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An integrated assessment of the potential for change in storm activity over Europe: implications for forestry in the UK

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Abstract

An investigation into the potential changes in windstorm occurrence over the North Atlantic and Europe as a result of greenhouse gas-induced climate change has been conducted with the aim of assessing the impacts on forestry in the UK.

Cyclone climatologies, based on NCEP Reanalysis mean sea level pressure, have been constructed in order to validate the Hadley Centre's intermediate high-resolution atmosphere-only global model (HadAM3H) and regional model (HadRM3H) over the North Atlantic and the United Kingdom regions for the 1961-90 baseline period. Changes in cyclone activity have been assessed across these two regions from the A2a and B2a scenario experiments for the future period, 2070-99.

Present results indicate that there will be no significant alteration in the spatial or annual distribution of cyclone activity across the North Atlantic or UK regions. However, the regional model suggests a shift in seasonality of the more intense cyclones across the UK with the peak in activity shifting from the climatological winter to earlier in the year into autumn.

Introduction

Windstorm has important implications for economic activities throughout Europe. The forestry sector is particularly vulnerable. It is estimated that 10% of the French forest was lost during the storms at the end of 1999. The October 1987 storm in the UK destroyed 15 million trees, representing 5 months' production of coniferous wood and 2 years of broadleaf timber production (Quine, 1988).

There are two objectives to this work. The first is to assess and identify any changes in windstorm activity over Northwest Europe and the second is to analyse the implications any changes may have on the UK forestry industry. The first stage uses results from climate models developed by the Hadley Centre (HadAM3H), in conjunction with storm tracking software, to develop climatologies of storms (track position, intensity, speed of movement) for Europe at the present day (1961-1990, as a baseline for exploration of future trends) and in a future world (2070-2099) affected by global warming. The focus is then shifted to the UK scale using the Hadley Centre regional climate model (HadRM3H).

The second stage includes the development of a forest impact model for the UK that is used to explore the implications of any observed windstorm changes on this sector of the economy. This impact model has been developed within a GIS environment and is based on the ForestGALES model (developed by the UK Forestry Commission – Dunham et al 2000). The aim is to apply the GIS model to enable an evaluation of the impact of any change in windstorm frequency or severity on the UK forestry industry. This model produces generalised profiles of risk across the UK as opposed to stand level mechanistic models that can only be integrated over relatively small areas and provide a classification of risk rather than the losses in a single storm event.

Assessment of Changes in Cyclone Activity across the North Atlantic

These results are based on the detection and tracking algorithm developed in Hanson (2001) which has been used on the NCEP mean sea level pressure data and the algorithm developed in Hodges (1994, 1995) on the HadAM3H data and focus on the winter period defined as October to March. The following criteria were used to assess any changes in cyclone activity:

1. Intensity distribution – are there any changes in the tails of the distribution of cyclone intensities (based on the minimum central pressure and maximum deepening rate achieved at any point in the lifespan of the cyclone) and thus a change in the extremes?
2. Will there be an increase in annual/monthly/seasonal frequency in the future?
3. Will climate change affect the spatial distribution of cyclones?

1 Intensity Distribution

An important factor when considering the implications of future cyclone activity for sectors of the economy is the change in cyclone intensity. Will cyclones become more intense under climate change? Fundamental to answering this question is how well HadAM3H replicates the present day intensity distribution based on central pressure and deepening rates.

From Fig. 1a it can be seen that the three ensemble members for the A2 scenario produce the observed normal distribution of intensities but is shifted to the left. However, although all four data sets are normally distributed, HadAM3H underestimates the number of deeper cyclones and overestimates the number of weak cyclones.

The distribution of deepening rates for the baseline period (Fig. 1c) also shows an overestimation of the weaker cyclones and an underestimation of the deeper cyclones, although again, the general shape of the distribution is similar to that of NCEP.

The future distribution (Fig. 1b and d) shows that the overall distribution does not change shape in the future and that generally, cyclones become slightly shallower.

2 Temporal Distribution

HadAM3H underestimates the annual frequency of cyclones and fails to simulate the observed increase in cyclonic activity across the North Atlantic during the last three decades of the Twentieth Century but it does replicate the decadal scale variability identified from many historical studies (e.g., Schmith et al 1998). The 2070-99 simulations reveal a continuation of present day cyclone levels in the future.

