Ofcom's fixed asset market review – overview of climate change impacts

www.ukcip.org.uk

UKCIP, School of Geography and the Environment, OUCE,
South Parks Road, Oxford OX1 3QY

T: 01865 285717
E: enquiries@ukcip.org.uk

Executive summary

This report describes the current broad scientific and policy landscape for climate impacts and adaptation in the UK, including the extent to which a changing climate has been considered by the telecommunications sector. The varying responses of a selection of other sectors (and regulators) to the challenge of climate change are considered and the likely changes faced by the UK are described, using the UKCP09 climate projections. Based on these findings, the report concludes with recommendations for future research which would examine how these changes may impact on the ability of Openreach to maintain business continuity and service quality in a changing climate. The desk-based nature of this study does not allow a detailed assessment of Openreach's vulnerability to climate change or provide a full description of climate risks within the telecommunications sector. However, the report does provide an overview of the main findings of recent climate modelling and projections for the UK, and also covers some major issues that may trigger further regulatory discussion and act as a platform for more in-depth research. The key findings for the telecommunications sector highlighted in this report are:

- An extensive body of research and evidence indicates that we are already experiencing the impacts of climate change.
- Increased climate variability, including extreme weather events, presents a challenge to infrastructure organisations to deliver services efficiently and effectively across the UK.
- Experience from other utility sectors suggests that regulatory authorities can have a key role to play in supporting adaptation and creating an 'enabling environment' within which other organisations can develop adaptation strategies.
- There are important elements of telecoms infrastructure that are long lasting and require timely adaptation decisions to be factored into longer-term business planning cycles.
- Some parts of the telecoms sector, less focussed on external physical infrastructure and service, may be able to evolve more rapidly and more easily adapt to changes in climate and weather patterns.
- There is currently limited publically available information on how the telecommunications sector will be affected, but it is a critical sector on which many businesses and households depend.

In addition, findings and recommendations of specific relevance to Openreach are:

- Openreach is operating in a changing climate, characterized by an increasing level of variability; this needs to be reflected in its approach to service delivery and in its relationship with the regulator.
- Initial discussions with Openreach highlight concern regarding longer term climate change, as well as short term variability and extreme events.
- Given the possible increase in such events (or extremes becoming the 'new normal') there is likely to be a need for greater flexibility in service delivery.
- Due to a) uncertainty in the projections and b) the number of variables which shape the consequences of a changing climate for an organisation such as Openreach, any adaptation strategy will need to be flexible.
- Some infrastructure for which Openreach is responsible may have longer lifespans, hence the need for timely adaptation decisions that could be factored in to business planning cycles.
- There is currently limited information on how Openreach is vulnerable to the specific impacts of climate change and weather variability in published literature. Consequently, further research would be beneficial in understanding the full impact of climate change on Openreach's services.
- While climate projections are helpful in understanding possible climate changes, their impact will vary for a number of different reasons; these effects need to be explored in greater detail but they are likely to require Openreach to build greater flexibility into its infrastructure and service operations.
- An important step in developing a more effective sector-wide response to climate change (including coping with increased variability and extreme events) would be for both the regulator and service delivery organisations to develop a clear understanding of how each organisation can contribute to a more flexible, climate resilient sector.

Introduction

Openreach (a part of BT Group) operates and owns a fundamental part of UK telecoms infrastructure which underpins many major communications providers networks in the UK, and hence the vast majority of downstream UK businesses and retail customers.

Openreach also has a Universal Service Obligation (USO) that requires them to serve customers irrespective of extreme and challenging circumstances including severe weather. These challenging circumstances can be exacerbated by decisions beyond the control of Openreach, such as the development of new housing built on flood plains.

The report describes the current broad scientific and policy landscape for climate impacts and adaptation, including the extent to which a changing climate has been considered by the telecommunications sector. We then consider how other sectors (and regulators) have responded to the challenge of climate change then outline some of the likely changes faced by the UK, using the UKCP09 climate projections. Based on these findings, the report concludes with recommendations of future research to understand how these will impact specifically on the ability of Openreach to maintain business continuity and service quality in a changing climate.

The scientific and policy landscape to a changing climate

The fact that the climate is changing is no longer in question, what is in question is why it is changing, how it is changing and what are going to be the impacts of this change. The Intergovernmental Panel on Climate Change (IPCC) states that, 'Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level' (IPCC, 2007). For the UK, observations of changes in the weather are consistent with projections of a changing climate. For example, changing rainfall patterns leading to droughts and floods and variable temperatures leading to heavy snow and heatwaves (Stott and Walton, 2013 in press). This trend is expected to continue with a likely move towards warmer, wetter winters and hotter, drier summers during the course of this century.

The UK government has acknowledged that 'The scientific evidence that the world's climate is changing is clear and extensive' (Defra, 2013), providing a clear steer for building a national infrastructure that is resilient to this change. The Government's key measure for dealing with climate change is through the Climate Change Act 2008, which aims to address climate change with action on both adaptation (dealing with the impacts of a changing climate) and mitigation (minimising climatic changes by reducing greenhouse gas emissions).

Within the Act, the Government sets out key legislative vehicles that look to establish the extent of the UK's resilience to a changing climate. These measures include the Adaptation Reporting Power (ARP), the national Climate Change Risk Assessment (CCRA) and the National Adaptation Programme (NAP). Despite the Government's attempt to look at the risks to UK infrastructure, to date the reports suggest that there has been a reluctance to engage with the process on a national level (Defra, 2013).

The Government's recognition of the importance of the telecommunications sector in the national context is demonstrated in the UK Climate Change Risk Assessment (CCRA) in 2012. Loss of productivity due to ICT disruption (telecommunications is not considered separately in the CCRA) is indicated as a risk within the CCRA, but is deemed too uncertain to assess its likely consequence, although it does suggest the main impacts are likely to be felt at a local level, i.e. in the space where Openreach is most active

stating, "Very few impacts would be expected to affect the entire national ICT network. The majority of impacts would cause disruption at the level of individual organisations or local geographical areas. Some of the more remote parts of the UK may be particularly vulnerable, where the network is limited." (Defra, 2012). The CCRA goes on to note the low evidence base for climate change impacts in the sector which is characterised by short-term business models that make it more difficult to embed adaptation for the long-term. However, the CCRA does acknowledge the strategic importance of ICT, because so many other sectors are dependent upon it. This interdependence though is not one-way and it is recognised in the CCRA that the ICT sector is also heavily dependent on the energy sector. The lack of understanding in the CCRA led the report to recommend that further work to address the uncertainties around the potential impacts of climate change is needed, though to date, this has not happened.

Following the CCRA, the Government expects to publish the National Adaptation Programme (NAP), in July 2013. The National Adaptation Programme will set the framework for how government, businesses, communities and civil society should prepare for and adapt to climate change.

In addition to the Government's legislative requirements relating to adaptation to climate change, the Environment Agency (2013a), through its Climate Ready programme, also highlights the importance of the ICT sector, and champions the work of the Infrastructure Operators Adaptation Forum (Environment Agency, 2013b). This forum provides a channel for UK infrastructure operators to engage in dialogue leading to a shared understanding of best practice in climate change resilience. Currently, the members from the telecommunications sector are: Ofcom, BT and Intellect.

It can be seen that the Government, through the Climate Change Act 2008, set in place a number of mechanisms by which the UK's infrastructure can become more resilient to a changing climate. The next section looks in more detail at the Adaptation Reporting Power, and the extent to which this has led to change within the telecommunications network. It also looks at the opportunity for the telecoms sector to potentially learn from other regulators in how they are addressing the possible impacts of climate change.

Adaptation Reporting Power

The Adaptation Reporting Power (ARP) required key public bodies and regulatory authorities to report to the Secretary of State on the extent of their preparedness to a changing climate. Telecommunications businesses were not included in the first round of reporting in 2010, although Ofcom, along with other economic regulators, was required to report. The recent consultation about a second round of reporting under the ARP is proposing that telecommunications businesses should be asked to participate (voluntarily). However, the results of the consultation process have been published, and it would appear that there were no responses from the telecoms sector, including Ofcom. (Defra, 2013). This is perhaps surprising given that, for the second round of the ARP, the Government's consultation document specifically referred to the importance of the telecommunications sector stating that, 'Government will be working with the Telecoms Sector to promote climate resilience. Government would welcome engagement on the subject of adaptation reporting given the strategic importance of the sector and the many interdependencies with other organisations which were identified in the first round of reporting.' (Defra 2013). However, Defra's report on the consultation replies suggests that Government is already working with the Department for Business Innovation and Skills (BIS) and Ofcom, and that BT has agreed to produce a report.

Initial evidence relating to the potential climate impacts on the telecoms sector

It was not within the scope of this report to assess the potential vulnerability to specific climate impacts of Openreach or the broader sector. However, it was possible to identify where work had been undertaken in this area over and above the work completed for the Ofcom ARP report.

A Defra commissioned report by Horrocks et al. (2010) provides a comprehensive review of climate change impacts on the ICT sector (many of which would be relevant to the telecoms sector). It concludes that the sector is largely resilient and adaptive, although there are still impacts to consider. These are summarised as:

1. environmental degradation of infrastructure, leading to changes to the expected in service lifetime of longer lived structures (such as mobile transmission masts);
2. changes to the availability or reliability of ICT services, from disruption caused directly or indirectly by weather events;
3. changes to the quality of service provision, particularly connected to the dependence of wireless signal quality on environmental factors;
4. implications for repair and recovery following extreme weather damage or disruption in any aspect of the infrastructure, potentially resulting in additional costs;
5. changes to operational business costs, such as heating and air conditioning requirements;
6. changes to working environments and associated health and safety of employees; and
7. changes to the reliability of international ICT services.

Not all of these will be directly relevant to Openreach, however the disruption by weather events, its consequential impact on the ability to repair/recover service and detrimental effects on infrastructure maybe the most significant. In addition, there may also be other impacts that apply specifically to Openreach's operations that could be explored through further research.

