An uncertain future for the North Atlantic CO_2 sink

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Introduction:

One of the greatest sources of uncertainty in future climate projections is our limited understanding of how the relationship between CO_2 emissions and atmospheric CO_2 concentrations will evolve. To constrain this we need to understand the behaviour of the major terrestrial and marine CO_2 sources and sinks. The North Atlantic is an intense and highly variable sink region. Here we demonstrate a multi-model consensus that subpolar gyre Atlantic CO_2 uptake may peak in the near future before slowly declining. We link this change to a theoretical understanding of N. Atlantic CO_2 behaviour and attempt to constrain the controls on the magnitude and timing of the CO_2 uptake turnover.

1. Introduction

In a simple Atlantic carbon cycle box model Voelker et al. (2002) show that Subpolar Nort Atlantic air-sea CO_2 flux can follow a peak and decline structure (fig. 1) in response to the competing effects of 1) Increasing rate of change of CO_2^{atm} driving and increasing air-sea [CO_2] gradient, and 2) reduced high (relative to low) latitude CO_2 storage capacity due to the temperature dependence of the revelle factor in the future meaning that at increased CO_2^{atm}, CO_2 saturated water moving northwards will want to outgas CO_2 (relative to the present day).

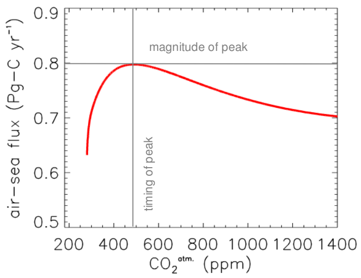

Figure 1) Peak and decline in SPG Atlantic CO_2 uptake occurring in response to rising CO_2^{atm} (after Voelker et al. 2002).

We want to understand:

1) Do we expect this behaviour in the real world?
2) What controls the timing of peak CO_2 uptake?
3) What controls the magnitude of peak CO_2 uptake?
4) Can we constrain the timing and magnitude of peak uptake in the real world?

2. CMIP5/OCMIP5 results

The peak and decline structure found in the box model is seen within many CMIP5 and OCMIP5 models (fig. 2). In a number of the models (HadGEM2-ES, MIROC and IPSL-CMA-MR) the curves appear fairly robust to the rate of change of CO_2^{atm} (1% rise versus RCP8.5 rise), indicating that the response may be largely driven by the absolute CO_2 concentration, and consequently basic ocean chemistry.

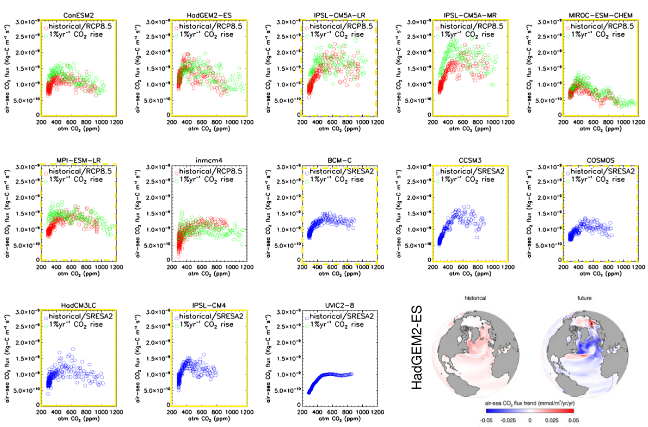

Figure 2) CMIP5 1% CO_2 rise (green) and historical/RCP8.5 (red) and OCMIP5 historical/SRESA2 (blue) air-sea CO_2 flux averaged over 20-60W, 45-65N. Bottom right – historical and future Atlantic air-sea CO2 flux trends.

3. Box model

We explore the sensitivity of Atlantic subpolar CO_2 uptake to changes in key variables within the 6-box model used in Voelker et al. (2002) (fig. 3).

