CLIMATE-INDUCED CHANGES IN OCEAN CO_2 UPTAKE MEDIATED BY CHANGES IN THE SUPPLY OF IRON-BEARING DUST

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ABSTRACT

The effect of changes in iron supply to the ocean on CO_2 uptake is examined. Dust deposition fields from a dust model driven by output from a future climate simulation of a coupled general circulation model (GCM) were used as input to an ocean GCM with an embedded ecosystem model. In simulations using dust produced in a future climate the primary productivity of the ocean increased by 56% compared to simulations using dust from the present climate. The sinking particle flux of carbon at 100 m depth increased by 46%. The net air-to-sea flux of CO_2 was 4.1 PgC/y greater in the future dust simulation. Most of these changes occurred in the Equatorial Pacific Ocean, where the model ecosystem was iron-limited with present-day dust inputs but which received a large increase in the dust supplied from the Amazon Basin. These perturbations to the marine biogeochemical system are large compared to other potential climate effects that have been observed in the model. Although these results are preliminary, they could form a large negative feedback on global warming.

INTRODUCTION

Iron is now recognized as an important and sometimes limiting micro-nutrient for the growth of marine phytoplankton. In many areas of the ocean the main supply of iron is by atmospheric dust. Anthropogenic climate change is expected to modify both the amount of dust produced on the continents and the strengths and patterns of the winds that carry that dust to the ocean. In some areas an increase in the supply of iron by this mechanism may lead to the ecosystem there being released from iron-limitation and increasing in its primary and export production. This would have important consequences for the carbon cycle because the export flux of carbon from surface to deep waters forms part of the biological pump which has a major role in regulating the atmospheric CO_2 concentration. An increase in primary production would be expected to cause a net air-to-sea flux of CO_2, reducing atmospheric CO_2 and forming a negative feedback on global warming.

MODEL SIMULATIONS

A version of the Hadley Centre Ocean Carbon Cycle (HadOCC) model [*Palmer and Totterdell*, 2001] was used to examine the potential magnitude, and the sign, of this feedback. The standard version is a simple nitrogen-based Nutrient-Phytoplankton-Zooplankton-Detritus ecosystem model with coupled flows of carbon and alkalinity, but the version used here was the Diat-HadOCC model, which splits the phytoplankton into separate compartments for diatoms and other phytoplankton. Since diatoms required silicate to form their shells the model also features a representation of the marine silicon cycle. The model diatoms are strongly affected by iron-limitation, agreeing with observations and making this version of the model suitable for this study, although the 'other phytoplankton' are weakly affected also. The marine iron cycle was represented using the third model of *Parekh et al.* [2004], which splits the total dissolved iron into free and complexed forms. Iron was an ocean model tracer; atmospheric dust was its only source and adsorption (of free iron only) onto particles was its permanent sink. Biological activity took up and recycled dissolved iron in a fixed ratio to carbon (0.025 mmol Fe/ mol C). Two simulations were run, using annual mean dust fields representative of the present day and one hundred years in the future. These dust fields were produced by the Hadley Centre dust model [*Woodward*, 2001], driven by forcings for the respective periods taken from the historical/future transient simulation of the Hadley Centre coupled climate model with interactive carbon cycle that was described by *Cox et al.* [2000]. That simulation showed a pronounced die-back of the Amazonian rain-forest during the second half of the 21^{st} century, and the extra dust that results from the transition to grassland in that area is a major feature of the future dust field. That dust is carried westwards by the winds and deposited mainly in the eastern Equatorial Pacific. The future field also shows increased dust supply from Australia, but very little extra dust from any source reaches the Southern Ocean. For this study, it was assumed that iron was a constant fraction of the dust, and that the solubility of that iron was also constant: both of these assumptions will be relaxed in future studies. The rate of supply of soluble iron was 0.26 and 0.49×10^{10} mol/y in the present and future fields respectively; both figures are within the range estimated by *Jickells and Spokes* [2001].

RESULTS

The simulations showed a dramatic 56% increase in the total primary production in the future run (run F) compared to that for the present day (run P). Most of this increase occurred in the eastern Equatorial Pacific: in run P this area had abundant nitrate and silicate but was strongly iron-limited, while in run F that limitation had been removed by the additional iron supplied by the dust from the de-forested Amazon basin. In this region both the diatoms and ‘other phytoplankton’ increased their production. The western side of the southern sub-tropical gyre in the Pacific also showed greatly increased production, with additional iron advected from the eastern Equatorial Pacific and directly from Australian dust relieving the iron limitation there. Because of a lack of silicate in this region, only the ‘other phytoplankton’ increased their production. There was no significant change in the primary production in the Southern Ocean. Globally, diatom production increased by 26% and that due to ‘other phytoplankton’ by 65%, with the proportion of total production due to diatoms dropping from 23% to 19%. The export production (here, the sinking particle flux at 100 m depth) showed an increase of 46%, with a similar geographical distribution to the total primary production. The air-to-sea CO_2 flux in run F showed a net ingassing of 4.1 PgC/y compared to run P; again, mostly in the eastern Equatorial Pacific. Note that, although the simulations used dust fields valid for the present day and for 100 years hence, the atmospheric pCO_2 value used in each case was the same pre-industrial value: the reason for this was that the simulations were run as ‘snapshots’ and it was judged that the size of the dust-induced perturbation would be more realistically represented by using an ocean and atmosphere in equilibrium, albeit a pre-industrial equilibrium, than to use the correct atmospheric value but to have the ocean far from equilibrium with it.

DISCUSSION

The perturbations produced by these simulations are large and act as a negative feedback on global warming. In other simulations without the dust-iron mechanism the main climate effects seen in the ocean by the year 2100 are a reduction of 7% in total primary production (due to reduced nitrate supply in a more stratified ocean) and a reduction in oceanic CO_2 uptake of around 1PgC/y (relative to a scenario of similar anthropogenic emissions but no climate change, which itself produces an ingassing of just over 4 PgC/y). Note that the ‘snapshot’ methodology used here means that the results will include any short-term transient response to the sudden increase in iron supply and may not accurately represent the longer-term response. However even though these results are preliminary they clearly show that the dust-iron mechanism examined here has the capacity to be significant and is worthy of further detailed study.

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