While there is considerable recognition of the important contribution of ICT to climate-resilient national infrastructure, an initial review suggests that there is little publically available research regarding the scale of impacts and the particular vulnerabilities the sector faces. However, there are some examples of specific risks, for example, Defra (2011) includes a summary of risks to infrastructure, including ICT. For copper and fibre optic cables, it suggests that an increased risk of flooding will affect low-lying infrastructure, access holes and underground facilities, and that flooding/erosion affecting roads and bridges will expose cables and trunk routes. However, there appears to be little or no published research of the implications of a changing climate for the timely delivery of services or the costs associated with meeting existing targets and obligations. It is anticipated that further evidence of impacts and adaptation actions in the telecoms sector may exist, and that an extended literature review, reviews of internal service delivery reports and interviews would uncover more detailed information about vulnerabilities, impacts and interdependencies.

From initial discussions with Openreach, it has been indicated that climate change may have significant impacts on areas such as local exchanges, cabinets, overhead networks, home environment, Openreach personnel and their supply chains. Although there is little publically available research on the implications of a changing climate for the timely delivery of services or the additional costs, it is our understanding that Openreach do have internal data available with regard to the impact of recent extreme events on its costs and ability to maintain its service delivery targets.

Role of interdependencies

Interdependencies are an important area for all infrastructure providers. ICT is dependent on a reliable energy supply, but is increasingly important in the delivery of all other infrastructure services, thus vulnerabilities to climate change within ICT and telecoms sector can exacerbate the vulnerabilities of other sectors. Similarly, effective telecoms can provide additional flexibility when other infrastructure is adversely affected by extreme events, therefore businesses and households may rely upon telecoms as part of their own adaptation responses. The ability to have steady and reliable data will contribute to the well-being of the UK's critical infrastructure, consequently adaptation can also be viewed as a business opportunity for Openreach if commercial and regulatory objectives can be aligned. For example, remote monitoring of infrastructure (such as the condition of roads or bridges) can help relevant professionals to assess the resilience of infrastructure, to monitor its performance and to plan for the future.

For the next round of the ARP, the Government's consultation document specifically referred to the importance of the telecommunications sector, with the summarized responses suggesting that any discussion with the Government should include the Department for Business Innovation and Skills (BIS) and Ofcom. It is noted in the same consultation paper that BT have already agreed to produce a report.

Infrastructure regulators and climate change – evidence from submissions under the Adaptation Reporting Power (ARP)

The Adaptation Reporting Power provided the Secretary of State for the Environment with the authority to request specific organisations to report on how they were prepared for a changing climate. In the first round of the ARP, reports from 91 organisations were requested, mostly representing critical national infrastructure. The regulators for telecommunications (Ofcom), energy (Ofgem), water (Ofwat) and the rail network (ORR) were also asked to provide submissions, though they were amongst the last to report, in autumn 2011. (Defra, 2012).

For the purposes of this assessment for Openreach, UKCIP has considered the regulatory approaches outlined in the industry regulators' ARP reports. In particular, we have considered if there are useful lessons to be drawn from Ofgem, Ofwat and ORR that might inform Openreach's discussion with Ofcom about its investment in adaptation.

These reports were written in 2011, so some of the regulatory frameworks may have changed, and the regulators' own thinking and understanding about adaptation may have developed.

Summary of regulators' ARP reports

It is worth noting that all regulators are constrained by their specific duties and functions. Their responsibilities and responses are, therefore, limited to measures that are linked to the efficient and effective provision of the regulated service, such as licensing, penalties, reviews and business plan assessments. However, achievement of these objectives is often linked to external influences (such as the weather) which can directly impact the ability of an infrastructure organisation to plan for and achieve operational efficiency targets. Within these constraints, some regulators have decided to take a more proactive approach on climate change adaptation. This may be working at the fringes of their regulatory function, or they may be reflecting the greater level of scrutiny they are expected to make of their sector, or the significance of the impact of climate change on their sector and its long-term sustainability and resilience.

Ofcom

In its ARP report, Ofcom considers adaptation largely from within the limits of its statutory duties. Ofcom is primarily an economic regulator and its role is to ensure effective competitive markets. Broadly speaking it defines policy objectives for the sector, and through a series of regulatory interventions it creates appropriate controls and incentives to support those goals (for example greater consumer choice, ease of switching telecoms provider etc.). However, the ARP report goes on to say that climate change adaptation is not a straightforward fit with this remit, and that Ofcom believes that it would be challenging to justify any action on climate change adaptation. They also judge that it would be difficult to make regulatory decisions on something as uncertain as climate change in a sector that is evolving very quickly.

The report does consider some areas where climate change will affect the sector and what mechanisms already exist to help manage these. Identified risks to infrastructure are: warmer temperatures (extremes and mean), rainfall leading to increased incidence of flooding, high winds and sea level rise for assets close to the coast. Impacts on the radio spectrum are also expected, but this is not currently central to Openreach operations, although this may grow in importance for access to the most rural areas on the UK.

Ofcom's ongoing monitoring will contribute to understanding the impacts of climate change on the sector, acting as an 'early warning system' if services are significantly affected by changing weather patterns; the sector already has systems in place to give, for example, priority access to emergency services. It is noted that Ofcom's infrastructure reports will be a resource to review past performance in the sector.

Ofcom also meets with other regulators as part of the Joint Regulators' Group, which discussed adaptation in autumn 2011, and business continuity managers from some of the regulators meet twice a year to share best practice.

Ofgem

Ofgem's approach to addressing the energy sector's climate change risks is through:

- regulatory tools and policies;
- an annual Sustainable Development Focus report; and
- a strategy containing 5 priorities including ensuring a secure and reliable gas and electricity supply.

Regulated companies within the sector are required to provide a cost-effective, reliable and secure service to customers with penalties for failing to meet these targets and incentives to achieve/exceed them. Ofgem expects companies to consider their climate risks as part of their overall operating and investment planning. Ofgem sees price controls as its main contribution to adaptation as it permits necessary investments by the sector. Companies are expected to consider longer-term risks and are able to invest in activities that produce value for money beyond the current price control period. At the time of the report, the new price control regime for the gas sector and for electricity transmission was being finalised (it began in April 2013), while the current electricity distribution price control regime is in place until 2015.

Ofwat

Ofwat aims to enable the provision of sustainable water, which immediately implies a long-term perspective that takes account of climate change. It is able to support adaptation by:

- enabling adaptive action (the right regulatory framework);
- building adaptive capacity (improving own understanding and evidence base available to companies);
- monitoring and evaluating (measuring performance to inform regulatory actions); and
- with price reviews the main opportunity to influence adaptation.

The report contains a helpful assessment of barriers and constraints that limit Ofwat's ability to act on adaptation for the water sector.

- Uncertainty about climate change and impacts can lead to wasted resources and it can be difficult to make a robust case for adaptation.
- Difficult to justify investment because adaptation actions yield benefits that are far in the future: problem for companies, problem for the regulator.
- Cost – additional investment has to deliver benefits. Affordability (via customer bills) will influence pace of adaptation.
- Competing objectives – balancing social, environmental and economic interests.
- Changing context – other risks (eg demographics) will influence adaptation and add to levels of risk and uncertainty.

This might be a useful starting point for thinking about Openreach's strategy for approaching Ofcom and could be considered in further research in this area.

Office of Rail Regulation (ORR)

The Office of Rail Regulation (ORR) is responsible for the regulation of Network Rail and its operations, but it is not responsible for rail services. The Network Rail licence does not address climate change or climate change adaptation directly, but it is implied in the requirements associated with, for example, network availability and asset condition. ORR also makes long-term sustainability requirements, including taking account of climate risks.

ORR guidance to the industry in its periodic review asked for weather resilience plans

(with a focus on extreme events), with a cost benefit analysis. The Initial Industry Plan (IIP) – the industry's preferred strategy for the next control period – included £70m expenditure on adaptation to climate change: mainly bridges and other civil engineering assets.

Some conclusions from a review of the regulators' ARP submissions

As referred to earlier, Ofcom, and the telecoms sector more generally, do not appear to have engaged in the ARP process to the same degree as some other sectors. Given the potential impacts on the telecoms sector and the fact that effective telecoms often play an important role in the flexible response of other sectors during extreme events (e.g. enabling homeworking or in ensuring early warning and preventative action) it would seem sensible for the whole sector that greater efforts are made to engage both service delivery organisations such as Openreach and the regulator. Reviewing the ARP submissions from other regulators highlights a number of issues which may be of relevance to Ofcom and Openreach when considering how best to respond to planning in the context of a changing climate.

Perception of risk to the sector

Ofgem, Ofwat and ORR acknowledge that there are substantial risks associated with the impacts of climate change on their respective sectors. They support their sectors to adapt in various ways so that they can continue to deliver effective and efficient services. With a lack of research and public information for significant direct impacts on the sector, as reported in the CCRA and the Ofcom report, it is difficult for Ofcom to begin to frame its role in relation to adaptation. However, it may be that service providers, such as Openreach are able to provide robust evidence to assist this process, including a better appreciation of climate change vulnerabilities and risks, as well as the independencies between telecoms services and other sectors.

Regulated industries are responsible for some very long-lived assets (bridges, reservoirs) where the means of delivery (rail network, transmission lines) are evolving relatively slowly. For telecommunications, there is a mix of long and short-term technologies with some assets evolving more quickly than others and which may not demand the same long-term planning. This may limit Ofcom's ability to make adaptation demands on the sector as a whole. However, initial discussions with Openreach suggested that infrastructure such as poles, duct, fibre, copper and cabinets can have accounting life times of 20-40 years, and in the case of poles and duct potentially much longer useful asset lives. It is these types of external physical assets that are most at risk from climate extremes.

