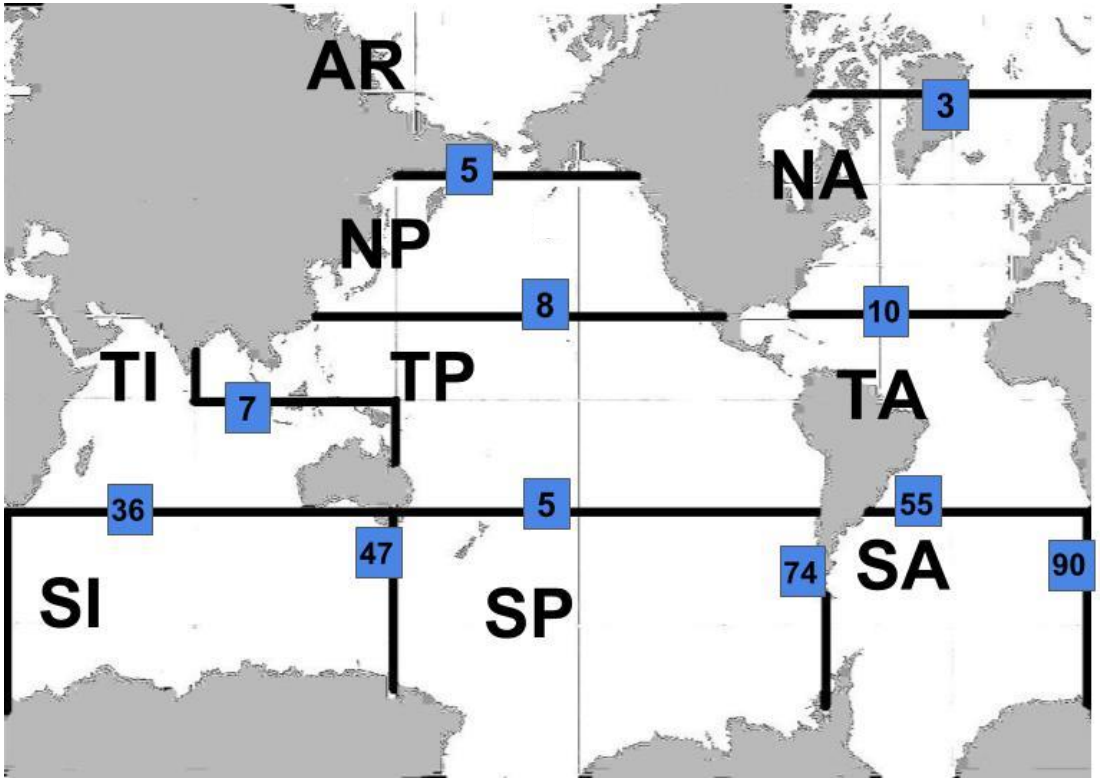
Northward in the Atlantic and Pacific

Southward in the Indian

Eastward in the Southern Ocean

PW $(= 10^{15}\ W)$

Advective heat transport variability: chaotic contribution

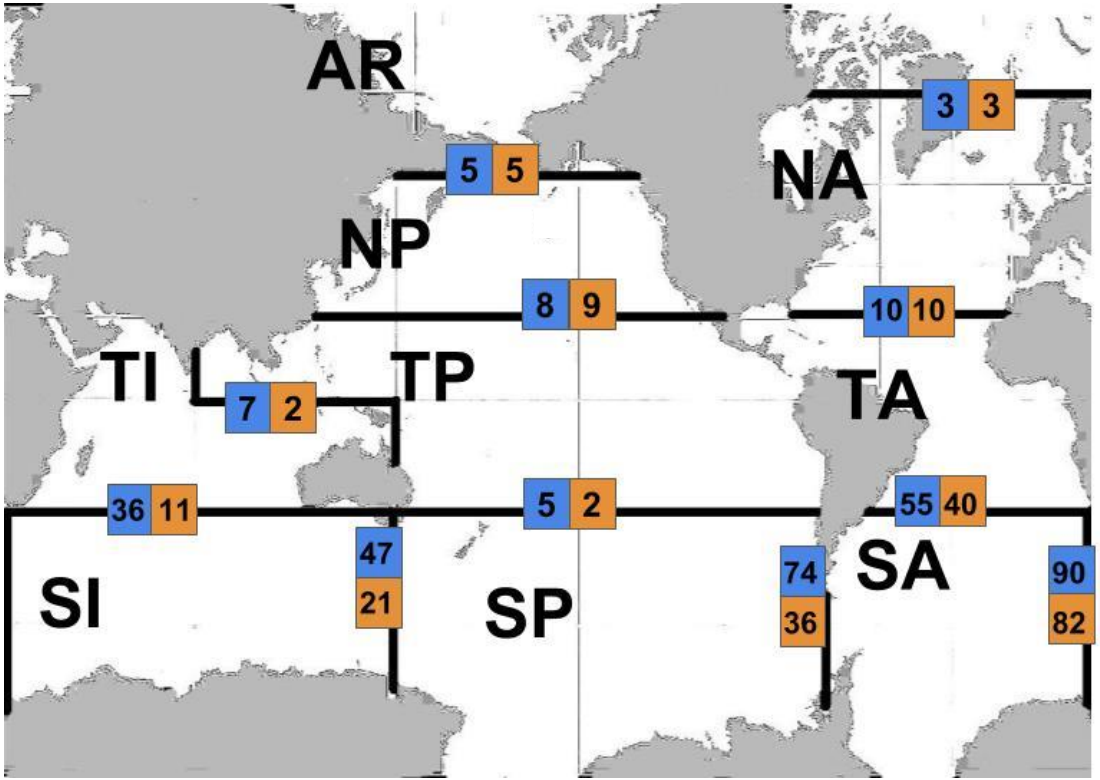


$$Ratio\ (R) = \frac{\sigma_I}{\sigma_T} X100\%$$

At High Frequency:
< 1.5 years

