Lifting the lid on London's air

Air pollution from Iceland's volcanoes

The worst air quality in the world?
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Editors
Tom Marshall and Mary Goodchild marodc@nerc.ac.uk

Design and production
Candy Sorrell cmso@nerc.ac.uk

NERC-funded researchers should contact: editors@nerc.ac.uk

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Welcome to the autumn issue of Planet Earth magazine. This time we’re focusing on one of the most important ways in which the environment threatens people’s health throughout much of the world – polluted air.

Whether tiny particles or noxious gases like sulphur dioxide and ozone, air pollutants cause health problems including lung complaints, heart disease and strokes. That’s before you even start to look at the other harm pollution can do – causing acid rain, for instance, or endangering food security by damaging crops. It’s a particular problem in the developing world, where authorities often have very little information about what’s in the air and what it’s doing to the people breathing it.

In the UK the problem may be less visible. But it’s still more serious than you might think; it’s estimated to cause some 29,000 premature deaths every year. This is one case when out of sight definitely shouldn’t mean out of mind.

The atmospheric research NERC funds today has potential to help in many different ways. The articles in this issue cover everything from efforts to understand why certain kinds of pollution have stayed so high in London to scientists’ investigation of how Indonesian wildfires and Icelandic volcanoes affect air quality, and why when it comes to the new generation of personal pollution sensors the reality falls short of the hype. Other articles look at how air pollution can travel across borders and UK scientists’ international efforts to tackle air pollution across the globe including China, India and West Africa.

By the time this magazine reaches you, NERC’s Into The Blue series of showcase events in the northwest of England will be kicking off. In early October our research ship RRS Discovery is sailing to Merseyside, and then later in the month the UK’s advanced atmospheric research aircraft – operated by the Facility for Airborne Atmospheric Measurements (FAAM) – will be in Manchester and open for visits, along with an exhibition of amazing environmental science aimed at enthralling the whole family. An exclusive photoshoot of the two pieces of world-class scientific equipment flying and sailing together off the coast of the Isle of Wight can be seen on page 23 of this edition.

As part of the Into the Blue celebrations, in this issue you’ll find a fantastic pull-out poster packed with facts about the FAAM plane. If you’re in the area, come and join us – to find out more, see www.nerc.ac.uk/latest/events/blue. We hope we’ll meet as many of you as possible there!

NERC invests around £3m a year in air pollution research. Since 1990, NERC-research has influenced policies which have reduced major air pollutants in the UK – generating total benefits worth at least £31bn. In fact, NERC’s 2016 impact report estimates the council’s investments in managing air pollution could be worth as much at £82bn to the UK economy, based on an analysis commissioned from Deloitte. These benefits arise largely from reductions in premature deaths, as well as from damages to crops and buildings and from avoided damage to ecosystems.

NERC research fed into the first international treaty on acid rain, the 1979 Convention on Long-range Transboundary Air pollution (CLRTAP) which obliges countries to cut emissions of sulphur dioxide, ammonia, heavy metals and other pollutants. From 1983, NERC scientists pioneered the first truly international project on acid rain, leading the UK to begin a £6bn programme to cut air pollution.

In the last ten years, large NERC investments includes the Air Pollution Information System, which lets local governments access the environmental impacts of proposed developments. APIS was used to make sure the £25m London Ashford Airport expansion could go ahead. The Clean Air for London projects helps reduce human exposure to particulate matter pollution, and its data was incorporated into the London Air Quality Network website which offers a mobile app used by more than 20,000 Londoners to view daily air-quality reports and avoid high pollution areas. Other areas of NERC science help individuals manage their exposure to air pollution to boost health and minimise risks to health.

Tackling air pollution: What have we achieved?
Spotlight on Chinese air quality

Chinese air quality will be in the spotlight next month as UK researchers travel to the country to help investigate what’s causing Beijing’s air pollution problem and how it’s harming citizens’ health.

Five teams of UK scientists have joined forces with their Chinese counterparts to carry out new research into an issue affecting millions in China and touching the lives of many more living in the world’s biggest cities.

Air pollution poses a serious threat to human health, putting those in polluted urban areas at higher risk of cancer, heart and lung conditions and premature death. The occurrence of ‘haze’ – a mist of airborne pollutants – has become more severe and frequent in urban areas of China over the past sixty years. Five hundred million people in 86 cities are thought to be affected by it. As a consequence, there has been a rise in associated health conditions, including an increase in asthma and other respiratory problems in children.

The four-year research projects have £5.5m UK backing as part of the Atmospheric Pollution & Human Health in a Chinese Megacity (APHH China) funded by NERC, the Medical Research Council (MRC) and supported by the National Natural Science Foundation of China (NSFC).

The projects include research into the sources and emission of pollutants led by Professor Roy Harrison, University of Birmingham (see page 15), and a study of air pollution processes led by Professor Ally Lewis at the University of York, who will be heading out with his team in November. The link between air pollution exposure and cardiopulmonary disease will be studied in two projects, led by Professor Frank Kelly, King’s College London and Dr Miranda Loh at the Institute of Occupational Medicine. The fifth project will concentrate on the socio-economic impacts of the increase of air pollution in Beijing and offer recommendations for management.

‘Air pollution will be an increasing challenge as the process of mass urbanisation continues to unfold, particularly in the developing world,’ says NERC’s chief executive, Professor Duncan Wingham. ‘The programme represents an investment in high-quality scientific research in Beijing, where air pollution is already affecting the population’s health. It’s a pressing issue and the results of this research will help inform action on what can be done to minimise the risks of air pollution.’

Prevention’s better than cure for cold-water corals

The UK’s oldest Marine Protected Area (MPA) is doing a good job of defending vulnerable and ecologically precious cold-water coral reefs, a new study by scientists at NERC’s National Oceanography Centre (NOC) and University College Cork has found.

But the corals are slow to recover from damage, so it’s far better to create an MPA seeing as much ecological harm is done by activities like trawling than to react after the event.

The researchers used underwater robots – including Autosub6000, NOC’s deep-diving autonomous submarine – to survey a section of the Rockall Trough, off northwest Scotland, before and after the Darwin Mounds MPA was set up around it in 2003.

They found that coral populations remained stable in areas that hadn’t been trawled before, but that areas that had previously been trawled before being closed off, still had hardly any live coral even after eight years of protection.

‘These findings are a really good example of how NOC’s technology and scientific expertise can help inform the management of marine protected areas to get the best possible outcome,’ says Dr Veerle Huvigne from NOC, the lead author of the study, which appears in Biological Conservation.

The area is where NOC scientists discovered the first UK cold-water corals, a kilometre beneath the surface, in 1998. They named the area after their research ship RRS Charles Darwin. Cold-water coral reefs provide valuable benefits to the wider marine environment, including sheltering a wide variety of fish, including many commercially-important species.

DOI:10.1016/j.biocon.2016.05.030
Ancient mosses created our oxygen-rich world

Without Earth’s oxygen-rich atmosphere, life on the planet would be unrecognisable. Apart from anything else you probably wouldn’t be reading these words, given that humans would never have evolved.

All that oxygen wasn’t always there, though. We know it appeared on Earth in its current form around 2.4 billion years ago, in what’s now known as the Great Oxidation Event. But oxygen didn’t approach modern levels in the atmosphere until around 400 million years ago. And for all this development’s vital importance, scientists still aren’t sure why it happened.