The monthly distributions as shown in Fig. 2 are based on the minimum central pressure only for the present day and future periods. HadAM3H A2 scenario for present day (red box with bars) underestimates the number of ≤1000hPa cyclones by 9-24% (based on the NCEP value and the maximum value identified by the A2 scenario range), and 27-66% for ≤970hPa cyclones. However, HadAM3H does replicate the general distribution of cyclones throughout the six-month period. Future cyclone distribution indicates significant decreases i.e., those beyond the bounds of present day natural variability, occur, for 1000hPa cyclones, in October (A2a only), November and March whilst for 970hPa cyclones, significant decreases are found only in February for the B2a experiment.

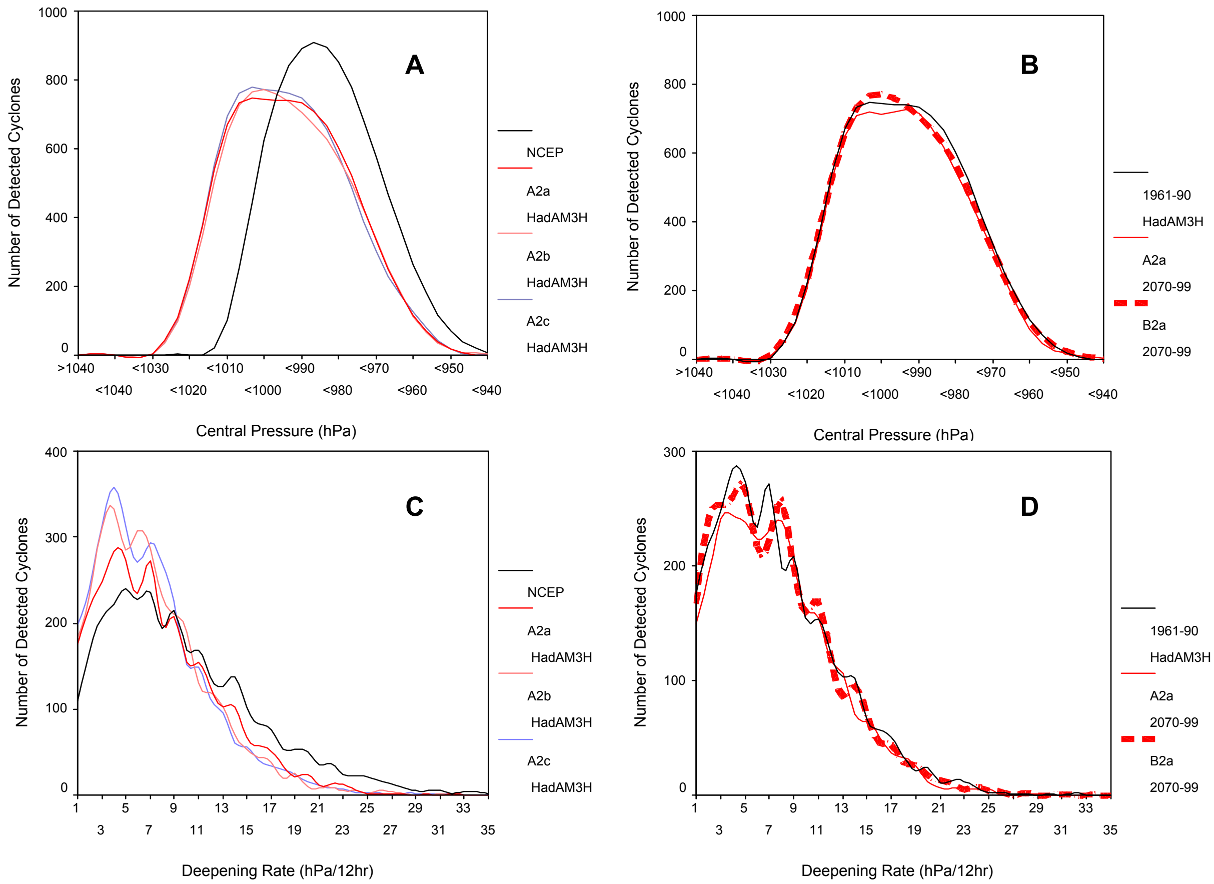

Fig. 1: Distribution of cyclone intensities based on minimum central pressure (hPa) and maximum deepening rate (hPa/12hr) achieved. A) distribution of intensities based on central pressure for the baseline period for NCEP and the A2 scenario (HadAM3H). B) baseline and future period intensity distribution based on central pressure for the A2a and B2a experiments. C) distribution of intensities based on deepening rates for the baseline period for NCEP and the A2 scenario (HadAM3H). D) shows the baseline and future period intensity distribution based on deepening rates for the A2a and B2a experiments.