Largest chaotic contribution to the heat transport variability in the Southern Ocean

Advective heat transport variability: chaotic contribution

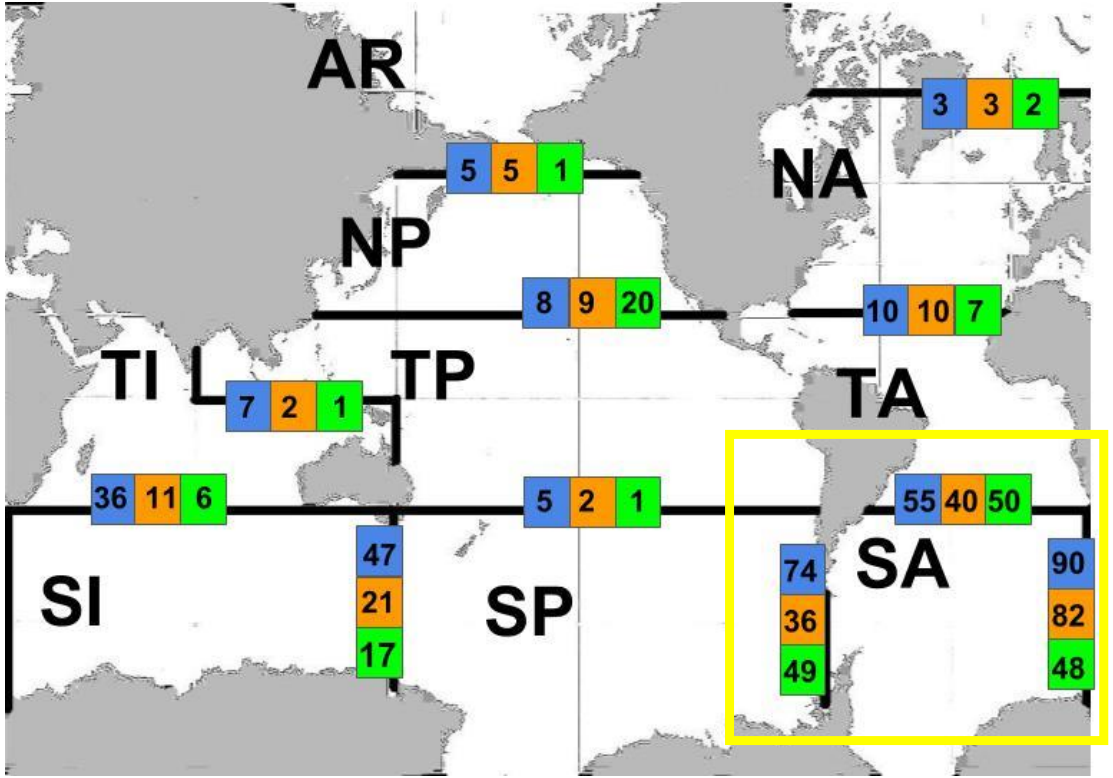


$$Ratio\ (R) = \frac{\sigma_I}{\sigma_T} X100\%$$

At Low Frequency:
1.5 years<LF <10 years

Largest chaotic contribution to the heat transport variability in the Southern Ocean

