Institution: University of Reading		
Unit of Assessment: 7 – Earth Systems and Environmental Sciences		
Title of case study: Improved assessment of extreme storm risk for the oil and gas and insurance sectors		
Period when the underpinning research was undertaken: Between 1 January 2000 and 31 December 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Len Shaffrey	Professor of Climate Science	1997 to Present
Kevin Hodges	Senior Research Fellow	1994 to Present
Pier Luigi Vidale	Professor of Climate Science	2004 to Present
Period when the claimed impact occurred: Between 1 August 2013 and 31 July 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Intense storms can result in high winds, heavy rainfall, large waves, and coastal flooding. Assessing the risks of extreme storms is therefore critical to mitigating these impacts. In the oil and gas industry, estimates of extreme waves are used to assess risks to offshore platforms. Similarly, the insurance industry uses estimates of particularly extreme winds in European windstorms to price and select risk. Over the past decade, research at the University of Reading has led to the novel use of climate model simulations and development of storm-tracking tools to assess wind and wave risk from extreme storms. The University of Reading and BP plc have used this research to co-develop a new operational method to assess risk for all of BP's North Sea and Caspian platforms. These new estimates have enabled BP to continue safe operations at some of the largest oil and gas production facilities in the North Sea. The EU Copernicus Climate Change Service has used the University of Reading research to develop new insurance products for European windstorm risk and the research also forms an integral part of the hazard models developed by world-leading insurance risk-modelling companies, such as Risk Management Solutions.

2. Underpinning research

The high winds, heavy rainfall, large waves, and coastal flooding associated with extreme storms can have serious impacts on society and the economy. Examples include the extreme storm of October 1987 that caused substantial wind damage to hundreds of homes and businesses across the UK - costing the insurance industry GBP2bn - and the extensive inland flooding in the winters of 2013/14 and 2015/16. However, the relatively short length of the observational record means that there are very large scientific uncertainties associated with characterising and assessing extreme risks from tropical and extratropical storms. Researchers from the University of Reading's Department of Meteorology have led in: i) characterising storm risk using large ensembles of high-resolution climate model simulations and ii) developing and using storm-tracking software to identify and characterise key storm risk information including storm paths, intensities and footprints in atmospheric datasets.

Characterising storm risk in high-resolution climate model simulations

The oil and gas and the insurance industries require risk assessments of particularly extreme, damaging storms; for example, 1-in-10,000-year storms for oil and gas ISOcodes and 1-in-200-year storms required for the Solvency II insurance directive. Traditional risk assessments (especially in the oil and gas industry) are performed by extrapolating from observational records. Since these observational records are relatively short (typically decades in length) this means traditional risk assessments introduce huge sampling uncertainties.

The University of Reading has been pioneering new research to assess extreme meteorological risks using large ensembles of high-resolution climate models. Large ensembles of climate model simulations can produce centuries of output, which substantially reduce these sampling uncertainties in risk assessments. Working jointly with the UK Met Office and the National Centre for Atmospheric Science HRCM (High Resolution Climate Modelling) Programme, the University of Reading has been a world leader in the development of high-resolution climate models. This research has led to the development of higher-resolution versions of the HadGEM1 [R1] and HadGEM3 [R2] Met Office global coupled climate models. Shaffrey et al. (2017, [R1]) and Mizielinski et al. (2014, [R2]) showed that increasing the resolution leads to an improved representation of key modes of climate variability in climate models such as ENSO (El Nino Southern Oscillation) and decadal variability in the North Atlantic. In addition, increasing the resolution of climate model leads to a better representation of extreme weather. For example, in 2015, Roberts et al., used the TRACK storm-tracking software to show that the representation of tropical cyclones in the 25km resolution version of HadGEM3 was able to better capture the number, intensity and interannual variability associated with Atlantic tropical storms [R3]. In 2018, Priestley et al., showed that the high-resolution version of HadGEM1 was capable of realistically capturing the large-scale atmospheric processes that give rise to the clustering of European windstorms (severe windstorms tend to occur in clusters during stormy winters, which increase the price of insurance) [R4]. Present day and future simulations with higher resolution climate models allows us to better address questions concerning current risks from extreme weather and assess the potential impact of climate change on those risks.

