



# From the sea to the sky

It is a truth universally acknowledged in environmental science that it is much easier to propose an exciting new hypothesis than it is to prove it. Ken Carslaw and colleagues from the Institute for Climate and Atmospheric Science in Leeds set out to test the 23-year old CLAW hypothesis – and came up with some surprising results.

If you wanted to identify one theory that launched Earth system science as a major subject of the 21st century it would be CLAW. The hypothesis takes its name from Charlson, Lovelock (of Gaia fame), Andreae and Warren, whose 1987 paper suggested that phytoplankton could help regulate Earth's climate. Phytoplankton – single-celled algae – emit a gas called dimethylsulphide (DMS) and the authors suggested that DMS forms tiny new particles (or aerosol) in the atmosphere which controls climate by affecting the amount of sunlight reflected by clouds. New aerosol particles from DMS have the potential to increase cloud reflectivity because they are effective cloud condensation nuclei (CCN) – they can increase the number of cloud drops.

But confirming CLAW as an important climate regulation mechanism has proved incredibly challenging. About 1800 articles have been written on the subject, involving studies of plankton biology, gas chemistry, aerosol physics, oceanography, ship cruises and satellite observations, computer model studies and long-term measurements.

## If you wanted to identify one theory that launched Earth system science as a major subject of the 21st century it would be CLAW.

Measurements taken at Cape Grim at the remote north-western point of Tasmania appeared to provide compelling support for the hypothesis. They showed that aerosol and DMS varied in unison over the seasons as the abundance of plankton varied. We also know that DMS reacts in the air to form sulphuric acid vapour, which can rapidly join up with water molecules to make new aerosol. But what we didn't know was how sensitive global CCN are to changes in the emission of DMS from the ocean.

To test the hypothesis we used a new and advanced global model of aerosols. A bit like a weather forecast model, it uses rapidly changing weather patterns to transport aerosols around the world until they are removed by rain a few days, weeks, or even months later. Our challenge was to simulate the aerosol from phytoplankton in great detail on a global scale.

When we put seasonally varying emissions of DMS into the model it predicted an almost identical seasonal cycle of aerosol to that observed at Cape Grim. CCN concentrations were about 60 per cent lower in the winter, when seawater DMS concentrations were about five times lower than in summer.

Does this mean we had confirmed CLAW? Not exactly: we had simulated reality but not tested the hypothesis. So we tried turning off the DMS emissions. We expected summertime CCN to fall below the wintertime levels, because lower summer wind speeds meant fewer particles would be coming from sea spray. But we got surprising results: in many parts of the southern hemisphere summertime CCN remained higher than in wintertime. It turned out that even without DMS lots of aerosol was coming from distant continental regions – from volcanic and pollutant sulphur sources – and this aerosol also peaked in the summer.

The model was telling us that in the modern atmosphere CCN are not as sensitive to changes in DMS as the seasonal variation at Cape Grim would suggest. And when we tested the effect of higher DMS production in a warmer climate we found only a fraction of a per cent change in CCN in the southern hemisphere – not enough to affect climate significantly.

Before we dismiss CLAW it's worth remembering that climate change throws up surprises, and we may yet see large changes in phytoplankton that are not predicted by current models. For example, disappearing Arctic summer sea-ice will create new DMS sources, which could be pivotal in a region where other aerosol sources are extremely small.

With all this interest in particles produced indirectly by phytoplankton, you might be wondering why we're not paying more attention to the aerosol we can actually see coming off the oceans as sea spray – doesn't this have a more direct effect on climate change? The answer would be yes, if the amount of sea-spray aerosol changed over time and caused clouds to get brighter or dimmer. As anyone who has stood on a windy beach will know, the most obvious thing that controls sea spray is the wind speed.

To work out how big an effect wind speed might have we looked at data from the southern hemisphere, where wind speed has increased by about 7 per cent across a wide belt of the

southern oceans since the 1980s. When we fed these winds into our aerosol model we calculated a 22 per cent increase in CCN between 50 and 65°S, and the climate-cooling effect of this extra sea spray turned out to be far larger than anything we calculated due to DMS. In fact, the cooling seems to be large enough to cancel out much of the warming caused by rising CO<sub>2</sub> since the 1980s, at least over large parts of the southern hemisphere. We now think that even small changes in wind speed around the world will be a more important climate regulator than CLAW.

But biology is not done yet. Another major shift in our understanding in the last few years is the discovery that a large fraction of the sea spray is not just salt, but also marine life and the organic substances it produces. A teaspoon of surface sea water typically contains a thousand microscopic animals, a hundred thousand microscopic plants, a million bacteria and more than a billion viruses. The level of biological activity in water can be measured by the amount of chlorophyll present – more chlorophyll indicates greater activity. By using satellite measurements of ocean chlorophyll, and global models, we worked out that the world's oceans emit a whopping 8 million tons of organic material per year, comparable to the mass of organic material emitted into the atmosphere from fossil-fuel burning. In summer, when the biology is most active, organic material can be more important than salt in forming the small CCN particles that most affect clouds.

Organic sea-spray particles are a newly discovered and very direct link between marine life and our climate, and a whole new area of marine research is now under way to pin down the climate effects – the essence of CLAW lives on.

So the next time you go down to the sea, keep in mind that windy days at the beach may be helping to keep our climate cool.

### MORE INFORMATION

Professor Ken Carslaw, Dr Dominick Spracklen and PhD student Matthew Woodhouse work at the Institute for Climate and Atmospheric Science in the School of Earth and Environment at the University of Leeds. More information about their global modelling research is available at [www.researchpages.net/glomap](http://www.researchpages.net/glomap).

Much of the work described above was supported through the UK Surface Ocean-Lower Atmosphere Study (SOLAS), a NERC research programme that has involved more than 100 researchers from around 20 different laboratories. [www.solas-int.org](http://www.solas-int.org).