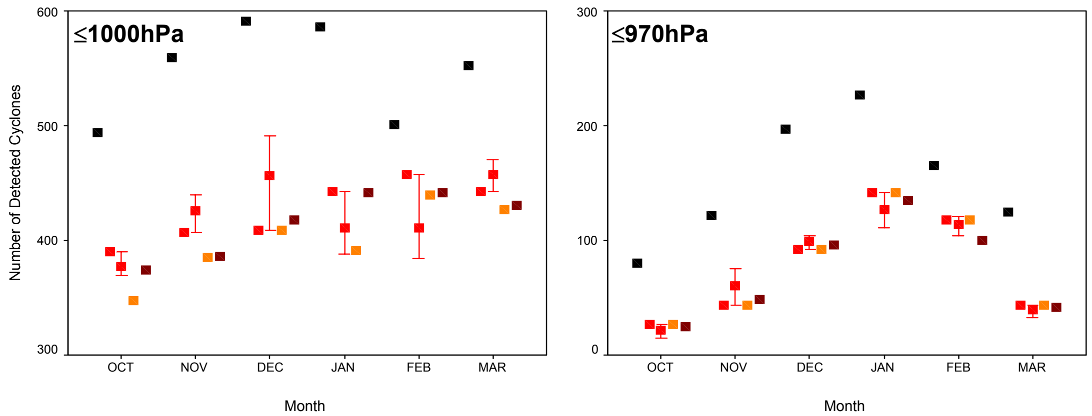

Fig. 2: Monthly distribution of baseline and future period cyclone frequency. Black represents NCEP baseline frequency and red with bars represents HadAM3H baseline frequency for North Atlantic/Northwest European cyclones. The HadAM3H range of frequency is determined from the maximum, mean and minimum frequencies identified per year from the three ensemble members for the A2 scenario. Red box represents A2a/B2a baseline frequency, orange box represents A2a future distribution and brown box B2a future distribution for cyclones achieving a minimum central pressure of ≤1000hPa and ≤970hPa.

Despite the fact that HadAM3H underestimates the numbers of cyclones it does accurately replicate the monthly distribution of cyclones. This fact enables us to have some confidence in the future scenarios.

