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ECG Bulletin – July 2007

Previous issues of the *ECG Bulletin* may be seen at:
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Unlocking past climates: *an ice core is harvested by a member of the British Antarctic Survey team (top picture) and sampled (bottom picture). 'Frozen in time: the chemistry of polar ice cores': 2007 ECG DGL: p 3.*

The ECG's Distinguished Guest Lecture

The decision to extend the ECG's annual DGL and Symposium from a half-day to a one-day meeting met with approval from members who attended this year's meeting at Burlington House in March. Plans for the 2008 DGL are well advanced and the theme for the 2009 DGL was agreed at the June 2007 committee meeting of the ECG. Both these DGLs will be part of a one-day symposium, and the venue for the next two meetings will again be Burlington House.

The title of the 2008 DGL & Symposium is 'The Science of Carbon Trading', but it is also hoped to include one or two speakers who can provide a business perspective on the economics of carbon trading. For 2009, the DGL & Symposium will be concerned with 'groundwater geochemistry and health', and will consider the effects of both contaminated land and natural geochemical processes on groundwater, as well as the objectives of the Water Framework Directive for managing groundwater.

The DGL has always been a highlight of the activities of the Environmental Chemistry Group. With the help of past *ECG Newsletters* and *ECG Bulletins*, the topics chosen by previous Distinguished Guest Lecturers since 1986 may be traced (see Table below). The ECG committee has attempted to cover a broad range of environmental chemistry and concerns in selecting suitable speakers for the DGL. But it may be that some issues or topics have been overlooked or understated. We would like to hear from you and learn your views on the future direction of the DGL (and the ECG for that matter). Please pass on your thoughts to the committee *via* Dr Leo Salter: leo.salter@cornwall.ac.uk

***Table**: ECG Distinguished Guest Lecturers 1986 to 2007*

Year	ECG Distinguished Guest Lecturer	Affiliation of Distinguished Guest Lecturer	Title of Distinguished Guest Lecture
1986[a]	Sir Richard Doll	Imperial Cancer Research Fund	The contribution of environmental chemicals to the causes of cancer
1987	Sir Jack Lewis	Chairman of the Royal Commission on Environmental Pollution	The work of the Royal Commission on Environmental Pollution
1988	Sir John Mason	Director of the Meteorological Office	The causes and consequences of acid rain
1989	Professor Brian Thrush	University of Cambridge	Reactions of air pollutants in the atmosphere
1990[b]	Professor Roger Perry	Imperial College	Professionalism in toxic waste management
1991	Professor Paul Crutzen	Max Planck Institute	Global atmospheric chemistry and its relationship to the biosphere, anthroposphere, and climate
1992	Dr David Slater	Chief Inspector, HMIP	Integrated Pollution Control
1993	Sir John Houghton	Chairman of the Royal Commission on Environmental Pollution	Environmental impact of transport
1994	Dr A. K. (Joe) Barbour	Rio Tinto Zinc	Environmental criteria: science based or regulatory responses to public concerns?
1996[c]	Professor Roy Harrison	University of Birmingham	The chemistry of urban air pollution
1997	Dr Dick Derwent	Meteorological Office	Atmospheric chemistry and climate change
1998	Dr Jan Pentreath	Environment Agency	Monitoring for regulatory purposes
1999	Professor Mario Molina	Massachusetts Institute of Technology	Global atmospheric chemistry challenges for the coming decade
2000	Sir John Houghton	Intergovernmental Panel on Climate Change	Global warming and climate change: the latest science and the likely impacts
2001	Dr John Emsley	University of Cambridge	What's so wrong with PVC?
2002	Professor Peter Liss	University of East Anglia	Environmental methylation and the global chemical merry-go-round
2003	Professor Bill Davidson	Lancaster University	Does biology or chemistry determine the availability of toxic metals in soils and sediments?
2004	Professor John Burrows	University of Bremen	Viewing the earth's environment from space: the challenges, the progress and the future
2005	Professor Jane Plant	The British Geological Survey	Metals, the environment and human health
2006[d]	Professor Mike Pilling	University of Leeds	Climate change and air quality: a chemist's perspective
2007	Dr Eric Wolff	British Antarctic Survey	Frozen in time: the chemistry of polar ice cores

[a] A Distinguished Guest Lecture (DGL) has featured as part of the (then) RSC's Environment Group Annual General Meeting since the founding of the Environment Group in the early 1970s. DGLs from 1986 onwards are identified here. The Group's name was changed to the Environmental Chemistry Group in 1993.

[b] From 1990, a half-day symposium has accompanied the DGL. In 2007, the symposium was extended from a half-day to a one-day event. The title for the symposium usually differs from that of the DGL. Only the title of the DGL is quoted here.

[c] Until 1994, the DGL was held in November or December of the calendar year. The DGL scheduled for late 1995 was shifted to March 1996, and the DGL and symposium have subsequently been held in March each year from 1996 to the present.

[d] The ECG Distinguished Guest Lecturer Medal was inaugurated in 2006, and Professor Pilling was the first recipient (see *ECG Bulletin* January 2006 for details of ECG DGL Medal).

Frozen in time: the chemistry of polar ice cores

Predicting the future of our Earth and its climate requires models that contain good representations of the key processes that might take place. Our only way to determine what these processes are, and to test the models, is to look at the past. Numerous "palaeo" [Gk *palaios* 'ancient'] archives exist, ranging from tree rings to marine sediments, but ice cores have played a crucial role in helping us to understand how the Earth works. For example, Greenland ice cores have shown us that extremely rapid climate changes centred in the North Atlantic region are possible, and that natural changes in concentrations of greenhouse gases and in climate have been closely linked in the past. Most of what is measured on ice cores is really chemistry. In this article, based on his 2007 ECG DGL, **Dr Eric Wolff** from the British Antarctic Survey, describes how ice cores work, and summarises some of the key findings that have emerged from measuring their chemistry.

The ice core record

Compared to other palaeo-records, ice cores have both advantages and disadvantages. On the plus side, they can be reasonable well-dated (though less so at sites where many years can be accessed); they extend back 800 kyr (800,000 years) in Antarctica and 123 kyr in Greenland so far; they are particularly good at recording signals of the atmosphere; and many variables can be obtained on the same core (for example, climate signals, and the greenhouse gas concentrations). The biggest negative point is that, although ice cores can be obtained at high altitude sites in the mid- and low-latitudes, these are hard to obtain and interpret. As a result, most ice cores come from the polar regions, which give us only a part of the picture about climate change.

The information in ice can be thought of in three categories, all of them involving chemistry of different sorts. Firstly, the isotopic content ($H_2^{18}O/H_2^{16}O$, or HDO/H_2O ratio) of the water molecules themselves is determined mainly by the temperature at the time of snowfall. The reason for this is related to the slightly lower vapour pressure of the "heavy" molecules, which means that an air mass becomes progressively depleted in heavy molecules on a path from a warm ocean source to a cold polar ice cap. Of course there are complications to the simple story, but the good news for us is that, with care, the isotopic content can be used as a proxy for atmospheric temperature.

When the snow falls, it takes with it aerosol particles and some gases that are in the atmosphere at the time. For example, if there has been a large volcanic eruption, SO_2 reaches the stratosphere, and eventually this will land on the snow as sulfuric acid, giving a layer of the acid in our ice core a year or so after the eruption (a very useful tool for dating cores). Pollutants such as lead (which I spent part of my career analysing), sea salt from the oceans and sea ice, and soil dust from continents are among the other components found in ice after being trapped in falling and fallen snow.

Finally, in places where there is no melting, loose snow turns into solid ice only by being sintered under the pressure of overlying layers of snow. At depths of typically 60-100 m, the ice closes all its channels, and includes tiny bubbles of air that contain a sample of all the stable gases in the atmosphere. If the ice is cracked open again, the air can be collected into canisters and analysed: it is in this phase that CO_2 for example can be measured.

The longest ice cores drilled have been over 3 km, but these are brought to the surface in lengths of perhaps 3 m at a time by a drill on a long cable. The cores, cylinders often 10 cm in diameter, are logged and partly processed at the field site and then transported to home laboratories in sections that can be cleaned, and then analysed by the state-of-the-art analytical methods required for the low concentrations or low sample volumes available.

Cores covering recent centuries

One aspect of the climate change debate that has rarely been questioned is that the concentrations of greenhouse gases have increased substantially above their normal range in the last two centuries. However, direct measurements in the atmosphere were made only for the last 50 years for CO_2 and even less for CH_4 (methane). All our other reliable information comes from measurements in the air bubbles

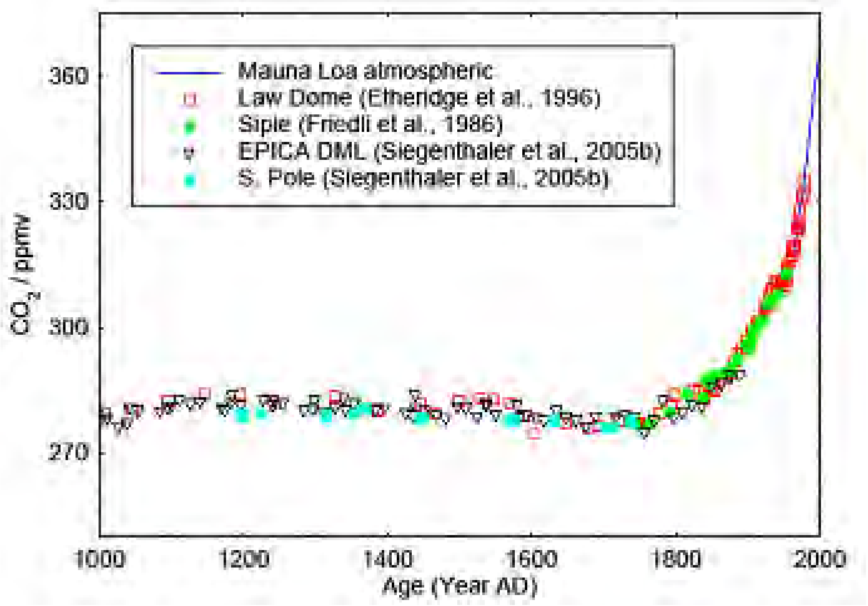

Figure 1: *Atmospheric CO_2 over the last 1000 years from a range of Antarctic ice cores, along with values measured in the atmosphere at Mauna Loa since the 1950s. The figure shows the level of natural variability and the recent rise.*

in ice cores. Using a site with exceptionally high accumulation rate (MacFarling Meure et al., 2006), very good time resolution has been obtained, including samples enclosed in ice that overlap with the instrumental record and therefore validate the faithful recording of the signal. For CO_2 (**Figure 1**), we learn that today's mixing ratio of 381 ppmv (parts per million by volume), is some 35% above the value of 280 ppmv that prevailed (with variations of order 5 ppmv) in the millennium before 1800 AD. For CH_4, the situation is even more stark, with today's value of 1730 ppbv (parts per billion, Antarctic concentration) being more than double the pre-industrial mixing ratio of around 750 ppbv. While there were natural changes in the concentrations of both gases during major climate changes in the past (discussed later), it is clear that today's concentrations of both gases are considerably higher than anything seen in the last 650 kyr, and probably much longer. In recent years, more demanding (because of the small volumes of air available from the ice) measurements of isotopic ratios (e.g. $^{13}CO_2$) in these gases have started to be made, giving new clues about the origin of recent changes.