Advective heat transport variability: chaotic contribution

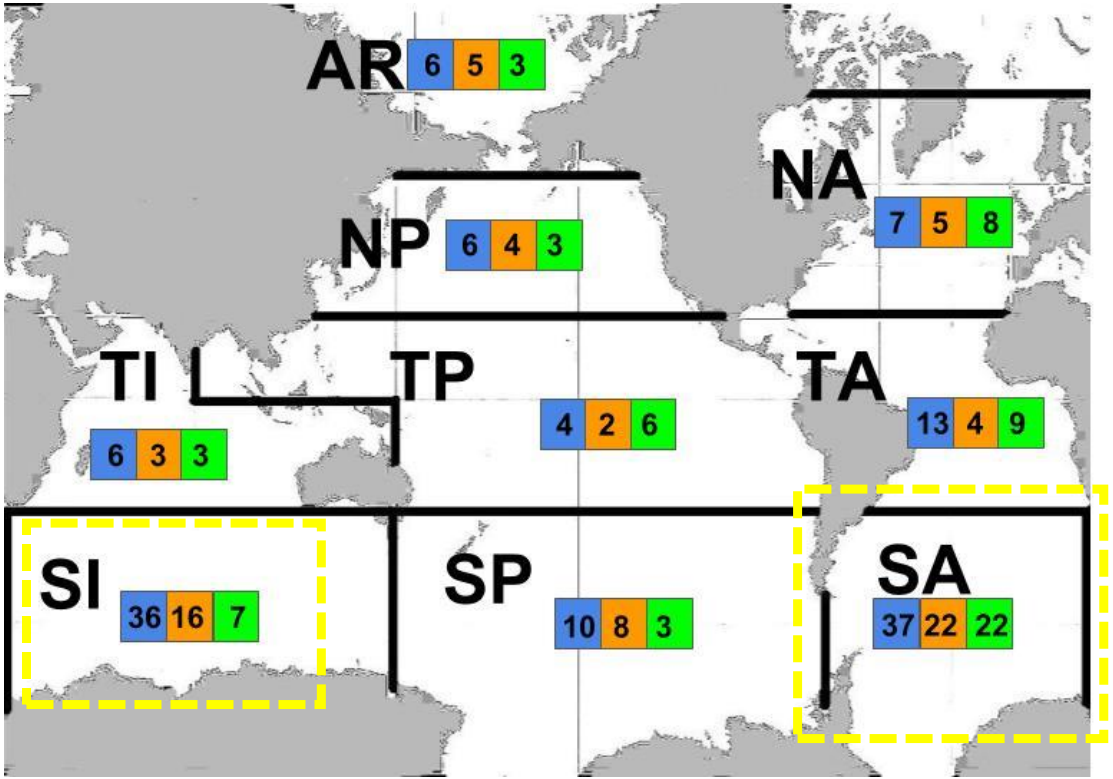


$$Ratio\ (R) = \frac{\sigma_I}{\sigma_T} X100\%$$

At Very Low Frequency: >10 years

Largest chaotic contribution to the heat transport variability in the Southern Ocean (Atlantic sector)

Ocean Heat Content variability: chaotic contribution



$$Ratio\ (R) = \frac{\sigma_I}{\sigma_T} X100\%$$

Largest chaotic contribution
to the heat transport variability
in the Southern Ocean
(Atlantic & Indian sectors)

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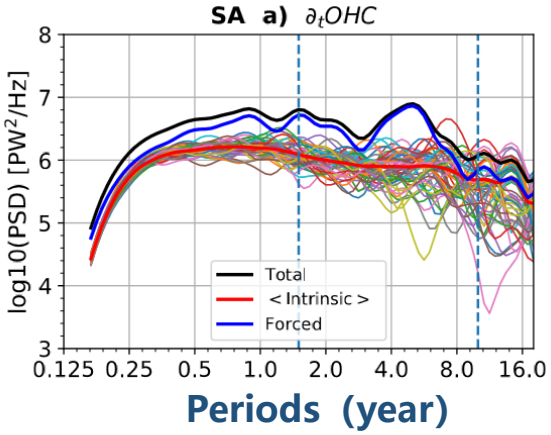
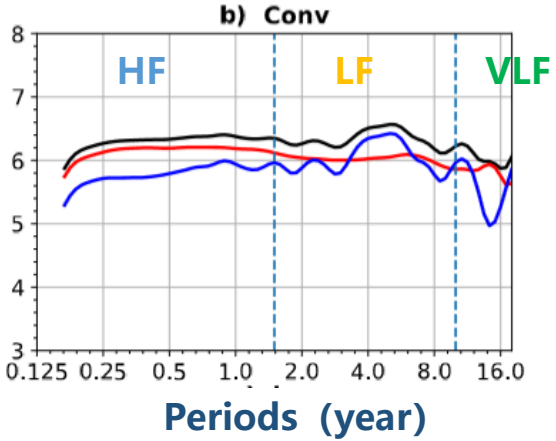
3.2 The South Atlantic

