Future winds: a review of the likely impacts of anthropogenic climate change on wind engineering in the UK

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1 INTRODUCTION

At the time of writing, hurricane Beryl is raging towards Texas, having ripped through the Caribbean. Beryl is the earliest forming 'Category 5' Atlantic hurricane on record. A single data point is not statistics, but it is clear beyond reasonable doubt – at least to the authors of this technical paper – that our climate is changing, and that these changes will continue into the foreseeable future.

In the field of wind engineering – as in many other disciplines – there is an urgent need to understand the expected changes to our climate and to incorporate such understanding into our assessments. However, while there is broad agreement on the general trend in temperature, for example, the picture for how the wind will change is less clear. A range of local and global factors combine differently depending on the region, resulting in either increases or decreases in mean wind speeds, and more frequent extreme events such as hurricanes, typhoons, tornadoes, and thunderstorms.

Current wind engineering practice (for the purpose of establishing design wind loads, or for predicting the potential impacts on pedestrian comfort and safety, for example) is based on statistical analyses of past weather events. While these methods are well-established, they are implicitly based on an assumption that past climate trends will remain applicable into the future, at least for the operational life of the buildings currently being designed. Considering the predictions that have been made about the impacts of anthropogenic climate change, especially in relation to the magnitude and frequency of extreme weather events, we should accept the possibility that methodologies based solely on the past climate may no longer be valid.

The purpose of this technical paper is to provide a synopsis on the historic and future trends of wind and storm events using scientific articles and grey literature (including projections by the Met Office, the Intergovernmental Panel on Climate Change (IPCC) and others), with respect to their potential impact on wind in the built environment. It goes on to discuss how traditional wind engineering assessments may be affected by climate change, and the potential risks of an inadequate assessment in this regard. Finally, recommendations are made for ways in which these assessments could be adapted to account for the predicted change in the climate of the UK.

The findings of this review will form the basis for a new position paper by the UK Wind Engineering Society (www.windengineering.org.uk). The purpose of the position paper will be to offer relatable, practical guidance in relation to the status of climate change modelling in the UK and the ways in which it could be incorporated into wind engineering assessments.

2 CURRENT UNDERSTANDING

The latest IPCC report from Working Group I [6] on the "The Physical Science Basis" provides an overview of the current understanding with regards to the projected changes to global and regional winds as a consequence of climate change. With respect to mean wind speeds, it is noted that "*...since the 1970s a worldwide weakening of surface wind has likely occurred over land…*", which is also echoed for the regional climate in Europe where "*mean surface wind speeds have decreased…over the past four decades…*". Furthermore, it is projected that "*wind stagnation events may become more frequent…in some areas of Europe…[with] potential consequences for air quality.*" However, there is "*…limited evidence that climate model historical trends are consistent with observed trends*", which is attributed to urbanisation and broader changes in the aerodynamic surface roughness, "*as well as natural variability*".

At the other end of the spectrum, whilst it is noted that "*quantifying the effect of climate change on extreme storms is challenging…*" due to a number of factors including the "*high degree of random variability*"

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and "*constraints in the models' ability to accurately represent the small-scale physical processes…*", the projections indicate that "*…average peak [tropical cyclone (TC)] wind speeds and the proportion of Category 4-5 TCs will very likely increase globally*", albeit that "*…the global frequency of TCs over all categories will decrease or remain unchanged.*" Similarly, there is "*medium confidence that changes in the [wind speeds] of [extra tropical cyclones] will be small, although changes in the location of storm tracks can lead to substantial changes in local extreme wind speeds…*". Finally, it is noted that "*climate models consistently project environmental changes that would support an increase in the frequency and intensity of severe thunderstorms,…but there is low confidence in the details of the projected increase.*"

In terms of Northern Europe specifically (which includes the British Isles), the report concludes that there is a "*…medium confidence of [decreasing mean wind speeds]…*" and a "*…slightly increased frequency and amplitude of extratropical cyclones, strong winds and extratropical storms is projected…by the middle of the century and beyond and for global warming levels of 2°C or higher*". In particular, an increased density of extratropical storm tracks over the UK is projected, albeit with low agreement between models in general.