New research led by University of Exeter scientists suggests the first land plants, including the ancient ancestors of modern-day mosses, may have played a key part in this profoundly important shift in the planet’s chemical makeup.

‘It’s exciting to think that without the evolution of the humble moss, none of us would be here today,’ says Professor Tim Lenton of Exeter, lead author of the Proceedings of the National Academy of Sciences study. ‘Our research suggests that the earliest land plants were surprisingly productive and caused a major rise in the oxygen content of the Earth’s atmosphere.’

The paper suggests that these early plants, which colonised the land around 470 million years ago, were responsible for raising oxygen levels. Their appearance and development permanently increased the amount of organic carbon being stored in sedimentary rocks, ultimately driving a second oxidation event and establishing a new, stable cycle of oxygen moving between rocks, living things and the atmosphere.

The earliest land plants were simple bryophytes, like moss – non-vascular organisms without vein-like systems to move water and minerals around. The scientists used computer simulations to calculate that by between 420 million and 400 million years ago, bryophytes could have caused modern levels of atmospheric oxygen.

DOI:10.1073/pnas.1604787113

New evidence links bee decline to pesticides

Researchers have found more evidence connecting the use of neonicotinoid pesticides to the long-term decline of wild bee populations.

The study, published in Nature Communications, was led by scientists at NERC’s Centre for Ecology & Hydrology (CEH). It analysed data on changes in the occurrence of 62 wild bee species against patterns of oilseed rape cultivation between 1994 and 2011 – the period over which neonicotinoid use became common.

The researchers found clear evidence linking the pesticides to large-scale, long-term decline in bee communities. On average the decline was three times stronger in species that regularly feed on oilseed rape, such as the buff-tailed bumblebee (Bombus terrestris), than on species that forage on a wide range of flowers. This suggests that oilseed rape – whose seeds are generally treated with neonicotinoids to provide protection from pests – is one of the main ways in which bees are exposed to neonicotinoids.

‘As a flowering crop, oilseed rape is beneficial for pollinating insects,’ says lead author Dr Ben Woodcock of CEH. But he adds that this benefit ‘appears to be more than nullified by the effects of neonicotinoid seed treatment on a range of wild bee species.’ He cautions, though, that neonicotinoids are unlikely to be the only factor in bees’ decline – other problems have also played a part, including the fragmentation and loss of pollinator-friendly habitats, the spread of diseases, climate change and the effects of other insecticides.

The researchers worked with data provided by Fera Science Ltd and the Bees, Wasps and Ants Recording Scheme. Their study forms part of a growing body of evidence that neonicotinoids have contributed to the trouble many bee species, both wild and domesticated, are in. A review of the risks these pesticides pose by the European Food Standards Authority is underway, and is expected to be completed by January 2017.
Climate change reshuffling UK wildlife calendar

The changing climate is already affecting wildlife in the UK in many ways. One of the clearest is the difference it’s making to the seasonal timing of natural events like flowering in plants and breeding in birds.

A new paper published in *Nature* suggests that seasonal events are generally more sensitive to changing temperatures than to shifts in rainfall or snow. And plants and animals are responding differently to temperature changes depending on when they happen in the year.

‘This is the largest study of the climatic sensitivity of UK plant and animal seasonal behaviour to date,’ says Dr Stephen Thackeray of NERC’s Centre for Ecology & Hydrology (CEH), the paper’s lead author. ‘Our results show the potential for climate change to disrupt the relationships between plants and animals, and now it is crucially important that we try to understand the consequences of these changes.’

These shifts in seasonal timing can have profound effects on ecosystems, particularly since species with different ecological positions are changing their annual schedules at different rates. For example, if an insect species starts appearing later in the year, birds that depend on it for food may go hungry. If they can’t find other prey or otherwise adapt, they may struggle to breed and raise their young. Over time, the biodiversity of UK landscapes could suffer badly. The study suggests animals in the middle of food webs, such as insects that feed on plants but are themselves food for other animals, are likely to change their seasonal behaviour most in future.

CEH scientists worked on the study alongside experts from 17 other institutions. They looked at more than 370,000 observations of seasonal events between 1960 and 2012, covering 812 marine, freshwater and land plant and animal species – from plankton to wildflowers and moths to mammals.

DOI:10.1038/nature18608

Ocean heatwave wipes out Australian kelp forests

New research suggests that extremely high sea temperatures in 2011 killed large areas of kelp forest in the waters off Western Australia, and that five years on there’s little sign they are recovering.

Kelp forests are extremely diverse and productive ecosystems, providing food and shelter for many marine plants and animals. Their widespread loss is likely to have serious knock-on effects in many other areas.

‘Temperatures during the 2011 marine heatwave exceeded anything previously experienced by these kelp forests and they collapsed,’ says lead author Dr Thomas Wernberg of the University of Western Australia.

The study, published in *Science*, analysed data collected between 2001 and 2015 along 2000km of coastline. It shows that coming on top of decades of more gradual ocean warming, the heatwave broke down long-standing patterns in the distribution of life on the seabed. Five years on, many cool-water fishes, seaweeds and invertebrates have disappeared and been replaced by ecological communities more like those found in the tropics.

Tropical grazing fish in particular have multiplied and are now preventing kelp from re-growing – especially at the northern end of the area the scientists looked at, where kelp forests have disappeared entirely from more than 100km of coastline.

‘The Western Australia study represents a compelling example of how quickly temperate marine ecosystems can undergo fundamental and widespread shifts in structure in response to extreme sea temperatures,’ comments Dr Dan Smale, a NERC-funded Independent Research Fellow at the Marine Biological Association and one of the paper’s authors. ‘Given that most ocean regions are warming rapidly, we can expect similar changes to occur elsewhere in the future, with significant socioeconomic implications.’

DOI: 10.1126/science.aad8745
What is air pollution? What are the harmful particles in the air that could be harming us?

Air pollution generally refers to either particles or particulate matter (PM) and a range of different gasses such as nitrogen dioxide and ozone. For PM we generally concentrate on PM10 which is any particle that is less than ten microns in diameter, which means it is small enough to enter your respiratory system via your nose and upper airways. The next classification is PM2.5 – anything less than 2.5 microns in diameter – and then the third classification is ultra-fine or nanoparticles and they are very small indeed, less than 0.1 of a micron. If you consider that a human hair is only 50 microns thick, then these particles are all invisible to the naked eye.

The gasses include nitrogen dioxide – in urban areas one of the major sources is from vehicle exhaust – and ozone, O3, which comes from the conversion of oxides of nitrogen and hydrogen into ozone by ultraviolet radiation, making it a spring and summer pollutant. Ozone is a very powerful oxidant and nitrogen dioxide is a free radical. This means both are highly reactive gasses. This means when they enter your respiratory system these gasses can cause a lot of problems.

In London, and big cities, what are the main causes of air pollution?

In this day and age it is the transport sector which is the main source of air pollutants in urban areas. The bigger cities, such as London, Manchester and Birmingham, have the bigger air pollution problems simply because of the number of vehicles on the road and the amount of congestion. A lot of the pollutants, the particles and the gasses, come from the exhaust. Increasingly European regulations and standards have been bringing traffic volumes and congestion under control but the wear and tear of tyres and road surfaces and the generation of particles from brakes are all increasingly important sources of particles in urban areas.

Are there other sources of air pollution, like industry?

In most of the large UK cities heavy industry is not within the urban area but outside. But there are still smaller sectors of industry which will be operating within the urban areas, and will produce some pollution. It may be just through the energy they are using or it may be through the heating systems. Also in big cities there are many fast food operations, many restaurants, and these are all generating particles, and nitrogen dioxide from the gas they burn.