3 Spatial Distribution

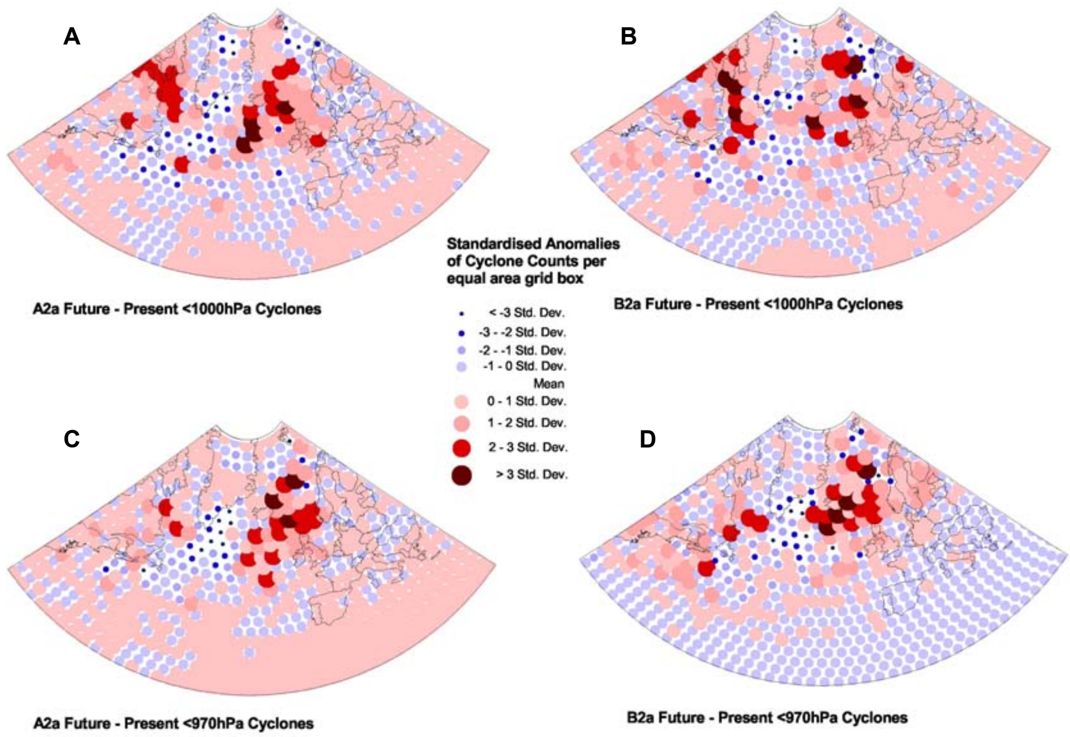

Fig. 3: Standardised anomalies of the difference between the future and baseline spatial distribution of cyclones achieving a minimum central pressure of at least 1000hPa and 970hPa for A2a (a and b, respectively) and for B2a (c and d) across the North Atlantic.

Standardised anomalies were produced to identify the differences between the future and baseline periods for the A2a and B2a experiments (Fig. 3). For the A2a experiment, statistically significant increases have been found over the Labrador Sea, over Iceland and to the north and west of the UK and also over south-eastern England for cyclones achieving at least 1000hPa (Fig. 3a). Significant decreases have been found to the north of Newfoundland and over Greenland. For the more intense cyclones (≤970hPa – Fig. 3b) increases in frequency are again found to the north and west of the UK, over Iceland and over the Labrador Sea. Similar changes have also been found in the B2a experiment although there is no significant change in the frequency of ≤1000hPa cyclones over the southeast of England. The presence of a statistically significant increase in frequency of cyclones in the A2a experiment over the south-east of England in the ≤1000hPa but not in the ≤970hPa category suggests that the increase in cyclones over this region will be of the weaker variety.

Assessment of Changes in Cyclone Activity across the United Kingdom

The following results compare the performance of HadAM3H and HadRM3H to the NCEP model for the region encompassing 13°W to 2°E and 50°N to 60°N. As a result of the Hadley Centre data being available only on a daily time step, the tracking algorithm developed here cannot accurately link pressure centres over a 24 hour period instead, the detection algorithm from the Hanson (2001) procedure has been applied to NCEP, HadAM3H and HadRM3H mean sea level pressure data. These climatologies will be directly comparable, removing any issues concerned with inconsistencies between the Hanson (2001) and Hodges (1994, 1995) procedures which could account for the differences in the NCEP and HadAM3H results in the North Atlantic study. Again, the focus is on the extended winter period of October to March. The results are based on central pressure as a measure of intensity. It can be assumed that as these analyses have been based on daily mean sea level pressure data, the number of individual centres identified can be used as a proxy for individual cyclone systems as it is unlikely that a cyclone will persist for longer than 24 hours over the UK.

In general, HadRM3H performs much better than HadAM3H over the UK, although as with the North Atlantic analysis, HadAM3H consistently underestimates cyclone frequency, this model accurately replicates the distributions of intensity and monthly/seasonal activity.

1 Intensity Distribution

The distribution of intensities for HadAM3H closely resembles that of the NCEP distribution (Fig. 4a) however, the actual frequencies are much lower. The skewness value for NCEP is –0.057. For the HadAM3H A2 scenario it ranges from –0.125 to 0.001, and for HadRM3H A2 scenario, -0.367 to –0.252 indicating that HadRM3H is more highly skewed than HadAM3H. HadRM3H (Fig. 4.4b) shows that the distribution is skewed towards higher pressure indicating that the model produces an excess of shallow centres and too few deep centres. However, for cyclones with a central pressure ≤1010hPa HadRM3H underestimates by only ~10%. The cause of the overestimation of weak centres is likely due to the method of detection applied here. As a result of the high spatial resolution of HadRM3H it is able to resolve pressure gradients more accurately than HadAM3H. The detection method applied here identifies a low-pressure centre by comparing a central point to its eight surrounding points – a centre can therefore be identified if the surrounding points are just 0.1hPa lower than the central point.