Although numerous cores covering a few centuries have been drilled, with many different analyses made, I will discuss just one other example of recent change here. Lead (Pb) occurs naturally in polar snow and ice only at the ng/kg level. However, it was shown that, in Greenland ice, the concentration had risen during the industrial era by about a factor 200, firstly due to metal smelting, and then due to the use of lead additives in petrol. Furthermore, as unleaded petrol was introduced in North America and then elsewhere, the concentration again decreased by an order of magnitude during the 1970s and 1980s (Boutron et al., 1991). My own group showed that even Antarctica was not immune, with concentrations (although always tiny compared to any water sample from Europe) increasing by a factor 5 or more, and then starting to decrease again. This story shows how the results of emissions in industrial areas reach the whole globe, but also how measures to clean such emissions really do have an effect.

Longer records: glacial-interglacial cycles

From a range of paleoclimate records, it is well-known that the most prominent feature of climate over the last few hundred thousand years has been successive warmings and coolings, accompanied roughly every 100 kyr by the waxing and waning of great ice sheets. At the height of the last cold (glacial) period 20 kyr ago (the last glacial maximum, LGM), large areas of North America and northern Europe were covered in thick ice sheets, Today we are in one of the short "interglacial" warm periods.

A number of Antarctic ice cores have now penetrated more than one of these so-called glacial cycles. The deepest core drilled so far, the Russian-led Vostok core, reached just over 400 kyr into the past. It showed (Petit et al., 1999) that Antarctica also cooled (by around 9 degrees) in the LGM. Most strikingly, it showed that CO_2 and Antarctic temperature tracked each other over the period of the core, with CO_2 levels typical of the pre-industrial period during warm periods, and mixing ratios around 180-200 ppmv in glacial maxima. This close coupling shows us about natural controls on the exchange of carbon between different parts of the environment and also shows us some of the feedbacks that amplified small changes in incoming solar radiation (due to changes in Earth's orbit) into major global climate shifts. CH_4 also rises and falls with climate.

Extending the record: the EPICA project

I have been lucky to be part of the European team that has drilled another core, extending our knowledge back to 800,000 years before present. The European Project for Ice Coring in Antarctica (EPICA) is a consortium of laboratories and agencies from 10 nations, who have drilled two cores in Antarctica, the oldest and longest being at Dome C. The core site is at 3233 m above sea level, and receives the snowfall equivalent of just 2.5 cm of rain each year. A team of typically 14 scientists and 7 core drillers arrived at the featureless site each summer to retrieve the core, and to section and analyse it. The drilling was completed to 3270 m depth in December 2004.

The core had first to be dated. This has been achieved through an ice flow model (that uses physical knowledge to estimate the initial thickness of each annual layer, and the way it thins with time as the ice flows). However, the unknowns in this model have been controlled by a large range of chemical analyses: for example, sulfate spikes that can be traced to volcanic eruptions of known date, or to the same unknown eruption in an already-dated core, and methane changes that occur at the same time in Antarctica and in Greenland (where they were already dated). A peak in ^{10}Be concentration occurring at an age of 780,000 years before present has a particular significance; ^{10}Be is produced by cosmic rays in the atmosphere, and these penetrate most easily when the Earth's magnetic field is weak. The peak seen at Dome C represents the last time the magnetic field flipped (and was therefore weak for a sustained period); because the date of this flip is already known it confirms our dating that places the deepest ice we can use at Dome C at just beyond 800,000 years ago.

The climate signal (deuterium values interpreted as Antarctic temperature) at Dome C shows a continuation of the 100,000 year periodicity seen at Vostok (EPICA Community Members, 2004). However, the amplitude of the cycles in the earlier parts of the record is much weaker (with interglacial temperatures significantly lower than in the recent ones), and it poses an additional challenge to us to understand why this is so. However, I believe it is crucial that we do so, because we cannot really claim to understand climate if we don't know why we are now in an interglacial, and in an interglacial with the characteristics it has.

The CO_2 and (to a lesser extent) CH_4 concentrations continued to move in line with Antarctic temperature right back to 650,000 years ago (as far as is published so far), with values of only around 250 ppmv for CO_2 in some earlier interglacial periods (Siegenthaler et al., 2005) (**Figure 2**). The startling similarity between the CO_2 and Antarctic temperature suggest that the most important processes controlling CO_2 atmospheric mixing ratios must lie in the Southern Ocean, and in the transfer of carbon from the deep ocean to the surface and atmosphere. This matters because we need to understand the capacity of the oceans to mop up some of the excess CO_2 in the atmosphere today.

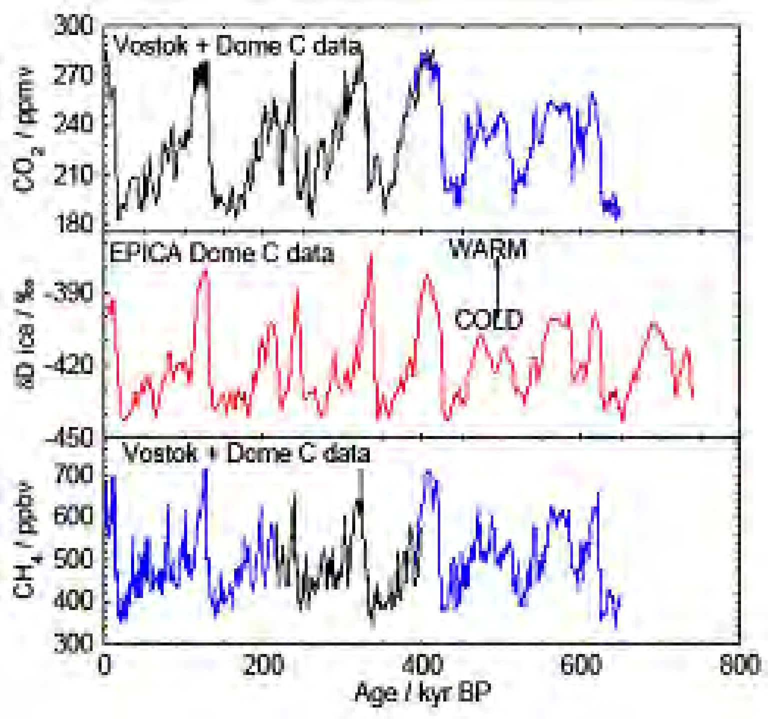

Figure 2: *Deuterium (Antarctic temperature proxy) from the EPICA Dome C ice core (EPICA Community Members, 2004), along with a composite of CO_2 (Siegenthaler et al., 2005) and CH_4 (Spahni et al., 2005) data over the last 650,000 years from the EPICA Dome C and Vostok (Petit et al., 1999) ice cores.*

Numerous other chemical measurements give us access to knowledge of other aspects of the environment over long time periods. Sea salt in ice cores arises from aerosol produced at the sea ice surface as well as from open water. In the interpretation I favour, the record of sodium ion concentrations tells us about past sea ice extent, a key variable for understanding climate. Not surprisingly, we therefore find higher concentrations in cold periods, and the Dome C sodium record (Wolff et al., 2006) can tell us about the relative timing of changes in sea ice, climate and CO_2.

Sulfate concentrations, after correction for the part coming directly from sea salt, and bearing in mind a sporadic volcanic contribution, arise from the oxidation of dimethyl sulfide (DMS), which is produced by some marine organisms. Surprisingly, the flux of sulfate to the ice sheet varies only within narrow bounds over glacial-interglacial cycles, contradicting earlier work that suggested major changes in marine productivity in the relevant section of the Southern Ocean. If such changes occurred, they must have occurred further north than the section of ocean that Dome C effectively samples.

Geochemical studies (using a range of isotopic and chemical fingerprints) on a few samples have previously shown that most of the terrestrial dust reaching Antarctica in cold periods at least came from Patagonia in South America. The huge (~20-fold) increases in the flux of calcium or iron (mainly terrestrial elements) during cold periods (Wolff et al., 2006) shows that large climate changes must have occurred at these times in Patagonia. They also indicate the pattern of deposition of potential nutrients (especially iron) into the ocean, something that may have been one contributor to changes in the uptake of CO_2 from the atmosphere.

Ice cores and the future

Taken together, the different measurements made for example on the Dome C core show the interplay of different parts of the Earth System, and therefore give clues to the mechanisms that need to be represented in models. Recent measurements have given us otherwise unavailable information about what changes have actually occurred. However, there is certainly potential to learn more. The international ice core community has recently developed an agenda for the next decade or more, with a series of priority projects. One of these for example aims to extend the Antarctic record to about 1.5 million years, a time when we know that the tempo of cold and warm climate was paced at 40 kyr intervals instead of 100 kyr. Why was that, and why does it no longer pertain today? Ice cores can help us answer that. At the other end of the spectrum, detailed measurements on well-dated records of the last 2000 years can fill gaps in our knowledge of the spatial pattern of recent climate change and of the natural variability on which it is superimposed. It goes without saying that chemistry, including existing techniques, but also new analytes, more sensitive methods, and faster measurements, is crucial to the future of ice core science.

Acknowledgments

I am grateful to my colleagues at BAS, and in the international ice core community, especially the EPICA project, for sharing the data that made this presentation possible.

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ERIC W. WOLFF

British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET

ewwo@bas.ac.uk

This article is based on a presentation by Dr Wolff at the ECG's 2007 Distinguished Guest Lecture and Symposium 'Environmental Chemistry in the Polar Regions'.

The surprising polar troposphere

Chemical processes in the troposphere are driven by a combination of factors. Emissions from the Earth's surface, either natural or anthropogenic, are the primary source of trace gases in the troposphere. The energy driving many chemical reactions is derived from the Sun, hence the reactions are "photochemical". Transport processes can distribute longer-lived trace gases to locations remote from their origin. In this article, **Dr Anna Jones**, from the British Antarctic Survey, describes some of the highly surprising phenomena that have been discovered in the polar troposphere over the past twenty years.

Introduction

An appropriate starting point is to consider what the polar regions are like, and to contrast the North Pole with the South Pole. Antarctica is a snow-covered continent, surrounded by the Southern Ocean and remote from major population centres. The overlying troposphere is therefore one of the cleanest parts of the Earth's troposphere, and is perturbed only by very long-lived pollutants such as CO_2 and methane. The Arctic contrasts somewhat, in that it comprises a polar ocean (ice-covered during the majority of the year) that is surrounded by continents (snow-covered to a greater or lesser extent). There are parts of the Arctic that are also remote and clean, but equally, there are areas that are exposed to pollutants, a well known example being Arctic Haze.

From this background, what was the polar troposphere expected to be like? The general *a priori* view was that the polar troposphere would be chemically fairly uninteresting, with low mixing ratios of the reactive trace gases like OH, HO_2, NO and NO_2. The snow was considered to be important because of its albedo effect (which indeed it is), but that otherwise it would merely act as a cap to emissions from land and ocean surfaces below.

Atmospheric chemists, who want to understand atmospheric composition and processes throughout the Earth's atmosphere, were nonetheless motivated to study there. The polar troposphere is unusual for a number of reasons: it is very cold; during winter it remains dark for up to 24 hours per day, and during summer the reverse situation occurs with extended hours of daylight. It therefore provides a good testing ground for numerical models of the atmosphere. Furthermore, the polar troposphere (in particular over Antarctica) is one of few remaining parts of the atmosphere that are genuinely clean, providing an opportunity to study a natural background atmosphere. Finally, of course, the polar troposphere makes up a significant part of the atmosphere, so we really ought to know what it is like.

