# USE OF THE GOCE MISSION FOR THE DETERMINATION OF SEA LEVEL AND ANTARCTIC CIRCUMPOLAR CURRENT

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## AIMS

We will use data from the GOCE satellite missions in order to determine structure and transport of the Antarctic Circumpolar Current and the Weddell Gyre. This will be the basis for the calculation of large-scale exchange processes between the Pacific, the Atlantic and the Indian Ocean. Our aim requires a detailed and exact description of the ocean circulation and its associated transports of heat and tracers which we propose to obtain by assimilation of highly accurate sea level data in an ocean circulation model. Data assimilation combines a set of diverse information that stems from oceanographic in situ measurements, remote sensing data, altimeter values and geoid models on the one hand with modelled ocean dynamics on the other hand. We derive a dynamically consistent, mass- volume-, heat- and salt-conserving solution of the ocean model. It describes the evolution of the sea level, currents and water mass distributions in accordance with the measurements and important transports and features of the global ocean circulation are derived.

## STATUS OF RESEARCH

The determination of the transport of the Antarctic Circumpolar Current causes problems in ocean models. A widespread use is the prescription of its value at Drake Passage. Alternatively an implicit prescription by tuning model friction, coastlines or bathymetry is commonly used. In this context inverse models are similar with the exception of box-inverse models. However, due to their very poor resolution only integral properties form reliable results. The spatial structure remains unresolved. The use of satellite altimetry to derive transport values sometimes leads to contradictory results [1] or remains unrealistic [2].

In addition to the Antarctic Circumpolar Current the deep ocean circulation plays a major role in the exchange between the large ocean basins. In this context the Weddell Gyre is a dominant location of Bottom Water production, which in turn ventilates the major part of the deep global ocean. Production rates are still difficult to estimate with confidence. An important process for the preconditioning of the water masses is the inflow of water into the eastern Weddell Gyre. The role of eddy transports compared to that of the coastal current is currently a focus of attention [3].

Until now, assimilation of altimetry referenced to a geoid model to infer absolute ocean currents is applied very little. The major reason is due to the fact that the accuracy of only a few centimeters which is required for this purpose can be achieved only for the largest spatial scales. This situation will improve substantially with the availability of GRACE and GOCE data and will enable us to use length scales which are relevant for the calculation of oceanographic transports [4].

## PREVIOUS WORK

For more than a decade the Antarctic Circumpolar Current and the Weddell Gyre have been a focus of research at the Alfred-Wegener-Institut. Different modelling approaches, in situ measurements and remote sensing data are being used in order to understand processes, describe water mass conversions and estimate fluxes. Hydrographic data were assembled and analysed in a Hydrographic Atlas of the Southern Ocean [5]. They form the basis for inverse studies [6]. Repeat hydrography and current measurements were combined by [7] in an inverse model for the southwestern Weddell Gyre.

Assimilation of sea level data into eddy resolving quasi-geostrophic models was presented in a number of articles [8,9,10]. For the Antarctic Circumpolar Current these models were applied by [2] and [11]. On the whole the results remained unsatisfactory. Concerning the global circulation the LSG model was used by [12] to assimilate hydrography, altimetry and other data types much in the sense of 'eclectic modelling' as suggested by [13]. In a sensitivity study prepared for ESA [4] the impact of the GRACE and GOCE missions on improving our oceanographic knowledge was considered. The study focusses on climatologically-important large-scale transports and their error budget. For the Antarctic Circumpolar Current we hope to achieve reductions in uncertainty of 50% and more [14].

In this context, the transformation of a geoid error covariance calculated in spherical harmonics onto common oceanographic basis functions posed a surprisingly complex problem. One has to take care to prevent omission errors due to a finite expansion in one basis to project substantially onto the new basis of expansion and thus reduce the possible accuracy. A filtering technique which fulfills this requirement is presented by [15] in his dissertation.

A spectral expansion of altimetric surfaces into eigenfunctions of the shallow- water equations was derived by [16]. It was applied for simple geometries in order to describe the slowly varying part of the sea-level fluctuations and the associated barotropic currents.

## WORKPROGRAMME

The proposed work concentrates on three interleaved areas:

1. Assimilation

The finite element model FENA of the SEAL Project is modified to cover the South Atlantic region south of 30°S between Drake Passage and the Kerguelen Plateau. At the open boundaries a solution of the global LSG model is imposed. This solution is derived in the SEAL project. Whether the inflow in the eastern part of the Weddell Gyre is driven by the mean flow or by eddy fluxes is one of the main questions. In order to study this issue the resolution of the finite element model has to be refined. Because of increased computational demand one has to port the model code to massive parallel computer architectures. For similar reasons the assimilation technique employed will be Ensemble Kalman Filtering.

