Contact: lpatara@ifm-geomar.de

Simulated response of the Antarctic Circumpolar Current to decadal wind changes

Lavinia Patara, Claus Böning, Arne Biastoch

Leibniz Institute of Marine Sciences (IFM-GEOMAR), Kiel, Germany

Introduction

The decadal response of the Antarctic Circumpolar Current (ACC) to the recent strengthening of the Southern Hemisphere westerly winds is investigated. Available observations suggest that the ACC was relatively insensitive to the recent wind increases [*Cunningham et al.* 2003; *Böning et al.* 2008], in contrast with the behavior shown by coarse resolution climate models [*Fyfe et al*. 2007].

By performing global ocean simulations at two different horizontal resolutions (ORCA05 and ORCA025), two issues are here tackled:

- **Control of spurious drift**: Global ocean models are frequently characterized by a spurious ACC drift owing to incorrect across-ACC density gradients [*Treguier et al.* 2010]. This hinders the study of ACC decadal trends.
- **Towards the role of eddies**: Increased eddy activity due to stronger winds is suggested to oppose wind-driven increases in northward Ekman transport and thus to reduce the sensitivity of the ACC transport to the wind strengthening [*Spence et al.* 2010].

Conclusions

The **decadal response of the ACC transport to wind changes** was investigated by performing hindcast simulations with the NEMO-LIM global ocean-sea ice model at different horizontal resolutions. **By controlling the ACC spurious drift,** the ACC variability could be investigated on decadal time scales.

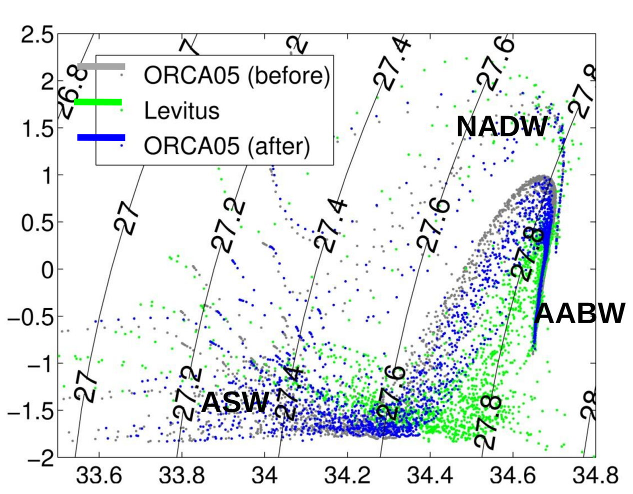
The 1/2 model (non-eddying) and 1/4 model (large eddies are resolved) show strikingly different responses to the westerly wind strengthening in recent decades. In the **lower resolution** model **the ACC transport increases by 22%. In** the **higher resolution** model **the ACC transport increases only by 7%, whereas eddy kinetic energy (EKE) increases by 10% to 50%** in several areas along the ACC. The hypothesis can be made that wind increases in the last decades enhanced EKE instead of steepening isopycnal slopes, thereby reducing the ACC sensitivity to wind increases.

These results bring evidence of the **importance of resolving eddies** (or of correctly parameterizing them) for the adequate simulation of **the Southern Ocean response to future climate change**. The next step in this study will be the explicit simulation of eddies within a 1/12 degree nested model in the ACC regime.

1) Control of ACC spurious drift

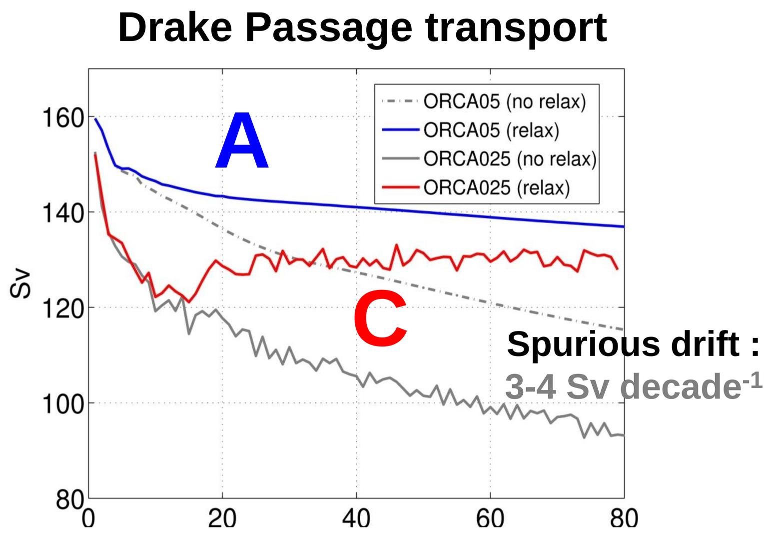
Effect of relaxation in climatological simulations

