Met Office

Collaboration and inspiration
Best way forward

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The big picture

Barometer

Issue 29 www.metoffice.gov.uk Met Office magazine

Steve Noyes, our new Operations and Services Director, returns to the Met Office ready to face new challenges with a fresh perspective.

Observations and insight

In many ways, the Met Office is very familiar as I worked here for 28 years before leaving seven years ago to work as the Executive Director of Brussels-based EUMETNET, which organises co-operative programmes between its 31 members (European national meteorological services) and also represents its members with the European Commission and other European bodies.

Early in my career I was a forecaster and between 2000 and 2007 I held several different positions on the Met Office Board and Executive, looking after for Business, Technology, Operations and Customer Service, as well as directing the Met Office's relocation from Bracknell to Exeter. After leaving, I also chaired a cross-agency committee as part of the Pitt Review which eventually led to the formation of the Flood Forecasting Centre.

It is great to be back and, although the Met Office is familiar ground, I return a different person, having learnt a lot so I now bring a new perspective to the role. My first impressions of the Met Office after seven years are very positive; especially how is has continued to develop and grow and to see significant and beneficial impact it is having in the UK and around the world.

During my time with EUMETNET I gained valuable experience and insights into the European meteorological community. It was one of the best jobs in European meteorology – a unique role and a privilege. I visited 45 countries in seven years, getting to know many different weather services, how they work, the challenges they face, how they overcome problems and make the most of opportunities. I worked with them to identify common opportunities for collaboration to improve their efficiency, their infrastructure or their capability to deliver services to their customers. The Met Office plays a leading role in several EUMETNET projects such as the Single European Sky (SES) initiative and E-AMDAR (EUMETNET Aircraft Meteorological Data Relay), which works with airlines to gather observations from commercial flights over Europe and around the world.

The Met Office has a clear vision of increased collaboration, working with partner organisations around the world, including Europe. You can read more about our international relationships on page 7 with an interview with Bruce Truscott, Head of International Relations. I return to the Met Office with an improved understanding of how the European meteorological community works and I intend to feed my insights into the Met Office in order to help it integrate further with our peers across Europe.

Now is the right time to strengthen the Met Office's cooperation with our European counterparts; more than ever before, we need to work together in a number of strategically important areas, for example to improve the efficiency and effectiveness of our common infrastructure and in meeting the increasing demand for integrated pan-European services, for example for aviation.

The Met Office is a big collaborator and, I believe, a force for good throughout the world. Much of our work is international, for example our partnership with China (page 9) and our research on how climate impacts food security (see page 6). Similarly, the Joint Operational Meteorological and Oceanographic Centre (JOMOC) produces and distributes environmental information for national and NATO military customers on operations worldwide.

In re-joining the Met Office I am responsible for our Observations, Forecasting and Service Delivery and International teams. I'm really excited to be back and I'm ready to apply my experience gained in Europe and learn more as the Met Office continues and grows its international collaborations. I would like to see the Met Office working actively with the international meteorological community on projects ranging from infrastructure, innovation, services, science or IT, and I'm especially keen to explore the possibilities of collaborating in an operational environment.

***Barometer* is also available online at www.metoffice.gov.uk/barometer**

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Barometer is a controlled circulation magazine distributed free of charge to decision-makers in government, science and commerce, for whom weather and climate information has an impact.

Product information is correct at the time of publication but may be subject to change.

The *Barometer* back catalogue is available online at www.metoffice.gov.uk where readers can also complete a subscription form.

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Record breaking

A striking number of temperature and rainfall records have been broken in recent years.

Met Office research suggests that recent decades have seen an unusually high number of UK records. The analysis looked at the number of records within each decade in the UK national statistics compiled by the Met Office's National Climate Information Centre. Records were counted and weighted according to their importance, depending on duration and size of the area covered.

The UK's climate shows a large variability but the analysis reveals some interesting patterns. For instance, since 2000, there have been 10 times as many hot records as cold records. The increase in hot records and decrease in cold records in recent decades is consistent with the long-term climate change signal. When 2014 is included, the eight warmest years in the UK since 1910 have all occurred since 2002.

However, since 2000 there have also been almost

10 times as many wet records as dry records. Interestingly, there have been more wet records since 2010 than any other decade – even though it is only a five year period. Prominent wet records in this period included winter 2013/2014 and April, June and year 2012. The large number of recent wet records may be indicative of trends in rainfall patterns and is consistent with predicted increases in heavy rainfall due to climate change (read more on page 15).

In contrast with temperature and rainfall there are no clear trends in sunshine records. The reasons for the records are an ongoing area of research.

Developing science and innovation

The Met Office is a Delivery Partner for the Newton Fund – part of the UK Government's development assistance aiming to develop science and innovation partnerships that promote the economic development and welfare of developing countries.

The Met Office is delivering the Newton Fund through the Climate Science for Service Partnership (CSSP) Programme. In our role as Delivery Partner, we are awarding funding to UK partner organisations through open competition and single tender where appropriate.

The programme has two main elements: the Climate Science for Service Partnership China and the Weather & Climate Science for Service Partnership South Africa, with the potential for more projects in the future.

CSSP China is delivering peer-reviewed scientific papers, has awarded 22 contracts and held workshops with our partners at the China Meteorological Administration & the Institute of Atmospheric Physics at the Chinese Academy of Sciences.

WCSSP South Africa is also well underway, with ongoing meetings to refine work objectives with our partners, the South African Weather Service.

➔ Find out more about CSSP China on page 9.

Express yourself

There was a great response to our Customer Attitude Survey which gave Met Office customers the opportunity to tell us if we are meeting their needs.

The Customer Attitude Survey found out how customers rate the service they receive from the Met Office and which elements are most important to them and their business.

We spoke to 196 contacts across 126 of our customer and partner organisations. Overall the research found positive perceptions of the Met Office. Four in five respondents agreed we are recognised as the best weather and climate service. There was also an improvement in the willingness of customers to recommend the Met Office to others.

The research also enabled us to identify some key priorities for improvements to our service. For example, in addition to our ongoing work to improve accuracy and capability, proactive behaviour to meet the needs of customers and aftercare for both contract set-up and resolving problems will both be focus areas. We will also continue to conduct regular surveys to check how we are doing.

➔ If you have any questions or ideas on how we can help you more please do not hesitate to let us know.

The best way forward

Rob Varley, Met Office Chief Executive, describes how working at the forefront of weather and climate science doesn't mean working in isolation.

