
NATURAL ENVIRONMENT RESEARCH COUNCIL
PlanetEarth
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Winter 2010
How biodiverse is a
polar archipelago?
Killer whales
Splitting continents
Winds of change
Measuring carbon from space

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Planet Earth
Winter 2010

FEATURES

COVER STORY

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NERC scientists: we want to hear from you

Planet Earth is always looking for interesting NERC-funded science for articles and news stories. If you want to see your research in the magazine, contact the editors to discuss. Please don't send in unsolicited articles as we can't promise to publish them. We look forward to hearing from you.

Front cover: Biodiversity in a polar archipelago – see page 20.

Bringing it all together – integrated environmental science

Alan Thorpe *Chief Executive, NERC*

The UK can lead the world by acting as a beacon for multi-disciplinary environmental science.

It is 45 years since the royal charter gave NERC responsibility for funding environmental science research, and the world looks very different now. Environmental science is no longer just about pushing forward the frontiers of human knowledge – it is also at the forefront of issues that will affect our health, economy and perhaps our very future.

So in 2011 we stand at a crossroads. Environmental science in the UK is mature and interconnected enough that we are poised to transform our approach, and make it truly multidisciplinary. It's a timely and important change because it will enable researchers to address the major environmental challenges we face in a holistic way, be they to do with climate change, biodiversity loss or natural hazards.

This isn't to say that environmental scientists don't already work together. Programmes like Quantifying and Understanding the Earth System (QUEST) bring together scientists from many disciplines to build a more sophisticated understanding of how the Earth works. This includes specialists in areas ranging from the ancient climate to the effects of vegetation on today's carbon cycle. But this approach needs to be the rule, not the exception.

An intrinsic part of NERC's role is its contribution to the UK's 'national capability' – the ships, aircraft, polar bases, monitoring and survey datasets, computing capability and instruments on which environmental science relies. Until now this has been delivered within the six separate sectors that NERC supports: marine, atmospheric, geological, terrestrial and freshwater, polar, and Earth observation. NERC runs six research centres, each focusing on one of these science sectors, and you will have read contributions from many of them in *Planet Earth* magazine. Each sector has its own distinctive scientific community, and its own national capability strategy.

In 2011 NERC will grasp the new multidisciplinary opportunity by planning and operating these core national capability activities through a single, integrated strategy.

This is the next step in delivering NERC's strategy, *Next Generation Science for Planet Earth*, and will involve environmental science sectors working together seamlessly and strategically.

It means establishing a common national capability that can focus on the big science questions, and be exploited by the whole environmental science community. For this approach to work, environmental scientists in NERC centres and the wider academic community will need to collaborate more across the traditional disciplinary and organisational boundaries.

All this is driven by the needs of the science, irrespective of our organisational set-up. It will let us tackle the major environmental crises that we face by combining the expertise of specialists in diverse disciplinary areas – some of which have worked separately until now. The UK can lead the world by acting as a beacon for multidisciplinary environmental science.

Of course this integration will also help UK environmental scientists work with the other research disciplines outside NERC's remit – like engineering, economics and social science. It will not just transform environmental research in the UK – the benefits will be felt all over the world, strengthening our already strong track record of international collaboration.

Biodiversity – the complex picture

Biodiversity loss is a big problem, not least because we all depend on the 'ecosystem services' the natural world provides us – like a steady supply of clean water from our wetlands, pollution control and carbon storage by soils and plants, not to mention food, fuel and many of our medicines. So understanding exactly what's causing different species to decline is crucial for our own well-being.

When the 10th conference of the Parties to the Convention on Biological Diversity opened in Nagoya, Japan, in October, 20 draft targets for preserving global biodiversity were brought to the table. It was a challenging agenda and many delegates stayed beyond the official close of the conference to see it through. In the end, participating governments sent a strong message that protecting the health of the planet has a place in international politics.

But the final targets of protecting 17 per cent of the world's land surface, and 10 per cent of the oceans, by 2020, were not as tough as many conservationists would have liked.

The participating governments acknowledged that to have any hope of meeting even these targets, they have to tackle the causes of biodiversity loss – including the expansion of farming, pollution, invasive species and climate change.

They pledged to phase out incentives, such as subsidies, that are harmful to biodiversity. They also agreed that farmed and forested areas should be managed sustainably and that fisheries should have no impact on vulnerable ecosystems or threatened species. And they promised to take the important step of incorporating biodiversity into national accounting and reporting systems.

Such measures could make a world of difference, but to put them into practice will take vast amounts of money, and countries will have to work together to achieve them.

There is optimism that biodiversity loss can be slowed, but setting targets is just the beginning.

IUCN Red List – crisis and confidence

The International Union for Conservation of Nature (IUCN) Red List of Threatened Species is the world's most comprehensive source of information on the status of plant and animal species around the world.

Scientists from 115 institutions across 38 countries have used the latest Red List for an assessment of 25,000 species of the world's vertebrates, which was presented to delegates at Nagoya.

The study, published in *Science*, reported an extinction crisis, with one in five species threatened by the expansion of agriculture, logging, land-use change and invasive species. But the study is also the first to present clear evidence of the benefits of conservation efforts around the world, highlighting 64 species whose status has improved, including three that were extinct in the wild and have been reintroduced: the California condor, *Gymnogyps californianus*, and the black-footed ferret, *Mustela nigripes,* in the US, and Przewalski's horse, *Equus ferus*, in Mongolia.

So conservation works, given resources and commitment, but the study warns that these efforts will need to be scaled up to meet the magnitude of the threat.

Richard Bartz

High brown fritillary, *Argynnis adippe.*

Some global figures from the latest Red List

Species assessed	55,926
Extinct	791
Extinct in the wild	63
Critically endangered	3565
Endangered	5256
Vulnerable	9530
Near threatened	4014

Among the Red List's threatened species are many of Britain's butterflies. More than a third of our 62 butterfly species have now either disappeared from the country or are considered threatened, and four species have gone 'regionally extinct'.

The details come from two butterfly recording projects: Butterflies for the New Millennium, launched by the charity Butterfly Conservation in 1995, and the UK Butterfly Monitoring Scheme, run by both the Centre for Ecology & Hydrology (CEH) and Butterfly Conservation. Both rely heavily on citizen scientists – members of the public and butterfly enthusiasts – to record information. The results are published in *Insect Conservation and Diversity.*

As elsewhere, the new Red List is likely to be used as a tool to focus conservation efforts. There are many examples of successful butterfly conservation projects; the Large Blue disappeared from Britain in 1979 but was reintroduced to south-west England and is now thriving.

Extinction is not the only issue

A recent *Science* paper compiled by DIVERSITAS, an international collaboration of biodiversity experts, says biodiversity will continue to decline during this century. But it offers new hope that this decline could be slowed, provided emerging policies are put into action.

The paper's authors say the creation of the new Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) will be an important step towards reducing uncertainty over the likelihood of massive extinctions over the coming century.

But they also emphasise that changes in species distributions and population sizes are, if anything, more important than extinctions as short-term indicators of the pressures humans are putting on ecosystems.

Surveys don't tell the full story

DIVERSITAS contributor Professor Georgina Mace, from Imperial College London, warns that the way biodiversity surveys average out trends in population figures can obscure details about what's actually happening.

'Big trends hide the variability which is important for predicting which species might be at risk in the future and being able to intervene effectively,' she says.

Mace and colleagues from Imperial College London, the Institute of Zoology and the University of Queensland in Australia, wanted to unpick the species-level data underlying average trends. Their work is published in the *Philosophical Transactions of the Royal Society B*.

The scientists found that most species showed little variation in abundance or range change from year to year. Instead, just a few species were experiencing a dramatic decrease in abundance or geographic range.

They also saw that the species showing the most marked responses change over time – so as some declining species stabilise others begin to suffer. This suggests that new threats appearing in the environment – like habitat loss due to land-use change – are suddenly causing a few species to decline rapidly.

The researchers also write that the links between biodiversity and ecosystem processes are poorly understood and that biodiversity richness in itself isn't a direct indicator of the security of our ecosystem services. Instead, it would be better to look at the 'functional traits' of different species, and the specific role they play in an ecosystem.

It's about ensuring you have the right sorts of species in the right places – a wetland community, for example, need not be very diverse to function effectively.

But, says Mace, this can be a confusing message. We mustn't lose site of the fact that biodiversity loss is a big problem.

In brief

NEW Audio diaries

Our science news website *Planet Earth Online* has featured something new this year: we've given audio recorders to researchers heading off to places like Borneo, Uganda and even Antarctica, so they can capture their experiences in audio diaries. They've sent us some fascinating material, and we're going to be featuring some of it in future editions of *Planet Earth* magazine. In this installment, Tim Cockerill from the University of Cambridge reports from northern Borneo, where he's studying insects in the rainforest. *Be warned:* it's not for the squeamish. Click icon to listen.

Sustainable coral research

If you're one of the world's two million aquarium owners, chances are you've put some coral in there to make it homely for its occupants. But have you ever wondered where it came from? With more than 2000 species of coral kept in private and public aquariums worldwide, and a quarter of the world's reefs considered to be damaged beyond repair, it's a question worth asking.

The Coral Aquarist Research Network (CARN) aims to create a more sustainable future for the world's coral reefs, by bringing together the coral trade, the research and conservation communities and aquarium owners, including hobbyists.

'These diverse groups have generally worked independently on many common issues – like finding ways to improve coral growth,' explains NERC knowledge exchange fellow Philippa Mansell, CARN project manager. 'Each group has its own wealth of information and by combining this knowledge these issues could be tackled far more effectively.' For example, advances in aquaculture and projects that focus on growing corals sustainably are aiding reef restoration programmes and UK coral-linked industries. So there's every reason for collaboration.

To find out more, and how you could get involved in CARN, visit www.carnuk.org or contact Philippa: pippa@carnuk.org

Barbastelle bats use stealth echolocation

Given the choice, bats would eat moths at every meal – they're fat, tasty and don't have an annoying shell. But many moths have evolved ears that can detect bats' ultrasonic calls.

Now scientists have discovered that barbastelle bats, *Barbastella barbastellus*, have a sneaky way to outwit these moths – they whisper. This means they can feed almost exclusively on moths with ears, while other bats are lucky if they manage to catch one.

'Normally bats use ultra loud echolocation calls – which are as loud as jet engines if we could hear them – to detect their prey,' says Dr Holger Goerlitz from the University of Bristol, lead author of the study published in *Current Biology*. 'But this bat uses very low amplitude calls to overcome moths' defences.' Click the icon above to listen.

The scientists tracked the flight paths of bats in the wild in 3D, using arrays of microphones, while at the same time recording how active the nerve in the ear of the moth *Noctua pronuba* was.

They found that while most moths can detect bats as far off as 30m, the barbastelle got as close as 3.5m – sometimes just 1.9m – before *Noctua pronuba* picked it up, and by then the moth's fate was decided.

Other bats do use low-amplitude echolocation but they mainly feed on insects that sit on leaves. For these so-called gleaning bats, scientist aren't sure if these lower amplitude calls evolved to counteract moth hearing or to stop the echoes from plants' leaves deafening the bats.

Although the barbastelle bat is found throughout most of Europe, its natural woodland habitat is disappearing, so it's becoming increasingly rare in Britain and is found only in the southern half of the country.

The research was funded by the Biotechnology and Biological Sciences Research Council, NERC, Mammals Trust UK, the Countryside Council for Wales, Natural England and Bat Conservation International.

Dietmar Nill/Nature Picture Library

Yang zhenq/AP/Press Association Images

Climate change and crop failure

Large-scale crop failures, like the one that caused the recent Russian wheat crisis, are likely to become more common with climate change, a new study shows.

However, the worst effects of these events on agriculture could be mitigated by improved farming and the development of new crops. The researchers, from the University of Leeds, the Met Office Hadley Centre and the University of Exeter, conclude that the best approaches will combine building up crop tolerance to heat and water stress with socio-economic interventions.

The unpredictability of the weather is one of the biggest challenges faced by farmers struggling to adapt to a changing climate. Some areas of the world are becoming hotter and drier, and more intense monsoon rains carry a risk of flooding and crop damage.

The team studied spring wheat crops in north-east China. They used a climate model to make weather projections up to the year 2099 and then looked at the effect on crop yields. Then they looked at socio-economic factors to determine how well farmers could adapt to drought.

'Due to the importance of international trade crop failure is an issue that affects everyone on the planet, not just those in crop-growing regions,' says Dr Andy Challinor, from the University of Leeds, lead author of the report which is published in *Environmental Research Letters*.

'More extreme weather events are expected to occur in the coming years due to climate change, and we have shown that these events are likely to lead to more crop failures. What we need to do now is think about the solutions,' he adds.

While the study looked only at crops in China, the authors say this methodology can be applied to many of the other major crop-growing regions around the globe.

The work was carried out by the NERC consortium EQUIP: www.equip.leeds.ac.uk

Wanted

Fresh Scientists to develop teaching resources

Could your research bring science to life in the classroom? Fresh Science is a scheme that brings researchers and teachers together to develop material for a 12-week 'course'. To get involved you'll need to create a profile about yourself and your work, upload a small dataset that teachers can use in their lessons, and a blog talking about your data. Teachers can then use your dataset directly or work more closely with you to develop teaching resources. Guidance and training is provided – for details see https://ecpd.slcs.ac.uk/FreshScience/?q=node/24

Supercooled water threat to aircraft fuel systems

Tucked up snugly in the cabin of an airliner, it's easy to forget that outside the temperature is probably less than -50°C – easily low enough for ice to form where it's not wanted.

Happily there are few incidents where ice is thought to have caused engine problems. But in 2008, when both engines on a Boeing 777 failed almost simultaneously just before landing, the accident investigators cited ice crystals in the fuel system as the likely cause.

Researchers in the School of Chemistry at the University of Leeds, and their contacts at ice crystallisation specialists Asymptote Ltd in Cambridge, realised their own research was directly relevant to the investigation.

The incident investigation was based on the assumption that water freezes at 0°C. In fact it's possible for droplets of pure water to remain liquid well below this – if they're small enough they can 'supercool' to as low as -36°C.

But if the droplets come into contact with solid particles or surfaces they begin to freeze before they get this cold. The collaborators suspected that supercooled water, not ice, had been present in the aircraft's fuel system. To test their idea they submerged micron-sized droplets of water in drops of Jet A-1 fuel, cooled them to -41°C, and filmed what happened as the temperature fell.

'Because we could use the equipment designed for our atmospheric research, it was very straightforward,' explains Dr Benjamin Murray, now at Leeds' School of Earth and Environment, lead author of the report published in the journal *Fuel*.

The film showed that droplets at -30.9°C were still liquid, but they began to freeze at -36.6° and at -39°C all the droplets had frozen.

So, instead of ice sticking together, the researchers think the aircraft's problems could have begun when supercooled water droplets came into contact with solid surfaces in its fuel system, instantly freezing and resulting in a build-up of ice that could have restricted the flow of fuel.

'You really have to know if you're dealing with liquid or solid particles or you won't be able to understand exactly what's going wrong,' says Murray.