TS diagram in the Weddell Sea before and after relaxation



Weddell Sea waters are too fresh and cold in the surface, too warm in the 27.6-27.8 kg m^{-3} sigma0 classes.

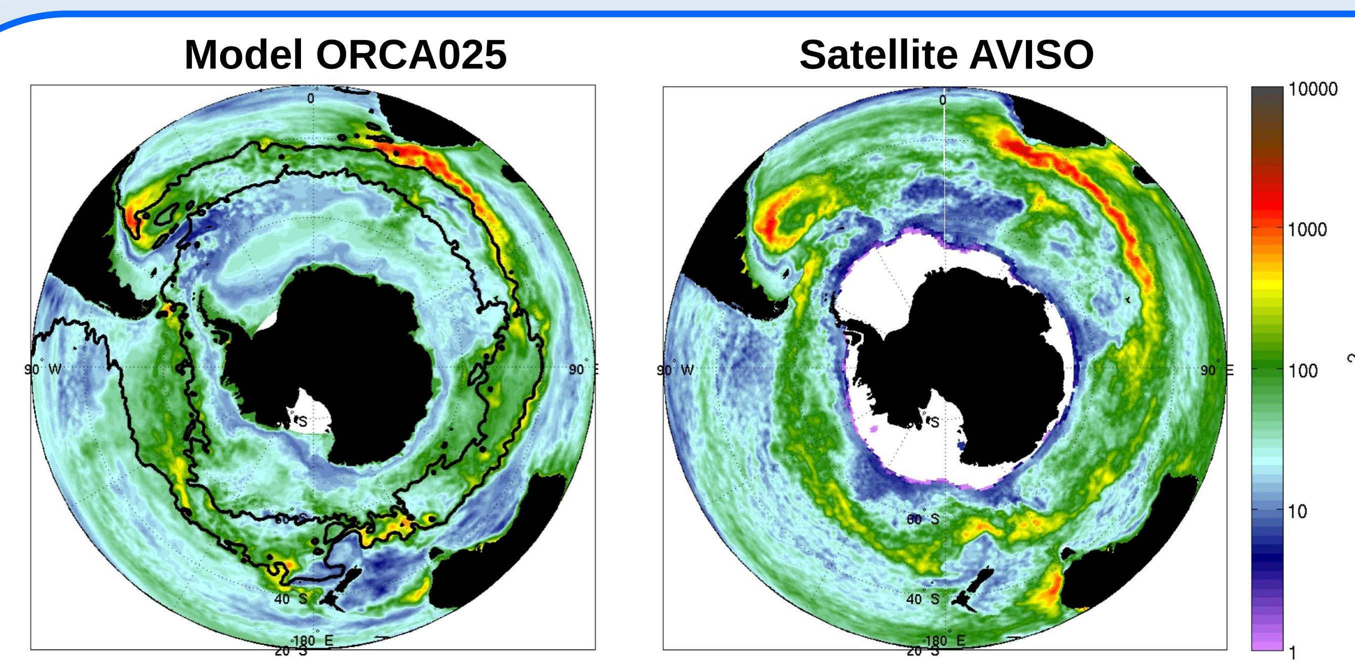
Drake Passage transport



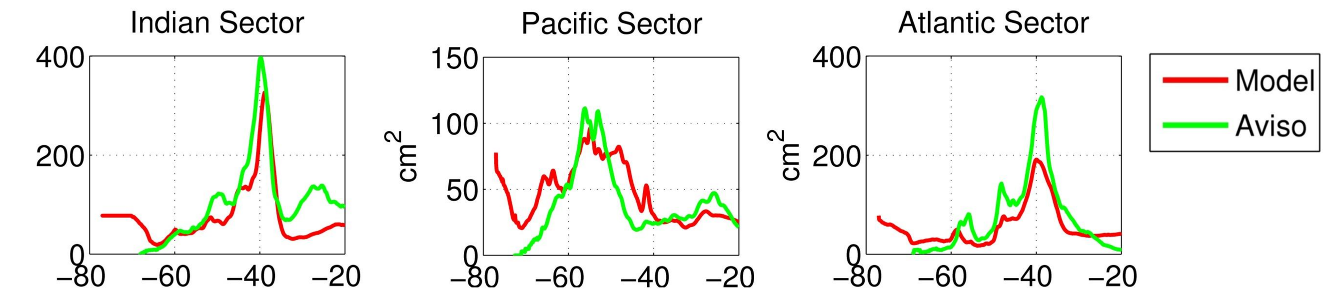
ORCA05: after relaxation, the ACC spurious drift is **corrected by 60%**

ORCA025: after relaxation, the ACC spurious drift is **totally corrected**

