The short and long term role of the ocean in Greenhouse Gas mitigation

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Introduction

The carbon dioxide concentration in the atmosphere is rising rapidly, mostly as a result of fossil fuel burning. This is leading to more trapping of solar radiation in the atmosphere with the expectation that the world's climate will change. Rapid climate change has a downside risk of endangering the food security of the poor and raising the spectra of large scale transmigration.

The UNFCCC was an agreement amongst most of the sovereign nations of the world to slow the rate of such climate change by controlling the concentrations of Greenhouse gases in the atmosphere. Scientists are considering strategies to moderate the build up of these gases and this can be approached either by reducing emissions or increasing the sinks of carbon. Sinks can either permanently sequester the carbon (for thousands of years) or store the carbon for hundreds of years until the supply of fossil fuels are is exhausted and alternative energy sources are developed. This paper will examine the oceanic classes of sinks and consider the impact they may have on the marine food supply. Since 800 million people are undernourished at present and the population is rising rapidly the issue of providing additional food is as important as that of managing climate change. In fact the two issues are inextricably linked as climate change may unsettle existing terrestrial food production.

Public perception of new technologies can influence their adoption. The ocean "commons" hold a special place in the minds of some people and these people are likely to oppose new uses for the ocean such as an enhanced carbon sink. A holistic view of new technologies tries to balance the risks and the benefits because new ideas must be introduced for mankind to advance. These societal issues may be as important as the technical constraints in creating a major sink of carbon dioxide in the ocean.

The Ocean Sink

A large amount of carbon is dissolved in the waters of the ocean, much more than is stored in the atmosphere. However the atmosphere and the ocean are in contact over about 70% of the area of the globe. In the surface layers of the ocean and the atmosphere there is a continuous exchange of inorganic carbon which can be modeled

with the aid of Henry's Law. Carbon is also stored in the upper ocean as organic biomass which forms a system isolated from the atmosphere.
The relative amount of carbon in the atmospheric surface layer to that in the ocean is dependent on the temperature, the pH and partial pressure of carbon dioxide. As the atmospheric carbon dioxide rises, the pH of the sea water decreases and the concentration of dissolved carbon rises. Given enough time much of the carbon dioxide released into the atmosphere would end up in the ocean with only a possibly manageable increase in atmospheric CO_2 partial pressure.

The ocean can be characterised as a well mixed surface layer with little vertical density gradient overlying a stable region of dark slowly moving water which is isolated from the atmosphere. Near the poles surface water sinks to the sea floor while a little closer to the Equator it is subducted to intermediate depths. The time scale for water to be upwelled and be in contact with the atmosphere again varies with depth from years to centuries. With this vertical circulation of water is a corresponding flow of carbon. About 50 Gtonnes of carbon is upwelled into the surface mixed layer each year. As well as advection there is a "pumping" of organic carbon into the deep ocean as a result of primary production. Plausible values for the fluxes are shown in Fig 1.

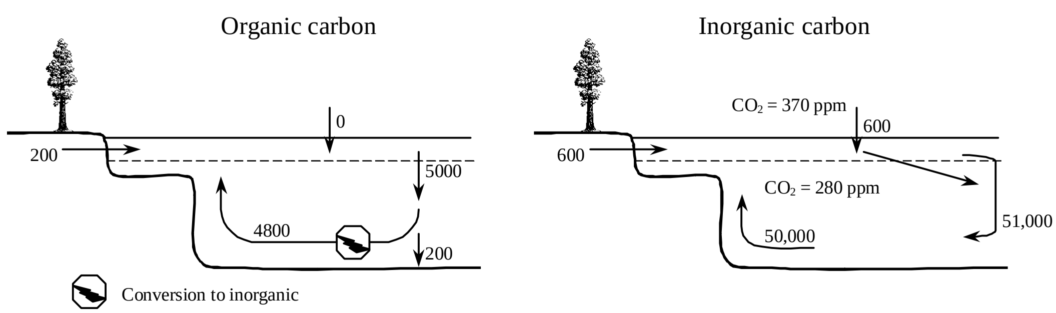

Fig 1. The fluxes of carbon in Mtonnes from the land and the atmosphere into the ocean and the loss to the sea floor sediments. These values are purely indicative and assume new primary production has been constant for the last 1000 years.

The downwelled water leaves the ocean surface with the carbon concentration about in equilibrium with the atmosphere. During its journey through the ocean the carbon is increased by the rain of biological debris from the photic zone. When it is upwelled to the photic zone this debris carbon and associated nutrients is again pumped into the deep ocean. If the atmosphere is now at a higher partial pressure than when the water was downwelled, the remaining carbon concentration in the surface water is below the equilibrium with the atmospheric value. Thus the sudden increase in carbon dioxide in the atmosphere since the Industrial Revolution causes the downwelled water to carry away more carbon than the upwelled water. The magnitude of this export of carbon is limited by the rate of upwelling of the water. At present the volume of upwelled water is not under human control.

