# A Numerical Study of the Annual Variability of the Western Boundary Currents of the South Atlantic Ocean

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### *Introduction*

It is known, both, from observations, and numerical experiments, that the Brazil/Malvinas Confluence undergoes a seasonal meridional displacement. The Confluence is located farther south during summer, and farther north during winter. This seasonal behavior is believed to be related to the annual cycles of the transports of the Brazil (BC) and Malvinas Currents (MC). The annual cycle of the transports of these two western boundary currents are in opposition of phase. The Brazil Current has its maximum/minimum transport, while the Malvinas Current has its minimum/maximum transport, during summer/winter. It is, however, unknown what part of their annual cycles is generated locally, and what part is generated elsewhere in the Southern Ocean. Throughout this analysis we shall see that the annual cycle of the western boundary currents of the South Atlantic Ocean (SA) are composed by the interaction between the locally generated signal with those contributions generated in the Indian and Pacific Oceans.

### *Goal*

The goal of this study is to investigate the relative contributions of local and remote forcings to the annual cycle of the western boundary currents of the South Atlantic Ocean.

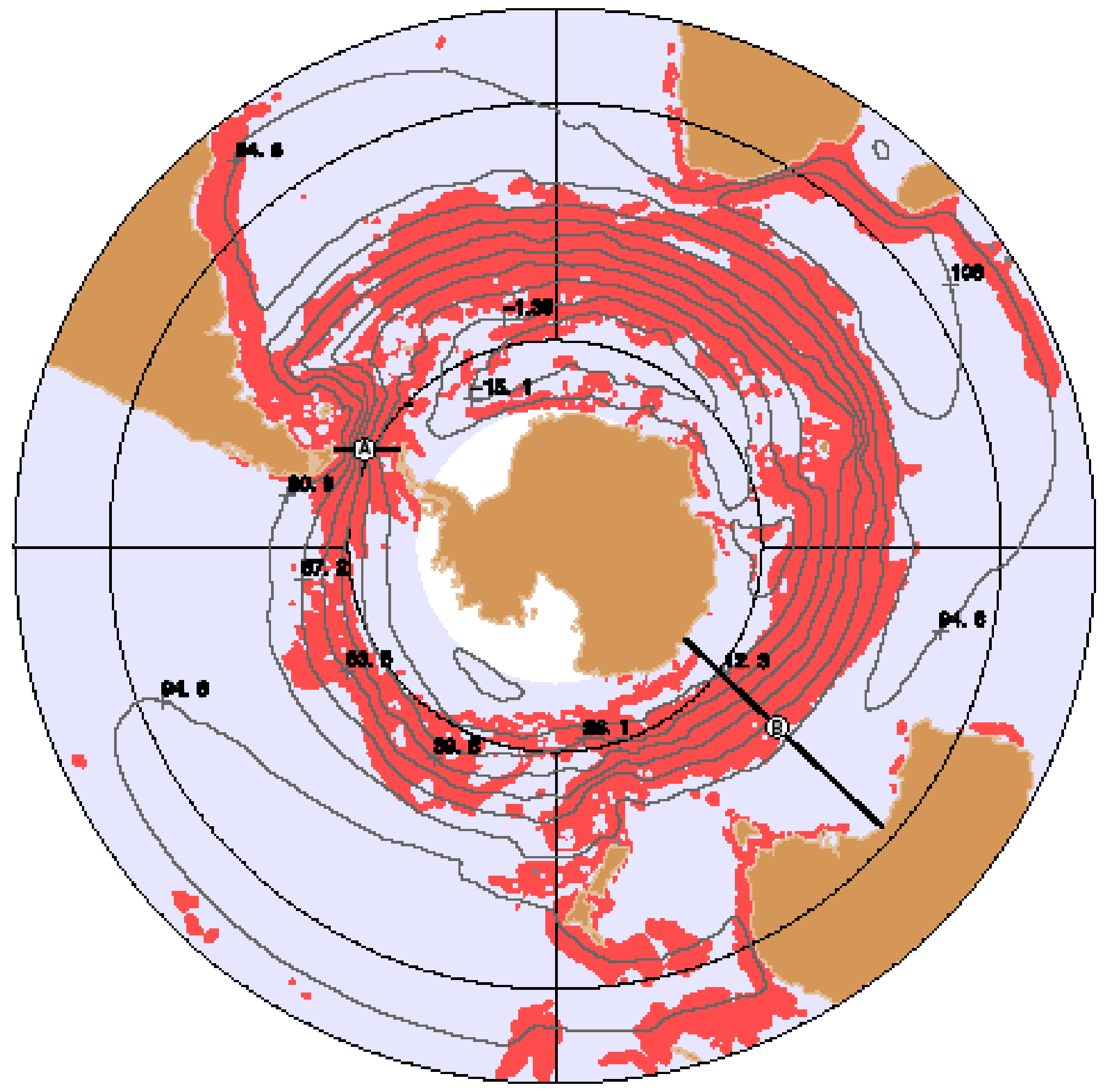


Fig. 1: Mean stream function of the Southern Ocean, and the location of the two ACC sections used in this analysis.

### *Research Strategy*

In this study, we used the Modular Ocean Model (MOM) to execute a series of numerical experiments. The idea is to isolate the contribution from each oceanic basin by forcing the model with a climatological wind stress field everywhere in the domain, except over one specific basin, which its contribution we want to investigate. Over this basin, the wind field is allowed to vary monthly. The model setup is:

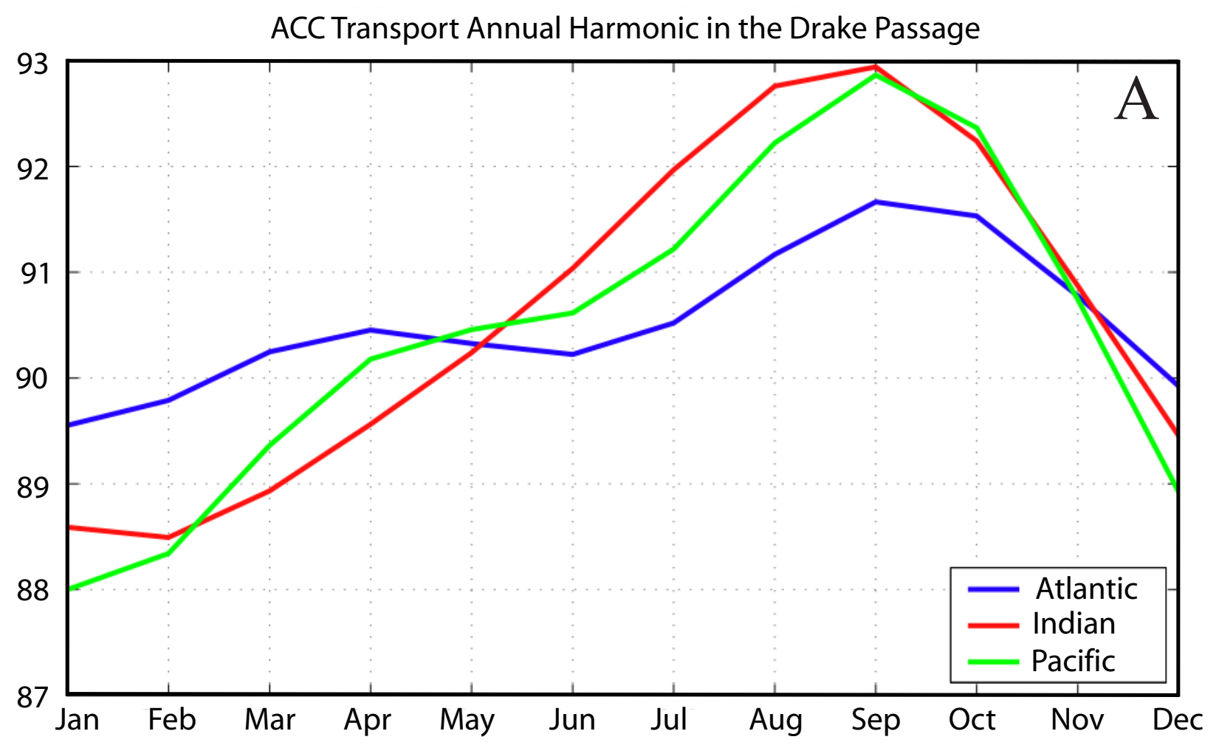
- Domain: a circumpolar window from 70°S to 20°S (Fig. 1)
- Horizontal resolution of 1/2° with 25 vertical levels
- Surface forcings:
  - monthly means of ERA-40 ECMWF reanalysis wind stress (1979-2002)
  - restoring of surface salinity and temperature to Levitus annual means
- Laplacian mixing