2) Verification of model eddy variability



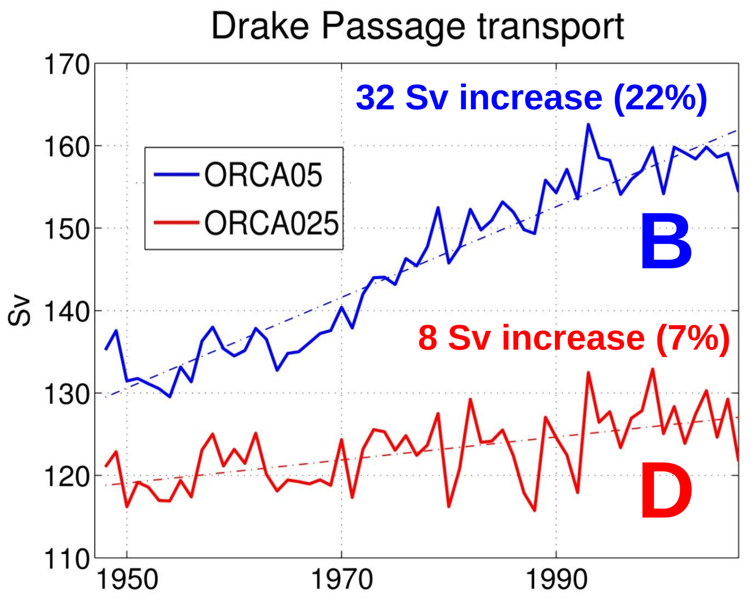
Colors: Sea surface height variance in 2000-2007. Contours: mean horizontal streamfunction (Sv) in ORCA025 (0 and 110 Sv contours)



Right: Zonal means of SSH variance for ORCA025 model (red) and AVISO satellite data (green)

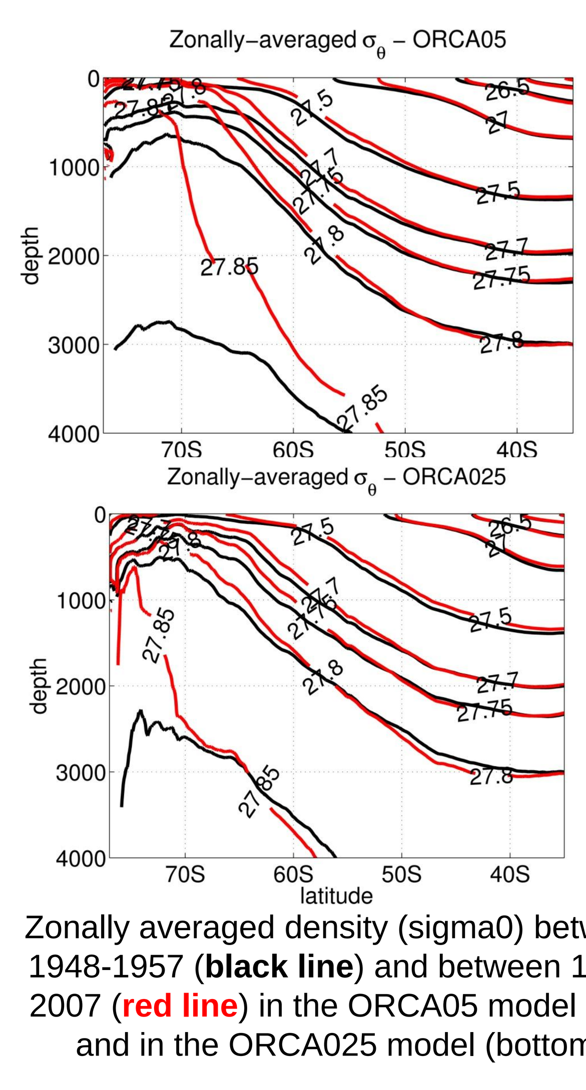
3) ACC response to wind changes: towards the role of eddies