It's an important insight for aviation engineers who are trying to find ways to prevent, or engineer around, the problem. And it's a nice example of basic science finding unanticipated, direct applications to real-life problems.

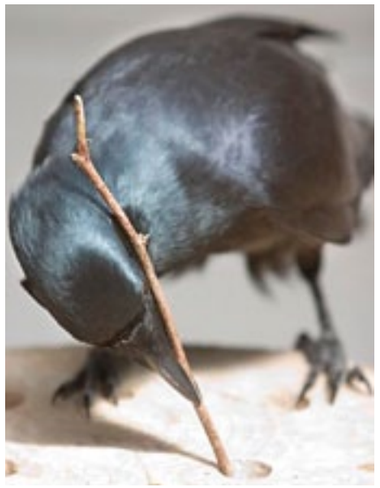
Crowing with satisfaction

Tool-use is rare in the animal kingdom, but the New Caledonian crow is a master – to the extent that it can get most of its energy by luring wood-boring longhorn beetle larvae from their burrows with twigs.

Because tool-use is thought to have played a significant role in human evolution, scientists are keen to understand the benefits of this type of behaviour in animals and whether it makes them 'fitter' than their rivals.

New Caledonian crows eat a range of food, but only the longhorn beetle larvae are 'caught' with tools. To understand how important this tool-use is to the birds, scientists wanted to find out what proportion of the crows' diet came from tool-derived food. But the birds live on a densely forested South Pacific island, so it's difficult to see what they're actually eating.

To solve the problem, a project led by researchers from the Universities of Oxford and Exeter used a CSI-style approach; they analysed the crows' blood and feathers for the larvae's distinct chemical signature. The researchers discovered that the crows need just a few of the fatty larvae each day to satisfy their energy needs. But as it's not at all easy to extract the larvae with a beak, this kind of sophisticated tool-use gives the crows a distinct competitive advantage.



Dr Simon Walker

The research is published in *Science*.

Urbanisation increased immunity to disease

New research has found that a genetic variant, which reduces the chance of contracting diseases such as tuberculosis and leprosy, is more prevalent in populations with long histories of urban living.

The research, published in *Evolution*, shows that modern inhabitants of areas with a long history of urban settlement are more likely to possess this genetic variant.

In ancient cities, poor sanitation and high population densities would have provided an ideal breeding ground for disease. Natural selection should mean that humans would have developed resistance to disease in long-standing urbanised populations over time. However, this association has been very difficult to prove, especially in prehistoric populations.

Ljiljana Pavkov/istockphoto.com

So researchers from University College London (UCL) and Royal Holloway tested the theory by analysing DNA samples from 17 different human populations living across Europe, Asia and Africa. They also searched archaeological and historical literature to find the oldest records of the first city or urban settlement in these regions.

By comparing rates of genetic disease resistance with urban history, they were able to show that past exposure to pathogens gave ancient populations increased resistance to disease. This resistance was then passed down through the generations.

'The results show that the protective variant is found in nearly everyone from the Middle East to India and in parts of Europe where cities have been around for thousands of years,' explained UCL's Professor Mark Thomas.

'This seems to be an elegant example of evolution in action. It flags up the importance of a very recent aspect of our evolution as a species – the development of cities as a selective force. It could also help to explain some of the differences we observe in disease resistance around the world,' added Dr Ian Barnes from Royal Holloway.

The research was co-funded by NERC and the Arts and Humanities Research Council.

Dolphins can readily distinguish between fish and similarly shaped decoys, or detect fish hidden under sediment.

Signalling success

Most of us use sight to find out about our environment, but echolocating animals – like bats, dolphins, oilbirds and cave swiftlets – use sound. Now scientists are trying to apply the techniques animals use, to help us in many fields of human endeavour. John Rees from the British Geological Survey tells us more.

Echolocating creatures 'see' using echoes, judging an object's distance and size from the reflections of their calls. And they can identify and measure objects with much greater resolution than we can using sight. It's an amazing ability. Take dolphins, for instance. They can detect objects smaller than a centimetre from a distance of more than 100m. And they do so using acoustic wavelengths that are far larger than the targets they are identifying – so they can locate something no bigger than a millimetre using wavelengths of several centimetres.

Perhaps most intriguing is their ability to sense the physical properties of objects just using their calls. Dolphins can readily distinguish between fish and similarly shaped decoys, or detect fish hidden under sediment. Even more incredibly, they do all this in highly cluttered acoustic environments – where there's not just a lot of noise from their own calls reflecting off neighbouring objects or organisms but where many other animals are also communicating and echolocating. These skills are not unique to cetaceans, like dolphins and whales; other echolocating animals have evolved very similar capabilities over millions of years.

We've made some headway towards understanding animal acoustic systems, and some aspects have already been applied successfully in engineering, for example in the development of sonar systems. But these look exceedingly primitive compared to the complexity of biological echolocation. Clearly we need to know more about how these animals function.

The Basic Technology Programme for Biologically Inspired Acoustic Systems (BIAS) was created to address that need. It involved scientists and engineers from the British Geological Survey and the universities of Edinburgh, Leeds, Leicester, Southampton and Strathclyde. And it combined many diverse disciplines: animal acousticians, mathematicians, signal processors, acoustical engineers, and geological and medical physicists, who all came together to work out how the techniques of echolocating animals could inspire technological solutions to human problems.

One aspect we looked at in detail was echolocator calls, particularly how the animals vary the sounds they emit to help them navigate and catch prey. Bats use a wide and complex array of signal types – pulses of sound at fixed and fluctuating frequencies, many typically lasting only a quarter of a millisecond. The BIAS team captured and analysed these calls, and have stored them in an extensive call library.

Something we wanted to do early on was record bat echoes as they're received by the animals themselves, as opposed to the signals recorded by microphones as the bats fly past. So we designed a tiny, lightweight recorder that could be carried in a backpack strapped to adult Egyptian fruit bats. Capturing the sounds the bats themselves hear while flying has revealed some of the tricks they use when catching prey – for example they use both higher and lower frequencies than we'd previously thought.

An Egyptian fruit bat with a sensor attached to its back using velcro.

Through experiments like these we realised we needed to pay particular attention to subtle shifts within sound waves as they change over time. Analysing such shifts within animal signals isn't straightforward, so we designed our own signals and new tools to enable us to process them. It's proved to be a highly successful strategy. The new signals are more than ten times more accurate than the ones previously used for distance measurement and, most significantly, they have a similar performance to those emitted by the animals themselves.

We used these bio-inspired signals to explore the physical characterisation of materials too, and it's produced some notable successes, in diverse fields. For example, the transmission and reception of bat- and dolphin-like signals in human tissues, using high-frequency sound, has helped in the measurement of moving heart tissue in cardiac imaging. And we've used lower frequency signals to determine the characteristics of solid and granular geological materials.

> We designed a tiny, lightweight recorder that could be carried in a backpack strapped to adult Egyptian fruit bats.

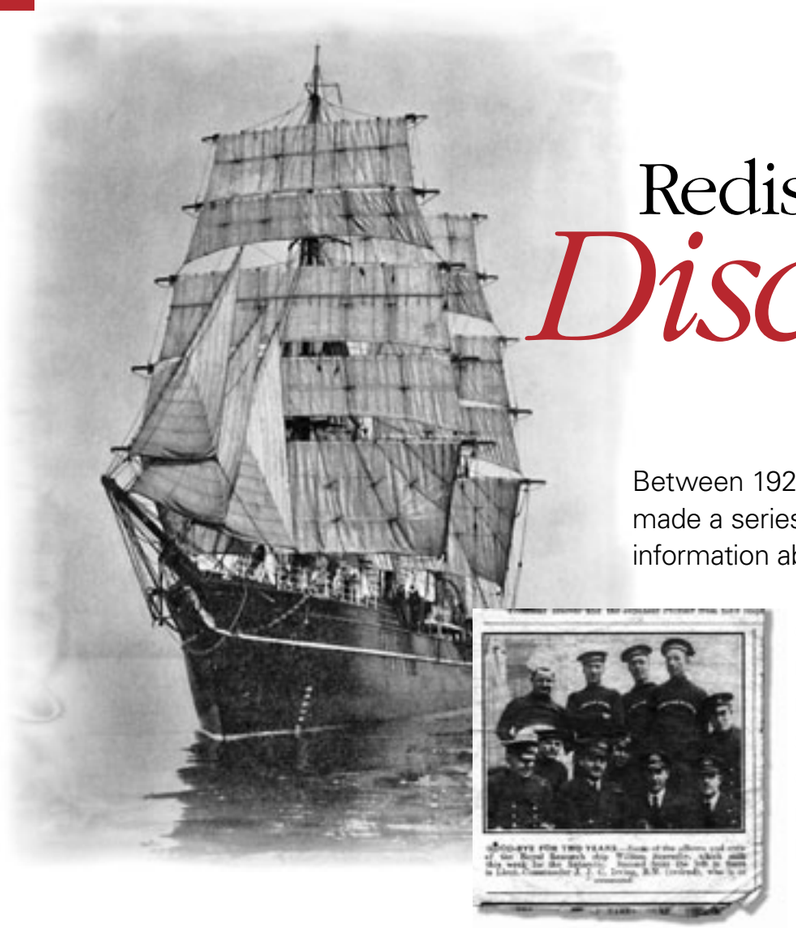
One of the immediate benefits to stem from the project has been the development of a range of novel transducers – instruments that emit and receive bio-inspired signals. These possess improved sensitivity and bandwidth when compared with conventional counterparts.

The project has led to significant advances in the resolution with which we can sense objects and identify what they are. This new knowledge is already being put to practical use, for example in non-destructive evaluation (NDE) of materials – such as screening the content of cargoes to see if they contain what they're supposed to. There's lots of potential here too, such as helping position robotic vehicles working in cluttered or noisy environments, like nuclear reactors; and research on object recognition could help hearing-impaired people through a new generation of hearing aids or cochlear implants. And the BIAS team is actively exploring several environmental science applications, including the characterisation of underwater sediments.

These advances are exciting, but the project has brought home to us just how far we still have to go to come anywhere near the sophistication of echolocating animals. As Carl Sagan said, 'It is of interest to note that while some dolphins are reported to have learned English – up to 50 words used in correct context – no human being has been reported to have learned dolphinese.' That remains true, but BIAS has made a start.

MORE INFORMATION

Professor John Rees is NERC's Natural Hazards theme leader and represented BGS in the BIAS project.Email: jgre@bgs.ac.uk To find out more about BIAS visit: www.biasweb.org



Rediscovering the *Discovery*

Between 1925 and 1951, three research ships made a series of pioneering voyages to gather information about the Southern Ocean. The *Discovery* Investigations are well documented, but the valuable raw data they brought back remained out of reach of modern science. Andrew Mackey explains how these important records are finally seeing the light of day.

As I look through a large box containing all sorts of paraphernalia, I pick up a hand-drawn illustration of icebergs floating along the coast of a mountainous land. Under this is a notebook that belonged to one of the crew of the RRS *William Scoresby*. It opens on a page dated 3 November 1927, which describes the awful smell as the ship approaches a whaling station on the island of South Georgia. This is fairly typical of the hundreds of boxes around me, here at the National Oceanography Centre (NOC) archives in Southampton. They contain the records from the *Discovery* Investigations.

The Royal Society commissioned the *Discovery* Investigations, one of the most ambitious scientific studies ever undertaken. It was led by the RRS *Discovery* – the vessel that carried Scott and Shackleton on their first successful journey to the Antarctic. Among the esteemed crew of 47 was the director of the Investigations, Dr Stanley Kemp – according to the journal *Nature*, 'probably the leading authority on oceanography'. He was joined by Sir Alistair Hardy, founder of the Sir Alistair Hardy Foundation for Ocean Science (SAHFOS) and inventor of the Continuous Plankton Recorder (CPR), a device – used today more than ever – that is towed through the ocean collecting and preserving plankton on an ever-moving band of silk: ingenious! The following year *Discovery* was accompanied by the RSS *William Scoresby*, a trawler much better suited to maintaining the consistent speed needed for ocean sampling. *Discovery* was powered by coal-fired steam but relied on sail for long journeys. As a result she was replaced from 1929 by her namesake *Discovery II*, the largest research ship ever to explore the Southern Ocean.

The aim of the expeditions was to investigate all aspects of the ocean affecting the distribution of whales. Antarctic whale numbers were in steady decline, but no one knew enough about their distribution and migrations, or about the food chain supporting them, to do anything about it. Gaining this knowledge meant studying the biology, chemistry and physical oceanography of some the harshest seas on the planet. The data gathered resulted in 34 volumes of *Discovery Reports*, which contributed enormously to our understanding of this remote region. They were the first to describe the importance of krill – shrimp-like, planktonic crustaceans that form a critical link in the food chain – and the existence of the Antarctic Convergence. This is an oceanographic phenomenon that marks the physical boundary of the Southern Ocean, an area rich in marine life where cold, northward-flowing polar water meets warmer sub-Antarctic waters.

Baleen whales live almost exclusively on zooplankton, so the research into these tiny marine animals in particular was of paramount importance. In total nearly 4000 observation points or 'stations' from around the Southern Ocean were sampled for the composition and abundance of their plankton, along with hydrological readings such as water temperature and salinity. Most of these observations were made from the surface down to more than a thousand metres in depth.

Historical data can contribute a great deal to research into the effects of environmental change. Plankton are excellent 'biological indicators' – they are highly susceptible to changes in their environment and their response, in turn, can tell us about those changes. By understanding past ecological changes in the plankton community, scientists will be better equipped to predict future changes. That's why this raw data is so valuable – it gives us a window on the last 80 years.

But scientists need access to complete, original ecological datasets to make meaningful comparisons with the past, and much of the documentation that was used in the synthesis of the now famous *Discovery Reports* has become separated and jumbled over the decades, so this information just hasn't been available to the scientific community. Until now.

This is where I come in. I work for the British Antarctic Survey (BAS) and, together with NOC and the Natural History Museum, London (NHM), I am working on a project to restore the true value of these incredible voyages, by bringing all the documents and data from the investigations together for the first time.

The idea is to make all the data available through an open-access, online data portal, giving everyone from the public to marine scientists the world over direct access. There will also be links to maps, graphs and the original *Discovery Reports*. NHM also has more than 27,000 jars containing the actual plankton samples. By carefully piecing together the various bits of information we can link a sample record with its corresponding jar. We're also identifying those yet to be analysed – several thousand jars may never even have been opened since they were collected, offering the exciting prospect of first-hand analysis of an 80-year-old ecosystem.

A crucial part of the process is the painstaking entry of the original data onto spreadsheets. Tedious though this sounds, it's probably the most important stage in the data recovery. Without meticulous attention to detail, an error could lead to seriously wrong conclusions being drawn further down the track.