Ofgem sat on the group overseeing restoration work after Carlisle floods in 2005, illustrating how it is possible for a regulator to engage with the longer adaptation agenda as well as determining responses to extreme events, which do affect short-term service provision.

Price controls

The economic regulators principally exert influence through their various pricing regimes. Ofgem and Ofwat price control regimes include provision for variation between major reviews where this is justified. Even with the possibility of review, there remain challenges associated with the uncertainties around future climate change, and the difficulty of demonstrating future benefits. These are acknowledged by Ofwat, and described as a problem shared by the regulator and the industry.

Perception and understanding of impacts on the sector

Water, energy and rail transport can be directly affected by changing weather patterns in ways that have a substantial impact on their operations. The impacts on the telecommunications sector are sometimes less obvious, but these can be both direct (failure of communications infrastructure due to lightning strikes, failure of copper cables due to ingress of water, fog, condensation etc) or indirect (power failures, flooding of assets etc). Initial discussions with Openreach suggest that extreme weather events and intra-seasonal variability do have a direct impact on workload management, efficiency and ability to meet service targets.

While not specially identified in the ARP reports, it is worth noting the Openreach have identified two distinct types of cost impacts. The first relate to impacts on operational expenditure, such as redeployment of staff or additional sub-contractors in response to weather-related incidents. The second relates to capital costs, such as the repair of, or anticipatory investment in, telecoms infrastructure.

Knowledge exchange between regulators

There are a number of fora that exist for regulators. Ofcom refer to a Joint Regulators' Group, which discussed adaptation in 2011, and a sub-group that shares business continuity best practice. Ofgem refers to a regulators' group set up after the ARP to investigate shared areas of interest. If Ofcom is involved in any or all of these, it may be evidence of an increasing understanding of the importance of adaptation and add to publically available knowledge on potential impacts to the sector.

Long-term vs short-term planning

Most regulated sectors have long-lived assets, some very long-lived, (e.g. bridges, reservoirs) – and their investment planning has to include climate change because of this. Information in the Ofcom ARP suggests that they have not viewed the telecommunications sector in this way, so for them consideration of issues beyond the current pricing period is difficulty. Where longer-lived assets can be identified (e.g. underground and overground conduits and wiring, dependence on international cable links), it would be useful to determine what the climate-related impacts have been and how this might change in future. In such cases, Ofcom and the owners and users of these assets should be encouraged to consider the longer planning horizons than traditional review periods currently enable. In this context, the ability of both the regulator and individual organisations to cope with increased climate variability and build in appropriate levels of flexibility and resilience will be important. A sound starting point for this will be to understand how the sector currently copes with extreme events and 'unusual' weather such that, in the future, it is more resilient to increased climatic variability. This will be particularly true for organisations such as Openreach operating throughout the UK and in both urban and rural areas, where the impacts of climate change may vary considerably.

The UK's changing climate

As mentioned, the scientific consensus indicates that the critical questions are no longer whether the UK's climate is changing or not, but a) what is the likely extent of the change (and by when) and b) the effect this will have on the seasonal weather patterns. In the last decade, the UK has already experienced changing patterns in temperature and precipitation as highlighted in a recent Met Office meeting, and summarised in Table 1 below which lists some examples of 'unusual' UK weather using data since 1910 (Met Office, 2013). Understanding of why the past decade has experienced such unusual weather and the possible trends for such weather extremes is still being researched. In particular, attention has focussed on understanding the reasons for recent jet stream fluctuations and 'blocking' patterns over Europe as the shifting jet stream is a primary cause of the change in weather patterns we are experiencing in the UK.

Table 1

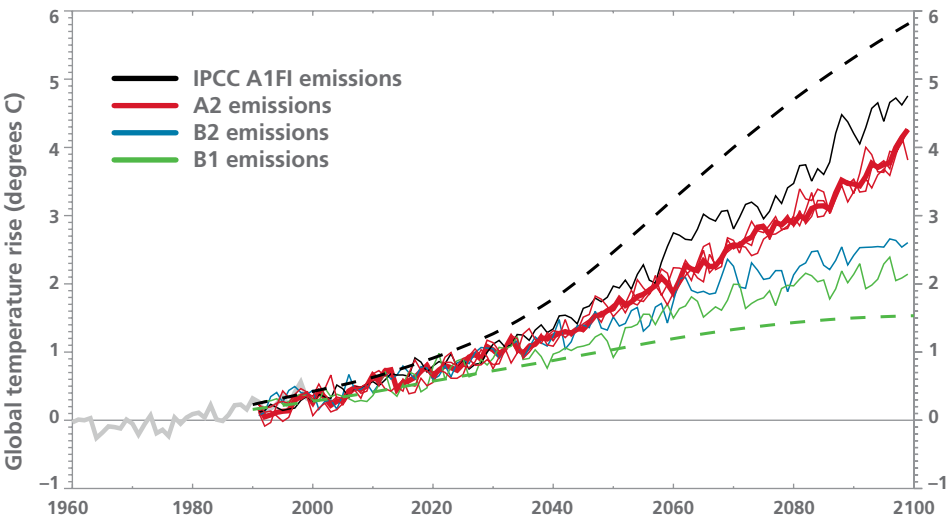
Spring 2013	Mean temperature of 6.0°C; 5th coldest in the series; coldest since 1962 (ie coldest in 51 years)
March 2013	Mean temperature of 2.2°C; joint 2nd coldest in the series; coldest since 1962 (ie coldest in 51 years)
Year of 2012	1334.8 mm of rain; 2nd wettest year in the series; the wettest since 2000
Summer of 2012	379.2 mm of rain; 2nd wettest in the series; wettest since 1912 (ie wettest for 100 years)
June 2012	149.0 mm of rain; wettest in the series
April 2012	128.0 mm of rain; wettest in the series
Winter 2010 to 2011	Mean temperature of 2.43°C, which is 1.3°C below the 1981 to 2010 average
December 2010	Mean temperature of –0.9°C; coldest in the series
Recent summers	Five out of six recent summers have had above average rainfall, with only 2010 being average
Summers of 2012, 2011 and 2007	Saw the triple 'disappointment' of having below average temperatures, below average sunshine, and above average rainfall

However, it needs to be considered that higher occurrences of extreme weather events are not the only factor which determines the impact on a system. A range of non-climatic components interact with the climatic changes to determine the consequences for an organisation, community or service. For example, increased precipitation is just one factor, which influences the likelihood of a damaging flood event. Others might include the intensity of the rainfall, the topography of a local area, the amount of permeable and impermeable surfaces, the quality of drainage and the preparedness of individuals and communities. The projections outlined below must therefore be understood as one (albeit important) variable in a complex operating context, which shapes Openreach's ability to delivery services in a changing climate.

The models that are used to generate future climate projections, such as the ones used in this report, will only show the changing pattern of the climate and not individual/seasonal weather patterns. This is because the weather data is averaged over a 30-year period to identify climatic change, which allows for better predictions of future climate, but can mask the extreme events that can often cause the greatest disruption to network systems. The averaging process also masks the decadal trends that exist within the climate system, and which lead to greater weather variability particularly with regard to temperature and precipitation patterns (Keenlyside et al. 2008). It is recognised that these decadal trends play an increasingly important role for organisations near-term planning though the modelling of future trends, particularly in the North Atlantic (which is a very significant influence on UK weather) is still in its infancy (Meehl et al., 2013). This only increases the need for any future planning strategy to be flexible enough to respond to these uncertain short-term trends and potential increases in risk, whilst also adapting for a longer timeframe.

The UK Climate Projections (UKCP09), published in 2009, represent the latest set of climate projections for the UK, providing the most comprehensive data on the potential future climate that could be experienced in this country. The probabilistic nature of the projections, for the first time, makes the uncertainty overt by offering a range of values that need to be considered rather than using a single value. UKCP09 also allows the user to identify future climate change using a range of emission scenarios identified in the last IPCC report, 2007. For the purpose of this report it is assumed that the greenhouse gas emissions will remain high, although in reality there is little difference during the near-term between the 3 emission scenarios and their effect on the climate system (see Figure 1, the black line represents the 'high' emission scenario in the projections).

Figure 1



© Met Office Hadley Centre

As described earlier, the telecommunications sector is vulnerable to a range of weather variables, however, the models used to identify possible future climate are not capable of showing all these variables, in particular storm events. This report has therefore focusses on two key variables, changes in temperature and precipitation. This section of the report will focus on these two key climate variables using a high emission scenario and for the decades of 2020s and 2050s (represented by the periods 2010–2039 and 2040-2069 respectively). The maps show the possible likely range of change that could be experienced across the UK in these time periods. These are represented as being the 10th and 90th percentile. It is possible that the UK could experience temperatures and precipitation outside of this range, but it is considered unlikely. When using the likely range for planning purposes, an understanding of risk and vulnerability will help inform what level to choose. For example, for extremely vulnerable areas that have high risk associated with them, then planning for the 90% level would seem appropriate, however, for low risk assets considering a lower range of values may be more judicious. The figures also show the relative change in the temperature and precipitation, which is based on the difference from a baseline figure for the period 1961–1990.

Although the data in the images below are presented as maps, the data are not spatially coherent in that what may be experienced in Cornwall under this emission scenario does not necessary mean that Norfolk would experience the same level of likelihood.

It is also important to note that the report focuses on relative values, that is, how much the variable is likely to change by and not what the temperature or precipitation levels will be. It is anticipated though that in future research, once threshold levels have been identified, it may be more relevant to look at absolute values and the point at which these values are exceeded leading to faults in the network. It will also be possible to identify greater detail in terms of spatial and temporal distribution of the key variables, for example, number of consecutive rain days that could lead to increased fault reporting.

