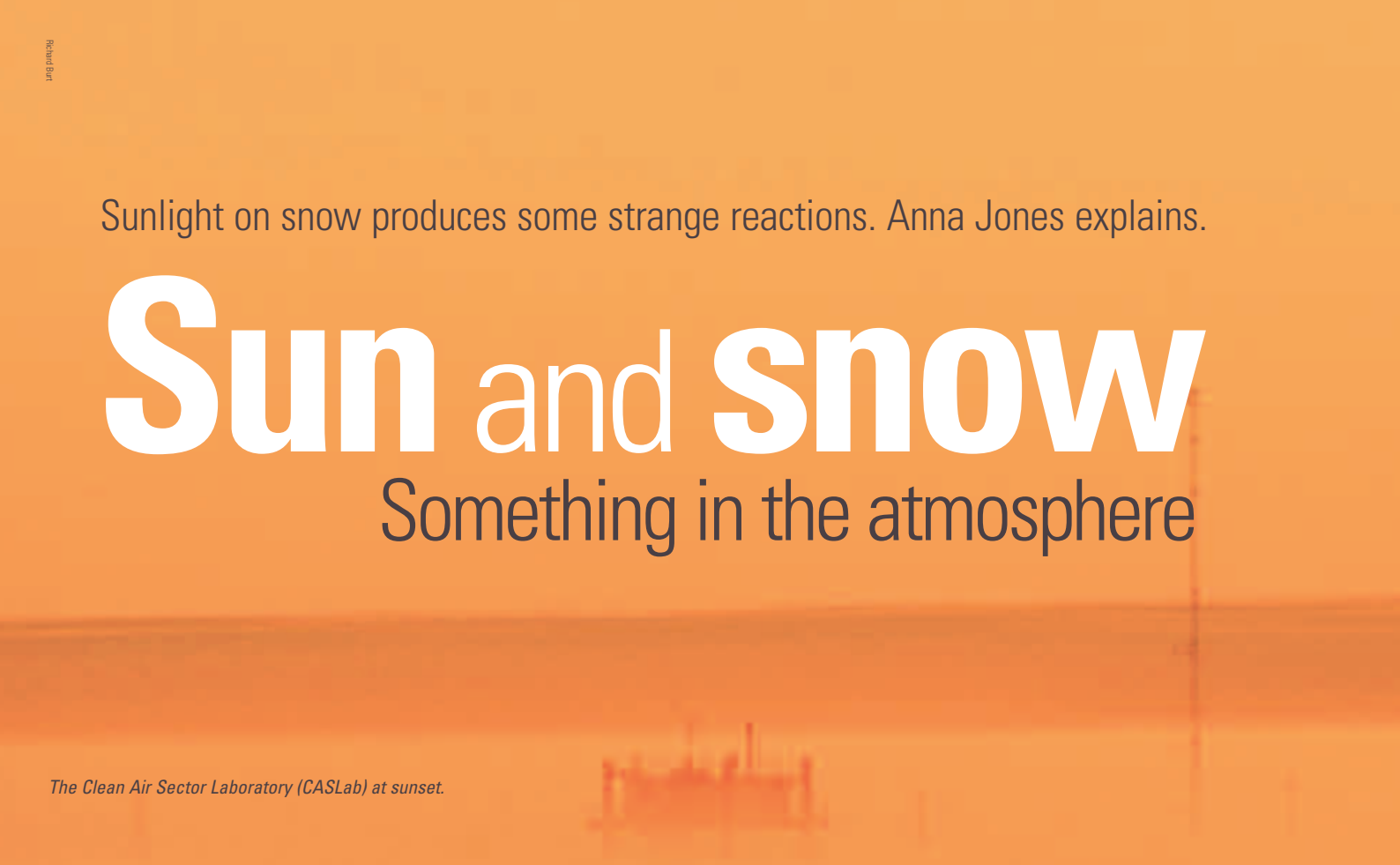
Richard Burt

Sunlight on snow produces some strange reactions. Anna Jones explains.

Sun and snow

Something in the atmosphere



The Clean Air Sector Laboratory (CASLab) at sunset.

In December 2003, four enthusiastic scientists arrived at the Halley Research Station in Antarctica. They had a little over six weeks of the Antarctic summer in which to unpack a shipping-container full of equipment and turn it into a fully functioning atmospheric chemistry laboratory that would operate with just two staff throughout the coming winter. The researchers were studying the chemistry of snow and how it influences the air above it. Why all the fuss, you might ask? Until recently, most atmospheric scientists would have raised the same question. Snow was considered inert, something which affected how much light reflects back into the atmosphere (albedo); something acting as a physical barrier to gases moving between the atmosphere and the biosphere (the Earth's 'life zone'), but something essentially chemically inactive. Then, in 1998, right at the end of a research trip in Greenland, an American scientist sampled the air between snow crystals within the snowpack, in order to help elucidate some puzzling measurements. The results surprised everyone. He found higher concentrations of reactive nitrogen oxide (NOx) trace gases than were measured in the overlying atmosphere, suggesting some of the gases were coming from within the snowpack itself. The main source of atmospheric NOx is pollution, and the amount of NOx in the atmosphere has a big influence on the type of chemistry going on in the air. In a 'clean' atmosphere like that over Greenland, you would expect very low concentrations of NOx—unless there was a local source, as the snow turned out to be. Researchers discovered that sunlight was providing the energy for nitrate impurities in the snow to break down, producing the gases.