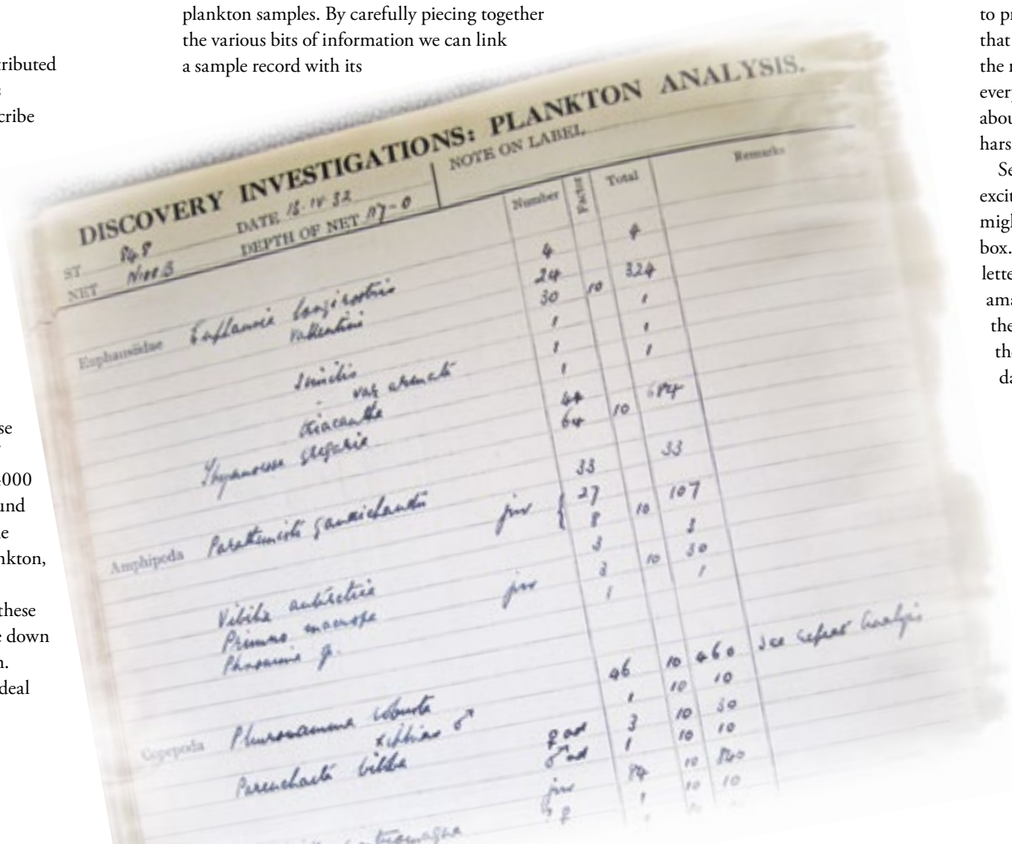
> Historical datasets can provide important context to new observations, and help scientists analyse longer-term trends and changes.

Research often focuses on gathering new data through expensive fieldwork and experimentation, but doesn't fully explore the potential of the large quantities of existing historical data. This means that important information is often neglected. Historical datasets can provide important context to new observations, and help scientists analyse longer-term trends and changes. Global climate change and ocean acidification would have meant little to the scientists and crew of the *Discovery* Investigations, but the data they collected may help us understand these phenomena. Changes in the abundance and distribution of plankton could have profound effects higher up the food chain, with potentially catastrophic consequences.

Since these historic voyages, many regions of the Southern Ocean have become warmer, particularly in the south-west Atlantic sector, and the old data will help us better understand whether the distribution of zooplankton communities has changed across the Southern Ocean as a result. So as well as making the records accessible to other researchers, we'll be publishing the results of our own modern analysis of the data. This will establish a baseline against which to compare present and future findings that will effectively extend our knowledge back in time, and give important context to the environmental changes we're seeing today.

The final *Discovery* voyage was made in 1950-51, 26 years after the first. The knowledge gathered by the investigations was not enough to prevent the massive exploitation of whales that has taken place during the last century. But the mindset of those involved, to investigate everything and overlook nothing, did bring about a comprehensive understanding of this harsh and most demanding of oceans.

Searching through the collections is an exciting part of my work; I never know what I might find once I open the lid of another old box. Sometimes I'll find beautiful, handwritten letters, black-and-white photographs of amazing scenery, and newspaper cuttings from the 1920s. But what I'm really looking for is the priceless plankton-catch data. These raw data sheets are the real treasure.



MORE INFORMATION

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www.antarctica.ac.uk/bas_research/data/access/esodap/discovery.php

www.nhm.ac.uk/research-curation/research/historical-marine-collections/nhm-collections/discovery

There are killer whales, and then there are *killer* whales

Main: Martin Buegner/Photolibrary.com. Inset: Andy Foote

The killer whale, with its distinctive black-and-white markings, is one of the most familiar marine predators. But great variety lies behind their majestic livery. Andy Foote explains why these differences are so significant.

Ivor Fred Polson

Andy Foote and Harriet Bolt whale watching from *Adenia*.

Most people would instantly recognise a killer whale. But take a closer look at killer whales across the globe, and even at different populations in the same area, and differences in form – sometimes subtle, sometimes striking – become apparent. In fact, even though they're still considered to be a single species, there's an astonishing diversity in killer whale morphology (their appearance and structure) and ecology (how they live).

Long-term field studies in the north-east Pacific first identified different 'ecotypes' of killer whale more than two decades ago. The behavioural differences between the types was striking: whales that eat marine mammals hunt silently in small groups, taking long dives to try to capture seals and porpoises by surprise. In contrast, fish-eating types are both more sociable and more vocal, because fish don't hear well at higher frequencies and can't tell the whales are coming. But the morphological differences between the two were subtle – you couldn't readily tell them apart just by looking. More recently though, scientists at the Southwest Fisheries Science Center in California have identified four killer whale types in Antarctic and sub-Antarctic waters that have remarkably different morphology.

Why is studying this variation in killer whales important? Maintaining biodiversity is currently a high priority for wildlife management and conservation bodies. These different types of killer whale have diverged ecologically and in some cases, as we shall see, genetically. So they are on their way to becoming (or, some would argue, already are) distinct species. To maintain biodiversity it's important to study the biology of each distinct type and consider them as 'evolutionary significant units' so we can understand their role in their particular ecosystems. If we clump all killer whales together we'll overlook important implications for the preservation of marine biodiversity.

All this led us to investigate whether such different forms could be found closer to home in British waters.

Finding one type of killer whale in the waters around Britain is no easy matter, let alone characterising different ecotypes, but we have been able to track them in their natural habitat. In the summer we follow pods of whales as they hug the shoreline hunting for seals. In the autumn we join the pelagic fishing vessel *Adenia* during its offshore mackerel-fishing trips around Shetland.

Each time the crew hauls in its catch, groups of killer whales gather around the boat to feed on the exhausted fish that slip through the nets. At times we have seen more than 100 whales around the boat – what felt like countless fins in every direction. On these trips we use a small, specially designed dart to collect small pieces

Andy Foote

Two adult male jaws from the Natural History Museum, London, showing differences in tooth wear and tooth count.

Natural history museums are very much like icebergs – only one tenth is above the surface.

of skin from the whales, and extract DNA to test for genetic differences. A third population on the west coast of Scotland appeared to be quite different ecologically again, and was seen hunting other whales and dolphins.

These field studies only provide a snapshot into the lives of these whales. We wanted to find out if these groups are ecologically divergent over the long term. Luckily we have the resources to answer this question, thanks to generations of diligent curators at our national museums.

Natural history museums are very much like icebergs – only one tenth is above the surface. The majority of the collections are housed out of sight in great warehouses reminiscent of the closing scenes of *Raiders of the Lost Ark*, but with the rows of arks replaced by hundreds of skeletons of every conceivable type of creature. Now, using ancient DNA and stable isotope analyses on these valuable collections, a new generation of bio-archaeologists looks set to unlock exciting new findings about how these species lived and evolved.

We started sampling these collections in 2006, and by 2009 had studied close to 100 samples from more than a dozen museums. And we were starting to notice a pattern. Most of the adult-sized specimens had extremely worn teeth, something we had also noted in the field with live killer whales feeding on herring or mackerel. However, a few very large specimens had no tooth wear, and also had fewer teeth in each lower jaw.

At the NERC Life Sciences Mass Spectrometry facility in East Kilbride, we conducted stable isotope analyses on small amounts of tooth and bone drilled from the museum specimens. This analysis looks at the distribution of isotopes – different types of the same chemical elements – to give an indication of the different types of food the animals were eating.

We found that the specimens with tooth wear had quite a varied diet. Some appeared to have foraged mainly on fish, whereas others had a more mammal-based diet. We are not sure, but we suspect the tooth wear could be from sucking up lots of small prey one at a time, wearing the teeth down over many years.

In contrast, the larger whale specimens with no tooth wear showed almost no variation in isotopic ratios, suggesting their diet was highly specialised. The stomach of one individual contained minke whale baleen (the bony filter that sieves small animals from sea water), and field studies are also beginning to suggest this larger type is a specialised minke-whale-hunting form.

Genetic work was conducted on modern samples at the University of Aberdeen and on the museum samples by Tom Gilbert at the Centre for GeoGenetics, University of Copenhagen. Tom had previously sequenced DNA from mammoth hair and 10,000-year-old sub-fossil human poo, so we were confident it wouldn't prove too much of a challenge to extract and sequence the DNA from 100-year-old killer whale samples.

The results showed that the large, specialised whale was genetically different from the more common smaller form – in fact, it shared its most common recent ancestor with the Antarctic ecotype that also specialises in hunting minke whales.

The story isn't over yet: we still have more work ahead of us. A key question is whether the two types of killer whale that occupy UK waters are reproductively isolated, or whether they can still breed with each other. So far we've been working with mitochondrial DNA, which is only inherited from the mother; to find out if different maternal lineages are inter-breeding we'll need to use DNA markers inherited from both the mother and the father. Then we'll be able to see if females are breeding with males outside their own lineage or ecotype.

We are also working on even older sub-fossil specimens dating back more than 10,000 years. This will let us study the ecology of this long-lived species over timescales long enough to show us how these creatures have evolved and adapted to changing environments.

The ever-advancing fields of ancient DNA and stable isotope analysis are providing fresh insights into our valuable museum collections. New DNA sequencing technologies are producing exciting genomic studies of both old and new samples. And they're not just giving us a more objective approach to species classification – they're shedding new light on the ecological processes underlying the emergence of new species.

MORE INFORMATION

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This work was done in collaboration with Jason Newton of the NERC Life Sciences Mass Spectrometry facility, SUERC Institute, East Kilbride; Stuart Piertney of the University of Aberdeen; and Tom Gilbert of the Centre for GeoGenetics, University of Copenhagen. www.northatlantickillerwhales.com

News

Ocean trench cruise finds new fish

A recent research expedition to the south-east Pacific has identified an entirely new species of fish and found a feeding frenzy of cusk-eels, in a place where nothing was thought to live.

An international team of marine biologists made the discoveries in the litte-explored Peru-Chile trench, with a specially-designed unmanned lander which sinks down to the seabed, attracts local animals with fish bait and photographs them with an automated camera.

The photographs lend support to the idea that each ocean trench has its own unique kinds of snailfish that have evolved there in isolation. They show a completely new species of snailfish, as well as a swarm of cusk-eels seven kilometres down, where the researchers didn't expect to find anything.

'We'll be scratching our heads over this for a while,' says team leader Dr Alan Jamieson of the University of Aberdeen's Oceanlab research centre. 'It's absolutely not what we were expecting. These results highlight the significance of the individual trench environment rather than simply depth itself.'

The expedition was the latest leg of the Hadeep project, a collaboration between the Universities of Aberdeen and Tokyo. The expedition ended in September, but you can experience it yourself through Alan Jamieson's blog on *Planet Earth Online*: http://planetearth.nerc.ac.uk/blogs/story.aspx?id=804

Oceanlab, University of Aberdeen

Judy Ledbetter/istockphoto.com

Warmth of the sun?

New research challenges currently held views on the effects of solar radiation on the Earth's temperature. A new study suggests that the effects of this 'radiative forcing' on surface temperature are out of sync with solar activity – so when the sun is at the dimmest point of its 11-year cycle it warms the Earth most, and vice versa.

The re-think comes from a better understanding of how the mixture of light emitted by the sun changes as its intensity shifts.

The research, published in *Nature*, was led by Professor Joanna Haigh from Imperial College London. It used data collected by the Solar Radiation and Climate Experiment (SORCE) between 2004 and 2007, during a declining phase in the solar cycle.

For the first time, the researchers measured solar radiation across the entire spectrum from X-rays to infrared light, which showed that the mix of different wavelengths of light – for example infra-red and ultraviolet – was very different to what had been expected.

The data showed that the intensity of the ultraviolet (UV) light in the sun's rays fell by up to six times more than predicted over that period, while the amount of visible light increased. The researchers say these changes in UV radiation appear to have led to a significant decline in ozone in the stratosphere (below 45km), which they also see in independent measurements of ozone. However, it is mostly the visible radiation which reaches the lower atmosphere and influences climate, so the increase at these wavelengths would have tended to produce a warming.

The scientists point out that there's so far not enough evidence to confirm their theories. But, says Haigh, 'If further studies find the same pattern over a longer period of time, [then] we may have overestimated the Sun's role in warming the planet.'

Future measurements will enable scientists to understand if the reversal of the link between solar intensity and warming on the Earth seen between 2004 and 2007 is normal or an anomaly.

Whales get sunburn too

A recent study has shown that the thinning ozone layer may pose a risk to the health of whales and other mammals, just as it does to humans.

Since the twentieth century ozone depletion has led to more ultraviolet radiation (UVR) reaching the Earth's surface, but until now no one has known what the effects might be on mammals in the wild.

To find out, a research team led by scientists from the Institute of Zoology in London, studied blue, sperm and fin whales in the Gulf of California. The study revealed that whales suffer from the same type of lesions commonly associated with severe sun damage in humans.

And, as in humans, lighter skinned whales are more sensitive to UVR than those with darker skins.

Factors like the amount of time spent at the surface breathing, and the whales' migratory patterns, also affected their susceptibility to sun damage.

But significantly, the researchers found that blue whales suffered increasing numbers of blisters over the three years for which they had data. So it looks like increasing levels of UVR are causing more damage to the whales as time goes on.

Diane Gendron (CICIMAR)

The research is published in the *Proceedings of the Royal Society B*.

With domestic supplies dwindling, gas storage has become a major issue for the UK's energy security. British Geological Survey expertise has been helping develop our underground gas storage capability. David Evans gives us the low-down.

Going underground

Natural gas is the UK's energy source of choice. As the world's third-largest consumer, after the USA and Russia, gas accounts for more than half the country's energy needs.

Since the late 1960s and 1970s, the UK has been able to rely on its huge offshore oil and gas reserves. But production has declined so much that domestic supply can no longer meet periods of peak demand. It's estimated that by 2020 the UK will be importing more than 80 per cent of its gas.

