PROCESSES AND DIFFUSION NEAR A LIQUID CO_2 – SEAWATER INTERFACE

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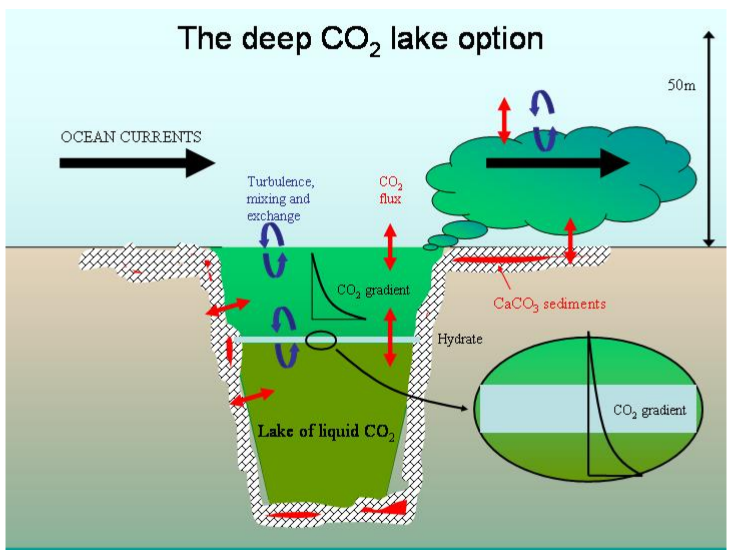
ABSTRACT

If liquid CO_2 is stored as a dense "lake" on the deep ocean floor, it is expected to dissolve in seawater. Ocean currents and turbulence may increase the net rate of CO_2 release by several orders of magnitude compared to molecular diffusion. However, density stratification in the seawater created by dissolved CO_2 will tend to reduce vertical mixing. By comparing results from different model formulations, this study aims to increase our understanding of the processes in such a layer of CO_2-enriched seawater, and decrease the uncertainties about storage efficiency and subsequent environmental impact. The study is also relevant to the case of saturated water leaking from subseabed geological storage through bottom sediments.

INTRODUCTION



Among the options considered for carbon management, geological formations and the deep ocean have sufficiently large storage capacity to make deep cuts in the emissions if carbon taxes are introduced. Dissolution of CO_2 at depths of around 3000m in the ocean provides equilibration times of centuries to millennia, which may be sufficient to provide a bridge to other energy sources. Climate and near surface impacts of elevated CO_2 are then avoided at the expense of a local environmental impact in the water column near the injection site. Storage of CO_2 on or below the deep seafloor could potentially further delay dissolution into the water column, thus reducing the environmental impact in the ocean and delaying equilibration with the atmosphere.

DISSOLUTION OF LIQUID CO_2 AT THE SEAFLOOR

There exist very few experimental data describing the behaviour of liquid CO_2 in the deep ocean. Experiments led by Peter G. Brewer at Monterey Bay Aquarium Research Institute (Brewer et al., 2005, and references therein) have begun to explore the behaviour of the hydrate covered interface by controlled experimentation at the 1 meter scale. Recent theoretical modelling studies of the boundary layer above an imagined lake of kilometer length scale have used simplified diffusion and advection models, coupled with turbulence models of different complexity [*Fer and Haugan*, 2003, *Haugan and Alendal*, 2005] and a representation of liquid CO_2 diffusion through the hydrate covered interface depending on friction velocity. These studies suggest that a liquid CO_2 lake may deliver dissolved CO_2 to the bottom boundary layer at rates corresponding to a vertical lake shrinkage rate of order meters per year. There is a clear dependency on externally specified water velocity such that benthic storms (lateral currents of order 20 cm/s) provide much more dissolution than background deep ocean currents (assumed of order 5 cm/s). However, many uncertainties still remain in these models. Among them are the interaction between shear driven turbulence and damping by stratification which in turn is generated by surface stress.

NEW MODELLING APPROACH

To properly allow for vertical velocity and motion also in the liquid CO_2 layer, we employ a 3D Navier Stokes solver originally developed for direct numerical simulation, coupled to the General Ocean Turbulence Model (GOTM) [*Burchard* 2002]. This coupled model has recently been used to study dense brines in the deep sea [*Enstad, L.I., G. Alendal and P.M. Haugan. A numerical study of a density interface using the General Ocean Turbulence Model (GOTM) coupled with a Navier Stokes solver, Deep-Sea Research, submitted 2005*]. In order to obtain a velocity scale and a length scale for the eddy viscosity and diffusivity, we have chosen to use the k-ε model as the turbulence model. Of the many different stability functions we have chosen to use the one by *Canuto et al.* [2001]. This set of stability functions have proved to be robust through testing by Burchard and his team.

From the Navier Stokes solver we obtain the mean velocity field and scalar field which give us the production of turbulent kinetic energy (TKE) due to shear and the production/destruction due to buoyancy of TKE. The turbulence model gives us the eddy viscosity and diffusivity in the vertical direction which together with the depth of the flow and the mean velocity at the surface give us two non dimensional numbers; the Reynolds number and the Peclet number which are put back into the Navier Stokes solver to find the new mean velocity and scalar fields. The model is described in greater detail in Enstad et al. (2005), who show that for the case of a dense brine lake, the exchange of salt across the interface is proportional to the velocity. The flux from the CO_2 lake is here modelled in a similar way as *Haugan and Alendal* [2005].

The domain is 18850 meters long and 3000 meters deep. The grid is uniform in the horizontal direction with 1024 grid points in the streamwise direction giving a grid spacing of 18.4 meters. In the vertical direction the grid is non uniform with a clustering of the points near the bottom. We employ periodic boundary conditions in the horizontal direction. At the bottom we have a no-flux condition for the scalar and a no-slip condition for the velocity. The CO_2 lake is in the region between 184 meters and 700 meters in the beginning of the computational domain. The poster and final paper will show results from this model in relation to previous studies, and discuss the need for experimental testing to address key uncertainties.

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