The headline message from the Projections is for the UK to experience warmer wetter winters, and hotter drier summers, whilst also experiencing a greater amount of extreme weather events. However, as is evidenced in the figures in the next section, this pattern is far more variable and the level of uncertainty, particularly with regard to precipitation is much greater. However, this uncertainty is not a question of the science being poor, but rather a question of the variability of the climate to forces affecting it in ways that cannot always be modelled. The variability also extends to regional and temporal scales, where changes in climate in one area may not be expected in another and even if it was it may not happen at the same time. Again, as evidenced in the figures below, the spatial pattern is not always a simple north/south or east/west divide, but can be variable from one 25 km grid cell to another. This uncertainty is amplified for service and infrastructure organisations like Openreach, who have a national footprint and a USO obligation and hence are exposed to the whole range of diverse environments in the UK and the high variability expected by region, season etc.

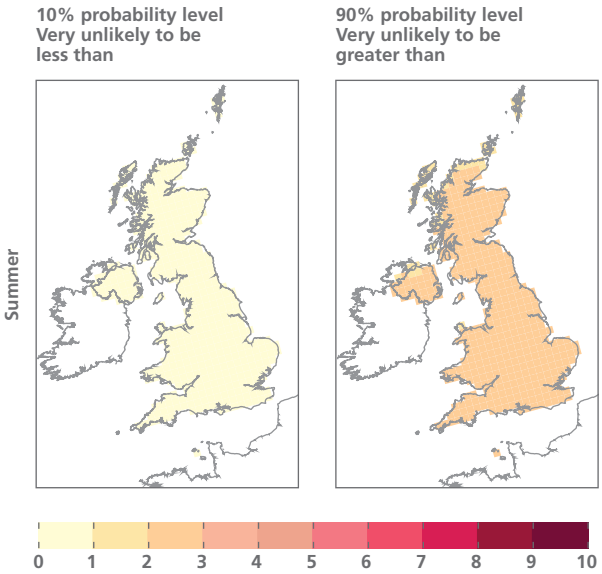
Therefore, when it comes to using the data to support planning decisions, any adaptation planning needs to be flexible and robust enough to cope with the potential range of climate that could be expected across a range of spatial and temporal scales. However, it is acknowledged within the sector that this increased variability will increase difficulties in developing robust plans, and may therefore potentially require Openreach to adopt a more reactive policy rather than proactive leading to a consequent increase in service costs.

Change in UK Temperature

The temperature in the UK during the next century is expected to increase, although any change will not necessarily be spatially uniform. The following figures show the change in average mean temperature for the winter and summer seasons in the 2020s and 2050s, as indicators of near and medium term changes. The averaging of the values will mask any extremes in heating and cooling and over what time period they may occur. Further analysis of the daily distribution of temperature would be possible with further research.

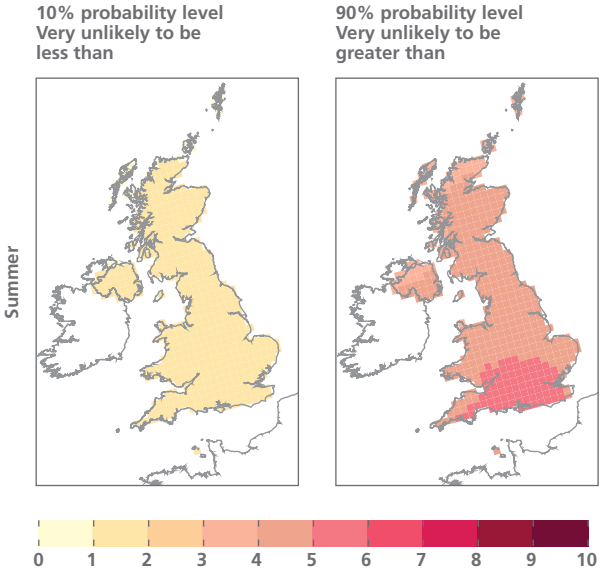
When looking at the broad pattern of change in the UK's average (mean) temperatures it can be seen that it is relatively uniform with the likely range in 2020s being between 0°C and 3°C (Figure 2). By 2050 there is the possibility that there will be a greater divide within England with the likely range across southern counties increasing to between 2°C and 6°C, whilst northern counties could experience a smaller range of average temperature increase from between 2°C and 5°C (Figure 3). It is the increase in sea-surface temperatures that will lead to an increase in the frequency and intensity of extreme events.

Figure 2



Change in summer mean temperature (°C) for the 2020s, High emissions scenario

Figure 3

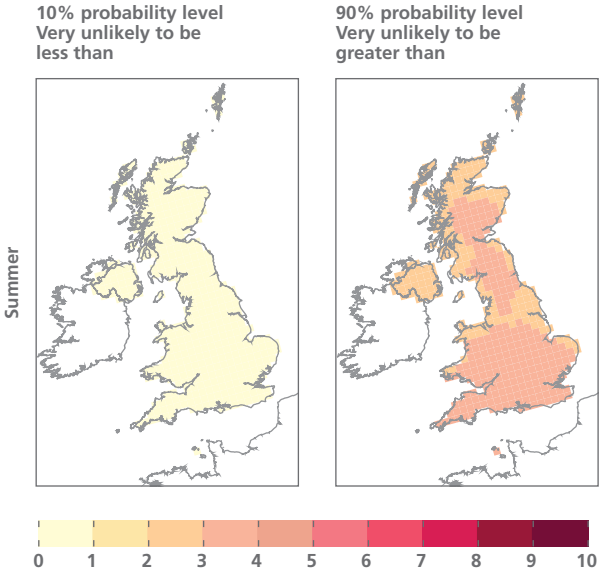


Change in summer mean temperature (°C) for the 2050s, High emissions scenario

As can be seen in Figure 4, the average maximum summer temperatures are expected to increase in the 2020s by between 0°C and 4°C although the average maximum summer temperature on northern coastal margins may only increase by between 0°C and 3°C.

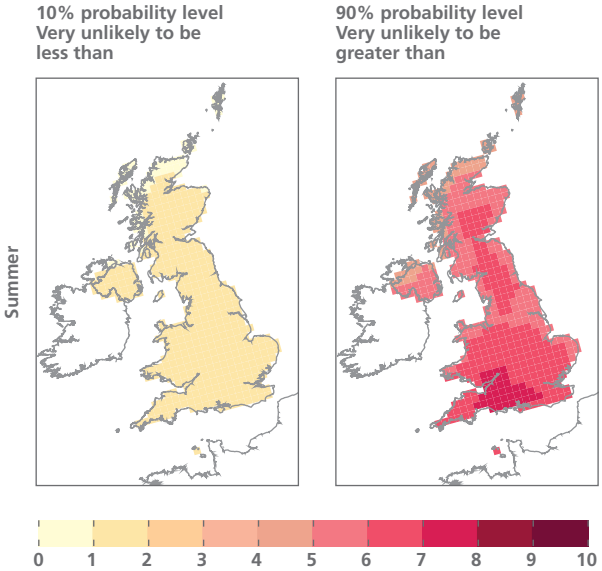
In comparing this to the 2050s (Figure 5), the likely range of increase in the average maximum summer temperature could rise to between 1°C and 7°C, with areas in the South West potentially rising by 8°C.

Figure 4



Change in summer mean maximum temperature (°C) for the 2020s, High emissions scenario

Figure 5

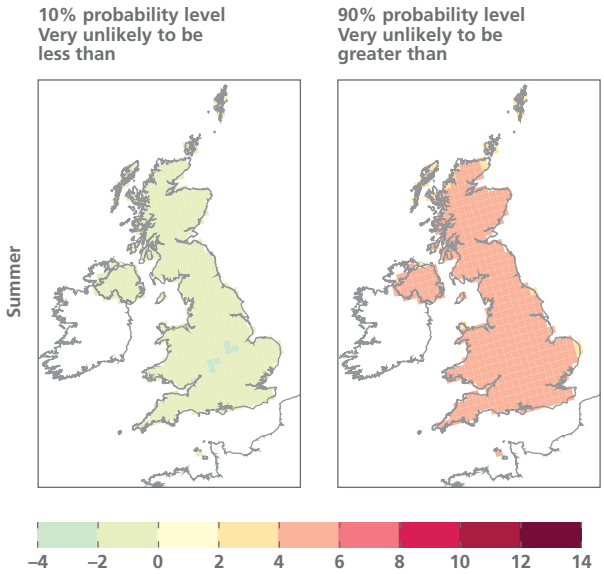


Change in summer mean maximum temperature (°C) for the 2050s, High emissions scenario

As with all weather patterns peaks and troughs in the maximum and minimum temperatures can be expected and with a changing climate, this is expected to be exacerbated. Figures 6 and 7 show the likely range of the increase of the warmest day in summer in the 2020s and 2050s. As can be seen, in the near-term there is a greater degree of uncertainly of the change in temperature of the hottest day could increase, with the projections suggesting there is a possibility of cooling as well as heating with the likely range being between –2°C and 6°C. With some areas in central England cooling as much as 4°C.

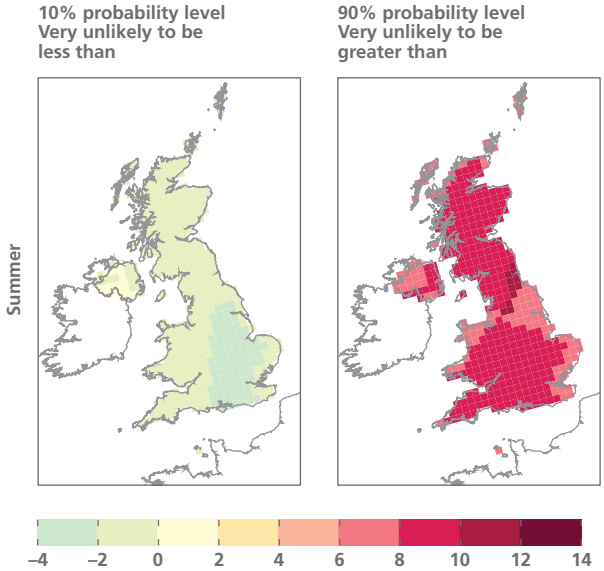
By the 2050s, this range increases from between –2°C and 10°C, with large sections of the east of England experiencing a drop in the warmest day temperature by –4°C, and areas in the North East experiencing a possible increase by 12°C. Eastern coasts could warm up to 8°C.

