Atmospheric origins of variability in the South Atlantic meridional overturning circulation

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Abstract

Insights from the RAPID–MOCHA observation network in the North Atlantic have motivated a recent focus on the South Atlantic, where water masses are exchanged with the neighboring Indian and Pacific ocean basins. Moreover, the South Atlantic meridional overturning circulation basin-wide array (SAMBA) was recently launched to monitor variability in the South Atlantic MOC (SAMOC) at 34.5ºS. In this study, we are interested in understanding the processes which generate volume transport variability that would be observed at this latitude band. To perform this attribution, we compute sensitivities of the SAMOC at 34ºS to atmospheric state variables (e.g. wind stress, precipitation) using the adjoint of a global ocean model which is fit to a vast number of ocean observations over the past 20 years. These sensitivities isolate the impact from each atmospheric variable, and highlight the oceanic mechanisms, such as Kelvin and Rossby waves, which carry atmospheric forcing perturbations to the SAMOC. The domain of influence for the SAMOC is shown to be quite broad, covering neighboring ocean basins even on short time scales. This result differs from what has previously been shown in the North Atlantic, where Atlantic meridional overturning circulation (AMOC) variability is largely governed by dynamics confined to that basin. We convolve historical forcing variability from ERA-Interim with the computed sensitivities in order to attribute seasonal to interannual SAMOC variability to each atmospheric component. The seasonal cycle of the SAMOC is therefore shown to be largely driven by local zonal wind forcing. Interannual variability, however, is shown to have originated from remote locations across the globe, including a nontrivial component originating from the tropical Pacific. We conclude with preliminary results which employ both modeling results and an analysis of modern altimetry observations to show how El Niño Southern Oscillation variability might influence the South Atlantic.

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Motivation

- South Atlantic hosts complex water mass exchanges, review: [Garzoli and Matano, 2011]
- SAMOC variability impacts severity of summer monsoon [Lopez et al., 2016]
- What mechanisms control variability in the SAMOC?

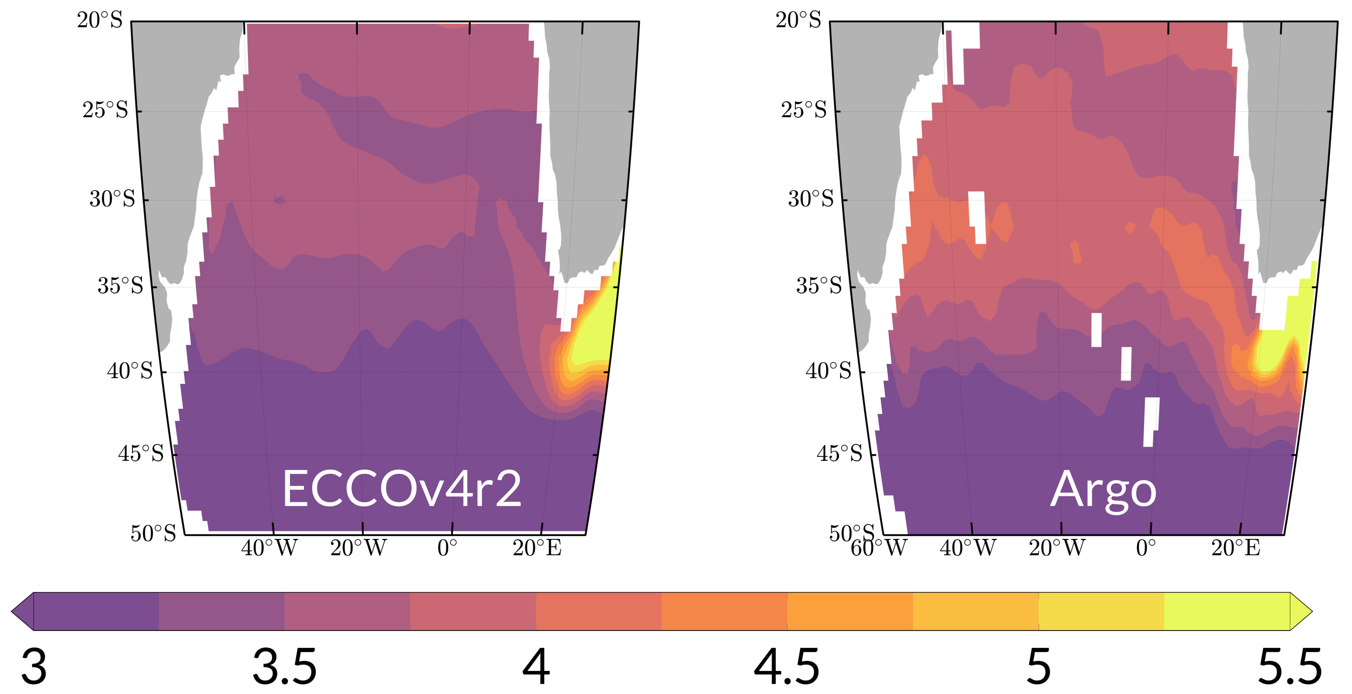
Goal

Attribute seasonal to interannual variability in the SAMOC at 34°S to its geographical origins as atmospheric perturbations.