Just like the weather, our work is on a global scale. It is clear that the world faces some tough challenges as the changing climate adds to the pressures on our fragile planet and increases the risk of extreme and dangerous weather.

These unprecedented environmental risks are intensified by increasing population, urbanisation and our reliance on interconnected, but environmentally vulnerable, technologies – escalating the demand for accurate meteorological information. There is now growing recognition that the reality of climate change requires solutions that help us to adapt to the changing environment and mitigate its impacts, with a particular focus around the world on disaster risk reduction.

No individual, organisation or nation can address these challenges alone – we need to bring together skills and expertise from a wide range of disciplines and perspectives. So at the Met Office we are working with a widening network of partners both in the UK and around the world in collaboration and knowledge sharing.

Collaboration

We are building multi-disciplinary partnerships with a goal of providing more contextualised, more relevant and more useful services. For example, our recently opened Space Weather Operations Centre at Exeter is a partnership with a range of expert collaborators. These include US National Oceanic and Atmospheric Administration, British Geological Survey, British Antarctic Survey, Finnish Met Institute, UK Space Agency, South African Space Agency, Airbus and several universities, building together the knowledge and capability to forecast space weather for the UK. This work crosses scientific and sectoral boundaries to deliver the kind of innovative service that our modern, interconnected world depends on.

Another example of collaborative working on an international scale is our work with the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). Typhoon Haiyan, which affected the Philippines in 2013, was one of the strongest ever recorded. Over 6,000 people died when winds reached 195 mph and a storm surge topped 6 m. This was despite the fact that global weather forecast models identified the likely track of the developing tropical cyclone as it developed into a typhoon over a week beforehand.

Our collaboration has helped PAGASA improved its warnings and deliver a more consistent communication of dangerous weather conditions to the Philippine Government and population, ultimately helping to save lives.

Inspiration

These are exciting times. To help people stay safe, well and prosperous, we rely on world-leading science from leading institutions in the UK and abroad. Building strong and productive partnerships is enabling us to address the very real challenges we face, as well as making the most of the opportunities offered by our developing scientific and technical expertise, bringing rich, varied and real benefits. Through such partnerships we multiply the benefits, and inspire others to join us in this global endeavour. By sharing expertise we can achieve far more than we ever will working in isolation, so maximising the benefits meteorology can bring.

Hot on the trot

2014 was the warmest year in our UK record dating back to 1910, knocking 2006 from the top spot. Similarly, 2014 was one of the warmest years on record globally and the global mean temperature for 2015 is expected to be above the long-term average.

In the UK, all months in 2014 except August were warmer than average, and 2014 was the warmest year on record for the UK. It was also wetter than average for many locations, particularly south-east England and eastern Scotland.

Towards the end of 2014, the unsettled and mild theme of October continued through most of November, with only short periods of drier weather. Low pressure was often over or to the west of the UK for the first half of the month bringing rain and strong winds at times. However, with these winds frequently from a southerly direction, the month again had well above average temperatures.

For much of December the weather was from the west, giving milder, wetter spells, particularly in the north and west, interspersed by drier brighter days. The moist, mild Atlantic air gave some high temperatures but there were colder spells too from 3rd to 14th and more from 27th to 30th. Although it was unsettled for much of the time, rainfall totals were mostly below average in the south and east and in these areas there was plenty of winter sunshine. On Boxing Day there were some snowfalls at lower elevations in Wales in northern England, followed by a notable spell toward the New Year which brought clear skies, hard frosts and the lowest UK temperatures of the calendar year.

With the New Year, January brought snow and ice in places accompanied by strong winds. The Met Office issued various severe weather warnings for different parts of the UK, advising people to stay up-to-date with the latest picture of what to expect.

After a mild spell from 5 to 14 January, the end of the month brought "thundersnow", icy roads and travel disruption, before turning colder. Freezing temperatures continue into February after a dry

A hot topic

Globally, 2014 was one of the warmest years on record. The global mean temperature forecast for 2015 – including the range of uncertainties – suggests the coming year is very likely to be among the warmest in a record dating back to 1850.

2014 was one of the warmest years since 1850. Average air temperature over the land and sea surface was 0.56 °C (±0.1C*) above the long-term average, tied with 2010 as the joint warmest year on record. The uncertainty ranges mean it's not possible to definitively say which of several recent years was the warmest.

The global mean temperature for 2015 is expected to be between 0.52 °C and 0.76 °C above the long-term (1961 to 1990) average of 14 °C, with a central estimate of 0.64 °C.

Using the 1981-2010 long-term average of 14.3 °C, the range is between 0.22 °C and 0.46 °C, with a central estimate of 0.34 °C. Taking into account the range of uncertainty in the forecast, it is very likely that 2015 will be one of the warmest years in a series dating back to 1850.

The outlook for 2015 is warmer than our forecast for 2014, which had a range of 0.43 °C to 0.71 °C with a central estimate of 0.57 °C (using the 1961 to 1990 long-term average).

The potential increase in global mean temperature in 2015 is based on the ongoing warmth of the tropical Pacific Ocean, weak El Niño conditions, the warmth of the Arctic and the ongoing increase in greenhouse gas concentrations. These factors are similar to those that contributed to 2014 being one of the warmest on record.

(*0.1°C is the 95% uncertainty range.)

2014 WAS THE **WARMEST YEAR** ON RECORD **FOR THE UK**

2014 WAS ALSO ONE OF THE WARMEST YEARS **GLOBALLY**

2015 IS EXPECTED TO BE ANOTHER **WARM ONE GLOBALLY**

Food security climate impacts: The big picture

The Met Office Hadley Centre's fast expanding climate security team is in demand – making connections between the latest climate change science and outcomes for the way people will live in the future, right across the globe.

As the evidence surrounding climate change grows stronger, so does interest in its implications from both governmental and private sector organisations. They're increasingly looking for help to understand what it means for the way countries will be governed and businesses managed. This is where the climate security team really comes into its own.

"Our aim is to go beyond the direct impacts of climate change – for example on rainfall, crop yield and water availability," explains team founder and principal consultant, Kirsty Lewis. "We look at the future effect on issues such as food production, conflict and migration. We can then help policymakers and businesses see what the world might look like from a human dynamics angle 30 years from now and beyond."