The net flux of carbon by advection away from the sea surface is not enough to keep up with the present carbon dioxide emissions. Orr and Aumont (1999) calculated for a reasonable estimate of the available fossil fuel, that 2000 Gt of carbon would flow to the ocean after 1,000 years. This is about half of the predicted anthropogenic emissions. Thus the ocean will naturally be a very large sink of carbon dioxide in the long term. It is the short term (100 years) that needs addressing. There are three possible strategies to increase the short term uptake of the ocean to form an enhanced sink of carbon, changing the alkalinity, direct injection of carbon dioxide and Ocean Nourishment. We will examine these below.

It is also possible to store carbon dioxide below the sea floor in geological structures e.g. Koide et al (1997) or in the sea floor sediment as a solid, e.g. Guevels et al. (1996). These options are not considered here, nor is the carbon deposited as carbonate or organic carbon to form the marine sediments. For a more general discussion of disposal of carbon dioxide see Haugen and Eide (1996).

Changes to Alkalinity

If the atmospheric partial pressure of carbon dioxide is larger than that of the water, carbon will flow to the ocean. The partial pressure of carbon dioxide increases with temperature, but decreases with pH and total alkalinity. The first option to increase the flow of carbon to the ocean is to change the pH and alkalinity of the surface water to allow more carbon to be dissolved in the ocean at the same atmospheric carbon dioxide partial pressure. Bicarbonate ions are the main contributor to alkalinity and Broecker and Takahashi (1977) pointed out that the calcium carbonate stored in the marine sediments will on a very long time scale play a role in adjusting the oceanic partial pressure of carbon dioxide. Dissolution of marine $CaCO_3$ sediments will decrease pCO_2. If bicarbonate were added to the surface waters, it would increase alkalinity despite the surface waters being supersaturated with calcium carbonate. Calderia and Rau (2000) have discussed a scheme where limestone is dissolved and introduced to increase pH. Their cost estimate is US$19 per tonne of CO_2 sequestered in favourable situations.

It is unlikely that realistic levels of alkalinity change will have much effect on the food chain. At present there is a decrease in surface pH due to the increasing atmospheric carbon dioxide. The increase in pH by adding calcium carbonate (neutralising the acidification) can be expected to preserve the existing ecology.

Direct Injection of Carbon Dioxide

Carbon dioxide at the pressure and temperature of the ocean below about 3000 m remains a liquid and may form a lake on the seafloor. If it is deposited by pipe or (falling blocks of solid carbon dioxide) at a lesser depth it may stay with the water with which it was placed. This means that eventually it is expected to be in contact with the atmosphere again. The sink capacity of the ocean has been estimated as between 1,400 and 20,000 Gt of carbon by Haugen and Eide (1996), much larger than the expected fossil fuel reserves. Hertzog (1999) has described a *proof of concept* demonstration of direct injection of carbon dioxide to reduce the technical uncertainties.

Very locally the injection of carbon dioxide is likely to have an impact on marine life but over the ocean on the whole the consequences of injection is not expected to either enhance or hinder the marine food chain. The costs of capturing carbon dioxide for injection remain high.

Ocean Nourishment

The third strategy is to increase the biological pump. Photosynthesis in the sunlit zone converts inorganic carbon in communication with the atmosphere into organic matter. Following the death or consumption of the organic carbon it sinks out of the mixed layer. This process continues until the nutrients needed by phytoplankton are exhausted. The variants of ocean nourishment involve supplying additional nutrients to increase *the new primary production* and consequently the export of carbon to the deep ocean.

Extensive ocean nourishment will change both the physical and biological nature of the ocean. Increased photosynthesis in the upper ocean will weakly change the solar absorption while the consumption of oxygen in the thermocline will rise as to the rain of detritus remineralises.

A benefit of ocean nourishment is that it will enhance the fish stocks which have been seriously depleted in the last fifty years. Unlike intense agriculture, the strategy does not encourage a monoculture. Agriculture has concentrated on a few species to the detriment of diversity. Ocean nourishment, by supporting the base of the food chain, aims not to disrupt the biodiversity of the ocean.

There are some areas that are short in iron as has been demonstrated in experiments described by Coale et al (1996) or Boyd et al (2000). Jones (2001) looks at some of the impacts of widespread use of ocean nourishment. Shoji and Jones (2001) look at the cost. Proposed experiments in the Sulu Sea to monitor the impacts of macronutrient additions are described by Young and Gunuratnam (1996). Jones and Young (1997) examine the role ocean nourishment might have in providing both income and food to developing countries while Matear and Elliott (2001) model the efficiency with which the addition of macronutrients sequester carbon from the atmosphere.

Legal framework

The UNFCCC provides a legal framework in which carbon credits can be traded and thus provide the resources to fund ocean sequestration. This trading option however has its critics.

Activities which are on the high seas would seem to be governed by the Convention for the Prevention of Marine Pollution by Dumping of Waste and other Matter commonly known as the London Convention 1972. The direct injection of carbon dioxide into the ocean might be addressed by this Convention. On the other hand, the purposeful introduction of nutrients or the changing of the alkalinity would not seem to fall under the definition of dumping. Dumping, as defined under the Convention does not include the placement of matter in the sea for purposes other than mere disposal.