ECCOv4 state estimate

- represents observations [Forget et al., 2015]
- provides a physically consistent, 4D picture of the ocean state
- equipped with model adjoint for sensitivity analysis

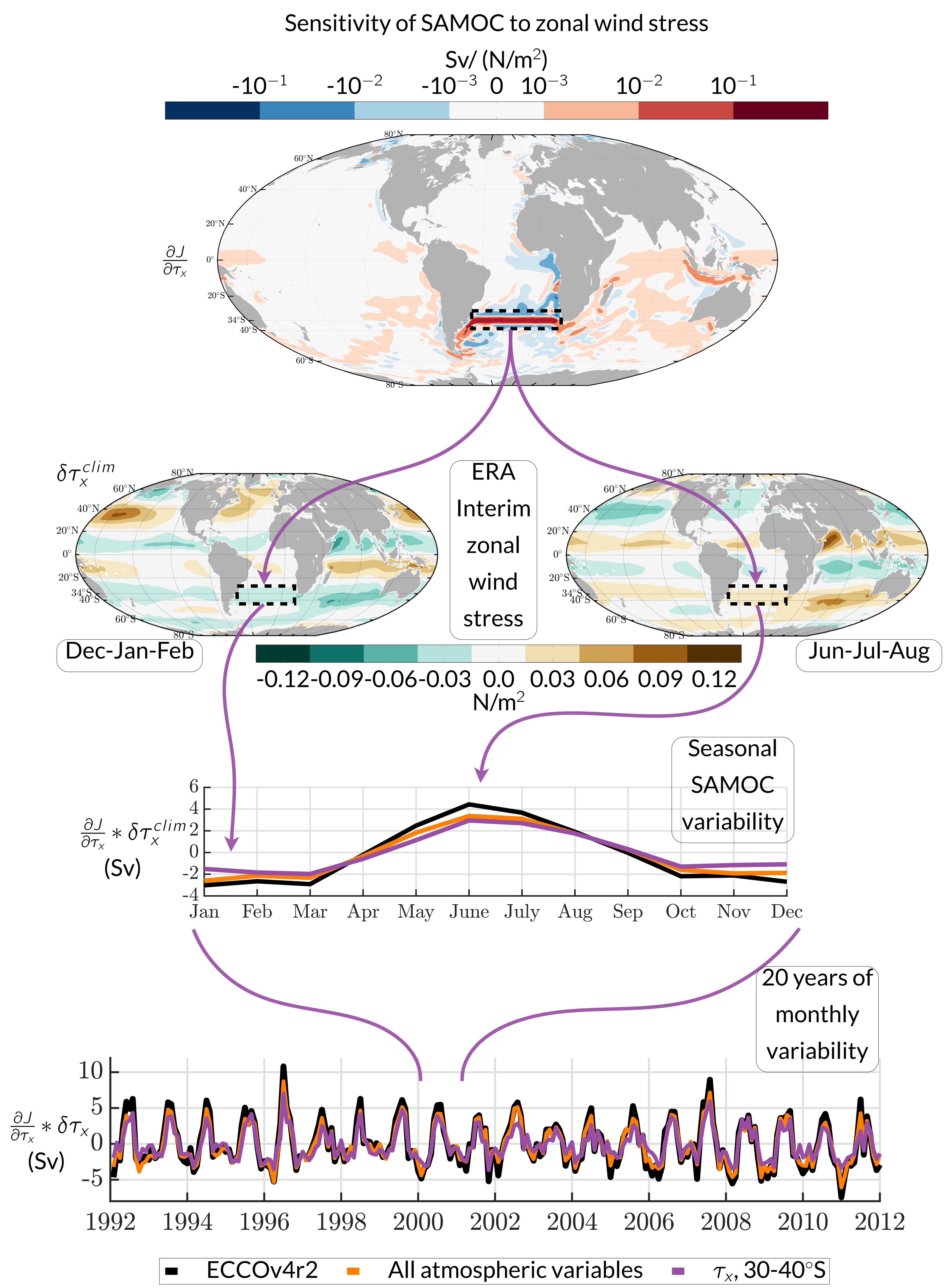
Comparison to observations



Time mean temperature at 1000m depth (°C)

Gridded Argo data from [Roemmich and Gilson, 2009].