What are the known health effects of exposure to air pollution?

There are both short-term, acute effects and long-term effects. The short-term effects generally occur in a sub-section of the population who tend to be particularly susceptible to pollution. They tend to be individuals who already have a disease, either a respiratory or cardiovascular condition such as asthma or chronic obstructive pulmonary disease, and these individuals...
find that whenever pollution concentrations rise they experience effects such as difficulty breathing, or they are not able to exercise freely or even walk as far as they normally would. There are very good warning systems now that these people can use to understand when pollution is going to be higher so they can manage their medication. The more serious effects come from long term exposure to pollution, meaning many decades of exposure, and we know through research that people who live in areas with higher pollution concentrations tend to have lower life expectancies, which is why we link pollution exposure to premature death. This has been initially studied in America in the ’90s and subsequently confirmed right across the world. These robust associations have been seen everywhere. So, it is clear that something about the air that you breathe can influence the respiratory and cardiovascular systems, which ultimately means that someone can have a life-threatening condition earlier than they should have done. It is estimated there are 9,500 premature deaths attributed to air pollution exposure in London each year. That takes into account exposure to the PM2.5 pollution and nitrogen dioxide pollution, which is particularly high in London.

You’re doing research in east London focusing on schoolchildren. What can you say about this so far?
East London tends to have very high traffic volumes, including a lot of diesel vehicles. As a consequence, nitrogen dioxide concentrations are very high. There is a lot of residential housing and schools which are close to busy roads, so the study in schoolchildren has looked at their respiratory function in relation to their exposure to air pollution. The initial findings from the first three years suggested these children had lower lung capacities than expected for their age and ethnicity. We are just finishing off the last three years of the study, and the preliminary analysis suggests those initial findings are robust, so it does seem to be that if a child grows up in a more polluted environment then there is the potential for the child’s lung not to develop as fully as it should do in a less polluted environment.

It’s a particularly difficult public health issue because when children reach the age of around 18 their lungs stop growing altogether. Children exposed to air pollution therefore never have the capacity to catch up missed lung growth, so the teenage years really are an important window for full lung development. It can mean that later in life, if you end up having another challenge to your lungs, then it could have a much bigger effect than it would do in someone who was not exposed to those early life effects.

What does the future of clear air look like in London?
In London, the major challenge is to clear up our transport system. A large part of that is the public transport system, so the busses and the taxis and the diesel trains all need to be modernised, and to use a much cleaner energy source such as electricity. There are still far too many private vehicles on the roads in London which leads to a lot of congestion, and it’s quite clear now that if you own a diesel unfortunately it will produce a lot more pollution that an equivalent sized petrol vehicle. So we need to remove diesel vehicles from the roads in London and ultimately, we need to decrease the volume of traffic. We also need to encourage more active transport, more walking and cycling. There is a real health dividend to be gained if we decrease pollution. It’s a win-win situation.

What can people do to protect themselves from city air pollution?
As we go through this transition period towards a cleaner urban environment, people can increasingly take informed decisions about their own exposures. So they can, for example, avoid rush hour and cycling on very busy roads. They can look for alternative routes where they might be able to reduce their exposure. Generally, any lifestyle change that decreases their own personal emissions as they move around the city, and to avoid other people’s emissions, will be useful in both the short and long term.
Last year’s El Niño brought drought to south-east Asia, creating the conditions for enormous wildfires that sent vast amounts of carbon into the atmosphere and endangered people’s health across the region with terrible air pollution. Martin Wooster of King’s College London and NERC NCEO reports.

The worst air quality in the world?

You might recall that 2015 was one of the strongest El Niño years on record.

In some places, El Niño brings welcome rain. Yet elsewhere – Indonesia, for example – it typically brings drought, and this can have terrible consequences for air quality.

By the second half of 2015, Indonesia was receiving far less rainfall than usual. The country’s tropical ecosystems may be able to cope with this relatively well in their natural state, but decades of deforestation and sometimes unsuccessful development policies have made many landscapes much more flammable and drought-sensitive.

Indonesia’s peatlands were particularly badly affected. These cover around 200,000km$^2$ and represent around 65 per cent of the world’s tropical peat, storing much more carbon than the country’s trees. This peat is composed of semi-decayed plant material accumulated over millennia, and is typically many metres thick. More than half its mass is carbon, and when dry it burns easily.

Over the decades many Indonesian peatlands have been drained for agriculture, by digging canals to carry away the water and lower the water table. When El Niño brought drought, it was not long before large areas of these degraded peatlands became dry enough to burn.

As well as fuel, fires also need an ignition source. Throughout much of SE Asia it is common to use fire to dispose of farm waste or to clear new land cheaply, so there is no shortage of fires to get things started.

Problems with fires and smoke pollution are quite common in parts of Indonesia, but in 2015 the combination of a dried landscape, multiple ignitions and plenty of carbon-rich fuel proved disastrous for air quality. By early September, large areas of Kalimantan (the Indonesian part of Borneo) and Sumatra were burning, with huge smoke plumes visible in satellite imagery.

In addition to the large areas affected, the burning peat behaved differently from most vegetation fires, where a ‘flaming front’ typically moves across the landscape consuming the available vegetation and leaving behind mostly ash and charred remains, mixed with plants that withstood the flames. In Indonesia the soil is so carbon-rich it can keep burning long after the surface vegetation is gone, meaning vast areas of ignited peatland continued smoking for weeks, only stopping in late October when strong rain finally came.

Satellite data on the area affected and the amount of heat being released let us rapidly estimate how much vegetation and peat was being consumed, and even on average how deep into the ground the peat was burning. But we wanted to understand the fires’ effect on atmospheric greenhouse gas concentrations and air quality, so we needed to know what exactly was in the smoke.

Measuring air quality. Martin Wooster
mean PM10 values of 101 μg/m\(^3\) reported in microgrammes of PM10 particles and so cause the most serious health problems. To penetrate into the deepest part of the lungs, biomass, and these particles are small enough usually dominate in smoke from burning micrometres or less. In fact PM2.5 and smaller being classed as PM10, with a diameter of 10 micrometres or less. This smoke, locally called ‘haze’, was being caused by the huge peat fires all around the coastal city of Banjarmasin and drove the last 200 km while measuring the concentration of various atmospheric gases and particles with instruments in the back of our truck.

Smoke detectives

By the time we got to Palangkaraya our noses told us the air was full of smoke, but it was past midnight and the darkness made it hard to tell how bad things were. Just before going to sleep though, I turned on one of our gas measuring instruments to download that day’s data for safekeeping and was surprised when I saw a carbon monoxide concentration of 30 parts per million (ppm) in the hotel – enough to set off some European smoke alarms – even though we were many miles from the fires themselves. We wondered if sleeping in such polluted conditions was entirely safe.

The next day the view from the hotel’s sixth floor showed the buildings of Palangkaraya peeking out from a fog-like layer of smoke, with visibility of just a few hundred meters. This smoke, locally called ‘haze’, was being caused by the huge peat fires all around the city. Unfortunately for local people, most of the particles in the ‘haze’ are very small – being classed as PM10, with a diameter of 10 micrometres or less. In fact PM2.5 and smaller usually dominate in smoke from burning biomass, and these particles are small enough to penetrate into the deepest part of the lungs, and so cause the most serious health problems.