The UKCP18 [4] projections over land for wind speeds in the UK indicate that "*there are no compelling trends in storminess…over the last four decades.*" Furthermore, whilst "*an increase in near surface wind speeds over the UK for the second half of the 21st century for the winter season…accompanied by an increase in frequency of winter storms over the UK*" is projected, "*…the increase in wind speeds is modest compared to interannual variability*". Furthermore, in their own summary of the current understanding of the UK climate, the Met Office [8] indicate that there will be "*more winter storms, including disproportionately more severe storms*", but that "*summer cyclones will become less frequent*" and that "*smaller scale convective summer storm activity is also projected to increase over the UK in the future*". Acknowledging the projected increase in the strength of tropical cyclones, it is noted that there is the potential for these to "*…retain more strength as they move into subtropical and temperate areas, such as the UK, and have a greater effect here than they do currently.*"

In their review of the future projections for North Atlantic and European Extratropical Cyclones, Zappa & Shaffrey [12] conclude that whilst "*…the total number of North Atlantic cyclones and those of strong wind intensity tend to decrease in response to climate change*", there is an "*…increase in the track density of strong cyclones between the British Isles and Scandinavia*" during the winter months. Furthermore, it is noted that "*weakening of the [Atlantic Meridional Overturning Circulation (AMOC)], might strengthen the storm-track activity over the eastern Atlantic by enhancing the surface atmospheric baroclinicity*", although it is noted that further research on the impact is required. Rahmstorf [10] recently argued that "*…risk of critical AMOC transition is real and very serious, even if we cannot confidently predict when and whether this will happen*". Moreover, there is a "*…much larger risk than previously thought*", in part because the "*…AMOC is generally too stable in climate models*": if the AMOC is "*…too unstable [it will collapse] for the present climate...[and] the model will be "repaired"…[but if] too stable...the present-day climate is correctly reproduced.*" However, Priestley et al. [9] note that "*with a changing climate, it is expected that positive [North Atlantic Oscillation (NAO)] states will become more common…*", which could also lead to "*…more cyclones with higher intensities than neutral or negative phases*", despite "*a positive phase of the NAO strengthen[ing] the AMOC…*" as indicated by Delworth & Zeng [3].

With respect to thunderstorms, whilst Brooks [1] notes that modelling suggests climate change will "*…lead to more frequent environments favorable for severe thunderstorms*", it is concluded that "*…how severe thunderstorms will change in the future is still an open [question].*" Haberlie et al. [5] demonstrate that the regional response (based on a study of the Conterminous United States) of thunderstorms to climate change is complex with "*…an overall increase in convective instability but spatially varying changes in convective inhibition*" meaning that "*regional and seasonal variability is noted in the response of thunderstorm activity…[to] two climate change scenarios.*" However, Brooks [1] notes that "*…it is unclear how well the lessons learned [in the United States] apply to the rest of the world.*"

In more general terms, based on Weibull distributions derived from UKCP09 projections of future mean wind speeds, Manis & Bloodworth [7] indicate a "*…decrease in the future in the probability of wind speeds up to 15 m/s and an increase in the probability of speeds higher than 15 m/s, indicating climate change causing an increase in magnitude and frequency of future extreme storm events.*"

In summary, whilst there is a significant degree of uncertainty about future projections for wind speeds across the UK, the general consensus is that mean wind speeds are expected to decrease and extreme wind

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speeds (both from extra tropical cyclones and thunderstorms) are expected to increase both in frequency and intensity.

3 IMPLICATIONS FOR WIND LOADING

There is a general consensus that the frequency and intensity of extreme wind events in the UK will increase. Consequently, current design wind speeds, which are typically derived from assessments of historical wind records from suitably sited anemometers, may result in reduced resilience of structures subjected to future wind loads. Whilst an increase in design wind speeds could in principle be used to account for future climatic trends, this would require careful consideration as – by leading to designs with a greater carbon footprint due to the requirement for strengthening of the structure – this choice has the potential to accelerate anthropogenic climate change.

