# Marie Curie IEF "WEDDEL" Final Summary Report *

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April 14, 2010

## 1 Introduction

The Southern Ocean has a strong influence on the global climate. Significant percentages of the global oceanic uptake from the atmosphere of heat and carbon are directly associated with the circulation in the Southern Ocean. For this reason it is important to assess how it is represented the current class of climate models. WEDDEL has compared the 25 global coupled climate models (GCMs) that participated in the Coupled Model Intercomparison Project Phase 3 (CMIP3) that was part of the IPCC AR4 (*IPCC*, 2007) in this respect. During the work on the project three distinct work fields emerged. First, it was investigated why the strength of the Antarctic Circumpolar Current (ACC) varies so strongly across the control runs of the AR4 climate models (see sec. 2.1). Second, WEDDEL contributed to an assessment of the 21st century climate model scenarios with respect to future changes of the ACC (sec. 2.2). The projected ACC changes vary widely and don't even agree on the sign of the changes. Both these work fields identified the crucial role of eddy-induced transports for the large-scale circulation of the Southern Ocean. Unfortunately these could not be directly analysed because the respective data are generally unavailable. However, for WEDDEL's third work field the parameterized eddy-induced transports for one climate model are compared in detail with an eddy-permitting ocean model (sec. 2.3).

*Grant Agreement No. PIEF-GA-2008-220607

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## 2 Results

### 2.1 Quantifying the influence of eddy parameterizations on the ACC in global coupled climate models

Within the class of global coupled climate models used for the IPCC AR4, the strength of the Antarctic Circumpolar Current (ACC) is not well confined. At the end of the control runs, the volume transport through Drake Passage ranges from 34 Sv to 338 Sv, compared with the observed 137 Sv (1 Sv = $10^6$ $m^3s^{-1}$). This is unsatisfying since such a wide range poses a large uncertainty in the scenarios for the future climate. *Russell et al.* (2006) discussed the factors determining the ACC strength in individual models. However, those factors, like the zonally averaged zonal wind stress, cannot explain the ACC variations across all models.

In one part of WEDDEL (*Kuhlbrodt et al.*, 2010) we try to explain the across-model variance using a simple scaling for the baroclinic part of the ACC transport $U_{bcl}$. The scaling is derived theoretically in a way similar to *Marshall and Radko* (2003). It is based on the zonally averaged zonal wind stress $\tau_x$, the meridional density difference across the ACC $\Delta\rho$ and the eddy-induced thickness diffusivity parameter $\kappa$ from the parameterization of the eddy-induced transports that goes back to *Gent and McWilliams* (1990):

$$U_{bcl} \propto (\tau^x/\kappa)^2 \Delta\rho \,. \qquad (1)$$

This scaling is applied to the 25 AR4 climate models. The model data are available at the Program for Climate Model Diagnosis and Intercomparison (PCMDI, `http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php`). [1]

[1]We acknowledge the modelling groups, the PCMDI and the World Climate Research Programme's (WCRP) Working

In those climate models where $\kappa$ is a prescribed constant field, this scaling correlates very well with the ACC strength, with a coefficient of 0.91 in a logarithmic plot (Fig. 1) and thus explains the across-model variance. However, the exponential dependence of the ACC strength on the scaling across the models is much weaker than predicted by the scaling. If the three quantities in the scaling (1) are correlated individually with the ACC strength it becomes clear that the eddy-induced thickness diffusivity explains most of the variance. The importance of $\kappa$ is further underlined by the fact that it is significantly anti-correlated with the models' oceanic heat uptake efficiency [as diagnosed by *Gregory and Forster* (2008)].