Managing gas supplies is no simple matter because demand varies as much as the weather: on the coldest winter days we use three or four times as much as on an average summer day. Seasonal variation in demand is reflected in daily movements in the prices charged by gas exporters, which are highest in winter. Aside from the economic implications, this puts increasing pressure on the national transmission system, which has to move gas around the country according to seasonal and daily changes in demand. So relying on imports makes us vulnerable.

Countries without domestic oil and gas reserves have been using underground gas storage (UGS) for many years. The first storage sites opened in the USA in 1915, but the UK's oldest purpose-built facility, at Hornsea in East Yorkshire, opened in 1979 and our capacity is currently only around 4 per cent of our consumption.

Market demand for UGS is growing, and the government recognises that it offers the potential for the safe and reliable extra storage that will buffer the UK against demand and supply fluctuations.

Ed Hough/Marcus Dobbs

What are underground gas storage facilities?

In the UK there are three main places where natural gas can be stored underground:

- Depleted oil and gas reservoirs – which once held gas or oil in tiny connected pore spaces between sand grains. Gas is injected back into these pores.
- Large caverns – effectively large, gas-tight underground pressure vessels created in thick beds of halite (rock salt) by dissolving the salt away.
- Aquifers – porous sandstone rocks where the water held naturally in the pore spaces is pushed out and replaced by the injected gas.

How does it work?

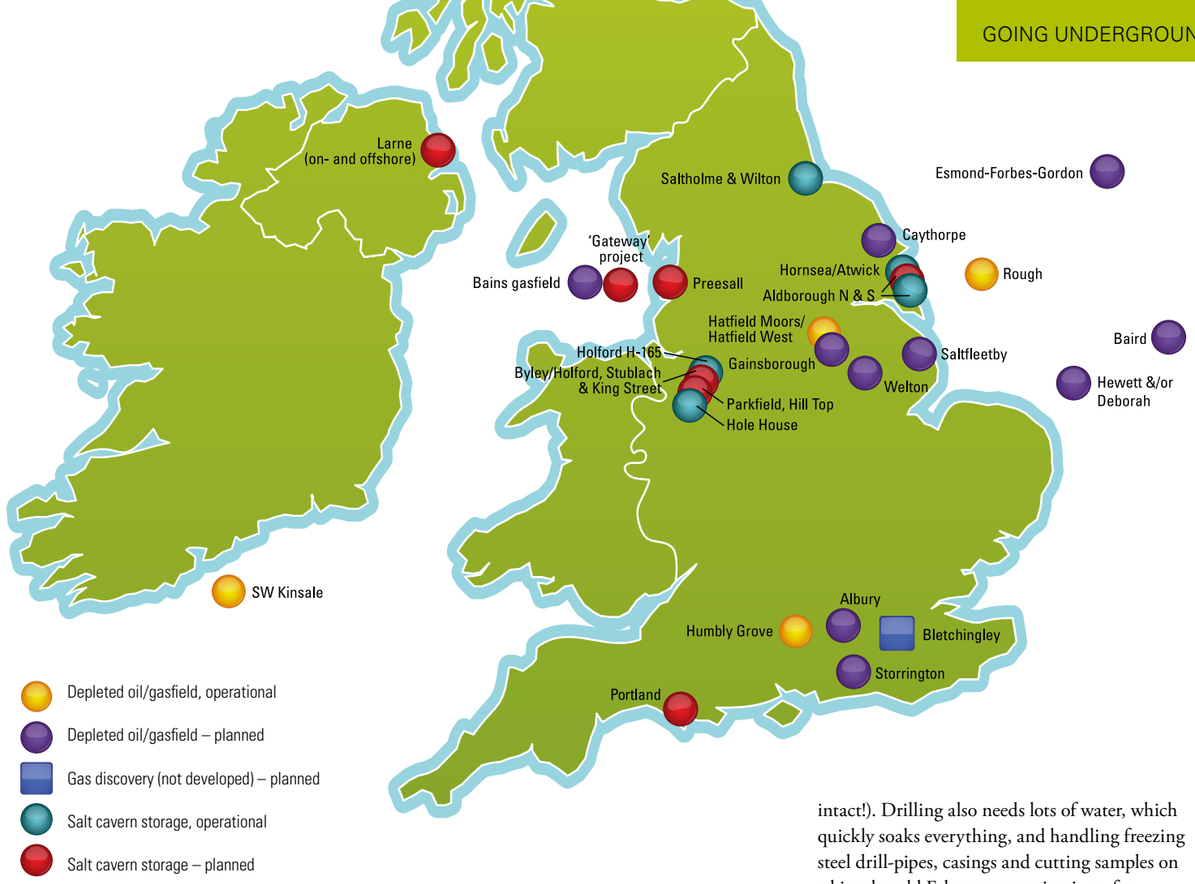
UGS works by injecting gas deep underground, where it's held under pressure in the rocks. The higher the pressure, the more gas can be stored. Storage pressures are limited by rock strength, which normally increases with depth so, in general, deeper formations can store more gas. Deeper storage has the added advantage that the overlying strata will be tightly compacted by the weight of the rocks above, so it's much harder for gas to leak out and make its way to the surface. But this isn't always the case and careful studies are needed for each site.

Different gas storage types together create a hierarchy of supply flexibility. The above-ground tanks we're all familiar with provide small volumes for daily supplies; they empty quickly but can be refilled quickly too. Salt caverns can respond on a daily or weekly basis. Depleted reservoirs and aquifers take longer to fill and empty, and this is generally done during times of lower demand (the summer), to provide monthly or seasonal supply.

Developing UK capacity

Because of their very specific requirements, UGS locations are limited to places with suitable geological features, reservoirs and/or gas-tight rocks. Britain currently has several operational facilities but there is significant potential for more, both on- and offshore. There are currently no plans to develop any aquifer sites.

Planning and commissioning UGS facilities takes a long time in the UK. Safety is paramount in their design, construction and operation, and potential sites have to be investigated in detail to ensure the geological structure is sound and that the rocks are up to the job.



These concerns can be addressed through detailed investigation of potential sites, which means coring and sampling in the field, with *in-situ* tests in boreholes, followed by further tests, analysis and modelling in the lab.

BGS and UGS

We've been working on UGS since 2003, using oil-industry techniques to describe the geology of potential storage sites. Experts in rock mechanics or cavern design then use our data to assess the suitability and operational limits of the site in question.

In the field we use seismic reflection surveys to image the subsurface strata, recording sound waves as they 'bounce' back off the different rock layers deep below ground. This effectively produces a cross-section through the rock layers. Then, to take a more direct look, we drill boreholes and lower a range of geophysical probes and sensors that give us information about the properties of the rocks. Core samples (cylinders of rock) are retrieved during drilling, which are described and logged in detail. Selected samples are then sent to the lab where the rock is tested for strength and gas tightness.

By combining all this information we have produced 3D models of rock-salt beds for developers, which make it easy to relate the geology to surface features like towns or major infrastructure. All of this helps the relevant experts to identify any potential problems which can be investigated further, so that if construction does go ahead it will be safe at the outset and won't encounter problems down the line.

One such project saw myself and colleagues Ed Hough and Marcus Dobbs working on a drilling rig in north-west England in winter – calling for hard hats, steel-toe-capped boots and lots of warm drinks! We had to oversee the drilling and take cutting samples from the borehole every 15 minutes or so. The cuttings are crushed bits of rock produced by the drilling bit, which are flushed to the surface by the drilling fluid in the borehole and caught in a large shaker (sieve). By carefully monitoring these we know when the drill has reached the right place for larger core samples to be taken.

Drilling rigs are dangerous places at the best of times, with lots of large machinery to negotiate and 9m-long steel drilling rods and core barrels being swung around. One slip could lead to the loss of fingers, or worse (it is rare to find a driller with all his teeth and fingers intact!). Drilling also needs lots of water, which quickly soaks everything, and handling freezing steel drill-pipes, casings and cutting samples on a bitterly cold February morning is no fun.

BGS's growing experience of UGS means we sometimes have to swap our flourescent jackets for suits. I have advised county council planning officers on the geological aspects of planning applications, ensuring that the developer has demonstrated a good understanding of the site geology, and our expertise has also been called on in public inquiries.

We have hosted an international conference to share knowledge of, and developments in, UGS across the UK and Europe. In 2008 we produced a report for the Health and Safety Executive (HSE) to develop a risk assessment methodology for land-use planning. And we will continue to provide regulators and potential developers with the tools and means with which to understand the geology of proposed storage sites, to help ensure safety and develop mitigation strategies in the event of any problems.

So, whether it means stamping our feet against the cold or tapping our fingers on a keyboard, BGS will continue to provide and develop geological expertise in this exciting and important field.

MORE INFORMATION

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Meticulous sea-level research at Southampton University's School of Ocean and Earth Science (SOES) suggests that large long-term sea-level rise is coming our way unless we take drastic action soon. Eelco Rohling tells us what this projection is based on.

The rise and rise of the SEA

You don't have to delve far into the climate science literature to spot that predicting sea-level rise is difficult. But it is becoming increasingly apparent that the numbers don't look good.

In its most recent (2007) report, the Intergovernmental Panel on Climate Change (IPCC) projected a rise in sea level of up to 70cm by 2100. That sounds a lot, but this figure is probably too low and the IPCC knows it. The report clearly states that the responses of the world's great ice sheets to warming were not included in the projections, and that such reductions in ice volume will cause significant additional rise.

The total volume of ice on Earth is equivalent to roughly 70m of sea-level rise, but ice decay lags behind global warming. So the IPCC projections serve as baselines to which scientists must add realistic projections of the rate of contribution from melting ice sheets. The problem is that the size of these rates remains poorly understood.

Our project has shown that the last time Earth was as warm as it is predicted to be later this century, sea level rose by 1-2m per century. We also found that, even if CO_2 emissions were stabilised now, similar rates may be expected to continue over many centuries until global mean sea level reaches 15-25m above the present level. This far exceeds most recent predictions – so how did we arrive at these numbers?

Since the 2007 IPCC report, other researchers have estimated total sea-level rise in the next century, using statistical projections based on observations from the last few centuries and coastal geology going back two millennia. This work suggests that sea levels may rise twice as quickly as the IPCC's worst-case prediction, or even faster. Estimates of the potential sea-level rise contributions from the great ice sheets support this possibility. A recent report suggests that the sea-level contribution from Antarctic ice alone could reach up to 1.5m by the end of this century.

These are very big numbers. They mean that significant planning and construction work will be needed to protect our current way of life in the coastal regions, especially when you add in the impacts of tides and storm surges.

But how realistic are they? Predictions are all very well, but is there actually any evidence that Earth has experienced similar rates of sea-level rise in the recent geological past?

To find some answers, our team at SOES produced the first ever continuous record of sea-level change through the last 520,000 years. This period covers five complete ice-age cycles, with global sea-level fluctuations between -130m and +10m, relative to the present-day level. The record we produced with our new method is based on evidence taken every 100–200 years from sediment cores from the Red Sea. It provides real-world data that let us test the reality of sea-level projections for the future, by revealing whether different climate conditions in the past actually resulted in similarly large and fast sea-level fluctuations.

Our new data came from studying changes in conditions in the Red Sea. This land-locked sea receives hardly any rainfall or river inflow from outside, and has some of the highest rates of evaporation in the world. The Red Sea's only natural connection with the open ocean, which prevents it from becoming ever saltier, is through the narrow and shallow (137m deep) Bab-el-Mandab Strait.

Because there's a limit to the amount of water that can be 'squeezed' through such a small passage, the Red Sea's salt content is highly sensitive to changes in sea level in the very shallow strait. And so is the ratio of the stable oxygen isotopes ^{16}O and ^{18}O in the water. The lighter ^{16}O isotope is more likely to evaporate, so when sea level is lower and there is less water moving through the strait the water contains a higher proportion of the heavier ^{18}O isotope. These properties are recorded in the shells of tiny marine creatures found in sediment cores from the Red Sea floor, letting us reconstruct past changes in sea level.

Together with researchers from Tübingen University, Germany, we used this method to look in particular at the last interglacial, 125,000-117,000 years ago. At that time, the Earth was a few degrees warmer than today because of variability in its orbit around the Sun, and sea level reached 6-10m above the present. We found that the rate of sea-level rise, from present levels to these maxima, was on average 1-2m per century.

A corer in action.

> Think of it like standing in front of a freight train – it's travelling slow enough for you to be able to avoid it, but if you stand still you can be sure that it will hit you.

These results provide important context to the proposed high rates of sea-level rise for the future, and they should not be ignored. Even though rates of up to 2m every hundred years seem alien to our (human) experience, they are not at all alien to our planet. In fact, we have found that these kinds of rates are very common in the geological record.

Next, we compared the entire sea-level record with records of past temperature and CO_2 concentrations, from Antarctic ice cores. On the scale of ice-age cycles, the sea-level record closely matches temperature, as one might expect. When the temperature goes up, sea levels rise. When the climate cools down, ice caps expand and sea level drops. We can assume that these observed natural relationships give us a reasonable model for a future with sustained global warming.

The relationships we've seen clearly indicate that, for current CO_2 concentrations, sea level may eventually (over several thousand years) creep up towards almost 25m above the present. It's hard to imagine, but geological studies tell us that around three million years ago, this was reality. At that time, atmospheric CO_2 concentrations were about the same as today (due to differences in the balance of the geological release and removal of CO_2) and sea level stood between 15 and 25m above the present level.

Modern CO_2 changes are dominated by anthropogenic emissions, but the greenhouse-gas properties of CO_2 remain the same. Our results therefore suggest that – given a sufficiently long period of time – even stabilisation at current CO_2 concentrations would lead to a big enough loss of global ice for sea level to rise to similar heights of 15-25m above the present.

How inevitable is this? Think of it like standing in front of a freight train – it's travelling slow enough for you to be able to avoid it, but if you stand still you can be sure that it will hit you.

It now looks very likely that we will see significant (1m or more) sea-level rise during the next century. Already, tide-gauge and satellite observations show that sea level is rising at or above the fastest rate proposed by the IPCC in 2007. For the longer term, stabilising and then reducing CO_2 concentrations within the next century or so will allow us to dodge the freight train. Alternatively, we could close our eyes and ears, stay in the middle of the tracks, and hope for the best.

MORE INFORMATION

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www.soes.soton.ac.uk/staff/ejr/ejrhome.htm

For information on Antarctic ice and sea-level rise: www.scar.org/publications/occasionals/ ACCE_25_Nov_2009.pdf

Winds of change?

Severe weather has been big news in recent years. The cold European winter of 2009-10 was followed by a deadly heatwave in Russia and devastating floods in Pakistan. Unsurprisingly, people want to know why these events happen and whether they are caused by climate change. Tim Woollings responds.

The key feature that links many severe weather events is their persistence. Individual storms can be very damaging of course, but when storm after storm hits the same region the effects are much worse. Similarly, a period of settled weather is warmly received, but as weeks without rainfall mount up, it begins to outstay its welcome. These are examples of long-lived weather regimes and, outside the tropics, these regimes are usually linked in some way to a movement of the jet streams.