These findings led to an explosion of 'snow photochemistry' research. Other researchers found NOx was also produced within the Antarctic snowpack. And wintertime field work in Michigan State, USA, showed that this was not solely a polar phenomenon, but that NOx could also be produced from mid-latitude snow. Nitrate is a ubiquitous impurity in snow, so it is now accepted that this process is probably happening wherever there is snow and sunshine.

And the story is not limited to NOx. Researchers started investigating other trace gases as well. Unexpectedly, concentrations of the reactive hydroxyl radical (OH) in air near the ground at the South Pole are as high as in the tropics. This is because of the action of sunlight on snow, coupled with a very stable and shallow layer of air just above the ground (the boundary layer) that concentrates the unusual chemical system into the very lowest part of the atmosphere. Measurements at Alert, in northern Canada, showed that snowpack concentrations of various alkanes, aldehydes and alkyl nitrates were all higher than levels in the overlying atmosphere, indicating that some very unusual chemistry was going on. Some of these chemicals are probably produced by the action of sunlight within the snow- pack, and others may be by-products of these reactions—we don't yet know.

> Some of the gases were coming from within the snowpack itself.

So, rather than being barren areas with uninteresting atmospheric chemistry, we now know the polar boundary layer and underlying snowpacks are chemically active and highly complex. They're also very interesting because of their unique characteristics of extreme cold, long periods of darkness alternating with continuous sunlight, and this newly discovered interaction between the snowpack and the overlying atmosphere make them a real challenge for the models that researchers use to

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help us understand the global atmosphere. The chemistry of the air at the poles, and the way it interacts with snow, is also important to scientists trying to reconstruct the history of climate changes from ice cores. This work relies on measuring the chemical composition of air bubbles and impurities within ice laid down over thousands of years. It's absolutely crucial to understand how air and ice interact.

So atmospheric scientists from the British Antarctic Survey, Imperial College and the universities of Leeds, East Anglia, Bristol and York launched a year-round study called the Chemistry of the Antarctic Boundary Layer and the Interface with Snow (Chablis) project. It was to be the most extensive and long-lasting field study ever attempted in coastal Antarctica. We chose to work at a newly built laboratory, dedicated to atmospheric science, at the British Antarctic Survey's Halley Research Station.

The project was ambitious to say the least! The four scientists set up numerous and highly complex instruments to study a wide range of trace gases in the atmosphere.

At the end of the summer season, half the team returned to the UK, leaving only two people to run a suite of instruments that would normally need a dozen or so operators. It is to their very great credit that the instruments kept running throughout the study—troubleshooting simply became a part of daily life!

During the next summer, we sent three more instruments and four extra operators to Halley to study oxidant chemistry (essentially, how the atmosphere 'cleans' itself of long-lived gases, which, in populated areas, are normally pollutants). The most complex piece of equipment they took was a Fluoresence Assay by Gas Expansion (FAGE) instrument, to measure hydroxyl and hydroperoxyl radicals (OH and HO_2). The hydroxyl radical is the most potent oxidant in the air, sometimes referred to as the 'atmospheric vacuum cleaner'. It is highly reactive, interchanging rapidly with hydroperoxyl, which is why you need to measure both if you want to understand OH chemistry. FAGE uses lasers and enormous pumps, and had to be housed in its very own shipping container. It was a considerable logistical challenge to deliver this to the Halley research site, and we expected problems from such a delicate instrument. But everything went well and we got five weeks of continuous measurements, with some additional days both before and after.

So far, we've been able to confirm that oxidant levels in this area of the coast are not as spectacularly elevated as they are at the South Pole, presumably because of the less shallow boundary layer at Halley. But we now know for sure that the concentrations of oxidants in this region of Antarctica have a lot to do with photochemistry within the snowpack. Since this is also the case at the South Pole, we think snowpack photochemistry is probably a big influence on oxidant concentrations across the whole of the Antarctic continent.

In the spring, we found surprisingly high levels of iodine oxide (IO), another oxidant that we think is important at this time of year, when hydroxyl concentrations are lower. Some complex chemistry goes on during spring in the polar regions. Ground-level ozone is destroyed, but unlike ozone destruction in the stratosphere (which gives us the ozone hole), this is a natural process. We know that bromine compounds play a role, but our results suggest that iodine compounds may be involved too. Iodine oxide may also form ultra-fine aerosol particles in the polar atmosphere, from which larger particles grow. Interestingly, it seemed that at least some of the iodine oxide came from within the snowpack.

We haven't yet finished analysing the data, but we already know that the chemistry of the Antarctic boundary layer is complex and highly unusual. And if snow here is so important for atmospheric chemistry, it may be crucial elsewhere as well. We'll need to know more if we're to predict how our atmosphere and climate will change as the world warms and snow melts.

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