Eric Robinson[1], Michelle Cipullo[1], Peter Sousounis[1], Cagdas Kafali[1],
Shane Latchman[2], Stephanie Higgs[2], Paul Maisey[3], and Lorna Mitchell[3]

UK Windstorms and Climate Change

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[1]AIR Worldwide, Boston, MA USA

[2]AIR Worldwide Limited, London UK

[3]UK Met Office

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Contact Information

If you have any questions regarding this document, contact:

AIR Worldwide Corporation
131 Dartmouth Street
Boston, MA 02116-5134
USA

Tel: (617) 267-6645
Fax: (617) 267-8284

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Introduction

In 2009, the Met Office and AIR collaborated on a report for the Association of British Insurers (ABI) to assess the impacts of global temperature increases of 2, 4 and 6°C on the frequency and intensity of UK windstorms, UK flooding and China typhoons, and the consequent implications for the UK insurance industry. In the intervening period there have been substantial advances in climate science, and the ABI now wishes to update the UK windstorm section of the report.

In this report the impact of three global temperature scenarios on the frequency and intensity of UK windstorms will be assessed. When considering UK windstorms, similar to the previous report, the focus will be on windstorms occurring during the winter (December – February), because this represents the time period when the majority of severe windstorms occur over the UK. For example, the Extreme Windstorm Catalogue (XWS) lists the top 50 European windstorms over the time period 1979 – 2013, and 44 of these events occur during December – February1[1]. October, November, March and summer extratropical cyclones, however, will not be explicitly excluded from the stochastic loss results, but represent a very small percentage of the overall insured loss.

Review of climate science since 2009

The Intergovernmental Panel on Climate Change (IPCC) is an international body for assessing the science related to climate change, and for providing an objective and scientific view on climate change and its associated impacts. The IPCC produce reports approximately every 4-5 years that consolidate the progress in climate science. The IPCC Fourth Assessment Report (IPCC AR4) was published in 2007. In 2013 the IPCC AR4 was replaced by the IPCC Fifth Assessment Report (IPCC AR5). The previous report produced for the ABI in 2009 relied upon data generated for the IPCC AR4 assessment and the QUMP (Quantifying Uncertainties in Model Projections) Met Office climate ensemble. Since this report there have been substantial advances in climate science, namely: the publication of the IPCC AR5 report; and the availability of new climate models (e.g. Coupled Model Intercomparison Project - CMIP5). This section discusses the main advances in climate models and climate science related to the North Atlantic storm track.

Climate models often describe a range of climate scenarios that represent different magnitudes of climate change and associated impacts. In the IPCC AR4 report, climate scenarios were known as SRES scenarios. The SRES scenarios were designed to take into account that future greenhouse gas emissions are a result of complex dynamical systems. Therefore the SRES scenarios covered a wide range of demographic, economic and technological factors to analyse how these different factors influence future greenhouse gas emissions.

The climate scenarios used within IPCC AR5 are known as Representative Concentration Pathways (RCP). There are four RCP scenarios: RCP2.6, RCP4.5, RCP6, and RCP8.5, as well as the historical simulation. In the historical simulations, climate models are forced by the observed greenhouse gas concentrations, ozone, solar forcing, land use and aerosols over the last 150 years. In this report the focus is on RCP4.5 and 8.5 scenarios since these scenarios result in temperature changes closest to the scenarios of interest (1.5° C, 3.0° C, and 4.5° C). The RCP4.5 simulations are

[1] XWS: www.europeanwindstorms.org. Last accessed: 28th October 2016.

future scenarios conditional on a mid-range mitigation of greenhouse gas emissions. In particular, this scenario projects atmospheric carbon dioxide (CO_2) concentrations peak by 2040 and then decline to a value of 543ppm by 2100. This corresponds to roughly a doubling of atmospheric CO2 concentrations with respect to pre-industrial conditions. The RCP8.5 simulations are future scenarios conditional on high greenhouse gas emissions. In this case, CO2 concentrations continue to rise throughout the 21st century (Meinshausen et al., 2011). The RCP scenarios replaced SRES scenarios to allow the climate scenarios to be more appropriate for policy makers (e.g. investigating approaches to achieve a 2°C climate change target), and risk management (e.g. adaptation approaches to reduce climate change impacts).