What was found was by no means what was expected. Here I will report on two of the real surprises held by the polar troposphere.

Tropospheric ozone depletion

Most people will have heard about atmospheric ozone in the context of the stratosphere. However, ozone is also present in the troposphere, in much smaller amounts, but nonetheless important; it is involved in production of OH which is the most reactive radical in the atmosphere, responsible in large part for the removal of long-lived (including pollutant) trace gases.

In the polar regions, it was assumed that surface ozone would have a simple seasonal cycle. A minimum in the summer was anticipated, resulting from destruction by photochemically-driven reactions; conversely, during winter, with photochemistry effectively switched off, ozone could be transported into the polar regions by the general movement of the atmosphere resulting in an annual maximum. And indeed, there are places, such as the South African base, Sanae, situated 170km inland from the coast of Antarctica, where such a seasonal cycle is observed. But it has turned out that there are significant deviations from this cycle observed elsewhere.

The first hint of something unusual came from measurements made at Alert, on the northern tip of Nunavut, Canada. Measurements were made during springtime, soon after the sun had risen from the winter darkness. Initially ozone concentrations were in line with what was expected, roughly 30 parts per billion by volume (ppbv). But then strange features were observed: ozone concentrations dropped suddenly to around instrumental detection limits of only a few ppbv; they remained low for a day or so, and then recovered to more normal amounts. These features were observed on several occasions during that first springtime study at Alert.

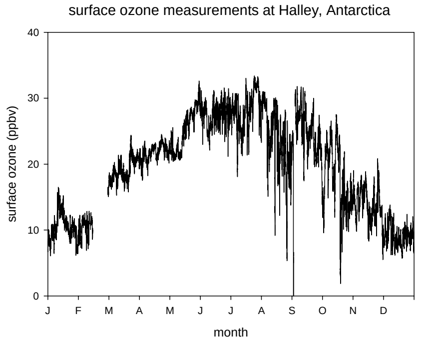


Figure 1: *A typical seasonal cycle of surface ozone measured in coastal Antarctica. The springtime ozone depletion events are evident in August, September and October.*

The first question then was – are these features real, or is there an artefact in the measurements? Further measurements made in the Arctic during subsequent springtimes revealed the same features, showing that this was a real atmospheric phenomenon.

Given that these measurements were made in the Arctic, which can be subject to anthropogenic pollutants, the next question was – are these natural or man-made effects on ozone levels? The answer lay in Antarctic measurements, which showed that these features of rapid ozone loss, now known as Ozone Depletion Events (ODEs) were also measured at research stations in coastal Antarctica (see **Figure 1**). These data confirmed that ODEs were a natural phenomenon.

Ongoing research in both polar regions progressively built the now familiar picture of ODEs. They occur only during the spring; sometimes ozone concentrations drop from normal amounts to near-zero within the space of a few minutes; sometimes ozone loss can be less complete, and can occur more gradually; ozone can remain suppressed for several days; vertical profiling using balloons has shown that the ozone loss can extend up to ~1500 m in altitude and that they are contained within the planetary boundary layer by a capping inversion. An important observation was that ODEs are associated with transport of air masses over sea ice.

So what causes ODEs? Early observations in the Arctic showed a very clear anti-correlation between surface ozone and what was referred to as "filterable bromide", i.e. whatever was captured on a cellulose aerosol filter paper and gave a bromide peak when analysed on an ion chromatograph. Subsequent development both of theories and instrumentation, revealed a major role for gaseous bromine monoxide (BrO). A novel instrument, the Differential Optical Absorption Spectrometer, measured BrO and showed it to be unusually enhanced during ODEs. Measurements of BrO made on satellites, showed that during spring in the polar regions, BrO could be significantly enhanced over enormous areas of the sea ice zone. Again, the association with sea ice was clear.

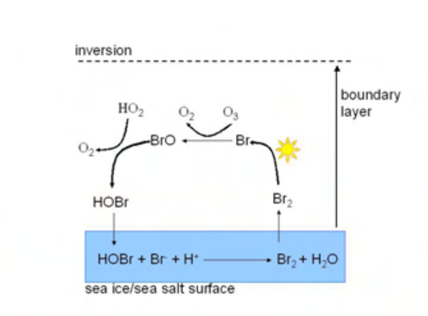


Figure 2: *Schematic showing the "Bromine Explosion". Gaseous HOBr reacts with Br^- in the snow or aerosol surface, thus liberating Br_2. Photolysis releases two Br atoms which destroy O_3. These reactions appear to be facilitated by a strong capping inversion.*

The mechanism that is driving surface ozone loss is known as the “Bromine Explosion”, and is autocatalytic in bromine in the sense that one gaseous bromine going into the system results in two gas-phase bromines coming out (**Figure 2**). Bromide is liberated from the quasi-liquid layer on some sort of sea ice surface (exactly which is still open to debate). The possible candidates include sea salt aerosol, sea salt deposited onto the snowpack, or frost flowers – delicate dendritic ice crystals which are highly saline and grow as new sea ice forms. Interestingly, elevated BrO has also been measured in other locations where large areas of exposed salt exist, such as salt pans and the Dead Sea.

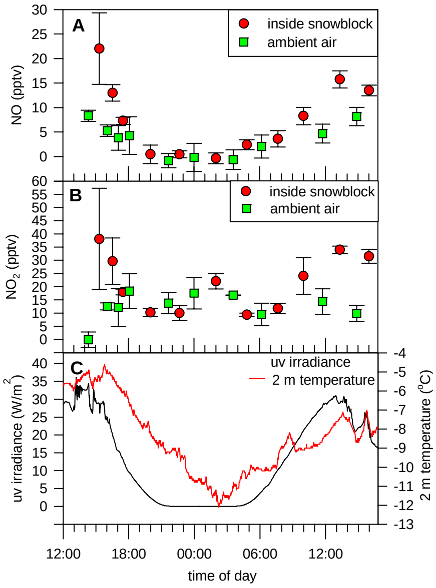


Figure 3: *Results from an experiment whereby air was sampled through a block of snow and compared with ambient. NO and NO_2 measurements provide evidence of production by the snowblock, and that that production varied over the course of a day. The bottom panel shows uv irradiance and air temperature, both of which vary over the course of a day.*

ODEs have been significant for atmospheric chemists for a number of reasons. They highlighted new reaction pathways that are important for halogen chemistry in the boundary layer. They have a potential radiative role that could be relevant on a regional scale, if air that is low in ozone is mixed to higher altitudes where ozone is particularly radiatively important. Finally, they were completely unanticipated, and so provide a nice example that the natural world still holds surprises for us!

Photochemical reactions in snow

As outlined above, our initial view of the polar troposphere was that it would be relatively uninteresting from a chemical point of view. Low mixing ratios of the reactive trace gases such as OH, HO_2, NO, NO_2 were expected, and the snow was anticipated to be important for albedo and as a barrier to surface exchange; it was not anticipated to be chemically active. The assumption that snow is a chemically-inert substrate has since been turned completely on its head. In order to explore the new subject of snow photochemistry, I will describe the story of NO_x production from snow.

In the 1990s, a group of atmospheric scientists were working at Summit, Greenland. They had instrumentation to make an integrated measurement of all oxidised nitrogen trace gases referred to as NO_y, (= NO + NO_2 + HNO_3 + HONO + ….), as well as NO_x (= NO + NO_2). Given that NO_x has relatively few natural sources, the majority in the present-day troposphere being anthropogenic, the scientists were anticipating low mixing ratios of NO_x and a lot more NO_y. What they found were extraordinarily high mixing ratios of NO_x, and a high ratio of NO_x to NO_y, suggesting that there had to be a highly significant local source of NO_x. They turned their attention to the snow. Snow is not a solid medium, but is porous to a greater or lesser extent. The instruments measuring NO_y and NO_x sucked their air sample through a piece of Teflon tubing. The tubing was now inserted into the snowpack to allow the scientists to sample the interstitial air and to compare it with ambient. What they found was quite astonishing: both NO_y and NO_x that was sampled from within the snow was present at mixing ratios many times higher than in the ambient air. There appeared to be a major source of NO_x from within the snowpack. The scientists measured for roughly 1½ days, and found that their results were robust throughout this time period. They also found a signal of a diurnal variation, and suggested that this was due to variation in the amount of solar radiation reaching the snow surface.

I heard about this research at the American Geophysical Union conference in December 1996. A month later I travelled to Antarctica as part of a collaborative project between the British Antarctic Survey and the German Alfred Wegener Institute for Polar and Marine Research to study oxidised nitrogen chemistry. The fieldwork was carried out at the German research station, Neumayer, using instrumentation to measure NO_y, NO, and NO_2. We decided to try to replicate the Greenland work to see if these processes operated in Antarctica, and also to try to quantify the production of these species. We found that ambient air was processed as it passed through the snow, and that both NO and NO_2 were produced. The diurnal variation was also present, and we tested to see if this was driven by changing solar radiation or by temperature; it was the former (**Figure 3** and **Figure 4**).

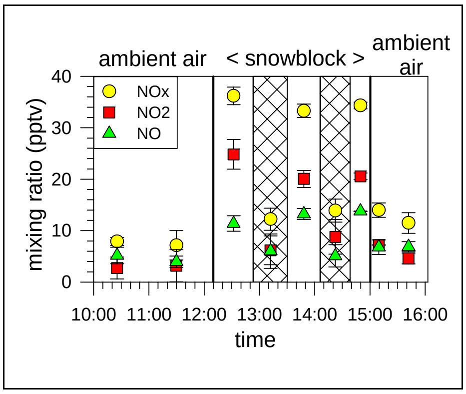


Figure 4: *This figure shows results of a shading experiment, where we alternatively shaded and unshaded the block of snow while measuring air from within the block. Data points are averages over the measurement period. The plot shows that when the snowblock was exposed to sunlight, the amount of NO and NO_2 measured was significantly higher than when the block was shaded – i.e. the production of NOx was driven by the sun.*

Box 1

The surface of snowgrains is sufficiently disordered that it can be described as "quasi-liquid" and we can assume that aqueous phase chemistry applies. Nitrate photolysis in the aqueous phase is classically considered to proceed via two channels:

$$NO_3^- + hv \rightarrow NO_2 + O^- \qquad (R1)$$

$$NO_3^- + hv \rightarrow NO_2^- + O(^3P) \qquad (R2)$$

The ratio of R1 to R2 is roughly 8:1

Reaction R2 can be followed by the photolysis of nitrite (NO_2^-) to produce NO via:

$$NO_2^- + hv \rightarrow NO + O^- \qquad (R3)$$

Alternatively, NO_2^- can react with oxidants such as ozone or OH to generate further NO_2:

$$NO_2^- + OH \rightarrow NO_2 + OH^- \qquad (R3a)$$

So, an extremely interesting new phenomenon had been found in both polar regions, but to have an influence on the atmosphere, the NO_x had to be emitted from the snowpack and into the overlying boundary layer. For three days at Neumayer we measured gradients of NO_x above the snowpack, and using coincident meteorological data, calculated fluxes of NO_x out of the snow. So, NO_x was both being produced within the snowpack and being released into the overlying boundary layer. It was highly significant to find a local source of this important trace gas in these remote locations.

Production of NO_x from snow has now been measured at every polar location where it has been studied. The NO_x is produced by the photolysis of nitrate impurities within the snow, and as nitrate is a ubiquitous impurity, this appears to be a process occurring wherever sunlight shines on snow (see **Box 1**).