Figure 6



Change in temperature of the warmest day of summer (°C) for the 2020s, High emissions scenario

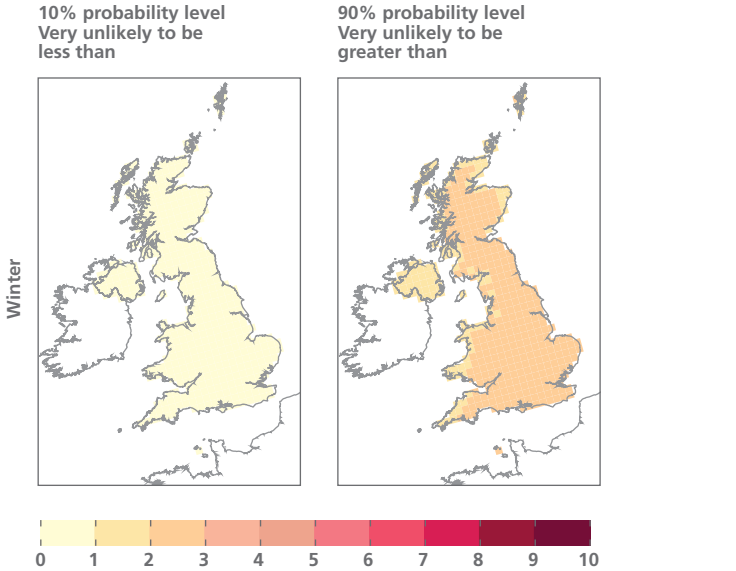
Figure 7



Change in temperature of the warmest day of summer (°C) for the 2050s, High emissions scenario

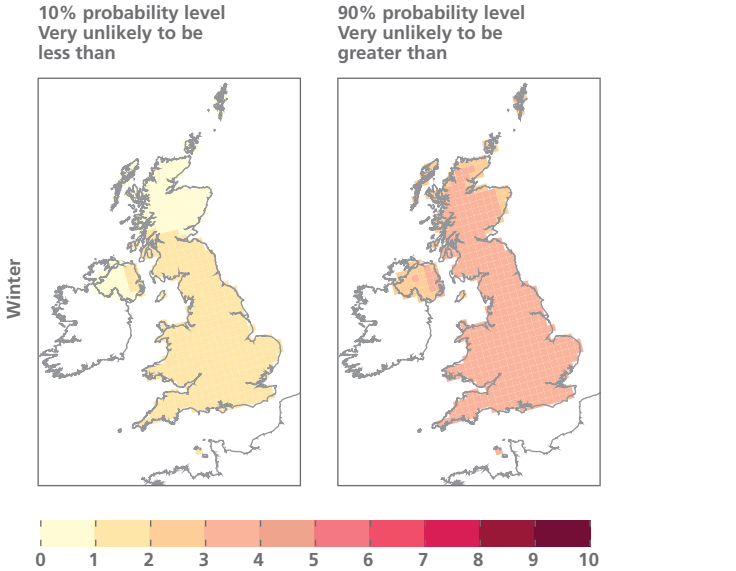
It is not only the summer temperatures that are expected to be affected by a changing climate, but also winter temperatures as well. Figures 8 and 9 show the change in the increase in the average winter temperature in the 2020s and the 2050s respectively. As can be seen, the likely range of increase in 2020s is between 0°C and 3°C with pockets in the South West increasing by a likely maximum of 2°C. By the 2050s this likely range would have changed to between 1°C and 4°C

Figure 8



Change in winter mean temperature (°C) for the 2020s, High emissions scenario

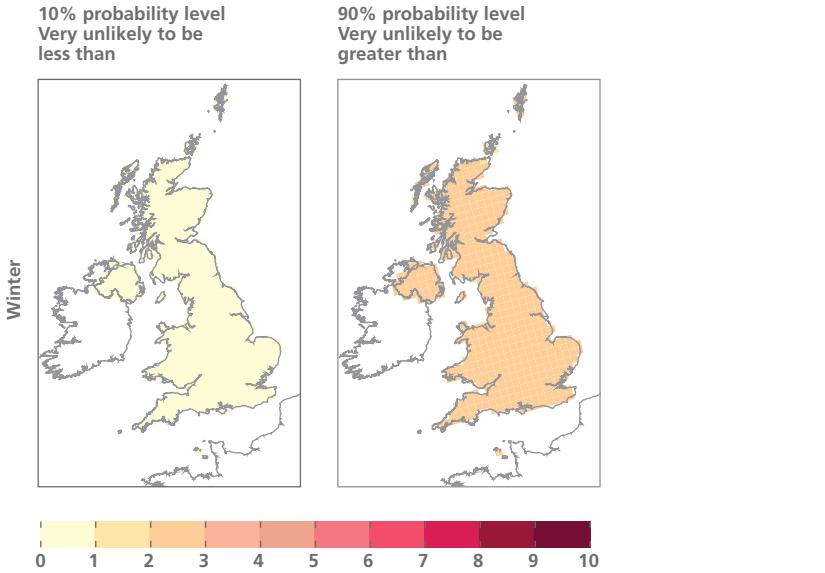
Figure 9



Change in winter mean temperature (°C) for the 2050s, High emissions scenario

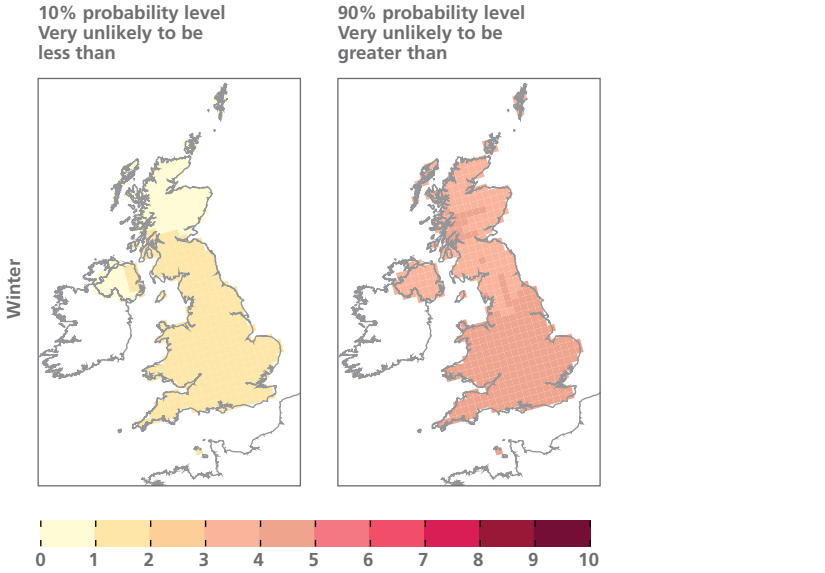
Figures 10 and 11 show the likely range of average minimum winter temperature in the UK for the 2020s and the 2050s. Both near and medium term projections suggest a warming where the minimum winter temperature could increase between 0°C and 3°C in the 2020s and 1°C and 5°C in the 2050s.

Figure 10



Change in winter mean minimum temperature (°C) for the 2020s, High emissions scenario

Figure 11



Change in winter mean minimum temperature (°C) for the 2050s, High emissions scenario

The previous figures illustrate the likely range of change in temperature for the UK up until the 2050s. As seen, there is a trend towards a warming climate, although this trend is not spatially consistent across the country. The next section looks at the potential change in precipitation that could be experienced in the UK until the 2050s. As previously mentioned, this change is far more uncertain than for temperature with a greater range of likely values that reflect a potential drying as well as increased precipitation.

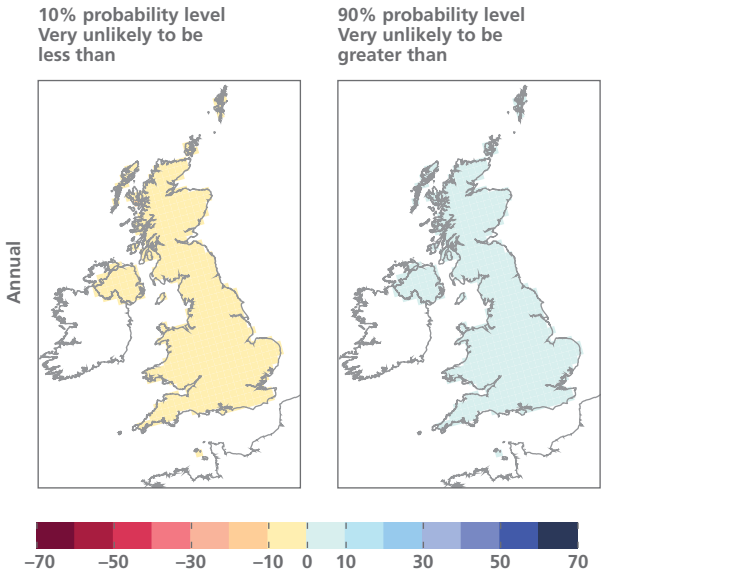
Change in UK precipitation

The other key weather variable that could potentially impact on telecommunication networks is precipitation. The current projections do not distinguish what form the precipitation will take, for example rain or snow, both of these would have differing impacts on service maintenance and provision. In addition, the projections can only show averaged weather patterns for the UK, which will mask any short-term variability that will potentially impact on the service provision. It is possible to identify the pattern of potential daily distribution of precipitation, but due to the nature of the science, it is not possible to address this in the current report, but can be explored in further studies. However, when considering the impact of high precipitation on service provision, planners need to take into account the importance of other variables both climatic and non-climatic that could lead to flooding events.

