Southern Ocean ventilation and the impact on carbon uptake

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Is this a CASE studentship? YES, subject to a BAS review of funding priorities in spring 2018
If so, please state intended CASE partner: British Antarctic Survey

Introduction:

Our aim is to understand how the ocean uptake of atmospheric CO_2 is controlled by the transfer of surface waters into the ocean interior over the Southern Ocean. This ventilation process occurs at the end of winter and is particularly strong in a few formation regions: surface waters in contact with the atmosphere in these localized regions in the Southern Ocean then spread over much of the southern hemisphere [*Jones et al.,* 2016]. This ventilation process then contributes to setting the heat and carbon properties over much of the global ocean.

Project Summary:

Climate model studies suggest that the uptake of carbon by the Southern Ocean plays a key role in regulating atmospheric carbon dioxide (CO_2) [*Frölicher et al.*, 2015]. The ocean ventilation process affects the ocean uptake of atmospheric CO_2 through competing effects from upper and lower overturning cells (Fig. 1) [*Lauderdale et al.,* 2017]. There is ocean outgassing of CO_2 from upwelling of cold, carbon-rich deep waters and ocean uptake of atmospheric CO_2 from surface waters being transferred into the ocean interior. This transfer of surface waters into the ocean interior preferentially takes place at the end of winter in the surface mixed layer in a few locations.

What is unclear is how the ocean uptake of atmospheric CO_2 varies with the physical representation of the Southern Ocean, namely the details of the circulation (as depicted in Fig. 2), the effects of surface mixing, and how the uptake of carbon in the Southern Ocean is transported to the global ocean.

The student will address these challenges by conducting the following analyses:

(i) examine the rate at which the Southern Ocean is ventilated, drawing upon model-based analyses of the surface circulation (Fig. 2) and the winter mixed-layer distribution, and identify the “hot spots” of ventilation;

(ii) examine the rate at which the ocean is taking up carbon, by combining the estimates of the ventilation rate with recent global ocean analyses for dissolved inorganic carbon (GLODAPv2);

(iii) identify the pathways by which the “hot spots” of ocean ventilation then spread over the global ocean using output from ocean circulation models, and identifying the accompanying transfer of heat and carbon within the models (e.g. *Lauderdale et al.* [2017]).

(iv) identifying the sensitivity of the ocean uptake of carbon to the physical state of the circulation (exploiting a formal adjoint approach), revealing how the representation of surface mixing and representation of current systems affect the global distribution of carbon.

Hence, the project will exploit state of the art ocean models and analysis techniques to reveal how a central part of the climate system operates --- namely how the Southern Ocean takes up atmospheric CO_2 and redistributes the carbon over the global ocean.

The student will become a part of the NERC Doctoral Training Programme at the Universities of Manchester, Liverpool and National Oceanography Centre. The studentship will be a CASE project and the student will work for 3 months at the British Antarctic Survey at Cambridge, where the ocean models and analysis techniques are developed by the CASE supervisors (as part of the UK national programme: Ocean Regulation of Climate by Heat and Carbon Sequestration and Transports). Through the BAS partner, there may be an opportunity to go to sea in the Southern Ocean, such as via one of their regular transects across Drake Passage to Antarctica.

The project involves analysing large model outputs and data sets, so it is crucial that the student has an aptitude for quantitative and numerical work. Detailed prior experience in numerical modelling is not though required as training in analysing data and developing simple models is provided in the first year of the PhD.

Image 1 –

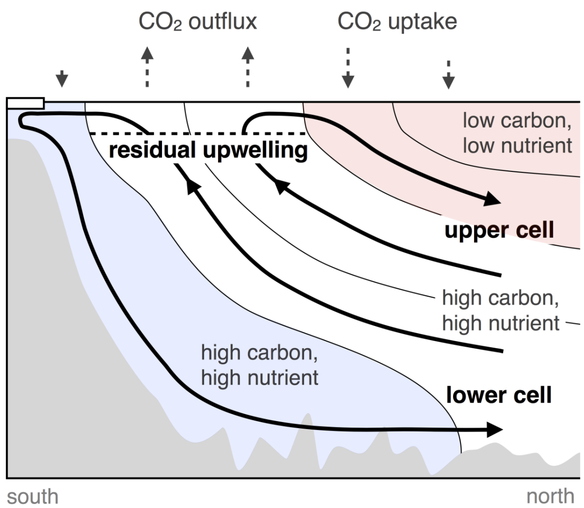

Image 1 Caption – A schematic view of the Southern Ocean overturning and the impact on the air-sea flux of atmospheric CO_2 (Lauderdale et al., 2017).

Image 2

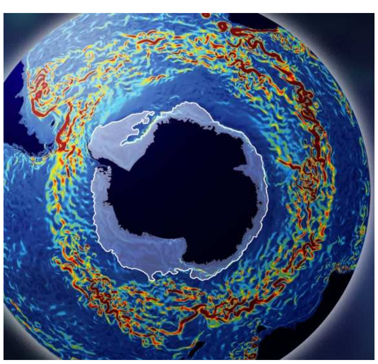

Image 2 Caption A snapshot of the surface speed revealing strong jets, fronts and eddies over the Southern Ocean (red, fast flows, blue, weak flows). Estimate from the Southern Ocean State Estimate (Mazloff et al., 2010).

References (* are those involving the research team)

Frölicher, T.L., J.L. Sarmiento, D.J. Paynter, J.P. Dunne, J.P. Krasting, and M. Winton, 2015. Dominance of the Southern Ocean in anthropogenic carbon and heat uptake in CMIP5 models. *J. Climate,* 28, 862–886, doi:10.1175/JCLI-D-14-00117.1.

*Jones, D. C., Meijers, A. J., Shuckburgh, E., Sallée, J. B., Haynes, P., McAufield, E. K., & Mazloff, M. R., 2016. How does Subantarctic Mode Water ventilate the Southern Hemisphere subtropics? *J. Geophysical Research: Oceans*, *121*(9), 6558-6582.

*Lauderdale, J.M., R.G. Williams, D.R. Munday and D.P. Marshall, 2017. The impact of Southern Ocean residual upwelling on atmospheric CO2 on centennial and millennial timescales. *Climate Dynamics*, 48, 1611. doi: 10.1007/s00382-016-3163-y.

Mazloff, M.R., P. Heimbach, and C. Wunsch, 2010. An Eddy-Permitting Southern Ocean State Estimate. *J. Phys. Oceanogr.,* **40**, 880–899, doi:10.1175/2009JPO4236.1.