Particulate measurements are typically reported in microgrammes of PM10 particles per cubic meter of air (μg/m\(^3\)). In the UK, daily mean PM10 values of 101 μg/m\(^3\) or above are considered ‘very high’ – the most severe level usually seen here – and the US Environmental Protection Agency (EPA) views 300 μg/m\(^3\) or more as hazardous, advising everyone to consider avoiding physical activity outdoors under such conditions.

Palangkaraya’s local air quality monitoring station turned out to be frequently reporting PM10 concentrations around 2000 μg/m\(^3\), and sometimes closer to 4000 μg/m\(^3\). This was probably the worst outdoor air quality of any city on Earth at the time, and hospital admissions soared. Beijing for example has notoriously poor air, but even on its worst days it doesn’t come close to these levels.

Wearing masks, we ventured out to sample the smoke itself. Different fuels produce smoke with diverse composition, and we wanted real close-to-source measurements to enable us to convert our satellite measurements of peat and vegetation burning into emissions estimates. We easily found areas of extensive burning, and our measurements of the gases and particles in the smoke are now being used to make better calculations of the fires’ true emissions. Our findings have already shown that the emissions factor of methane (the amount of CH\(_4\) released per kg of peatland fuel burned) appears far lower in reality than it was when the peat was collected, dried and burned within laboratories, giving us a clearer idea of how the carbon the fires are releasing to the atmosphere is split between CO\(_2\), methane and carbon monoxide. This matters because each gas has a different effect in the atmosphere, and because 2015 turned out to show the single largest increase in atmospheric CO\(_2\) since records began in the 1950s, and we want to know what role the Indonesian fires played in that increase.

We are now analysing the data on particulates, and early results indicate PM2.5 emissions factors far higher than from landscape fires in other tropical or temperate biomes, probably because the dried peatland mostly smouldered rather than flamed, and smouldering produces more particulates. This also helps explain why the air quality decrease in Indonesia was quite so extreme, and why particle-laden air was able to reach places like southern Thailand, Cambodia and the Philippines, as well as closer countries like Malaysia and Singapore that are more often impacted by ‘haze’ from Indonesian fires.

The last El Niño of comparable size to 2015 was 1997-98, and recent estimates suggest the Indonesian fires that accompanied it resulted in thousands of additional deaths. It’s too early to know whether the 2015 fires had a similar effect, but already its clear just how bad air quality got and so how seriously it may have harmed the health of people in southeast Asia.
Lifting the lid on London’s air

When scientists flew a research plane over London in 2013, they didn’t just establish that a new sensing technique could let us monitor emissions in real time. They also stumbled on the traces of one of the biggest corporate scandals ever. Tom Marshall finds out more.
Facility for Airborne Atmospheric Measurements

The FAAM aircraft started life as a passenger and freight plane. As the first ever BAE-146-100 and 301 series, it was designed for short-haul flights around the UK. Now, expertly converted into the UK’s most advanced research aircraft, FAAM can take atmospheric measurements at 10km high, zoom through monsoons, fly into a hurricane, or soar above Arctic icecaps, taking up to ten measurements per second to help scientists understand our climate.

BAe-146

- Crew: 3
- Science crew: Up to 10
- Wingspan: 25m
- Max Altitude: 10.67km
- Min Altitude: 15m
- (over the sea)
- Range: 3,700km (approx)

FAAM is bristling with scientific equipment. Below the wings are probes designed to measure the physical properties of clouds.

Radiometers study things like the temperature of the atmosphere and turbulence probes measure air currents. Lidar is like a radar that uses lasers to map the terrain on the ground. There are all sorts of antennae for receiving and transmitting information – from VHF radio antennae to satellite communications (Satcom) antennae.

Overhead luggage storage and most of the passenger seats were taken out to make space for up to 100 scientific instruments weighing up to 4 tonnes — that’s around the weight of an elephant! Added fuel tanks mean the plane can carry 12 tonnes of fuel which last up to six hours in the air.

Scientific equipment is fitted into racks within the cabin. These instruments are then connected to sensors or sampling inlets on the outside of the aircraft. This data is sent back to the aircraft where it is processed and forwarded to the Met Office super computers to help with weather forecasting — all while the flight is still happening.
FAAM took its first research flight in 2004 and has since flown around 1.3 million miles. It’s embarked on science missions from around 30 countries and spent approximately 5,000 hours in flight. The aircraft is owned by the Natural Environmental Research Council (NERC) and operated in partnership with the MET Office.

**1. Monsoons**

In summer 2016, the FAAM aircraft was sent to India to measure the onset of the Asian monsoon for the first time, and help scientists learn how to predict the heavy rains which are so important for the country’s farmers. Indian research ships and underwater marine robots were also used as part of the campaign. The findings will help scientists better understand how the monsoon phenomena affect global weather systems in light of man-made climate change.

**2. Polar Regions**

Clouds usually have a cooling effect on the surface of the Earth, but above the Arctic and Antarctic — where the white, icy surface reflects heat back into the atmosphere — the effect is reversed and clouds act like a blanket trapping heat beneath them. FAAM research aims to help understand how clouds affect the climate in the polar regions and what affects this has on global weather patterns.

**3. Deserts**

FAAM science has been used to explain massive dust outbreaks in the Saharan desert — investigating how particles interact with the atmosphere above Africa in the grand scheme of the global climate. Dust particles lifted from the Saharan desert play a major role in cloud formation. Saharan dust is deposited all over the world and helps to fertilise the oceans and the Amazon rainforest.

**4. Oceans**

The oceans have a huge effect on the Earth’s climate. The FAAM aircraft helps climate scientists understand how the seas drive cloud and rain formation, impacting global weather systems. FAAM is also helping scientists to understand how global warming and ocean acidification are affecting the chemical make-up of the sea and its biodiversity.
Many people think of London air pollution as a problem we solved long ago. We’ve certainly come a long way from the great smogs of the mid-twentieth century – ‘pea-soupers’ that cut visibility to a few metres and killed thousands. These days there’s rarely more to see than a thin haze above the city.

But if the capital’s air usually looks clear and isn’t the horrifying brew of noxious chemicals it was, it’s still nowhere near clean enough. It routinely breaches EU air quality guidelines, causing an estimated 10,000 premature deaths a year – not just through breathing problems like asthma and chronic obstructive pulmonary disease, but also through less obvious consequences like heart disease, cancer and strokes.

One problem group of pollutants is the oxides of nitrogen (NOx) – specifically, nitric oxide (NO) and nitrogen dioxide (NO₂). The first isn’t harmful itself, but it quickly reacts in the atmosphere to form NO₂ which damages respiratory health, particularly for those who already have lung problems. NOx comes from many sources, but in big cities vehicle engines account for more than half the total.

NOx levels have puzzled scientists for some time – based on the data we had on what was being emitted, they seemed far too high, often exceeding EU standards by some 50 per cent. Official UK emissions inventories, which estimate how much pollution is entering the atmosphere in a particular area by adding up all the sources we know of – from power stations and factories to cars – persistently suggested NOx should be much lower than the actual readings taken in London and elsewhere.

‘It’s been clear for years that NOx levels in UK cities and towns are disturbingly high and often breach regulatory limits,’ says Professor Nick Hewitt, an atmospheric chemist at Lancaster University. ‘We know it’s a big problem and that we need to do something, but we didn’t understand what was causing it; until recently it was a real puzzle as we thought vehicle emissions were falling.’