The jet streams are literally jets of fast-moving air that are strongest about 10km up in the atmosphere – around the level where airliners fly. They are still felt at the surface, however, and in Europe our prevailing westerly winds are part of the west-to-east flow of air across the Atlantic, called the North Atlantic jet stream. Jet streams steer storm systems, so changes in the jet stream determine which regions are battered by storms and which are starved of rainfall.

Jet streams vary in strength from week to week. One of the most common variations in the North Atlantic jet stream is for the whole jet to shift to the north or the south. These shifts are referred to as the North Atlantic Oscillation (NAO) and they have a particularly strong impact on the weather in Europe. The prevailing westerly winds have a moderating, 'maritime' influence on Europe, keeping us warm in winter (when the Atlantic Ocean is warmer than the land) and cool in summer (when the land is warmer). The bitterly cold winter of 2009-10 was a classic example of a negative NAO event, when the jet stream shifted to the south and Europe lost its maritime influence. It's the persistence of these shifts that has such strong effects: in this case the jet stream stayed south for much of the winter, and Europe remained gripped by cold.

While the North Atlantic jet stream generally points roughly due east, straight across the Atlantic, it often meanders north and south. These meanders are the signature of so-called Rossby waves, which are similar to the familiar waves on the surface of water. However, instead of water moving up and down, Rossby waves consist of large air masses, often thousands of kilometres across, moving north and south. When an air mass moves north it starts to spin clockwise (when viewed from above), forming what's called an anticyclonic weather system – a high-pressure system associated with settled weather. When air moves south it spins anti-clockwise and becomes cyclonic – a low-pressure system which is prone to wet weather.

A Rossby wave can therefore lead to a string of alternating high- and low-pressure systems, with the jet stream snaking around them from west to east.

Like water waves, Rossby waves generally move relative to an observer on the ground, and this movement leads to changes in the weather from week to week. In fact, the Rossby waves themselves always move towards the west, which means they are always swimming 'upstream' against the eastward-flowing jet. If conditions are right and the wave speed matches that of the jet, the wave will remain stationary. Then the high- and low-pressure systems are no longer moving relative to the ground, and a persistent weather regime is born. Summer 2007 was a good example of this: a low-pressure system remained stationary over the UK and led to widespread flooding, while just downstream a high-pressure system brought heatwaves and drought to the Mediterranean and Eastern Europe. The UK had the trough of the wave and Eastern Europe had the peak – see the top right image.

When waves on the ocean surface become too large they overturn and break, resulting in very turbulent motion. When Rossby waves break, the resulting weather situation is known as blocking. In this case the turbulent flow often becomes dominated by an anticyclonic air mass cut off from its origin in the subtropics. This high-pressure system blocks the normal passage of the jet stream, and a regime of dry, settled weather sets in.

When this happens in winter, blocking leads to a bitterly cold spell, as the mild westerly winds are replaced by winds bringing cold continental air from the east. When it happens in summer the result is drought and heatwaves, and blocking contributed to the events seen this summer in Russia. At the same time, downstream of Russia, a Rossby wave trough remained and interacted with the monsoon system to bring flooding to Pakistan.

So, is climate change to blame? The short answer is no, but the longer answer is more complicated. There is a well-known analogy between weather regimes and rolling a dice. Imagine you have a loaded dice that comes up with a six more often than it should, then imagine you roll the dice and it comes up six. Now ask yourself, did you get that six because the dice is loaded or would it have come up anyway? By loading the dice you have changed the statistics of how it behaves over many rolls – if you roll it 1000 times and get a six on 500 of those rolls, you know that's because the dice is loaded but you can't attribute any individual six to that fact.

That's the equivalent of the question about climate change – by adding greenhouse gases to the atmosphere we are effectively loading the dice, so that the statistics of climate are changed. But it does not make sense to ask if any given weather regime occurred because of climate change. Persistent weather regimes such as the examples above are, thankfully, fairly rare, but they are not unprecedented and they might well have happened anyway.

To begin to answer the climate change question properly, we have to look at the numbers of these events over several decades. Of course, we'd rather not wait for several decades to see if the occurrence of certain weather regimes is changing, so we look at hundreds of years of simulated weather data from climate models. Here, however, there is still much uncertainty.

Climate models are starting to show some agreement that the jet streams will shift slightly closer to the poles in response to increases in greenhouse gases, but there is still considerable disagreement between different models. This discrepancy will only be reduced through steady improvement in our understanding and modelling of climate. The future is particularly uncertain for regions like Europe, whose climate is so strongly influenced by the jet stream – because Europe lies at the boundary between maritime and continental climate zones it is particularly sensitive to changes in the winds.

So can we really say nothing about whether events like these will become more common? One thing we can say is that even if the statistics of weather regimes do not change, we may feel the impact of some of them more strongly. In particular, if the background temperature is a few degrees higher than it is now, settled weather regimes in the summer will lead to more intense heatwaves and droughts than they do now.

To stretch the dice analogy a bit further, this is like having a larger bet on the outcome of our throw, so we're hit harder when the dice don't go our way.

MORE INFORMATION
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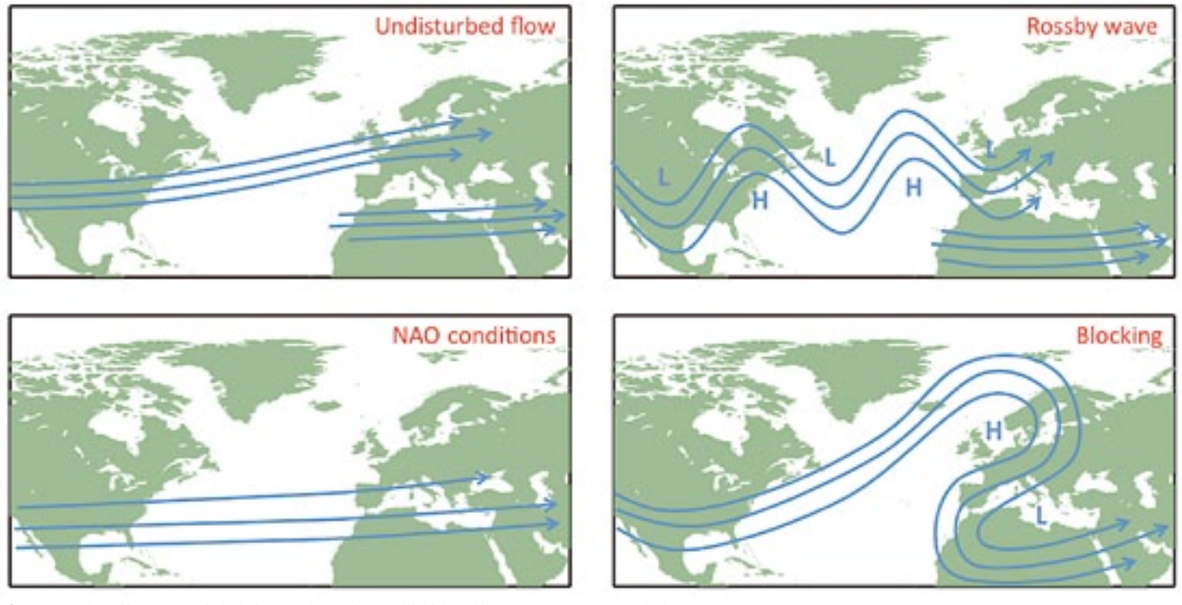

Some examples of jet stream winds during weather regimes, with high and low pressure systems marked.

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All images ©BAS

How biodiverse is a polar archipelago?

It's a simple question. How many species are there around the South Orkney Islands? David Barnes describes how the answer surprised almost everyone.

For half a century, textbooks have told us biodiversity falls as you move from the tropics to the poles. The idea seemed plausible – after all, how many species can you see on ice-covered land, or ice-scoured shore or shallows?

But nobody seemed to have any evidence for it, or even a good estimate of how many species lived in any particular polar area, except within a few single groups of animals. Even at a time when the International Polar Year and the first World Conference on Marine Biodiversity were approaching, we still didn't know something as basic as this.

You may be thinking, so what? But there are several very good reasons to understand polar biodiversity. The poles are among the fastest-warming places on the planet, as well as the most vulnerable to ocean acidification, caused by CO_2 dissolving in seawater. This is where the planet's surface is changing most fundamentally – from white to blue.

Polar life may be the most sensitive anywhere to changes in temperature. Experiments have shown polar organisms are least able to cope with short-term warming, perhaps because they have lived for millions of years in an environment whose temperature varies less than anywhere else on Earth. Because of their sensitivity, these organisms can give us information about how life responded to environmental change in the past and so provide an early-warning system for how it will react to what are expected to be the most drastic changes since humans evolved.

Some of this information, such as changes in growth rate, comes from the skeletons of long-lived species. Other insights come from comparison of subfossil and fossil abundances over time and in current species distributions and genetics.

Polar life is clearly very important. So in 2008 a team from the British Antarctic Survey and Hamburg University set about estimating how much of it there is, as well as assessing how good this estimate was.

An isolated archipelago makes the job easier, as it has a definite boundary – the edge of the continental shelf. Confining ourselves to animals larger than a millimetre made it easier still; now all we needed to do was go through thousands of scientific papers, a century of Antarctic expeditions, tens of museums and several international databases, and then mount an expedition to sample across realms, habitats and animal types.

I had spent the early years of my career as a marine biologist continuously working in this archipelago. My boss had spent much of his working life there, and so had his boss. None of us knew what the answer would be – but it would not be 42. On land, in fresh water and on the shore, we quickly built up a picture from the literature; the animals were small and few.

Rich sea, poor land

With 100 species, the South Orkney Islands are rich in land animals compared to elsewhere in the Antarctic, but at the same time poor compared with similar-sized areas in the subantarctic or Arctic, and very poor compared with lower latitude places. Only very young, isolated islands might come close to having so few land species – even a modest garden would have more. Unlike anywhere else, though, just two of these 100 were known to be non-indigenous aliens. This is one of the few terrestrial communities on the planet that remains near its 'natural' state.

Lakes and streams were similarly impoverished, with just 65 species. But we found records of 43 known from the shore.

1. A variety of brittlestars.
2. Sea spiders have more species than anywhere else in the world and are among the animals that grow far larger than their warm-water relatives.
3. Octopus seemed to be particularly common in the study area and were found in most trawls.
4. Feather stars are very mobile – both adults and larvae eat phytoplankton (marine algae) and as such may track the changing patterns of marine algae.
5. Ice fish have no red blood cells and have glycerol in their blood acting as antifreeze.
6. A basket star expanding its curly, branching arms outwards.

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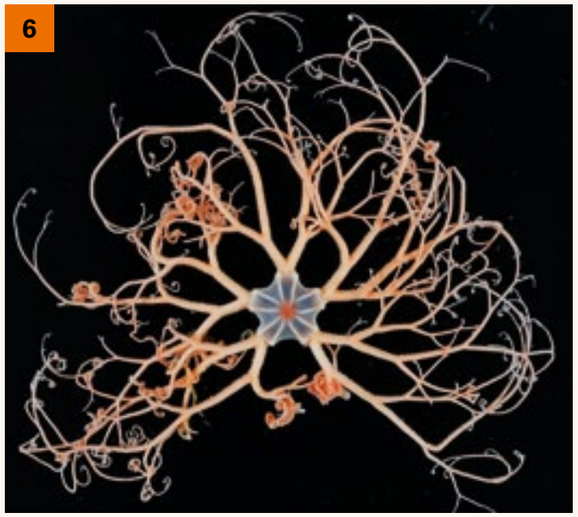

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This makes the intertidal zone – the area between high and low tides – by far the richest known anywhere around Antarctica yet probably more impoverished than any shore north of it – a striking difference. Stepping ashore from a tourist or research ship would reveal none of the striking bands of seaweed and animal zonation found elsewhere. Only in hidden refuges between pebbles and under boulders can life escape the crushing forces of ice scour.

Polar seas are full of life, famous for the abundance of the krill and other tiny crustaceans like copepods that fuel the largest animals ever to live on Earth, along with hundreds of thousands of seals, penguins and fish. Indeed, our search of the literature confirmed that, more than anywhere else, life in the South Orkneys is dominated by sea-dwellers.

However, fewer than 20 per cent of them live in the water; the seas have almost no reptiles (like turtles), almost no cartilaginous fish (like sharks and rays), and few bony fish. As in fresh water, on the land or shore, there were fewer species in the water column than anywhere outside the Southern Ocean.

I recorded 21 classes of animal on a single scuba dive. This would be a challenge even on the Great Barrier Reef.

But, on the seabed the story was completely different. We found 158 species from 19 classes (major body types) in our own samples – rich diversity for a small area. And putting together all the literature we could find, it seemed an impressive 1026 'large' marine species have been recorded.

This was around a fifth of all those estimated for the entire Southern Ocean at the time, but the South Orkney shelf covers just one per cent of this area. It was also more marine species than are known around any small islands anywhere – more than the Galapagos Islands in the Pacific, the Mascarene Islands in the Indian Ocean, or most small tropical islands in the Atlantic.

Even more impressively, these species represented 50 classes – this sea is staggeringly rich in major animal types. I recorded 21 classes on a single scuba dive there. This would be a tough challenge even on the Great Barrier Reef.

So how good is our estimate? In recent years of sampling, each sample increases the total by nearly one per cent. So new records are being added more slowly than in most polar areas, but many species remain undiscovered and new small species will still be cropping up a century from now. This is simply because big animals tend to be found and described more easily and quickly than small ones, and equipment to catch the tiniest creatures only samples areas of about a square metre.

Canary Islands

But the total number is not the most interesting part. Of the 1026, not one species is thought to be alien, which is unique, to my knowledge. Aliens are everywhere in the sea – tens of thousands of species are on the move every day thanks to us, carried in or on packaging, clothing, vehicles and refuse.

Furthermore, most of the rich seafloor biodiversity is not found outside Antarctica – it looks different even at first glance. Giant nemertean worms cruise looking for limpets to swallow; sea spiders wider than an adult handspan suck encrusting animals out of their shells beside a cluster of 80-year-old brachiopods (lampshells). Reefs of bryozoans cling to cliffs beside sponges that divers could sit in, competing for plankton food with crowded meadows of sea cucumbers, worms and brittlestars.

The archipelago is a pivotal place; a big part of the nearby continental shelf has just become the world's first high seas Marine Protected Area. The shallows are among the fastest-changing environments on Earth, rapidly warming and losing sea ice, and yet the deeper shelf bathed in the Weddell Sea gyre – a large circular current – may be among the slowest-changing.

These waters are our climate-change canary for how marine life will respond. Receding sea ice will probably also mean that animals there perform an increasingly vital role for the planet, drawing down more carbon that will ultimately be buried in sediments. As environmental change gathers pace, scientists' eyes are on the many species spanning the fast-changing shallows, the constant depths and everything in between.

MORE INFORMATION

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News

Fossil blob hints at our ancient ancestors

Scientists have identified the fossil of a previously undocumented ancient creature – a primitive relative of the brachiopods that lived around 425 million years ago.