A key difference between the RCP and SRES climate scenarios is that they are not designed to represent a specific set of assumptions about future demographic, economic or technical factors, but rather aim to span the range of scenarios found in the academic literature. Although the RCP scenarios were not designed to match the SRES scenarios, there are similarities between the expected temperature projections between the two, and global mean temperature projections for the end of the 21st century for the RCP scenarios are very similar to the closest matching SRES scenario. However, the rate at which the warming occurs differs between the RCP and SRES scenarios (Table 1).

Since 2009 the main advance in climate modelling has been the publication of the most recent ensemble of climate models: CMIP5 (the fifth phase of the World Climate Research Programme's Coupled Model Intercomparison Project; Taylor et al., 2012). CMIP5 is a collection of modelling experiments in which many climate modelling centres produced a set of historical and future climate simulations. For some models there are multiple simulations for each period, based upon different model initialisations.

Table 1: Taken from Rogelj et al. (2012). Mean similarities and differences between temperature projections for SRES scenarios and RCPs.

RCP	Similar SRES Scenario	Particular differences
RCP2.6	None	
RCP4.5	SRES B1	Median temperatures in RCP4.5 rise faster than in SRES B1 until mid-century and slower afterwards.
RCP6	SRES B2	Median temperatures in RCP6 rise faster than in SRES B2 during the three decades between 2060 and 2090, and slower during other periods of the twenty-first century.
RCP8.5	SRES A1FI	Median temperatures in RCP8.5 rise slower than in SRES A1FI during the period between 2035 and 2080, and faster during other periods of the twenty-first century.

Impact of climate change on the North Atlantic storm track

The IPCC AR4 report concluded that the North Atlantic storm track would shift northward in the future, resulting in fewer mid-latitude storms (Meehl et al., 2007). Since this publication, further research has led to a revision of this result (e.g. Collins et al., 2013; and, Zappa et al., 2013) and the IPCC AR5 report concluded that there was less indication of a poleward shift in the North Atlantic storm track. Recent studies suggest that the future North Atlantic windstorm track is likely to be characterised by a tripolar pattern with an increase in the number and intensity of ETCs over central Europe, and a decrease in the number over the Norwegian and Mediterranean Seas (Zappa et al., 2013; Sansom et al., 2013; Mizuta 2012).

Focusing on the UK winter, recent studies have indicated that in the future there is a small but significant increase in the number of windstorms affecting the UK (Zappa et al., 2013; and, Sansom et al., 2013). Zappa et al. (2013) and Mizuta (2012) also showed that the frequency and intensity of the most extreme windstorms will increase over the UK during the winter months.

IPCC AR5 noted that the biases in the North Atlantic storm track have improved significantly in CMIP5 models compared with previous climate models used in the IPCC AR4 (Flato et al., 2013). This increased confidence in the ability of the models to represent the general characteristics of the North Atlantic storm track is largely the result of: increased horizontal resolution and improved model simulation of stratospheric dynamics leading to improved representation of natural variability (e.g. NAO, ENSO). However, the IPCC AR5 also concluded that CMIP5 models produce a storm track that is too zonal and underestimates cyclone intensity (Flato et al., 2013).

Studies looking at the impact of European windstorms on insured losses indicate an overall increase in extreme wind speeds and subsequent insured losses over central and northern Europe associated with changes in storm tracks (e.g. Beniston et al., 2007; Rockel and Woth, 2007; Rauthe et al., 2010; and, Pinto et al., 2012). However, there is no evidence that the observed increase in European storm losses is directly attributable to anthropogenic climate change (Barredo, 2010), and it is well recognised that the near-term frequency and intensity of windstorms affecting the UK is dominated by natural variability (Collins et al., 2013).