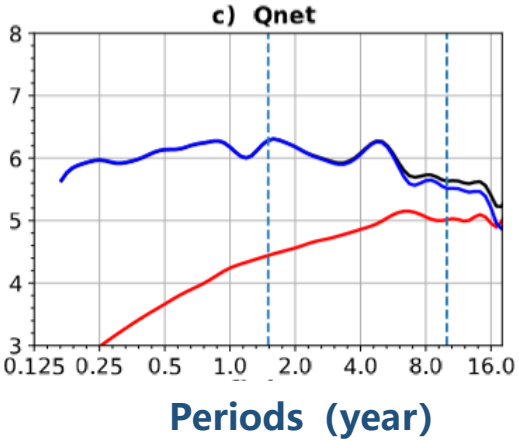
Power spectra density

$$\partial tOHC = Conv + Qnet$$

$$Total = Forced + Chaotic$$







∂tOHC variability is mostly forced (but 50% only at decadal scale)

Conv variability is mostly intrinsic (except 3-6 yr)

Qnet variability is highly forced

3.2 The South Atlantic

Power spectra density

$$\partial tOHC = Conv + Qnet$$

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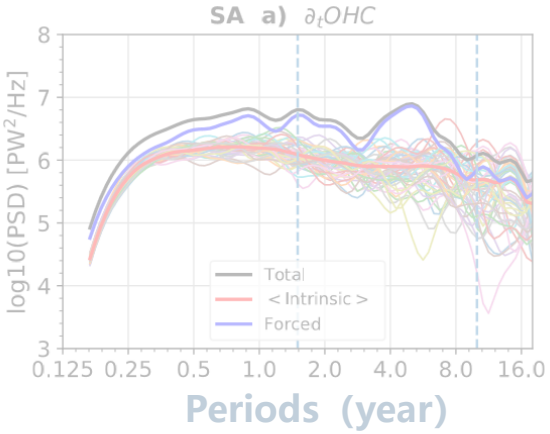