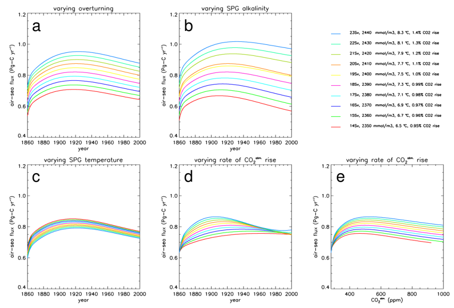

Figure 3) N. Atlantic air-sea CO_2 flux change with varying overturning strength (a), subpolar gyre alkalinity (b) and temperature (c) with CO_2^{atm} increasing at $1\%yr^{-1}$. N. Atlantic air-sea CO_2 flux change with varying rate of change of CO_2^{atm} plotted against time (d) and CO_2^{atm} concentration.

Across the range of conditions simulated by the ensemble discussed in the next section, we find:

1) Overturning strength exerts a strong control on the peak flux magnitude (3a)
2) Alkalinity exerts a strong control on peak flux magnitude (3b)
3) Change in temperature plays a minimal role (3c)
4) Change in atmospheric CO_2 controls timing of peak (3d) but largely through the absolute CO_2 concentration (3e)

4. Perturbed parameter ensemble

Members of an ensemble of simulations in which atmospheric and ocean physics, terrestrial carbon cycle and aerosol parameters were perturbed (Booth, Lambert et al., in prep) show similar peak and decline behaviour (fig. 4). Using this ensemble we look for the influence of the controlling variables identified in the box model within GCMs (fig. 5)

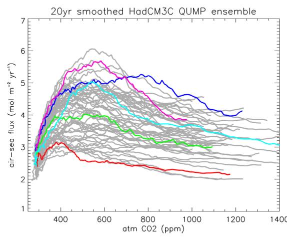

Figure 4 (RIGHT). N. Atlantic air-sea CO_2 flux from 57 member perturbed parameter ensemble (historical/RCP8.5).

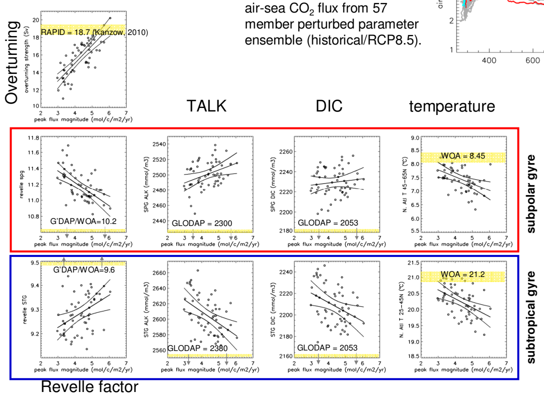

Figure 5 LEFT) Average value of variable (max Atlantic overturning strength, subpolar/subtropical alkalinity/dissolved inorganic carbon/temperature) from historical period plotted against magnitude of peak air-sea CO_2 flux. Lines show least squares regression and 95% confidence intervals on that regression.

The ensemble confirms the existence of significant correlations between overturning strength, alkalinity and temperature with the peak flux magnitude, although within the GCM we can't easily show that the relationships are causal or deconvolve covariability (fig 5). No strong relationships appear between timing of peak uptake and controlling variables.

5. Conclusions so far…

Observational estimates of variable's values allow us to begin to constrain how the N. Atlantic air-sea CO_2 flux may vary in the future (fig. 5). Although tentative, combining the observed overturning strength and revelle factors with the trends found across the ensemble members suggests that peak air-sea CO_2 flux magnitude in the real N. Atlantic could be at the high end of that simulated by the ensemble, although from the perturbed parameter ensemble at this stage it is difficult to put any constraint on when the peak might occur. However, multi-model analysis suggests that peak the air-sea flux may well occur between ~400-600ppm in the context of RCP8.5 and SRESA2 scenarios. It will be important to understand the mechanism controlling this and relate the controlling variables to the state of the real world before making any firm statements about the timing of the peak air-sea flux. Further work will examine the influence of transient climate change on the air-sea flux response, and extend the analysis undertaken using the perturbed parameter ensemble to the CMIP5 and OCMIP5 simulations.

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