Guiding governments

Kirsty's team is already advising the UK government. Working with the Department for International Development and the Foreign Office, the team is helping countries become more resilient in the face of climate change. With climate recognised by the government as a security threat, the team is also exploring scenarios that illustrate the impacts of climate change on the 40% of food we import.

For the Ministry of Defence, the work involves looking at climate impacts from a national security and military tasking angle – as well as the way defence equipment might perform. It's also helping global bodies such as the World Food Programme focus on the long-term implications of climate change and its future ability to respond to food insecurity. In the commercial arena, climate security specialists are advising international food businesses on the outlook for valuable commodities such as coffee and cocoa.

Telling it how it is

Whoever the client, Kirsty Lewis is well aware of the importance of providing objective information rather than advocating any particular course of action. So the Met Office Hadley Centre's recently published 'Human dynamics of climate change' poster typifies this approach. It's an ambitious, groundbreaking study that analyses and integrates the Centre's own latest data modelled for the IPPC's AR5 report, along with the work of other leading climate science institutions.

"The project came about when the Foreign Office became interested in overlaying the multiple impacts of climate change on global vulnerability 'hotspots'," says Kirsty. "This led us to create a useful tool for diplomats when negotiating on carbon emissions – helping countries to understand the effects of climate change mitigation, but not telling them what to do."

The human dynamics poster took four to five months to complete. For the first time, it brings together the effects of climate change in a 'business as usual' greenhouse gas scenario ('RCP 8.5' that shows impacts if no action is taken) in the context of human dynamics using the 'middle of the road' population scenario 'SSP2'.

More thought for food

With the initiative proving a big success since its July 2014 launch – supported by a comprehensive set of slides enabling speakers to tailor presentations for local relevance – Kirsty Lewis and her team will be expanding their work in food security in the future. Asking questions about the link between events such as 2010's Russian drought, higher grain prices and unrest in grain-importing Middle Eastern countries, or the ability of irrigated agriculture to insulate regions from erratic rainfall, are just some of the key topics on their agenda.

Above all, the team will continue to draw on multi-disciplinary expertise to shed light on some of the biggest challenges facing global communities as climate change impacts lives – and lifestyle.

Human dynamics of climate change: A global human perspective

The Met Office Hadley Centre's human dynamics of climate change poster is a thorough synthesis of the latest climate change data. It means the science is as relevant and up-to-date as it can be as it charts differences between now and the end of the 21st century.

A central global map shows present day human dynamics – setting the context for population density, water-stressed areas and information on four key world crops: wheat, maze, soya beans and rice. Other features include fish catch volumes, glaciers, tropical cyclone exposure, infrastructure and a 'fragile state index' that assesses a country's ability to deal with climate impacts.

Regional case studies summarise likely impacts, with six maps covering eight impacts including water runoff, water demand, average crop yields, drought, hottest temperature of the year, inland and coastal flooding, plus sea-surface temperature change and population growth. Red icons show increase in climate stress; green icons the decrease.

The Sub Sahara Africa narrative is just one example of the way the initiative brings climate change and human dynamics vividly to life. With so many fragile states, a huge increase in water-stressed population and little external trade to benefit other areas through imports, climate impacts are almost all negative.

Whatever the context for using this detailed and compelling resource, it's a powerful tool for driving the climate change conversation – worldwide.

➔ **Find out more at www.metoffice.gov.uk/climate-guide/climate-change/impacts/human-dynamics**

Reaching out to the world

Strong international links have long been important for **Bruce Truscott** – recently appointed Head of International Relations at the Met Office.

When it comes to the subject of relationships with weather-related organisations around the world, Bruce is emphatic. "Our business and the meteorological community simply could not operate without effective collaboration with other national meteorological services and international bodies," he says. "It underpins just about all that we do."

Taking observation to new levels

Building on a keen interest in meteorology that was first inspired by a passion for sailing, Bruce's distinguished Met Office career has included some influential international observations roles. He spent five years setting up the deep ocean buoy network that collects weather information from remote North Atlantic locations – leading to a collaborative project with Meteo-France. Later, he was project leader on another groundbreaking observation initiative –the implementation of the AMDAR (Aircraft Meteorological Data Relay) system across Europe to gather weather data from onboard commercial aircraft, working with other national meteorological offices under the EUMETNET framework.

"I loved developing the software and working on our weather buoys deployed in depths of more than 2,000 m of ocean," says Bruce. "It was a nice mix of science and engineering that left a robust and very successful system in place. But it was the AMDAR aircraft data project, which I originally set up with British Airways, which gave me my first real taste of international collaboration."

Bruce went on to hone his international credentials as the Operations Manager for the European Composite Observing System (EUCOS) – formally joining the International Relations team in 2002 to carry out this role. Keen to broaden his engagement in international collaboration, he took on responsibility for managing UK interests at EUMETSAT – Europe's organisation that develops and operates weather satellites – and working by then as Deputy Head for Observations, he was delighted to be elected chairman of EUMETNET's Science and Technology Group in 2012. This gained him vital additional grounding before his appointment as department head in June 2014.

In it for the long term

Today, Bruce retains responsibility for the Met Office's satellite policy interests, as well as managing relationships with

a wealth of international organisations. These include EUMETNET, EUMETSAT, the World Meteorological Organization (WMO) plus the 34-member European Centre for Medium-Range Weather Forecasts (ECMWF).

"My job – and that of my colleagues – requires a really good understanding of our activities and policies. And our main focus is making sure both the Met Office and UK engages strongly internationally," says Bruce.

One of the biggest recent successes for the International Relations team has been collaborating on the EUMETSAT EPS-SG Programme a (new system of low earth orbiting satellites). This should secure the future provision of an essential component of Europe's future weather data gathering infrastructure and will be operational into the 2040s. Following formal setup of the programme from mid-2016, the project will see the first satellites head skywards in the early 2020s. Another example of International Relations' work outside Europe is its relationship with the WMO.

"There we've performed a key role in helping to further strengthen the efficiency and effectiveness of the organisation – leading some of the working groups and providing chairmanship of the Audit Committee," adds Bruce. "The result is that this work has led to the National Audit Organisation (NAO) recognising WMO as demonstrating the best audit practices within the UN Organisations."

By fully engaging in a global forum, his team makes sure the UK's national interests are best served.

Navigating complexity

Alongside success, there's naturally no shortage of challenges. However, the EU and European Space Agency continue to collaborate on satellites and services around climate change, air quality, marine environments and associated environmental science. And the more players that are interested, the more complex relationship building becomes.