Developing storm-tracking software

The University of Reading has developed storm-tracking software that is used to characterise tropical and extratropical storms. This software is known as TRACK and is used to identify key properties used in storm risk assessments such as storm paths, intensities, and footprints from large, gridded datasets, such as atmospheric reanalyses and climate model simulations. The latest version of TRACK is described in Hodges et al. [R5]. In this research, TRACK is applied to four atmospheric reanalyses and shows that there is strong agreement between them in terms of how they represent extratropical storms. TRACK has also been widely used in a range of applications. These include: i) evaluating how storms might respond to climate change in the Fifth Coupled Model Intercomparison Project that informed the fifth IPCC assessment report on climate change; ii) regional evaluations of climate change, such as the UK 2018 Climate Model Projections; and iii) the widespread use of TRACK in the Met Office and other international forecast centres to validate weather forecasts.

TRACK can also be applied to large, gridded datasets, such as atmospheric reanalysis, to characterise extreme storms. In this regard, TRACK was used to develop the XWS European Windstorm Catalogue (European eXtreme WindStorm) [R6]. In this study, TRACK was used alongside Met Office model-generated information to produce the first publicly available catalogue of wind gust footprints for the 50 most extreme windstorms in Europe between 1979 and 2013. This research attracted a great deal of outside interest, resulting in funding for a new Windstorm Information Service (WISC) for the insurance sector as part of the EU Copernicus Climate Change Service (C3S).

3. References to the research

Research Quality Statement: All references were published in the peer-reviewed literature and meet or exceed the two-star quality criteria (“provides useful knowledge and influences the field”; “involves incremental advances”). Evidence of influence is indicated by Web of Science Citations in square brackets, as of December 2020.

[R1] Shaffrey, L. C., Hodson, D., Robson, J., Stevens, D. P., Hawkins, E., Polo, I., Stevens, I., Sutton, R. T., Lister, G., Iwi, A., Smith, D. and Stephens, A. (2017). ‘Decadal predictions with the HiGEM high resolution global coupled climate model: description and basic evaluation'. *Climate Dynamics*, **48** (1), 297-311. DOI: https://doi.org/10.1007/s00382-016-3075-x [11]

[R2] Mizielinski, M. S., Roberts, M. J., Vidale, P. L., Schiemann, R., Demory, M. E., Strachan, J., Edwards, T., Stephens, A., Lawrence, B. N., Pritchard, M., Chiu, P., Iwi, A., Churchill, J., del Cano Novales, C., Kettleborough, J., Roseblade, W., Selwood, P., Foster, M., Glover, M. and Malcolm, A. (2014). 'High resolution global climate modelling; the UPSCALE project, a large simulation campaign'. *Geoscientific Model Development*, **7** (4), 1629-1640. DOI: https://doi.org/10.5194/gmd-7-1629-2014 [50]

[R3] Roberts, M., Vidale, P.L., Mizielinski, M., Demory, M.E., Schiemann, R., Strachan, J., Hodges, K., Camp, J., Bell, R. (2015). 'Tropical cyclones in the UPSCALE ensemble of high-resolution global climate models'. *Journal of Climate,* **28,** 574– 596. DOI: 10.1175/JCLI-D-14-00131.1 [81]

[R4] Priestley, M. D. K., Dacre, H. F., Shaffrey, L. C., Hodges, K. I. and Pinto, J. G. (2018) 'The role of serial European windstorm clustering for extreme seasonal losses as determined from multi-centennial simulations of high resolution global climate model data'. *Natural Hazards and Earth System Science*, **18**, 2991-3006. ISSN 1684-9981 DOI: https://doi.org/10.5194/nhess-18-2991-2018 [3]

[R5] Hodges, K. I., Lee, R. W., and Bengtsson, L. (2011). 'A Comparison of Extratropical Cyclones in Recent Reanalyses ERA-Interim, NASA MERRA, NCEP CFSR, and JRA-25'. *Journal of Climate*, **24**, 4888-4906. DOI: https://doi.org/10.1175/2011JCLI4097.1 [190]