As can be seen in the figures below, the likely range of precipitation is far more variable than for temperature, with data showing that there could be a potential decrease as well as increase in the amount of precipitation in the UK until 2050s. In addition, within these averaged climatic data there will be changes in the spatial, temporal distribution that are not identified in the figures.

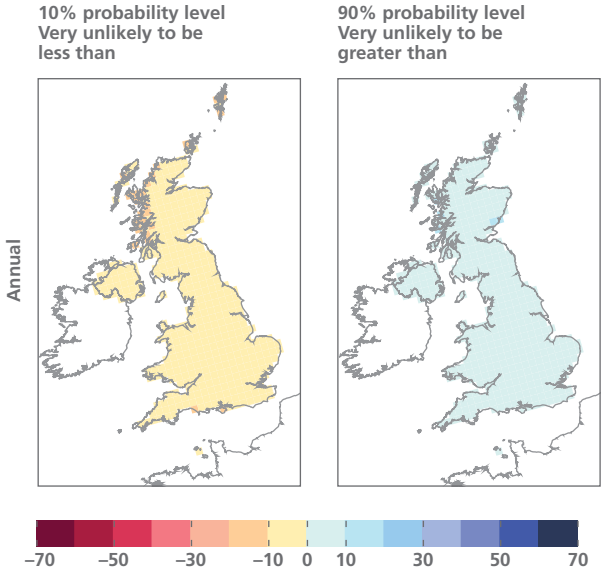
Looking at the overall pattern of likely change in the annual average of UK precipitation until 2050s (Figures 12 and 13) it can be seen that there is potential for both decreases as well as increases in the amount of average UK precipitation with the range being relatively uniform across the UK. The likely range until 2050 is between –10% and +10% change in precipitation levels.

Figure 12



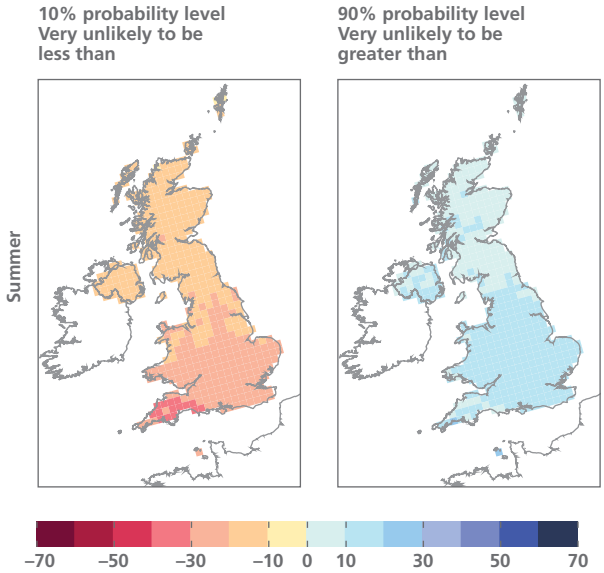
Change in annual mean precipitation (%) for the 2020s, High emissions scenario

Figure 13



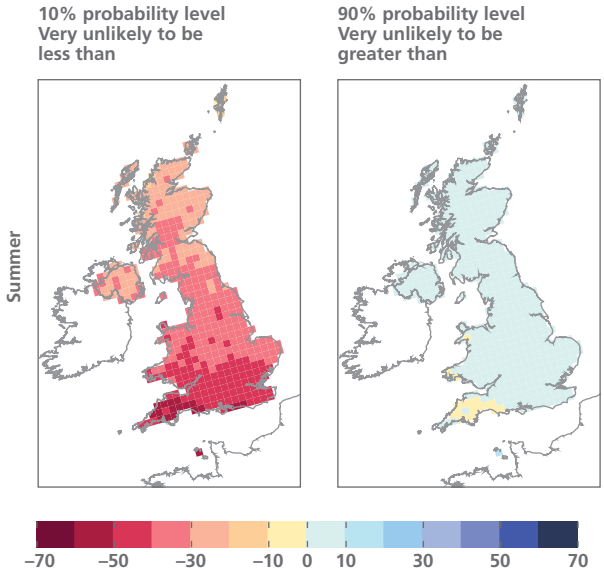
Change in annual mean precipitation (%) for the 2050s, High emissions scenario

Figure 14



Change in summer mean precipitation (%) for the 2020s, High emissions scenario

Figure 15



Change in summer mean precipitation (%) for the 2050s, High emissions scenario

As with the annual change in precipitation, the seasonal change also shows that within the projections the data suggests that it is likely that there is both an increase and a decrease in the likely range of precipitation. In addition, there is also a greater change in the geographic distribution of the precipitation.

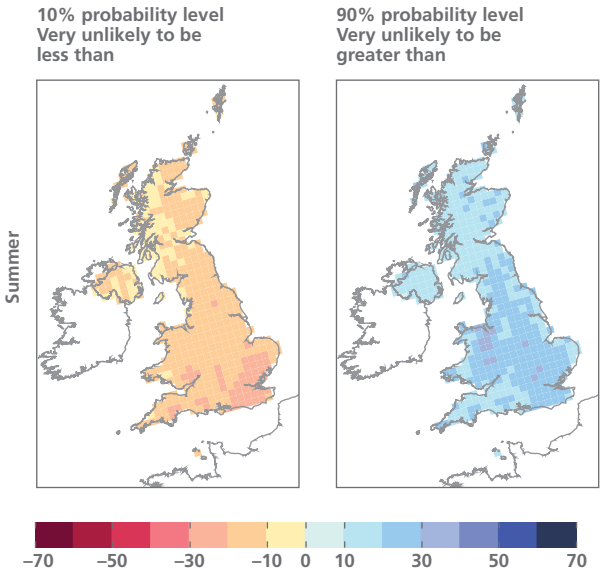
The change in seasonal distribution can be seen in the following figures. The likely change in the average (mean) precipitation in the summer (Figures 14 and 15) for the 2020s in the South of England is between –30% to +20% with parts of the South West possibly seeing a range between –40% to +10% change. The Northern parts of England have a likely range of change in the 2020s of between –20% and +20%.

By the 2050s (Figure 15), the likely range in the South of England is between –50% and +20% with areas of the South West possibly experiencing a likely range of –60% and 0%. In northern areas of the country the likely range is between –40% and +10%.

Figures 16 and 17 show the change in the wettest day in the summer. The pattern is more chaotic than for the other variables, however, general patterns of change can be identified. In the 2020s, the South East England could expect a likely change in the wettest day in the summer between –30% to +30%, whilst the rest of England could expect a change of between –20% and +20 to 30%. Within this distribution, it can also be seen that there are areas of England that could expect an increase in the wettest day of +40%.

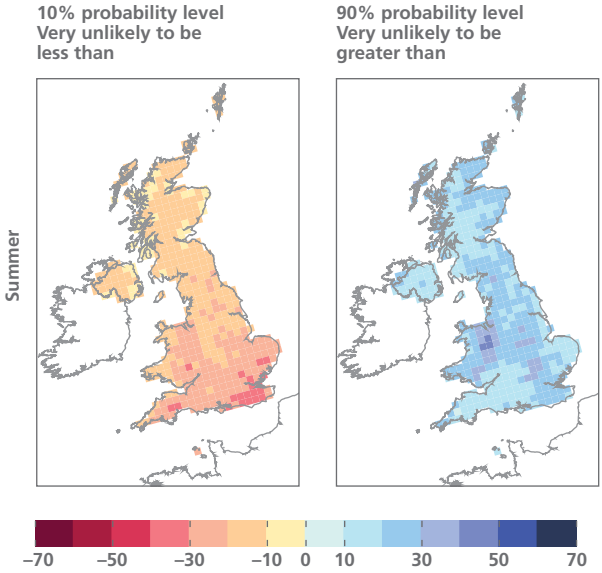
By the 2050s the change in the wettest day in England could see the South of England drying by –30% or getting wetter by +20 to 30%. Parts of the South though could experience a reduction in the wettest day by –40% with an increase of +40%. In the North of England the wettest day could change between –20% to +30%, whilst the South West could experience a likely range between –30% to +20%.

Figure 16



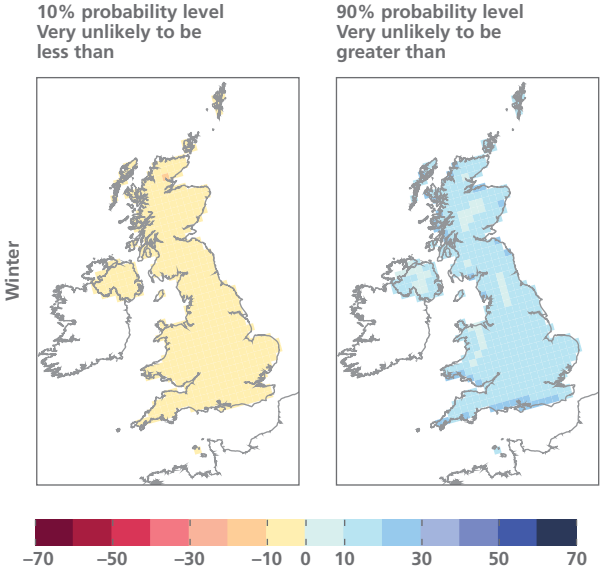
Change in precipitation (%) on the wettest day of summer for the 2020s, High emissions scenario

