Assessment of ocean ventilation in a nested earth system model

Are simulated oceanic bottlenecks between ocean and atmosphere realistic at high spatial resolution?

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Kurzgefasst

- Simulations with a nested version of the Earth system model FOCI with transient tracers are envisioned.
- Experiments will enable a comparison between simulated regionally eddy-resolving convection events and observations and thereby facilitate the development of more reliable tools projecting into our warming future.
- A total of 195 kNPL and 85TB are being requested for the period 01.04 - 31.12.2023.

Context In a warming world, the fate of greenhouse gases emitted to the atmosphere ranks among pressing societal question. Among the tools employed to quantify fluxes of carbon between the ocean, the atmosphere and land are numerical Earth System Models (ESM) featuring an explicit representation of the oceanic carbonate system. The reliability of ESM in terms of simulating atmospheric CO_2 concentrations is linked to the reliability of their ocean circulation module. As the oceanic circulation turns over abyssal water and exposes them to the surface (that is subject to air-sea gas exchange) an equilibrium between atmospheric and oceanic carbon pools evolves. Hence, a quicker or slower oceanic carbon overturning modulates atmospheric greenhouse gas concentrations. This, in turn, implies that a realistic representation of ocean circulation in general and ocean ventilation in particular is inevitable - if ESM projections of oceanic carbon uptake and resulting atmospheric greenhouse gas concentrations are to be trusted.

Problem Ocean ventilation, i.e. the exchange between surface and abyssal waters cannot be observed directly. Processes involved include turbulent diffusion driven by breaking internal waves, double diffusion resulting from differences in the molecular diffusion of salt and heat, wind driven up- and downwelling resulting from divergences (and convergences) in surface currents and buoyancy-driven convection events such as effected by cooling surface waters which thereby gain density and destabilize the water column. A direct observation of all these processes is hindered by their temporal intermittency and rather small spatial scales (e.g. centimeters to kilometers for convective events) and general challenges associated to monitor in situ 3-dimensional flow fields. An alternative approach to assessing the realism of ocean ventilation in ocean circulation models that bypasses these challenges, is to focus on cumulated effects of ocean ventilation which are easier to observe. This has triggered interest in so-called transient tracers - substances that feature temporally varying atmospheric concentrations which equilibrate with respective oceanic concentrations and which can be measured in seawater down to sufficient accuracy.

The transient tracers CFC-11 and CFC-12, both chlorofluorocarbon gases of purely anthropogenic origin are linchpins in assessing simulated ocean circulations as relevant for the oceanic carbon uptake of anthropogenic carbon. Among the reasons is an emission history starting in the 1930s that is similar to CO2, a comprehensive quantitative understanding of air-sea transfer, negligible oceanic sources and sinks, and a comprehensive global dataset of observations.

Among the challenges associated with using transient tracers to assess ocean circulation in general and oceanic ventilation in particular is that the inference of mean ventilation ages from CFC concentrations is not straightforward because this inference is potentially biased by: effects of gridding, internal ocean variability and effects of the nonstationarity of the atmopsheric transient in combination with oceanic mixing. This necessitates the explicit simulation of CFC-11 and CFC-12 rather than using artificial, computationally more efficient approaches to estimate ventilation ages in ocean circulation models.

Numerical Method The planned project is designed to allow for an assessment of simulated oceanic convection as relevant for the uptake of anthropogenic carbon in a global coupled atmosphere ocean circulation biogeochemical model featuring a spatially highly-resolved nest in the convection regions of the North Atlantic. The model to be assessed is the FOCI model as currently employed within the EU Horizon 2020 OceanNETs project. In a nutshell FOCI couples general ocean circulation models of the atmosphere and the ocean. The respective circulation models are basically numerical solutions to the Navier-Stokes equations. Because of the size of respective numerical grids used to discretize the ocean and the atmosphere the respective computations are High Performance Computing tasks necessitating access to large scale facilities such as the HLRN.

For all of our simulations, we will follow the experimental protocols outlined in HLRN-FOCI project shk00043 with the only differences being in the nested configuration of the model and an explicit representation of chlorofluorocarbon gases in the ocean module of FOCI instead of pelagic biogeochemistry. Each simulation will be integrated for 5 decades which resembles the utmost time period to be resolved with CFCs. The time period covers the rapid increase in CFC-11 and CFC-12 between 1950 and 2000 and will give guidance on the question as to the extend the model can reproduce the intrusion of CFCs into the ocean realistically. Further, the simulations proposed here will be compared with coarse-resolution simulations (note that the respective computational demand is not listed here because it can be covered by in-house facilities).

Experimental Design The project faces the challenges that the inference of mean ventilation ages from CFC concentrations are potentially biased by effects of gridding, internal ocean variability and effects of the non-stationarity of the atmospheric transient in combination with oceanic mixing (e.g. Fine et al. 2017). We will address these challenges by resampling the model analogous to the observational sampling schedules instead of binning and extrapolating observations prior to analysis. Further we will perform an ensemble of simulations in order to assess the effect of internal variability and the sensitivity to ocean mixing.

In total, we will perform an ensemble of 5 simulations each of which starting off existing spinups obtained in shk00045. More specifically we will branch off all simulations from historical shk00045 runs. The ratio behind the experimental design is to get a measure of the uncertainty that is associated with (1) ocean variability as effected by potentially chaotic intrinsic variability of the coupled ocean-atmosphere system and (2) the effects of oceanic mixing. This will facilitate the interpretation between simulation and observations because the respective deviations can then directly be ranked against the effects of mixing and intrinsic variability.

As for the effects of intrinsic variability we propose to integrate three simulations that are identical except for that their respective spinups had been branched off at differing time slices of a preindustrial spinup run into quasi-equilibrium. This will provide three timeseries that differ (slightly) in terms of their internal dynamic state at the start of the CFC releases into the atmosphere.

As for the effects of oceanic mixing we propose to integrate 2 simulations featuring a modification of the prescribed oceanic background diffusivity by plus and minus 20%. Note that the öcean mixingëxperiments are not intended to explore the effect of mixing on the general circulation which, in turn, affects the distribution of CFCs in the ocean. Rather, we set out to explore the direct effects of changes in prescribed mixing.

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http://www.geomar.de

Weitere Informationen

[1] Fine, Peacock, Maltrud, and Bryan (2017). A new look at ocean ventilation time scales and their uncertainties, JGR Oceans.