Simulated ACC variability in recent decades



Despite same atmospheric forcing and same relaxation south of the ACC:

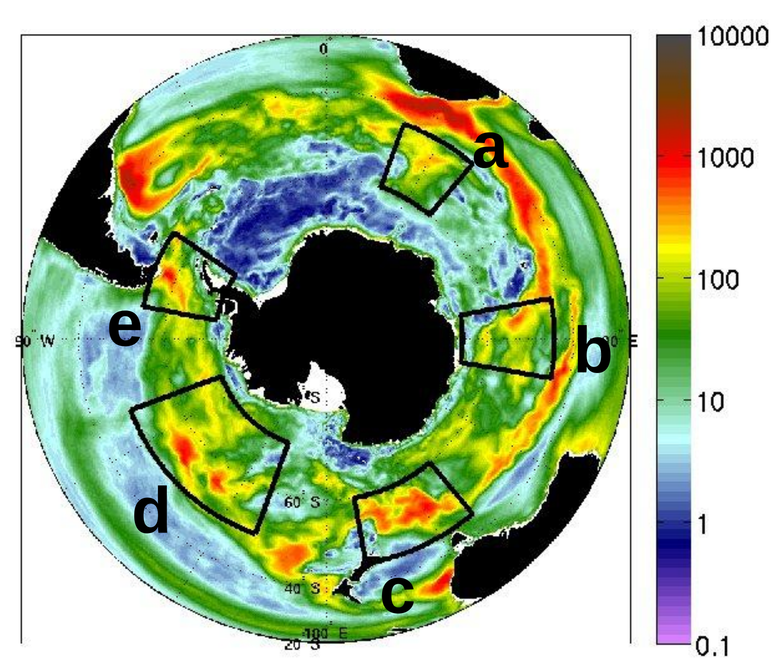
- In the ORCA025 model the **ACC transport** is **less sensitive** than the ORCA05 **model** to the wind increase.
- In the ORCA025 model the **across-ACC isopycnal slopes** steepen less than in the ORCA05 model.

