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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In Short

- Simulations of transient abiotic tracers from 1930 to 2020 are planned in an Earth system model FOCI.
- Experiments will enable the comparison between simulations and the most updated CFCs/SF6 observations and thereby contribute to understanding ventilation processes in a warming ocean.
- This research aims to investigate the mismatch of deoxygenation between general model simulations and observations.

Observations indicate that up to 2% of dissolved oxygen (O_2), the basis of survival for marine animals, has been lost in the ocean from 1960 to 2010 [1]. It is abundantly clear that this declining O_2 brings extra pressure to the ecosystems[2]. However, this process, as so-called ocean deoxygenation, is not well represented in the current Earth system models [3]. Addressing the significant underestimation of deoxygenation and the large biases in the volume of the oxygen minimum zone in the model ocean requires further investigation of the physical processes that supply O_2 and the biological processes that consume it in a transient ocean.

The ventilation, the transport process from the ocean surface to the ocean interior, plays an important role in O_2 supply in the ocean. Under a warming ocean, the possible slower ventilation contributes up to 85% of total O_2 loss [4]. However, this oxygen supply process i.e. the mixing of 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).

An alternative easier approach to assess ocean ventilation in ocean circulation models is to focus on the cumulated effects of ocean ventilation e.g. passive tracers which are easier to observe. The transient tracers CFC-11, CFC-12, and SF6, all gases of purely anthropogenic origin are linchpins in assessing simulated ocean circulations. These abiotic transient tracers are not involved in biological activities and are (almost) merely passively transported by ocean circulation.

In the past four decades, CFC-11, CFC-12, and SF6 have been intensively measured. In the most recent Global Ocean Data Analysis Project data product (GLODAPv2.2022), more than 370,000 CFC-11, 380,000 CFC-12, and 100,000 SF6 valid measurements cover the global ocean including the Arctic [5]. Observed CFC-11 reflects global ocean circulation patterns with high concentrations of CFC-11 in regions with deep convection (Figure 1). The CFC-11 distribution at 300m indicates that the ocean is mainly ventilated in the North Atlantic (North Atlantic Deep Water), at the coast of the Antarctic (Antarctic Bottom Water), and around 40°S where the Antarctic Intermediate Water forms. While, in the typical oxygen minimum zone, e.g., off the coast of California, the CFC-11 concentration is relatively low compared to previous regions. At 2000m, two major regions with deep convection can be identified one in the North Atlantic and another one in the Weddell Sea.

The planned project is designed to allow for an assessment of simulated oceanic ventilation as relevant to O_2 supply process, the uptake of anthropogenic carbon, and will contribute to the understanding of remineralization of organic matter in a global coupled atmosphere-ocean circulation biogeochemical model. 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 difference an explicit representation of chlorofluorocarbon gases in the ocean

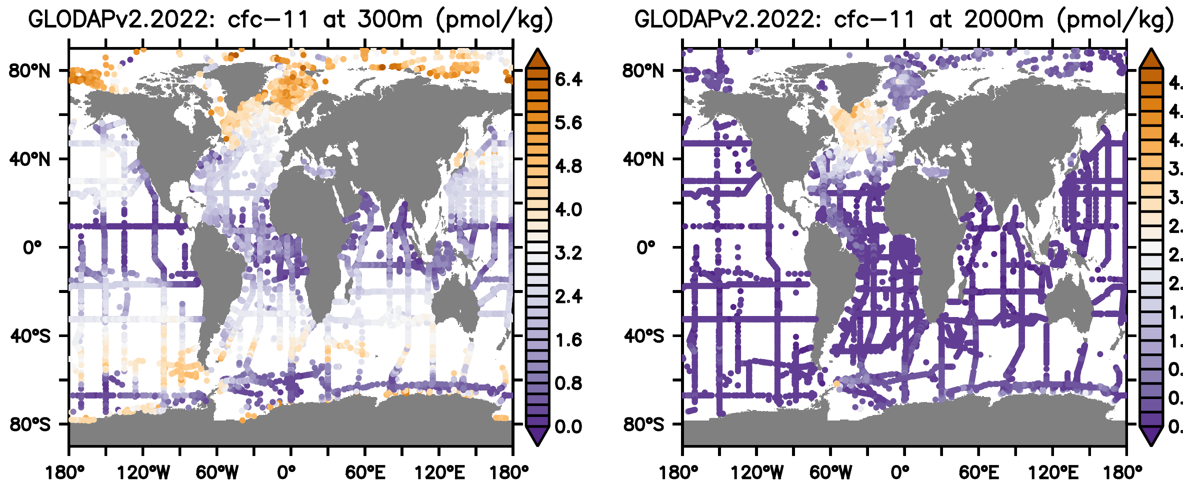

Figure 1: *The measured CFC-11 distribution at 300 +/-10m (left) and 2000 +/- 100 m (right). The data is from GLODAPv2.2022 [5].*

module of FOCI instead of pelagic biogeochemistry. Each simulation will be integrated for 9 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 also SF6 (between 1996 and 2020), and will give guidance on the question as to the extend the model can reproduce the intrusion of CFCs/SF6 into the ocean realistically.

In total, we will perform an ensemble of 8 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 representation of air-sea gas exchange in sea-ice areas, and (3) 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 time series that differ (slightly) in terms of their internal dynamic state at the start of the CFC releases into the atmosphere. The sensitivity of CFCs/SF6 distribution to air-sea gas in the ice cover area will be explored with changing parameterization. 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 50%. 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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More Information

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