Taking to the skies

In 2013, a group of NERC-funded researchers including Hewitt set out to investigate by flying over London in the Dornier aircraft of NERC’s Airborne Research and Survey Facility. They took some of the first airborne measurements of the rate at which NOx and other pollutants were being emitted – also known as their fluxes – using an innovative technique called eddy covariance.

Of course, there are plenty of air-quality sensors on street corners and buildings around London. But they usually measure each pollutant’s concentration – how much there is in the atmosphere – and not how much is being emitted right now. For that, you need much more sophisticated sensors – and plenty of computer power to make sense of the results. The instruments the scientists installed on the Dornier were among the first that could pull this off, and flying them high over the city let them survey emissions from all over London rather than in just one place. Comparing the results with traffic data gave them even more insight into the sources of pollution.

What they found confirmed the strange discrepancy between what the inventories predict and measurements show. Even using an improved, more accurate version of the London pollution inventory, NOx emission rates were between 30 and 40 per cent higher than they should have been. The team were baffled. ‘We kept looking for alternative explanations,’ Hewitt explains. ‘Maybe hospitals in central London were emitting more NO₂ than we thought? Maybe it was coming from diesel trains? But none of them added up.’

When the VW emissions scandal broke last year, it turned out the answer was surprisingly simple – car companies were gaming the system. Pollution inventories work by taking emissions data for each kind of vehicle and multiplying by the estimated number on the road. These emissions numbers come not from vehicles’ on-road performance, but from how it does in lab tests. And many manufacturers have been manipulating these. ‘As we now know, most diesel cars emit much more NOx on the road than they do in tests,’ Hewitt explains.

Rigging the system

VW, the worst offender we know of, created special software so its diesel cars could sense
engine settings to slash NOx emissions at the cost of fuel efficiency and carbon emissions. Other carmakers didn’t go as far; merely optimising engines to do well in emissions tests rather than entering a special test mode with completely different performance characteristics. But the result was similar.

‘We strongly suspected the test cycles weren’t that representative of real-world performance, but we had no idea the difference was so huge. NOx emissions were supposedly falling, but concentrations in the atmosphere hadn’t dropped in a decade – that told us something was wrong,’ says Dr James Lee of the University of York, another atmospheric chemist involved with the research. ‘In retrospect we were naïve to trust the inventories. Now we know the tests are misleading, everything becomes much easier to understand.’

The UK government has encouraged people to buy diesel cars with favourable fuel and vehicle excise duty treatment – but these emit more NOx. To meet NOx emissions regulations without hurting fuel efficiency, VW cheated. ‘The NOx issue is really an unintended consequence of the move to diesel, intended to cut CO2 emissions,’ says Lee. ‘Dealing with this is going to be the next big challenge for regulators.’

What now for NOx?
Technology is improving faster than ever before. Eddy covariance instruments that were at the cutting edge of design when they flew on the plane in 2013 are now available for constant real-time monitoring, and Lee plans to install them at the BT Tower atmospheric measurement station in 2017 – he’s already made some flux measurements from the tower, but from next year they’ll be routine. The eddy covariance sensor’s been improved, and the data-processing software backing it up has been streamlined so it can now be left alone with only occasional checks.

BT Tower measurements don’t cover as much of the city as those taken from the plane – just part of central London. But research planes are expensive, and have to be booked months ahead. Instruments on towers can stay for years, giving scientists their first detailed information on how air quality changes from season to season. In the future we won’t just know that levels of various pollutants are too high; we’ll also be able to see precisely where they’re coming from. This is the first step towards creating policies to cut them.

How? In the short term, carmakers are being punished financially for their transgressions. VW’s updating its software in a way that should cut NOx emissions, and other manufacturers are likely to roll back some of the moves they’ve made to optimize their engines in ways that have proved harmful. And from 2017, European regulations will mean vehicles have to pass a test of real-world driving emissions. Yet more radical changes are needed. Lee suggests that trucks and other heavy vehicles could be kept off the streets at certain times of day in cities, and that enthusiasm for diesel cars is likely to wane as governments and people realize their fuel economy comes at the cost of local air quality.

‘I think the situation will probably improve as the percentage of diesel vehicles falls, congestion charging starts to target particularly polluting vehicles and development of electric cars accelerates,’ he explains. He says flux measurements don’t show much improvement yet, but that things should get better, particularly as the fleet of buses moves from diesel to electric engines.

Hewitt believes a major shift in the culture of how we get around is needed. ‘There’s great reluctance to change people’s driving habits, but we really need to reduce numbers of cars and lorries passing through our cities and encourage more people to cycle, walk and use public transport,’ he says. ‘It’s too easy for able-bodied people to drive everywhere in cities. That isn’t just bad for their health; the pollution they create means it’s bad for us all.’
Taking UK atmospheric science global

A round the world, many big cities have enormous air-pollution problems and virtually no good information on what specifically is causing them. This means governments are in the dark about what they should do to protect their citizens. Right now, air pollution claims an estimated 3.5m lives a year globally. UK atmospheric scientists are working with local academics and policymakers to help change this.

For instance, Professor Roy Harrison of the University of Birmingham – an expert on pollution and its health effects – is now leading a big project aimed at applying similar techniques to the air of Beijing. This will measure emissions of pollutants including particles, NOx and volatile organic compounds (VOCs) in real time from a tower in central Beijing, in both winter and summer.

China’s air-quality problems are far worse than the UK’s, and the authorities there have much less good information on them. Air pollution there contributes to the deaths of an estimated 1.3m people a year, and some half-billion Chinese city-dwellers are thought to be at risk of ill-effects from breathing the pervasive grey haze. The economic cost is vast too – estimated at nearly a trillion pounds a year in China alone.

‘If you look at PM2.5 particle pollution (tiny particles that can penetrate deep into people’s lungs, causing serious harm), in the UK it’s estimated to cause about 29,000 premature deaths a year,’ says Harrison. ‘London accounts for something like 5,000 of those. In Beijing, concentrations are typically ten times higher and the city itself has a much bigger population (nearly 22.7 million people this year according to official figures, compared to a little over 8.5 million in London), so the overall impact on health is far more severe.’

He explains that the Chinese public is becoming much more aware of these problems, so there’s growing pressure on authorities to clean up the air. The researchers will analyse the chemical composition of Beijing’s pollution, assigning it to different parts of the city and different types of activity and thus helping local policymakers and academics create more accurate emissions inventories.

‘We want to help the local authorities understand where that pollution is coming from, and what they could do about it,’ Harrison explains. ‘For example, is it being produced locally, or is it blowing into the city from upwind? This kind of information is vital if they are going to manage air quality more effectively – mitigation depends on having good knowledge of where pollution is being generated. This information will lead to better air-quality models that will let the authorities predict the effect of different possible interventions – from issuing pollution improvement plans to problem factories to changing traffic regulations to discourage driving at particular times.

Both Lee and Hewitt will be involved in Beijing, looking after the NOx and VOC tower measurements respectively. They are also planning a variety of other exciting research trips – the China work will be followed up by a similar collaborative project between Indian and UK researchers, and Lee plans to visit Delhi to make pollution flux measurements in 2018 with Hewitt and others. In the meantime he’s heading to Togo as part of an EU-funded project that will fly over West African cities and measure fluxes of pollutants including NOx, ozone, soot particles, carbon monoxide and greenhouse gases.