Methods

The 2009 report focussed on temperature increases of 2, 4, and 6 °C. The switch to RCPs and the fact that CMIP5 models show that the global temperature will not likely exceed 4 °C (by 2100 with the uncertainty in this ranging from 3 - 5.5 °C; Figure 2) means that it is not possible or desirable to replicate the temperature increases in this update. Instead, the impact of temperature increases of 1.5, 3 and 4.5°C on the frequency and intensity of UK windstorms is analysed. This corresponds to RCP 4.5 (2050-2059), RCP 8.5 (2070-2079), and RCP 8.5 (2090-2099), respectively. A lower global temperature increase of 1.5 °C was chosen as following the Paris Climate Conference (COP21) in 2015, there has been focus on trying to limit global temperature increases to within 2 °C, and ideally to no more than 1.5 °C . A historical time period of 1995-2004 was used as the baseline to calculate any changes in the future storm track. This time period was chosen as it corresponds to the most recent historical data available.

Track density analysis

In order to assess the change in frequency of UK windstorms, storm track density statistics were calculated that show the mean storm track and the related uncertainty for the three projected temperature increases. The storm track density indicates the number of times per winter (December - February) that a windstorm passes through points on a grid.

Following the approach in Zappa et al. (2013) the mean storm track density is estimated from averaging the mean of the multi-simulation CMIP5 model track densities. In other words, if multiple simulations were available within a CMIP5 model, then those track densities were first averaged for each temperature scenario, and then these CMIP5 model-average track densities were used to estimate the average storm track density over all CMIP5 models. This ensures that each CMIP5 model is equally weighted within the analysis irrespective of the number of model runs. Track densities are analysed on a 4°x4° grid covering the UK and surrounding areas. The storm tracks provide the position of the storm at 6-hourly intervals. It was this information that was used to create the storm track density plots, and therefore an assumption has been made that if the grid boxes defined are large enough then the storm will not travel so fast as to pass through more than one grid box within 6 hours. The storm track density plots suggest that 4°x4° grid boxes are large enough as there is spatial coherence between the track density patterns and numbers under different temperature increases indicating that the results are not dominated by sampling uncertainty related to storms being miscounted.

Assessing changes in insured losses due to climate change scenarios

AIR Worldwide was tasked with assessing the insurance impacts of the various climate scenarios put forth by the Met Office. Using state of the art catastrophe models, AIR has developed "climate conditioned" catalogues of potential future events and compared the resulting losses based on projected climate scenarios with the baseline risk associated with today's climate. Changes in risk are measured using several key metrics, in particular, the average annual loss (AAL) reflecting the expected annual insured loss aggregated over an entire year, the 1.0% exceedance probability (100-year) loss, and the 0.5% exceedance probability (200-year) loss. "AAL" refers to the loss that can be expected to occur per year, averaged over a period of many years. Significant events are not expected to happen every year, so it is important to emphasise that the AAL is a long-term expected loss. The 100-year loss is the loss threshold that has a 1.0 percent probability of exceedance in any given year.

These metrics are derived from versions of AIR’s standard stochastic catalogue for European Windstorms that has been adjusted to account for the range of differences seen in the Met Office analysis. Primarily, individual storm tracks were either removed of perturbed spatially in order to increase or decrease the local value of storm track density or intensity. This process was performed iteratively using varying degrees of perturbation. The final scenarios used in this analysis were those that resulted in the smallest root mean squared error (RMSE) when compared to the three temperature scenarios provided by the Met Office.

Results

Track density and intensity changes

Figure 1 shows the percentage change in average track density for the projected storm tracks within the CMIP5 models. Under a global temperature increase of 1.5°C, the number of storms over the UK generally decreases with the largest decrease in storm occurrence over the southwestern UK. Under a global temperature increase of 3.0 and 4.5° C, the number of storms over the UK generally increases by up to 15% of the CMIP5 baseline. An exception to this is over southern UK where we see a decrease which gradually lessens with increasing temperature. In general, the activity over the UK increases between subsequent climate change scenarios.