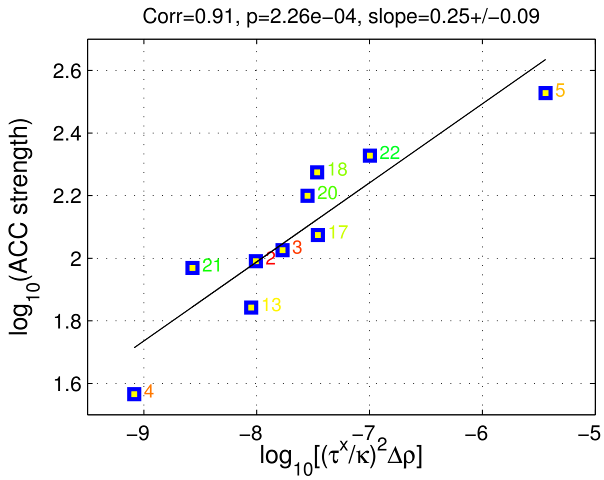


Figure 1: *The ACC strength at the end of the models' control runs against* $(\tau^x/\kappa)^2\Delta\rho$*, a combination of variables according to the scaling (1). The axes are scaled logarithmically. Each dot represents one model. Key to model numbers: 2: CCCMA_CGCM3_1_T47, 3: CCCMA_CGCM3_1_T63, 4: CNRM_CM3, 5: CSIRO_MK3_0, 13: IAP_FGOALS1_0_G, 17: MIROC3_2_HIRES, 18: MIROC3_2_MEDRES, 20: MPI_ECHAM5, 22: NCAR_CCSM3_0. The slope of 0.25, in combination with the strong correlation of 0.91, suggests that actually* $U_{bcl} \propto (\tau^x/\kappa)^{1/2}\Delta\rho^{1/4}$*. The small p-value indicates a high significance (>99%) of the correlation coefficient.*

The core result of WEDDEL is to have identified the crucial parameter from the eddy parameterizations as the strongest control of the ACC strength in the control runs of the climate models. As a first measure to reduce the dependence of a large-scale ocean current and the global heat balance on an individual parameter, the results of *Kuhlbrodt et al.* (2010) suggest using a parameterization of eddy-induced transports with a variable coefficient. The development of high-resolution climate models that resolve the eddy-induced transports should be fostered to eventually overcome the need to parameterize them.

Group on Coupled Modelling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset.

## 2.2 Analysing projections of the ACC transport for the 21st century

Concerning the projections of the ACC strength for the 21st century, the AR4 climate models give a widely diverging picture. From the ensemble mean it cannot be inferred whether the ACC is more likely to strengthen or to weaken in the future. WEDDEL has contributed to a study (*Wang et al.*, 2010) that analysed the AR4 climate models in detail to assess the reasons for this diverging picture. While all models show stronger westerlies over the Southern Ocean, which should accelerate the ACC through Ekman pumping, changes in the heat and freshwater fluxes have the opposite effect in some models. In other models the subtropical and subpolar gyres change their extent. This narrows and thus weakens the ACC.

The southward shift of the westerlies and the initial oceanic stratification can have strong effects in individual models. The analyses suggests that eddy-induced transports play a very important role as well since in the models changes of these transports are linked to changes in the three-dimensional density field. The subtle balance of all these effects could also explain why the ACC in the real ocean has hardly changed at all in the past decades in spite of the accelerated westerlies (*Böning et al.*, 2008).

## 2.3 The eddy-induced overturning circulation in the Southern Ocean

Mesoscale eddies are an essential part of the circulation in the Southern Ocean. From experiments with eddy-resolving models (*Hallberg and Gnanadesikan*, 2006) it is known that the eddies achieve a substantial southward heat transport. For estimates of the heat uptake of the Southern Ocean, or the heat transport within the Southern Ocean, it is therefore crucial to represent the eddy-induced transports properly in models. In this part of WEDDEL, a typical AR4 GCM (HadCM3) with parameterized eddies is compared in this respect with an eddy-permitting ocean model (ORCA025). This comparison is done within an ongoing collaboration with the University of Stockholm, Sweden, and the Royal Meteorological Institute of the Netherlands (KNMI).

For the comparison of the models meridional overturning streamfunctions are a useful tool. First results from HadCM3 indicate that the contribution of short-term variability to the total (or "residual") overturning is very similar in shape and strength to the eddy-induced overturning. This is remarkable since HadCM3 cannot resolve oceanic eddies. Obviously there is considerable short-term variability in the velocity field in the Southern Ocean. The analysis suggests as well that the parameterized eddy-induced overturning does not have such a short-term variability component.

Further analysis will cover the effect of spatial averaging, which should reveal the contributions of small-scale variability and large-scale meanders, or "standing eddies". It is planned to submit a common paper with the Swedish and Dutch collaborators, including the results from ORCA025, later in 2010.

# 3 Socio-economic Impact

The project WEDDEL was set in the field of physical oceanography and was built mainly on the analysis of data from the ocean components of climate models. This has led to recommendations how to improve the existing climate models. These models, in turn, have a strong socio-economic impact since the general discussion about climate change rests on scenarios of the future climate computed with these models. Therefore it is obviously desirable to continuously improve these climate models.

It is hoped that WEDDEL has contributed to these ongoing improvements by identifying the need to improve, and eventually overcome, the parameterization of eddy-induced transports in ocean models. It is very likely that this will lead to a more realistic and more reliable representation of the general circulation in the Southern Ocean, including the directly climate-relevant processes of heat and carbon uptake.

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