For model-data comparisons, cf. [Dong et al., 2014].



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Smith & Heimbach, J. Clim. (2019)

Sensitivity analysis

- Define $J :=$ monthly mean SAMOC at 34°S
- Seek **sensitivity** to atmospheric forcing: $\partial J/\partial \mathbf{F}$
- **Adjoint:** computationally tractable means to compute $\partial J/\partial \mathbf{F}$

Attribution

in the linearized setting

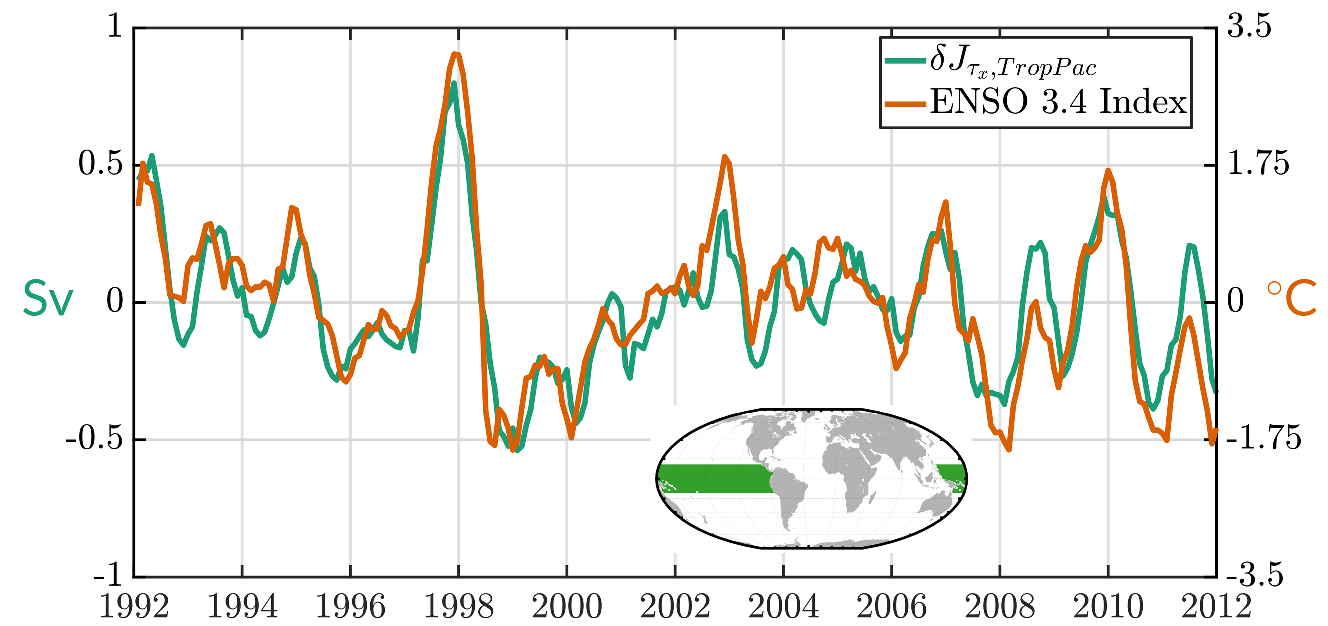
$$J(t) = \underbrace{J_0}_{20\,year\,mean} + \delta J(t)$$

$$\delta J_{Rec}(t) = \sum_k \int_{t-\tau_{mem}}^{t} \int_x \int_y \frac{\partial J}{\partial F_k}(x,y,s-t)\,\delta F_k(x,y,s)\,dx\,dy\,ds$$

requires two ingredients:

- $\delta\mathbf{F} :=$ atmospheric forcing from ERA Interim with ECCOv4r2 adjustments [Dee et al., 2011, Forget et al., 2015]
- $\frac{\partial J}{\partial \mathbf{F}} :=$ sensitivity of SAMOC to atmospheric forcing

ENSO fingerprint



Interannual SAMOC variability attributed to tropical Pacific zonal wind anomalies, communicated via Kelvin wave dynamics

Conclusions

- Zonal wind generates most seasonal SAMOC variability in ECCOv4r2
- Interannual variability has more remote and complex origins
- ENSO can generate variability with similar amplitude as local forcing
- Is this signal observable?

References

[Dee et al., 2011] doi: 10.1002/qj.828
[Dong et al., 2014] doi: 10.1002/2014GL060428
[Forget et al., 2015] doi: 10.5194/gmd-8-3071-2015
[Garzoli and Matano, 2011] doi: 10.1016/j.dsr2.2010.10.063
[Lopez et al., 2016] doi: 10.1175/JCLI-D-15-0491.1
[Roemmich and Gilson, 2009] doi: 10.1016/j.pocean.2009.03.004