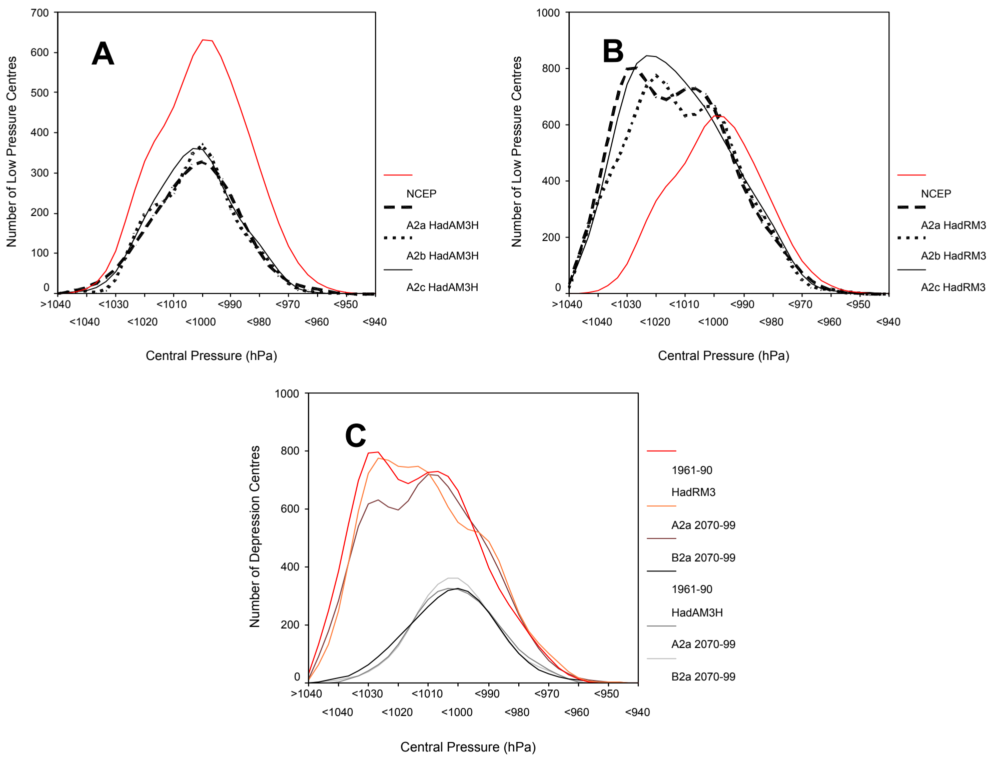

Fig. 4: Distribution of cyclone intensities based on minimum central pressure (hPa) achieved. A) distribution of intensities for the baseline period for NCEP and the A2 scenario for HadAM3H, B) for the baseline period for NCEP and the A2 scenario for HadRM3H, C) for the A2a/B2a common period (1961-90) and future experiments (A2a and B2a) for the 2070-99 period.

The future distributions of intensity (Fig. 4c) show that, as for the North Atlantic study, there is no significant change in the tails of the distribution.

2 Seasonal Distribution

The climate models have been found to accurately represent the seasonal distribution of cyclone activity over the UK (albeit, underestimating the actual frequency). In Fig. 5 for ≤1000hPa centres, both models reveal a decrease in spring, summer and autumn activity but increases in winter. During the climatological winter (DJF), ≤1000hPa centres increase on average in the future in HadRM3H from 7 per year to around 9 in the A2a experiment and 8 in B2a and in HadAM3H, from 4.5 per year to 5 and 4 for the A2a and B2a experiments, respectively. During the climatological autumn (SON) HadRM3H shows a decrease in the future from 6.5 to 4.5 (A2a) and 6 (B2a) and HadAM3H also shows a decrease from 4.5 to 3.5 (A2a) and 3 (B2a). For ≤970hPa centres HadRM3H shows an increase in autumn indicating that although overall numbers of cyclones will decrease, intense events will become more frequent. HadAM3H shows no significant change. The two models produce similar results for spring. During the climatological winter we see a decrease in the number of intense cyclones from the regional model, suggesting that the frequency of intense events will decrease whilst the proportion of weak events will increase. HadAM3H produces different results suggesting that the overall number of cyclones will increase in the future over the UK but the proportions of weak and intense cyclones will remain the same – this indicates an increase in intense cyclones.

HadRM3H suggests a possible shift in seasonality with intense cyclones increasing in frequency during the autumn and decreasing in winter. HadAM3H indicates the persistence of present day activity levels but with increases during DJF.