Figure 17



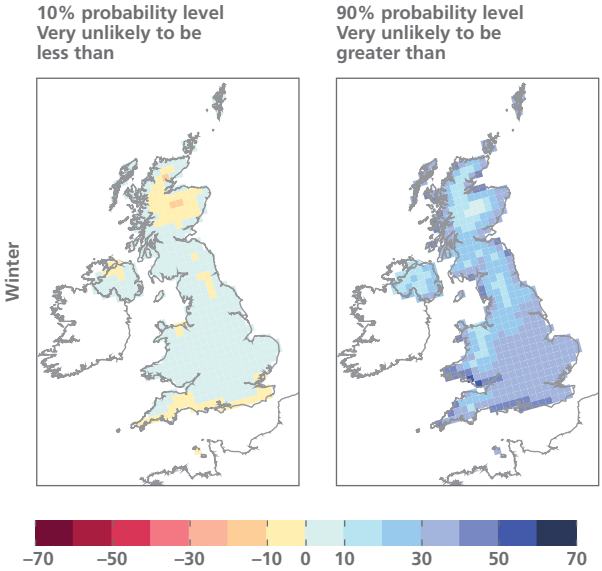
Change in precipitation (%) on the wettest day of summer for the 2050s, High emissions scenario

Figure 18



Change in winter mean precipitation (%) for the 2020s, High emissions scenario

Figure 19



Change in winter mean precipitation (%) for the 2050s, High emissions scenario

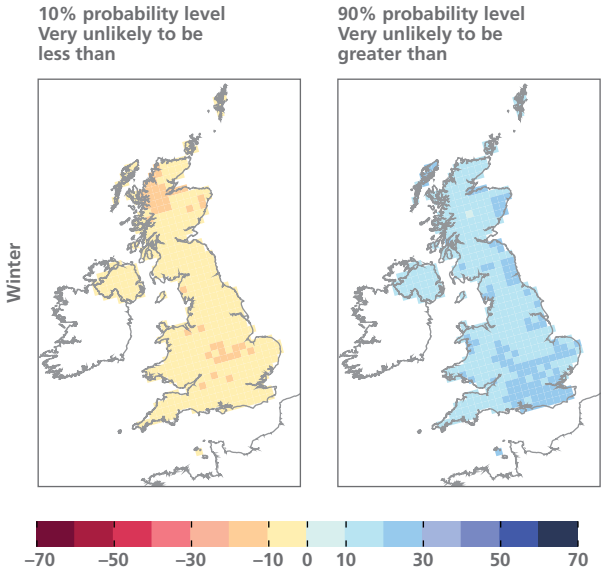
Figures 18 and 19 show the change in average winter precipitation for the 2020s and 2050s. The change in the average winter precipitation in the 2020s is between –20% and +20% with a relatively uniform distribution across the country, however, the upper range in parts of the South coast experiencing a 30% increase.

By the 2050s (Figure 19) the likely range changes to 0% to +40% with areas of the South coast potentially experiencing a likely range of between –10% and +50%

When looking at the change in the wettest winter day (Figures 20 and 21), the likely range in the 2020s is –10% to +20% with certain areas, including the South East, experiencing the possibility of an increase of up to +30%.

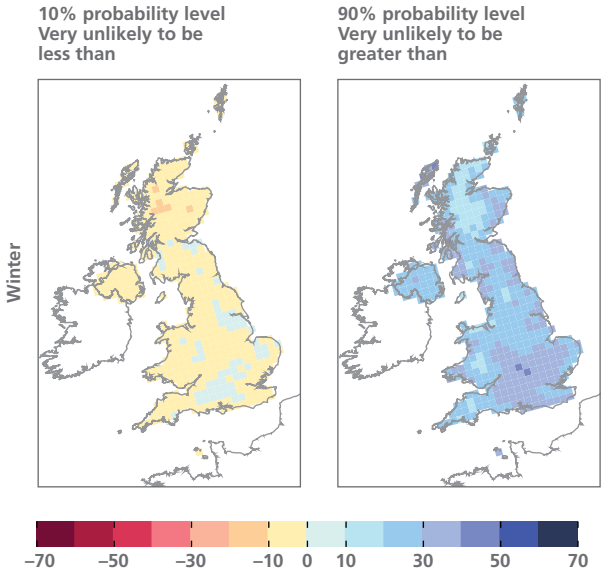
By the 2050s the wettest day in winter could range between a slight drying of up to +10% but also becoming up to +40% wetter in the South East and midlands with the rest of England up to +30% wetter.

Figure 20



Change in precipitation (%) on the wettest day of winter for the 2020s, High emissions scenario

Figure 21



Change in precipitation (%) on the wettest day of winter for the 2050s, High emissions scenario

As shown in the previous figures, the pattern of change in the precipitation that the UK could experience in the course of the next 40 years is more uncertain than for temperature, with a far greater range of change in terms of amount and distribution expected. Although the change is not uniform, what they do demonstrate is that the precipitation will change and that any review of the security of service provision needs to reflect this. Service and infrastructure organisations will need to be sufficiently flexible in their adaptation planning to respond accordingly.

The role of extreme events

It is anticipated that as part of the UK's changing climate, we can expect to experience a greater level of exceptional weather events, in the form of heatwaves, droughts, floods high winds etc. These patterns have already been experienced with higher levels of rainfall with 4 of the 5 wettest years occurring this century (Met Office, 2013a). In 2012 April and June were each the wettest such months in both the UK series from 1910, and the England & Wales precipitation series from 1766 (Met Office, 2013b).

Extreme weather patterns have also been indicated via recent drought events, for example, in the period between winter 2009/10 to March 2012, particularly in the spring, autumn and winter seasons. According to the Met Office:

> "For England and Wales, this was one of the ten most significant droughts of one to two years duration in the last 100 years. Across southern England, the two-year period April 2010 to March 2012 was the equal-driest such two year period in records from 1910, shared with April 1995 to March 1997" (Met Office, 2013c).

This pattern is confirmed in the last IPCC report where they state, "The frequency of heavy precipitation event has increased over most land areas, consistent with warming and observed increases of atmospheric water vapour." (IPCC, 2007b)

There have always been extreme weather events such as heatwaves, floods and droughts, long before concentrations of atmospheric greenhouse gases started to increase as a result of industrial activity. However, climate models now project that a warming atmosphere will bring more extremes, including more extreme temperatures and more intense precipitation (Seneveriatne *et al.*, 2012). Given that near-surface temperatures have warmed on average by about 0.75 °C over the globe (Morice *et al.*, 2012), it is not unreasonable to question whether we are already seeing the effects of human-induced climate change in the recent instances of extreme weather.

Until recently, attribution of an individual extreme weather event to anthropogenic or natural causes was not possible. After all, in an atmosphere containing more than 30% more carbon dioxide than pre-industrial levels, and given that any extreme weather event is inevitably associated with natural processes, for example a heatwave being associated with a blocking high pressure, both anthropogenic and natural factors are involved in the formation of any such event. However, research over the last decade has shown that the concept of attributable risk (Allen, 2003) can be applied to specific extreme weather events to determine how human influence has changed the risk of a particular event. In this way, the risk of the European heatwave of 2003 was shown to have very likely (prob >90%) more than doubled as a result of human-induced warming (Stott *et al.*, 2004), and the risk of the floods in the UK in 2000 was shown to have increased by a factor of more than 90% in 2 out of 3 simulations (Pall *et al.*, 2011). In addition to a changing climate increasing the likelihood of flood events occurring, it has also been considered that a changing climate can reduce the likelihood of flooding events occurring (Kay *et al.*, 2011).

The development of 'attribution science' is potentially interesting for organisations such as Openreach. It could help to make explicit the difference between an extreme event which is part of natural variability in weather systems, the costs of which will often be 'evened out' through insurance and capital reserves which allow for 'good' and 'bad' years, and events which may be part of a longer term trend linked to climate change. In the case of the latter, existing coping mechanisms may become overstretched or ineffective thus more fundamental adaptation to business functions may be required. However, such event attribution studies are still in their infancy with relatively few studies quantifying changed risk in this way. At times, the attribution studies that do exist appear to come to opposite conclusions. One analysis of the Russian heatwave of 2010 appeared to indicate that natural variability was mostly to blame (Dole *et al.*, 2011) while another that human influence was mostly at fault (Rahmstorf *et al.*, 2011). The recent BAMS report (Peterson *et al.* 2013) highlighted research into global extreme events in 2012. For the UK context Sparrow *et al.* (2013) looked at the summer rainfall patterns in 2012, concluding that whilst 2012 was the wettest on record since 1910 (with the exception of 2000) the models suggest the possibility that this was brought about by human-induced climate change is minimal. However, in the context of the weather extremes seen in the recent decade 2012 appears consistent with the recent decadal period, as highlighted recently by the UK Met Office.

As mentioned, it is the reasons behind the changing pattern in weather that is being discussed by scientists. The Met Office have identified that the recent wet weather in 2012 was as a result of a shift in the jet stream bringing a succession of Atlantic low pressure systems and associated fronts across the southern half of the UK (Met Office, 2013c). What is not understood is the extent to which the jet stream is expected to shift in the future bringing more extreme events. It is important to note that this report focuses upon climate change rather than single weather events or shorter term changes in weather patterns. Such changes can act to mask or exacerbate longer term trends in climate. Consequently, it is important not to attribute short term, localised trends to a longer term anthropogenic climate change unless there is clear evidence to do so. However organisations such as Openreach are exposed to all these uncertainties be they short term weather variations, decadal scale climate patterns or long term man made climate change and need to plan resources and investment accordingly.