It has features that hint at possible details of the ancient ancestors of all animal life.

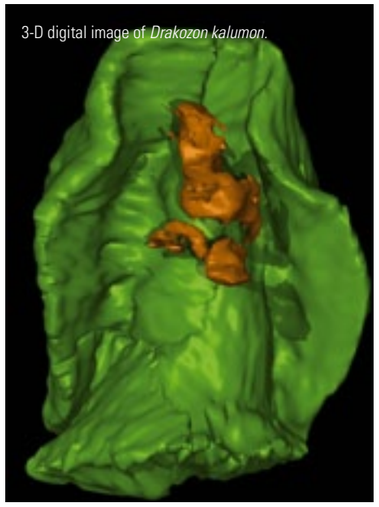
Brachiopods are bivalved sea creatures – they have a two-part hinged shell. But this organism, which the researchers have named *Drakozon kalumon*, had no hard shell.

A team of researchers from the UK and US found the 1.7mm-long fossil attached to the fossil of a shelled brachiopod in a nodule of Herefordshire Lagerstätte rock near the Welsh border. They took microscopically thin sections through the sample and photographed them to construct a digital 3-D image, which enabled them to examine the fossil in detail from all angles.

The researchers describe the creature in *Biology Letters*. It is a lophophorate, which means it fed with a lophophore – a pair of tentacles that surrounded its mouth.

But its most significant feature is a series of ridges and furrows that suggest it had a serial structure, with a series of repeated 'sections' – a caterpillar would be an extreme example. Later brachiopods do not have this segmented structure.

'There are hints in the fossil record and from the study of living animals that their common ancestor built itself in this way,' says Dr Mark Sutton of Imperial College London, lead author of the report. 'New evidence of serial construction in a primitive lophophorate is another hint in that direction.'



3-D digital image of *Drakozon kalumon*.

Bacteria can spread genes in the wild

Scientists have found that a bacterium that's used to modify plants' genes can also change the DNA of life forms in the wild.

Agrobacterium tumefaciens infects plants in the wild through wounds in their outer skin and transfers its own genetic material into them, making them form what are called 'crown galls'.

Scientists already know which bit of the bacterium's DNA gets transferred to the new host; removing this DNA and adding new genetic material from another source is the main way of genetically modifying plants like soya beans or oilseed rape, to increase their resistance to pesticides or their vitamin content, for example.

To transfer DNA to a plant, *Agrobacterium* needs a wound in the plant's skin, as well as a hormone called acetosyringone, which plants make when they're injured. Acetosyringone is supplied artificially in genetic modification, and the bacteria are removed with antibiotics once the job is done.

In this new research, published in the open-access journal *PLoS ONE*, University of Bristol PhD student Claire Knight used lab-grown plant samples to show that enough acetosyringone occurs naturally around a wound on a plant to let the bacterium transfer genes to the common fungal pest *Verticillium albo-atrum*.

Kirsty Foster

In most cases this won't be a problem, as the new genes won't do anything to help the fungus survive. But in particular cases it could be harmful, transferring genes that confer pesticide resistance or some other valuable trait to a harmful pest species.

'This study suggests that the encounter between this bacterium and a fungus on the plant surface may lead to gene flow in a previously overlooked way, potentially leaking GM genes into the natural world,' says Professor Gary Foster of the University of Bristol, one of the study's authors.

'If a plant is still carrying *Agrobacterium* and is planted out, not only other plants but also fungi could receive the new DNA,' says Dr Andy Bailey, a plant pathologist at the University of Bristol who took part in the research. 'So it's important to be absolutely certain all the *Agrobacterium* has been removed.'

Marine animals suggest recent Antarctic shelf collapse

The West Antarctic Ice Sheet (WAIS) may be vulnerable to collapse if temperatures continue to rise. Now a new report suggests that this has already happened, and as recently as 125,000 years ago.

The idea is not new, but the study, published in *Global Change Biology,* reports the first evidence that a trans-Antarctic seaway linking the Weddell Sea to the Ross Sea opened in response to a collapse of the WAIS.

The conclusions are based on observations of bryozoans, a group of unassuming marine creatures that build coral-like structures up to a metre across.

They live attached to the ocean floor and don't travel far when they're larvae. This means that every region of the Southern Ocean has its own distinct collection of bryozoan species.

Dr David Barnes, of the British Antarctic Survey, and geologist Dr Claus-Dieter Hillenbrand, analysed the bryozoans found around much of the Antarctic continental shelf and the deep waters beyond, as part of the Census of Antarctic Marine Life.

Their results were striking: the most similar areas in terms of bryozoan assemblages are the Weddell Sea and the Ross Sea, which are currently separated by the WAIS and the islands buried under this large ice mass. Geography might place them a world apart, but the two seas share 77 per cent of their bryozoan fauna.

'Our data implies the existence of a seaway between the Weddell and the Ross Sea during the recent past,' the researchers write. 'This is only possible without much of the West Antarctic Ice Sheet in the way, and this means global sea level rise up to five metres.'

'Clearly the WAIS is very vulnerable to changes in temperature,' Barnes says. 'It has collapsed in the past, under climate conditions similar to the ones we're observing today.'

The conclusions have important implications for studies on the stability of the ice sheet, but Barnes is confident of his findings. 'This is by far the simplest explanation of our results,' he says.

Morales Morales/Photolibrary.com

The growing pains of blue tits

Childhood isn't easy for blue tits; there's as much conflict lurking beneath the surface in the birds' families as in the most fractious human household. Mark Mainwaring, Megan Dickens and Ian Hartley explain.

When you look inside a bird's nest and see the chicks taking food from their parents, you are looking at a battleground. Parents are in conflict with each other over workloads, and offspring are in conflict with their parents, and with each other, over the distribution of food and other limited resources.

You can see the evolutionary effects of these conflicts for yourself. Perhaps the most obvious are the elaborate begging signals of nestlings, such as yellow gaping mouths and loud calls. Another effect is the size variation that can be seen in many species of birds.

In many songbirds, the last laid egg frequently hatches a day after the core brood. The delayed start means that this last chick is always smaller than its siblings and so ends up as the 'runt'. This phenomenon has been interpreted as being an adaptation by the parents to let them reduce the size of their brood when food is scarce: better to lose one weak chick quickly than the entire brood slowly. The nestlings, however, are not passive in this arrangement. Clearly, being the runt puts an individual at a disadvantage, but can it fight back, and if so, how?

As part of our work to understand the effects of family conflict in birds, we studied blue tits (*Cyanistes caeruleus*) breeding in nestboxes near Lancaster University. Blue tits are an ideal species for this type of work, as their clutches hatch out over a period of two to three days, and so runts are regularly seen in broods.

Most blue tit eggs hatch together to form the core brood, and the later hatching egg(s) produce the marginal brood or runts. We visited nests each day after hatching began and marked individual chicks so that we could follow their development and identify their hatching status as 'core' or 'marginal'. We then closely monitored the growth of their weight, skeleton and feathers by measuring them every other day.

Sibling rivalry

Older chicks reach key growth landmarks, such as acquiring sight or developing leg muscles, sooner than younger chicks, which give them an advantage when begging for food from their parents – they can see the food coming and reach up higher to grab it.

This means marginal chicks are less competitive, and so receive less food than the core chicks, but their growth patterns are very different. When comparing the growth of core and marginal nestlings, we found that at a given age, marginal chicks had longer legs, similar masses but shorter flight feathers, suggesting a trade-off in the growth of various traits.

This was interesting as it suggested that marginal chicks grew their legs faster, to reach higher in the nest and stay in the competition for food; even if they were less competitive than core chicks, at least they were not starving to death. However, the downside of the trade-off was likely to be that their shorter feathers would reduce their ability to fly and manoeuvre at fledging.

There are two possible mechanisms that might be responsible for these differences in growth. They could be an environmental effect brought on by hatching asynchrony, where the competitive environment a chick finds itself in directly influences its growth patterns.

Or they could be due to a maternal effect relating to differences in egg composition – for example, the mother could routinely lay larger eggs later in the laying sequence, or she might supply the last eggs she lays with different hormones or nutrients, influencing the growth of the chicks that emerge.

In order to separate the environmental and maternal effects, we had to experimentally disrupt the order in which eggs were laid and subsequently hatched. We did this by carefully removing the first eggs on the day they were laid and replacing them with clay model eggs that looked identical to real blue tit eggs. Females lay one egg a day and they remain dormant until incubation begins, which is usually when the penultimate egg is laid.

Both images Ian Hartley

Older chicks reach key growth landmarks, such as acquiring sight or developing leg muscles, sooner than younger chicks.

The experimental eggs were safely stored in an artificial nest very close to the natural nest, to ensure they experienced the same conditions as the rest of the clutch before incubation started. We then waited for the mother to finish laying the clutch and begin incubating. A day later, we replaced the model egg with the experimental, real egg. This let us create experimental chicks, which would have naturally hatched first, but actually hatched last because we had adjusted the start of incubation and given the rest of the clutch a day's head start.

If environmental effects were important, then the experimental chicks should have shown growth patterns similar to marginal chicks in natural broods. If maternal effects were the main factor, then the experimental chicks should have shown growth patterns similar to core chicks.

We measured and analysed the growth of the chicks as before, and found that experimental chicks grew legs relatively faster but at the expense of having slower feather growth, which closely matched the growth patterns of naturally marginal or 'runt' chicks.

This suggested that the experimental chicks' growth was determined by the environment in which they found themselves. This lends support to the argument that the environment into which chicks hatch is more important than the resources their mothers put into the eggs they hatch from in explaining the variation in their growth patterns.

So we know these young birds get a raw deal out of life, and we've learnt a lot about how they survive their early days. But it could be that they pay the price later – fledging with shorter wings, for example, means they might not be able to out-manoeuvre aerial predators like sparrowhawks, which prey heavily on fledgling blue tits. Now that we know what causes these differences between runts and their siblings, our next challenge is to discover whether their early success results in more grief later on in life.

MORE INFORMATION

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FURTHER READING

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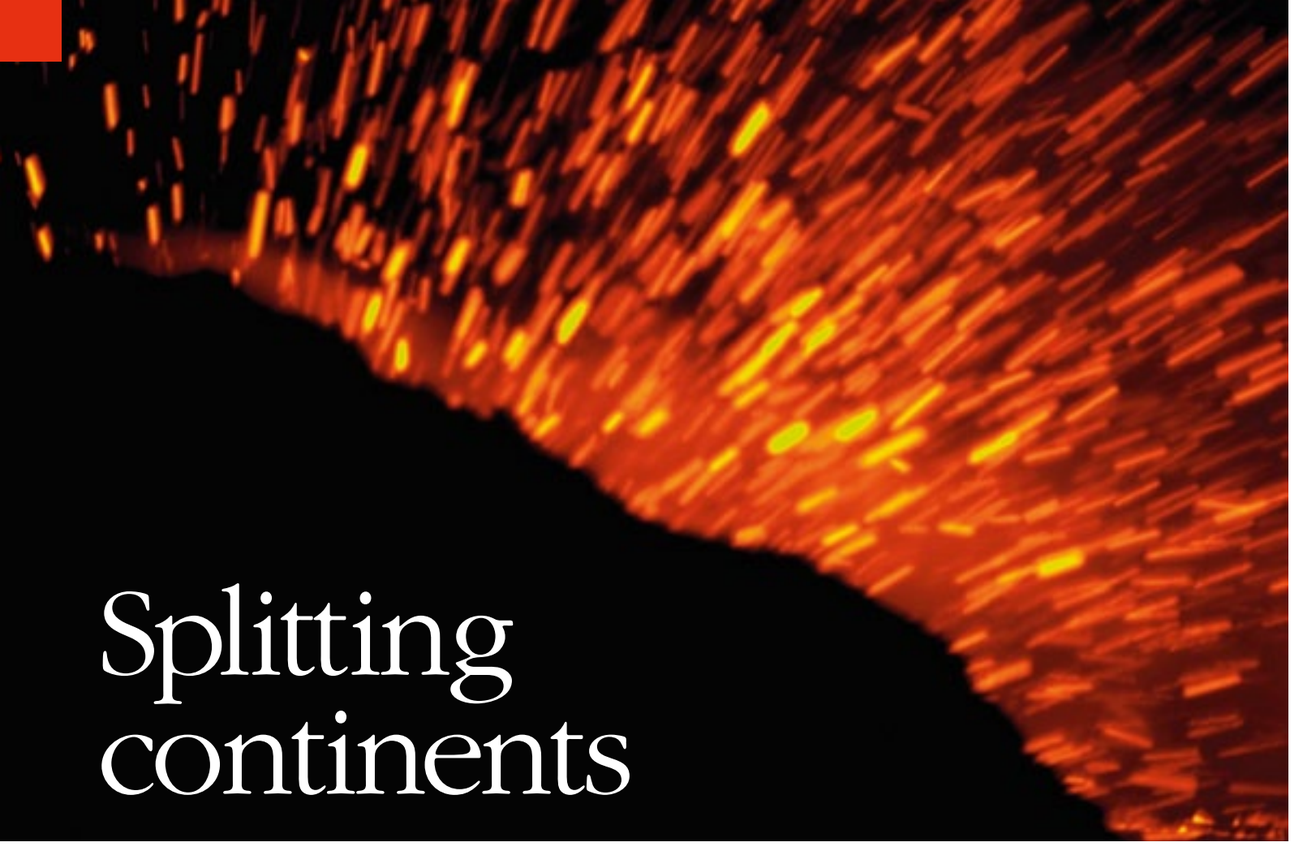

Splitting continents

Why do some pairs of continents trigger lots of volcanoes when they break apart, while others don't? Jenny Collier describes how her team's work is providing answers, suggesting the truth is a lot more complex than traditional theories have assumed.

According to Plate Tectonic Theory, the Earth's outer rigid shell (or lithosphere) consists of a dozen or so 'plates', which float on a viscous mantle like slabs of ice on a pond. These plates move constantly, driven by the release of energy from the Earth's molten interior. This motion has characterised our planet for the past 4.5 billion years, and will probably continue for another 4-5 billion years until, finally, the heat supply runs out. Then the Earth will be geologically dead like the Moon or Mars, and no new oceans or mountain chains will be created.

Because of plate tectonics, in the past the continents have undergone cycles of collision and amalgamation followed by splitting and separation. These major reorganisations of the landmasses have dictated many climatic and evolutionary developments. The last phase of the cycle started around 167 million years ago, when the super-continent Gondwana started to break up. In the time that followed, the various continental blocks separated and positioned themselves to form today's familiar world map.

Continental break-up is a fundamental part of Earth history. We know that when it happens, it can do so either with a bang – a period of excessive volcanism – or with a whimper, with hardly a volcano in sight.

The consensus among scientists before our work was that these very different styles of break-up are controlled by the temperature of the mantle beneath the separating continents. According to this theory, if hot mantle is present, for example due to an underlying plume rising from deeper in the Earth, then a volcanic margin will form. This has been the cornerstone of our understanding for 20 years.