Bruce adds, "National weather services have a long and very successful history of working closely together but at the same time are all different – so as we work together to find a common way forward we will consider a range of views on how best to achieve this."

Looking ahead, Bruce sees collaboration and trusting partnerships with others as becoming ever more important – as states grapple with the challenges of climate change and global weather systems that know no border. He is in no doubt that the meteorological community, working with others, has a great deal more to offer given its proven ability to pull through world leading science into enormously valuable environmental services, delivered through operationally robust infrastructures.

He is also sure that his team has an important role to play: "As we now think about how the International Relations team will evolve into the future to support and lead our international work, it is clear that it will continue to have a great deal to offer," adds Bruce, "combining our in-depth knowledge of the international landscape and ability to identify and understand collective interests."

"My job requires a really good understanding of our activities and policies. And our main focus is making sure both the Met Office and UK engages strongly internationally."

Future proofing

The Climate Science for Service Partnership China (CSSP China) is a scientific research programme – led in the UK by the Met Office – that aims to develop the climate services needed to navigate the challenges of a changing climate.

From floods and droughts to rising seas, humanity faces some serious climate-related challenges which vary on timescales from seasons to decades. While they potentially affect everyone around the world, certain regions are more vulnerable than others. One such region is East Asia, where rapid economic development and a growing population mean the impact of extreme weather events could be particularly severe.

To help the region protect itself against climate risks, the Met Office has joined forces with Chinese academic organisations, including the China Meteorological Administration and the Institute of Atmospheric Physics at the Chinese Academy of Sciences. Working closely together, we have drawn on combined expertise and experience to develop a shared research programme that addresses some of the challenges that may lie ahead.

Professor Stephen Belcher, Head of the Met Office Hadley Centre, has played a vital role in getting the partnership off the ground.

"It's one of the Met Office Hadley Centre's largest – and I would say most exciting – collaborations. Not only will the partnership develop cutting edge climate science, but it will then apply this expertise to help develop climate services that support climate-resilient growth and development," Stephen describes.

Leading the way

The Met Office is a global leader in climate science, thanks not only to cutting edge technology, but also to dedicated scientists and a network of partners across the globe. It's this position that, as Stephen explains, enables the organisation to, "reach out to other parts of the world and form the partnerships needed to strengthen our understanding, and ability to address, the challenges and opportunities presented by a changing climate."

CSSP China is supported by the Department for Business, Innovation and Skills (BIS) through the Newton Fund – a recently launched fund to enable the UK to promote the economic development and social welfare of partner countries.

As a 'delivery partner' of the Newton Fund, the Met Office uses its support from BIS to work with climate



scientists across the UK. In doing so the partnership draws on the 'Best of British' to promote excellence in research and innovation, and critically gets science out of the seminar room and into services that improve people's lives, safeguard their homes and livelihoods, and supports a global effort to tackle our changing climate.

Delivering internationally excellent research

Research projects for CSSP China fall into five different work packages. The first focuses on measuring the climate of East Asia. A large part of this means drawing together China's enormous observational records, including information from ships' logs going back over 100 years. It will then be a case of recording data and measurements in a uniform way, so they can be used to create a time sequence that shows how the climate has changed over the years.

The second work package takes a global perspective to look at China's climate and discover what impact global oceanic and atmospheric patterns have on the region's weather and climate variability.

The third focuses on the East Asian climate and high impact weather. Projects in this work package explore the extent to which high-resolution modelling systems could predict East Asian monsoon rainfall patterns months in advance.

The fourth work package looks, more generally, at climate projections. For instance, Professor Belcher says there's a possible opportunity to nurture something similar to the UK Climate Projections in China, working closely with their scientists. "The Chinese don't have such a unified system... so one of my ambitions is to see if there's an appetite for them to develop a set of national climate scenarios."

These work packages pave the way for the fifth work package, which will draw on the expertise and information developed in the other research strands to develop pilot climate services, based on meeting user needs. These climate services will translate world-leading science into useful services that help governments, communities, businesses and society make decisions resilient to the challenges of a changing climate and make the most of the opportunities it presents. The assessment of user needs in this work package will also influence the research across the CSSP.

The climate services could include tools for the renewable energy sector to help assess supply and demand on seasonal timescales for operations, and longer-term under a changing climate, both in terms of managing risks from a changing climate and exploiting any predictability for energy-relevant metrics. China is a major producer and consumer of staple crops, and other services could address global and local issues for food security.

"Not only will the partnership develop cutting edge climate science, but it will then apply this expertise to help develop climate services that support climate-resilient growth and development."

China has a rapidly growing urban population and a growing number of megacities. Services could help urban decision-makers and communities prepare for risks from flooding and storm damage.

Building a strong, sustainable partnership

One of the partnership's challenges will be realising the value of scientific expertise spread across the globe. As well as coordinating around 20 different CSSP China projects across the UK, the Met Office Hadley Centre has held several workshops in China to coordinate research on both sides of the world. There's also a visiting scholars' exchange programme in place – Chinese scientists have come over to the Met Office Hadley Centre, and Met Office scientists will also work in China for extended periods.

Thinking ahead

CSSP China is expected to run for at least five years, but Professor Belcher hopes the partnership with scientific organisations in China will run far beyond that. "We are building a strong, mutually beneficial, partnership that I'm sure will last beyond the end of CSSP China," he says. "China has an enormous range of scientific talent, and breadth of experience in tackling the challenges of climate change. Through CSSP China we are building a collaborative framework that will be the foundation for future work together. By drawing on our combined expertise, CSSP China and whatever follows, I am confident that we can provide the information and support needed to tackle a changing climate."

Support on all fronts

Think of any major global weather-related crisis event from the past year. The chances are, the Joint Operational Meteorological and Oceanographic Centre (JOMOC) was working hard behind the scenes – and even on the front line – distributing information to relevant parties.

Jointly manned by the Met Office and the Royal Navy, JOMOC serves as the main centre for producing and distributing worldwide environment information for both the UK's armed forces and NATO customers, to support strategic planning, overseas operations and exercises. It may be based four floors deep underground within the Northwood Command Centre, part of the Permanent Joint Headquarters (PJHQ) in Northwood, but its reach is global.

Its activities range from supplying routine forecasting and analysis for ongoing operations, to assessing long-term climatology and its impacts on defence operations. It also supports the Mobile Meteorological Unit (MMU) – a sponsored reserve unit of the RAF whose members undergo both military and meteorological training and are deployed on operations around the world.