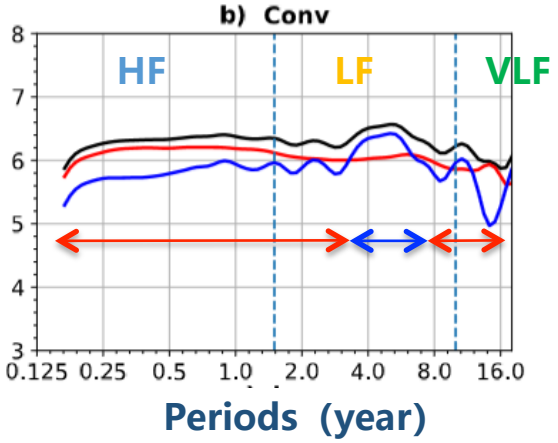

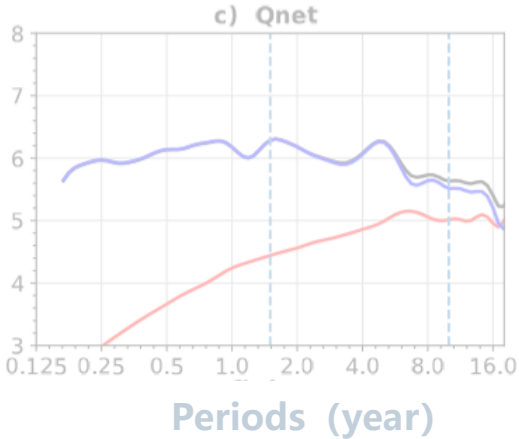

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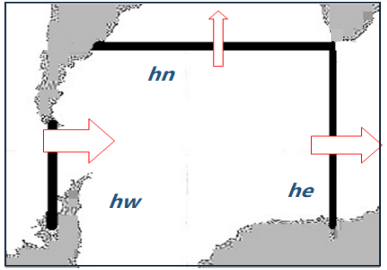
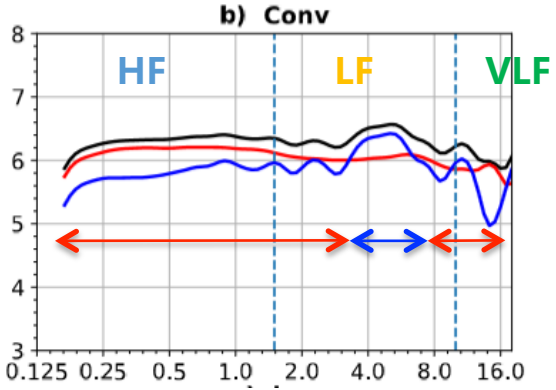
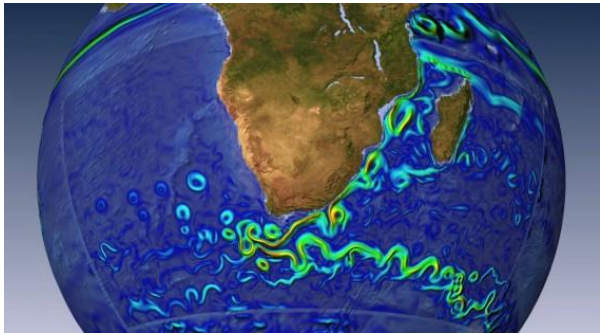
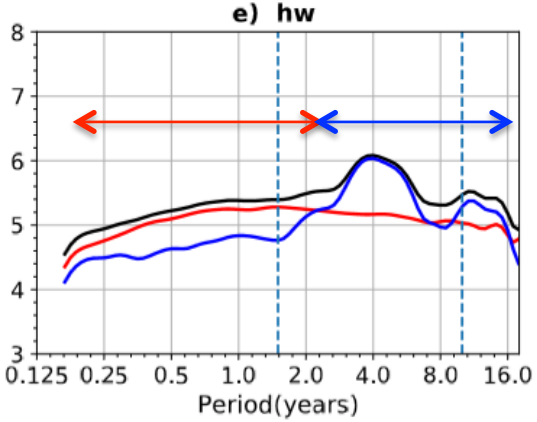
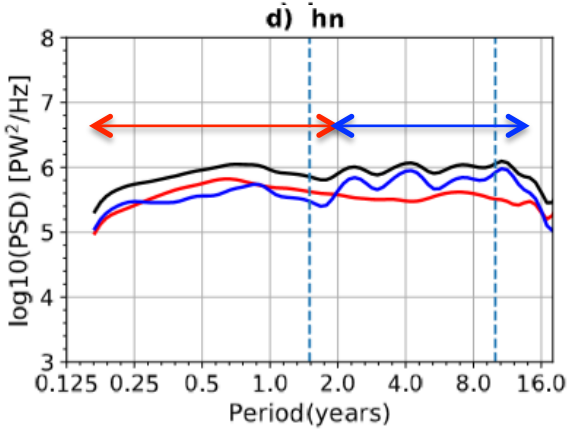
$$Conv = hw - he - hn$$

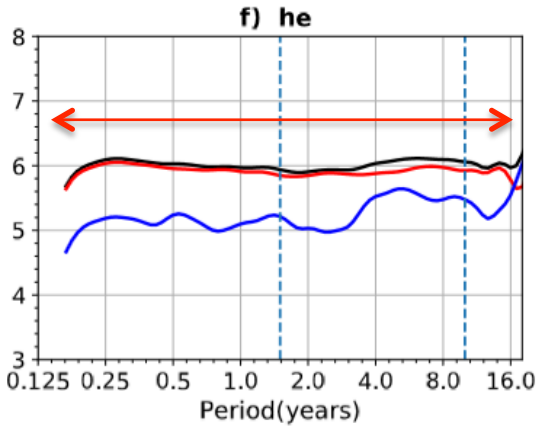












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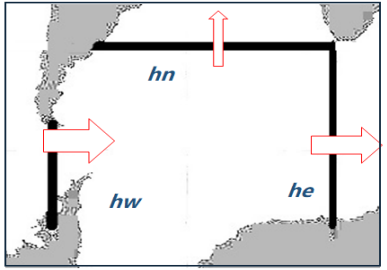
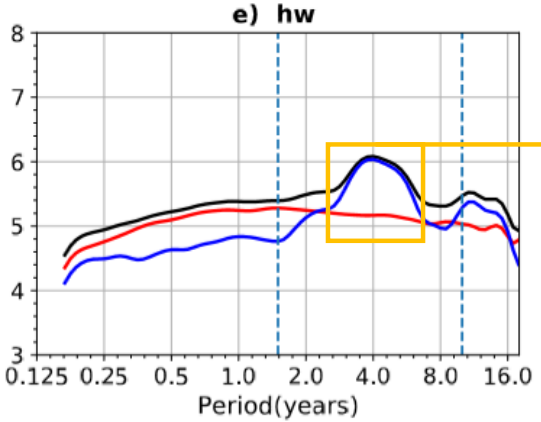
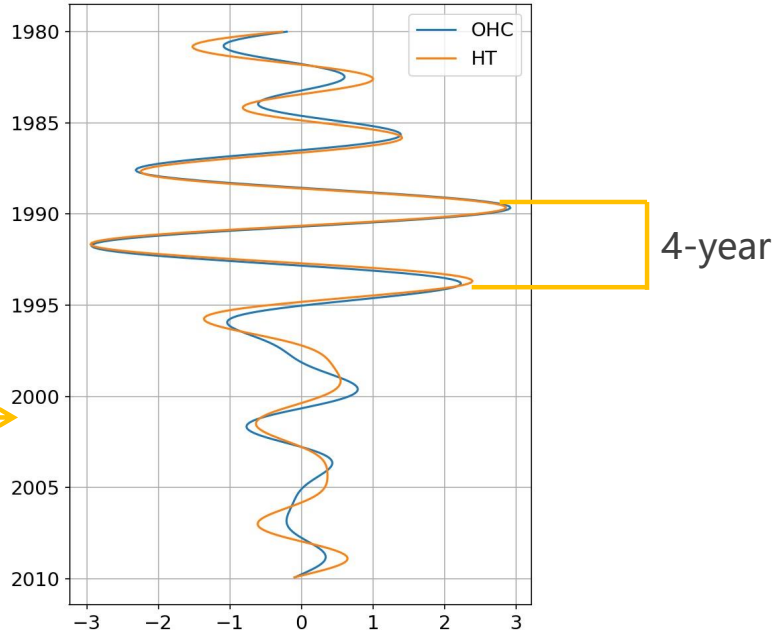