2. Spectral Decomposition

Once gravity is known with high resolution altimetric data quality has to increase as well. The common practise of closing data gaps with the help of objective analysis deteriorates the originally high resolution along track. We will expand altimetric measurements into spectral functions (Proudman functions, eigenfunctions) and thus produce continuous and dynamically consistent fields of the sea surface topography. These spectral functions provide a clearly improved spatial resolution. They can also be used for predicting the sea level evolution.

3. Gravity Field

In addition to hydrography and altimetry the gravity field is needed as a frame of reference for assimilation. The data must be weighted according to the gravity fields error covariance. Shape and size of the error covariance will therefore have an effect on the solution. We will use various geoid models and error covariance estimates. Residuals are part of the solution obtained by data assimilation. The analysis of their structure together with the error covariances yields interpretations of their origin. Are they systematic ocean model errors or geoid undulations not contained in the geoid models?

## RELATIONSHIP TO OTHER PROJECTS

This project builds on previous work and on work performed in the context of the HGF-Strategiefondproject 'SEAL'. In SEAL the sea level of the past 15 years is reconstructed from oceanographic, hydrologic and altimeter data. A nesting technique is applied in the North Atlantic and North Sea using the regional models FENA and TRIM3D for an increased spatial resolution. In contrast to SEAL the focus is changed here. By assimilation of GRACE and GOCE data with their increased resolution we will use the measurement of the sea level to improve our knowledge about the ocean circulation.

## REFERENCES


[1] P. LeGrand, Impact of the GOCE gravity mission on ocean circulation estimates: Part I. Volume fluxes in a climatological inverse model of the Atlantic. Submitted to *J. Geophys. Research*., 2000.

[2] G. Seiss, J. Schröter, V. Gouretski, Assimilation of GEOSAT altimeter data into a quasi-geostrophic model of the Antarctic Circumpolar Current, *Monthly Weather Review*, 125,1598-1614, 1997.

[3] M. Schröder, E. Fahrbach, On the structure and the transport in the Eastern Weddell Gyre, *Deep-Sea Research* II, 46, 501-527, 1999.

[4] E. Dombrowski, P. Legrand,, C. LeProvost, P.Y. LE Traon, M. Losch, F. Ponchaut, J. Schröter, B. Sloyan, N. Sneeuw, Impact of the GOCE mission for ocean circulation study, Report European Space Agency, Contract ESTEC Nr 13175/98/NL/GD, 157pp, 1999.

[5] D. Olbers, V. Gouretsky, G. Seiss, J. Schröter, Hydrographic Atlas of the Southern Ocean, Alfred-Wegener-Institut, Bremerhaven, 1992.

[6] U. Dobrind, Ein Inversmodell für den Südatlantik mit der Methode der Finiten Elemente, Dissertation, Universität Bremen, 131pp, 1999.

[7] A. I. Yaremchuk, J. Schröter, Spectral analysis of symmetric operators: Application to the Laplace Tidal Model, *Journal of Computational Physics*, 147, 1-21, 1998.

[8] J. Schröter, U. Seiler, M. Wenzel, Variational assimilation of GEOSAT data into a eddy-resolving model of the Gulf Stream extension area, *Journal of Physical Oceanography* ,23, 5, 925-953, 1993.

[9] A. Vogeler, J. Schröter, Assimilation of satellite altimeter data into an open ocean model, *Journal of Geophyscal Research* , 100, 15951-15963, 1995.

[10] A. Vogeler, J. Schröter, Fitting a regional ocean model with adjustable open boundaries to TOPEX/POSEIDON data, *Journal of Geophysical Research*, 104, 20789-20799, 1999.

[11] J. Zou, J. Schröter, Nudging TOPEX/POSEIDON sea surface height data into a eddy-resolving quasi-geostrophic model of the Southern Ocean, *Berichte Fachber. Physik*, 78, Alfred-Wegener-Institut, Bremerhaven, 1997.

[12] M. Wenzel, J. Schröter, D. Olbers, The Annual Cycle of the Global Ocean Circulation as Determined by 4DVAR Assimilation, *Progress in Oceanography*, in press.

[13] C. Wunsch,, An eclectic ocean circulation model Part I: The Meridional Flux of Heat. *J. Phys. Oceanogr.*, 14, 1712-1733, 1984.

[14] J. Schröter, M. Losch, B. Sloyan, Impact of the GOCE gravity mission on ocean circulation estimates: Part II. Volume and heat fluxes across hydrographic sections, *Journal of Geophysical Research*, submitted.

[15] M. Losch, Analyse von hydrographischen Schnitten mit Hilfe von Satellitenaltimetrie, Dissertation, Universität Bremen, 2000.

[16] M. Yaremchuk, D. Nechaev, J. Schröter, E. Fahrbach,, A dynamically consistent analysis of circulation and transports in the southwestern Weddell Sea, *Annales Geophysicae*, 16, 1024-1038, 1998.