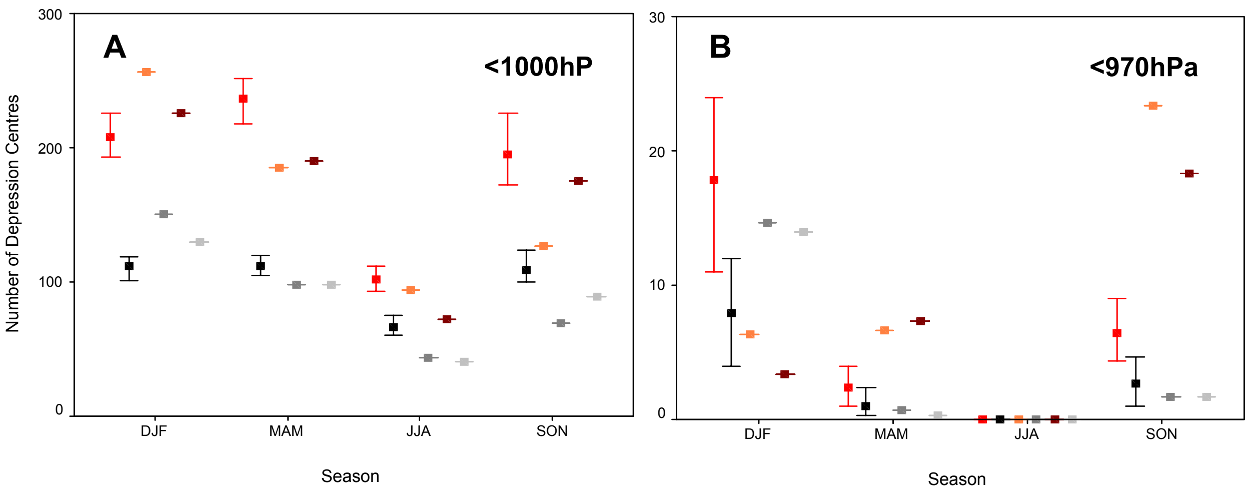

Fig. 5: 30 year totals of the seasonal distribution of depression centres across the UK region for the A2 scenario range for HadRM3H (red) and HadAM3H (black) for the baseline period (1961-90) and for the future period (2070-99) for HadRM3H (orange, A2a and brown B2a) and HadAM3H (dark grey, A2a and light grey B2a). A and B show seasonal distributions of ≤1000hPa and ≤970hPa, respectively.

3 Spatial Distribution

Fig. 7 shows the spatial distribution of cyclones achieving a minimum central pressure of no more than 970hPa for the present-day (left) and future periods (right). Both models identify the northwest/southeast gradient in cyclone activity found over the UK for the present-day. This distribution is also found in the future for the A2a and B2a experiments. The regional model identifies a strengthening of this pattern with an increase in activity in the northwest but also an increase in the southeast, indicating a shift southwards of the cyclone track over the UK.