West African governments often have little or no information on atmospheric conditions – a NERC-funded flight around Lagos nearly a decade ago collected the first ever airborne measurements of aerial pollution in the region, and there’s been very little since. Until they know how bad each kind of pollution is, and where it’s coming from, it’s near-impossible for them to target the limited resources available for cleaning up the air effectively.
In September 2014, a huge volcanic eruption in Iceland emitted up to nine times as much sulphur dioxide per day as all European industry combined. Anja Schmidt and Claire Witham explore what this did to air quality across Europe.

Air pollution from Icelandic volcanoes

In the early hours of 31 August 2014 a truly spectacular eruption began at the Holuhraun lava field in Iceland, 45km away from the Bárðarbunga volcano. Compared to the ash-producing 2010 Eyjafjallajökull eruption, the Holuhraun eruption was a rather different beast, producing very little volcanic ash but lots of lava and toxic volcanic gases that were detected at air quality monitoring stations as far away as Austria.

Events like Holuhraun are known as effusive eruptions, and specifically as fissure eruptions. The biggest of these produce enough lava to fill up to 100,000 Olympic-sized swimming pools per day for months to years. These big eruptions occur on average every 200 to 500 years, whereas smaller-volume fissure eruptions like Holuhraun occur every 40-50 years.

Less ash, more gas
During its first month, the eruption at Holuhraun was extremely powerful, spewing fountains of lava up to 150 metres high along a 1.5km long crack in the Earth’s crust (putting the ‘fissure’ in ‘fissure eruption’). By the time the eruption had ended six months later, it had produced about 1.5km$^3$ of lava, covering an area of around 86km$^2$ – about 50 times the area of Regents Park in London, or equivalent to covering Regents Park in 1km of lava.

It quickly became clear that the eruption was emitting truly staggering amounts of sulphur dioxide (SO$_2$) into the lower parts of the atmosphere. SO$_2$ is a toxic gas that is converted to sulphuric acid aerosol particles. Both of these can affect air quality, causing respiratory problems for people exposed to them, particularly those who already have asthma or other lung difficulties; sulphuric acid can also lead to acid rain. Due to the remoteness of the eruption site and the weather conditions in Iceland continuous ground-based monitoring...
and measurement of SO$_2$ was very challenging. This is where satellite observations of the volcanic SO$_2$ plume came to the rescue. Our team analysed satellite data and combined it with computer modelling using the Met Office’s NAME model. This let us track and compare the dispersion of the volcanic gas cloud, as well as estimate how much SO$_2$ was emitted. We found that at its most powerful the eruption emitted about 120 kilotons of SO$_2$ per day – eight times more than the total from all man-made sources in Europe. During September 2014, Holuhraun emitted a total of 2.0±0.6 million tons of SO$_2$, making it the largest volcanic sulphur pollution event in Iceland for more than 200 years. Its bigger sister, the Laki eruption, took place in 1783-1784AD and produced, over eight months, an order of magnitude more lava and about 60 times more SO$_2$ than Holuhraun did in 2014.

Detecting and monitoring volcanic pollutants

Over the course of the eruption, air quality monitoring stations in Iceland recorded unprecedented levels of SO$_2$, often significantly exceeding the current 10-minute mean air quality standard set by the World Health Organization (WHO) to protect public health. Yet the pollution was not confined to Iceland: we found the gas was transported over very large distances and detected by air quality monitoring stations up to 2750km away from Iceland.

Away from Iceland there was no risk of long-term detrimental health effects because exposure to volcanic pollutants was brief. For instance, on 6 September 2014, volcanic pollution reached Ireland, where monitoring stations recorded short-lived (up to 24 hours) spikes in surface SO$_2$ concentrations of just above 500μg/m$^3$. Air pollution regulations introduced in the 1980s mean that SO$_2$ levels from industrial emissions are very low nowadays, so the concentrations recorded on 6 September 2014 were particularly unusual.

Air quality monitoring stations across Europe were essential in detecting and characterising the pollution resulting from this eruption. These observations and our model simulations show that volcanic pollution from Icelandic fissure eruptions can easily reach Northern Europe and degrade air quality temporarily. Right now the number of SO$_2$ monitoring stations across Europe is steadily declining. SO$_2$ concentrations are usually very low as a result of new laws aimed at reducing man-made emissions since the 1980s, so constant monitoring doesn’t seem as important as it once did.

We think existing air quality monitoring stations ought to be retained, or even extended, to monitor volcanic pollutants from future eruptions in Iceland. This would help us characterise and mitigate volcanic gas and aerosol particle hazards, which could be severe in the event of a large-magnitude Icelandic eruption like a repeat of the Laki eruption. In a 2011 study, we calculated that a future Laki-type eruption could degrade air quality across Europe for several weeks potentially resulting in more than 100,000 premature deaths across the continent.

The next eruption...

Every eruption is different, and those of Holuhraun and Eyjafjallajökull have shown that future Icelandic eruptions will pose new hazards and challenges for science and society. With each event, we learn more about the volcanic processes involved and broaden our understanding of how to best use observations and computer models to understand these hazards and inform decision makers.

We cannot predict the next eruption, but recent activity proves that in Europe we should prepare for the impacts of not only volcanic ash but also volcanic gases and airborne particles. Work on this source of air pollution has informed UK Government policy and led to volcanic gas and airborne particle hazards being recognised alongside more established volcanic ash hazards. As a result there are now contingency plans in the event of a future eruption, which will make society better-prepared and more resilient. This in turn is expected to minimise disruption, costs and potentially save lives.

Anja Schmidt is a researcher in the Institute for Climate and Atmospheric Science at the University of Leeds. Email: ear5as@leeds.ac.uk; @volcanofile.

Claire Witham leads the Volcanic and Chemical Dispersion group at the Met Office; Email: claire.witham@metoffice.gov.uk; @claireswitham

To find out more about the NAME model, see www.metoffice.gov.uk/research/modelling-systems/dispersion-model.

Excess mortality in Europe following a future Laki-style Icelandic eruption – DOI:10.1073/pnas.1108569108

Satellite detection, long-range transport, and air quality impacts of volcanic sulfur dioxide from the 2014–2015 flood lava eruption at Bárðarbunga (Iceland) – DOI:10.1002/2015JD023638
Who’s to blame for bad air?

Controlling our own emissions is a good idea, but plenty of the pollution problems most nations face come from abroad. Stefan Reis, Massimo Vieno and Eiko Nemitz explore the role of transboundary air pollution in local air quality, and the need for international action to tackle it.

In March and April 2014, the British media ran a story about a developing episode of very high air pollution near the surface across large parts of the UK. The culprit was quickly identified as a dust cloud which originated in the Sahara, made its way north and covered parts of France, reaching up across the British Isles. Even the prime minister referred to this ‘naturally occurring event’ in an interview and, like many Britons, refrained from exercising outdoors to avoid breathing in fine particulate matter (PM) at potentially harmful levels.

Yet a more thorough analysis, using both computer models to simulate how air pollutants move through the atmosphere and advanced measurement techniques, revealed a more complex story. A Saharan dust cloud was indeed covering part of the UK, but models showed it was high above the surface for most of the time PM concentrations were high.

At the same time, a major plume of PM formed by the combination of emissions of nitrogen oxides and ammonia, known as secondary inorganic aerosols – in this case, mainly ammonium nitrate – was blown across the Channel from northern France, the Benelux region, northern Germany and Denmark.