A glance at JOMOC's recent activities reveals the sheer breadth of its scope. In 2014 alone, it advised the UK aid effort in response to the Ebola crisis in Sierra Leone called Operation GRITROCK, supplied forecasts in the search for both the missing British yacht Cheeki Rafiki and flight MH370. It supported Operation SHADER in aiding refugees in northern Iraq followed by the subsequent Intelligence, Surveillance and Reconnaissance (ISR) activities and kinetic strikes in the area. It also supports Operation TORAL, the ongoing Resolute Support Mission in Afghanistan by supporting the MMU forecaster on the ground in Kabul as well as many planned exercises across the globe.

It also advised the defence community on tropical storms and other extreme weather events throughout the year. In the case of Typhoon Hagupit, JOMOC worked with the Met Office's Global Guidance Unit (GGU), issuing defence-specific severe weather assessments that helped the UK Government both to support the Philippines' own meteorological service and make its own decisions on whether UK aid would be needed.

Almost everyone at JOMOC has clocked up significant experience working with the army, RAF and Royal Navy, and many have worked as part of the MMU in the field. This depth of experience makes a difference: "It helps in understanding the kind of operational stresses involved and how to communicate with our customers," explains Nick Roe, Senior Operational Meteorologist and Flight Lieutenant in the Royal Air Force Regiment at JOMOC.

Moving with the times

Much has changed since JOMOC was first established in 2008. Back then, its main focus was on wind, weather and waves and how these affect the tactical battle space. Today, it's a different story. As technology has advanced with developments in ISR and satellite communications technologies, planning at both the strategic and operational levels of command have taken centre stage. This, in turn, has created a greater

"As technology develops, the weather becomes a more limiting factor. A guy on the ground isn't too bothered about the rain, whereas an aircraft would be – especially if it's trying to look at the ground."

need for accurate information about environmental conditions and their impacts on military assets

Nick explains, "As technology develops, the weather becomes a more limiting factor. A guy on the ground isn't too bothered about the rain, whereas an aircraft would be – especially if it's trying to look at the ground."

Here's where JOMOC can step in, supporting routine ISR activities by delivering satellite forecasts that determine when such an aircraft will be able to see the earth below.

But it's not just technological advances in the defence sector that has effected a step change in how JOMOC works and what it delivers. Improvements in the Met Office's own models have led to more accurate forecasts. This, in turn, has changed the way the defence community operates. "A few years back, organisations such as PJHQ did not always plan using our forecasts," explains Adam Thornhill, Contingent Land/Air Senior Operational Meteorologist at JOMOC. "This has since changed, mainly as a result of procedures put in place after Typhoon Haiyan, and my role which is embedded in the defence community, they now have increased trust in our capabilities and put operational plans in place based on our forecasts."

The deployment of RAF Sentinel – a battlefield and ground surveillance aircraft – is a case in point. In the past, its crews would put poor performance of its radar down to faulty equipment, not realising that the real culprit was the environment. Today, the RAF uses JOMOC's forecasts to plan and position RAF Sentinel in a way that reduces the affect of the environment on the radar and optimises the return signal.

Serving the defence community

Operations evolve and change – and so do the needs of JOMOC's customers. Besides providing routine products, JOMOC's contingency arm is always on call to respond to new requirements from customers anywhere in the world, particularly from front line stations such as air bases or ships at sea. How this information is delivered is up to the customer. So an established base with a secure internet connection will have the capacity to receive PowerPoint files and images. But sometimes it's as simple as a quick phone call or even text message sent to an operative standing at the top of a hill with a satellite mobile phone.

This level of flexibility is critical. As operations become increasingly complex with joint and coalition forces working together, access to timely intelligence and tailored advice about the environment has never been more important. The last year was a busy one for JOMOC – and looking at the global political and security situation this year, or the next, is unlikely to be any different.

Understanding lightning

From large-scale sporting events to North Sea helicopter operations, lightning is a major hazard that's difficult to forecast. But thanks to the Met Office's state-of-the-art prediction models, it's now possible to pinpoint where it will strike. And for developing countries around the world, that's helping to save lives.

Power cuts. Travel chaos. Even danger to lives. Lightning can have a huge impact on the UK, but it is notoriously difficult to predict. While in the past it's been possible to identify prime conditions for thunderstorms to form – areas of atmospheric instability – anticipating where lightning might actually strike had been a huge challenge. In fact, estimations could typically span hundreds of miles.

But now – with developments to the numerical weather prediction (NWP) model – the Met Office can produce much narrower, and therefore far more practical, forecasts. Using a complex set of mathematical equations, the model analyses real-world weather data and predicts atmospheric instability, enabling forecasters to isolate specific areas where lightning will occur.

"Previous predictions could involve an area typically the size of Wales, but today location accuracy could be down to as little as 30 to 50 miles," explains the Met Office's Dr Jonathan Wilkinson, who specialises in cloud microphysics modelling.

Having an accurate, localised picture of potential strikes means that both public organisations and private businesses – from the emergency services to aviation and rail industries – can put plans in place to swiftly deal with the effects of lightning – keeping the country moving, and safe.

London 2012: a global stage

When it came to putting the model into practice for the first time, a prestigious opportunity presented itself. On 27 July 2012, around 80,000 spectators gathered in London for the Olympic Games opening ceremony. It involved a Red Arrows flypast, a towering copper cauldron and a surprise stunt involving a helicopter, a parachute and the Queen – all of which would have been at risk if lightning were to strike.

On the day of the ceremony, Met Office forecasters contacted Jonathan's team, having spotted lightning on the other side of the English Channel. Coupled with the light rain that had fallen near the stadium that afternoon, this suggested potential weather

"Narrowing down where thunderstorms will occur is really going to impact on people – it's going to save lives."

hazards could disrupt festivities. Fortunately, thanks to the NWP model, the team was able to quickly and confidently confirm that lightning was unlikely to occur over London that evening.

Taking flight

The research has also proved critical to helicopter operations. North Sea helicopter pilots face a very particular challenge known as 'helicopter-triggered lightning' – strikes that happen due to the presence of the aircraft, despite there being no observed lightning activity in the area.

