Ocean–atmosphere Interactions

Gas exchange and climate

Photo: Peter Minnett, RSMAS, University of Miami

Tangaroa weathering the high wind speeds typical of the Southern Ocean that contribute to strong surface exchange between the atmosphere and ocean.

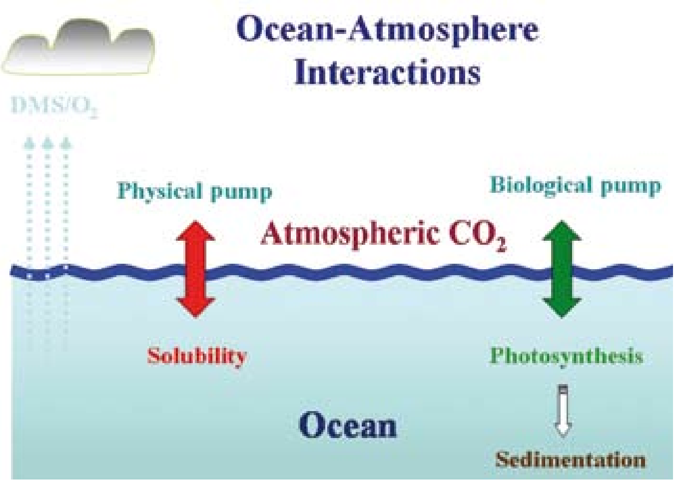
***Murray Smith** and the **SAGE Team** went to sea to investigate the connection between wind, waves, and CO_2.*

Global warming is now widely recognised as being caused by the accumulation of greenhouse gases such as carbon dioxide (CO_2) in the atmosphere, and it is generally accepted that human activity is causing these high concentrations of gases. However, global warming would be much more rapid were it not for the vast expanse of oceans, as they absorb nearly half of the anthropogenic CO_2. This is due partly to oceanic physics and partly to oceanic biology. On the physics side of things, cold ocean surface water allows CO_2 to dissolve more readily, and also sinks to depth. The combined effects act to pump CO_2 into the ocean interior – the 'solubility pump'. On the biology side, phytoplankton absorb CO_2 when they grow. When they die, they sink, carrying that carbon to the bottom of the ocean – the 'biological pump'.

The air–sea interface

A limiting step in this transport is the transfer of CO_2 across the air–sea interface. This transfer is highest in regions of the ocean where surface concentrations of CO_2 are lowest, often as a result of elevated biological activity (photosynthesis), and where windspeeds are highest. These conditions are satisfied on our doorstep in the Southern Ocean, providing New Zealand scientists with optimal conditions to examine ocean–atmosphere exchange.

The processes at the interface involve breaking waves, turbulence, and diffusion, and are too complex to allow us to estimate transfer rates from a purely theoretical basis. We can, however, carry out measurements to determine exchange under different conditions. This was one of our objectives in the SOLAS SAGE experiment (see box below), which took us to sea for a month in the subantarctic waters of the Bounty Trough.



The rate of transfer of gases across the air–sea interface is controlled by small-scale processes such as turbulence and wave-breaking. The physical or solubility pump then moves CO_2 to greater depths when the cold, CO_2-rich waters sink. The biological pump transfers CO_2 through photosynthesis by phytoplankton; when the phytoplankton die, the carbon they have absorbed sinks with them to the seabed.

Tracing the air–sea transfer

The key part of the physics side of the experiment was to follow the same patch of water for several weeks and measure how the concentrations of two tracer gases changed according to different wind and wave conditions. The two tracers we used – sulphur hexafluoride (SF_6) and an isotope of helium (^3He) – are found naturally in the ocean in only minute quantities. The tracers went into the ocean together with an iron sulphate solution, which was added in an attempt to stimulate the growth of plankton and thereby enhance the uptake of CO_2 (see next article).

Since SF_6 and ^3He transfer across the ocean–atmosphere interface at different rates, we were able to separate the effects of the escape of gas to the atmosphere from the spreading of the patch. From these measurements we were able to calculate the gas exchange rate at the high wind speeds typical of the Southern Ocean. In fact, exchange rates were measured at the highest windspeeds to date. (This was good for the experiment, but not so good for the scientists and crew!)

Knowing the rate of transfer of gases between atmosphere and ocean is a crucial step in modelling and predicting the world's changing climate. Armed with this information, we are now re-evaluating the amount of carbon being taken up globally by the oceans. W&A

The SAGE experiment

SOLAS (Surface-Ocean Lower-Atmosphere Studies) is an international programme studying the key biogeochemical-physical interactions and feedbacks between the ocean and atmosphere, and how this coupled system affects and is affected by climate and environmental change.

SAGE – the SOLAS Air–sea Gas Exchange experiment – was a New Zealand-led voyage involving 17 organisations in 6 countries. The G of the SAGE logo shows the water temperature we measured as the *Tangaroa* followed a tracer-labelled patch of water around an ocean eddy.