[R6] Roberts, J. F., Champion, A. J., Dawkins, L. C., Hodges, K. I., Shaffrey, L.C., Stephenson, D. B., Stringer, M. A., Thornton, H. E. and Youngman, B. D. (2014). 'The XWS open access catalogue of extreme European windstorms from 1979 to 2012'. *Natural Hazards and Earth System Sciences*. **14,** 2487-2501. ISSN 1561-8633. DOI: https://doi.org/10.5194/nhess-14-2487-2014 [55]

4. Details of the impact

Oil and gas industry

BP is the main operator for over 12 offshore oil and gas platforms in the West Shetland and Central North Sea areas. In Norway, BP (as AkerBP) is the main operator for the Valhall, Ula, Ivar Aasen, Alvheim and Skarv platforms. These assets require substantial capital investment; for example, the new Clair Ridge facilities in West Shetland required investment of more than GBP4.5bn. BP also extracts oil and gas in offshore regions around the globe, for example the new GBP4.6bn Azeri Central East facilities in Azerbaijan, and installations in the South Caribbean Sea.

Storms, and the waves they produce, are the key environmental risk to offshore installations. They can affect structural integrity, the safety and transport of personnel, and – potentially – production. Estimates of very extreme wave heights (typically 1-in-10,000-years) are used to design and manage risks. Previous industry methods estimate these extremes by statistically extrapolating from observed wave heights. There are large uncertainties in these estimates, due to: i) sampling and extrapolating from short observational records; and ii) epistemic uncertainties arising from statistical models that poorly represent physical processes governing extreme wave height. These uncertainties present a massive challenge for BP and the wider oil and gas industry.

To address these challenges, a Knowledge Transfer Partnership (from 2014 to 2016) was established between the University and BP plc to make use of Reading's climate and storms data and expertise to develop a new physically-based method to estimate extreme wave heights, known as the NS1200 dataset. NS1200 consists of 1,200 years of modelled North Sea wave heights generated using calibrated surface winds and pressures derived from an ensemble of historical HiGEM high-resolution climate simulations [R1] to drive the WaveWatch-3 spectral ocean wave model. This new approach significantly reduces problems with both sampling and epistemic uncertainties. The development of the NS1200 dataset was peer-reviewed during the project through a series of meetings with other North Sea operators (Shell, Maersk, Conocophilips, Equinor, and Woodside), the UK Health and Safety Executive, and the Norwegian Petroleum Directorate.

NS1200 has now been widely adopted within BP to assess the design criteria and safety parameters for its North Sea platforms. According to BP, *"The absence of NS1200 would have reduced BP's ability to accurately quantify wave-in-deck risk at our offshore facilities and to thoroughly verify our evacuation procedures"*, which has resulted in *"huge reduction in the uncertainty of abnormal wave loads."* This has *"informed significant mitigation measures, now being implemented to keep our people safe on platforms west of Shetland and the central North Sea"* and *"permitted BP to improve the safety of operations at some of the largest oil and gas production facilities in the UK sector"* (Testimonial letter from Oliver Jones, BP [S1]). As a measure of the extent of the impact from the NS1200 dataset, the outcomes from NS1200 have been disseminated widely within the oil and gas industry. For example, Shaffrey delivered a presentation 'How might extratropical storms change in the future?' at the International Association of Oil and Gas Producers workshop on 'Our Future Climate,' which was co-sponsored by the World Climate Research Programme on 26 September 2018 [S2]. BP's Oliver Jones presented 'Application of a Long Climate Simulation to Improve Estimate of Abnormal Wave Heights' at the Offshore Structural Reliability Conference on 20 September 2018 – also to address the needs of practitioners and end-users in the oil and gas industry [S3]. In addition, BP has shared the NS1200 dataset with five other major North Sea operators (see above), improving *"confidence in the accuracy of platform structural reassessments and leading to safer facilities"* [S1].

