# Ocean anthropogenic $CO_2$ uptake

**Assessing anthropogenic carbon uptake using Chlorofluorocarbons and Lagrangian particles in a global eddying ocean model**

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## In Short

- we estimate anthropogenic carbon ($C_{ant}$) uptake, which is important to understand the global carbon cycle, using Chluorofluorocarbons (CFC)
- we simulate CFC uptake during the last 30 years with a global high resolution ocean model
- we apply a novel technique using modelled Lagrangian transit time distributions
- combined with CFC observations, this high resolution modelling project will assess anthropogenic carbon uptake in the ocean and its dependence on surface forcing variability

Geochemical tracers, such as Chluoroflourocarbons (CFCs) have contributed significantly to our understanding of ocean circulation, water mass transformations, anthropogenic oceanic $CO_2$ ($C_{ant}$) uptake and climate. Knowledge of the oceanic uptake and resulting inventory increase of $C_{ant}$ is important to understand the global carbon budget. Since the $C_{ant}$ increase in the ocean resulting from the rising atmospheric $CO_2$ is small relative to the large background dissolved inorganic carbon signal in the ocean, it has to be inferred by indirect measures. CFC distributions are often used to estimate $C_{ant}$ in the oceans using Transit Time Distributions (TTDs).

The TTD describes the distribution of different ages of a fluid elements since the last surface contact due to different interior pathways and mixing (e.g. Steinfeldt et al., 2009). A tracer concentration in the oceanic interior can be expressed with the TTD (or Green's function $G$) and the surface concentration. $G$ generally also depends on the surface source, and in an unsteady flow, on two independent time arguments, the field time and the source time, and not just the transit time. This would mean to employ an ensemble of many boundary impulse response or TTD simulations, in many different regions, involving a large number of tracers which is not feasible in eddying ocean models.

The way out of this problem are Lagrangian particles. They provide a unique way to track water masses, to characterize water mass ages and transport pathways, including the effects of multiple paths between the surface mixed layer and the interior ocean. Probability density distributions (PDFs) of particle displacement are often considered in Lagrangian statistics, from which dispersion characteristics and diffusivities can be estimated (e.g. Griesel et al., 2014). Those displacement PDFs are related to the TTDs when the displacement is calculated wrt the surface source region, and the isopycnal diffusivities are a component of the measure of the width of the TTD. In fact, Lagrangian TTDs allow to decipher the different effects of advection by the mean flow, isopycnal mixing by mesoscale eddies, and diapycnal mixing by small-scale mixing.

We use a global eddying ocean model to support and extend the analyses of water mass formation rates and $C_{ant}$ storage and their changes, assess the validity of assumptions (for instance the TTDs), provide a more complete insight into error estimation and analyse the mechanisms responsible for changes in watermass formation rates and $C_{ant}$ storage rates in the Southern ocean. The planned work combines analyses on different spatial and time scales with a new set of methods and tools, using observations and a global eddying model.

The model to be used is the $1/10^o$ Parallel Ocean Program (POP) (Maltrud et al., 2010), to study the uptake of tracers in the time periods where observations are available. This model shows a realistic depiction of Southern Ocean mixed layer depths, which are important to simulate tracer uptake in this region. POP has been used in a previous simulation with CFCs employing climatological forcing without interannual variations (Douglass et al., 2012 and Fig. 1), showing the capability of realistic depiction of CFC inventories.

We run experiments with POP for the years 1930-2009 with CFC-11 using repeat annual cycles on the one hand and realistic interannually varying forcing on the other. The difference between the simulations will reveal the impact of wind- and buoyancy forcing driven variability of the circulation on the CFC uptake and storage. The new runs will archive velocity and tracer data with high temporal resolution for detailed analyses and offline calculation of Lagrangian particle trajectories to infer Lagrangian TTDs.

## WWW

http://www.ifm.uni-hamburg.de/

## More Information

[1] E. M. Douglass, S.R. Jayne, S. Peacock,

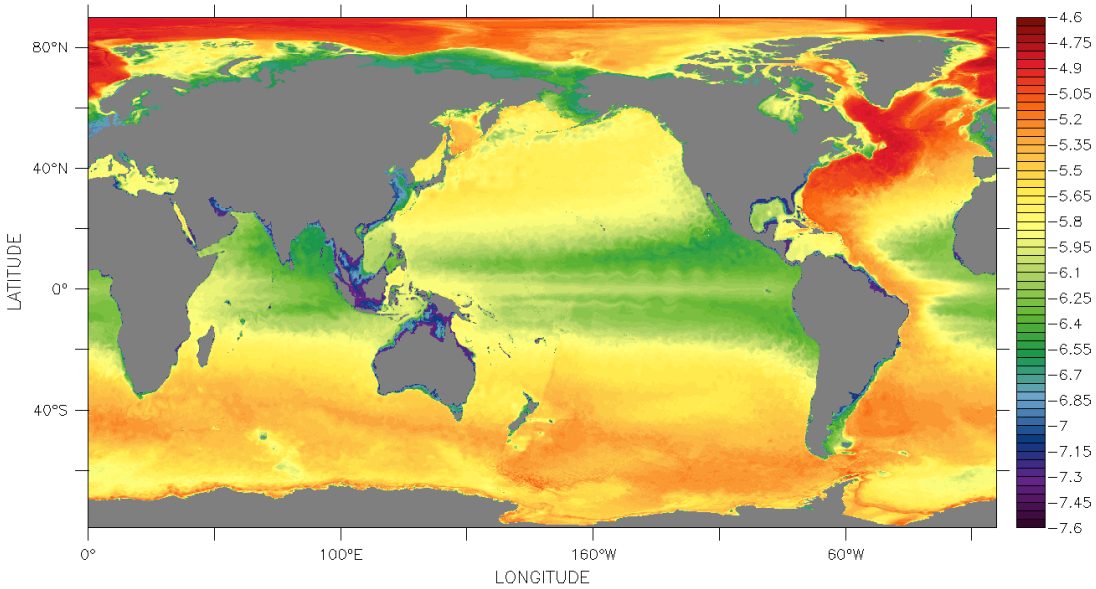


***Figure 1:*** *CFC-11 inventory in micromoles/m$^2$ in POP in 1994 from a simulation with climatological forcing (M. Maltrud, Los Alamos National Laboratory, pers. comm.)*

F.O. Bryan, *J. Phys. Oceanogr.* **42**, 126-140 (2012).

[2] A. Griesel, C. Eden, N. Koopmann, E. Yulaeva, *Ocean Modelling* **94**, 33-45 (2015).

[3] M.E. Maltrud, F. Bryan, S. Peacock, *Env. Fluid Mech.* **10**, 275-295 (2010).

[4] R. Steinfeldt, M. Rhein, J. L. Bullister, and T. Tanhua, *Global Biogeochem. Cycles* **23** (2009).

## Project Partners

M. Rhein, R. Steinfeldt, D. Kieke, Universität Bremen

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