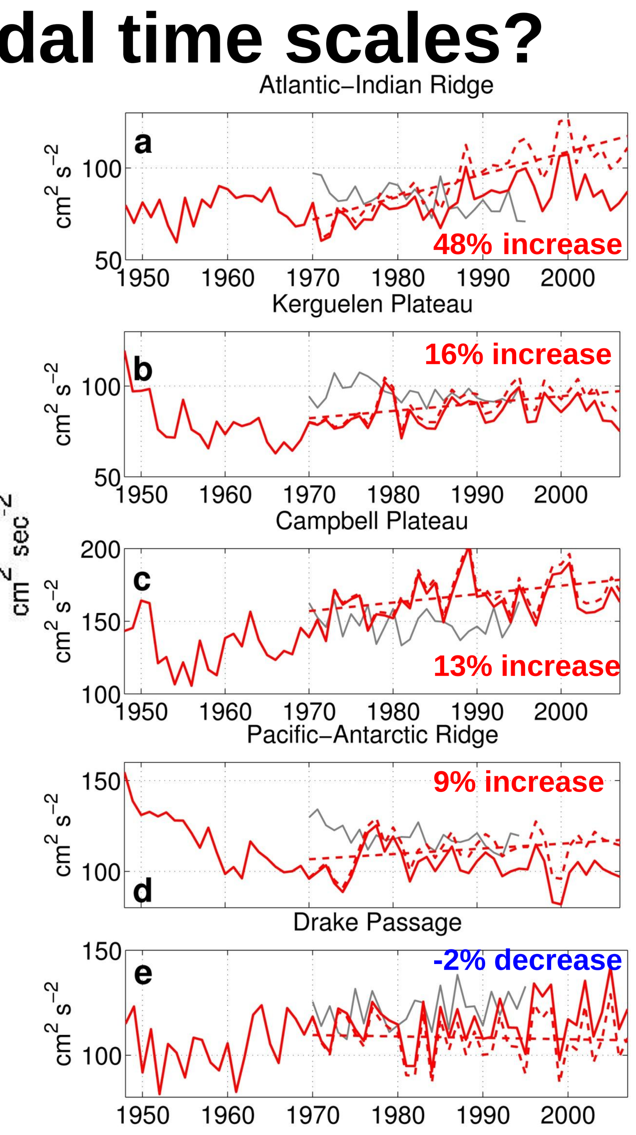


Zonally averaged density (sigma0) between 1948-1957 (**black line**) and between 1998-2007 (**red line**) in the ORCA05 model (top) and in the ORCA025 model (bottom)

Do increased winds enhance eddy kinetic energy (EKE) on decadal time scales?

Mean eddy kinetic energy (cm^2 sec^{-2}) at 55 m depth in **ORCA025**





Right: Time series of EKE in ORCA025. Grey line: climatological experiment. **Red line**: hindcast experiment (dashed lines: time series detrended with climatological linear trend).

Hypothesized mechanism for an eddying model:

Stronger winds increase EKE (as shown also by other studies on interannual time scales, *e.g. Meredith and Hogg, 2006*)

⇩

More eddies are expected to increase southward heat fluxes (yet to be confirmed in this study)

⇩

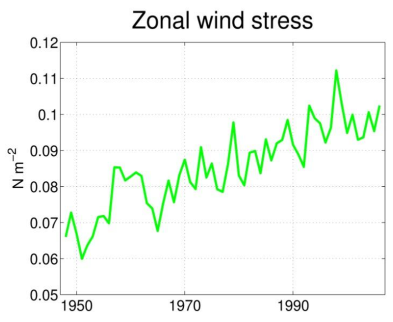
The isopycnal slope steepening in response to wind increases is reduced (shown in this study)

⇩

ACC is less sensitive to decadal wind strengthening

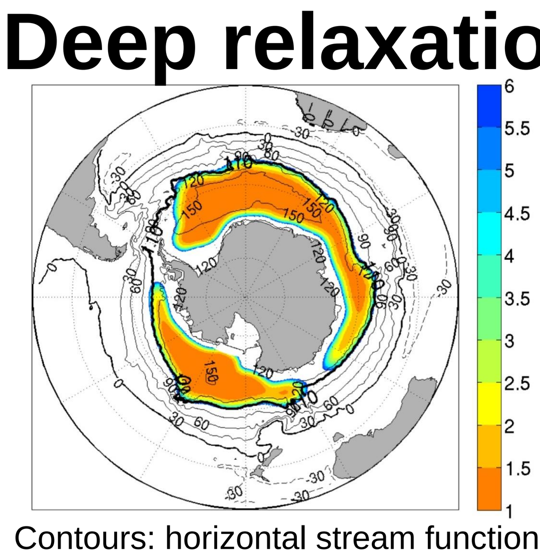
Model configurations

- Model: NEMO-LIM2 [*Madec,* 2008], DRAKKAR configuration.
- Horizontal resolution: 1/2 degrees (**ORCA05,** non-eddying) and 1/4 degrees (**ORCA025,** large eddies are simulated).
- Atmospheric forcing: COREv2 [*Large and Yeager*, 2009]: **climatological** (repeated seasonal cycle) and **hindcast** (interannual forcing for 1948-2007) forcing