Public perceptions regarding the ocean

It is claimed humans have despoiled the land and polluted the rivers, therefore with this poor record, they should not interfere with the sea. Such views if widely held may have a strong influence on the adoption of the above technologies for carbon management.

Some people appear to have a special emotional attachment to the sea. They feel that the ocean is the last pristine domain of nature. There is a mystery about the sea which is romantic. While the ocean is a vast resource of animal life, energy and minerals, people's experience is mostly in the coastal zones. When people have a vision of the ocean it is usually of sparkling waters, of sailing or snorkeling on a tropical reef. It is not a perception of the endless dark deep ocean forty times the area of the USA, and deeper than Mt Everest is high.

Of the 6 billion human beings sharing the resources of the planet some 4 billion cannot read and write therefore their opinions on the ocean cannot be scientifically well informed. Some, such as fishermen, have strong local knowledge but have no opportunity to see a regional or global picture. In fact very few people have access to the information which would allow them to hold sensible views of the issues.

Climate management

It is considered presumptuous by some, to attempt to manage Nature or manipulate the climate. Experiments of adding iron to high nutrient low chlorophyll waters to change the primary productivity of the food web have been carried out. The Iron Experiment participants felt the need to issue a disclaimer as follows:

> *Finally, we wish to make it clear that the purpose of these experiments is to understand the nature of the controls on productivity and ecosystem function in HNLC waters. Such experiments are not intended as preliminary steps to climate manipulation. (*Martin et al 1994)

Opposition to Innovation

New concepts are strongly resisted in general. People are more comfortable with the familiar. Advocates of very large and truly innovative ideas are often labeled 'cranks or crackpots' and considered dangerous. This is a way of dismissing them without addressing the issues. People try and constrain the implementation of new ideas nowadays by using the power of the State. In the past they used the influence of the Church as the celebrated case of Gallileo witnesses.

Commentators can be predicted to oppose manipulations of the ocean, focussing on the uncertainties rather than on the potential benefits. They will be playing to the public's fear of the unknown. People are ready to passively accept an escalation of an established practice (e.g. dumping CO_2 in the atmosphere) while being wary of innovations that might improve their future well being. They have an uneven aversion to risk.

Public Outreach

Liberal democracies require that the public be informed of the issues such as those involved in experimenting on ocean sequestration of carbon dioxide and climate management. The public has the right and the ability to influence policy that constrains technical solutions. Kildow and Harrington (1998) assert that a partnership is needed between scientists and the public,

> *with the goals of 1. establishing trust, 2. educating the public about the science and the application and 3. educating the scientists about the concerns of the public.*

The members of the public are stakeholders when the consequences of an action may impact on their lives and they are entitled to know what the risks and benefits are. An uninformed public can attack and block beneficial changes through not understanding the issues (Kildow, 1997). The public resistance to genetically modified food is an example of the failure to adequately explain the new technology.

However, public policy is influenced by small groups in society and some of these are hostile to the exploitation of the ocean. Their concerns may be insensitive to the needs of the poor illiterate farmers and fishermen of developing countries who have a different risk profile

Conclusion

The developed countries have grown rich through the use of cheap fossil fuels since the Industrial Revolution. If the developing countries behave in the same way they will consume much of the known fossil fuel reserves in the next 1,000 years. It hardly seems equitable if there were an expectation that the under developed countries should forego this cheap resource. As Young and Jones (1995) pointed out however, following the same development path as the West, would lead to enormous emissions of carbon dioxide. The International Energy Agency expects a 70 % energy increase over the next quarter of a century and this will be predominantly from fossil fuel usage. With these pressures we do not think the total production of carbon dioxide will be abated despite the Kyoto Protocol. Enhanced carbon sinks will be necessary to control the atmospheric concentration.

Without intervention the fossil carbon will go into the atmosphere, leading to a dramatic change in carbon dioxide concentration and modification of the climate. With time (a millenium) about half the carbon will be sequestered into the ocean with a carbon dioxide concentration in the atmosphere of about four times the present value. The debate is whether this natural process of sequestration of carbon should be accelerated in the short term. Techniques such as direct injection or enhanced biological sequestration are able to move significant amounts of carbon into the deep ocean immediately.

There is uncertainty amongst some people about direct intervention in managing the climate. The members of the public who influence the decision making process need to be given the information about such projects that the specialists already have.

International organizations such as Green Peace and the World Wide Fund for Nature are lobbying against using the ocean as an enhanced sink. Failure of public outreach may be more significant than the risk of technical failure in ocean sequestration.

The choice for the future in the climate debate is balancing the relative risks of using new technology over the risk of remaining passive. Ocean nourishment widens the climate change policy debate to bring in the issue of food security. Here is a scheme able to sequester carbon and in the same process produce extra fish resources for the rapidly rising population. Policy makers have the challenge ahead of them to help eliminate poverty and hunger amongst all people.

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