After an initial spin-up of 40 years, four experiments were executed:

- Control Experiment: variable wind stress field over the entire domain.
- Atlantic Experiment: variable wind stress field over the Atlantic Ocean; constant elsewhere
- Indian Experiment: variable wind stress field over the Indian Ocean; constant elsewhere.
- Pacific Experiment: variable wind stress field over the Pacific Ocean; constant elsewhere.

### *Seasonal Variability of the ACC transport*

To estimate the seasonal variability of the ACC transport, we calculated its annual harmonic in sections (a) and (b) (Fig. 1). The annual harmonic, in the Drake Passage, for the four experiments with real topography is shown in Fig. 2A. The annual and semi-annual amplitudes are summarized in the table of the Fig. 2B. The results show that the maximum ACC transport occurs in September. The Pacific and Indian basins account for 90% of the ACC transport annual cycle. While, the Atlantic and the Pacific basins account for 80% of its semi-annual cycle.



B

Annual and semi-annual amplitudes

| | Annual Amplitude | | | Semi-annual Amplitude | | |
|---|---|---|---|---|---|---|
| Exper. | Atlantic | Indian | Pacific | Atlantic | Indian | Pacific |
| Drake | 0.72 | 2.15 | 1.94 | 0.53 | 0.38 | 0.88 |
| Australia | 0.67 | 2.17 | 2.00 | 0.53 | 0.34 | 0.90 |

Fig. 2: A) Annual harmonic of the ACC transport at the Drake Passage, for the Atlantic, Indian and Pacific experiments, B) Annual and semi-annual amplitudes, south of Australia and at the Drake Passage, for the Atlantic, Indian and Pacific experiments.