3-6 yr band-pass filter

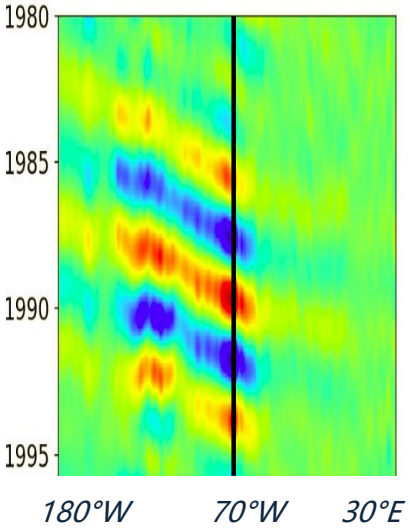
Forced heat transport variability across Drake Passage



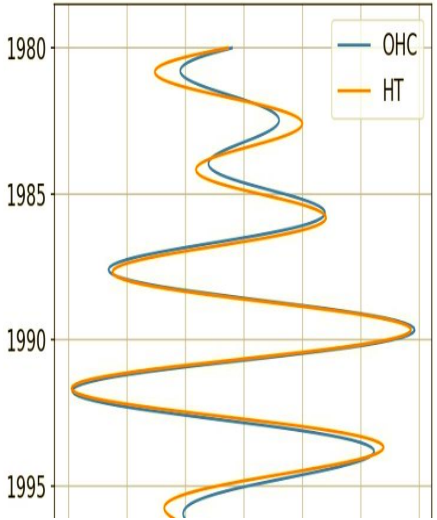
3.3 Forced Antarctic Circumpolar Wave

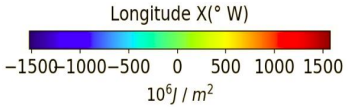
Model

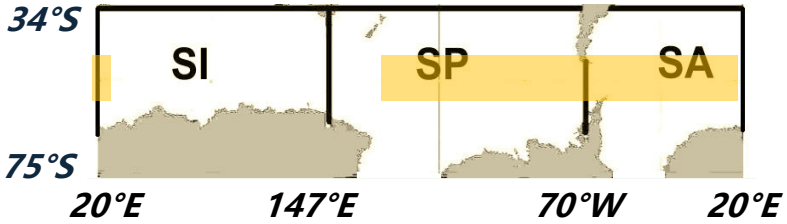
OHC 55°-60°S



Drake Passage(70°W)