Southern Ocean average of zonal wind stress between 1948-2007

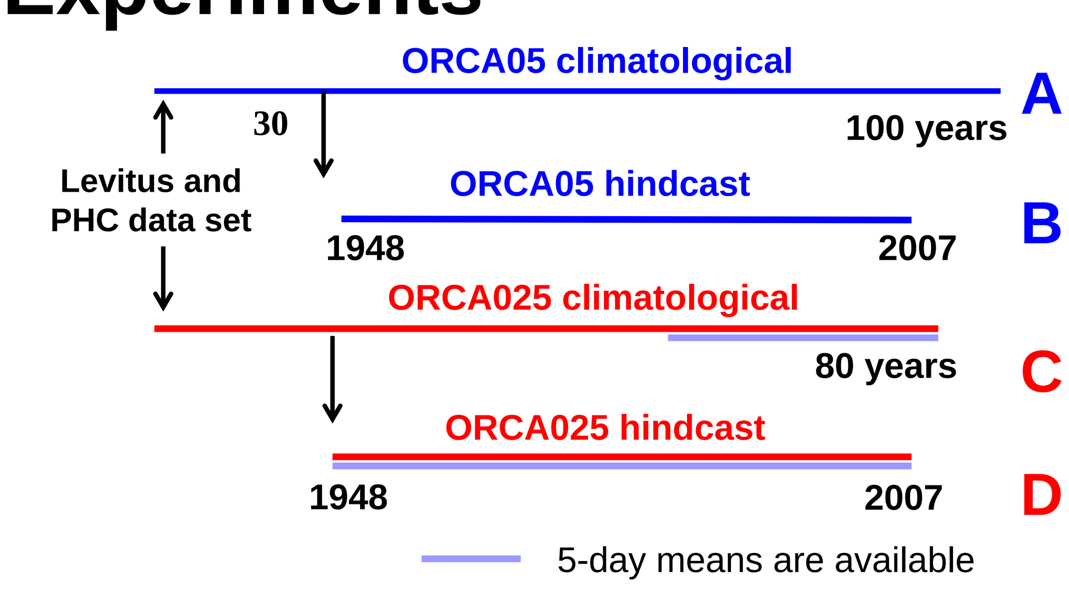
Deep relaxation



Contours: horizontal stream function (Sv), colors: relaxation time scale at 100 m depth (years)

A weak relaxation (>=1 year time scales) to observed temperature and salinity (Levitus-PHC data set) is applied **south of the ACC, deeper than 500 m and away from boundaries**

Experiments



A, B: *Gent and McWilliams [1990]* parameterization for eddy-induced velocities

C, D: No parameterization for eddy-induced velocities

References: Böning et al. (2008), The response of the Antarctic Circumpolar Current to recent climate change, Nature Geosciences, 1(12), 864-869; **Cunningham** et al. (2003), Transport and variability of the Antarctic Circumpolar Current in Drake Passage, JGR, DOI: 10.1029/2001JC001296; **Fyfe** et al. (2007), The role of poleward-intensifying winds on Southern Ocean warming, Journal of Climate 20 (21), 5391; **Gent and McWilliams** (1990), Isopycnal mixing in ocean circulation models, JPO 20(1), 150-155; **Large and Yeager** (2009), The global climatology of an interannually varying air-sea flux data set, Climate Dynamics, 33 (2-3): 341-364; **Madec** (2008), NEMO ocean engine, Note du Pole de modélisation, IPSL, France, No 27 ISSN No 1288-1619; **Meredith and Hogg** (2006), Circumpolar response of Southern Ocean eddy activity to a change in the Southern Annular Mode, GRL, doi:10.1029/2006GL026499. **Spence** et al. (2010), Southern Ocean Response to Strengthening Winds in an Eddy-Permitting Global Climate Model, Journal of Climate, doi: 10.1175/2010JCLI3098.1; **Treguier** et al. (2010), Response of the Southern Ocean to the Southern Annular Mode: Interannual Variability and Multidecadal Trend, JPO, 40 (7), 1659-1668.

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