Predicting the frequency of future post-tropical cyclone impacts on Europe under greenhouse gas-induced climate change (Ref IAP2-18-93)

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In partnership with the British Geological Survey and CASE partner Liberty Specialty Markets

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Key Words
1. hurricanes, extra-tropical storms, climate change, greenhouse gases, storm recurvature

Overview

Recent research reveals that North Atlantic tropical cyclone (including tropical storms and hurricanes) tracks (hereafter TC tracks) have shifted northward since the onset of the Industrial era (~1870 AD) (Baldini et al. 2016; see map figure). Baldini et al. (2016) demonstrate that the observed shift toward more northerly TC tracks is due to a shift in the relationship between the Intertropical Convergence Zone (the tropical rainfall belt) and mid-latitude high pressure centres (a band of air circulation that envelopes the globe at the tropics) due to Hadley Cell expansion under rising greenhouse gas concentrations. Satellite observations over the last thirty years and climate model simulations (e.g., Lu et al., 2007; Hu and Fu, 2007) support this interpretation. Current projections suggest that the NE coast of the USA is likely to experience more frequent and more powerful storms in the coming decades due to the combined effects of a continued decrease in Northern Hemisphere aerosol emissions and an increase in greenhouse gas emissions, both resulting in a northward shift in North Atlantic atmospheric circulation belts over the coming Century. Not all storms will impact the NE USA, however. A currently unquantified percentage of storms are likely to recurve eastward into the open Atlantic Ocean or track northeastward from the Main Development Region, such as the 2017 post-tropical cyclone Ophelia. Model simulations suggest that hurricane-force storms derived from North Atlantic tropical cyclones are increasingly likely to impact western Europe under greenhouse gas induced warming (Haarsma et al., 2013). The model predicts that greenhouse gas-induced warming may shift the Main Development region (the breeding ground for TCs that currently lies in the tropical North Atlantic between 20 and 80 degrees W longitude and) and higher SSTs will increasingly allow for reintensification of storms as they approach Europe. Whether the northward migration

Image of a North Atlantic hurricane tracking toward western Europe. A scenario of increasing likelihood according to recent research. NASA Goddard photo 2010
of TC tracks observed by Baldini et al. (2016) was accompanied by a concomitant increase in European TC landfalls has yet to be determined. This, combined with a comprehensive examination of the factors responsible for the large-scale migration of dominant North Atlantic TC tracks under greenhouse-gas induced warming is the subject of the proposed PhD research.

Northward tropical cyclone track migration since 1650 A.D. reconstructed from a Belizean stalagmite (Baldini et al., 2016). Determining the extent that northward tracking tropical cyclones are increasingly recurving eastward toward Europe is the subject of the proposed research. Image Credit: Cartographic Unit, Durham University 2016

Methodology

The proposed research will take advantage of available online climate datasets, modelling software, and more sophisticated (NCAS) model simulations to assess the extent that TC tracks have increasingly recurved toward western Europe and the UK since the start of the observational record (~1850 AD). TC track position through time will be determined using the National Oceanic and Atmospheric Administration (NOAA)’s Historical Hurricane Tracks tool and the revised Hurricane Database (HURDAT2). The NOAA’s Air Resources Laboratory’s Hybrid Single Particle Lagrangian Integrated Trajectory model will be used to reconstruct meteorological and atmospheric conditions along each storm’s trajectory to investigate the factors that promote North Atlantic TC recurvature, vitality and/or reintensification en route to western Europe. Although herein we use the descriptor ‘hurricane-force’, the NCAS reanalyses/model simulations have the ability to differentiate moisture-laden systems from those which are predominately wind extremes, providing an additional level of sensitivity to the analyses. Model and statistical output data will be compared to the mean state of the North Atlantic at the time of storm passage related, in part, to North Atlantic sea surface temperatures and the strength and phase of the North Atlantic Oscillation (NAO). The effect of the NAO on the spatial distribution of European mean precipitation is well-known but less is known about its impact on extremes. The research will also investigate teleconnections with low-latitude ocean-atmosphere phenomena including El Niño Southern Oscillation (ENSO) and Intertropical Convergence Zone (ITCZ) position. One intriguing result of Baldini et al. (2016) was the observation that the 1783 AD Laki eruption resulted in an abrupt southward migration of the tropical rainfall belt and temporary reinvigoration of low latitude TC activity. This result was consistent with other research documenting a southward shift in ITCZ position following large northern hemisphere eruptions (Baldini et al., 2015; Ridley et al., 2015). Conversely, other studies suggest that high latitude eruptions like Laki should induce El Niño-like conditions in the tropical Pacific (Pausata et al., 2015), a condition that is typically associated with reduced North Atlantic TC activity. Thus, the proposed research will also investigate the impact of northern and southern hemisphere volcanism on the frequency and strength of European TC landfalls over the observational record and attempt to disentangle the role of ENSO in modulating North Atlantic TC activity. Finally, model simulations suggest that greenhouse gas-induced warming will not only affect the frequency of hurricane-force storms impacting western Europe but also their intensity and seasonality (Haarsma et al., 2013), thus, the proposed project will also investigate changes in storm strength and seasonality since the Industrial Era began.