This transformative approach, using the climate model and reanalysed storm datasets developed in Reading, is now being extended to other locations of interest to BP and other oil and gas companies; for example, to assess environmental risks for eight BP platforms in the Azerbaijan sector of the Caspian Sea. Furthermore, BP has fully funded a University of Reading project (between 2018 and 2020) to deliver historical and climate model data in the southern Caribbean, where BP operates 15 offshore platforms and two onshore processing facilities. These facilities account for over 50% of Trinidad and Tobago's oil and gas production. The new project will enable BP to better manage storm risk in the region.

Insurance industry
Severe windstorms are one of the major hazards that affect the European insurance industry. For example, the damage caused by three windstorms that hit Europe in December 1999 (Lothar, Martin, and Anatole) resulted in over EUR20bn of insured losses. Assessing the risks from European windstorms is essential for pricing, portfolio and policy selection, and company solvency. Research at the University of Reading is used by insurance companies to assess European windstorm risk.

Building on the XWS dataset [R6], the University of Reading played a key role in launching WISC in 2017 (the Windstorm information service for the insurance sector) as part of the EU Copernicus Climate Change Service (C3S). The WISC European Windstorm catalogue uses Reading's TRACK software to characterise approximately 150 severe European windstorms and was co-designed with nine major insurance companies including Swiss Re and Willis Towers Watson, (Copernicus C3S presentation on WISC, [S4]). WISC is considered by the Copernicus Climate Change Service to be *"… a great success. The people we worked with in the insurance sector and the different users we had were very excited about it, as demonstrated by the large volume of data that has been downloaded"* (Carlo Buontempo, Copernicus C3S Sectoral Information System Manager, [S5]). By July 2019, there had been approximately 2,500 data explorations or downloads of the WISC catalogue, mainly from the insurance sector (Copernicus C3S website diagnostics, [S6]). Reading is also playing a key role in developing a new operational windstorm service which will provide updates to the WISC catalogue after every winter (Copernicus C3S announcement of the new operational service, [S7]).

Risk Management Solutions (RMS) is one of three major international catastrophe modelling companies providing services to the insurance industry. Reading's TRACK is considered to be *"the best tool available"* to enable RMS to *"gain insight into the dynamics and further specific features of extratropical storms"* (Testimonial letter from Christos Mitas, Vice President of Model Development, RMS, [S8]). TRACK has been used by RMS since 2010 and has been used to develop three new versions of the RMS winter storm risk model including the most recently released version. According to RMS, TRACK forms an *"integral part of our hazard models for Europe and North America"* [S8].

Summary

Assessing extreme wind and wave risk from extreme storms is critical to mitigating the damaging impacts of storms. This includes assessing risks for design and operation of offshore oil and gas platforms and the pricing of insurance risk. Research at the University of Reading has provided innovative solutions, enabling companies in the oil and gas and insurance sectors to better manage storm risks. The University and BP have co-developed a new operational method using long climate model simulations to assess extreme wind and wave risk for all of BP's North Sea and Caspian platforms, which has enabled BP to improve the safety of operations at some of the largest oil and gas production facilities in the UK sector. Reading research has also been used to develop new insurance products for European windstorm risk in the EU Copernicus Climate Change Service and forms an integral part of risk assessments within Risk Management Solutions - one of the world's leading insurance risk-modelling companies.

5. Sources to corroborate the impact

[S1] Testimonial from BP, September 2020

[S2] Oil and gas industry event and presentation on the NS1200 dataset: International Association of Oil and Gas Producers workshop on 25-27 September 2018, a) 'Our Future Climate – understanding the spread of physical risk for the oil and gas industry' b) Shaffrey's presentation

[S3] Oil and gas industry event and presentation on the NS1200 dataset: 2018 API Offshore Structural Reliability Conference, presentation by Oliver Jones of BP on 20 September 2018, session 4:a) Overview and b) Programme

[S4] WISC presentation given at Sectoral Information Service Meeting, October 2016 (slide 4)

[S5] Quote from sectoral information system manager for the ECMWF-run Copernicus Climate Change Service on the launch of the WISC platform in news article, April 2018

[S6] WISC https://wisc.climate.copernicus.eu/wisc/#/ and Copernicus Access records

[S7] New sectoral information system: access here

[S8] Testimonial from Vice President (Model Development) at Risk Management Solutions, August 2020