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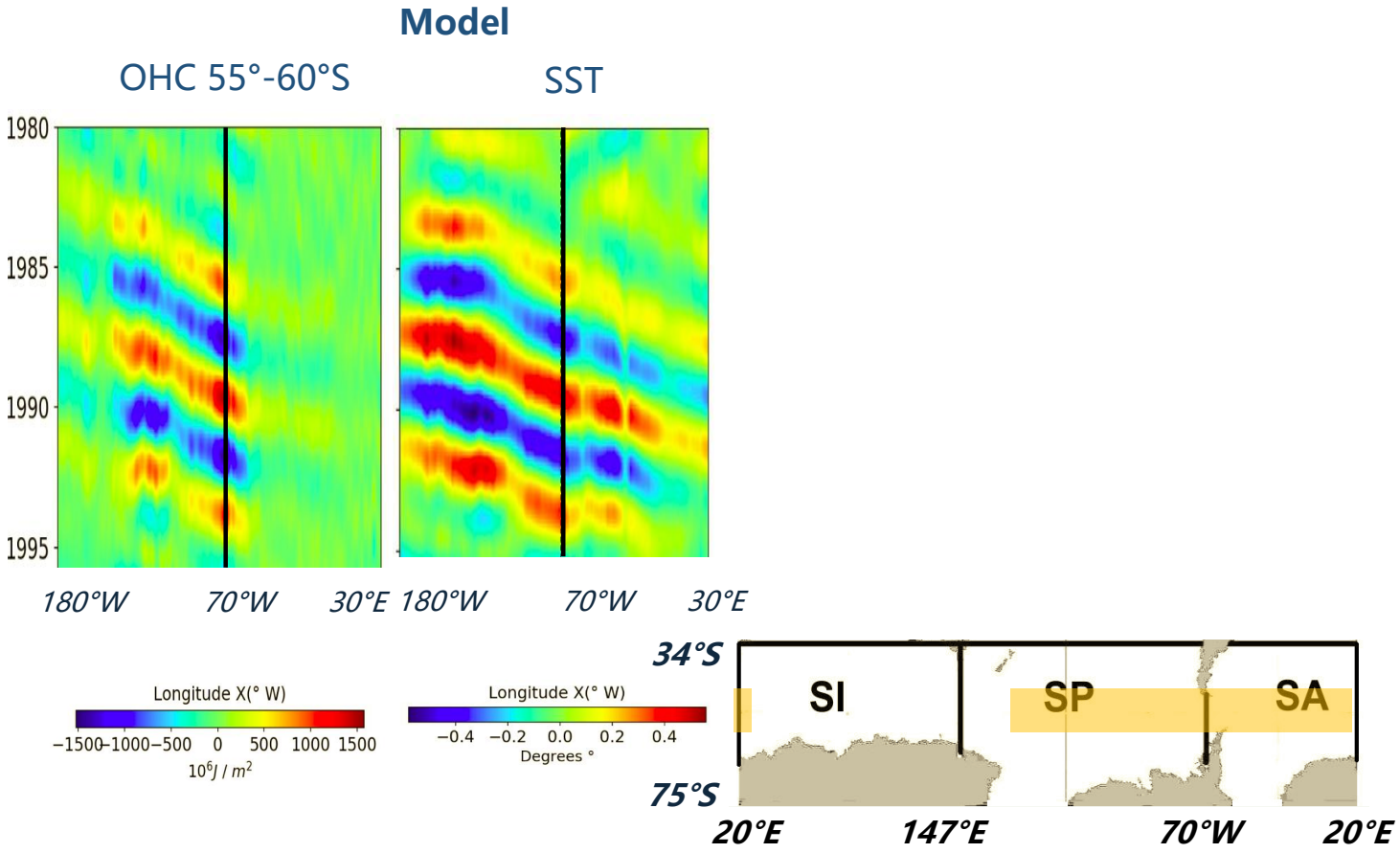

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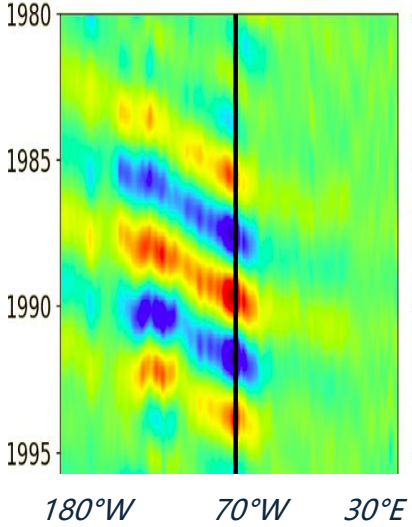
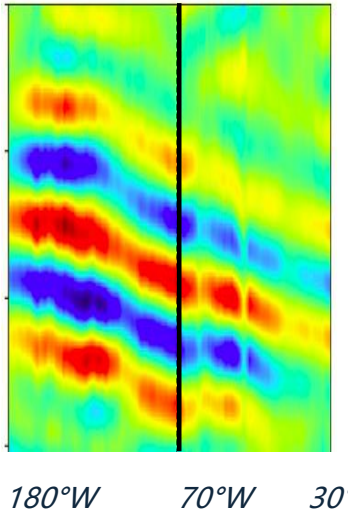
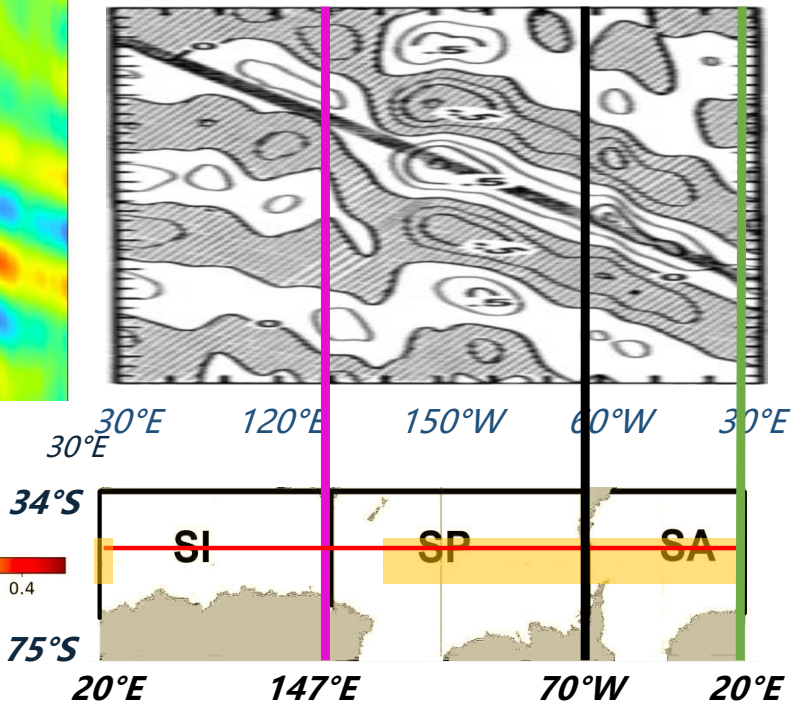