These results broadly agree with other studies (e.g. Zappa et al., 2013; and, Sansom et al., 2013) which indicate that under the RCP4.5 and RCP8.5 scenarios, the frequency of storms over the UK will increase by 0.3 to 1.2 over the majority of the UK, apart from over southern UK where the number of storms will decrease by up to 0.3 storms per year. The main difference in the results is that under a global temperature increase of 1.5°C we are indicating a decrease in the number of storms affecting the UK.

The stochastic representation of each scenario is presented in the bottom half of Figure 1. It should be noted that there are some differences between the CMIP5 scenarios and the ones generated from the stochastic model; however the differences are well within the range of uncertainty implicit to the CMIP5 analysis, and the broader-scale patterns over the UK are represented faithfully. As in the CMIP5 data, we see an overall decrease in activity over most of the UK in the 1.5 °C case, with subsequent increases seen in the 3.0 °C and 4.5 °C cases. The largest differences are found in central UK in an area spanning Birmingham, Liverpool, and Sheffield.

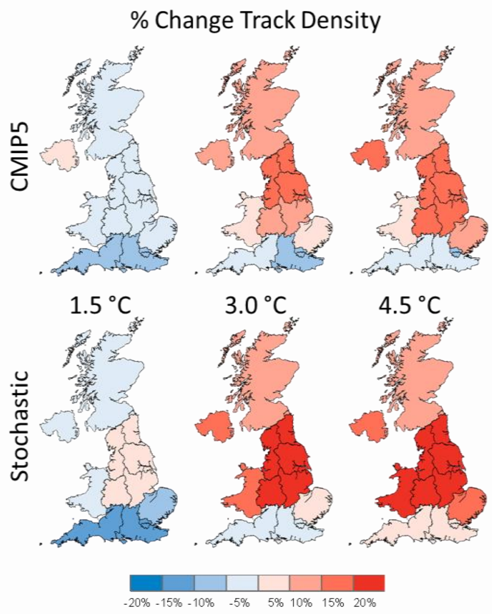

Figure 1: Track densities from climate conditioned views of AIR stochastic catalogue (bottom), and the 1.5, 3.0, and 4.5 °C CMIP5 scenarios (top). Plot values are percentage changes from the respective baseline.

These changes can also manifest as changes in the distribution of observed wind speeds. Even without an overall increase in the domain-wide average strength of European windstorms, areas of increased frequency have an increased likelihood of experiencing extreme winds. Figure 2 shows the changes in the average 100-year and 250-year return period wind speeds across the UK from the stochastic scenarios. It should be noted that these winds from the AIR stochastic catalogue are 3-second gusts. As expected, the changes generally follow the same pattern as the changes in track density, with areas of decreased frequency experiencing weaker wind speeds and areas of increased frequency experiencing stronger ones. Similar to track density, subsequent climate change scenarios show a tendency towards stronger wind speeds. Wind speed differences range from -5%-+7%, representing a change in regional average return period wind speeds on the order of 1-5 m/s.