Whilst the impact of an increase in synoptic winds on structural design is generally well understood, thunderstorms are very localised and short-duration phenomena, incompatible with the grid size of standard climate models, and cannot be accurately captured by the standard anemometers located at airports that are generally used to determine design wind speeds. Brooks [1] states "*...severe thunderstorm events are typically "target of opportunity" observations. They require the presence of an observer and a system to collect the observations.*" Wind speeds associated with thunderstorm events have the potential to be comparable in magnitude or higher than those generated by strong synoptic events, leading to the documented collapse of many structures around the world, especially low-rise structures (e.g. power grid failure due to pylon collapse). Conversely, tall structures in mixed or thunderstorm dominated climates are likely to be over-designed [11] as codes of practice are based on logarithmic wind profiles that overestimate the wind actions arising from a thunderstorm downburst, which is characterised by a maximum velocity close to the ground. Ongoing research on the effect of thunderstorm downbursts on civil structures aims to enable future codification of these events in order to facilitate safe design. However, the absence of reliable full scale measurements inhibit the assessment of the impact of climate change on these phenomena.

4 IMPLICATIONS FOR WIND MICROCLIMATE

Wind microclimate encompasses two related elements: wind comfort (associated with the typical day-to-day wind conditions that dictate how suitable the wind environment would be for its intended use) and wind safety (associated with infrequent strong winds that might push someone off balance, potentially resulting in injury). With regard to wind comfort, it is expected that current assessment methods will remain valid given that mean wind speeds in the UK are projected to remain broadly unchanged, with potential for a slight reduction in strength. Conversely, the assessment of wind safety will be affected by the projected increase in frequency and severity of winter storms, and thus warrants further consideration as to how this can be accommodated within a robust wind microclimate analysis.

Currently, wind microclimate assessments utilise the probability of occurrence of a given wind speed from a given direction based on their frequency of occurrence in a historical data set. In principle, whilst it is feasible to incorporate the projected increase in strong wind events within these statistics, in practice the choice of climate scenario and associated uncertainties make this difficult, with the potential to be overly conservative in ways that may be detrimental to building design in other respects. Alternatively, the wind safety criteria could be re-examined to determine if there is already sufficient conservatism or otherwise adjust the threshold to account for the projected increase in strong winds. In either case, a more detailed investigation of the wider implications is necessary.

Finally, whilst mean wind speeds are not expected to change significantly, the importance of wind as a component of outdoor thermal comfort (the combination of wind, sunlight, temperature and humidity) becomes increasingly relevant as climate projections point towards increasing temperatures (especially during summer) and increased risk of dangerous heat stress. Maintaining or introducing air flow into an area can be beneficial in offsetting the effects of increasing temperature, and will increasingly need to be considered during the design of new buildings in the UK. Through the adoption of thermal comfort guidelines, such as those of the City of London [2] or similar, and accounting for the projected increase in temperatures, our urban environments might be made more resilient to the changing climate.

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5 CONCLUSIONS

Our climate is changing and we need to change our approach to wind engineering to adapt to, and mitigate, the impacts of that change. However, a significant amount of uncertainty persists in future projections of wind speeds, and among the many questions that need answering, some key topics include:

1) Projections for changes to future winds in the UK are generally modest, although significant uncertainty persists and there are a number of tipping points (e.g. collapse of the AMOC) that could fundamentally alter our climate in ways that have not yet been studied in detail.
2) Whilst there is an encouraging body of ongoing research into thunderstorms, there is an urgent need to codify the results so that they can be applied in design. Furthermore, current climate models are unable to fully resolve thunderstorms, meaning there is significant uncertainty in how these events will evolve as a consequence of climate change.
3) Methodologies for the assessment of new buildings that account for the projected changes to wind conditions need to be developed, ensuring that they are adaptable to changes in the projections, and in such a way as to avoid making the problem worse (e.g. 'over-engineered' solutions with impacts that are more detrimental than those that they mitigate).

Evidently, there is a clear and pressing need for the wind engineering community to be more proactive, both in terms of increasing the resilience of our assessments to account for future winds and, in synergy with the wider design team and all interested parties, being more aware of the impact of those assessments on the global climate.

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