Ocean–atmosphere Interactions

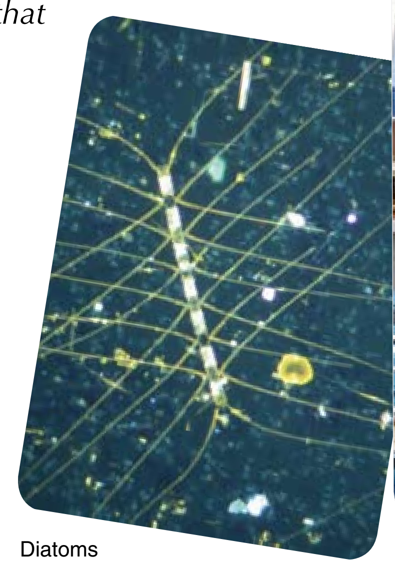
Plankton, iron, and climate

*In the subantarctic waters southeast of New Zealand, **Cliff Law** and the **SAGE Team** have found that pumping iron doesn't always build bulk.*

About half of New Zealands' EEZ lies in nutrient-rich subantarctic waters. However, phytoplankton, the microscopic plant cells that live in the surface layer, do not grow to their full potential in these waters due to a lack of dissolved iron, which they need for photosynthesis and growth. This iron-limitation of phytoplankton is found in other regions, such as the Southern Ocean and the Gulf of Alaska, where iron-infusion experiments have resulted in large phytoplankton blooms visible from space. As part of SAGE (see box below), we studied the effects of iron addition in the southwest Bounty Trough, about 250 km east of the Otago Peninsula.

Phytoplankton and trace gases

Our aim was to use the surface ocean as a natural laboratory, by adding iron to stimulate a phytoplankton bloom that would alter the air–sea exchange for a variety of gases. When phytoplankton grow, they remove carbon dioxide (CO_2) from the water and convert it to organic carbon, some of which sinks to the deep ocean via the 'biological pump'. This decreases the dissolved CO_2 and so increases CO_2 uptake from the atmosphere into the water, and has led to speculation that large-scale iron fertilisation of the ocean could slow the build-up of CO_2 in the atmosphere. Phytoplankton also release compounds that stimulate production of trace gases such as nitrous oxide and methane, which are greenhouse gases, and dimethylsulphide (DMS), which affects cloud formation in the atmosphere. Through these compounds, phytoplankton indirectly influence earth's climate; by stimulating a phytoplankton bloom we hoped to learn more about the air–sea exchange of these climate-reactive gases.



Diatoms are one of the main phytoplankton groups that respond to iron addition.

Preparation for release: the deck of RV *Tangaroa* with the iron tanks on the left and the SF_6 tracer tanks on the right.

Photos: diatom: Mary Silver, University of California, Santa Barbara; ship's deck: Matt Walkington

Adding iron

We prepared the iron solution in two 7500-litre tanks and pumped 1.35 tonnes of dissolved iron sulphate into surface waters during each infusion. To the iron solution we added a tracer, sulphur hexafluoride (SF_6), that allowed us to track the movement of the fertilised patch (see previous article). The phytoplankton responded rapidly to the iron addition, with an increase in the photosynthetic ability of the phytoplankton in the iron patch that was maintained throughout the experiment. However, after four iron infusions over 15 days, chlorophyll-*a*, the phytoplankton pigment used to measure total phytoplankton, had only doubled, and we saw little evidence of enhanced CO_2 uptake or increased production of DMS and other trace gases.

Iron isn't everything

The phytoplankton response was modest compared with other iron-fertilisation experiments, and seems to have been limited by other factors. These could include limited light availability for photosynthesis or lack of other important micronutrients. It is also possible that the patch diluted too rapidly for phytoplankton to accumulate, or that the phytoplankton were rapidly grazed down by zooplankton.

At a recent international meeting at NIWA in Wellington (see *Water & Atmosphere 14(1)*: 6), participants compiled results from 10 iron-fertilisation experiments. Light availability was identified as critically important, with the SAGE experiment conducted under the lowest light levels of any experiment to date. Although the SAGE experiment did not generate strong gas gradients, it provided an important contrast to other iron-fertilisation experiments and showed that iron addition alone is not a panacea to promoting phytoplankton stocks and CO_2 uptake in iron-limited waters. W&A

For more information on this experiment, see: www.niwascience.co.nz/rc/atmos/sage and to learn more about SOLAS see: www.solas-int.org/

Dr Murray Smith is a physicist and Dr Cliff Law is a biogeochemist; they're both based at NIWA in Wellington. Other members of the SAGE Team are listed on the SAGE web page: www.niwascience.co.nz/rc/atmos/sage