The emphasis on mantle temperature as the main control on what happens when you stretch and break the lithosphere was mostly based on observations made along the borders of the Atlantic Ocean. These areas were the best studied as they are in easy reach for most European and North American research vessels. However, the mantle temperature model was so simple and elegant that it was applied globally, even where there was no direct data to support it.

Stretching the theories

As scientists went out and studied other areas, the idea started to be questioned. Some researchers suggested, for example, that the rate at which the stretching occurred before break-up had been overlooked. If it happened faster, would it lead to more volcanism? We decided to test this in an area that stretched much more quickly than the Atlantic examples, yet was also thought to sit over hot mantle: we went to the Indian Ocean to study the separation of India from the Seychelles.

Continents can break up either with a bang – a period of excessive volcanism – or with a whimper, with hardly a volcano in sight.

This break-up occurred shortly after the extrusion of the Deccan Traps – a vast pile of basaltic rocks that covers about a third of India to a depth of about 2km. We wanted to look for the offshore extension of these volcanic rocks that, according to the prevailing theory, should have formed when the two continents separated.

Our project was ambitious, so we compiled a team of researchers from three institutions – Imperial College, London, the National Oceanography Centre in Southampton, and Leeds University – and arranged for geophysical instruments from four different organisations to be delivered in three 30ft containers. Planning for the cruise in 2002 and 2003 was tense, with the build-up to the Iraq war resulting in several changes to our port and start date. It was a huge relief when we finally set sail with all the equipment on board!

Our goal was to collect the data needed to produce a seismic image from which we could identify any volcanic material that had been erupted as the continents split apart. We needed to determine the seismic velocity – the speed at which a seismic wave travels through rock – below the seabed by letting off bursts of compressed air and recording the signal with seismometers placed on the seabed.

We wanted to record signals that had travelled 20-30km into the Earth, so we assembled one of the loudest airgun arrays ever fired from a NERC vessel and a total of 32 receivers. All this equipment covered the decks of the RRS *Charles Darwin* completely. First we surveyed the Indian side of the divide then sailed across the equator to survey the Seychelles side. One highlight for the novice sailors on board was an ancient maritime initiation to mark their first 'crossing the line' with a colourful ceremony in which the ship's crew played the traditional roles of Neptune and his court.

Back home we started in earnest to process and interpret the data. This work is labour-intensive and takes many months in front of the computer reading off the times of the seismic arrivals. These observations are then used to build a computer model, consisting of blocks with different seismic velocity to explain the observed travel times. Much of this analysis was done by students – in total three PhD and four MSc students have worked on the data so far.

A mysterious lack of volcanoes

Once we'd built a model that satisfactorily matched all the observations, we interpreted it by delineating different regions – for example, areas of continental crust and volcanic rocks added during break-up – based on their seismic velocity. Our results were puzzling – rather than the massive volcanism everyone had predicted, we found very little.

Existing theories simply couldn't explain the near-complete absence of volcanism along the India-Seychelles margins. Was it possible that despite the presence of the Deccan Traps there had been no mantle plume? What about the stretching rate? We set out to test our understanding of how the Earth works using state-of-the-art modelling.

In our computer model we simulate the initial stretching and break-up of a piece of lithosphere and use it to calculate how much volcanism erupts to the surface. At any time we can vary the temperature of the mantle (for example, to simulate the arrival of a hot plume), stop, then restart the stretching and alter the stretching rate. To make sure that the model was working correctly we also compared its predictions to the well-studied case of the North Atlantic.

The results showed that the difference between bang and whimper break-up is not down to anything as simple as 'hot or not'. Instead, the geological history of the region is critical. It is not simply the stretching rate that matters, but rather the relative timings of the phases of extension and arrival of hot material beneath the thinning lithosphere. In the North Atlantic, we found that earlier extension focused the hot upwelling mantle, allowing it to reach shallow depths quickly and leading to melting and volcanism when break-up occurred.

In the Indian Ocean, there was also an earlier episode of extension but it caused more thinning and happened closer in time to the break-up, so it tapped and exhausted the hot mantle. Therefore despite similar hot mantle temperatures below the thinning lithosphere in both cases, in the Atlantic the pre-break-up events enhanced volcanic eruptions, whereas in the Indian Ocean they turned them off.

Our research shows the need for a major review of the traditional hot-mantle volcanic margin hypothesis. We have found that rift history can either suppress or enhance the production of magma and is just as important as mantle temperature in controlling what happens. This underlines how much we still have to learn about how our planet works – and that the only way to do this is to get out there and make new observations.

MORE INFORMATION

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FURTHER READING

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Brave new reptilian world

The collapse of the Earth's first rainforests 305 million years ago caused reptile diversity to explode. Howard Falcon-Lang, Mike Benton and Sarda Sahney explain how 'island theory' may shed light on the evolution of life on land.

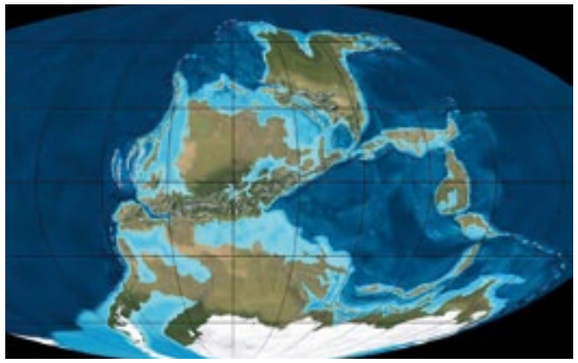
When rainforests collapsed 305 million years ago small gecko-like reptiles experienced a major evolutionary leap forward.

James Robins

Three hundred million years ago, the world was a very different place. All the continents were joined together as a single landmass called Pangaea. The fragment of the Earth's crust that would become Britain lay on the equator and was covered by steamy rainforests.

In this Carboniferous Coal Age – so called because the compacted remains of its dense vegetation formed coal seams – life on land was experiencing its first golden age. Tropical rainforests were alive with giant dragonflies, millipedes, cockroaches and our own closest ancestors – the amphibians and reptiles.

Then, suddenly, something happened. Right across the tropics, the rainforests started to collapse. No one is sure exactly how quickly this happened, but it must have been only a matter of a few thousand years at most. The cause of the collapse is much better understood than the rate it took place at. First, the Earth was gripped by a major ice age. Sea level dropped by a hundred metres and the tropics dried out.



Ron Blakey

During the Carboniferous Period, all the continents were joined together as a single landmass called Pangaea and Britain lay on the equator.

New Mexico Museum of Natural History

A skull of an Early Permian reptile called Sphenacodon from New Mexico. Spectacular fossils like this have helped to track reptile evolution.

Only 'islands' of rainforest survived this initial climate crisis, mostly confined to wet valleys that crisscrossed the tropics. But when a brutal period of global warming reversed this climate trend, the remaining rainforests were finally wiped out.

Over the past year we've been investigating how the abrupt collapse of the Carboniferous tropical rainforests affected populations of amphibians and reptiles. To do this, we constructed a database of the many spectacular sites that have produced fossils from this time period. These include places like the Joggins Fossil Cliffs on Nova Scotia's Bay of Fundy, which is now a UNESCO World Heritage Site.

Sir Charles Lyell, father of geology and mentor to Charles Darwin, discovered some amazing fossil skeletons in these crumbling sea cliffs in 1852. Later, in 1859, his colleague William Dawson discovered the oldest known reptile, *Hylonomus lyelli,* a small, scampering gecko-like animal. Over the century and a half since, hundreds more skeletons have been found at odd intervals. So we know that Joggins, and sites like it, provide reliable information about the kind of animals that lived at a given place and time.

The initial impact of habitat fragmentation is devastating, with most of life dying out from lack of resources.

To find out how amphibians and reptiles responded to rainforest collapse, we studied 22 fossil sites that dated from before and after the event. The results were startling. Before the collapse, the same species existed everywhere across tropical Pangaea, including much of what is now Europe and North America. But afterwards each surviving rainforest 'island' developed its own unique mix of species. We also found that reptiles fared much better than amphibians. While the reptiles diversified into more species, many amphibian species became extinct. Not only that, but reptiles also started to develop more diverse tastes, eating plants and meat when before they had only eaten fish and insects, like their amphibian cousins.

So how can we explain these evolutionary changes? Ironically, a theory that was originally developed for oceanic islands has helped us make sense of this key phase in the evolution of life on land. 'Island theory' is a concept that explains how evolution progresses when populations are restricted into isolated pockets.

It applies equally to oceanic islands separated by seas and to traffic islands separated by motorway carriageways – as well as, of course, to rainforest islands separated by dry savannah, as in our Carboniferous study. In each case, the initial impact of habitat fragmentation is devastating, with most of what lives there dying out from lack of resources. Then, as surviving animals re-establish themselves, they adapt to their restricted environment to take advantage of the new allotment of resources – and diversify.

The new evolutionary pattern we've discovered, as the Carboniferous rainforest collapsed, is totally consistent with 'island theory'. For example, rainforest collapse would have divided populations, and each pocket would have evolved in its own way, resulting in a unique species mix which ecologists call 'endemism'.

And in the drier, more seasonal environments that followed, early amphibians would have found themselves like fishes out of water. These animals must return to ponds to lay eggs, and were probably unable to cope outside the rainforest belt. In contrast, reptiles – whose eggs have a hard shell and can therefore be laid on land – were better adapted to the brave new world, and diversified to take advantage of the new resources available.

As a global community, we are right to be deeply concerned about the combined way that climate change and deforestation are devastating tropical rainforests today. At the current rate of decline, it seems likely that modern rainforests will disappear much more rapidly than their Carboniferous counterparts, resulting in massive loss of biodiversity.

But, while the scale of this catastrophe should not be underestimated, the deep history of our planet gives us some interesting insights into how ecosystems have responded to such abrupt environmental shocks in the past. For the Carboniferous at least, rainforest collapse triggered an evolutionary spurt that laid the foundation for the dinosaurs and everything that followed, including us. Only time will tell whether we will be even half as lucky.

MORE INFORMATION
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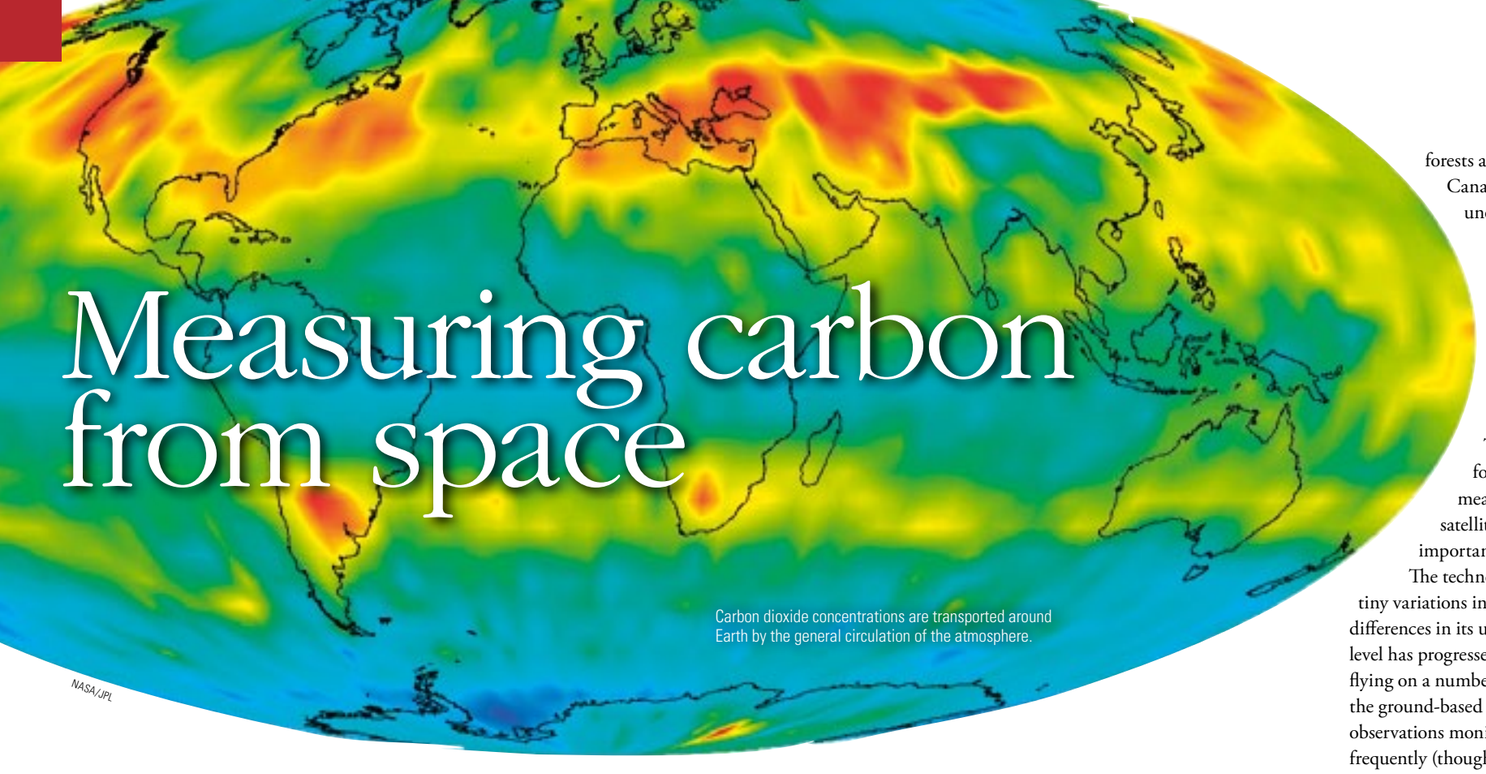
FURTHER READING
Sahney, S, Benton, MJ, and Falcon-Lang, HJ, 2010. Rainforest collapse triggered Pennsylvanian tetrapod diversification in Euramerica. *Geology* 38 (12), 1079-1082, doi: 10.1130/G31182.1

Measuring carbon from space



Carbon dioxide concentrations are transported around Earth by the general circulation of the atmosphere.

NASA/JPL

Understanding changes in the global atmospheric concentration of carbon dioxide (CO_2) is as much a political imperative as a scientific one. But are these demands realistic with the instruments available? Paul Palmer, Hartmut Bösch and Andy Kerr explore the science and politics of measuring CO_2 from space.

For both scientists and policy-makers, one of the biggest challenges is finding out where and how CO_2 is released and absorbed by natural and human-influenced land and ocean processes. Inventories of emissions from each country suggest that approximately two thirds of human-induced greenhouse gas (GHG) emissions arise from fossil-fuel emissions, and one third from agriculture, forestry and other changes in how land is used. This includes around 18 per cent from deforestation.

Based on accurate measurements at ground level, we know that on average less than half of the CO_2 emitted by human activities remains in the atmosphere. The rest is apparently being taken up by the world's oceans, plants and soils. However, there are substantial uncertainties associated with these natural components of the carbon cycle – where is carbon being taken up, how much, and will this situation last? Without understanding these natural fluxes – the difference between the amount emitted and the amount absorbed – we cannot reliably predict the future climate, nor can we establish a robust emission verification scheme. Knowing how much each country is emitting is critical if we are to reduce global GHG emissions.