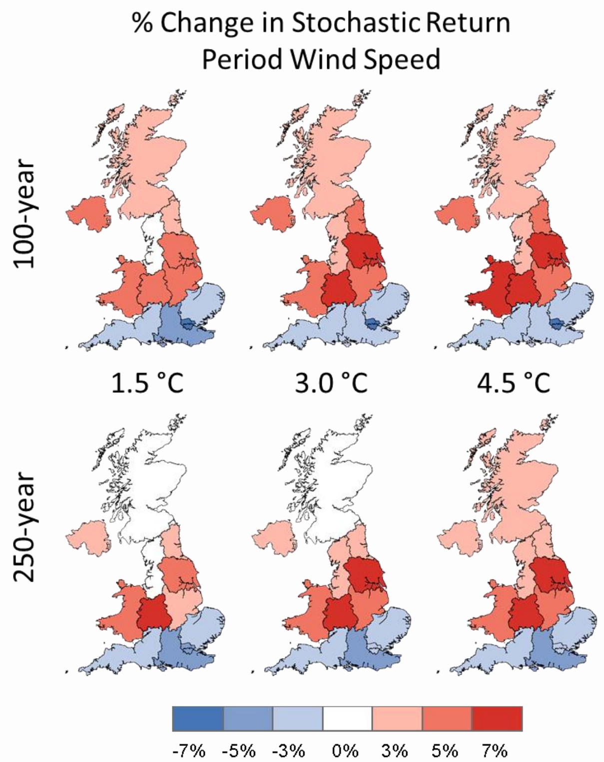

Figure 2: Changes in return period wind speeds for three CMIP5 scenarios

Changes in projected losses from UK windstorms

Both changes in frequency and intensity can affect the distribution of insured losses expected under each scenario. Figure 4 shows an overview of how the AAL is distributed amongst regions in the baseline stochastic scenario. This baseline stochastic catalogue was run against AIR's industry exposure database, which as of the publication of this report, has a 2009 vintage (2007 for exposures in the UK). The results are shown in EUR (2007) per km^2 in order to account for the differing sizes of the regions. As expected, the highest AAL region is located near London and the surrounding suburbs, where population and exposure concentration is high. The aggregate loss distribution may change under the various climate scenarios. The results in Figure 4 indicate a change in the domain-wide AAL of 11%, 23%, and 25% for the 1.5 °C, 3.0 °C, and 4.5 °C cases, respectively (Table 2).

Perhaps more notable, the scenarios suggest a possible increase of up to 40% in the 200-year return period loss, and approximately up to a 30% increase in the 100-year return level loss. Looking at the results spatially in Figure 5, the UK-wide loss numbers appear to be the result of two competing areas: an area of increasing loss starting at approximately 52 °N and extending northward, and an area of decreasing loss to the South. As the temperature rises, the area to the south shows smaller decreases, whereas the area to the north shows larger increases. This explains the increasing percentage change in AAL with temperature, and highlights that while the domain-wide AAL sees little change at 1.5 °C, regional AALs may experience significant differences.

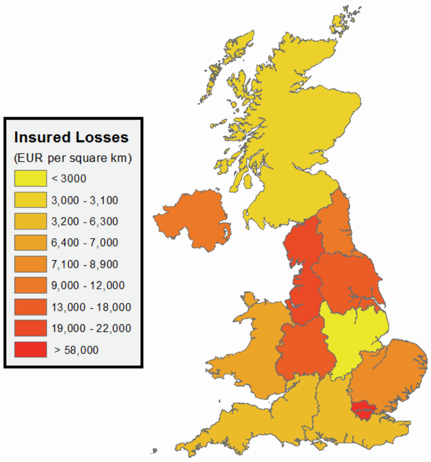

Figure 3: Regional AAL values (in EUR (2007)/km2) for the baseline stochastic case. Note the non-linear colour bar used in order to preserve regional detail.

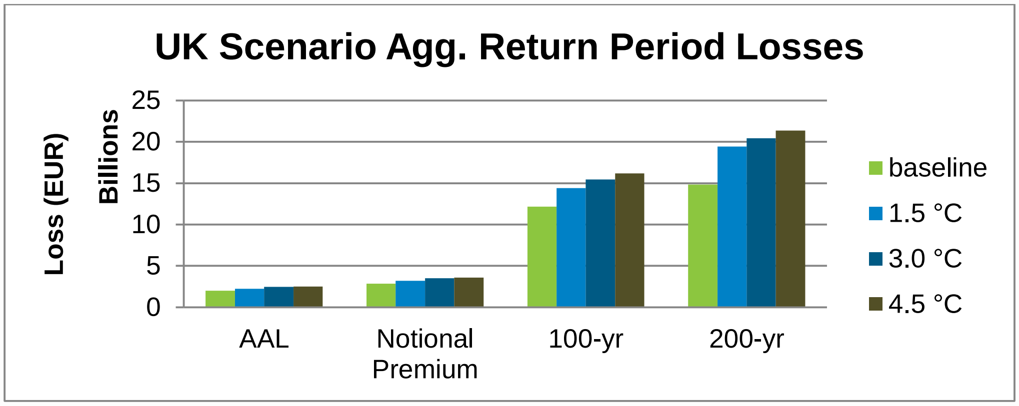

Figure 4: Average Annual (AAL), Notional Premium (AAL+1/3*SD), 100-year, and 200-yr losses over the entire UK for the 3 CMIP5 scenarios