The Met Office has been working closely with pilots to calculate the conditions likely to create thunderstorms, and created a tool that gives access to weather data via a web browser. This enables pilots to establish the probability of strikes along a particular route and the degree of accuracy it provides means they can amend flight paths to avoid risk, rather than having to abandon outings entirely. With hundreds of costly helicopter movements across the North Sea every day, the service has proved invaluable.

Going global

Benefits are being felt internationally, too, such as in Manila in the Philippines. As one of world's most densely populated cities, it is particularly vulnerable to intense rain and thunderstorms – and the devastating flooding that can be a direct result. Meanwhile, on the other side of the globe in a much less built-up area, research has been of great benefit to fishermen on Lake Victoria – a notoriously challenging environment, where squalls have frequently proved fatal.

In remote regions, access to communications can be limited and people often rely on mobile phones for weather updates. So while forecasting thunderstorms is vital, it's only part of the picture – and getting warnings to the right people at the right time is also critical. That's why the Met Office works closely with international weather authorities, either providing data or helping them generate their own forecasts. Armed with this information, regional forecasters can then send out storm alerts locally, providing warnings that could ultimately save lives.

The lightning of the future

Jonathan's team is now turning its attentions to future global climates; a hot topic, as recent research suggests climate change could bring about increased lightning activity. Met Office scientists have been examining Convective Available Potential Energy (CAPE) and investigating the potential for more lightning in warmer weather. But the next step is to establish exactly where strikes might occur.

"Rather than just saying 'we think there will be more lightning in warmer climates', we want to know specifically whether this will happen across the whole of the UK, or the South East corner where we expect it to get warmest," explains Dr Wilkinson. "Then we want to understand the precise effects on a global scale."

What is lightning?

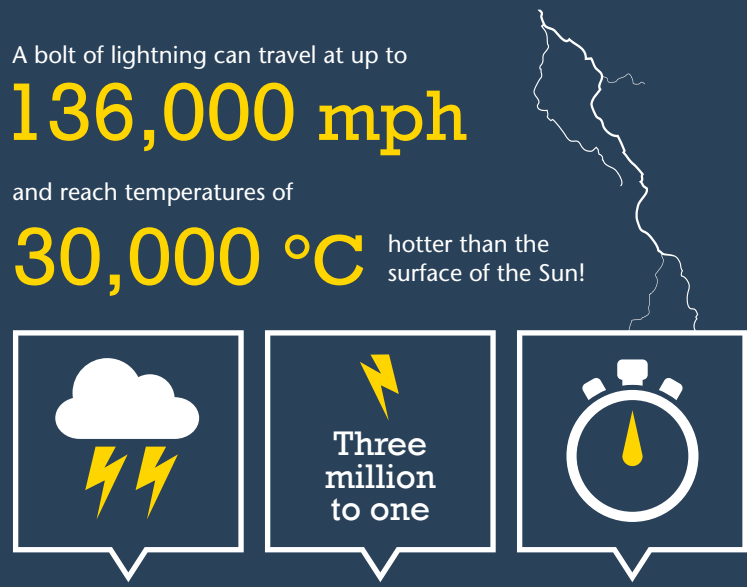
Lightning is a large electrical spark caused by electrons moving from one place to another. Electrons cannot be seen, but when they are moving extremely fast, the air around them glows, causing the lightning flash. The actual streak of lightning is the path the electrons follow when they move.

A bolt of lightning can travel at up to

136,000 mph

and reach temperatures of

30,000 °C hotter than the surface of the Sun!



Sprites, Blue Jets and Elves are all types of lightning which occur high in the sky, often travelling upwards from the top of a thundercloud.

Being hit by lightning can be deadly — but the chances of that happening to you are extremely small – about three million to one.

There are about 16 million lightning storms around the world every year, with about 100 lightning flashes happening every second.

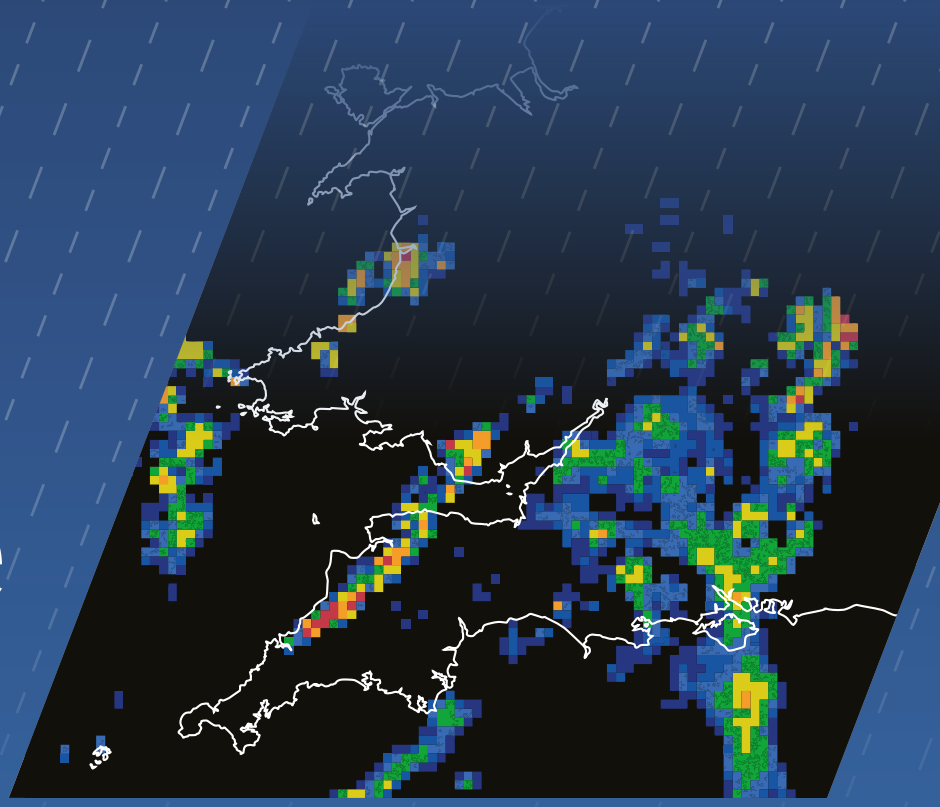
What causes lightning?

The answer lies in the clouds. Lightning naturally occurs in areas of atmospheric instability – when warm air collects beneath areas of colder air. This causes deep cumulonimbus clouds to form, in which ice and hail accumulate. When they collide, hail develops a negative charge, while ice remains positive. In the right set of circumstances, this energy is discharged towards the Earth in what we know as a bolt of lightning.