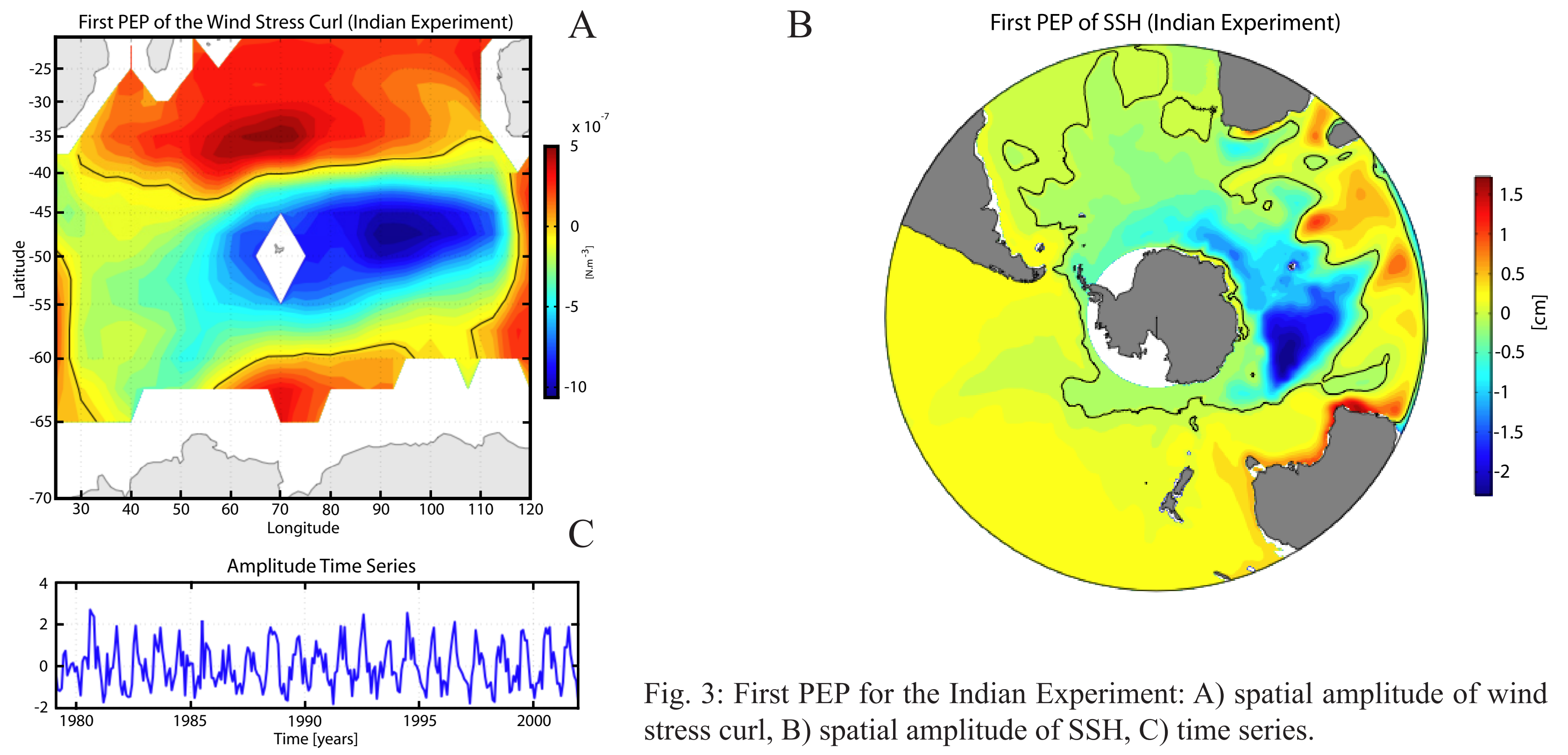


Fig. 3: First PEP for the Indian Experiment: A) spatial amplitude of wind stress curl, B) spatial amplitude of SSH, C) time series.

### *Contribution of the Indian Ocean*

To quantify and the contribution of the winds, over the Indian basin, to the annual cycle of the western boundary currents of the SA, we computed the Principal Estimator Patterns (PEP) of the wind stress curl and sea surface high (SSH). Fig. 3A-C shows the first PEP of the Indian Experiment. There is a maximum/minimum of wind stress curl, east of the Kerguelen Islands, forcing a corresponding maximum/minimum of SSH over the same area. This mode is circumpolar, and it affects, not only the ACC transport, but also the MC transport. The first mode time series (Fig. 3C) shows a strong annual modulation, with maximum/minimum occurring in September/March (winter/summer). Vertical sections of zonal velocities, in the Drake Passage, for the Indian Experiment (not shown), reveal that the Indian signal has almost no vertical shear, and it affects mostly the Polar Front.