The effect on the polar troposphere varies considerably with geographical location; at the coastal Antarctic stations, for example, NO_x in the boundary layer is present only at low mixing ratios, albeit higher than would occur without emissions from the snowpack. The most extreme case is the South Pole station, where NO mixing ratios are routinely over 500 pptv. The exceedingly high mixing ratios are driven by several factors including a very shallow and stable boundary layer into which emissions are concentrated, high concentrations of nitrate impurities in the top layers of the snowpack, intense solar radiation at such a high elevation (South Pole is at 2830 m above sea level) and the fact that South Pole is downslope of the polar plateau, and therefore receives air that has been exposed to much snow.

The importance of NO_x emissions for polar boundary layer chemistry lies in the response of other trace gases, whose mixing ratios are significantly altered compared to those in a low-NO_x environment. For example, the OH:HO_2 ratio is shifted towards OH as a result of the reaction:

$$NO + HO_2 \rightarrow NO_2 + OH$$

The result is that OH has been measured at concentrations of the order 10^6 molecs. cm^{-3}, more typical of tropical regions. Another example is ozone, whose only chemical source in the troposphere arises from the photolysis of NO_2:

$$NO_2 + hv \rightarrow NO + O\,(^3P)$$

$$O(^3P) + O_2 \rightarrow O_3$$

Normally this suite of reactions is associated with polluted regions, but mixing ratios of NO_2 at the South Pole are sufficiently large for *in situ* production of ozone in the summertime boundary layer.

The production of NO_x from snow was a case study to illustrate the mechanisms at work, the extent of the phenomenon, and the potential influence on other atmospheric chemistry. Other trace gases, such as HONO, HCHO, and ethene to name just a few, have also been shown to be produced by the action of sunlight on snow.

Summary

Snow photochemistry and the boundary layer ozone depletion phenomenon described earlier, are both new and exciting areas of science, and have opened a completely new way of thinking about the polar troposphere. Rather than being the chemically uninteresting place that many anticipated, it has turned out to be a fascinating region to study, and full of surprises!

Dr ANNA JONES

British Antarctic Survey,
Natural Environment Research Council,
High Cross,
Madingley Road,
Cambridge CB3 0ET

This article is based on a presentation by Dr Jones at the ECG's 2007 Distinguished Guest Lecture and Symposium 'Environmental Chemistry in the Polar Regions'.

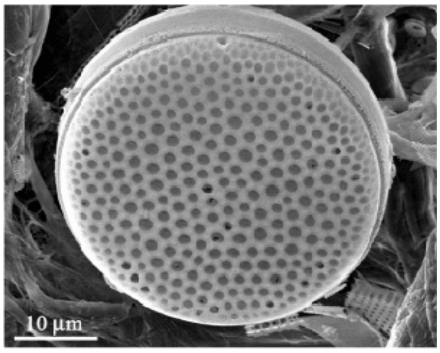
Colour versions of the Figures in this article may be seen on the ECG page of the RSC's web site at http://www.rsc.org/Membership/Networking/InterestGroups/Environmental/bulletin.asp

Primary productivity in Antarctic coastal waters

Production of phytoplankton in the oceans

Primary production in the oceans is dominated by microscopic phytoplankton living in the upper layers (about the top 100 m) of the oceans. Their rate of growth depends on the availability of light and key nutrients, of which nitrogen (as nitrate, nitrite, ammonium and various dissolved organic nitrogen compounds: DON), phosphorus (as dissolved inorganic phosphorus, the dissociation product of phosphoric acid, and dissolved organic phosphorus), dissolved silicon (silicic acid) and dissolved iron are recognised as particularly important.

The importance of these nutrients reflects their vital role in biological reactions and their relatively low abundance in natural waters, meaning that their supply can become limiting for rates of growth. Silicon is unique among these nutrients in being used to form the skeletons of one major group of phytoplankton, the diatoms, while the other nutrients are used for cellular functions by all algae. Hence silicon limits the type of algae that grow, but not the overall productivity.



SEM image of diatom

The role of oceanic phytoplankton

Phytoplankton and associated bacteria form the basis of the food web within the oceans, being consumed by larger zooplankton, which are in turn eaten by other zooplankton, fish, birds and marine mammals. The breakdown of their cells also fuels the bacteria, the action of which contributes to the regeneration of the nutrients. In addition to ultimately sustaining life within the oceans, primary production is also responsible for the exchange of very large amounts of CO_2 across the air-sea interface. The sinking of the organic carbon produced by primary production into the deep ocean represents an important mechanism for removing CO_2 from the atmosphere and hence influencing climate.

Influence of light on phytoplankton production

Over the tropical regions of the oceans light is available throughout the year, but the warming of surface waters by the sun creates a stable stratification which restricts mixing with deep water reservoirs of inorganic nutrients. Here primary productivity removes almost all of the inorganic nutrients, and primary production rates are then limited by rates of nutrient supply by mixing from below or from external inputs − the rivers or the atmosphere. At high latitudes in the Arctic or Antarctic, productivity is limited in winter by lack of light, but cooling of surface waters during winter allows deep mixing and the supply of inorganic nutrients from deep water which are ultimately the regeneration products of sinking organic matter. As the light climate improves in spring, algae begin to grow rapidly in the absence of light or nutrient limitation, creating the so called “spring bloom”. This tends to continue for a period of a few weeks until nutrient utilisation exceeds supply and nutrient limitation sets in and persists through the summer.

Influence of iron on phytoplankton production

Productivity in the Southern Ocean is relatively low compared to some regions of the high latitude northern hemisphere and concentrations of inorganic nitrogen, phosphorus and silicon do not fall to limiting levels. Over the last two decades we have discovered that this is because in these regions productivity becomes limited by the supply of iron. Iron is rather insoluble in seawater and is rapidly removed to sediments compared to the other metals and nutrients. Complexation by organic ligands (siderophores) acts to retain the iron in the water column to some extent, but the supply from deep water is often inadequate to allow utilisation of the other nutrients. Over many parts of the oceans, this deficit of iron is made up by supply from the atmosphere *via* the transport of soil dust. This dust is derived mainly from the great deserts of the world and these are concentrated in the northern hemisphere, for instance the North African, Arabian and Chinese deserts. Dust supply to the remote Southern Ocean is very limited, contributing to the iron limitation in these waters.

The paradigm of iron limitation of the Southern Ocean is now well established and applies to much of this vast ocean. However, it is clear from satellite imagery of ocean colour (a measure of phytoplankton abundance) that there are exceptions to this with some regions of high productivity within this area, particularly associated with land masses such as islands and sea mounts. There is a particularly striking feature in the region between the Antarctic Peninsula and South Georgia, which is probably associated with the South Scotia Ridge. It seems likely that the supply of iron in these regions is enhanced by supplies from sediments by resuspension, dissolution and redox processes. However, oceanographic data from this region to confirm this is limited because of the remoteness and difficulty of working in the Southern Ocean, hence the value of satellite imagery although persistent cloud limits its applicability.

Phytoplankton production in the coastal waters of Antarctica

Along the Antarctic Peninsula region itself, satellite imagery suggests even higher phytoplankton abundance. Access to this region is again very difficult due to sea ice persisting throughout a significant part of the year. However, near to major research bases along the peninsula, for example the British Antarctic Survey (BAS) base at Rothera, it is possible to have rather good regular access to the Antarctic coastal waters, allowing the seasonal cycle of productivity in these waters to be investigated.

It is possible to sample through the ice in winter and *via* boat in the summer allowing a seasonal cycle to be investigated, although the weather and environmental conditions regularly severely restrict sampling. BAS have been engaged in measuring the seasonal cycle of phytoplankton and nutrients in the coastal waters off Rothera for many years, and with Antarctic Funding Initiative (AFI) support this activity has been enhanced over recent years. This work is ongoing but several important results are already available. First the work confirms that the waters are indeed very rich in algae and that this persists throughout the ice free season. Secondly, the phytoplankton abundance is much greater than seen during the spring bloom in the North Sea for comparison, and also persists throughout the season, rather than lasting just for a few weeks as it does in the North Sea.

We still have much to learn about the coastal waters of Antarctica. They are not just an excellent laboratory in which to test out ideas about how ocean productivity is regulated. They are also ecologically very important; the high productivity helps sustain the large seabird and marine mammal populations in this area that first lured humans to this stunning area, at that time primarily for commercial whaling. In addition, the Antarctic Peninsula is one the fastest warming parts of the earth, and climate change will profoundly affect this region with possible ramifications throughout the whole Earth System.

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Web link *Iron and phytoplankton production* http://www.atmosphere.mpg.de/enid/1vw.html

T. JICKELLS, K. WESTON, R. CHANCE

School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ;

A. CLARKE

British Antarctic Survey, Cambridge, Madingley Road, Cambridge CB3 OET

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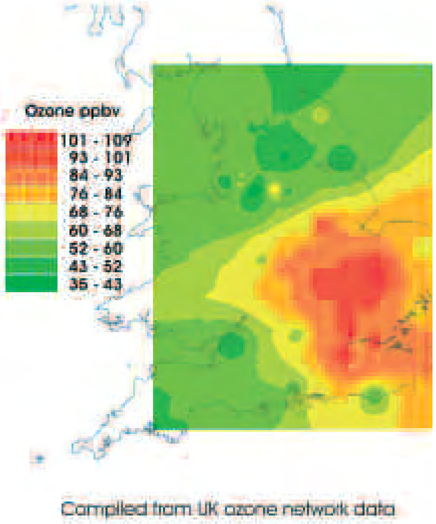
Air quality and climate

Polluted Troposphere Programme

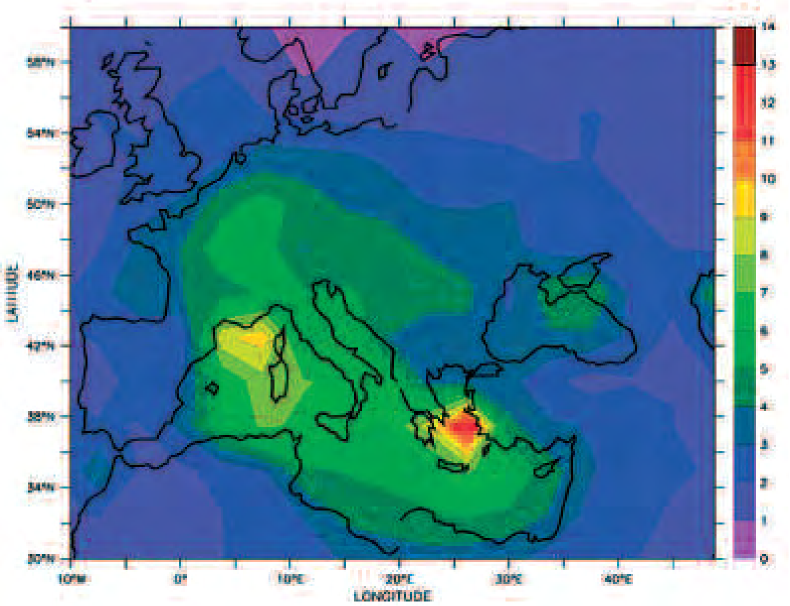
Climate change is a long-term, complex process. One major issue is how climate change will affect air quality, in particular how higher temperatures will modify emissions of a range of pollutants in the atmosphere. NERC's Polluted Troposphere programme investigated this issue. Human activities emit a wide range of pollutants into the atmosphere that can affect climate both directly and indirectly. Direct effects include emissions of small particles, known as particulates or aerosols, that can change the Earth's radiation balance. Indirect impacts include changing the amount of time long-lived greenhouse gases remain in the atmosphere.