Table 2: Percent changes in AAL, Notional Premium (AAL + 1/3 SD), 100-yr, and 200-yr losses

	1.5° C	3.0° C	4.5° C
AAL	11%	23%	25%
Notional Premium	12%	24%	26%
100-yr Aggregate	18%	27%	33%
200-yr Aggregate	31%	38%	44%

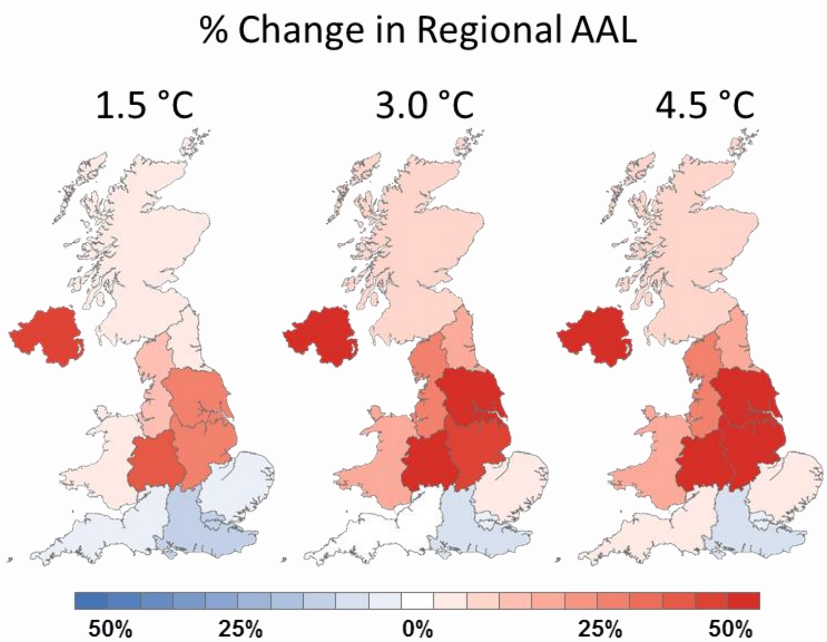

Figure 5: Percent changes in regional AAL relative to the stochastic baseline

In general, the changes in loss mirror those of the track density and wind speeds. The patterns most closely resemble the track density changes, which is to be expected since aggregate annual loss results tend to be dominated by the overall frequency of events. The relationship is not necessarily linear, however, as the additional storms may be of higher or lower intensity than the average storm that occurs over this area in the baseline scenario.

More specifically however, the AAL changes relative to and across the temperature scenarios they represent, are noticeably non-uniform with temperature increase. However, it is important to note that the 1.5 °C temperature scenario represents a more conservative scenario and for an earlier time (RCP 4.5 at 2050-59) than the 3.0 and 4.5 °C ones (RCP 8.5 at 2070-79 and RCP 8.5 at 2090-2099). The absence of any substantial increase in AAL exhibited by the 1.5°C scenario is certainly a combined result of compensating decreases and increases from London to the south and Birmingham and other industrial towns to the north. This scenario at 2050-59 likely reflects an intermediate response of the climate system, perhaps one where the tripolar storm track pattern is beginning to materialise spatially but has not yet reached its mature state. Despite the intermediate state, and despite the absence of a change in AAL, it is easy to recognise that in regions where frequency and intensity have increased, that the opportunity and hence loss for a 100- or 200-year event UK-wide has increased relative to the base state.