But man can also trigger lightning. As a helicopter flies and the rotary blades spin, they produce a strong charge. When they land, this is usually released into the earth.

But if, when flying, they meet an area of thundercloud with its own electrical charge, a static discharge happens – which can actually bring about a lightning strike.

Batten down the hatches



Recent research from the Met Office Hadley Centre predicts British summers are likely to have more heavy downpours as a result of climate change. Elizabeth Kendon, Senior Climate Scientist at Met Office Hadley Centre, explains the findings of the recent study.

Our study shows the first evidence that summer downpours in the UK could become heavier with climate change. We used a very high-resolution model more typically used for weather forecasting to study changes in hourly rainfall. Unlike current climate models, it has a fine resolution and is able to represent hourly rainfall, enabling us to make future projections with some confidence.

We found that summers are likely to become drier overall by 2100, in a warming climate. But our results suggest that when it does rain, it will be heavier in short outbreaks. In particular, intense rainfall with the potential to cause serious flash flooding could become a more common occurrence.

The study provides a much more complete picture of how UK rainfall may change in the future. Climate models generally work at coarse resolutions, using grids of around 12 km square or larger. These have been able to accurately simulate winter rainfall, which generally comes from sustained, long-lasting periods of rain from large-scale weather systems. These models point toward wetter winters, with the potential for greater daily rainfall in the future.

But summer weather is harder to predict using such coarse models. It is changes on an hourly basis that are important, as rainfall tends to come in short but intense bursts during the summer – as seen during the Boscastle flooding of 2004 and "Toon Flood" in Newcastle in 2012. So far, climate models have lacked the resolution to accurately simulate the smaller-scale convective storms (intense showers formed by rising air) which cause this type of rain. To deal with this issue, our study uses the most high-resolution model ever used before in long climate simulations to examine rainfall change, based on a 1.5 km square grid (the same as the Met Office weather forecast model for the UK), leading to much higher accuracy.

We ran this model to simulate two 13-year periods; one based on the current climate and one based on the climate at the end of the century under a high-emissions scenario. The simulations were so computationally intensive that it took the Met Office's supercomputer – one of the world's most powerful – about nine months to run the simulations, and even then we could only run the model for the southern half of the UK, about as far north as Manchester.

The simulation showed increased hourly rainfall intensity during winter, consistent with the simulations for the future provided by coarser resolution models and previous studies looking at changes on daily timescales. However the finely grained model also revealed that short-duration rain will become more intense during summer, something that the coarser model was unable to simulate.

This finding is of major importance due to the potential for flooding: a threshold of 30 mm per hour is used by the Met Office and Environment Agency Flood Forecasting Centre as guidance to indicate likely flash flooding. Our results suggest this may be exceeded more often (up to five times) and over a wide area in the future.

Our findings are only the results of one climate model so we need to wait for other similarly detailed simulations to see whether the results support these findings. However, an increase in summer storms in a warmer, moister environment is consistent with theoretical expectations, and with the limited observational studies we have of hourly rainfall.

This work is part of the joint Met Office and NERC-funded CONVEX project. The next steps are to see if the results are consistent with observations and predictions of hourly rainfall from climate models in other parts of the world, to be undertaken by the European Research Council-funded INTENSE project jointly run by Newcastle University academics in collaboration with the Met Office and other international scientists.

Science profile

The Met Office employs professionals and experts who are constantly expanding the boundaries of weather and climate prediction. Here we meet one of them...

Dr Lizzie Kendon

Dr Lizzie Kendon specialises in studying how heavy rainfall may change in the future. This includes changes in short intense downpours, caused by convective storms which can lead to severe flash flooding. Recently, she led a landmark study into the impact of climate change on this very specific type of weather – and how it might affect us in the future.

Lizzie's interest in meteorology grew out of a passion for mountaineering, where good weather and accurate forecasting are vital for the safety of any excursion. But it was concerns over climate change that drew her to focus on how weather extremes may change in future, as part of the Met Office's Understanding Climate Change group.

"Extreme rainfall has considerable impacts on society through flooding and drought – so it is crucially important to study how convective storms may change in the future due to climate change," explains Lizzie.

Stormy skies

Convective storms are triggered when heat from the Earth's surface combines with humidity in the atmosphere, which means they usually happen in the warmer months of summer.

They last for just a short period of time and tend to be fairly localised. This brings a unique set of challenges when studying them over long time periods.

"Convective rainfall is not well-represented in typical climate models, which means there's considerable uncertainty as to how it could change in the future."

To investigate possible future effects of convective storms, Lizzie ran the world's first very high-resolution climate change experiments looking at changes in hourly rainfall. These were conducted using the Met Office's weather forecasting model, which can study the weather across areas of the country just 1.5 km squared in size. This high-resolution model was applied to a climate change timescale that covered the present-day (1996 to 2009) – and a second one that encompassed another 13-year stretch, starting from the year 2100. The results, Lizzie says, were pretty startling.

"They showed future increases in the frequency of short duration, intense rainfall, not seen at the coarser resolution of typical climate models."

Put to the test

Lizzie's experiments broke new ground in the world of climatology and delivered results that could have wider benefits for the Met Office. They demonstrated how the high-resolution model performs over a long timescale and highlighted where possible improvements could be made – which, in turn, could influence weather forecasts over shorter timescales.

What's more, high-resolution experiments enable climate scientists to test typical climate models. Lizzie points out that, while it's vital to identify changes that lower resolution models can't show, it's conversely also essential to know where very high-resolution models don't add anything. As Lizzie says, "This helps gives us confidence in the value of using coarser level simulations in a range of situations."

Looking to the future

What next? So far, research into convective rainfall has focused purely on one small region of the UK. The obvious next step is to roll this out across a wider area.

"It took nine months for the Met Office supercomputer to run each 13-year climate simulation," says Lizzie. "Now we're hoping to work with other organisations across the UK and Europe on this sort of research so we can start to pull our results together."

Carrying out research is just one part of Lizzie's role. The other is to publicise the findings – in reports, journals, radio and newspaper interviews, as well as at international conferences. Last December, she spoke at the United Nations Conference of the Parties (COP) 20 in Lima, which called for greater action to build resilience to climate change across the developing world.

Lizzie is proud that her research supports a deeper understanding of the effects of climate change.