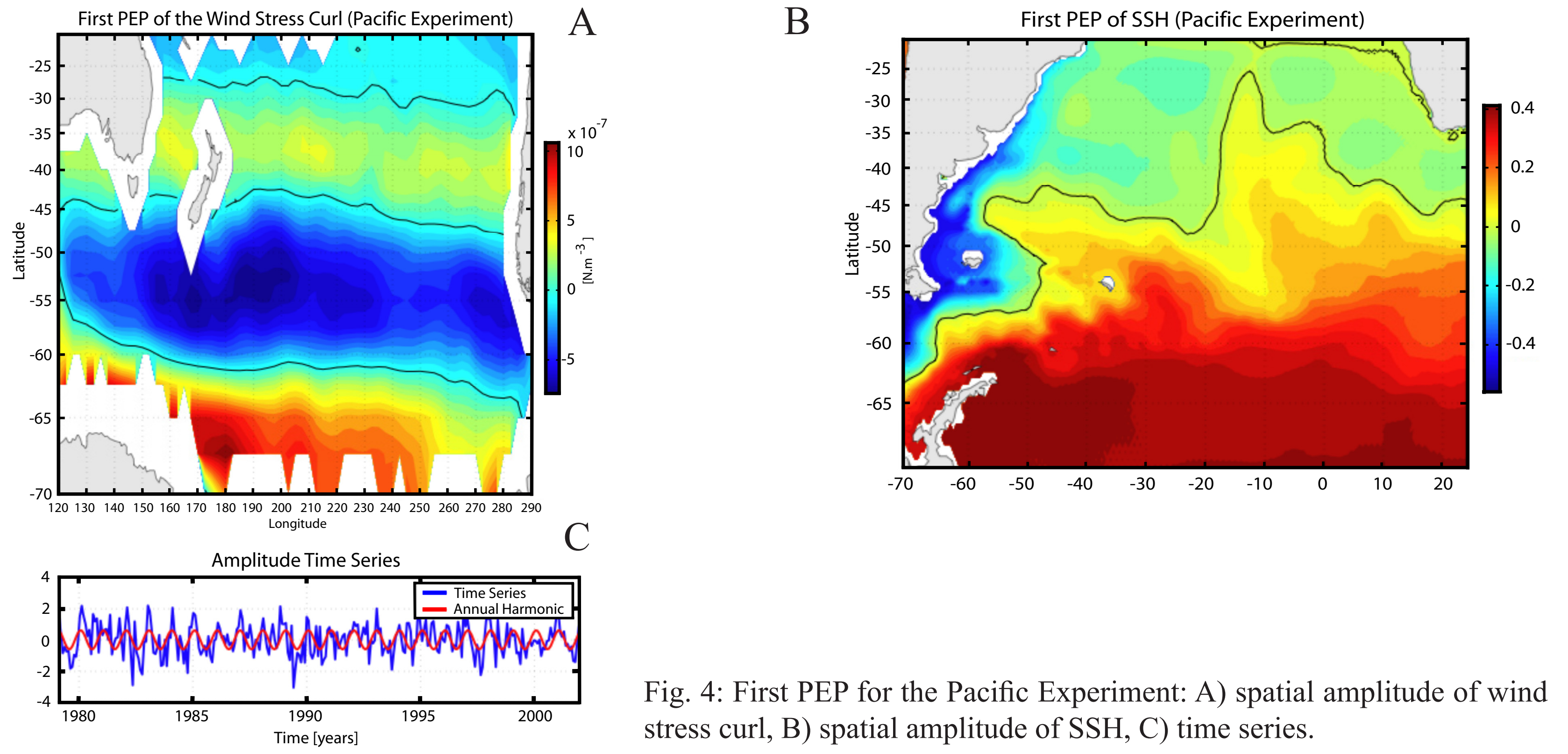


Fig. 4: First PEP for the Pacific Experiment: A) spatial amplitude of wind stress curl, B) spatial amplitude of SSH, C) time series.