For the 3.0 and 4.5 °C scenarios, especially because these are from a more aggressive RCP, the change in the tripolar pattern is perhaps more robust so the increases in frequency and intensity extend over a larger region so that the AAL increases considerably for the 3.0 °C scenario. For the 4.5 °C scenario, the AAL increases only marginally over that for the 3.0 °C one. This result is consistent with the fact that frequency changes are marginal between the two scenarios (frequency increases in the region south of London) and intensity being more noticeably stronger over the northern region of the UK, in areas with relatively little exposure currently. Additionally, because the two scenarios reflect 10-year averages separated by 20 years, climate variability could likely be influencing the frequency and intensity changes for these two time periods.

Key Caveats and Sensitivities

As with all climate change studies, there are significant caveats and sensitivities that should be acknowledged in this report. The climate system is intrinsically non-linear. Small changes or errors in the modelling can result in large changes in the final results. This is especially true in this case, where losses can be quite sensitive to small changes in the magnitude and location of future wind speeds. The range of uncertainty seen in the CMIP5 ensembles with respect to both track density and storm intensity is large, with the 5-95% confidence intervals ranging between positive and negative values (see Figure 6). Additional analysis suggests at least some sensitivity to both the choice of reference period and individual CMIP5 model ensemble members.

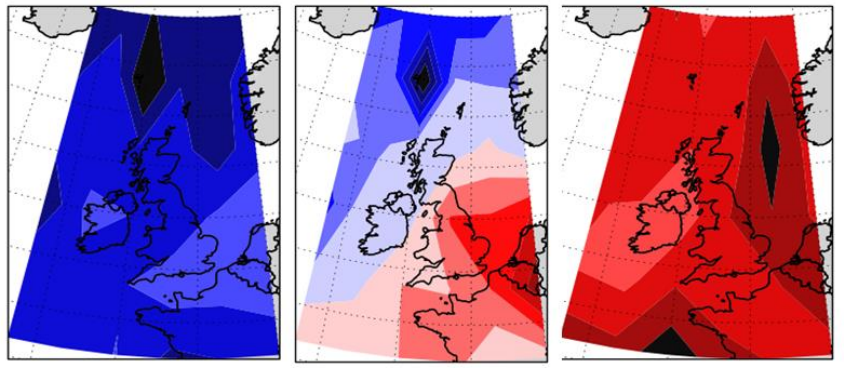

Figure 6: The 5th (left), median (middle), and 95th (right) quantiles of the change in average wind intensity for the 4.5 °C case. **Cool colours indicate negative changes, warm positive changes.**

It should also be noted that the analysis performed by the Met Office for this study looked at UK windstorms independent of their relative strengths, whereas by virtue of being a catastrophe model, the stochastic model used by AIR is intended to examine the strongest of these events. Additionally, it must be stated that the stochastic model used in this study is a pre-release version of AIR's upcoming Extratropical Cyclone Model for Europe, which may undergo additional calibration before being finalised.

Finally, there are many other aspects of the changing risk not addressed in this report. Chief among them are changes in storm clustering, global teleconnections (such as the NAO), storm surge, inland flooding, construction practices, exposure growth, and many others. An in-depth analysis of these various factors was beyond the scope of this work.

Summary and Conclusions

This project aimed to quantify the effect of changing global temperature on the risk posed by windstorms to the United Kingdom. Recent advances in climate modelling have allowed for a better representation of current and future climate, especially since the publication of the previous version of this report in 2009. Previous results had indicated a poleward shift in the North Atlantic storm track, resulting in fewer windstorms; however more recent studies suggest a more complicated, tri-polar pattern with localised increases in activity over the UK. A set of CMIP5 models were analysed to understand the climate response to three temperature thresholds and were found to be in broad agreement with recent studies showing an increase in windstorm activity over the UK. This increase, quantified as a change in track density, was introduced into a set of “climate conditioned” stochastic catalogues which showed a subsequent increase in future insured losses, both on an average annual (up to an 18% change over current day) and extreme exceedance basis (up to 30% change for the 1% exceedance probability, up to a 40% change for the 0.5% exceedance probability). These changes were highly regionalised, with the largest increases occurring in the central UK, and potential decreases in the Southern UK. The analysis also indicates, however, significant sensitivity and uncertainty with confidence bands that span both an increasing and decreasing view of risk over the entire UK.

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