SST



Observation

SST anomalies at 56°S [White et al.1996]



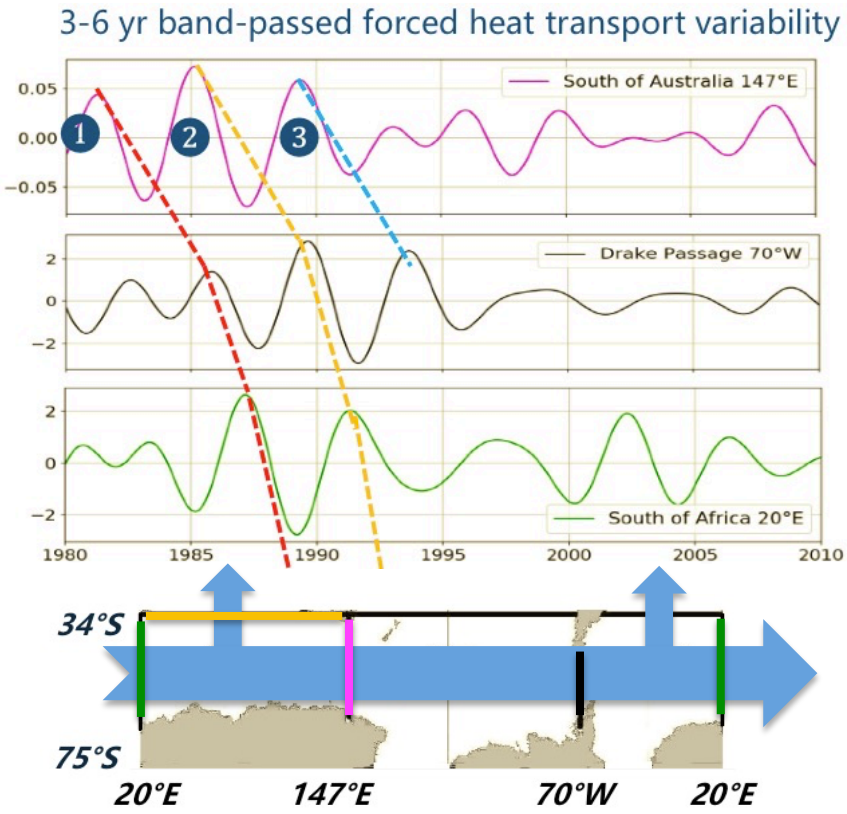
Property:

- Wavenumber : 2-3
- Period :4-5 yr
- Propagates eastward with the Antarctic Circumpolar Current(ACC)
- Average speed 6-8 cm/s, 8-10 years to encircle the Southern Ocean
- Connection with El Niño–Southern Oscillation

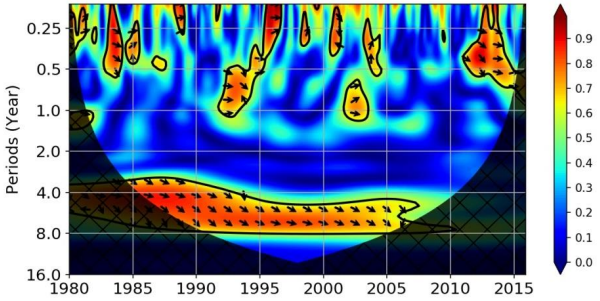
3.3 Forced Antarctic Circumpolar Wave

Eastward

Northward



South of Africa leads **34°S of the South Indian**



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4. Conclusion

1. **Chaotic intrinsic variability** has a large imprint on the ocean's heat budget at
   - the scale of **whole basins**
   - up to **decadal time scales**

2. **Low-freq. Chaotic intrinsic variability** is strongest in eddy-active regions
   - **Southern Ocean**
   - **Atlantic sector**

3. **Low-freq. forced variability** is important as well
   - Largest impact in the **Atlantic sector**
   - **Observed Antarctic Circumpolar Wave** well simulated (T~4 years)

4. OHC has a large influence on the atmosphere
   - **Impact of this low-freq. Chaotic intrinsic variability on the O/A coupled system?**
     other climate components?