People in the UK are well aware of the relationship between poor air quality and extremely warm weather and this is an obvious area where knowledge of atmospheric processes can bring positive benefits to both quality of life and human health. Scientists observe significantly higher levels of pollutants such as ozone, small particles and the oxides of nitrogen (collectively termed NOx) during photochemical pollution episodes, sometimes called smog.



Compiled from UK ozone network data

UK ozone bubble
UK ozone 'bubble' on one day of the 2003 heatwave (6 August). Levels rose above the high warning level. Courtesy of P. Monks and M. Jacob, University of Leicester.



A simulation of the effect of increasing emissions of isoprene with climate. *Courtesy of P. Young and J. Pyle, University of Cambridge.*

Higher temperatures cause faster chemical reactions and changes to both the rates and types of emissions. As a simplistic example, for the UK, there is a direct correlation between the severity of summertime photochemical episodes and daytime air temperature. Very high summertime air pollution, for example when ozone concentration rise above 90 parts per billion by volume (ppbV), is almost always associated with high pressures (anticyclones) and temperatures in excess of 28-30°C. Climate scientists predict that hot summers, such as those experienced during 2003 and 2006, when Europe saw substantial photochemical smog, will increase both in frequency and duration as a consequence of climate change.

The European heatwave in August 2003 starkly demonstrated the significance of high temperature air pollution. During a 10-day period a blocking anticyclone persisted over Western Europe, with consequent air temperatures of up to 40°C. This led to severe health problems, particularly in France, where the authorities reported around 15,000 extra deaths. In the UK, temperatures regularly exceeded 30°C with the Office of National Statistics reporting over 2,000 excess deaths during the heatwave. Of this number 400-800 of these deaths have been attributed to poor air quality through a combination of elevated concentrations of ozone and particulates in the atmosphere. Put in a national perspective, air pollution caused 20-40% of all excess UK deaths during the heatwave. But health was not the only issue: the heatwave caused a significant reduction in crop yield across Europe.

As part of NERC's Polluted Troposphere programme, scientists made detailed observations of atmospheric composition outside London and in East Anglia to highlight where our understanding of regional air pollution was good and where it was poor. Fortuitously, researchers were making these observations north of London during the 2003 heatwave, allowing a unique and detailed insight into the key chemical and physical factors affecting the production of photochemical smog under high temperature conditions.

The heatwave was characterised by high ozone concentrations. The team observed peak levels in the UK in excess of 110 ppbV on each of the five days of the heatwave. Analysis of the collected chemicals, and meteorological data, suggests that naturally-produced (biogenic) compounds from vegetation assisted photochemical smog formation. The team showed that plants responded to heat stress by emitting large amounts of a chemical called isoprene. Vegetation in this area does not normally emit much isoprene,

Greenwich Park during the heatwave of 2003.
Robert Stainforth/Alamy.

which is a very reactive chemical that can contribute to the formation of high levels of ozone when combined with nitrogen oxides.

Calculations show that during the heatwave biogenic emissions caused by the heat accounted for 33% of regional scale ozone formation on average, and typically 40-45% on the highest temperature days. This can be compared with a calculated contribution of about 20% during the remainder of the summer period. The results suggest an important role for biogenic oxidation in regional-scale ozone formation under heatwave conditions. Further to this, new analysis points to not only increased isoprene production in plants, but also increased amounts of particulates in the atmosphere during heatwaves.

This demonstrates that the relationship between natural emissions and poor air quality appears to be a major uncertainty in the context of a changing climate. Higher temperature may mean, for example, more plant emissions and therefore poorer air quality, emphasising the integrated nature of climate change and local air quality. Other factors such as carbon dioxide emissions, land use and future human-induced emissions are also important. The largest uncertainties are the magnitude and relative importance of many of the interactions between the atmosphere and nature.

On a national policy level, as recognised by the Department for Environment, Food and Rural Affairs (Defra), there is an important imperative to determine the links between air quality and climate policy. For example, the steps taken to reduce local and regional air pollution could be in conflict with climate goals (some pollutants such as particulates have a cooling effect on the planet) and similarly, the steps taken for climate mitigation could make local and regional air quality targets more or less attainable. Scientists and policy makers are working together on these policy trade-offs through NERC programmes such as Polluted Troposphere and NERC's National Centre for Atmospheric Science's Distributed Institute for Atmospheric Composition.

Atmospheric composition and air quality are intimately linked with climate and the NERC funded atmospheric programmes have shown the power of fully integrated atmospheric research.

Dr PAUL MONKS

Department of Chemistry,
University of Leicester,
Leicester, LE1 7RH, UK
p.s.monks@le.ac.uk

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Pollution: from city streets to global atmosphere

Upper Troposphere Lower Stratosphere (UTLS)

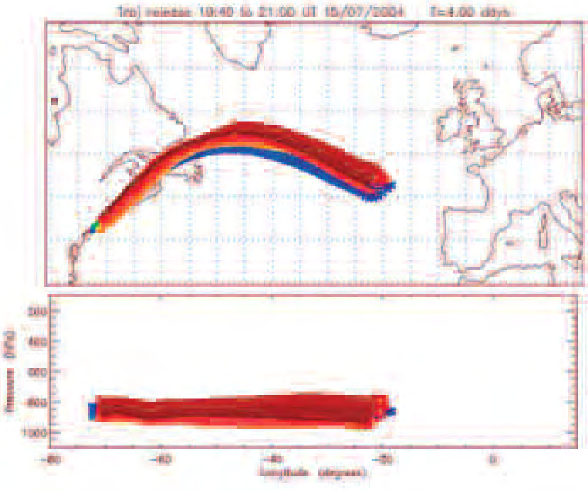
Air pollution is often thought of as a local issue affecting just small areas, for example, around towns and cities. Consequently, policy makers largely monitor and control air pollution at a local level. It has become increasingly clear however that, over the past decade, surface emissions from manmade sources can and do travel on continental scales.

City pollution in the lowermost atmosphere does not travel far. The major factor in longer-range movement of pollution is the up-lift of air from the boundary layer into the free troposphere lying above. The troposphere is split into two regions; the 1-2 km nearest the Earth's surface is the boundary layer, and the region above it is the free troposphere.

Once in the middle and upper troposphere, jet streams can move these gases and aerosols (small particles) thousands of miles, often in distinct stratified layers of pollution rich air. Based on observations and computer models, researchers now propose that for a wide range of atmospheric pollutants, this is the main method of transport on large scales. The transport of pollutants can therefore be considered as being 'embedded' within weather systems themselves, and has lead to the concept of chemical weather. Many different meteorological processes can aid the redistribution of surface pollutants from local to global, for example large-scale advection (horizontal movement), deep convection and convection embedded within frontal systems. Long-range transport of pollutants such as nitrogen oxides and volatile organic compounds can lead to further increases in free troposphere concentrations of ozone (formed when nitrogen dioxide is exposed to sunlight) and aerosols downstream, of significance to climate change researchers. In addition, when air subsides many thousands of miles downwind of its source, it may result in elevated pollutant concentrations re-entering the boundary layer. Any such increase in what may be considered the 'baseline' concentration prior to further local or regional production, may have significant impact in determining feasible local air quality targets, and will raise exposure levels of people, animals and vegetation to certain pollutants.

Over recent years NERC has supported a substantial amount of UK-led research in this area. Through the UTLS programme, scientists have placed a considerable emphasis on a better understanding of the mechanisms through which pollutants leave the boundary layer and enter the free troposphere. The project ‘dynamics and chemistry of frontal zones’ quantified the efficiency with which fronts sweep up surface level pollutants and pass them into the free troposphere. The project ‘atmospheric chemistry and transport of ozone’ laid the foundations for the detection of reactive and short lived chemical pollutants as a means of differentiating between advection and convection as mechanisms for pollutant transport into the free troposphere.

Our understanding of the effect of long-range pollution transport has relied heavily on the use of computer models but there has been only limited use of observations to validate such models. Providing validation from observations requires researchers to address the following questions. Can we detect a polluted air mass leaving a city or region and follow this as it evolves over thousands of miles? How does the composition change over time? Where do the emissions end up? To answer these questions requires a massive experimental and computational challenge, requiring models to make highly accurate predictions of weather and atmospheric transport, in combination using aircraft to make detailed and source-unique measurements, by flying into remote regions of the atmosphere. A successful coupling of model and measurements in the field provides the key validation of model performance, and from this, quantitative estimates of emissions and impacts.



Tracking pollution. *Tracking pollution from the US towards Europe.*

One of the largest atmospheric chemistry experiments ever staged, the International Consortium for Atmospheric Research into Transport and Transformation (ICARTT), addressed this issue for the first time. The UK, through UTLS funding, was a lead participant in this multinational project involving some 600 scientists and 100 agencies and research organisations. One of the overarching goals of ICARTT was to make detailed observations of chemical processing and change occurring in air moving from the USA to Europe. This involved intercepting and sampling, on many occasions, polluted air from coastal cities along the eastern seaboard of the USA, as it passed out over the Atlantic and on to Europe. UK scientists provided the key mid-Atlantic measurements, flying the NERC/Met Office aircraft into air masses that had been sampled on previous days by US research aircraft, and which would be studied once over Europe by French and German scientists.

The key achievement from ICARTT was that polluted air masses from the US could indeed be identified using specialised forecasts, and then successfully intercepted and re-sampled by up to four different aircraft over seven days and distances of up to 4000 miles. This was the first time that scientists have been able to follow a true source-to-receptor pathway for pollutants moving over intercontinental scales. To achieve this the teams needed to develop new tools and approaches for both forecasting and flight planning, in addition to high quality and highly detailed chemical measurements made from aircraft. By combining both measurements and models the project has made much more accurate estimates of emission strengths and long-range influence of pollutants.

Prof. ALASTAIR LEWIS

Department of Chemistry,
University of York
acl5@york.ac.uk

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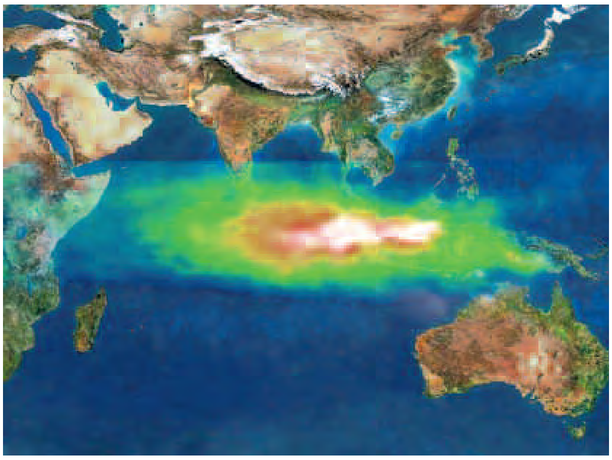


Pollution plumes. *A blanket of pollution over the Indian Ocean.*

Monitoring arsenic contamination in Latin America

In 2007 Cornwall College joined with partners from Spain, Argentina and Chile in a two year EU funded programme of research into the sustainable management of arsenic contaminated water and soil in the rural areas of Latin America. **Leo Salter** reports.