The climate in the UK is changing and is expected to continue changing through the course of the next century. What is not precisely known is the extent to which the change will bring about exceptional weather events that could impact on networks and systems. The UK Climate Projections suggest that the UK will experience warmer wetter winters and hotter drier summers, but these projections mask the high variability and extremes inherent in the models that may cause the greatest impacts. More research is clearly needed to be able to identify the nature of the extreme events that have been experienced in the UK, and what this might mean specifically for the telecommunications sector in their business continuity. However, care needs to be taken not to focus solely on extremes as gradual medium term changes in climate variables will also have significant effects on an organisation and its infrastructure. Additionally, the climate data presented in this report does not look at the detailed repercussions of the changing climate on Openreach, but rather the range of possible outcomes predicted for the UK climate. Further analysis will be needed to explicitly identify how Openreach could be impacted by climate extremes. However, from initial discussions with Openreach staff, potential impacts from a changing climate and resultant extreme weather events could include:

- extended periods of high rainfall affecting underground chambers, cabling and overhead infrastructure;

- pluvial flooding from extreme rainfall leading to equipment damage and disruption in road service affecting response rates;
- increasingly complex faults, need to pump out chambers, hoists and safety equipment required for overhead plant repair;
- high summer temperatures, potentially leading to lightning strikes and equipment damage;
- high summer temperatures increasing the temperatures in distribution cabinets and exchanges;
- higher summer temperatures causing health issues for staff working outdoors;
- increase in faults from precipitation, heat, lightening, fog etc. leading to loss of business reputation and additional costs to repair.

Conclusions

The following conclusions can be drawn from this report:

- Research indicates that we are already experiencing the impacts of climate change.
- Increased climate variability, including extreme weather events, presents a challenge to Openreach to deliver services efficiently and effectively across the whole of the UK.
- Initial discussions with Openreach have highlighted specific concerns regarding extreme events, and given the possible increase in such events (or extremes becoming the 'new normal') there is likely to be a need for greater flexibility in service delivery.
- There is limited public information on how the telecoms sector will be affected, but it is a sector on which most if not all businesses and households in the UK depend.
- Due to a) uncertainty in the projections and b) the number of variables which shape the consequences of a changing climate for an organization such as Openreach, any adaptation and/or response strategy will need to be flexible.
- Experience from other utility sectors suggests that regulatory authorities can have a key role to play in supporting adaptation and creating an 'enabling environment' within which other organisations can develop adaptation strategies.
- Openreach is operating in a changing climate, characterised by an increasing level of variability; this needs to be reflected in its approach to service delivery and in its relationship with the regulator.
- Some aspects of the sector appear to evolve rapidly therefore are able to adapt to changes in climate and weather patterns.
- However, some aspects of the infrastructure will be longer lasting and require timely adaptation decisions to be factored in to business planning cycles. This includes the type of external physical infrastructure for which Openreach is responsible.

- There is currently limited information as to how vulnerable Openreach is to the specific impacts of climate change and weather variability in published literature. Consequently, further work to explore and understand the impacts of climate change on Openreach's services would be beneficial.
- While climate projections can help us to understand some of the likely changes, impacts will vary for a variety different reasons; these other influencing factors could also be explored in greater detail.

An important step in developing a more effective sector-wide response to climate change (including coping with increased variability and extreme events) would be for both the regulator and service delivery organisations to develop a clear understanding of how each organisation can contribute to a more flexible, climate resilient sector. As we have noted, efforts to improve the coordination of adaptation responses across infrastructure sectors has begun (e.g. through the Infrastructure Operators Adaptation Forum) but it would seem that more could be done within the telecoms sector, especially given the number of others sectors who are dependent on the services it provides.

Further work

A further phase of work would be required in order to understand:

- The existing climate-related risks to Openreach's service delivery model.
- Detailed evaluation of the pattern of precipitation and temperature in relation to known threshold levels that lead to increased fault reporting.
- Evidence relating to the impact of recent extreme events of Openreach service delivery.
- How Openreach plans might fit within the larger context of adaptation for UK infrastructure as a whole.
- The potential impacts of a failure to adapt for other dependent sectors and industries.
- How climate change should be factored into long term planning decisions (e.g. Openreach will be making investment decisions which can have an accounting lives over a large range of perhaps 5–40 years and even longer useful physical lives.
- How climate change can be more effectively addressed within the relationship between Openreach and Ofcom.

References

Allen, M.R. 2003. Liability for climate change. *Nature*, **421** 891–892.

Defra 2011 Climate resilient infrastructure: Preparing for a changing climate. Available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69269/climate-resilient-infrastructure-full.pdf. Accessed 15 May 2013.

Defra 2012a The UK Climate Change Risk Assessment 2012, Evidence Report. Available online at: https://www.gov.uk/government/publications/uk-climate-change-risk-assessment-government-report. Accessed 15 May 2013.

Defra 2012b Copies of reports submitted by industry regulators to Defra under the adaptation reporting power. Available online at: https://www.gov.uk/government/publications/adaptation-reporting-power-received-reports. Accessed 15 May 2013.

Defra 2013a Adapting to Climate Change. Available online at: https://www.gov.uk/government/policies/adapting-to-climate-change. Accessed 15 May 2013.

Defra 2013b Adaptation reporting power: final summary. Available online at: https://www.gov.uk/government/publications/adaptation-reporting-power-final-summary. Accessed 15 May 2013.

Defra 2013c List of replies to the consultation. Available online at: https://www.gov.uk/government/consultations/government-s-proposed-approach-to-the-second-round-of-the-adaptation-reporting-power. Accessed 15 May 2013.

Defra 2013d Government's proposed approach to the second round of the Adaptation Reporting Power. Available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/198193/arp-sum-resp-20130513.pdf

Defra 2013. Adapting to Climate Change: Ensuring Progress in Key Sectors. Available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/198195/arp-annexb-response-list-20130513.pdf. Accessed 15 May 2013

Dole, R., Hoerling, M. & Perlwitz, J. *et al.* 2011. Was there a basis for anticipating the 2010 Russian heat wave? *Geophysical Research Lett*ers, **38**.

Environment Agency 2013a. Why is adaptation so important to infrastructure? Environment Agency. Available online at: http://www.environment-agency.gov.uk/research/policy/132331.aspx. Accessed 15 May 2013.

Environment Agency 2013b Infrastructure operators Adaptation forum. Available online at: http://www.environment-agency.gov.uk/cy/ymchwil/polisi/146433.aspx. Accessed 15 May 2013.

Horrocks, L., Beckford, J., Hodgson, N., Downing, C., Davey, R. & O'Sullivan, A. 2010. Adapting the ICT Sector to the Impacts of Climate Change – Final Report, Defra contract number RMP5604. AEA group, published by Defra. Available online at: https://www.gov.uk/government/publications/adapting-the-ict-sector-to-the-impacts-of-climate-change.

IPCC 2007a Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC 2007b. Emission scenarios. IPCC Fourth Assessment Report: special reports available online at: http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=3. Accessed 23 May 2013.

Kay, A.L., Crooks, S.M., Pall, P., & Stone, D.A. 2011. Attribution of Autumn/Winter 2000 flood risk in England to anthropogenic climate change: A catchment-based study. *Journal of Hydrology,* 406.

Keenlyside, N. S., Latif, M., Jungclaus, J., Kornblueh, L., & Roeckner, E. 2008. Advancing decadal-scale climate prediction in the North Atlantic sector. *Nature* **453**, 84–88.

Meehl, G.A., Goddard, L., Boer, G. *et al.* 2013 (in press). Decadal Climate Prediction: An Update from the Trenches Bulletin of the American Meteorological Society.

Met Office 2013 Meeting on UK's run of unusual seasons. Available online at: http://metofficenews.wordpress.com/2013/06/18/meeting-on-uks-run-of-unusual-seasons/. Accessed 19 June 2013.

Met Office 2013a Statistics for December and 2012 – is the UK getting wetter? Available online at: http://metofficenews.wordpress.com/2013/01/03/statistics-for-december-and-2012-is-the-uk-getting-wetter/. Accessed 23 May 2013.

Met Office 2013b England and Wales drought 2010 to 2012. Available online at: http://www.metoffice.gov.uk/climate/uk/interesting/2012-drought. Accessed 23 May 2013.

Met Office 2013c Record rainfall – April to July 2012. Available online at: http://www.metoffice.gov.uk/climate/uk/interesting/april-july2012. Accessed online 23 May 2013.

Morice, C.P., Kennedy, J.J., Rayner, N.A. & Jones, P.D. 2012. Quantifying uncertainties in global and regional temperature change using an ensemble of observational estimates: The HadCRUT4 dataset, *Journal of Geophysical Research Letters*, **117**.

Pall, P, Aina T, Stone DA, *et al.* 2011. Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. *Nature*, **470**: 382–385.

Peterson, T. C., M. P. Hoerling, P. A. Stott & S. Herring, Eds. 2013. Explaining Extreme Events of 2012 from a Climate Perspective. *Bulletin of the American Meteorological Society*, **94** (9); S1–S74.

Rahmstorf, S., Coumou, D. 2011. Increase of extreme events in a warming world. *Proceedings of the National Academy of Sciences of the United States of America*, **108**: 17905–17909.

Seneviratne, S.I., Nicholls, N., Easterling, D., *et al*., 2012. Changes in climate extremes and their impacts on the natural physical environment. In: Field, C.B., Barros, V., Stocker, T.F., *et al*. (Eds.) Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press: Cambridge, UK, and New York, NY, USA.

Sparrow, S., Huntingford, C., Massey, N. & Allen, M.R. 2013. The use of a very large atmospheric model ensemble to assess potential anthropogenic influence on the UK summer 2012 high rainfall totals. In: Explaining Extreme Events of 2012 from a Climate Perspective. *Bulletin of the American Meteorological Society*, **94** (9), S36–S38

Stott, P.A., Stone, D.A. & Allen, M.R., 2004. Human contribution to the European heatwave of 2003. *Nature*, **432**: 610–614.

Stott, P., & Walton, P. 2013. (Invited paper in press) Attribution of climate-related events: understanding stakeholder needs, Weather.

UK Government 2008 Climate Change Act. Available online at: http://www.legislation.gov.uk/ukpga/2008/27/contents. Accessed 29 May 2013.

The UK Climate Change Risk Assessment 2012, Evidence Report. Available online at: https://www.gov.uk/government/publications/uk-climate-change-risk-assessment-government-report. Accessed 26 June 2013.