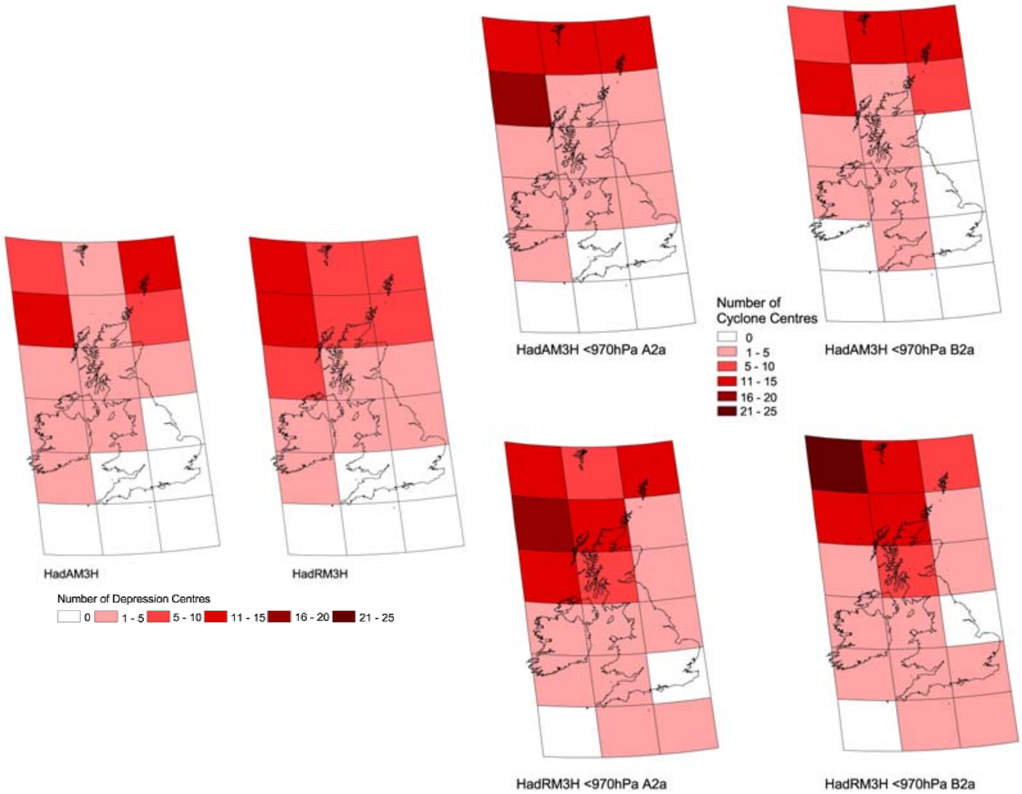

Fig. 7: Spatial distribution of cyclone activity across the UK for the present day period (left) for HadAM3H and HadRM3H, and for the future A2a and B2a experiments (right) for HadAM3H (top) and HadRM3H (bottom).

Forest Damage Modelling

Building on the cyclone climatologies constructed from the NCEP, HadAM3H and HadRM3H models, a GIS-based windstorm damage model has been developed based on the Forest-GALES model. This model is based on the physical characteristics of mid-latitude cyclones and their relationship to forest damage. We have applied the GIS model to enable an evaluation of the impact of any change in windstorm frequency or severity on the UK forestry industry. This model produces generalised profiles of risk across the UK as opposed to stand level mechanistic models that can only be integrated over relatively small areas and provide a classification of risk rather than the losses in a single storm event (Fig. 8).

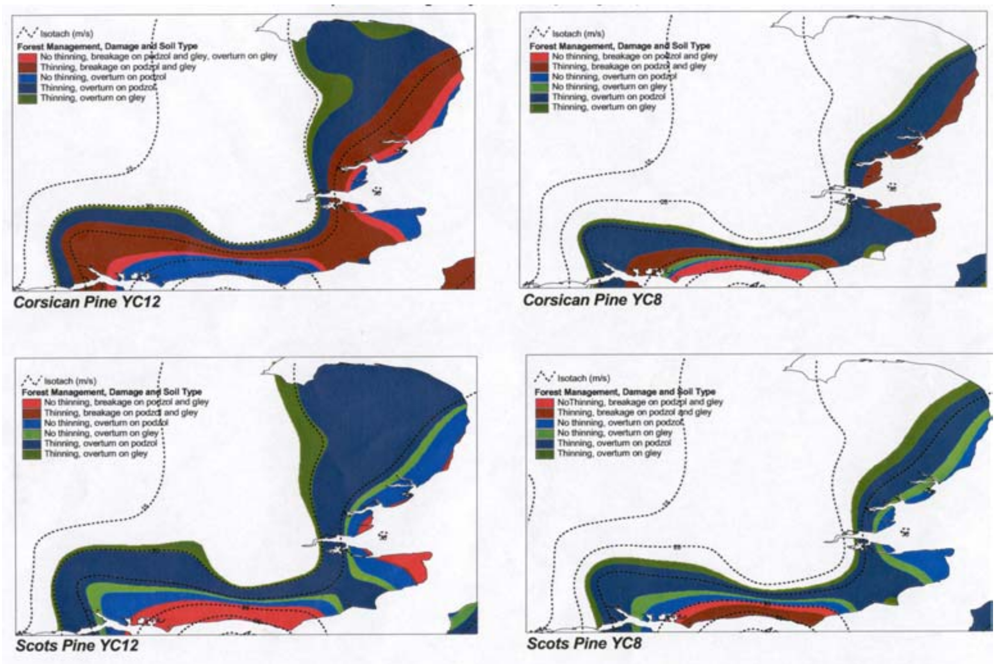

Fig. 8: Areas susceptible to overturn or breakage of trees for the 'Great Storm' wind field (October 1987).

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