Gases to gases

Isoprene produced at sea has profound effects on our climate and on ocean ecosystems, but until recently it's received limited attention. Dan Exton explains how this neglected gas is at last getting the notice it deserves.

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For hundreds of millions of years, photosynthesis – the process plants use to turn sunlight into energy – has played a key role in controlling our climate. In fact, the gases exchanged with the atmosphere during photosynthesis are fundamental for life on Earth. The evolution of life was stimulated by a build-up of oxygen in the atmosphere, while the removal of carbon dioxide helped maintain the planet's temperature. Often overlooked, though, are the numerous trace gases involved in this process, which have major effects on climate because of their reactivity.

Over the past few decades, interest in these trace gases has grown enormously, with scientists investigating the roles they play in regulating climate, and the benefits organisms get from producing them. This interest spans both terrestrial and marine sciences.

Terrestrial scientists have focused on the hydrocarbon isoprene, which is the most abundant trace gas produced by vascular plants like trees and grasses. Emissions of isoprene to the atmosphere are roughly equal to those of methane, a powerful greenhouse gas (see pp28-9). Ocean scientists have focused on the sulphur compound dimethyl sulphide (DMS), the main sources of which are marine plankton and seaweeds.

But while DMS is almost exclusively produced in the marine environment, isoprene is made by many organisms that photosynthesise both on land and at sea. Yet few studies have been carried out on isoprene in the world's oceans.

Isoprene is particularly important because it has significant effects on the climate. Being highly volatile, it oxidises rapidly in the atmosphere. Its presence leads to an increase of ozone in the lower atmosphere, which is itself a greenhouse gas and responsible for many health complaints in humans. Isoprene also increases the lifetime of methane in the atmosphere, prolonging its damaging greenhouse effect.

So it's important that we do more research, to understand how isoprene is produced, the role it plays in marine communities and ecosystems, and how environmental change will affect its future production.

Taking the heat?

Until recently, we thought some of isoprene's harmful effects would be negated by its ability to stimulate the formation of aerosols, which cause clouds to form (see pp20-21). The presence of isoprene was thought to help reflect the sun's rays with a layer of cloud, cooling the planet and reducing global warming. But new evidence suggests the opposite – that isoprene actually inhibits cloud formation and so will only make global warming more severe. If this is right, the effect of isoprene in the atmosphere above the oceans could work against that of DMS, which is known to drive cloud formation.

Another angle to the isoprene story is the benefits to the organisms that produce it. Essentially, making isoprene strengthens cell membranes and increases their thermotolerance – it protects them from damage caused by high temperatures. The effect can be so dramatic that in some cases isoprene has been shown to increase the maximum temperature plants can tolerate by 7.5°C. But this protective role could mean isoprene production increases as the planet warms in the future. So not only could isoprene be responsible for an important proportion of atmospheric change, it could also drive a positive feedback pattern – a vicious circle of higher temperatures causing more isoprene emissions, which in turn help drive temperatures even higher.

We are also looking at isoprene's role as an antioxidant, protecting plant cells from damage by harmful molecules including ozone and hydrogen peroxide. Although this is often thought to be an evolutionary coincidence, which came about as a side-effect of developing thermotolerance, the benefits to isoprene-producing organisms are still important. Isoprene has also been shown to act as a signal to other living things, for example deterring herbivores from feeding on certain isoprene-producing plants.

What little work has been done on isoprene in marine systems has been largely restricted to sources in the open ocean, which dominate in terms of area but not in rates of productivity. Yet emerging evidence suggests that isoprene plays a major role in the world's oceans, particularly in coastal habitats.

By the sea shore

These important ecosystems could represent a vastly underestimated source of isoprene. At the University of Essex, we have been improving our knowledge of isoprene in marine coastal systems, where photosynthetic activity is generally much higher than in the open ocean due to a higher biomass of marine organisms. As part of a NERC-funded project, we are investigating the isoprene production rates of important habitats like salt marshes and different organisms like seaweeds, seagrasses and corals – in many cases for the first time. Using specially designed gas-tight equipment we are looking at how these organisms respond to a range of conditions, particularly varying temperature and light, and beginning to understand how the environment controls isoprene production and the different amounts organisms produce.

Coasts and estuaries often have a wide range of environmental conditions in a relatively small space and, particularly in temperate zones, these can change significantly by day and by season. This means they can provide valuable information about how ecosystems may respond to environmental change, and in turn how the production of isoprene may change under future climates. To make the most of this we're carrying out a year-long field survey to monitor isoprene production along a UK estuary. This builds on a recent Essex-led study which found that diverse microbes living there consumed significant amount of isoprene making it an important energy source for coastal bacteria. This also suggests that algae are actually producing far more isoprene than we are detecting in the atmosphere.

Alongside these studies, a recent technological advance is enabling us to analyse isoprene production from marine sources in real time. To do this, NERC-funded scientists at Essex have modified a sensor normally used in atmospheric and terrestrial studies. It uses a chemical reaction to measure isoprene, so it can take marine measurements of the gas ten times a second. This important development promises to allow research to be carried out in much greater detail and will help address many unanswered questions.

Alongside existing research into isoprene in marine systems, projects like these should soon give us a much better understanding of the connection between isoprene production and environmental change. This will be a critical step in evaluating the role and potential feedback of isoprene in future climates on planet Earth. It will also help us judge how big an impact marine isoprene could have relative to both terrestrial isoprene and marine DMS. When we know all this we'll be much better placed to understand the balance of power of these trace gases across the planet as a whole.

MORE INFORMATION

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FURTHER READING

Acuña Alvarez, L, Exton, DA, Suggett, DJ, Timmis, KN and McGenity, TJ (2009). Characterization of marine isoprene-degrading communities. *Environmental Microbiology* 11, 3280-3291.

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