This plume was observed by measurements at the heavily-instrumented EMEP ‘supersite’ at Harwell, where the different components of PM concentrations are routinely analysed. Model simulations, utilising the EMEP4UK-WRF model framework, illustrated the source regions and the movement of this plume, as well as those of the Saharan dust cloud. By combining the model results and the observations, a clearer picture emerged. This episode of high PM concentrations at ground level wasn’t a natural phenomenon; it happened because man-made emissions combined with weather conditions which brought them to the UK.

High emissions of ammonia from farmland across north-western continental Europe, caused by the application of animal manure and mineral fertilisers, coincided with a general meteorological pattern channelling continental air masses north across the UK. This is not a rare event. Nor is it limited to the UK, as similar episodes of particle pollution over Paris and other European cities have shown in recent years.

Modelled daily-mean surface concentration of PM2.5 (in micro-grammes per cubic metre) for 31 March and 1 April 2014, showing ammonium nitrate plume stretching from northern continental Europe across much of the UK. CEH
Agricultural soils inevitably release ammonia if conditions like temperature and soil moisture are right following the application of manure or mineral fertilisers that contain reactive nitrogen compounds. Stables and storage facilities for manure and slurry also emit it. While ammonia itself is typically deposited within a few hundred metres of its source, as soon as it combines with the oxidation products of nitrogen oxides or sulphur dioxide and forms secondary inorganic aerosol, it can be carried hundreds of kilometres. Ammonium nitrate evaporates at higher temperature, so it contributes to secondary aerosol formation mainly during periods of cold or cool weather. Pollution episodes involving nitrate aerosol are much rarer in summer or warmer parts of Europe.

An unnatural phenomenon

This has profound implications for environmental policy. The notion of a ‘naturally occurring phenomenon’ suggests there’s nothing we can do. Yet with agriculture contributing around 82 per cent of ammonia emissions (UK National Atmospheric Emission Inventory, 2013) and road transport or other fossil fuel burning accounting for most nitrogen oxides emissions across Europe, the formation of secondary inorganic aerosols is well within human control.

This episode and others like it also show that health risks across Europe are influenced by the movement of air pollution across national borders. We need to act together to cut emissions to combat the harm to people’s health.

While emissions of sulphur dioxide and nitrogen oxides have been reduced substantially since the 1970s (by 91 and 70 per cent respectively according to the UK National Atmospheric Emission Inventory), ammonia emissions have remained relatively stable. But there are things we could do to reduce emissions from agriculture, and they are often free or cheap compared to costly measures to reduce nitrogen oxide emissions from road transport and other combustion sources (see p12).

The Task Force on Reactive Nitrogen, set up under the ‘Air Convention’ of the United Nations Economic Commission for Europe (UNECE), has compiled a document detailing measures to reduce agricultural ammonia emissions, and what they would cost.

They include using nitrogen more efficiently and exploiting advanced technologies to inject liquid manure or formulations of mineral fertilisers into the ground, so less ammonia escapes into the atmosphere. They vary in applicability, cost and effectiveness depending on each farm’s size, type and local conditions, as well as on the way agricultural production systems are set up and operated at national and regional scale.

Our economies are interconnected by trade and material flows, and this intricately links the processes that contribute to transboundary air pollution problems to potential solutions. So international air pollution-control policies have a vital role to play, and have made substantial improvements in recent decades.

A recent report of the ‘Air Convention’ of the UNECE summarises these achievements, and highlights the challenges that remain. It concludes: ‘Because transboundary sources are often major contributors to urban pollution, many European cities will be unable to meet WHO guideline levels for air pollutants through local action alone. Even national and Europe-wide action may not be enough in some cases.’

The 2014 episode illustrates the need to find out more about the underlying causes of such events, and of bad air quality more generally. But we don’t only need to have the right tools available to make such assessments – the way scientific evidence is communicated to policy decision makers is equally important.

The ‘science-policy interface’ is vital to ensure that scientific findings are taken into account when policies are designed, but equally to safeguard that researchers understand policy priorities and needs when conducting analyses. And despite the improvements in air quality since the times of the London smog in the 1950s or acid rain in the 1970s, air pollution is not quite a problem of the past. Much of Europe’s vegetation is not yet protected from the effects of acid and nitrogen pollution, to which ammonia makes a major contribution, despite reductions in unprotected European land in the past 30 years since the peak of acid deposition.

The forthcoming sixth edition of the UN Global Environment Outlook statement says: ‘Air pollution is now the greatest health risk in [Europe], with more than 95 per cent of the EU urban population exposed to levels above WHO guidelines, for example. Over 500,000 premature deaths in the region were attributable to outdoor air quality and 100,000 to indoor air quality in 2012.’

This also highlights that transboundary air pollution and climate change have to be addressed in an integrated way. Only by working across national boundaries can we avoid unintended consequences and contribute to a substantial and lasting improvement of public health by reducing exposure to harmful air pollution levels.

The episode wasn’t a natural phenomenon; it happened because of man-made emissions.
Ship emissions
Monitoring, enforcement and human health

Air pollution from ships is a serious problem that doesn’t get enough attention. Kelvin Boot explains how environmental science can help ensure industry plays by the rules.

Europe has an estimated 80,000 ship-visits to ports each year, and many of those ships burn cheap, low-quality fuel that creates polluting exhaust emissions, containing sulphur, nitrogen oxides and particulate matter. This thick, dirty, tar-like fuel oil is what’s left behind after the crude oil has been refined into petrol and other petroleum products.

The millions of tonnes of polluting chemicals ship exhausts emit are identified as causing or contributing to lung and heart disease and cancers, leading to around 50,000 human deaths a year in Europe – so there is no doubt pollution from shipping is a serious problem. Whilst these emissions can affect the climate and modify atmospheric chemistry when out at sea, it is when the ships are in coastal waters and ports that they directly threaten human health.

Regulation is easy, enforcement is hard
To reduce the impact of ship emissions, the International Maritime Organization (IMO) introduced new regulations in January 2015. These aimed to reduce maximum open-ocean emissions of sulphur dioxide (SO₂) from the then current level of 3.5% of the total mass of fuel to 0.35% by 2020.

Near the coast the IMO designated Sulphur Emission Control Areas (SECA’s) including the English Channel and surrounding European waters; here, maximum sulphur content must fall to 0.1% by mass by 2015. Complying could add thousands per day to each ship’s fuel bill! Some global shipping companies have taken the regulations seriously, but others will want to avoid extra expense. Figures suggest only one in a thousand ships is checked in port – and of those around half failed testing.

A reference point for future emissions
Researchers at Plymouth Marine Laboratory, who took continuous atmospheric measurements at the Penlee Point Atmospheric Observatory (PPAO), spotted an opportunity to assess the success of the IMO Regulations. The PPAO site is on the western side of the English Channel, a busy shipping lane and a designated SECA. Measurements started seven months before the 2015 regulations came into force, providing a reference point for future changes in emissions.

Dr Tim Smyth, Dr Mingxi Yang and colleagues operate the PPAO as part of the NERC-funded Western Channel Observatory. What the data told them was clear. ‘We found that the SO₂ mixing ratio in southwesterly winds from the Atlantic was generally low and showed a daily cycle that is largely consistent with dimethyl sulphide oxidation – a naturally occurring part of the sulphur cycle over the ocean,’ Yang explains. ‘When analysing emissions carried by southeasterly winds from the Channel things were quite different; they were elevated and SO₂ mixing ratios were more variable. We interpret this being due to an additional contribution from ships, which were far more numerous in that part of the English Channel. In 2015, we witnessed a three-fold reduction in this ship contribution compared to 2014, suggesting a high level of compliance (>95%) with the IMO regulations for ships near Plymouth.’