"Flash flooding can pose a real threat to communities," she says. "And until this study we really haven't had much of an idea about how these sorts of events might change in the future. It's very important to understand these effects."

Strength in partnership

Tropical cyclones are notoriously difficult to predict. But recent improvements to the Met Office forecasting model and an exciting partnership with the Philippines are helping improve forecast accuracy and mitigate what can be devastating impacts.

In 2013, Typhoon Haiyan wreaked havoc across the Philippines, leaving over 6,000 people dead and millions displaced. It was one of the most powerful tropical cyclones ever recorded – and the Met Office saw it coming. However, while the global model may have predicted the storm's track accurately, it underestimated its intensity.

This is an issue for any global model; while their resolution is improving as increased computer power becomes available, it's still not enough to replicate the conditions at a tropical cyclone's typically compact centre, where winds can reach 190 mph and pressure as low as 900 millibars. But this is changing.

Better model, better predictions

Last July, we implemented major improvements to our global model. While these weren't specifically aimed at improving tropical cyclone prediction, this was the area in which they had the biggest impact. Besides improving intensity predictions, tracking predictions improved by almost nine percent.

An even more recent change has taken advantage of the observational estimates made by tropical cyclone warning centres around the world. Assimilating these data into the global model has improved tracking predictions by another six percent. We are also testing a high-resolution regional model using a fixed domain over the Philippines. Once our supercomputer is online, this regional model will be implemented in real-time over every tropical cyclone that's occurring at any one time.

This is just one of the projects we are running in partnership with the Philippines' weather service, the Philippine Atmospheric, Geophysical and Astronomical Service Administration (PAGASA). Besides supplying data feeds from the Met Office Unified Model (UM) – the Met Office is also helping PAGASA raise its in-country capability by offering training and developing impact forecasts to support the responder community. This year, with the Met Office's assistance, PAGASA plans to acquire a supercomputer so that it can become a UM partner and run regional models itself.

Forecasting Typhoon Hagupit

The strength of this partnership was demonstrated when Typhoon Hagupit hit in December 2014. Unlike Typhoon Haiyan, this was very hard to predict, with global models from different meteorological services around the world giving different forecasts of the typhoon's track. This made it difficult for PAGASA to assess and supply accurate information to government and the public.

The Met Office Global Guidance Unit (GGU) stayed in touch with PAGASA, running additional models and connecting regularly on Skype. "Because we had a closer partnership with them, we had better lines of communication and it was much more two-way," explains Julian Menadue, Senior International Development Manager.

As Dr Vicente B. Malano, Acting Administrator of PAGASA, said, "The guidance documents and invaluable insights provided were really very helpful and guided us to better understand Typhoon Hagupit's behaviour and validate our forecast. This heightened our capacity to assess the different models and provided the opportunity to enhance our capability in weather forecasting."

This partnership is set to continue. This year, the Met Office is working with both PAGASA and the Department for International Development (DFID) to provide technical assistance – including the latest climate modelling – and inform how Philippine infrastructure, including roads, can be rebuilt to be more resilient and less vulnerable to tropical cyclones.

Not your 'garden-variety' gardener

Windowsills. Allotments. Inner-city rooftops. For **Alys Fowler** gardening is about making the best of the space you have. And with a changing climate to contend with, that's never been more important.

From rural roots to urban spaces

Growing up on a smallholding in the Hampshire countryside, Alys Fowler's love of the great outdoors began at an early age. But when she moved overseas to study at the New York Botanical Gardens in the Bronx, she swapped rural life for the big city, and found herself with only a fire escape to grow plants on.

The new environment inspired her to explore Manhattan's thriving community of gardeners, and she soon found herself part of a scene that included young artists and musicians.

"At the time, gardening in Britain was seen as something you tended to take up as you got older, but in New York it was different – people were doing it because it was a really creative and expressive thing to do."

It's clear from her newspaper columns, bestselling books and television programmes that creativity is a big part of gardening for Alys. But she also acknowledges the scientific side, in the need to understand how things grow – and even a semi-spiritual element of gardening. As she explains, "You're making something beautiful by creating a garden, but you're also cultivating a relationship with the natural world around you."

A garden for all seasons

It's that sense of a connection to nature that has made Alys acutely aware of the increasing unpredictability of our weather. Gardening is very much about seasonal rhythms, and so a changing climate can cause innumerable difficulties when it comes to growing any plants – including food. Once there were strict planting dates for carrots – and specific seasons when apples would ripen. Today things can be much more erratic.

"The thing that becomes really apparent when you spend a lot of time outside, working with nature is how the cycle is becoming less and less predictable. And that's so risky for us, because we can't predict what our growing pattern is going to be."

Her response is a proactive one. She tries to grow lots of different produce so no matter what the weather throws at her, she can be sure that something, at least, will succeed. Planting large volumes – and a wide variety – of plants also entices vital pollinators, such as bees, back to the garden.

"Encourage as much life and variety as possible. The more you put in, the more you'll support all the life around the garden – and the less weeding you'll have to do."

Going green

For Alys, it's important to make the most of what you have, whether that's an unseasonably dry summer or wet winter, big back garden or just a windowsill. Her top tip for tiny spaces is to plant salad.

"You can grow an awful lot of salad in a small space. A packet of seeds will provide you with a summer's worth to eat, and it will be local and organic, because it's grown on your back door."

Trying to be as organic as possible is a big part of Alys' mission, too. She avoids using peat at all costs and stays away from pesticides, which "by their very nature kill insects, but kill a lot of life in the soil, too". And she encourages amateur gardeners to make their own, homemade compost, because "it's the very best thing you can give to your plants… and it's free!"

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Art and the elements

Artist Tony Plant has been has been creating a diverse range of work for more than twenty years. He interacts with the environment transforming beaches into canvasses by drawing in the sand using a rake. He then leaves the drawings to be washed away by the waves.

Tony describes how weather is intimately linked with his work:

"I was born on the south coast of Cornwall, so I learnt to read a weather map from an early age. Weather, tides, wind and clouds affect every aspect of my work, not simply the where, when and how but the actual physicality of the spaces I work in. Low pressure systems and the winds associated with them will change the very colour of the beaches I draw on by scouring and replacing one weight/colour sand with another, overnight! Coastlines, and the memories associated with them, change shape daily, my paintings and whole beach drawings are a personal response to spending time in that environment, at that intersection between water, rock, sand, weather, memory and time."

Find out more at www.tonyplant.co.uk