The Universities Buenos Aires and Valladolid together with Cornwall College, the CICITEM (Centro de Investigación Científica y Tecnológica para la Minería) and the Castille and Leon Agrarian Institute, are being supported via Framework Six International Co-operation funding to examine one target zone in Argentina (SE Cordoba province) and one in Chile (Calama and San Pedro de Atacama) in relation to the impacts, monitoring and possible remediation of arsenic contaminated groundwater.

In both locations the phreatic waters have high concentrations of arsenic and this in turn has caused diseases such as HACRE (El **H**idro**a**rsenicismo **C**rónico **R**egional **E**ndémico; Chronic Endemic Regional Hydroarsenism). The extensive area of arsenic contaminated land in Cornwall and the need for cheap and effective remediation methods for it, together with the current interest in arsenic at Cornwall College, made the College a natural partner in the programme and an initial meeting took place in Buenos Aires in late February 2006.

In general, in both Chile and Argentina, arsenic in water and soils is of geochemical origin – though there is some environmental arsenic associated with the mining and smelting operations to the east of the Chilean zone. Arsenic concentrations in the range 0.006 - 11.5 mg dm^{-3} were present in groundwater in Cordoba though concentrations in soil and sediment were low (2.1 - 8.2 mg kg^{-1}). For Chile total arsenic concentrations of up to 2.5 mg dm^{-3} in river waters were found.

The Atacama Desert in Chile: *a possible location of arsenic contamination*

The project will focus on the impacts of arsenic on agriculture and husbandry. Carrots, Swiss chard, onions and garlic are sold in the cities close to the Chilean zone and wheat, corn, soy bean and sunflower are the main Argentinean crops. Arsenic has been found in wheat (1850 µg kg^{-1}) and potatoes (860 µg kg^{-1}) in Chile and several studies have been carried out in Argentina to assess the transfer of arsenic to milk (Cordoba province supplies 35% of the milk in Argentina).

The initial part of the programme will focus on mapping the existing data from the two regions with attempts being made to map epidemiology, farm type and extent, catchments, soil arsenic concentrations and water arsenic concentrations (and other water chemistry parameters) via GIS.

Using this mapped database a monitoring plan will be proposed to provide robust chemical information from remote river systems in the catchments – part of this process will include recommendations concerning the appropriate monitoring devices. A broad range of water quality indicators will be monitored.

Subsequently the target zones' agricultural practices will be reviewed and gateways for the entry of arsenic into the population identified. An evaluation will then be made of the next suitable changes to practices for the improvement of food safety. Finally, simple and appropriate techniques for water and soil remediation will be suggested.

Dr LEO SALTER
Cornwall College,
Pool, Redruth, Cornwall

leo.salter@cornwall.ac.uk

Meeting report

Indoor air quality

The Institution of Environmental Sciences and the Institute of Air Quality Management held a conference in January 2007 at the Building Research Establishment (BRE), Watford, with the title *Personal Choice or National Responsibility for Indoor Air Quality?*

Derrick Crump (BRE) opened the proceedings by emphasising the potential health effects of indoor air pollution. Pollutants such as VOCs, allergens, and fibres can be sourced from indoors (e.g. furnishings, cooking, smoking) and outdoors (ambient air); and the concentrations of such pollutants indoors is intimately connected to building heating, cooling and ventilation systems.

Tadj Oreszczyn (Bartlett School of Graduate Studies, UCL) spoke about the use of Building Physics Models to examine the balance of energy use and ventilation in terms of pollutant concentrations indoors – and the vital need for such models to be grounded with field data. He illustrated the importance of occupant behaviour by reference to conservatories – originally a retro-fit energy reduction intervention but now (depending on the way the conservatory is heated, whether it can be isolated and whether it is used in winter) of uncertain benefit.

Ben Croxford (UCL) focused on the risk associated with indoor gas appliances. His project examined 597 households in east London and of these 23% had some kind of problem appliance: 3% had a very high risk of carbon monoxide poisoning (there was also a 5% high risk and 9% medium risk).

In the final presentation of the first session **Jo Barnes** (Air Quality Unit, Cornwall College) discussed recent measurements of arsenic concentrations in ambient air in Cornwall and their implications for health. In particular, evidence was presented that for residents in historic mining areas in Cornwall indoor arsenic exposure should be monitored. The case was also made for indoor baseline monitoring of other metals/metalloids in all areas where there was an exposure risk.

Dudley Shallcross (Bristol) opened the second session with a talk about the complexities of the relationship between urban outdoor air pollution and its indoor penetration and circulation.

Vian Kukadia (BRE) continued this theme and described how the BRE was attempting to raise awareness of indoor air quality issues and was undertaking extensive monitoring “. . . to provide industry with guidance and solutions”.

Nicola Carslaw (York) described the application of master equations used to model tropospheric chemistry in studying indoor air pollution. Three features of the indoor system stand out. First, although photolysis is minimised indoors, hydroxyl radical concentrations are still significant – 40 times less than outdoor summer concentrations, but similar to outdoor night-time and winter concentrations. Secondly, there are much larger surface areas indoors than outdoors (0.02 cm^2/cm^3 indoors and 1 x 10-5 cm^2/cm^3 outdoors). Thirdly, terpenes and liminoids (often from air fresheners and similar) are important indoor sources of hydrocarbons in indoor air chemistry.

The final presentation (**Mike Ashmore**, York) dealt with the use of (total) personal exposure modelling as a tool for policy assessment. He emphasised that knowledge of the frequency distributions of exposure in a population (Population Exposure Frequency Distribution) based on the way individuals divide time between indoors and outdoors, roadside and elsewhere, work and home etc. and their activity patterns (e.g. groups such as bus drivers, schoolchildren office workers) was essential in evaluating risk and in designing intervention strategies. Exposure to HGVs seemed to be a particular hazard.

In summary, indoor air pollution has great significance for individual health. Its links to building design, occupant behaviour, outdoor pollution and geographical location are complex and under-researched.

Jo BARNES
Cornwall College,
Pool, Redruth, Cornwall

jo.barnes@cornwall.ac.uk

Meeting report

2007 Environmental Chemistry Group Distinguished Guest Lecture and Symposium

Environmental chemistry in the Polar Regions

The 34th RSC Environmental Chemistry Group Distinguished Guest Lecture and Symposium took place in the Council Room of Burlington House on Tuesday March 6th 2007. Attendees from the UK and other EU countries listened to a programme of five lectures on the theme of environmental chemistry in the Polar Regions.

The symposium was opened by **Brendan Keely** (University of York) who spoke about sediment records of environmental change in Antarctica during the last 10 000 years. Although difficult to analyse, pigments preserved in Antarctic lake sediments can be used as biological markers to provide information about source organisms. The talk focused particularly on photosynthetic pigments (chlorophylls derived from algae) since these are biological markers which relate exclusively to primary producer communities. The analysis and identification of such pigments are challenging because they are present in complex distributions of defunctionalised forms. However, by using multiple diode array high-pressure liquid chromatography (HPLC) and multistage tandem mass spectrometry (MS) (seven stages), a great deal of information was obtained.

Results from the Larsemann Hills region in East Antarctica (the low altitude lakes Pup Lagoon and Kirisjes) showed the presence of the farnesyl functional group, suggesting that the chlorophylls present were predominately those from anoxygenic bacteria. Additionally, results from different sediment layers also revealed changes in alkylation at C_8 and C_{12}, which provide a record of changes in ambient light intensities. Interpretation of such data led to an understanding of the way in freshwater dominance gave way to an anoxic 300 year marine inundation (6525-6205 BP), which itself gave way to a further freshwater system. This level of detail about Holocene sea level change in Antarctic contributes significantly to the understanding of natural variations in global climate.

Tim Jickells (UEA) then spoke on how productivity in Antarctic waters is controlled. Primary productivity is dominated by microscopic phytoplankton (the basis of the oceanic food chain and a significant global carbon dioxide sink) which are regulated by the availability of light and nutrients (e.g. nitrite, nitrate, ammonium, dissolved inorganic phosphorus, and iron). Arctic waters are very productive which contrasts with the iron-depleted Antarctic waters which are not productive. This is because global dust fluxes (from the great deserts) are the natural sources of iron, and deposition in Antarctica is low. However, some areas of the Antarctic have relatively high productivity which is thought to be due to sediment iron supply from the Antarctic Peninsula ('a filament of iron-rich water extending from the peninsula fertilising the waters before the iron precipitates out'). Temperature, salinity, light penetration and density also have a large effect on water column structure and productivity. The annual productivity of chlorophyll has a summer peak (December – April) and inter-annual variability is high. Seasonal cycles in the concentrations of ammonium, nitrate, silica and phosphates are marked.

Although there is recognition of its importance to marine (and global) food chains and although there is acknowledgement that climate change will have a profound effect, it is apparent that the understanding of the control of productivity in Antarctica is incomplete and that without support for further exploration of its complexities, it will remain so.

Following these two papers about biological activity in Antarctica, **Anna Jones** (British Antarctic Survey; BAS) turned the attention to tropospheric chemistry (*Tropospheric Chemistry in the Polar Regions*). Originally it was thought that the remote polar troposphere would be fairly chemically uninteresting with low mixing ratios of reactive trace gases ('the Antarctic – remote and clean; the Arctic – less remote and clean') hence it was thought that it would be a good place to study a clean background atmosphere. Anna Jones discussed two aspects of the tropospheric chemistry which challenged this assumption – tropospheric ozone depletion events (ODEs) and photochemical processes which occur in snow.

In the Polar Regions, tropospheric ozone was expected to follow a seasonal cycle with a minimum in summer and a maximum in winter. However, significant deviations from this expected behaviour are found. In coastal stations, such as the Alert Arctic Station and the Antarctic station Halley rapid ODEs have been observed. Back trajectory calculations show that these events are associated with sea ice. The species responsible has been identified as BrO arising from sea ice source such as sea salt aerosols or frost flowers. Springtime conditions of extensive sea ice, an appropriate wind direction and inversions can produce depletions which extend up to several kilometres in height and which last for several days. The understanding of ODEs makes an important contribution to the modelling of atmospheric chemistry in the Polar Regions and the understanding of regional climate.

Assumptions about chemistry at the poles included the belief that the snowpack was chemically inert. However, in the mid 1990s measurements in Greenland showed elevated levels of NO_x within the snowpack. This was subsequently found to be due to the photolysis of nitrate present in the snow. As a consequence NO and NO_2 are released into the boundary layer. The most extreme example of this photochemical effect is at the South Pole where emissions from snow (driven especially by the high UV radiation and high concentrations of nitrates in the snow) are concentrated into the shallow boundary layer resulting in the high levels of NO. This enhanced NO affects other chemistry, including OH chemistry.

Dwayne Heard (University of Leeds) complemented the environmental chemistry described by the previous speaker by focussing on the measurement of free radical concentrations in the Polar Boundary Layer − particularly OH radical concentrations and those of HO_2, RO_2 and the halogen oxide radicals, BrO and IO.

Because concentrations of radicals are low (for OH ~ 10^6 molecule cm^{-3}), *in situ* fast and sensitive techniques are required. FAGE – which uses laser induced fluorescence to quantify OH and HO_2, CIMS (Chemical Ionisation Mass Spectrometry) for OH, HO_2 and RO_2, and DOAS (Long Path Differential Absorption Spectrometry), for BrO and IO, have all been used in polar environments. The data obtained are then compared to predictions of box models using detailed chemistry, for example the Master Chemical Mechanism. The level of agreement with the model is a powerful indication of whether we understand the chemistry of the Polar Regions.