Smyth also sees much wider potential in applying the technology to ensuring compliance with pollution regulations. ‘We are working with industrial partners to develop an on-ship monitor that will link with the tracking system used on ships to report back ship identity, position and emissions composition to ground stations for scrutiny and hopefully avoidance of non-compliance by the ship’s operators,’ he says. ‘It’s an excellent example of science becoming relevant to a real world challenge.’
New kinds of smart sensors are hitting the market, and they could transform how we cope with health risks from polluted air by putting information at our fingertips. Asthmatics could stay indoors when sensors show lots of particle pollution; urbanites might skip their evening jog if nitrogen dioxide levels are high.

There’s just one problem – most of these devices are unreliable and some are practically useless, according to the scientists who tested them. Until manufacturers are more open about the accuracy and limitations of sensors, they’re little more than a curiosity and should not be used to make decisions about health.

‘Like many atmospheric scientists I’d heard about these sensors and was rather dismissive,’ says Professor Ally Lewis of the University of York, deputy director of NERC’s National Centre for Atmospheric Science. ‘But we were unsure how well they’d perform, so we started testing them in the lab. The results weren’t very impressive.’

Measuring atmospheric pollution is hard. You often need to find just one molecule of gas in every one billion in air, while managing other factors that could distort the result, like weather or other pollutants. There’s a reason atmospheric chemists and those responsible for meeting legal obligations on pollution use big, high-powered lab equipment and not convenient handheld metres.

Most of the air quality sensors on the market rely on old technology re-purposed from products like fire alarms or car exhaust sensors. Few were designed to monitor air pollution to protect health. ‘Often it’s not clear what performance people should expect from their sensor,’ Lewis says. ‘Sometimes the marketing does suggest they’re just for fun, but manufacturers can’t control how the data will be used. Ultimately most people are interested in air quality for health reasons – and data from these devices could well be for used for health decision-making and medication.’

But sensor data isn’t very reliable. Many sensors reacted inconsistently to a given input. They can respond as much to humidity, temperature or other gases like hydrogen or CO₂ as to the pollutants. The team put 20 identical ozone sensors on a roof and tested them; the highest and lowest readings varied by a factor of six.

This wouldn’t be so troubling if sensors made this uncertainty clear. If users knew they were accurate to within a factor of 50, they’d know not to trust them. Failing to provide this information is a problem because dealing with invisible pollution means we have no clear sense of what the right result might look like, making it hard to know when it is wildly inaccurate.

Lewis says some of the sensors’ technology could be improved, but trying to turn scientific instruments into hand-held devices is hard. Many of the instruments he uses in the lab can’t shrink beyond a certain point because of the basic physics of how they work. ‘Our instruments get better, but they don’t tend to get any smaller,’ he notes.

Lewis argues scientists should do more to test these devices and tell the public about their strengths and limitations. They should report findings even when they find no evidence a device works – failure to do this is a big part of why there’s so little objective information to counterbalance the hype. Sensor labelling should be clearer about reliability and what they should be used for, and there should be a scheme to ensure they meet minimum standards of accuracy.
The Indian monsoon is among the most dramatic examples of the annual cycle. As winds change from winter to summer, they bring much-needed moisture from across the ocean and supply India with 80 per cent of its annual rainfall between June and September.

But there is a problem: we can’t make good monsoon forecasts more than a day or so ahead. Farmers, industry and policymakers want predictions weeks, seasons or years ahead, but it’s difficult to offer reliable information. The models we use for monsoon forecasts often don’t represent the physical processes controlling the timing, intensity and duration of rainfall. Perhaps they are not at high enough resolution – the grid on which physical equations are solved is too coarse – and we don’t have enough observations of the real tropical environment to properly design our models in the first place.

We hope to go some way to solving the monsoon problem with results from our recent field campaign for the INCOMPASS project. We used the FAAM research aircraft from before the onset of monsoon rains in early June into mid-July to fly over coastlines, deserts and mountains in northern and southern India. Together with our partners we also installed several instrument towers to measure the moisture and heat passed between the surface and atmosphere, and also launched several radiosondes (weather balloons).

We hope the information we gathered will help answer vital questions about the monsoon in India and its relationship with Earth’s surface:

- How does the temperature and humidity of the atmosphere change moving across from the Indian Ocean, across the coastline of India and across mountains?
- How do the transitions between sparse desert regions and moist agricultural landscapes affect the development of monsoon storms?
- Do small showers before the monsoon provide moisture that helps prepare the atmosphere for more violent storms later?

This was the aircraft’s first visit to India, and the first time foreign airborne research has been performed there for such a long period. INCOMPASS is part of the most ambitious atmospheric observational campaign yet by NERC scientists.

Such unique fieldwork brought its own hurdles. How would we get permission to fly for research in a nation more familiar with commercial air traffic? How would scientists and engineers cope with working in the extreme heat and humidity of monsoon India? All of this required months of planning and negotiation. Once in India, flights had to be planned meticulously: flight-plans had to be filed with the authorities around two days in advance. This made accurate forecasting of the weather vital since we had to know in advance where we could find the most interesting data. Using a specially developed Met Office model, each day we worked with our Indian colleagues to forecast the monsoon and plan the best routes.

By consulting air traffic control during flights, the pilots could then choose a variety of altitudes to get the data we wanted. Sometimes we spent an hour or more only a few hundred feet above mountains and fields! We measured variables including temperature, humidity, and atmospheric radiation. Other on-board instruments such as the lidar, which works like radar except with lasers instead of radio waves, looked at the layers of cloud and dust towards the ground.

The fieldwork was exciting and at the same time exhausting – it represents a fantastic effort from many across India and in the UK. Now it is over, the rest of the science begins: we’ll spend the next few years analysing data and solving some of the problems of the monsoon.

Dr Andy Turner is a lecturer at the Department of Meteorology and National Centre for Atmospheric Science, based at the University of Reading.

Email: a.g.turner@reading.ac.uk

The Drivers of Variability in the South Asian Monsoon programme

INCOMPASS (Interaction of Convective Organisation with Monsoon Precipitation, Atmosphere, Surface and Sea) is one of three projects jointly funded by NERC and India’s Ministry of Earth Sciences from 2015-2018. It is led jointly by University of Reading and the Indian Institute of Science, including researchers at the University of Leeds, Met Office, Centre for Ecology & Hydrology and a host of other Indian partners. Other projects under the programme are SWAAMI and BoBBLE. The INCOMPASS field campaign was recently completed between May and July 2016, involving airborne and ground measurements.
Pictured together for the first time, two of NERC’s key scientific instruments capture the essence of *Into the blue*, a public showcase of environmental science in the northwest of England where both ship and aircraft will be on display.

The RRS *Discovery*, one of the world’s most advanced research vessels providing UK marine scientists with a platform for world-leading oceanographic research, welcomed visitors on board in Liverpool in early October.

The FAAM aircraft, which is on the UK’s front line for investigating air pollution, weather patterns and cloud formations, is on show at Manchester Airport from 25-29 October alongside an interactive exhibition featuring presentations, debates and hands-on science demos by real scientists to showcase the environmental science we live and breathe.

Find out more at [http://intotheblue.nerc.ac.uk/](http://intotheblue.nerc.ac.uk/)
Next issue

Keeping back the floods

What causes different kinds of flooding?
Can natural flood management help?
How will we cope in the future?