### *Contribution of the Pacific Ocean*

The first PEP of the Pacific Experiment (Fig.4A-C) shows a maximum/minimum of wind stress curl centered southeast of New Zealand. This mode shows a corresponding response of the ACC, in the Drake Passage, and of the Malvinas Current as well. The time series also has an annual modulation with maximum/minimum occurring in September/March. Vertical sections of zonal velocities, in the Drake Passage, of the Pacific Experiment (not shown), reveal that the Pacific signal has a strong vertical shear, and it affects mostly the Subantarctic Front.

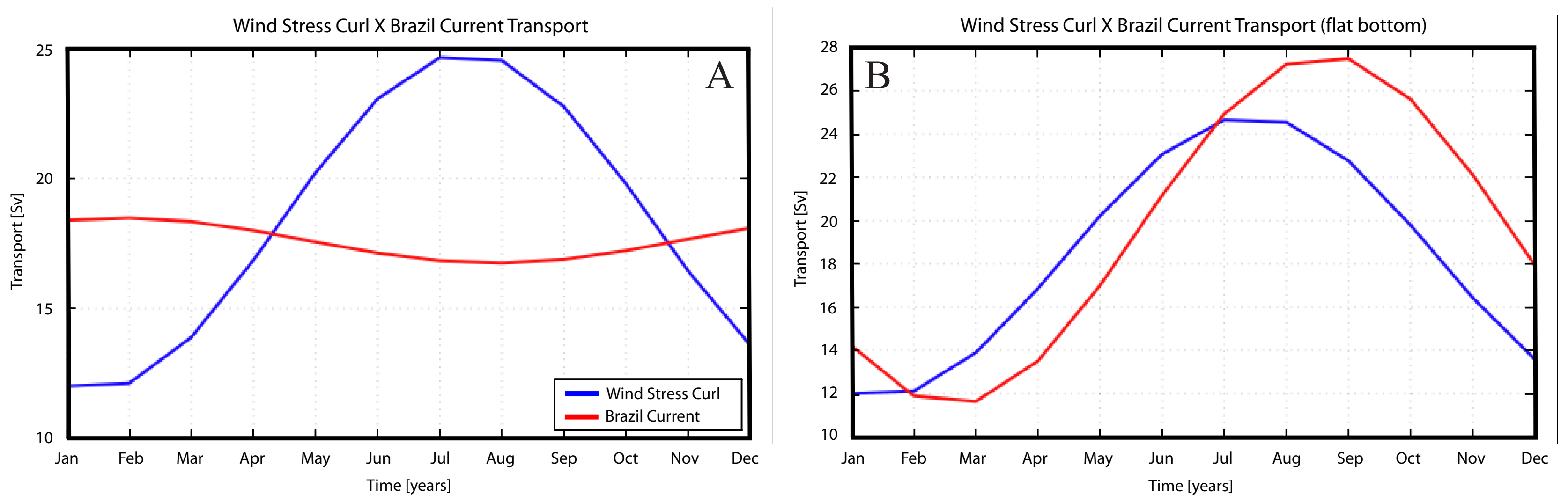


Fig. 5: Annual harmonics of the zonally integrated wind stress curl over the South Atlantic Ocean and of the BC transport: A) real topography, B) flat bottom.

### *Contribution of the South Atlantic Ocean*

The annual cycle of the South Atlantic Subtropical Gyre is in Sverdrup balance in the flat bottom experiment (Fig. 5B). However, when a realistic topography is introduced, not only the amplitudes of the zonally integrated wind stress curl and BC transport are different, but also, they are in opposition of phase (Fig. 5A). Part of the explanation for this, is that, the locally generated annual cycle of the BC transport is actually correlated with the wind stress curl on the southern part of the basin (Fig. 6A). The maximum amplitude of the local contribution to the annual cycle of the BC transport (not shown) occurs at Rio Grande Rise. This signal is then advected southwards by the mean flow of the BC (Fig. 6B). The final phase of the annual cycle of the western boundary currents transport, in the South Atlantic, is determined by the interaction of the local signal with the Indian and Pacific contributions. The Indian and Pacific signals enter the South Atlantic, through the Drake Passage, and propagate northward, through topographic waves, along the Continental Slope of South America (Fig. 6B). The final phase of the annual cycle of the MC and BC is given by the black line in Fig. 6B. It shows that the maximum/minimum BC transport, and the minimum/maximum MC transport occur during March/September.