Data from various stations (Palmer Station Antarctica, Summit Station Greenland, South Pole and Halley) were presented together with model calculations. Hydroxyl radical concentrations at Palmer Station were low (average 1.1 x 10^5 molecules cm^{-3}) and consistent with it being a remote pristine environment. The higher levels measured at Summit in Greenland and South Pole (up to a few 10^6 molecules cm^{-3}) were consistent with observations of snow emissions of NOx, nitrous acid and formaldehyde, which accelerate the cycling of radicals and increase OH. For OH and HO_2 measurements from Halley, agreement with model calculations was improved when the reaction of HO_2 with IO and BrO was included, together with the photolysis of HOI and HOBr photolysis as sources of OH. The levels of BrO and IO were measured to be highest in oceanic winds when the air came from regions likely to contain frost flowers. The chemistry of OH at Halley in the summertime appears to be controlled by coupling with halogen chemistry, which was unexpected.

The **2007 Environmental Chemistry Group Distinguished Guest Lecture** (*Frozen in time: the chemistry of polar ice cores*) was given by **Eric Wolff** (BAS).

The study of palaeoclimates and palaeoatmospheres by examining the gaseous content of ancient ice cores is essential not only for an understanding of how climate (and the Earth) responds to different conditions and but also for the testing of models being used to predict future climate. Ice cores contain a record of ancient air often with well-dated annual resolution and (currently) they provide data on the earth's atmosphere as far as 800 kyr (800,000 years) ago (this is from Dome C a drilling site 900 km inland from the Italian station at Terra Nova Bay).

Drilling for cores takes place at a variety of sites. Vostok (the Russian Station) has provided cores with 420 kyr of ‘measurable’ ice. Dome A (1200 km from the China station at Zhongstan) is one of several sites which offers promise as a drilling site with data from a million years ago. However, there are problems with coring. Access to cores is geographically limited, their acquisition is expensive, and dating does become poorer in sites with a low snow accumulation rate.

A variety of signals can be obtained from cores. The oxygen and hydrogen isotopic content of the water molecules provides information about temperatures at the time of snowfall; both soluble and insoluble species are trapped at the surface by falling snow and there is also dry deposition and gaseous uptake onto the surface (e.g. sulfur from volcanoes, biogenic sulfur from DMS); as the snow gets deeper, pressure turns the loose snow into solid ice with bubbles of trapped air containing a sample of stable gases from the atmosphere (e.g. CO_2).

There is clear evidence that anthropogenic activities have increased methane, nitrous oxide and carbon dioxide over the last 200 years – and although natural variability in these species has been observed in the ice core record, it is not of the same amount as has happened over that time.

The cores from Dome C have evidence of 100 000 year cycles in temperature (Milankovitch Cycles – associated with changes in the eccentricity, axial tilt, and precession of the earth’s orbit) and gas analysis shows that carbon dioxide (oceanic control) and methane (terrestrial control) concentrations increased when average temperatures were high but decreased when average temperatures were low. However, prior to this there were 40 000 year cycles. The transition between these two periodicities is thought to have occurred at the limit of the available data (i.e. about a million years ago). Hence a future core covering an even longer time span will be important for investigating the transition and, particularly, the reason(s) why it occurred. A dramatic reduction in atmospheric carbon dioxide seems likely to have been involved.

Rapid climate change events also occur and 23 such events have been recorded between 110 kyr and 23 kyr BP. These events are much stronger in the Arctic than the Antarctic and the climate variability in cores from Greenland are much stronger than those from Antarctica. These Dansgaard-Oeschger events are linked to changes in the oceanic conveyor belt. Amongst other changes global temperatures are up by 10 °C, methane is up by 100-200 ppbv, and there is more snowfall during these warm events compared to the cold periods around them.

Eric Wolff co-chairs the International Partnership in Ice Core Science (IPICS) which aims (starting in 2012) to drill for two ice cores, with Dome A as perhaps the site for one of them. The data obtained from the million year old ice cores will help us to understand how the Earth works, and therefore to have better models to understand the future and hence determine the way we prepare for it.

Dr LEO SALTER

Cornwall College,
Pool, Redruth, Cornwall

The Royal Society of Chemistry Gas Kinetics Discussion Group Summer Meeting

Monday September 10th and Tuesday September 11th 2007

Devonshire Hall, University of Leeds

Programme, Location and Costs

The Gas Kinetics Discussion Group is pleased to announce details of the 2007 Summer meeting. The meeting is an opportunity to celebrate the career of Prof Mike Pilling who officially retires in September 2007. In addition to a session reflecting Mike’s many contributions to the field there will be sessions on ‘*Synergies between Experiment and Theory*’ and ‘*Kinetics in field measurements and modelling*’ for which oral contributions are requested. On Monday evening there will be a poster session prior to dinner.

The conference will take place at Devonshire Hall, approximately 15 minutes walk from the University. Registration will be £90 per person (if paid by 15th June, £110 thereafter) with a student rate of £50 per person (if paid before 15th June, £70 thereafter). Registration includes lunches, dinner, refreshments, book of abstracts etc. B&B accommodation will also be at Devonshire Hall, with standard rooms at £30 per person per night and en suite accommodation at £40 per person per night. The conference will begin at lunchtime on the 10th and conclude after tea on the afternoon of the 11th. B&B accommodation will be available on the night of the 9th and 11th of September for those who have far to travel.

An informal workshop on ‘*Synergies between Experiment and Theory*’ is planned for Wednesday 12th September. More details to follow shortly.

Registration and Payment

Please register on-line at:

www.chem.leeds.ac.uk/gkdg2007

Payment can be made by credit or debit card (download, complete and return the payment form by mail or fax) or by cheque. Early registration is advised to ensure your choice of accommodation and to take advantage of reduced costs. It is hoped that there will be additional student bursaries available from RSC funding.

Contact Details

Conference Organiser: Dr Paul Seakins, Email: p.w.seakins@leeds.ac.uk, tel: +44 (0)113 3436568.

Conference Secretary: Miss Mandy Clarkson, Email: gkdg2007@leeds.ac.uk,

tel: +44 (0)113 3436450, fax: +44 (0)113 3436401.

Provisional Programme

Monday 10th September

1.00 pm Lunch

2.00 pm *The Pilling Legacy!* – Speakers include Prof Mark Brouard and Dr Nicholas Green (Oxford) and Prof Andrew Orr-Ewing (Bristol).

6.00 pm Poster Session

7.45 pm Dinner

9.15 pm Bar and informal poster discussions.

Tuesday 11th September

9.00 am ‘*Synergies between Experiment and Theory*’, invited speaker Dr Steve Klippenstein, Argonne National Laboratory, USA, and contributed 20 min presentations.

12.30 pm Lunch

1.30 pm ‘*Kinetics in field measurements and modelling*’, invited speakers include Prof Dwayne Heard (Leeds) and Prof Alastair Lewis (York) plus contributed presentations.

4.30 pm FINISH

Wednesday 12th September

Informal workshop on *Synergies between Experiment and Theory* at the School of Chemistry, University of Leeds. More details to follow.

Travel Information

Devonshire Hall (http://www.universallyleeds.ac.uk/maps/devtetcol.pdf) is on Cumberland Rd, off the main A660 Otley Road, just north of the main University campus (http://www.leeds.ac.uk/visitors/getting_here.htm). Frequent buses run from just outside the main train station, past the University to Cumberland Rd.

For those travelling by plane there are a number of direct flights to Leeds Bradford Airport (taxi to Devonshire or buses via centre) from several UK and European cities. A frequent train service links Manchester Airport to Leeds city centre. Limited parking is available at Devonshire.

Books on the Environment published by the RSC

The Royal Society of Chemistry publishes a range of products in the environmental field.

Our two key journals in this area are the *Journal of Environmental Monitoring* and *Green Chemistry* both in their 9th successful year. The *Journal of Environmental Monitoring* provides comprehensive coverage of physical, chemical and biological research related to the analysis, detection, measurement and elucidation of all environmental processes and impacts. It also covers the management of contaminants in all natural and anthropogenic environments. As well as high quality research the journal publishes topical news and legislative issues from around the world.

The *Green Chemistry* journal publishes cutting-edge research aimed at reducing the environmental impact of the chemical industry by developing alternative sustainable technologies. It provides a unique forum for the publication of original and significant cutting-edge research that is likely to be of wide general appeal. Environmental research can also be found in other RSC journals such as our flagship weekly publication *Chemical Communications*, *The Analyst* and *PCCP*.

The very best science is also highlighted in the chemical supplements, *Chemical Technology*, *Chemical Biology* and *Chemical Science*. News and features on all areas of the chemical sciences can also be found in *Chemistry World* the society’s monthly magazine and online at **www.chemistryworld.org**

Complimenting the journal portfolio, the RSC publishes a number of books. The popular series Issues in Environmental Science and Technology presents authoritative reviews on a number of diverse and important environmental topics. New titles to the series include *Alternatives to Animal Testing* which discusses issues such as the safe evaluation of chemicals, international validation of alternative tests and the regulatory framework; *Biodiversity Under Threat* reviews the current opinion and knowledge on the impact of pollution, climate change and agricultural practices on biodiversity. And finally *Nanotechnology: Consequences for Human Health and the Environment* discusses the highly topical issue of engineered nanoparticles.

The RSC also publish a number of text books. The popular *Practical Environmental Analysis* is now in its second edition and outlines practical experiments for the analysis of air, water, soil and plant tissue. An *Introduction to Pollution Science* discusses the basics of environmental pollution drawing upon chemistry, physics and the biological sciences. Finally *Principles of Environmental Chemistry* provides an in depth introduction to chemical processes influencing the atmosphere, fresh water, salt water and soil.

Other books relating to the environmental field published by the RSC include *Water Contamination Emergencies: Enhancing Our Response* which highlights contributions from leading experts in the field and discusses water contamination emergencies, emergency planning and threats to the water industry.

To find out more about RSC products visit **http://www.rsc.org**

Environmental Science Books

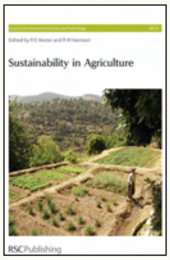
Issues in Environmental Science & Technology

Series Editors:

R E Hester and R M Harrison
Format: **Hardback**
Price: **£45.00**
RSC Member Price: **£29.25**

Written by leading experts, this series presents a multidisciplinary approach to pollution and the environment. Focussing on the science and broader issues including economic, legal and political considerations.

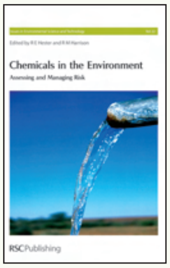
Sustainability in Agriculture
Vol. No. 21



Discusses the key factors impacting on global agricultural practices including fair trade, the use of pesticides, GM products and government policy.