The main focus of activities under the UN Framework Convention on Climate Change (UNFCCC) has been to manage GHG emissions from the production and use of energy. Emissions from agriculture, forestry and other land uses have traditionally been the poor relation, receiving less attention because of the temporary nature and complexity of the way carbon is stored in terrestrial ecosystems – a process known as 'sequestration'. However, the international policy framework aims to increase the sequestration of CO_2 by encouraging beneficial changes in land use.

Central to these efforts is the need to measure, report and verify carbon emissions and sequestration from land-use projects and policies in different countries, so we can compile national emissions inventories and comply with emission reduction market mechanisms. Currently, emissions are calculated by 'inputs', based on how the land is being used, rather than from measuring levels of emissions in the atmosphere.

The importance of reducing emissions from deforestation has been largely ignored until recently, when the REDD (Reducing Emissions from Degradation and Deforestation) agenda took centre stage in the run-up to the UNFCCC meeting in Cancun in November 2010. The debate focuses on how to value carbon stored in forests, offering financial incentives to slow down deforestation. But this depends on being able to make robust measurements to ensure countries are following the rules.

Recent analysis of satellite observations has reported that annual deforestation rates over the Amazon have dropped repeatedly since a peak in 2004. Since that peak the mean annual reduction is approximately 4000km^2, equating to an annual reduction of 117 million tonnes of CO_2.

Scientists and policy-makers both need to measure CO_2. But how good is our current observing system? The existing network of carbon-cycle measurements, taken with flasks, continuous sensors, tall towers and aircraft flights, provides an excellent measure of how global carbon fluxes vary over time, in different places and from season to season. However, these measurements are mostly taken over North America, Europe and the remote oceans, whereas vital, vulnerable carbon stores like the tropics and the boreal zone – the subpolar forests and tundra that cover much of Canada and Russia – are essentially unobserved.

Shifting our strategy

This means these regions remain poorly understood, and we urgently need dense and frequent observations to improve our understanding of the global carbon cycle. There is a compelling need for a radical shift in our measurement strategy, and satellite observations will be important in making that shift.

The technology needed to measure the tiny variations in atmospheric CO_2 caused by differences in its uptake and release at ground level has progressed rapidly, with sensors already flying on a number of satellites. Compared to the ground-based network, these space-based observations monitor the global atmosphere frequently (though they are less precise).

Current space-borne instruments work by measuring either thermal emission or reflected sunlight from the Earth's surface and atmosphere, in the infrared (IR) parts of the electromagnetic spectrum where atmospheric CO_2 is absorbed. Sensors measuring thermal infrared (IR) emission, such as NASA's AIRS and TES, and the European IASI instruments, are most sensitive to changes in CO_2 in the mid-upper troposphere (the lowest 6-10km of Earth's atmosphere). But they are less sensitive nearer the surface, so they provide limited information about how the land is emitting and absorbing CO_2.

In contrast, sensors measuring reflected sunlight in the shorter IR wavelengths are most sensitive to CO_2 in the lower troposphere. Three sensors of this kind have been launched so far: the European Space Agency (ESA) SCIAMACHY in 2002, Japan's GOSAT in 2009 and NASA OCO 2009, which failed to reach orbit due to a problem with the launch vehicle. SCIAMACHY provided the first tantalising glimpse of the total amount of CO_2 in the troposphere – known as the tropospheric column – and how this varies around the globe, but the instrument was not optimised for CO_2.

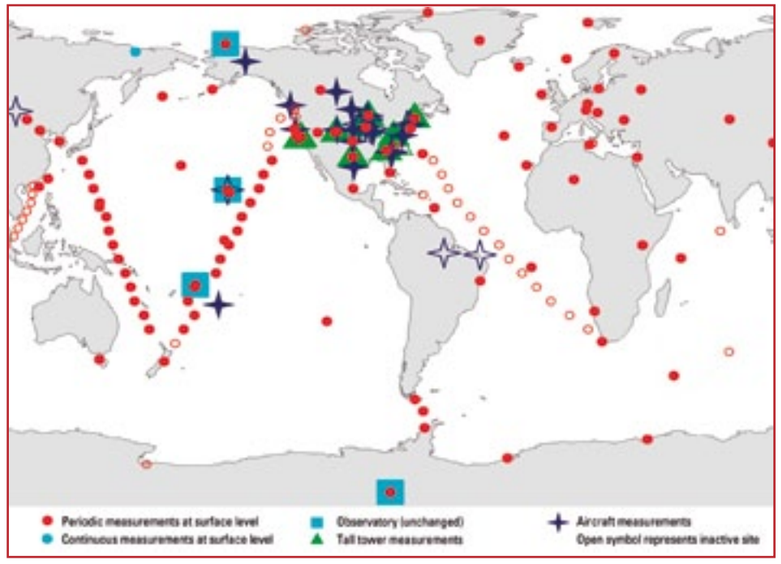
GOSAT was the first successfully-launched sensor dedicated to measure CO_2 in the lower troposphere. Initial data are promising and improvements are still being made. OCO-2, a near exact copy of OCO, is scheduled for launch in 2013, and several European concepts are being considered that will provide the necessary sensitivity to CO_2 near the surface. They will let us estimate carbon release and uptake over areas smaller than a continent and at weekly or monthly timescales.

The ongoing efforts to measure CO_2 accurately in the lower atmosphere reflect the technical challenge of measuring minute changes in CO_2. The variations of interest are of the order of a few parts per million (ppm – roughly equivalent to 1 per cent of the tropospheric column), against a background level of about 385ppm; consequently CO_2 measurements from satellites need to be extremely precise. It is these small variations in CO_2 that we can use, via computer models of the exchange of gases between land and atmosphere, and of how gases move around the atmosphere, to estimate how much CO_2 is being absorbed and emitted across a whole region.

Whilst current and planned instruments are a major step forward for improving models of the carbon cycle, the data they provide do not yet satisfy politicians' needs. International legislation requires us to measure annual CO_2 emissions to within one tonne in order to calculate emission inventories by states, or to calculate emissions from individual emission-reduction projects. Nevertheless, these developments do open the door to independent assessments of the impact on global emissions of regional changes in land use, such as deforestation in Southeast Asia, central Africa and South America.

To address concurrently the science and policy questions that require knowledge of carbon fluxes on a wide range of temporal and spatial scales, and with limited financial resources, we must strive both for improved ground-based networks and for satellite systems with denser and more frequent sampling over the regions we know least about.

A space-borne instrument that orbited only above the tropics, for instance, would provide unprecedented coverage of tropical land ecosystems, and would contribute significantly to verifying emissions from human activities as part of international efforts such as REDD. Such a mission would also complement the global survey orbits adopted by many other satellite instruments, and also the ground-based measurement networks which are mostly outside the tropics. Such efforts need to be integrated with existing surface and aircraft measurements of trace gases and land-surface properties. Watch this space.



The current network of carbon dioxide measurements available from the US National Oceanic and Atmospheric Administration.

MORE INFORMATION
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The future's bright... if you have the resources

The global population is growing incredibly quickly, and the UN estimates it could reach nine billion by 2030. This will put huge pressures on the environment and use up natural resources ever more quickly. Kathryn Goodenough and Daren Gooddy argue that the geosciences are essential to making sure the world's population can support itself while minimising environmental damage.

We rely on natural resources from the ground – aggregates for roads and buildings; oil and coal for transport and energy; rare metals for new technologies like electric vehicles and solar panels; and water, the basis of life on Earth. But what will we need in the future? And how will our needs change in response to developments in politics, technology and social and economic growth? How can we make sure our natural resources are used sustainably? To try to answer some of these questions, and understand the priorities for the geosciences in the future, BGS has put together a Science Futures Team.

The team developed a set of four possible, contrasting future scenarios, based on two important variables: how fast the Earth system changes and whether nations are cooperating or competing. The scenarios are based on our current knowledge of the most important issues likely to affect people's lives over the next 20 to 30 years. To illustrate them, let's look at some graduate scientists of the future and see how their lives might look under each scenario.

The four scenarios were developed by considering two contrasting factors – the rate of change in the Earth system and the degree of cooperation between countries.

Global village

Significant international agreements on climate change were finally signed following the droughts and pan-European heatwave of 2012, with richer countries recognising that they must work with developing nations. For Emma, graduating in Environmental Science and Economics in 2030, it's an exciting time. She can expect to work in a truly global industry, perhaps studying the effects on biodiversity of the new renewable energy power stations now spread across the world, or joining one of the green finance companies that trade globally in carbon credits and water stocks rather than money.

Travel is no problem; massive increases in duty on oil and gas after incidents like the 2010 Gulf of Mexico oil spill led to rapid development of hybrid and electric engines for cars, and much more efficient jet engines for planes. Oil is now largely the domain of the aviation industry, with almost all other transport powered by electricity from a network of power stations harnessing renewable energy sources, nuclear and coal with carbon capture. Some people complain about the pylons and power lines that now march alongside new roads across every country in the world, but in Emma's view, progress is necessary. The only thing she misses is meat – in the global push to feed the growing population, meat has become ever more expensive, as more and more land is turned over to growing genetically-modified food crops alongside biofuels.

All hands to the pumps

Climate change accelerated rapidly after 2010, with floods in Pakistan, droughts that devastated China's food production, and heatwaves across the Americas triggering a push for global emissions agreements. But despite the G20's efforts to cooperate, it seemed there was no way to slow environmental change. Attention turned to ways to adapt to a rapidly changing world.

For Hannah, a new graduate in Demographic and Technical Engineering, there are many opportunities. Across the UK, new infrastructure projects include the massive pipeline that brings water from the Scottish Highlands to south-eastern England, and building New Letchworth, a semi-underground city on the South Downs that will shelter hundreds of thousands of people who have lost their homes to flooding. Further afield, the Global Key Resources Programme is an international effort to identify new sources of critical raw materials, such as gallium for the arrays of solar panels spreading across the ever-widening Sahara Desert.

Sailing by

The slow rate of progress seen in Copenhagen in 2009 continued, with no global agreement on environmental change ever being reached. Disparate national and regional initiatives took the place of global ideas. In the UK, policy-makers chose to ignore the effects of climate change beyond their borders, instead planning for the UK environment as an isolated unit, balancing the need for natural resources with the requirement to protect the wealth of habitats and biodiversity. By the time Daniel graduates in Modern Landscapes and Geography in 2030, cheap travel is a thing of the past, and most British people work and holiday in the British Isles.

Imported oil and gas have become very expensive, so public transport is again many people's main method of travel. British coal and renewable energy keep the country running, and new techniques for deep mining have advanced rapidly. Although National Parks and other key countryside areas are fiercely protected, much of the land between is taken up by mines, quarries and factories, or by huge farms that now grow much of Britain's food. Daniel aims to work in one of the large government bodies that run much of the country's infrastructure, managing resources for UK PLC.

Raising the drawbridge

The world has changed a great deal. An international climate change agreement was never achieved, and developing countries' emissions kept growing. The effects were rapidly seen, with droughts and desertification advancing across southern Europe, Australia and Africa, while flooding and extreme weather affected northern Europe, North America and southern Asia. China developed a policy of preserving its own natural resources – and buying up those of poorer countries – and other nations followed. Eventually, the European Union splintered, with richer countries no longer able to support poorer ones.

By the time Andy graduates in Georesources in 2030, Britain is beleaguered, trying to fight off flooding and sea-level rises while dealing with summertime water shortages. Nearly all natural resources must come from within the UK, and some more abundant commodities have to be defended fiercely. Large swathes of the country have been industrialised; in the south the priorities are huge water-storage tanks, industrial-scale agriculture and new inland housing for those threatened by rising seas. Elsewhere, open-cast coal pits and giant quarries compete with enormous wind farms. Despite all this, Britain still depends on hugely expensive imported oil and gas. Andy would love to do research on Icelandic volcanoes, but he knows that he is most likely to get a job with one of the companies prospecting for oil, gas and other raw materials in ever more difficult and dangerous parts of the UK's continental shelf.

Where next?

The BGS Science Futures Team is using these scenarios to try to understand what the priorities might be for geoscience research in 20 years' time. The results will help us start thinking now about the questions that will be most important in future.

We need to prioritise our skills to ensure that as a nation we are equipped for the challenges ahead. This will probably include higher levels of numeracy and better computer modelling, as well as improving our ability to measure and monitor the environment.

Some topics prove important in all the scenarios – these will probably be vital whatever happens. For example, in any foreseeable future Britain will need to use its domestic mineral and energy resources, such as coal. This has big implications for geoscientists. We won't just need geologists to help us mine efficiently; we will also need people with expertise in capturing carbon dioxide emissions underground, or using other methods to reduce coal's environmental impact.

How can we ensure we have enough water? Understanding how water moves through the landscape is essential to help choose the best ways to protect it. If we build new nuclear plants to generate clean electricity, how will we store the radioactive waste they produce safely and permanently in underground repositories? Geoscientists are already working on the problem, and this research will only become more important.

Of course, these scenarios are extreme – the real 2030 will probably lie somewhere in between. We would be very interested to hear what *Planet Earth* readers think of any of the scenarios, or which they see as most likely!

MORE INFORMATION

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The BGS Science Futures Team comprises Jon Chambers, Daren Gooddy, Kathryn Goodenough, John Laxton, Jon Naden, Simon Price, Barry Rawlins, Helen Reeves and Dave Schofield. You can give feedback on which scenario you think is most likely on the BGS Science Futures web page: www.bgs.ac.uk/sciencefutures

Web news

Doors open on data

The Environmental Information Data Centre at the Centre for Ecology & Hydrology has just launched the CEH Information Gateway, a new web portal which provides direct access to information about our environment: https://gateway.ceh.ac.uk

The Gateway allows users to search and download a variety of environmental datasets including species distributions, river flows, land cover, soils and water chemistry – and more will be added over the next few months.

Having this new portal means anyone can open, view and overlay maps of the datasets. Researchers will find it particularly valuable for bringing together information from different disciplines to address integrated science questions. It has a really good built-in help function too, which will help you get started and answer any frequently asked questions – there's more information here: www.ceh.ac.uk/CEHInformationGateway.html

weatherathome

Global climate is changing but it's uncertain what this means for regional and local weather. The Met Office and www.climateprediction.net have launched weatherathome, so anyone with a computer and internet access can help find answers.

The models used for simulating global climate change still can't deal with many relatively small-scale features, such as weather fronts associated with storms and intense rainfall. And since extreme weather events are rare, many model-years of simulation are needed to gather reliable statistics.

So the new experiment uses a regional climate model which provides information on weather events in much finer detail than global climate models usually do. Results from different regions will be used directly by professional scientists specialising in the climates of those regions.
To find out how you can take part, go to http://climateprediction.net/weatherathome

To download copies of these and other publications, go to our website at www.nerc.ac.uk/publications or email: requests@nerc.ac.uk for further information.

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