Research Aims and Objectives
I. To investigate whether the model-predicted increase in European hurricane-force storm intensity, frequency, and seasonality is borne out by trends in the observational record.
II. To model simulations of varying complexity combined with reanalysis datasets to determine the atmospheric and meteorological conditions that promote North Atlantic TC track recurvature and European landfall.
III. To investigate low- to high-latitude teleconnections (specifically between ENSO, ITCZ position, NAO, and North Atlantic SSTs) and their influence on European hurricane-force storm activity
IV. To evaluate the role of aerosol (volcanic and anthropogenic) and greenhouse gas forcing of TC track position, strength and seasonality.

This project also involves collaborations with Prof. Pier Luigi Vidale and Dr Alex Baker, Department of Meteorology and National Centre for Atmospheric Science (NCAS), University of Reading.
Timeline

Year 1: During the first year of the project, the student will conduct a thorough literature review to develop an in-depth understanding of the state-of-the-art including thorough examination of the palaeotempestology database to provide a long-term perspective to the changes observed over the Industrial Era. During this time, the student will also begin compiling a database of hurricane-force storms that impacted Europe over the observational record using the NOAA’s Historical Hurricane Tracks tool and the HURDAT2 database. The student will also begin to familiarise themselves with the HYSPLIT model and investigate its potential for reconstructing atmospheric and meteorological conditions along historical hurricane tracks. During Year 1, the student will initiate training visits to the British Geological Survey and non-IAPETUS2 DTP collaborator, NCAS (U. of Reading). At NCAS, the student will begin to gain experience manipulating large, multi-dimensional model datasets (using Python) and develop a deeper understanding of the processes and physics of storm track recurvature. At BGS the student will be trained in coastal hazards management and resilience and investigate existing palaeotempestology records from Europe under the supervision of Michael Ellis. In September of Year 1, the student will attend the NCAS Climate Modelling Summer School where they will gain expertise in climate modelling and critical evaluation of model data.

Year 2: Climate modelling and statistical analysis will continue in Year 2 both at Durham and NCAS. Training visits to the British Geological Survey and NCAS will also continue in Year 2. Manuscript preparation and thesis writing will begin.

Year 3+ (until 3.5 years): Data analysis and climate modelling will be completed in Year 3 of the project. Key findings will be presented at two UK conferences and one international conference. Results will be published in high impact scientific journals. Insights gained from detailed examination of the observational record will be provided to NCAS to aid in model development and the evaluation of model projection uncertainties. Thesis preparation and submission.

Training & Skills

At Durham, the student will gain experience in the use of online climate modelling tools including but not limited to the NOAA’s Hurricane Tracks Tool, the Earth System Research Laboratory’s global gridded reanalysis products, and the Air Resources Laboratory’s HYSPLIT model. At Durham and the British Geological Survey, the student will receive training in the various palaeotempestology proxy archives (i.e., storm overwash deposits, stalagmites, corals, marine and lake sediments, tree rings, etc.) and use available records from the North Atlantic to help place the instrumental record into a long-term context. The student will also be trained in manuscript preparation and presentation of results at international conferences. The BGS (International Catchment Observatories) will provide guidance on placing the storm data into a coastal change context (past, present and future). The student will also interact with members of the Volcanology team to better understand volcanic eruptions like Laki and the mechanisms by which large sulphate-bearing eruptions can impact atmospheric circulation. At the University of Reading’s Department of Meteorology and NCAS, the student will gain valuable experience in the use of global and regional climate model simulations to understand the processes that drive storm track recurvature toward Europe. The student will also attend the NCAS Climate Modelling Summer School where they will gain valuable climate modelling expertise. Over the 3.5 year project, the student will gain an in-depth understanding of the Earth’s climate system including the complexities of ocean-atmospheric interactions, low- to high-latitude teleconnections, atmospheric circulation dynamics, and the major (natural and anthropogenic) climate forcings.

References & Further Reading


Further Information

If interested and you would like more information about this project, please contact Dr James Baldini (james.baldini@durham.ac.uk)