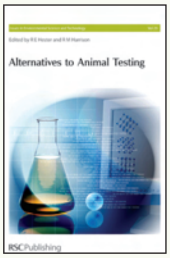
2005| xiv+130 pages | ISBN-10: 0 85404 201 6
ISBN-13: 978 0 85404 201 2

Chemicals in the Environment
Assessing and Managing Risk
Vol. No. 22



Beginning with a review of the current legislation, the books goes on to discuss scientific and technical issues relating to chemicals in the environment and future developments.
2006 | xvi+158 pages | ISBN-10: 0 85404 206 7
ISBN-13: 978 0 85404 206 7

Alternatives to Animal Testing
Vol. No. 23



Provides an up-to-date discussion on the development of alternatives to animal testing including; international validation, safety evaluation, alternative tests and the regulatory framework.
2006 | xii+118 pages | ISBN-10: 0 85404 211 3
ISBN-13: 978 0 85404 211 1

Practical Environmental Analysis
2nd Edition

By *M Radojevic and V N Bashkin*
A new edition textbook providing an-up-to date guide to practical environmental analysis. Ideal for students and technicians as well as lecturers wishing to teach the subject.

Hardback | 2006 | xxiv+458 pages | £39.95 | RSC member price £25.75 | ISBN-10: 0 85404 679 8 | ISBN-13: 978 0 85404 679 9

An Introduction to Pollution Science

By *R M Harrison*
A student textbook looking at pollution and its impact on human health and the environment. Covering a wide range of topics including pollution in the atmosphere, water and soil, and strategies for pollution management.

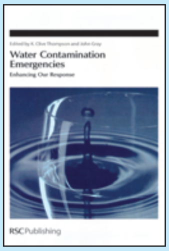
Hardback | 2006 | ca xii+322 pages | £24.95 | RSC Member Price £16.50 | ISBN-10: 0 85404 829 4 | ISBN-13: 978 0 85404 829 8

Clean Energy
(RSC Clean Technology Monographs)

By *R M Dell* and *D A J Rand*
Series Editor *J H Clark*
Covering a broad spectrum of energy problems, this highly accessible book discusses in detail strategies for the world's future energy supply.

Hardback | 2004 | xxxvi+322 pages | £89.95 | RSC Member Price £58.25 | ISBN-10: 0 85404 546 5| ISBN-13: 978 0 85404 546 4

Water Contamination Emergencies
Enhancing Our Response



By *J Gray* and *K C Thompson*
A look at the impact and response of contaminated water supplies including the threat of chemical, biological, radiological and nuclear (CBRN) events.

Hardback | 2006 | x+372 pages | £99.95 | RSC Member Price £64.75 | ISBN-10: 0 85404 658 5| ISBN-13: 978 0 85404 658 4

RSC Publishing

www.rsc.org/books

Arsenic contamination in groundwater

Recent review now available on ECG web page

As reported in previous issues of the *ECG Newsletter* and the *ECG Bulletin*, occurrence of high concentrations of arsenic in drinking-water has been recognized as a major public-health concern in several parts of the world for the past two or three decades. With the discovery of newer sites in the recent past, the arsenic-contamination scenario around the world, especially in Asian countries, has changed considerably. Before 2000, there were five major incidents of arsenic contamination in groundwater in Asian countries: Bangladesh, West Bengal, India, and sites in China. Between 2000 and 2005, arsenic-related groundwater problems have emerged in different Asian countries, including new sites in China, Mongolia, Nepal, Cambodia, Myanmar, Afghanistan, DPR Korea, and Pakistan. There are reports of arsenic contamination from Kurdistan province of Western Iran and Vietnam where several million people may have a considerable risk of chronic arsenic poisoning. Arsenic contamination in parts of Latin America is described elsewhere in this issue of the *ECG Bulletin*.

Adverse health effects of arsenic depend strongly on the dose and duration of exposure. Specific dermatological effects are characteristics of chronic exposure to arsenic. Salient dermatological features are melanosis (pigmentation) and keratosis (rough, dry, papular skin lesions), both may be spotted or diffuse. Chronic exposure to arsenic may also cause reproductive, neurological, cardiovascular, respiratory, hepatic, haematological, and diabetic effects in humans. Ingestion of inorganic arsenic is an established cause of skin, bladder, and lung cancer.

A recent article in the open access journal *Journal of Health, Population and Nutrition* (http://www.bioline.org.br/hn) gives an overview of the current world-wide situation on arsenic contamination with an emphasis on Asian countries: A. Mukherjee, M. K. Sengupta, M. A. Hossain [and 6 co-workers]. Arsenic Contamination in Groundwater: A Global Perspective with Emphasis on the Asian Scenario, *Journal of Health, Population and Nutrition,* 2006, **24**, 142-163.

With the kind permission of the one of the authors of this review, **Dr Dipankar Chakraborti**, Director and Head School of Environmental Studies, Jadavpur University, Kolkata 700 032, India Email: dcsoesju@vsnl.com, the entire article on arsenic contamination from the *Journal of Health, Population and Nutrition* has been added to the ECG page of the RSC web site (http://www.rsc.org/Membership/Networking/InterestGroups/Environmental/index.asp).

News of the Environment, Sustainability and Energy Forum (ESEF)

Sensors for the Atmosphere

ESEF is current engaged in a project on Sensors for the Atmosphere. The project aims to identify current and future challenges in this area and to bring together the relevant people and communities to propose solutions. The project has recently formed a steering group, chaired by Professor Rod Jones (Cambridge University) that is working on organising a series of events through 2007/08. Xameerah Malik at the Royal Society of Chemistry is leading this project on behalf of the RSC. If you would like more information please contact Xameerah (malikx@rsc.org).

RSC's response to the draft Climate Change Bill

The RSC, through ESEF, has responded to the draft Climate Change Bill. The RSC welcomed the ambition of the UK Government to lead by example in setting statutory carbon dioxide (CO_2) emission reduction targets. However, the UK accounts for only 2% of global greenhouse gases. Therefore if UK CO_2 emission reductions are not matched by concerted global efforts then the UK economy will suffer and the world will continue to warm. The RSC believes that it is absolutely critical that the legislation be fit for purpose and that it must be must be fully scrutinised so as to avoid unanticipated and detrimental effects. In the response the RSC recommended that members of the Committee on Climate Change be advised by shadow expert stakeholder groups so as to avoid biased advice and also that a dedicated position for an expert in adaptation be made on the Committee. The response can be found at:

http://www.rsc.org/ScienceAndTechnology/Policy/Documents/EnergyEnvironment.asp

UK long-term nuclear waste management

In February the RSC played a crucial role in launching the report "UK long-term nuclear waste management: next steps?" The report is a summary of a two-day workshop co-sponsored by 16 stakeholder organisations, held in Loughborough in November 2006. The report highlights the key scientific, engineering and technical next steps that are necessary to progress the Governments' decision to construct a geological repository for the UK nuclear waste legacy. The report can be found at:

http://www.rsc.org/Membership/Networking/InterestGroups/ESEF/Nuclear.asp

Dr JEFF HARDY
ESEF Manager,
Royal Society of Chemistry,
Burlington House,
Piccadilly, London W1J 0BA
Email: Dr Jeff Hardy

Recent books on the environment and on toxicology at the RSC library

The following books and monographs on environmental topics, toxicology, and health and safety have been acquired by the Royal Society of Chemistry library, Burlington House, during the period January to June 2007.

Bretherick's Handbook of Reactive Chemical Hazards

7th edition
Volumes 1 & 2
P. G. Urben (ed.),
Elsevier, Oxford, 2007,
Accession No: 20071062 & 20071063,
ISBN/ISSN: 9780123739452 & 9780123739469,
614.8 R

Concepts of Chemical Engineering for Chemists

S. J. R. Simons (ed.),
Royal Society of Chemistry, Cambridge, 2007,
Accession No: 20071610,
ISBN/ISSN: 9780854049516,
66.01

Freeze-drying of Pharmaceuticals and Biopharmaceuticals: Principles and Practice

F. Franks; T. Auffret,
Royal Society of Chemistry, Cambridge, 2007,
Accession No: 20071359,
ISBN/ISSN: 9780854042685,
615.012

Male-mediated Developmental Toxicity

(RSC Issues in Toxicology)
D. Anderson; M. H. Brinkworth (eds.),
Royal Society of Chemistry, Cambridge, 2007,
Accession No: 20071361,
ISBN/ISSN: 9780854048472,
575.224.4

Management of Ageing Processes in Graphite Reactor Cores

RSC Special Publication No. 309
G. B. Neighbour (ed.),
Royal Society of Chemistry, Cambridge, 2007,
Accession No: 20071546,
ISBN/ISSN: 9780854043453,
621.039

Staff at the RSC's Library & Information Centre are currently reorganising the library's catalogue. As a result some books on the environment acquired by the library a few years ago are now included in the online book catalogue:

Chlorine Dioxide: Chemistry and Environmental Impact of Oxychlorine Compounds

W. J. Masschelein; R. G. Rice (eds.),
Ann Arbor Science, Michigan, 1979,
Accession No: 20071608,
ISBN/ISSN: 0250402246,
546.13-13

Electrochemistry of Cleaner Environments

J.O'M. Bockris (ed.),
Plenum Press, New York, 1972,
Accession No: 20060629,
ISBN/ISSN: 0306305607,
541.13:628.5

Phosphorus in the Environment: Its Chemistry and Biochemistry

(Ciba Foundation Symposium No. 57)
Ciba Foundation, Elsevier, Amsterdam, 1978,
Accession No: 20071645,
ISBN/ISSN: 0444900314,
546.18:061.3

Selenium: Geobotany, Biochemistry, Toxicity and Nutrition

I. Rosenfeld; O. A. Beath,
Academic Press, New York, 1964,
Accession No: 20071675,
546.23

Essential Books

from **Wiley-Blackwell**

Introduction to Geomicrobiology

Kurt Konhauser, University of Alberta, Canada

"The most comprehensive general book in geomicrobiology, showing the great advances made in geomicrobiology during the past few years ... Packed with information."

JOURNAL OF SEDIMENTARY RESEARCH

ISBN: 9780632054541 • Paperback • 440 pages • 2006 • £34.99

Groundwater in the Environment: An Introduction

Paul L. Younger, University of Newcastle upon Tyne, UK

"What a pleasure this book is! If you teach introductory hydrogeology to students of any discipline, then this book, by Paul Younger, is the one to recommend to your students as precourse or supplementary reading. If they read it, you will not need to give any lectures explaining the context, concepts, or issues... Put it at the top of your courses' reading lists!"

GROUNDWATER

ISBN: 9781405121439 • Paperback • 312 pages • 2006 • £28.99

ALSO OF INTEREST...

Global Warming

David Archer, University of Chicago, USA

"David Archer has provided a masterful and lucid explanation of a complex environmental problem. This is all you need to understand the issues."

Ray Bradley, University of Massachusetts, USA

ISBN: 9781405140393 • Paperback • 208 pages • 2006 • £24.99

An Introduction to Environmental Chemistry: Second Edition

Julian E. Andrews, University of East Anglia, UK, et al.

"If I had to recommend one single textbook for courses in environmental science to students and all those interested from other fields, it would be this one. It is an excellent introductory reader and learning aid."

ENVIRONMENTAL BIOLOGY

ISBN: 9780632059058 • Paperback • 320 pages • 2003 • £26.99

To browse Blackwell's whole collection in the Earth Sciences visit **www.blackwellpublishing.com/earthscience**

Climate Change: Causes, Effects & Sollutions

John T. Hardy, Western Washington University, USA

"...Each chapter of the book is well illustrated with case studies..."

THE HOLOCENE

"... valuable contribution to the literature on climate change and does achieve its aim of providing a comprehensive coverage of an enormous subject..."

INTERNATIONAL JOURNAL OF CLIMATOLOGY

ISBN: 9780470850190 • Paperback • 260 pages • 2003 • £27.50

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