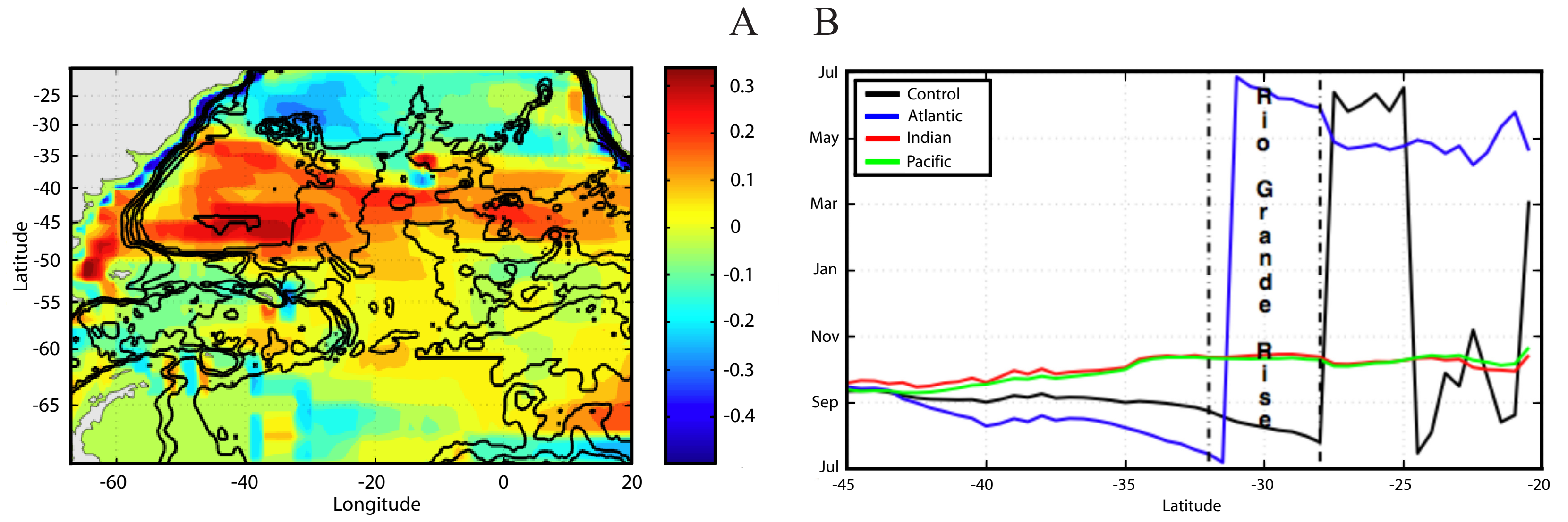


Fig. 6: A) correlation between BC transport and wind stress curl over the South Atlantic Ocean, B) phase of the meridional transport annual cycle ,as a function of latitude, along the coast of South America.

### *Conclusions*

- 90% of the annual cycle of the ACC is generated in the Indian and Pacific basins.
- 80% of the semi-annual cycle of the ACC is generated in the Atlantic and Pacific basins.
- The annual signals, of the ACC, generated in the Indian and Pacific basins, enter the South Atlantic through the Drake Passage, and then propagate northward along the Continental Slope of South America, through topographic waves. The contribution of the Indian Ocean is barotropic, and affects mostly the Polar Front. The contribution of the Pacific Ocean has a strong vertical shear and affects mostly the Subantarctic Front.
- The annual signal of the BC, generated in the South Atlantic, is maximum over the Rio Grande Rise. It is then advected southwards by the mean flow of the BC.